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Phenological responses of ash (*Fraxinus excelsior*) and sycamore (*Acer pseudoplatanus*) to riparian thermal conditions

Chih-Wei Tsai*, Thomas Young[1], Philip H. Warren, Lorraine Maltby

Department of Animal and Plant Sciences, The University of Sheffield, Western Bank, Sheffield S10 2TN, UK

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ABSTRACT

There is increasing evidence that riparian corridors have modified thermal conditions compared to non-riparian areas. However, the biological significance of this difference is less clear. Here we tested this by investigating the response of tree phenology to riparian thermal conditions. We monitored the timing of bud burst, leaf fall and growing season of riparian and non-riparian ash (*Fraxinus excelsior* L.) and sycamore (*Acer pseudoplatanus* L.) in the city of Sheffield over two years. We compared the phenologies between riparian and non-riparian trees and explored the relationship between tree phenologies and thermal environments. Tree phenologies varied between riparian and non-riparian areas and the effect was species specific. Bud burst and leaf fall were earlier in non-riparian than in riparian ash, but no location effects on either bud burst or leaf fall were detected for sycamore, or in the growing season for both species. Bud burst for the two species was highly correlated to spring temperature; warmer temperature resulting in earlier bud burst in ash but later bud burst in sycamore. No significant relationship between leaf fall and temperature was found for either species. A positive correlation between growing season and temperature was observed for ash but not sycamore.

1. Introduction

Riparian corridors, the habitats adjoining rivers, may have modified temperature regimes (Moore et al., 2005), suffer less from soil water deficit (Yanagisawa and Fujita, 1999), and have greater air humidity (Rykken et al., 2007) that habitats further away from rivers. Of increasing interest, from both an ecological and environmental management perspective, is the temperature difference: riparian corridors tend to consistently cooler in hot weather and warmer in cold weather (Moore et al., 2005; Rykken et al., 2007; Hathway and Sharples, 2012; Tsai, 2014). For example, the differences in summer temperatures between riparian and non-riparian areas were found to be between 1.5 and 5.5 °C in urban areas (Murakawa et al., 1991; Hathway and Sharples, 2012) and between 2 and 6 °C in rural areas (Brosofske et al., 1997) in temperate climate studies. This difference is of considerable interest, especially in urban environments where locally elevated temperature can occur as a result of urban heat island effects (Walsh et al., 2005). The observed effects of riparian environments on local climatic conditions raise the question of whether these lead to significant biological responses. One way to address this question is to examine shifts in plant phenologies associated with these riparian environments.

Phenology, the timing of recurrent biological events is an important indicator of how organisms respond to variations in climate (Menzel, 2002; Schwartz, 2013). Environmental temperature drives the phenology of many biological events, such as the timing of bird migration and nesting (Pennington et al., 2008; Thomas et al., 2010; Dunn and Møller, 2014), hibernation (Inouye et al., 2000), insect emergence and oviposition (Bentz et al., 1991; Xu et al., 2012) and the timing of bud burst, flowering, fruiting and leaf abscission of plants (e.g. Gordo and Sanz, 2010; Basler and Körner, 2012; Wolkovich et al., 2012; Gill et al., 2015). Even subtle changes in temperature may potentially affect the timing of biological events, a possibility borne out by the fact that in long term datasets regional warming associated with climate change has been found to be associated with a shift in the phenology of animals and plants (Walther et al., 2002). There are increasing numbers of experimental studies pointing out a causal relationship between temperature and phenology (Morin et al., 2010; Gunderson et al., 2012). However, information about how subtle

* Corresponding author. Present address: Department of Ecological Humanities, Providence University, 200, Sec. 7, Taiwan Boulevard, Taichung City 433, Taiwan.

E-mail addresses: chihwei.tsai@hotmail.com (C.-W. Tsai), tom.young@stri.co.uk (T. Young), p.warren@sheffield.ac.uk (P.H. Warren), l.maltby@sheffield.ac.uk (L. Maltby).

[1] Present address: Sport Turf Research Institute, St Ives Estate, Bingley, West Yorkshire BD16 1AU, UK.

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Table 1
River and riparian environments of twenty study sites.

Site	River	River width (m)	Stream gradient (%)	Riparian–non-riparian gradient		Altitude (m)	
				Distance (m)	Slope (%)	Riparian location	Non-riparian location
26–87	Sheaf	3.2	1.0	190	2.6	98	103
27–88	Sheaf	6.5	3.0	82	2.4	92	94
31–92	Sheaf	5.1	0.5	93	1.1	73	74
41–73	Rivelin	6.3	2.0	79	2.5	139	141
42–74	Rivelin	8.7	2.0	46	6.5	135	138
45–91	Don	23.5	1.0	246	1.6	53	57
47–100	Don	39	0.5	494	3.8	42	61
49–73	Loxley	5.8	5.0	59	6.8	115	119
49–75	Loxley	7.2	2.0	52	30.8	113	129
49–83	Loxley	7.8	0.5	119	13.4	78	94
50–78	Loxley	7	1.0	52	7.7	95	99
50–87	Loxley	11.5	1.0	207	2.9	63	69
53–106	Don	15.5	0.5	92	1.1	36	37
56–108	Don	20.5	1.0	172	5.8	41	51
56–110	Don	19	1.0	394	1.3	39	44
63–76	Don	13.5	1.0	42	9.5	96	100
67–75	Don	11.7	1.0	74	<1	98	98
72–72	Don	12.2	6.0	67	<1	111	111
73–71	Don	19	2.0	165	8.4	112	126
76–71	Don	11.8	4.0	115	6.1	118	125

variations in temperatures affect phenologies in the field is rather rare.

Temperature has been long recognised as the dominant factor driving the phenology of trees in temperate regions (e.g. Bailey and Harrington, 2006; Vitasse et al., 2009b; Polgar and Primack, 2011; Olsson and Jönsson, 2015). Because of the distinct seasonality in the temperate regions, bud burst in spring and leaf fall in autumn play essential roles in determining the length of the growing season and the reproductive cycle of trees (Kramer et al., 2000; Garonna et al., 2014). An extensive body of literature investigating the relationships between historical data of leaf phenology and temperature at regional scales has shown that, as a general rule, warmer temperatures in spring advance the timing of bud burst (Matsumoto et al., 2003; Menzel, 2003; Doi and Katano, 2008; Fujisawa and Kobayashi, 2010; Gordo and Sanz, 2010; Ibáñez et al., 2010) and warm temperatures in autumn delay the timing of leaf fall (Menzel, 2003; Garonna et al., 2014; Estiarte and Peñuelas, 2015). Furthermore, bud burst and leaf fall has been shown to respond to variations in elevation (Vitasse et al., 2009b), latitude and longitude (Doi and Katano, 2008; Gill et al., 2015), which are themselves correlated with temperature. Even though there have been some previous studies looking at how leaf phenology reacts to the differences in thermal conditions at more local scales (Aizen and Patterson, 1995; Tateno et al., 2005; Wang, 2006), most of them focused on one, or just a few, locations. Studies addressing phenological patterns at multiple locations across a local area are rare, though these can provide insights into the generality of plant phenological response to local temperature changes.

Here we investigated the effect of riparian thermal conditions on two species of deciduous tree (*Fraxinus excelsior* L. and *Acer pseudoplatanus* L.) at twenty sites across a river network. Both are identified as early successional native species (Huston and Smith, 1987; Basler and Körner, 2012), and previous studies showed that leaf phenology (i.e. bud burst and leaf fall) of the two species were sensitive to temperature changes (Vitasse et al., 2009b) but less sensitive to photoperiod (Basler and Körner, 2012, 2014). We used data on bud burst, leaf fall and growing season for ash and sycamore over two years, to test whether tree phenologies differ between riparian and non-riparian areas and to explore the relationship between the phenologies and the thermal environment.

2. Materials and methods

2.1. Study site

The study was conducted on rivers flowing into, and through, the city of Sheffield in the UK (53°22′ N, 1°20′ W). Twenty study sites were identified along the rivers Don, Loxley, Rivelin and Sheaf (Table 1 and Fig. 1). The lowest point of Sheffield stands in Tinsley, located in the northeast of the city centre, at just about 30 m above sea level, while to the west the land rises to up to about two hundred metres at the border of the Peak District National Park. The climate in Sheffield is temperate with mean annual precipitation of 826 mm (1971–2012), average annual monthly maximum temperature of 21.4 °C and average annual minimum temperature of 0.81 °C (Met Office, 2013).

2.2. Leaf phenology monitoring

Two tree species, sycamore (*A. pseudoplatanus*) and ash (*F. excelsior*), were chosen for their widespread occurrence in both riparian and non-riparian habitats in the study area.

There were two sampling locations at each site, one within 5 m of the river ('riparian') and the other over 50 m away from the river ('non-riparian'), the exact location of the latter being determined by the availability of a suitable group of trees. At each sampling location, six to ten individuals of each study species were selected by cluster sampling and marked. A range of sizes and ages, representative of the individuals present at each location, were used for monitoring. Trees were monitored in spring (March to May) for bud burst and in autumn (September to November) for leaf fall in both 2010 and 2011. As far as possible the same trees were used throughout the study, but in some cases changes in habitat and access meant that some trees had to be replaced. In 2010, bud burst was monitored in 448 trees and leaf fall in 433 trees; 414 were monitored for both bud burst and leaf fall. In 2011, bud burst was monitored in 546 trees and leaf fall in 466 trees; 459 trees were monitored for both bud burst and leaf fall. Understory trees, whose phenology might be potentially affected by microclimate in subcanopy habitats, contributed 10.7% of total individuals chosen in 2010 and 3.8% of total individuals in 2011. Eighty-three percent of trees were monitored over both years.