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EFFECTS OF AN EXPERIMENTAL FLOOD ON LITTER DYNAMICS IN THE MIDDLE RIO GRANDE RIPARIAN ECOSYSTEM

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ABSTRACT

The objectives of the study were to measure the effects of an experimental flood on : (1) leaf litter production by the riparian forest; (2) leaf decomposition; and (3) the amount of forest floor organic matter. The study area is located at Bosque del Apache National Wildlife Refuge, approximately 160 km south of Albuquerque, New Mexico. Experimental and reference study sites of about 3·1 ha were both located in cottonwood (*Populus fremontii*) riparian forests that had not been flooded for approximately 50 years. The experimental and control study sites were sampled for two years before flooding the experimental site. The experimental flood peaked on about 31 May, the average date of peak flow in the 100 year hydrograph for the USGS gauging station on the Rio Grande at Embudo, New Mexico. Litter fall was lower at the flood site than at the control site, whereas the rate of leaf decomposition was higher at the flood site during the period of inundation. However, the flood did not produce a measurable response in standing stock of forest floor litter. This pool of carbon may require the cumulative effects of several years of flooding to show a measurable response.

KEY WORDS: forest floor litter; manipulative flooding; Rio Grande; riparian ecosystems

INTRODUCTION

Periodic flooding is an integral part of large river–floodplain ecosystems and is an important mechanism for the exchange of materials and energy between rivers and riparian forests (Junk *et al.*, 1989; Sparks, *et al.*, 1990; National Research Council, 1992). However, flood control has generally reduced the frequency and intensity of flooding by many large rivers. For instance, the Rio Grande in central New Mexico was historically characterized by spring flooding during snowmelt in the upper basin and summer flooding in response to thunderstorms. Now, however, dams have eliminated most floods in the upper and middle Rio Grande. Flood control and other water management practices such as channelization and levee building have greatly altered various aspects of the floodplain ecosystem (Campbell and Dick-Peddie, 1964; Howe and Knopf, 1991). One observable feature of the present riparian ecosystems of the middle Rio Grande is an accumulation of large amounts of leaf litter and woody debris. We propose that the build-up of this material is at least partly due to the absence of substantial flooding during the past 50 years.

This study focuses on the effects of the first of a series of planned, manipulative floods on the production, decomposition and storage of plant litter in a riparian ecosystem. Plant litter dynamics reflect major ecosystem processes including: (1) primary production; (2) decomposition; and (3) nutrient cycling. The limited research that has been done on the litter dynamics of riparian zones has produced diverse results (Malanson, 1993). Peterson and Rolfe (1982) reported nearly identical rates of litter production in riparian and upland sites, whereas Shure and Gottschalk (1985) measured lower litter production in their wettest riparian sites. Similarly, whereas Shure *et al.* (1986) reported higher rates of decomposition in riparian zones than in drier upland areas, Chauvet (1988) encountered higher rates of decomposition in their drier study sites.

Our specific objectives were to measure the effects of an experimental flood on: (1) leaf litter production by the riparian forest; (2) leaf decomposition; and (3) the amount of forest floor organic matter. We predict that annual flooding (1) decreases litter production by the riparian forest, (2) increases rate of decomposition and (3) decreases the amount of litter stored on the riparian forest floor.

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METHODS

Study area

The study area was located at Bosque del Apache National Wildlife Refuge, approximately 160 km south of Albuquerque, New Mexico at an elevation of about 1400 m. The refuge includes about 14·5 km of the Rio Grande and its associated riparian vegetation, including cottonwood forest. During the summer of 1991, we established experimental and control study sites in cottonwood forest. We chose the two study sites because they were similar to each other in size and vegetative composition and because they had not been flooded for approximately 50 years. The forest floor of both the experimental and control study sites contained large amounts of leaf and woody plant litter.

The area of each study site was approximately 3·1 ha. The canopy of both study sites is dominated by Rio Grande cottonwood (*Populus fremontii* var. *wizlizeni*) 8–15 m in height, with subcanopies of Goodding willow (*Salix gooddingii*) and tamarisk (*Tamarix chinensis*). The dominant understory shrubs are seepwillow (*Baccharis glutinosa*) and New Mexico olive (*Forestiera neomexicana*), with scattered Russian olive (*Elaeagnus angustifolia*), screwbean mesquite (*Prosopis pubescens*), wolfberry (*Lycium torrevi*) and false indigo (*Amorpha fruticosa*).

Experimental design

We monitored the experimental and control study sites for two years before flooding the experimental site. The purpose of this pre-flood monitoring was to compare leaf litter production, decomposition and forest floor organic matter at the two study sites under non-flooding conditions before the experimental flood. This pre-flood comparison was performed to assess whether changes followed flooding of the experimental site. Such before–after comparisons are now widely applied to large-scale unreplicated experiments (Carpenter *et al.*, 1989; Carpenter, 1990; Rasmussen *et al.*, 1993).

Manipulative flooding

The water used for flooding the experimental site was diverted from a riverside irrigation canal which is, itself, diverted from the Rio Grande at San Acacia, New Mexico, about 45 km upstream from the experimental site. Water diverted from the canal flows about 200 m down a roadside borrow ditch to the experimental site. Groin dikes and variable-height spillways controlled the water level at the experimental site during flooding.

We timed the experimental flood to peak on about 31 May, the average date of peak flow in the 100 year hydrograph for the USGS gauging station on the Rio Grande at Embudo, New Mexico. In 1993, flooding was begun on 17 May, reached a maximum height on 27 May and was held at that level until 3 June. Flood waters were then gradually drained off the experimental site over the next two weeks.

Litter production

Litter production at each site was monitored with 12 circular rubber tubs, 50 × 10 cm deep. The tub contents were collected monthly from September through March, oven-dried for 48 hours at 60°C and weighed. The cumulative dry weight for each site was plotted against time to determine the timing and amount of annual leaf litter production in 1991, 1992 and 1993. Cumulative litter fall from September–March at the two sites was compared using a Wilcoxon rank sum test (NPARIWAY procedure, SAS Institute, 1989b).

Decomposition

Litter bags (15 × 15 cm) were constructed of fibre glass window screening (1 mm mesh) and filled with 5 g of air-dried cottonwood leaves. These leaves were collected in October as senescent leaves from 10 *P. fremontii* growing near the study sites. Each year, 20 decomposition bags were placed at the study sites and then retrieved in sets of five in late October or early November, on the initial day of placement, mid-April, late June and one year after placement. In the laboratory, the contents of the decomposition bags were oven-dried at 60°C for 48 hours, weighed and ashed. Ash-free dry weights of the litterbag contents at control and flood sites were compared on each collection date using a Wilcoxon rank sum test (NPARIWAY procedure, SAS Institute, 1989b). Significance values were Bonferroni-adjusted for multiple comparisons within each year.

Forest floor litter storage

The standing stock of forest floor litter was sampled during April and September of each year. On each sampling date we collected ten 10 × 10 cm randomly located samples of forest floor litter, removed down to the mineral soil horizon. Samples were taken back to the laboratory where they were dried at 60°C for 48 hours, weighed and ashed to determine the ash-free organic matter. Variation in forest floor organic matter across sites, years and collections was analysed using an ANOVA of square-root transformed ash-free dry weights (ANOVA procedure, SAS Institute, 1989a).

RESULTS

Litter production

Before the experimental flood, cumulative litter fall was very similar at the two study sites during both 1991–1992 (Wilcoxon, $p > 0{\cdot}05$, Figure 1a) and 1992–1993 (Figure 1b). In 1991–1992, the mean cumulative litter falls at the control and experimental sites were $46{\cdot}8 \pm 4{\cdot}04$ g/0·2 m^2 and $52{\cdot}5 \pm 4{\cdot}78$ g/0·2 m^2, respectively. In 1992–1993, the mean cumulative litterfalls at the control and the experimental sites were $47{\cdot}6 \pm 3{\cdot}81$ g/0·2 m^2 and $47{\cdot}5 \pm 4{\cdot}72$ g/0·2 m^2, respectively. After the experimental flood, however, the cumulative litter fall was significantly lower ($z = 2{\cdot}223$, $p = 0{\cdot}026$) at the experimental site ($42{\cdot}44 \pm 3{\cdot}74$ g/0·2 m^2) than at the control site ($59{\cdot}5 \pm 5{\cdot}78$ g/0·2 m^2, Figure 1c).

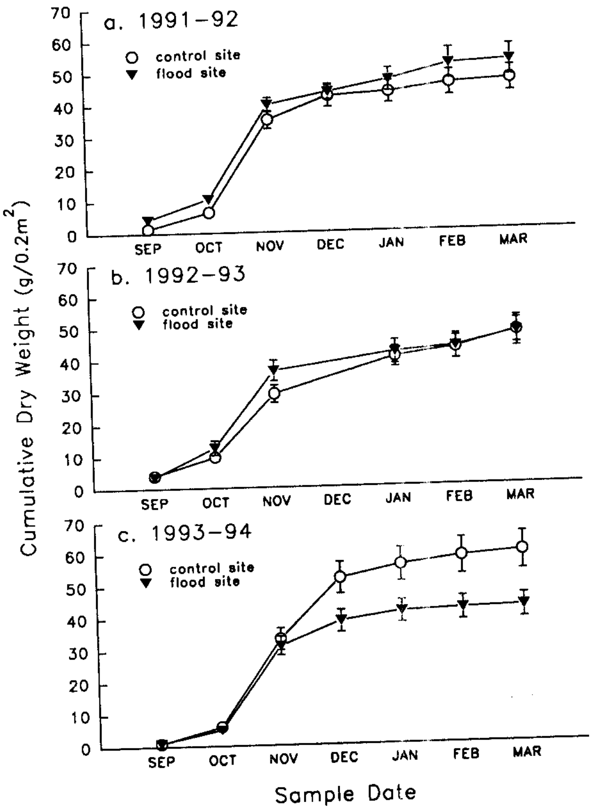

Figure 1. Mean cumulative dry weight (g/0·2 m^2) of litter fall at the flood and control sites during (a) 1991–1992, (b) 1992–1993 and (c) 1993–1994 (post-flood). Bars are one standard error ($n = 12$)

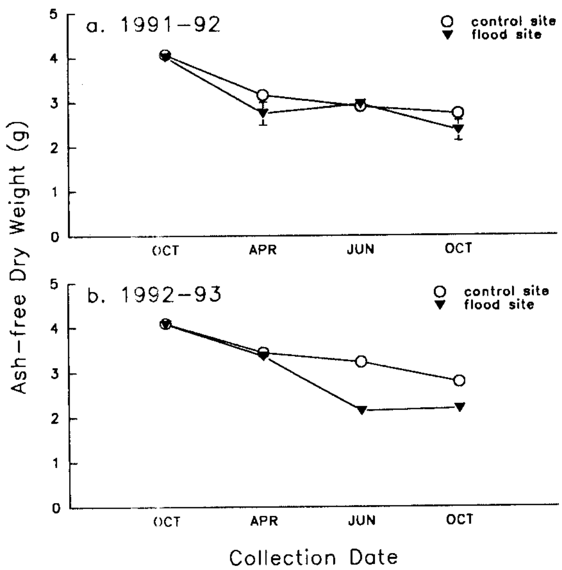

Figure 2. Mean ash-free dry weight (g) of leaves during decomposition at the flood and control sites in (a) 1991–1992 and (b) 1992–1993 (last two points are post-flood). Bars are one standard error ($n = 5$)

Decomposition

Our results indicated greater leaf mass loss at the flood site during and following the flood. In 1991–1992, patterns of leaf mass loss at the two sites closely paralleled each other (Figure 2a). At the end of the season the mean ash-free dry mass remaining in the litter bags at the control site was $2{\cdot}75 \pm 0{\cdot}05$ g versus $2{\cdot}35 \pm 0{\cdot}23$ g at the flood site. In 1992–1993, however, flooding produced a steep decline in litter weights at the cottonwood flood site (Figure 2b), with an average of $2{\cdot}18 \pm 0{\cdot}03$ g ash-free dry mass remaining at the flood site compared with $2{\cdot}78 \pm 0{\cdot}07$ g ash-free dry mass remaining at the control site. Pairwise comparisons between the control and flood sites indicated no significant differences during 1991–1992 or for the first two collections before flooding in 1992–1993 (Wilcoxon, $p > 0{\cdot}05$). However, differences in residual leaf mass at the two sites were significantly different in collections after the flood ($z = 2{\cdot}51$, $p = 0{\cdot}0122$).

Forest floor litter storage

ANOVA indicated significant temporal changes and treatment effects on forest floor litter (year, $F_{2,90} = 5{\cdot}04$, $p = 0{\cdot}008$; treatment, $F_{1,90} = 11{\cdot}73$, $p = 0{\cdot}0009$). For instance, the standing stock of forest floor litter decreased significantly at the control site from a mean of $17{\cdot}44 \pm 1{\cdot}65$ g ash-free dry mass/$0{\cdot}01\ m^2$ in September 1992 to $7{\cdot}86 \pm 2{\cdot}12$ g ash-free dry mass/$0{\cdot}01\ m^2$ in September 1993. Forest floor litter also declined at the flood site over this time period, decreasing from a mean of $9{\cdot}68 \pm 2{\cdot}86$ g ash-free dry mass/$0{\cdot}01\ m^2$ in September of 1992 to $8{\cdot}29 \pm 1{\cdot}57$ g ash-free dry mass/$0{\cdot}01\ m^2$ in September of 1993. Forest floor litter has tended to be lower at the flood site, even in the absence of flooding (Figure 3). However, in September 1993 following the experimental flood, the standing stock of litter was very similar at the flood and control sites, indicating that the flood had no detectable effect on the standing stock of forest floor litter.

DISCUSSION

Litter production

Reduced litter production at the flood site is consistent with results obtained by Shure and Gottschalk (1985) and Bell *et al.* (1978), who encountered reduced litter production at their wettest riparian study sites. However, the lower mass of litter produced at the flood site does not necessarily mean that fewer leaves

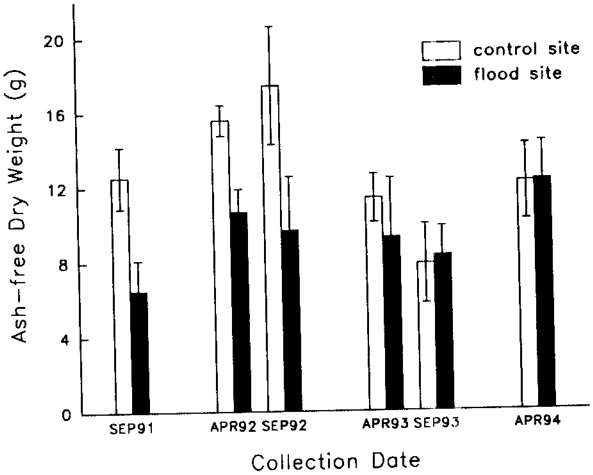

Figure 3. Mean ash-free dry weight (g) of forest floor litter at the flood and control sites during 1991–1994. Bars are one standard error ($n = 10$)

were produced at that site. The leaf quality could have differed significantly. Trees can respond to differences in nutrient availability and environmental factors by altering the structural composition of leaves (Horner *et al.*, 1987; 1993). Trees at the flood site may have put less energy into the production of lignin and waxy cuticles. We will assess leaf number and quality as well as mass of litter fall in response to future manipulative floods.

Leaf decomposition

The majority of work on decomposition in riparian zones indicates higher rates of decomposition at flooded sites than at non-flooded, elevated sites (Bell *et al.*, 1978; Peterson and Rolfe, 1982; Shure *et al.*, 1986). However, research by Chauvet (1988) indicates that the burying of litter by sediments may slow the decomposition of litter in riparian zones. Therefore, sedimentation effects may complicate analyses of the influences of flooding on decomposition rates. Another complicating factor is that many of the comparisons of decomposition in riparian versus upland sites have involved the litter of different plant species in the different study sites (e.g. Peterson and Rolfe, 1982; Shure *et al.*, 1986). Therefore, the results of these previous studies cannot be compared directly with the present study, which compares decomposition of leaf tissues from the same tree species, *Populus fremontii*, under flooded and non-flooded conditions.

Flooding may influence leaf decomposition and riparian ecosystem processing in several ways. Firstly, there may be rapid leaching of materials from leaves in response to wetting during the flood. The leaves of deciduous trees may lose up to 30% of their weight during just 24–48 hours of immersion in water (Cummins, 1974; Webster and Benfield, 1986; Bärlocher, 1992). Flooding may also affect the timing of nutrient release. Without flooding, most nutrient release in the Rio Grande Valley of central New Mexico would probably occur during the summer rains of early July–September. Consequently, nutrient release would be delayed until after the peak of the growing season. Under the historical flooding regime, nutrient release would usually occur during late May–early June, early in the growing season. Consequently, the historical flooding regime may have accelerated nutrient cycling within the Rio Grande riparian ecosystem of central New Mexico.

Forest floor litter

A number of studies have reported a reduced standing stock of forest floor litter from flooded sites (e.g. Bell and Sipp, 1975; Peterson and Rolfe, 1982). However, there may be several reasons why we did not observe significant reductions in forest floor litter in response to the experimental flood. A single, low intensity flood may remove such a small portion of the standing stock of litter that we could not detect a flooding effect. The current project is designed to examine the long-term cumulative effects of flooding and we did not expect an immediate response from a riparian ecosystem that has had 50 years without flooding. In addition, litter stored on the forest floor may be dominated by recalcitrant organic compounds and their decomposition may be more limited by nitrogen availability than by moisture.

Large-scale climatic influences may have also affected our results. Both 1991–1992 and 1992–1993 were El Niño years during which central New Mexico receives higher than normal autumn, winter and spring precipitation (Ropelewski and Halpert, 1986; Molles *et al.*, 1992). Wet conditions may have increased the rates of decomposition, particularly in the cottonwood control site, and obscured any potential contrast between the control and flood sites. Responses to additional experimental flooding during years of drier climatic conditions may help to differentiate among these factors.

CONCLUSIONS

Litter fall was lower at the flooded site than at the control site. Leaf mass loss was greater at the flood site during and following the experimental flood. However, the experimental flood did not produce a measurable response in the standing stock of forest floor litter. The pool of litter on the forest floor may require the cumulative effects of several years of flooding to show a measurable response. Over the long term we expect that manipulative flooding will reduce the standing stock of forest floor litter in the riparian forests along the Rio Grande in New Mexico and thereby increase the rate of nutrient cycling through the ecosystem.

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