

# Influence of Flood Connectivity on Bottomland Hardwood Forest Productivity in Central Ohio

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**ABSTRACT.** Aboveground net primary productivity (ANPP) in response to flooding and other environmental variables was evaluated at a 5.2-ha bottomland hardwood forest along the Olentangy River in central Ohio, USA. The forest is composed of two distinct sections that were hydrologically enhanced in 2001. To approximate natural flooding, the north section was enhanced by cutting three breaches in a more than 70-year-old artificial levee. A fourth breach was cut from a natural riverbank in the south section to connect a lateral swale and augment the existing flood regime. The objective of this study was to evaluate various factors that might affect forest productivity after restoration. In 2004, ANPP for the forest was estimated at  $847 \pm 50 \text{ g m}^{-2} \text{ yr}^{-1}$  ( $807 \pm 86 \text{ g m}^{-2} \text{ yr}^{-1}$  in the north section and  $869 \pm 86 \text{ g m}^{-2} \text{ yr}^{-1}$  in the south section). Mean ANPP for the entire forest was similar to an estimate prior to restoration and still below productivity levels reported at other bottomland forests along the Olentangy River and throughout the Midwest U.S. As part of this study, the influence of flood connectivity and other variables on intra-forest ANPP were also examined. Using daily river-stage data and by monitoring study plots at various flood stages, we estimated the number of days each plot was connected to the river. A significant and positive relationship was detected between plot ANPP and the number of days connected to the river during the 2004 water year (Oct. 2003–Sept. 2004). Forest ANPP was also significantly related to total tree basal area and topographic variability.

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## INTRODUCTION

Flood-control measures such as levees and dams have significantly altered bottomland forests in the United States and around the world (Nilsson and Berggren 2000, Hart et al. 2002). Because of the importance of flooding to bottomland ecology, hydrologic restoration is often prescribed where possible to restore ecological conditions and functions (Mitsch and Jørgensen, 2004). In their natural condition, bottomland forests are often highly productive because of the regular influx of nutrients, materials and energy from adjacent waterways; when flooding is reduced, forest ecology and productivity may be substantially altered (Nilsson and Berggren 2000, Robertson et al. 2001). The influence of floods on bottomland productivity has been the subject of numerous studies (Mitsch and Ewel 1979, Brown and Peterson 1983, Taylor et al. 1990, Mitsch et al. 1991, Megonigal et al. 1997, Tockner et al. 2000), and most have concluded that flooding has an important influence on these ecosystems. Along the Danube River in Austria, Tockner et al. (2000) found that floodplains were most productive when the hydrologic connection between river and floodplain alternated between a “disconnection phase” (during low river levels) and a “seepage/downstream surface connection phase” when an influx of low energy floods occurred. However, other studies have shown that the influence of flooding is less clear or may have conflicting effects on forest productivity. Mitsch and Rust (1984) found poor correlations between flood frequencies and tree basal growth along the Kankakee River in Illinois and Megonigal et al. (1997) found that there was little difference in productivity between periodically flooded and nearby non-flooded forest communities in the Southeast U.S. Both studies surmised that the benefit of floods as a nutrient subsidy may be negated by the physiological stress they can cause trees.

Although it has been assumed that restoring a more natural hydrology will ultimately restore ecological functions to a

bottomland forest, few studies have actually demonstrated this. One challenge of documenting this effect is the unknown time that may be needed. It is still relatively unknown how quickly a forest responds to a restored hydrology (or many other environmental stimuli) although it has been suggested that fully restoring forested wetlands may take decades (Mitsch and Wilson 1996). Several studies looking at canopy tree growth in response to environmental changes have shown multi-year delayed responses (Rentch et al. 2002, Holgen et al. 2003, Jones and Thomas 2004). Detecting a flood influence can also be difficult because of confounding factors that influence productivity. Geomorphology, soils, species composition, and precipitation are all factors that are related to hydrology but may elicit differences in forest productivity.

To increase our understanding of flood connectivity and bottomland forest restoration, a long-term study was initiated at the Wilma H. Schiermeier Olentangy River Wetland Research Park (ORWRP) in central Ohio. Hydrologic restoration at the bottomland forest was completed in April 2001 as part of a wetland mitigation project. These measures were expected to restore a more natural flood regime and associated bottomland functions including forest productivity. This bottomland was evaluated prior to restoration and showed relatively low productivity compared to other unrestricted forests along the Olentangy River and throughout the Midwest U.S. (Cochran 2001). The research described here examined the early response of forest productivity to hydrologic restoration. Our primary objective was to determine if greater flood connectivity within the bottomland forest elicited higher aboveground net primary productivity (ANPP). Secondarily, we were interested to see if hydrologic restoration had increased forest ANPP after more than three years.

## METHODS

### Study Site

The study was conducted at a 5.2-ha bottomland hardwood forest at the Wilma H. Schiermeier Olentangy River Wetland Research Park (ORWRP) along the Olentangy River, a fourth order river in central Ohio, USA (Fig. 1). The bottomland is a linear forest between 25–90 m wide and extends along the river for approximately 730 m. The forest consists of two sections (north and south, Fig.

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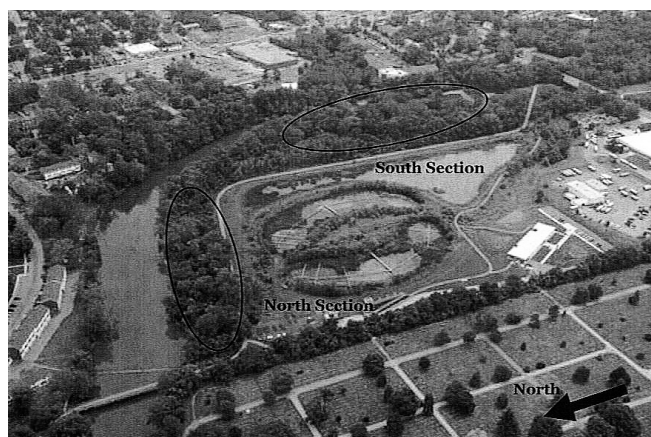


FIGURE 1. Aerial photograph of the bottomland hardwood forest at the Olentangy River Wetland Research Park indicating the north and south sections. Photograph was taken on 7 July 2005.

1) that remain separated even during high flood events (personal observation). It is an uneven-aged forest and based on calculated importance values at the time of the study, dominant tree species ( $IV_{300} > 35$ , Anderson 2005) in the north section were boxelder (*Acer negundo* L.), Ohio buckeye (*Aesculus glabra* Willd.), paw paw (*Asimina triloba* L.) and hackberry (*Celtis occidentalis* Willd.) while dominant trees in the south section consisted of *A. negundo*, *A. glabra* and eastern cottonwood (*Populus deltoides* Bartr. Ex). Soils

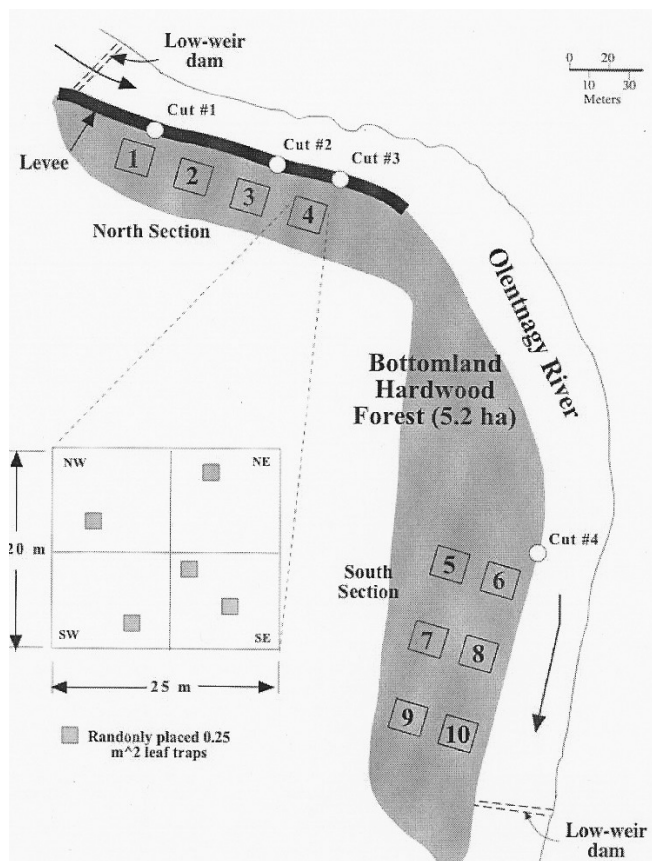


FIGURE 2. Experimental configuration at the Olentangy River Wetland Research Park bottomland hardwood forest indicating the location and dimensions of tree plots and litter traps. Each tree plot was divided into four quadrants (NW, NE, SW, and SE) for placement of random litter traps including a fifth trap near the plot center. Hydrologic restoration was conducted by breaching a levee (Cuts #1-3) along the north section and breaching the river bank at the south section (Cut #4).



FIGURE 3. Photograph of bank-full flooding into Cut #1 taken in May 2003. Note the remnant levee at the far side of the cut.

in the bottomland were alluvial Ross series (classified as a Cumlic Hapludoll) soils and consisted of silt loam, silt clay, and clay loams (McCloda and Parkinson 1980).

Restoration measures were conducted to restore a flooding regime that resembles the flashiness typical of low-order streams and rivers in this region. Because of a reservoir approximately 40 km upriver, river fluctuations along this section of the Olentangy River tend to be moderated and floods are most often dependent upon local rain events. The north section of the forest was previously disconnected from the river by a constructed levee (up to 2 m high) built over 70 years ago and extending along a 250 m stretch of the river. In June 2000, three breaches (Cuts #1-3, Fig. 2) were cut along the levee and floodwater now regularly flows into and out of this section during bank-full river events (Fig. 3, Zhang and Mitsch 2007). The levee only affected the north section of the bottomland. The south section was less restricted and periodically flooded; however expansive floods were infrequent and only occurred during extremely high river events. To increase flood connectivity and flow-through conditions, a fourth breach (Cut #4, Fig. 2) was cut through a natural riverbank to a lateral swale that extends through the south section. Breaches were adjusted in April 2001 to improve connectivity between the river and floodplain.

Studies were conducted prior to the bottomland restoration to assess existing conditions. Using plot-level data from Cochran (2001), mean ANPP in the flood-prone portions of the bottomland were estimated at  $813 \text{ g m}^{-2} \text{ yr}^{-1}$  for 2000 with lower productivity in the north section ( $542 \text{ g m}^{-2} \text{ yr}^{-1}$ ,  $n=2$ ) compared to the south section ( $950 \text{ g m}^{-2} \text{ yr}^{-1}$ ,  $n=4$ ). This was substantially lower than ANPP estimated at the same time at two other unrestricted bottomlands upriver (but still below the reservoir) that averaged  $1290 \text{ g m}^{-2} \text{ yr}^{-1}$ . Higher productivity in the unrestricted forests was attributed to their ability to receive river influx and the higher proportion of species adapted to flood conditions (Cochran 2001). Subsequent to hydrologic restoration, other measures at the ORWRP bottomland included control of invasive Amur honeysuckle (*Lonicera mackii* Maxim.) in the north section of the forest (Swab and Mitsch in press).

### Hydrology and Precipitation

Since 1994, river stage has been measured twice nearly every day using a permanent staff gauge immediately upriver from the ORWRP bottomland. Starting in 2003, whenever floods occurred



in the bottomland we recorded the spatial extent of flooding relative to river stage, river inflow sources (i.e. Cuts #1-4), internal flow patterns, and water depths. To compare with river conditions during the pre-restoration study, hydrographs dating back to October 1997 were prepared and compared to conditions leading up to this study. Similarly, precipitation data from this time period were compared with long-term averages from a Columbus, Ohio weather station operated by the Ohio Agricultural Research and Development Center ([www.oardc.ohio-state.edu/centernet/weather.htm](http://www.oardc.ohio-state.edu/centernet/weather.htm)).

### Aboveground Net Primary Productivity

Consistent with previously used methods in the ORWRP bottomland (Cochran 2001), wood and litterfall productivity were estimated to determine forest ANPP (Newbould 1967). Transects were randomly established in both sections but were designed to extend parallel to the river and through the flood-prone sections of the forest. Because the forest was wider in the south section, parallel transects were used to increase plot replication. A total of 10 plots (20 x 25m each, 0.05 ha) were measured and marked in the field (Fig. 2). It was noted during the study that Plot #5 in the south section (Fig. 2) was too high in elevation to become regularly flooded (unlike all the other plots) and therefore it was omitted from analyses.

In each plot, all trees with a dbh (diameter at breast height, 1.3m) >5cm were identified by species, tagged and measured for dbh in early April 2004 and late March 2005. These data were used to calculate the annual increase in tree basal area ( $A_i$ ) ( $\text{cm}^2 \text{yr}^{-1}$ ) using the following equation (Newbould 1967):

$$A_i = \pi [r^2 - (r-i)^2] \quad (1)$$

Where,  $r$  = radius of tree at breast height (cm), and  
 $i$  = radial increment per year ( $\text{cm}^2 \text{yr}^{-1}$ )

Tree heights were measured using a clinometer in May 2005 and the annual wood production per tree ( $P_i$ ) ( $\text{g yr}^{-1}$ ) was calculated by the following parabolic volume equation (Whittaker and Woodwell 1968, Phipps 1979):

$$P_i = 0.5\rho A_i h \quad (2)$$

Where,  $\rho$  = wood specific gravity ( $\text{g cm}^{-3}$ ), and  
 $h$  = tree height (m)

Wood specific gravity values were obtained from the U. S. Forest Products Laboratory (1974) and Alden (1995). The plot wood production was calculated as the summation of all tree wood production and converted to  $\text{g m}^{-2} \text{yr}^{-1}$ .

A total of 50 leaf litter traps (five per plot) were installed in May 2004. Each plot was divided into four quadrants and a leaf trap was randomly placed in each quadrant with a fifth trap randomly placed near the center (Fig. 2). Leaf traps were 15 cm tall, 0.25  $\text{m}^2$  in area, lined with a 2-mm screen and installed approximately 1.0 m off the ground to avoid flooding and litter saturation. Litterfall was collected for one year starting in May 2004. Traps were emptied twice a month from May to December and once a month from January to May. After each collection, the contents were separated into leaves, reproductive material, and woody material; air-dried at room temperature for one week; and then oven-dried at 105° C for four days or until constant mass prior to being weighed. Leaf traps were averaged per plot and the summation of all fine litter

production (leaf litter and reproductive materials) was calculated. Because of vandalism or flood/ice damage, several sampling periods had plots with less than the five traps available and in these instances were averaged using the undamaged plots. Using litterfall and wood production data, aboveground net primary productivity (ANPP) ( $\text{g m}^{-2} \text{yr}^{-1}$ ) for each plot was estimated using the following equation (Whittaker and Woodwell 1968):

$$\text{ANPP} = \text{plot wood production} + \text{plot fine litterfall production} \quad (3)$$

### Influencing Factors on ANPP

Flooding regime and other environmental factors that may influence forest growth were evaluated relative to plot ANPP in 2004. The river hydrograph and observations of flood extent at different river stages were used to determine the number of days that the river connected directly into each plot (a "flood connection") during the 2004 water year (October 2003-September 2004).

Other forest parameters were used to evaluate their influence on plot ANPP. Mean elevation (m MSL) for each plot was calculated by surveying each corner and each of the leaf litter traps within it (Fig. 3). Elevations were measured using an Ohio Department of Transportation benchmark and a TOPCON RL-H3C™ rotating laser level. To assess the potential influence of topographic variability, the variance of all elevations for each plot was also calculated. Other parameters used as predictor variables included canopy cover (%) and tree basal area ( $\text{cm}^2 \text{m}^{-2}$ ). Canopy cover was estimated for each plot in August 2004 using a convex spherical-crown densitometer. Cover was measured at each trap facing the four cardinal directions and the mean of all measurements was calculated for each plot. Tree basal area per plot was calculated based on the total basal area of all trees >5 cm dbh measured in April 2004.

Regression analysis was used to evaluate the relationships between forest productivity (ANPP and the components of ANPP- litterfall production and wood production) and the measured environmental variables [flood frequency (number of flood connected days per year), elevation, topographic variability, total tree basal area and canopy cover] at each plot. Significance of the regression analyses was tested by analysis of variance with p-values <0.05 considered significant. An unpaired t-test was used to detect differences in mean plot ANPP between the north and south sections and detected differences in mean plot ANPP using Cochran's 2000 data (pre-restoration) and data from this study (post-restoration). For both tests p-values <0.05 were considered significant. All variables were tested for normality using the Kolmogorov-Smirnov test and homogeneity of variances using Levene's test. Variables not meeting test assumptions were transformed as needed. Minitab™ v.14 was used to run all statistical analyses (Minitab, Inc. 2003).

## RESULTS

### Hydrology and Climate

Based on records of precipitation and Olentangy River levels (Fig. 4a and b), conditions during the study period were wetter than normal and much wetter than in the years leading up to the bottomland restoration. During the 2004 water year, a total of five flood events occurred and floods connected to study plots 11-36 days (Fig. 4a, Table 1). Starting in 2002, the minimum bank-full flood levels (>221.2 m MSL) were much more frequent than in previous years due to an exceptionally wet spring and summer

season although total annual precipitation was offset by drier than normal winter seasons (Fig. 4b).

Observed floods tended to be short-term events that rarely lasted more than a few days. River levels tended to rapidly rise and then fall back to normal flow levels (220.6 m MSL, Fig. 4a). It was normal for water to rapidly recede from low spots in the forest after several days, depending upon flood stage, post-flood river levels and season. The one exception was after winter floods where water often froze in the bottomland and stayed for several weeks. Spring/summer floodwaters typically dried out the quickest presumably because of enhanced evapotranspiration.

#### Bottomland ANPP and Influencing Factors

Based on plot-level flood and productivity data, a significant

relationship was found between plot ANPP and the total number of days flooded in the 2004 water year ( $R^2=0.45$ ,  $P=0.04$ , Fig. 5). Flood frequency did not have an influence on the separate components of ANPP (litterfall or wood production). Both ANPP and wood production were also significantly influenced by plot topographic variability (elevation variance was log-transformed to meet normality assumptions) and total tree basal area ( $\text{cm}^2 \text{m}^{-2}$ ) (Fig. 6a and b). Aside from those noted, no significant relationships were detected between any predictor variables and ANPP or its individual components (litterfall and wood production).

There was a substantial range in mean plot elevation and plot elevation variance (Table 1) in both the north and south sections of the forest. Topographic variability (plot elevation variance) was primarily due to flood induced ridges and swales in the south

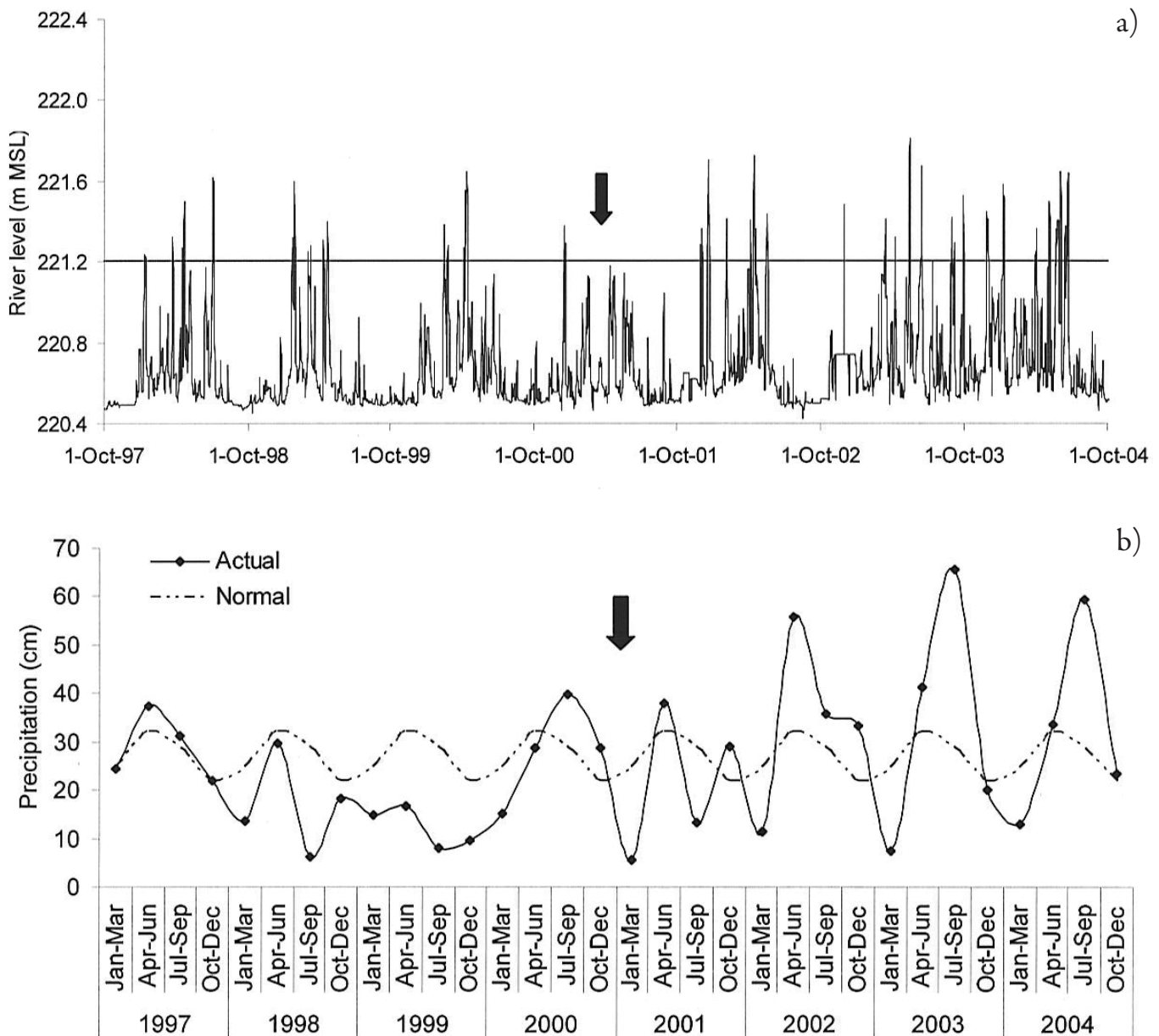


FIGURE 4. Patterns of a) daily river stage at the study site (1997-2004) and b) mean quarterly precipitation. Hydrologic restoration was carried out in June 2000 and completed in April 2001 (indicated by the arrows). The horizontal line indicates the bank-full flooding level (221.2 m above MSL) for the bottomland. Quarterly normal and recorded precipitation is for Columbus, Ohio based on data collected from the Ohio Agriculture and Development Center weather station ([www.oardc.ohio-state.edu/centernet/weather.htm](http://www.oardc.ohio-state.edu/centernet/weather.htm)). Hydrograph of river water levels for the Olentangy River for 1997-2004 based on data collected at the Olentangy River Wetland Research Park (Mitsch and Zhang 2004).

Table 1

*Synopsis of tree plot environmental data for the Olentangy River  
Wetland Research Park bottomland forest in 2004*

Plot environmental parameters	Mean ( $\pm 1$ SE)	Range
Aboveground NPP ( $\text{g m}^{-2}\text{yr}^{-1}$ )	$847 \pm 50$	622 - 1071
Number of flood events connected with river	$4.4 \pm 0.2$	4 - 5
Number of flood days connected with river	$25.7 \pm 3.4$	11 - 36
Plot elevation mean (m above MSL)*	$221.38 \pm 0.07$	221.08 - 221.86
Plot elevation variance*	$0.12 \pm 0.04$	0.02 - 0.43
Canopy cover (%)	$81.7 \pm 1.3$	72.9 - 88.2
Basal area ( $\text{cm}^2/\text{m}^2$ )	$39.2 \pm 4.2$	24.9 - 65.0

\*Plot elevation mean and variance were based on nine measured elevations per plot: the four corners and at each of the five randomly placed leaf traps (see Fig. 2).

section while much of the variability in the north section was attributed to spoil associated with the levee remnant. Differences in mean percent canopy cover among plots were relatively minor and ranged between 73 and 88% (Table 1).

Mean litterfall, wood production and ANPP for the bottomland were estimated at  $513 \pm 24$ ,  $328 \pm 38$ , and  $847 \pm 50 \text{ g m}^{-2} \text{ yr}^{-1}$  respectively and total ANPP ranged from 622 to  $1071 \text{ g m}^{-2} \text{ yr}^{-1}$  among plots (Table 1). There were no significant differences between mean ANPP in the north section ( $820 \pm 97 \text{ g m}^{-2} \text{ yr}^{-1}$ ) and the south section ( $869 \pm 56 \text{ g m}^{-2} \text{ yr}^{-1}$ ) based on a t-test ( $P=0.68$ ,  $T=-0.44$ ,  $df=4$ ). There were no significant differences detected between mean ANPP from comparable data in the pre-restoration (Cochran 2001) and post-restoration ANPP ( $P=0.81$ ,  $T=-0.25$ ,  $df=6$ ).

## DISCUSSION

### Factors Influencing Plot-Scale ANPP

Although the ORWRP bottomland did not show conclusive changes in pre- and post-restoration productivity, our results indicate that surface-water flooding had an important influence on ANPP in 2004. Plot-level responses to flooding were likely

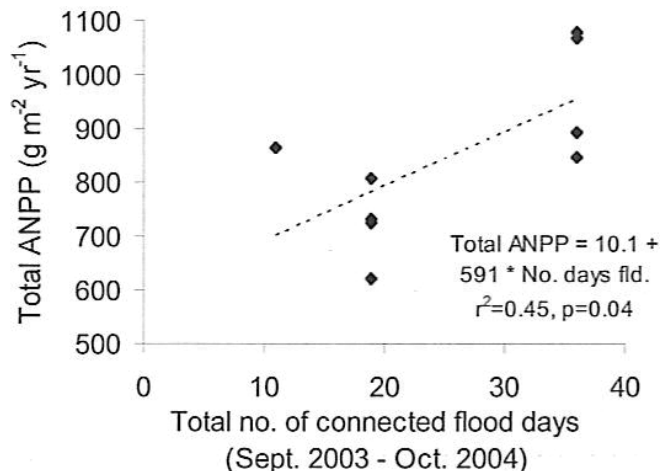


FIGURE 5. Linear relationship between aboveground net primary productivity in 2004 and the number of days flooded in water year 2004 (Oct. 2003-Sept. 2004) for experimental plots.

due to some combination of higher nutrient inputs and increased soil moisture. The study site is located within the urban setting of Columbus, Ohio and after storm events the Olentangy River can have high nutrient loads from surrounding urban runoff and occasional sewage overflow. These floods have been shown to deposit high amounts of sediment and nutrients into the bottomlands. Zhang and Mitsch (2007) monitored flood events from 2003 to 2005 at the ORWRP bottomlands and found that individual floods deposited  $127\text{--}149 \text{ g-dry sediment m}^{-2}$ ,  $5.2\text{--}19.9 \text{ g-C m}^{-2}$ ,  $0.49\text{--}0.92 \text{ g-N m}^{-2}$ , and  $102\text{--}119 \text{ mg-P m}^{-2}$ . Flooding also improves soil water availability which has been shown to be an important growth factor for trees at higher elevations in the ORWRP bottomland (Dudek et al. 1998). This can be particularly important for extending tree growth into the summer as river water levels subside and floods become relatively rare. In the 2004 water year, periodic flooding occurred up until late June and likely supported tree growth further into the summer.

In addition to providing a nutrient subsidy, floods likely had an indirect influence on productivity through geomorphic processes. Our data showed that topographic variability within plots also had a significant influence on ANPP. Floodplain bottomlands often have diverse topographies consisting of repeated ridges, swales and meandering scrolls (Leopold et al. 1964). The most variable topography is usually in close proximity to the river where flood energies are highest and scouring/sediment transport is most

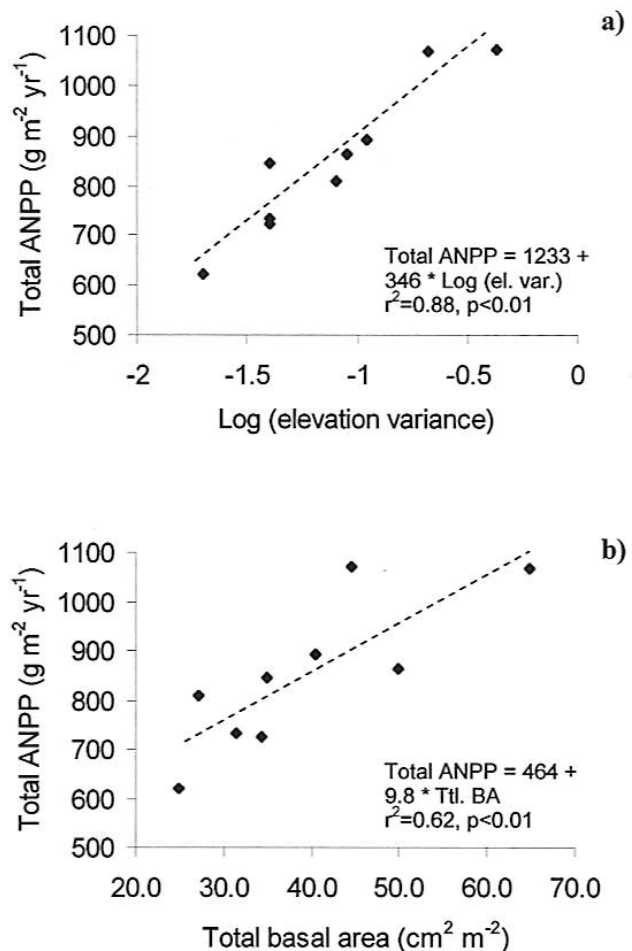


FIGURE 6. Linear relationship between aboveground net primary productivity in 2004 and a) topographic variability (log elevation variance) and b) total basal area for experimental plots.



prevalent. In the case of the ORWRP bottomland, topographic variability was provided by a series of swales and ridges in the south section, but in the north section it was also provided by sloughed spoil from the remnant levee. Consequently, bottomland plots with high topographic variability were not always those most frequently flooded (there was a poor correlation between topographic variability and flooding frequency,  $r=0.10$ ), but nevertheless they tended to have higher ANPP.

Topography has been shown to influence forest productivity in the southern Appalachian (Bolstad et al. 2001), riparian plant diversity in Alaska (Pollock et al. 1998), and canopy gap regimes in a Texas bottomland forest (Almquist et al. 2002); however there is little information in the literature linking topographic variability and bottomland productivity. For trees growing in flood prone areas, an uneven topography could allow surficial roots to grow along a greater elevation range. During floods, these trees would be more likely to have some portion of their surficial roots above inundation and therefore less susceptible to the physiological stresses. At the ORWRP bottomland, the highest topographic variability (and highest ANPP) occurred at a plot with an elevation range of approximately 1.0 m, while the lowest variability (and lowest ANPP) occurred in a plot with an elevation range of only 0.1 m. Topography has been cited as a reason for trees often having higher growth rates on natural river levees where there is high accessibility to water and nutrients but less susceptibility to flooding stress (Martens 1993, Tardif and Bergeron 1993). This advantage may also be realized in areas further within floodplains with undulating topographies.

### Comparing Pre- and Post-Restoration ANPP

Despite evidence of the importance of flooding, our results suggested that four years after restoring hydrology, ANPP has not changed substantially. Mean ANPP for the bottomland forest was comparable to pre-restoration estimates made by Cochran (2001) and still well below productivity levels recorded for other bottomland forests along the Olentangy River and throughout the region. It is important to point out that this study did not include a control to account for inter-annual variation and therefore we cannot be conclusive. Nevertheless, we were surprised that the forest did not show a response in productivity due to the more frequent flooding and higher than normal precipitation compared to conditions leading up to 2000 (during the referenced pre-restoration study).

Because of the regular influx of water, nutrients, and material, bottomland forests are usually highly productive with ANPP commonly  $>1000 \text{ g m}^{-2} \text{ yr}^{-1}$  (Taylor et al. 1990). At two other unrestricted bottomland forests upriver from the ORWRP site (both within 12 km), forest ANPP was estimated at 1283 and 1297  $\text{g m}^{-2} \text{ yr}^{-1}$  (Cochran 2001). Furthermore, ANPP in comparable forests throughout the Midwest have been measured and found to be substantially higher than estimates made at the ORWRP bottomland. Bottomland forest ANPP was estimated at 1280 and 1334  $\text{g m}^{-2} \text{ yr}^{-1}$  for two forests along the Ohio River in western Kentucky (Mitsch et al. 1991) and 1250  $\text{g m}^{-2} \text{ yr}^{-1}$  for a floodplain forests in Illinois (Johnson and Bell 1976). The disparity between ANPP at the ORWRP and other bottomland studies may be in part due to forest age and composition. Although there were sizable canopy trees in the bottomland (Anderson 2005), much of the forest was dominated by early successional trees (e.g. *Acer negundo*, *Populus deltoides*) that commonly establish after disturbances (Hupp and Osterkamp 1996). We have demonstrated that forest

basal area is an important predictor for ANPP (Fig. 6b) and more mature forests may be inherently more productive.

Although no conclusive shift in overall forest productivity was determined post-restoration, we have demonstrated that flood connectivity plays a role. It may take much longer for trees to acclimate (or species shifts to occur) in response to the restored flooding regime. There is some evidence to suggest that changes are imminent. Tree ring and basal area increment data from canopy trees in the ORWRP bottomland (particularly *A. negundo*) showed evidence of increased radial growth in 2003 and 2004 relative to trends dating back 15 years (Anderson 2005). Given the frequent flood conditions that have continued since 2002, this suggests a time lag between increased flooding and forest productivity. Lagged tree responses have been reported for other factors such as climate (Fritts 1976, Camill and Clark 2000), crown thinning (Jones and Thomas 2004, Rentch et al. 2004) and the removal of shelterwoods (Holgen et al. 2003). Continued monitoring will reveal if this is the beginning of a new growth trend, but we expect that as trees continue to physiologically acclimate to the new flooding regime they will eventually respond with greater productivity.

## CONCLUSION

Hydrologic restoration of the ORWRP bottomland forest was conducted in 2000 and 2001 and, as a result, the north section received direct surface flows from river floods and the south section increased its surface flow and frequency. A significant relationship between plot ANPP and the number of days each plot was flooded was detected and likely reflected the higher nutrient and soil moisture provided by floods. Topographic variability was also an important influence on ANPP and may be due to the wider elevation range and associated variability in soil moisture afforded to trees growing in these areas. Consequently, forest plots with high topographic variability may receive the benefit of nutrient subsidies from floods while being less susceptible to flooding stresses. Based on overall forest ANPP estimates in 2000 and 2004, we did not detect an increase in ANPP as a result of the restoration effort despite increases in flood occurrence. Future increases in ANPP are possible however if the forest demonstrates a lagged response to flooding coupled with other restoration efforts such as honeysuckle (*Lonicera mackii*) removal.

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