Table 1. **Species transplanted into degraded areas of the Montes Azules Biosphere Reserve in Mexico and their mean (± SE) monthly growth rates in descending order.**

Species	Family	Common name		Growth (cm/month)
		Spanish	English	
Cecropia obtusifolia	Cecropiaceae	Guarumo	Trumpet tree	8.61 (0.87)
Ochroma pyramidale	Bombacaceae	Balsa	Balsa	5.37 (0.48)
Ceiba pentandra	Bombacaceae	Pochota	Kapok tree	5.01 (0.52)
Spondias mombin	Anacardiaceae	Jobo	Yellow mombin	3.62 (0.40)
Castilla elastica	Moraceae	Hule	Mexican rubber tree	2.75 (0.30)
Pachira aquatica	Bombacaceae	Sapote de agua	Money tree	1.75 (0.13)
Schizolobium parahybum	Fabaceae (Caesalpinoideae)	Plumillo	Brazilian firetree	1.50 (0.08)
Vatairea lundelli	Fabaceae (Faboideae)	Amargoso	Danto	1.37 (0.16)
Licania platypus	Chrysobalanaceae	Cabeza de mico	Licania	1.25 (0.09)
Ficus sp.	Moraceae	Amate	Fig	0.48 (0.05)
Pouteria sapota	Sapotaceae	Sapote	Naseberry	0.31 (0.006)
Brosimum alicastrum	Moraceae	Ramón	Breadnut	0.08 (0.01)

However, restoration opportunities inside the Reserve are limited by the continued presence of some settlements that are still being negotiated. We consider resolution of land tenure conflicts imperative to the ecological restoration of degraded areas inside the Reserve and its buffer zone.

Acknowledgments

Funding was provided by the Comisión Nacional para el Uso y Conocimiento de la Biodiversidad (CONABIO). We are also grateful for field assistance by local people from Nueva Palestina, Frontera Corozal and Lacanjáh-Chansayáb *ejidos*, and staff from CONANP—PROFEPA. We thank J. Carabias for her motivation to develop this project and C. Martínez-Garza for comments and suggestions.

References

Carabias, J., P. Meli, G. Hernández and G. Almeida. 2006. Estrategia de restauración ambiental y prevención de incendios en ejidos ribereños del Río Lacantún, colindantes a la Reserva de la Biosfera Montes Azules. Final Project Report INE/A1-004/2006. Facultad de Ciencias/UNAM—Instituto Nacional de Ecología, México.

de la Maza, R. 1997. El paisaje: La visión primigenia. *In* V.H. Hernández Obregón and E.A. Blanchard (coords), *Selva Lacandona: Un Paraíso en Extinción*. Mexico City: Pulsar.

Dirzo, R. 1994. *Diversidad de la Flora Mexicana*. Mexico City: Agrupación Sierra Madre.

Martínez-Garza, C., V. Peña, M. Ricker, A. Campos and H. Howe. 2005. Restoring tropical biodiversity: Leaf traits predict growth and survival of late-successional trees in early-successional environments. *Forest Ecology and Management* 217:365–379.

Mendoza, E. and R. Dirzo. 1999. Deforestation in Lacandonia (southeast Mexico): Evidence for the declaration of the northernmost tropical hot-spot. *Biodiversity and Conservation* 8:1621–1641.

Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT). 2006. 5.1.e. Las ANP de la Selva Lacandona: Problemática y estrategia de atención. Pages 144–148 *in La Gestión Ambiental en México*. Mexico City: SEMARNAT.

Hurricane Effects on the Piedmont Forests: Patterns and Implications

Weimin Xi (The Knowledge Engineering Lab, Dept of Entomology, Texas A&M University, College Station, TX 77843, xi@tamu.edu), Robert K. Peet (Dept of Biology, University of North Carolina at Chapel Hill, Chapel Hill, NC 29599-3280, peet@unc.edu)

Restoring forest damaged by catastrophic wind events is a significant task for landowners and forest managers in the eastern United States. A better understanding of disturbance effects and subsequent forest recovery is essential for effective damage assessment and restoration planning (Walker 1999). This is particularly important as ongoing climate change is likely to sustain increased hurricane activity for the foreseeable future (Goldenberg et al. 2001).

Historically, hurricanes have been a large, infrequent natural disturbance causing serious forest damage in the Piedmont region. On September 6, 1996, Hurricane Fran struck the central North Carolina Piedmont and caused severe damage to the Duke Forest, a Long Term Ecological Research area with many years of baseline data on tree, seedling, and herb dynamics, in some cases dating to the early 1930s (Peet and Christensen 1987). The availability of Duke Forest data spanning the years before and following Fran provided a unique opportunity to separate hurricane-induced changes from the background successional dynamics.

We resurveyed all long-term monitoring plots in the Duke Forest during 1997 and 2000. During the surveys, in addition to continuing measurement of vitality, diameter (dbh), height, and survival, we quantified hurricane damage status for each stem in the plots (Palmer et al. 2007, Xi et al. 2008b).

Hurricane Fran's strong winds and high precipitation resulted in a highly heterogeneous pattern of forest

Table 1. Resistance (in descending order) of tree species to hurricane damage for the major trees in the North Carolina Piedmont region, USA, based on our field observations on uprooting and breakage damage in the Duke Forest and consultations with experienced foresters.

Uprooting	Breakage
Common hackberry (*Celtis occidentalis*)	Common hackberry
Eastern redcedar (*Juniperus virginiana*)	Eastern redcedar
American hornbeam (*Carpinus caroliniana*)	Sweetgum
Hophornbeam (*Ostrya virginiana*)	Blackgum
Blackgum (*Nyssa sylvatica*)	Hophornbeam
Sweetgum (*Liquidambar styraciflua*)	Flowering dogwood
American sycamore (*Platanus occidentalis*)	Southern magnolia
Winged elm (*Ulmus alata*)	American hornbeam
Slippery elm (*U. rubra*)	Northern red oak
Northern red oak (*Quercus rubra*)	Water oak
White oak (*Q. alba*)	White oak
Scarlet oak (*Q. coccinea*)	Scarlet oak
Southern red oak (*Q. falcata*)	Southern red oak
Willow oak (*Q. phellos*)	Willow oak
Chestnut oak (*Q. prinus*)	Chestnut oak
Post oak (*Q. stellata*)	Post oak
Black oak (*Q. velutina*)	Black oak
Eastern redbud (*Cercis canadensis*)	Eastern redbud
American beech (*Fagus grandifolia*)	American beech
Tuliptree (*Liriodendron tulipifera*)	Tuliptree
Southern magnolia (*Magnolia grandiflora*)	American sycamore
Loblolly pine (*Pinus taeda*)	Shortleaf pine
Shortleaf pine (*P. echinata*)	Virginia pine (*Pinus virginiana*)
Water oak (*Quercus nigra*)	Loblolly pine
Red maple (*Acer rubrum*)	Black cherry
Southern sugar maple (*A. barbatum*)	Bitternut hickory
Flowering dogwood (*Cornus florida*)	Pignut hickory
Black cherry (*Prunus serotina*)	Shagbark hickory
Bitternut hickory (*Carya cordiformis*)	Mockernut hickory
Pignut hickory (*C. glabra*)	Southern sugar maple
Shagbark hickory (*C. ovata*)	Red maple
Mockernut hickory (*C. alba*)	Black walnut
Black walnut (*Juglans nigra*)	Winged elm
Sourwood (*Oxydendrum arboreum*)	Slippery elm

disturbance across the landscape (Xi et al. 2008a). Uprooting was the dominant damage type for canopy trees owing to soil saturation by the heavy rain immediately before and during the storm. Much of the damage was concentrated at the topographic extremes, particularly along stream bottom areas where the wettest soils were located and on slopes facing the primary force of the winds. Tree damage correlated positively with prehurricane tree size.

Fran significantly increased within-stand spatial heterogeneity as a result of the intense small-scale (subkilometer scale) boundary layer rolling effects (equivalent to the Langmuir cells in aquatic systems; Wurman and Winslow 1998, Xi et al. 2008b). In addition, the hurricane resulted in a substantial increase in tree-gap size and a dramatic rise in understory light. On average, mortality of large trees approximately doubled during the five-year period that spanned the hurricane event as compared to the prehurricane level. Increased mortality of hardwood trees was not confined to 1996, but continued for several years following the hurricane. These significant structural changes in the forest appear likely to substantially influence stand development and future composition.

The hurricane significantly diversified the live-tree size distribution in damaged forest stands. The density and size of trees of the upper canopy layer in both pine and hardwood forests decreased substantially. Small tree (1–3 cm dbh) density increased spectacularly for several rapid-growing, light-demanding hardwood species, such as tuliptree (*Liriodendron tulipifera*) and sweetgum (*Liquidambar styraciflua*). Particularly conspicuous was the increase in red maple (*Acer rubrum*) stem density in smaller size classes, suggesting that the hurricane accelerated the successional trend of more shade-tolerant but fire-sensitive species like red maple replacing oaks (*Quercus* spp.) and hickories (*Carya* spp.) in the eastern United States (Xi et al. 2008b).

Variation in tree species susceptibility to windthrow can partially explain within-stand variation in damage (Table 1). Tree susceptibility is determined by tree canopy characteristics, leaf features, and root system characteristics. Among large trees of the Duke Forest, Fran caused a higher incidence of damage in hardwoods than pines, as hardwoods usually have broad, spreading canopies and flat leaves that can catch the force of the wind much more readily than the smaller canopies and needles of pine trees (Xi et al. 2008a).

The most rapid changes following Fran were in the understory. Seedling density and species richness experienced an immediate drop, followed by a rapid rebound in density and more gradual recovery and enhancement in richness and diversity. Seedling recruitment did not increase continuously over time and overall seedling density was relatively low compared to prehurricane levels. Changes in sapling density and diversity were varied. This observation is consistent not only with the hypothesized relaxation of competition, but also the hypothesis that windthrows contribute greatly to tree diversity in the Piedmont (Peet and Christensen 1987).

Piedmont forests exhibit remarkable resilience to hurricane damage because of advanced regeneration. Canopy gaps created by the hurricane resulted in release of established shade-intolerant and partially tolerant seedlings and saplings (Figure 1). Most seedlings and saplings approximately doubled their relative growth rates after the hurricane, although not uniformly across tree species. Resprouting of damaged individuals and vegetative production of additional shoots were also common.

In contrast to the profound structural changes, hurricane-induced changes in tree species composition and diversity were modest and depended greatly on damage severity, prehurricane stand characteristics, and the temporal and spatial scales of observation. Tree diversity increased slightly or was maintained in most of the damaged forest stands as a result of colonization by light-demanding species. In addition, the disturbed forests experienced an increase in exotic tree species, such as princess tree (*Paulownia tomentosa*) and tree-of-heaven (*Ailanthus altissima*).

Large hurricanes have profound impacts on the Piedmont forests. The occurrence of Hurricane Fran has served to further document and clarify the variable and nonequilibrium nature of late-successional, mixed-aged hardwood forests of the Piedmont. Forest managers may use this information to assess the vulnerability of forest lands to hurricane damage and to design efficient campaigns for mapping tree damage after heavy storms. Our field observations of tree species resistance to hurricanes may help forest managers to select suitable trees when restoring forest damaged by catastrophic wind events. Finally, our research suggests that posthurricane monitoring to detect newly established populations of invasive plant species is important.

Figure 1. This 2001 photograph from the Bormann plot of Duke Forest shows several loblolly pine (*Pinus taeda*) and tuliptree (*Liriodendron tulipifera*) saplings established quickly after Hurricane Fran in 1996. Photo by Weimin Xi

Acknowledgments

We thank many dedicated field assistants for their help with fieldwork. We are grateful to Drs. Henry McNab, Coleman Doggett and Chris Reyes for their constructive comments. This work was supported by a grant from the U.S. National Science Foundation (DEB-97-07551).

References

Goldenberg, S.B., C.W. Landsea, A.M. Mestas-Nunez and W.M. Gray. 2001. The recent increase in Atlantic hurricane activity: Causes and implications. *Science* 293:474–479.

Palmer, M.W., R.K. Peet, R.A. Reed, W. Xi and P.S. White. 2007. A multiscale study of vascular plants in a North Carolina Piedmont forest. *Ecology* 88:2674.

Peet, R.K. and N.L. Christensen. 1987. Competition and tree death. *Bioscience* 37:586–595.

Walker, L.R. 1999. *Ecosystems of Disturbed Ground*. Ecosystems of the World, vol. 16. Amsterdam: Elsevier.

Wurman, J. and J. Winslow. 1998. Intense sub-kilometer-scale boundary layer rolls observed in Hurricane Fran. *Science* 280:555–557.

Xi, W., R.K. Peet, J.K. DeCoster and D.L. Urban. 2008a. Tree damage risk factors associated with large, infrequent wind disturbances of Carolina forests. *Forestry* DOI 10.1093/forestry/cpn020.

Xi, W., R.K. Peet and D.L. Urban. 2008b. Changes in forest structure, species diversity, and spatial pattern following hurricane disturbance in a Piedmont North Carolina forest, USA. *Journal of Plant Ecology* 1:43–57.

Native Forbs Occurring in Brome Fields within a Mixed-Grass Prairie Landscape (North Dakota)

Nickolas A. Dufek (U.S. Fish & Wildlife Service, Kenmare, ND 58746, ndufe094@uwsp.edu) and Robert K. Murphy (Dept of Biology, University of Nebraska-Kearney, Kearney, NE 68849, murphyrk@unk.edu)

Smooth brome (*Bromus inermis*) is a cool-season, perennial grass introduced to North America's prairie regions from Europe in the late 1800s for use as livestock forage (Romo et al. 1990). Its ability to spread and outcompete native prairie flora makes the grass a major obstacle to reestablishing native vegetation in prairie soils that were previously cultivated. However, some native, herbaceous plant species may persist in or reinvade patches of brome, even in seeded monotypes of brome that are several decades old. Knowledge of which forb species can compete with brome successfully can assist land managers in improving seed mixtures used in agricultural field restorations. We believe multispecies seedings that include native forbs may better compete with brome while enhancing the structural diversity of the vegetation for wildlife.

To help provide such information for the northern mixed-grass prairie region, we measured the occurrence of native forb species in tracts of cropland that had been seeded to brome on the 2,200-ha Wilderness Area of the Lostwood National Wildlife Refuge in northwestern North Dakota. The Wilderness Area is mostly mixed-grass prairie interspersed with 0.2- to 10-ha seasonally flooded wetlands. Uplands are rolling to hilly, with thin loam soils. Nine 12- to 120-ha tracts of old cropland are distributed evenly across the area on the less hilly sites (6–15% slopes). The tracts were cultivated from about 1905 to 1950 then seeded to brome during the 1950s (USFWS 1998). Since its establishment in 1976, the Wilderness Area has experienced four prescribed burns, one wildfire, and four seasons of moderate cattle grazing.

We examined the tracts in July and August 2006, when the majority of plant species could be most readily identified. Within each, we delineated an interior zone (> 50 m from native prairie) and an edge zone (< 25 m from native prairie), separated by a 25-m buffer. We randomly selected

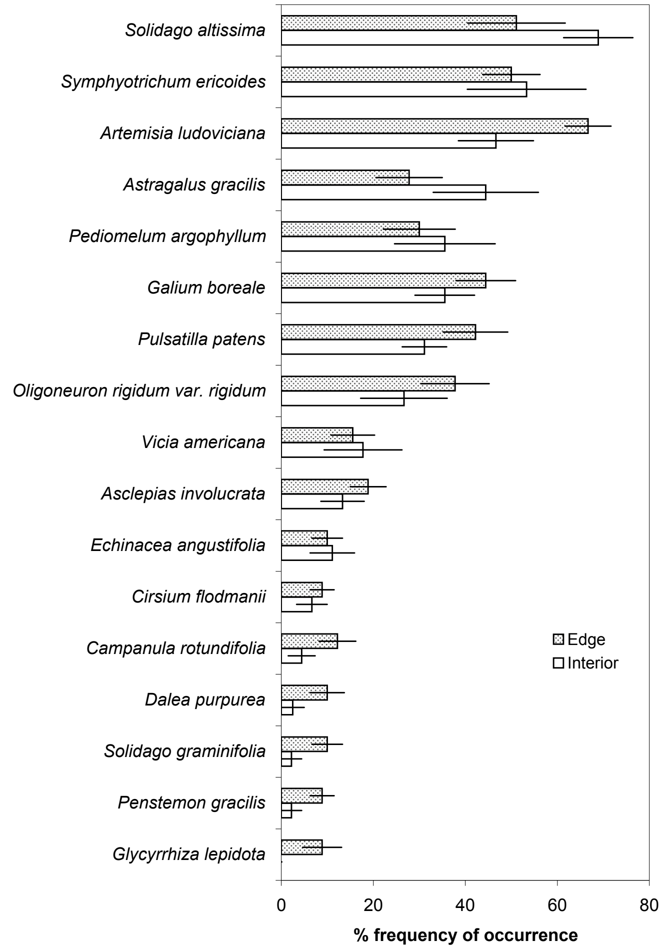

Figure 1. Mean frequency (± SE) of native forb species commonly found in nine cultivated tracts that were seeded to smooth brome (*Bromus inermis*) in the 1950s on the Wilderness Area of Lostwood National Wildlife Refuge, North Dakota, as documented during summer 2006. Not shown are 13 species that were detected less frequently: *Astragalus crassicarpus, Pediomelum esculentum, Thalictrum dioicum, Pulsatilla patens* ssp. *multifida, Liatris punctata, Oxytropis splendens,* and *Fragaria virginiana* were found only in edges; *Polygala alba* and *Lygodesmia juncea* were found only in interiors; *Thermopsis rhombifolia, Artemisia frigida, Erigeron philadelphicus,* and *Symphyotrichum laeve* were found both in edges and interiors.

15 points in each zone of each tract; points within a given zone were at least 25 m apart. At each point, we recorded species of forbs detected within a 1- × 12-m quadrat. We calculated frequency values for each of the 9 tracts and then determined overall means by species and zone. The Domin-Krajina ratings of cover-abundance allowed us to convert frequencies to cover estimates (Bonham 1989, 129). We used the paired *t*-test to compare edge and interior zones for each species.

Brome composed roughly three-fourths of the vegetation cover in the interior and edges of old croplands (range 10%-99%). We detected 30 species of native forbs, all perennials (Figure 1). The edge zones contained 28 species and 22 were in interior zones. Only one species, white sagebrush (*Artemisia ludoviciana*), differed significantly ($p = 0.024$) between zones; it was found more often in the interior.