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Title: Ecological Impacts from the Interactions of Climate Change, Land Use Change and Invasive Species

Investigators: C.J. Richardson (curtr@duke.edu), N. Flanagan and M. Ho.
Institution: Duke University, Durham, NC 27708-0328

Research Category: STAR

Project Period: 04/01/2008 -- 03/31/2012

Description and Objective of Research:

The primary objective of this study is to assess how predicted climate and land use driven changes in hydrologic flux and temperature regimes of floodplain ecosystems affect plant communities in terms of their vulnerability to the establishment and spread of invasive species, and in turn ecosystem functions and services. Future climate scenarios for the southeastern U.S. predict that surface water temperatures will warm (in concert with air temperature) and that stream flows will likely decrease, with a greater proportion of annual watershed hydrologic yield occurring during major storm events (IPCC 2001, Alcamo et al. 2003, Millennium Ecosystem Assessment 2005, Webster et al. 2005). Land use changes (urban vs. forested etc.) have been shown to also raise water temperature and increased pulsed water releases during storms (LeBlanc et al. 1997; Walsh 2000; Hester and Doyle 2011). We analyzed a series of riparian wetland sites along existing gradients of temperature and hydrology produced on dammed and undammed rivers to find the relative importance of a suite of environmental variables describing temperature, hydrology, soil characteristics, and watershed land use composition.

Summary of Findings:

Our results indicate the invasibility of riparian plant communities is driven by a combination of factors that determine the success or failure of invasive species establishment-most notably hydrology and temperature. A major objective of this study was to examine the environmental variables that are likely to be altered in future climate change scenarios and to relate these variables to our indicators of diversity and productivity at our sites. We found significant linear relationships between accumulated heat as measured by soil growing degree days (SGDD) and various facets of hydrology (flood power, duration, depth, frequency) and all of our diversity indicators (Shannon diversity, species richness, invasive abundance, and invasive biomass) indicating temperature is a significant diver community composition at our sites. To assess the predictive power of the environmental variables that we monitored in this study, we developed a series of multivariate models that rank the importance environmental forcing functions in structuring emergent plant communities. We consistently found the most important environmental predictors of our community indices were those that described aspects of temperature and hydrology with variables describing local soils and watershed land use characteristic typically being less important. Relationships between temperature and species richness have been studied since the founding of ecology as discipline (Merriam 1894). The relationships between species

richness and temperature we see in our study (Figures 1 and 2) are consistent with those seen in classic studies of biogeography where links are found between species and latitude. In recent years researchers are seeing indications of latitudinal shifts of species distribution in response to climate change (Allen et al. 2002; Walther et al. 2002; Parmesan 2003; Clarke and Gaston 2006). The diversity -temperature trends observed in our study echo the diversity latitude trends seen in many studies of global scale biogeography (where higher latitude is equated with lower temperature). The richness of naturalized alien species decreased as one moves the mid-latitude temperate zone to sub-tropical and finally tropical zone (Holdgate 1986; Sax 2001; Pyšek and Richardson 2006).

At regional and global scales Shannon diversity is strongly correlated with the number of species (Gentry 1988). This trend is opposite to the observed tendency for overall community species richness where the highest species richness is found in the tropics and decreases as one moves toward the poles (Fischer 1960; Pianka 1966; Stevens 1989).

Future climate scenarios predict alterations of both temperate and hydrology in southeastern riparian plant communities (IPCC, 2001). We found environmental factors consistently explained half of the variation seen in plant community structure seen at our sites, and variables related to temperature and hydrology were consistently the most important predictor of community composition and diversity.

The invasive species most dominant at our sites are those that originate at high latitudes and are able to tolerate a wide range of climatic conditions. It is likely that the propagules of these species originate in the cooler conditions

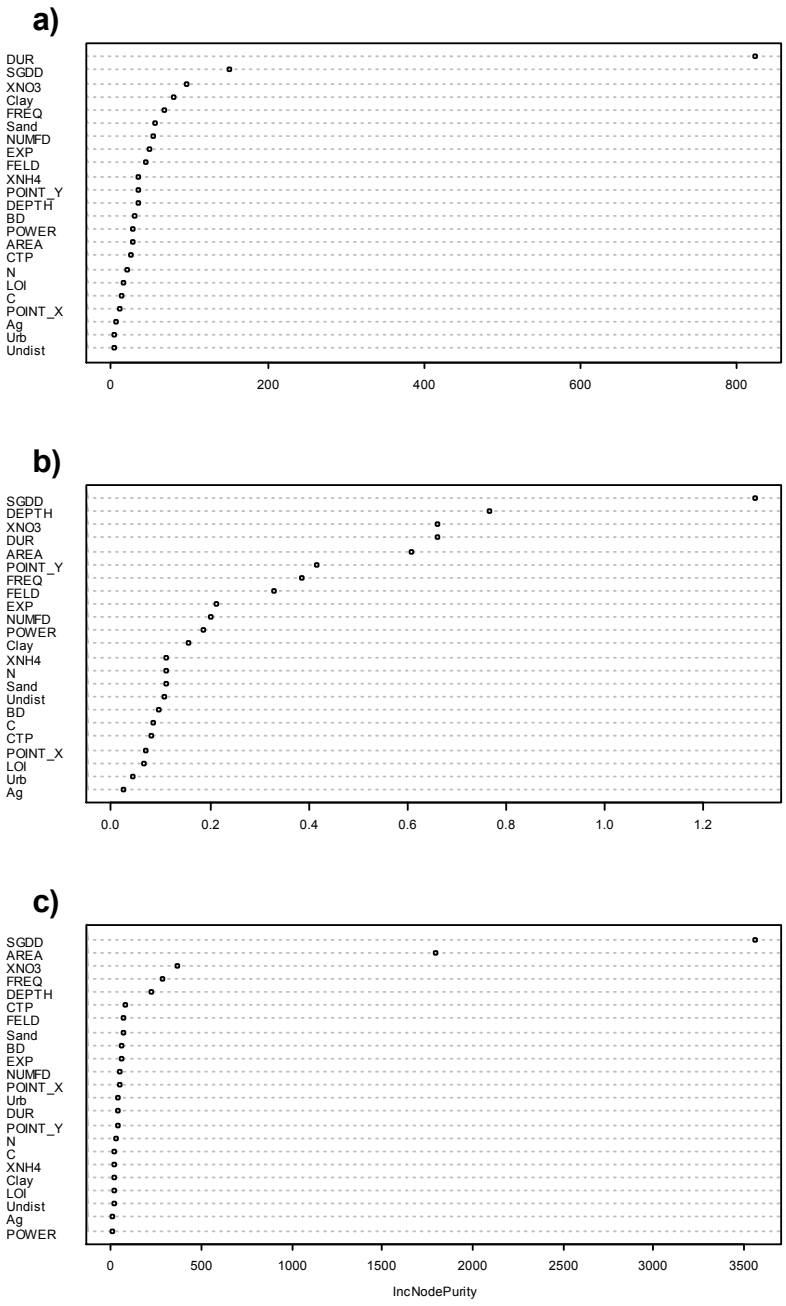

Figure 1. The importance of independent variables in explaining measures of site alpha diversity including: a) Species richness (Psuedo-R^2 = 51.26), b) Shannon (Psuedo-R^2 = 41.94), C) Percent Invasive by count. (Psuedo-R^2 = 62.94). Importance values are produced by procedure Random Forest.

found in the mountainous headwaters of our study rivers Thus, the invasive species at our study locations appeared to have a greater competitive advantage at our Cold sites most likely due to their broader ecological temperature tolerance.

Agricultural land use was also a significant predictor of community composition at our sites ("Ag" in Figure 2). Thuiller (2007) found that land use change and climate change were the most important drivers affecting biodiversity. Thus, management of land use may be a potential tool for mitigating the effects of climate change on hydrology and the sources of invasive species propagules (Miyawaki 2004). In addition, management of watershed land use may be an important tool to offset future increases in water temperature due to shading and effects on temperature, runoff during storms, and groundwater interactions in riparian zones (LeBlanc et al. 1997; Hester and Doyle 2011).

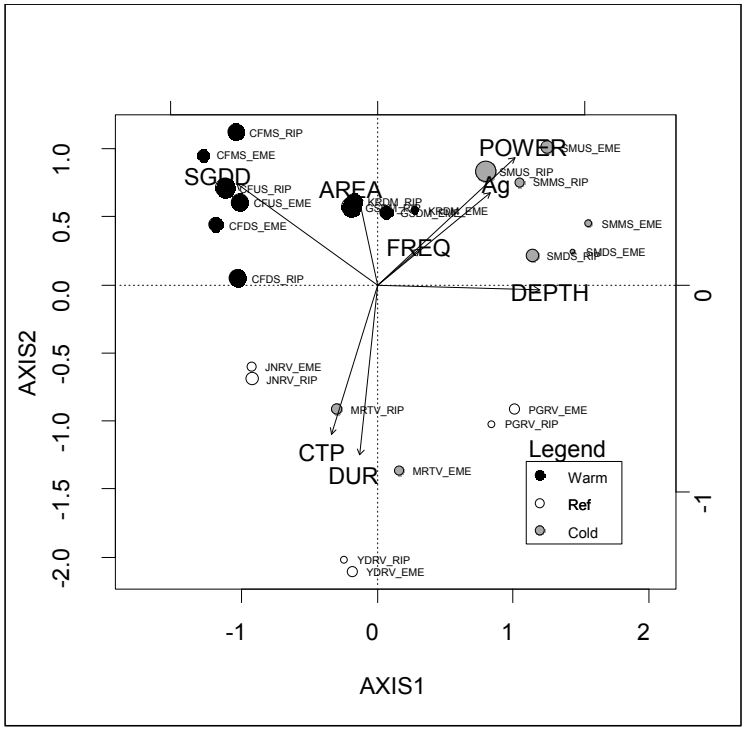

Figure 2. RDA ordination of site community similarity by treatment (Warm, Cold and Reference) and zone (Emergent and Riparian). Degrees of correlation of environmental variables with the axes are shown as vectors whose relative correlations with species space are expressed by length (2008, 2009, 2010 community data). The sizes of site symbols are scaled by relative species richness. POWER (flood power) SGDD (Soil Growing Degree Days), AREA (watershed Area), Ag (watershed proportion cultivated), FREQ (flood frequency), DEPTH (flood depth), DUR (flood duration, CTP (soil total P).

The importance of hydrologic variables in our study suggests the importance of managing climate-linked alterations of riparian hydroperiod as a tool to mitigate the impact of invasive species on riparian communities. Duration of inundation (DUR) was the most import factor in our model of species richness (Figure 1a), likely due to the relationship between drawdown and seed germination. It is likely that larger storms and extreme flood events will increase the spatial extent of hydrochory on floodplains and cause greater physical disturbance of existing plant communities, thus increasing the likelihood that invasive species will become established (Diez et al. 2012).

Conclusions:

Our study indicates that both the direct effects of temperature and the indirect effects of hydrology are potential drivers of community response to climate change. There is some reason to believe that warmer water temperatures predicted in future climate scenarios may actual favor the native communities at our sites (Bradley et al. 2009). However, it seems likely that the lower dominance of invasive species at our warm sites is related to propagule dispersion as much as temperature. Hydrology on the other hand appears as primary driver of community structure in every analysis we performed, and climate-induced changes in future hydrology (higher peak flows and lower base flows) are likely to increase the invasibility of southeastern riparian ecosystems.

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Publications/Presentations:

Publications:

Flanagan, N. E., C. J. Richardson and M. Ho. (in preparation). "**The Response of Riparian Plant Community Structure under Climate Change Scenarios: The Effects of Altered River Temperature and Hydroperiod"** (To be submitted to Global Climate Change).

Presentations:

Neal E Flanagan, Curtis J. Richardson and Mengchi Ho Dr. Flanagan presented a paper entitled "**Alteration of Riparian Plant Community Structure under Climate Change Scenarios: The Effects of Temperature and Hydroperiod"** at the 2012 INTECOL meeting in Orlando, FL. The presentation was authored by Drs. Neal Flanagan, Curtis J. Richardson, and Mengchi Ho Duke University Wetland Center Nicholas School of the Environment, Duke University.

Dr. Richardson presented a paper **entitled "Elevated Temperature and Land Use Flood Frequency alteration Effects on Rates of Invasive and Native Species Interactions in Freshwater Floodplain wetlands"** at the University of Oregon in May 2012. The presentation was authored by Drs. Curtis J. Richardson, Neal Flanagan and Mengchi Ho Duke University Wetland Center Nicholas School of the Environment, Duke University.

Dr. Richardson presented a paper entitled **"Climate Change Effects on Riparian Ecosystems in Southern Riparian Ecosystems"** at the Forest Service in Puerto Rico in February of 2011 at the request of the Forest Service.

Dr. Flanagan and attended an EPA STAR review workshop in September of 2011 and presented a paper entitled "**Elevated Temperature and Land Use Flood Frequency Alteration Effects on Rates of Invasive and Native Species Interactions in Freshwater Floodplain Wetlands."** The presentation was authored

by Drs. Curtis J. Richardson, Neal Flanagan and Mengchi Ho Duke University Wetland Center Nicholas School of the Environment, Duke University.

Dr. Richardson presented an invited paper entitled **"Climate Change Effects on Riparian Ecosystems in Southern Riparian Ecosystems"** at the McGill University in Montreal Canada. The presentation was authored by Drs. Curtis J. Richardson, Neal Flanagan and Mengchi Ho Duke University Wetland Center Nicholas School of the Environment, Duke University.

Dr. Flanagan presented a paper entitled "**The Effects of Temperature and Hydroperiod on Riparian Plant Community Structure: A Climate Change Scenario"** at the 2010 Society of Wetland Scientists Meeting in Salt Lake City, Utah. The presentation was authored by Drs. Neal Flanagan, Curtis J. Richardson, and Mengchi Ho Duke University Wetland Center Nicholas School of the Environment, Duke University.

Dr. Richardson and Dr. Flanagan attended an EPA STAR review workshop in May of 2008 and presented a paper entitled "**Elevated Temperature and Land Use Flood Frequency Alteration Effects on Rates of Invasive and Native Species Interactions in Freshwater Floodplain Wetlands."** The presentation was authored by Drs. Curtis J. Richardson, Neal Flanagan and Mengchi Ho Duke University Wetland Center Nicholas School of the Environment, Duke University.

Relevant Web Sites: Duke University Wetland Center website
www.env.duke.edu/wetland