Final Report, Joint Fire Science Program/Graduate Research Innovation Award, 2011-2012

Project Title:
Will Climate Change Alter Wildfire Behavior and Effects in Seasonally-Dry Wetlands?

Final Report: JFSP Project Number 11-3-1-22

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Abstract

The effects of edge on ecosystems is well documented on animal and plant species, as well as a number of ecosystem attributes. A substantial determinant of ecological edge effects is the effect of edge on microclimate parameters such as temperature and humidity. These effects have been described in detail in upland communities, but not in wetland forests. Of particular interest is whether hydrologic influence trumps edge effect; in other words, does the influence of inundation create a hydrologic "switch" that overwhelms edge effect? In a landscape with numerous wetland forest patches subject to seasonal hydrologic fluctuations, I measured microclimate in relation to edge distance during drought and inundation to determine the relative influence of edge effect on microclimate under contrasting hydrologic conditions. I also tested whether the occurrence of wildfire in the study area two years prior had lasting influence on edge-related microclimate. Predictions of edge effect on microclimate were observed in both wet and dry conditions, and in patches that were burned as well as unburned patches. While evidence did not indicate the presence of a hydrologic "switch" controlling the influence of edge, a stronger edge effect occurred during dry conditions than during inundation. Also, while sites experienced relatively little difference in edge influence on microclimate from fire after two years of recovery, the influence of edge effect under dry conditions compared to inundation was greatly magnified in burned patches compared to unburned patches. These findings suggest that under scenarios of warmer, drier conditions, the edge effects seen in this study could be increasingly important in providing refugia for humidity-sensitive plant species. Additionally, the gradient of sizes in which these measurements were taken may allow variably-sized cypress domes to be used as proxies for varying scenarios of future altered climate in seasonally-inundated wetlands.

Background and purpose

Edge effects in ecology are well accepted, and have been demonstrated across a variety of ecological systems and attributes (e.g., Harris 1988, Saunders et al. 1991). Among the numerous examples from forests ranging from the boreal (Schmiegelow and Mönkkönen 2002, Hamberg et al. 2009) to the neotropics (Laurance 1991, Laurance et al. 2000), the changing conditions from the edge of a patch toward its interior have been shown to affect animal populations (Paton 1994, Fletcher 2005) as well as plant populations (Gehrig-Downie et al. 2011, Obregon et al. 2011). While these relationships are explained by a number of factors that vary with the distance from the edge of a community or ecosystem edge (e.g., physical structure, and area of available habitat for animals; Margules and Pressey 2000), many components of edge effects are explained by changing microclimatic conditions.

Microclimate, or atmospheric conditions at a particular point on the landscape near the ground (Geiger 1965), influence a range of ecological processes (Meentemeyer 1978, Waring and Running 1998, McDonald and Urban 2005, Turner and Chapin 2005). Often, microclimate differences are studied between areas of contrasting vegetation communities, such as between forested patches and areas that have been cleared by logging or for road building (Asbjornsen et al. 2004). In the case of the former, clear changes have been observed in microclimate with increasing distance away from the edge of the interface of opening and forest, proceeding perpendicular away from the open area (Chen et al. 1993, Chen et al. 1995). In general, at increased distances from an opening toward the interior of a forest patch[1], values and variances of temperature, humidity, and wind speed are attenuated (Vanwalleghem and Meentemeyer 2009). The reasons for these changes include decreased wind penetrance into remnant forest, increased shading of soil and low vegetation strata, and decreased lateral diffusion of moisture to the atmosphere exterior to the forest patch.

In the same way that fragmentation results in changes to forest structure that affect microclimate attributes of resulting patches, other disturbance events that alter vegetation structure within a forest patch may exert control over edge effects on microclimate. Fire consumes standing live and dead biomass; and, by removing elements of forest structure and reducing forest canopy area (e.g., Cochrane et al. 1999), can increase insolation and air movement. Villegas et al. (2010) have shown seasonal effects on microclimate as conditions of canopy cover and evapotranspiration change substantially depending on leaf development and senescence. In addition to directly influencing microclimate, fire occurring in a forest patch may exert similar control over the influence of edge effect by reducing or eliminating those structural elements which attenuate microclimate with increasing distance from a patch edge.

Despite progress in understanding effects of edge distance (Chen et al. 1999, Vanwalleghem and Meentemeyer 2009) on microclimate, studies heretofore have been limited to terrestrial forests. Few studies have examined microclimate in wetland forests, and none have been published concerning edge effect and microclimate in these communities. Thermal mass of the water inundating a wetland or saturating its soil would influence temperature (and certainly humidity), perhaps more so than the effects of canopy shading or attenuation of air mixing. Under these circumstances, hydrologic effects on microclimate could overwhelm the edge effects on microclimate that otherwise would be predicted under non-hydric conditions: in other words, edge effects on microclimate could be governed by a hydrologic "switch."

In wetlands subject to strong seasonal variations in hydrologic regimes, is it possible that the occurrence of fires during droughts exerts control over edge effects on microclimate? Might seasonal inundation likewise create hydrologic control over the occurrence of edge effects on microclimate? I sought to investigate whether either wildfire or inundation govern the occurrence of edge effects on microclimate in seasonally-inundated forest patches.

Hypothesized hydrologic control on edge-mediated microclimate variation leads to the following predictions:

1. Under non-inundated (e.g., drought) conditions, microclimate variation in wetland forest patches adjacent to nonforest communities would exhibit similar trends in response to patch and edge effect as those observed in terrestrial forests; i.e., attenuated temperatures and higher relative humidity with increasing distance from edges toward centers of patches.

2. Inundation degrades these relationships, resulting in a partial or complete loss of relationship between distance from edge (DFE) and microclimate.

3. Wildfire sufficient to cause substantial changes to vegetation structure results in losses of edge influence, resulting in higher temperatures and lower humidity among domes experiencing fire compared to unburned domes.

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[1] For purposes of this discussion, "patch" should not be assumed to indicate a small fragment of forest or forest remnant, but rather any spatially-discrete unit of continuous forest regardless of size.

Hydrologic government of edge effect, if extant, could improve our understanding of the implications of severe droughts or future altered climate on wetland forest processes, particularly where issues of fragmentation or small patch size are concerned. Knowledge of fire impacts to microclimate and edge influence, meanwhile, may allow us to better forecast potential effects of future fires following wildfire events.

Study Description and Location

Big Cypress National Preserve in southwestern Florida USA (26° N, 81° W, Figure 1a) covers 300,000 ha of low-relief landscape. There, upland forests of south Florida slash pine (*Pinus elliottii* var. *densa* [Little and Dorman]) and prairies primarily composed of muhlygrass (*Muhlenbergia capillaris* [Lam.]) occur adjacent to swamps dominated by pondcypress (*Taxodium distichum* var. *imbricarium* [Nutt.]), a deciduous conifer characteristic of long-hydroperiod wetland forests across large portions of the southeastern United States. Small swamp patches, called domes because of their structure, occur frequently across large areas of the preserve (Figure 1b), providing the opportunity to investigate wetland forest processes in a landscape with generous replication of patches at a range of sizes. Mean annual precipitation of 1360 mm y^{-1} occurs primarily in the wet-season months of June – September (Duever et al. 1986). While the entire landscape experiences periodic inundation during periods of intense precipitation, standing water is generally confined during and shortly after the wet season to cypress swamps where soil elevations in are lower than those in the surrounding landscape by 1 m or more. Water infiltrates into the region's karst limestone readily after rains cease, and the shallow depressions in which cypress domes occur may become dry for 3 – 6 months during the late dry season (Ewel 1995).

As the first thunderstorms of the rainy season begin (usually in May), frequent lightning strikes occur on a landscape with plentiful available fuel. Naturally-ignited wildfires occur frequently during this seasonal transition, with the pyrogenic vegetation of flatwoods and prairie communities readily carrying fire to the edges of swamps and domes. Dry conditions can permit sufficient fuel continuity to allow fire to enter these wetland forests, where understory vegetation such as sawgrass (*Cladium* jamaicense [Crantz]) may burn readily. During drought conditions, large ground fuels, accumulated duff, or even the peat soils themselves may ignite, resulting in severe fires. In May 2009, during a severe regional drought, the Deep Fire was ignited by lighting and burned 12,000 ha in the northwestern corner of the Preserve. The fire burned through all vegetation communities within its perimeter, including desiccated cypress domes which experienced moderate to severe fire effects and substantial (23.5% overall) tree mortality.

Key Findings

Compared to open vegetation communities or those with sparse tree canopies, all 12 instrumented cypress domes displayed lower temperatures and higher relative humidity within their community boundaries. The prediction of lowered temperature and higher humidity with increasing distance under dry (non-inundated) conditions was observed as measured by pairwise comparisons between mid-transect and dome-center locations, with the exception of daily maximum temperature measurements in burned domes (Table 1). Regression analysis further confirmed the positive relationship between the distance within a given dome at which a measurement was taken and the difference between microclimatic conditions at that location and those at the location exterior to the dome (Table 2).

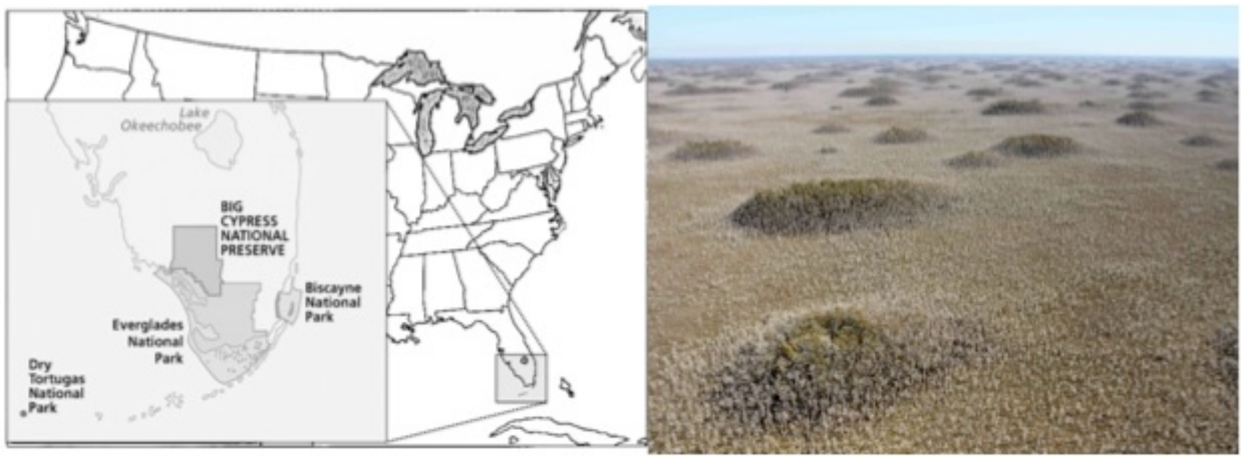

Figure 1. (a, left) Big Cypress National Preserve, in southern Florida, USA, protects 300,000 ha in a low-relief area characterized by subtropical climate. Strong seasonal distribution of rainfall mean that the region's many small depressional features (b, right) become inundated during the rainy season from approximately July to December. Rapid infiltration through shallow soils into the limestone bedrock leaves many swamps dry for up to a few months per year.

Table 1. Results of pairwise comparisons among daily maximum temperature and daily minimum relative humidity values in contrasting hydrologic conditions for both treatments.

	Control (unburned) Domes				Burned Domes			
	Max. Temp		Min. RH		Max. Temp		Min. RH	
Comparison	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Exterior – Edge	*	No	No	No	No	No	No	No
Edge – Mid	*	*	*	*	*	*	*	*
Mid – Center	*	No	*	No	No	No	*	No
Exterior – Mid	*	*	*	*	*	*	*	*
Exterior – Center	*	*	*	*	*	*	*	*
Edge – Center	*	*	*	*	*	*	*	*

Notes: Mid = midpoint of a transect extending from dome center to edge (i.e., positioned at ½ of radius); Wet = inundated conditions (i.e., observations from August – September); Dry = non-inundated conditions (i.e., observations from April – May); during both periods, canopy leaves were present. Tukey's W test ($\alpha = 0.01$) used for comparisons; an asterisk (*) indicates significant differences. Values for temperature were lower and humidity higher at the location closer to the center of domes.

Table 2. Linear regression of microclimate parameters by distance from community edge, control (i.e., unburned) sites.

Model	Season	Coefficient	Intercept	R^2
Daily Max ΔTemp ~ DFE, Control	Wet	0.014	4.81	0.02
Daily Max ΔTemp ~ DFE, Control	Dry	0.022	4.82	0.07
Daily Max ΔRH ~ DFE, Control	Wet	0.059	16.12	0.03
Daily Max ΔRH ~ DFE, Control	Dry	0.070	15.28	0.05
Daily Max ΔTemp ~ DFE, Burned Sites	Wet	0.016	3.26	0.04
Daily Max ΔTemp ~ DFE, Burned Sites	Dry	0.034	2.89	0.20
Daily Max ΔRH ~ DFE, Burned Sites	Wet	0.069	10.19	0.09
Daily Max ΔRH ~ DFE, Burned Sites	Dry	0.161	6.89	0.21

Notes: DFE = distance of a given location from the cypress dome edge (m); Daily Max ΔTemp and Daily Max ΔRH represent daily observations at which differences in maximum temperature (°C) or relative humidity (RH, %) are greatest between a given location within a dome (edge, mid-transect, center) and the reading recorded external to a given dome. Comparisons are for periods when canopy leaves were present (i.e., April – May for dry periods, August – September for inundated (wet) periods).

Low values for the coefficients of determination resulting from regression of temperature and humidity on distance from edge indicated that only a small portion of the variance in values for microclimate were explained by edge distance (Sokal and Rolfe 1995). This is unsurprising: the variation among temperature readings over the two-month periods examined in the regression analysis would be affected by seasonal climatic trends; precipitation and frontal passages; and other events with the likelihood of affecting temperature readings to a much greater extent than the influence of edge effect. The objective of regression analysis in this instance was to determine whether edge effect exists and varies with inundation and following fire, not to construct comprehensive forest climate models. In this study the discernable effect of edge distance was present in all regression models to a significant degree, influencing temperature and humidity consistent with theory on edge literature (e.g., Forman and Godron 1986).

Pairwise comparisons of microclimate conditions between adjacent sampling locations reveal fewer significant differences in maximum temperature or minimum relative humidity during inundation compared with drought conditions. Some differences in dome microclimate in relation to edge distance that were observed during dry periods, such as those between dome centers and locations halfway between centers and edges, disappear when wet-season inundation occurs. Inundation does not erase all predicted effects of forest patch interiors on microclimate, as illustrated by significant microclimate differences between edge and mid-transect locations during inundation (Table 1) as well as positive effects of edge distance on attenuation of microclimate under inundated conditions (Figure 2, Figure 3). However, the influence of edge distance on temperature and humidity within domes is greatly reduced when standing water is present. Also, while the effect of increasing distance from dome edge toward interior on VPD is seen across all four combinations of season and treatment, VPD is lower at all edge distances during the wet season than the dry season (Figure 4). Thus, while there does not appear to be a "hydrologic switch" caused by the thermal influence of standing water overwhelming that of edge distance, there does appear to be substantial hydrologic control over the importance of edge effect on microclimate in wetland forest patches subject to fluctuating water levels.

Cypress domes that had experienced moderate to severe fire two years prior to sampling were similar in microclimate to unburned domes during most months of the year. Exceptions were during the wet-season months of June – August, when maximum daily temperatures within domes were higher than those recorded in unburned domes. These findings of increased temperature within burned domes are consistent with expectations, but the observation of statistically significant differences during only three months of the study period offers little support of the hypothesized reduction in attenuation of microclimate within cypress domes. To the contrary, relative humidity values within burned domes were either similar or, in the case of three months (April, May, and July), greater than those in unburned domes. Also, the slope of regression lines describing the influence of edge distance on both temperature and humidity were greater for burned domes than unburned domes (although the differences observed under inundated conditions were much smaller than dry conditions). VPD showed the least difference in burned compared to unburned domes, with similar intercepts and coefficients of determination during the dry season and nearly indistinguishable regression models during the wet season (Figure 4).

Decreased humidity and increased temperature were expected based on observed post-fire changes in understory due to substantial consumption (Figure 5) as well as delayed overstory tree mortality rates of 23.5% observed in a study following the Deep Fire (Watts et al. 2012). However, the observations of this study indicated nearly the opposite effect compared to predictions. One possible mechanism to explain similar microclimate and increased effect of edge distance despite a reduction in canopy cover due to tree mortality may be the rapid regrowth of understory (Figure 6), perhaps from increased light as well as nutrients mineralized due to the fire. Vigorous regrowth in the understory may substitute for overstory canopy to some degree in the attenuation of temperature by providing additional shade, while evapotranspiration from rapidly-growing vegetation may explain RH values similar to or greater than those in unburned locations. Finally, the increased influence of edge effect may be partly explained by the exaggeration of the characteristic dome-shaped structure due to wildfire in these communities (Watts et al. 2012): following fire in cypress domes, mean tree heights toward dome edges decrease due to topkill, while mean heights toward dome interiors increase due to higher mortality among shorter trees. If exaggeration of dome structure by fire results in a greater reduction of canopy cover near dome edges compared to dome centers, then changes in temperature and humidity at edges compared to centers of domes may become greater.

Despite the capacity of water to moderate local climate by absorbing and releasing thermal energy, flooded conditions do not overwhelm the influence of edge effect on microclimate in cypress domes. However, while there appears to be no hydrologic "switch" that prevents the operation of edge influence when water levels are above the soil surface, inundation does substantially reduce the degree to which edge distance causes changes in temperature and relative humidity in cypress domes.

Figure 3-7. Regression models of within-dome temperature difference from exterior locations by distance for treatments, control vs. burned and inundated vs. dry

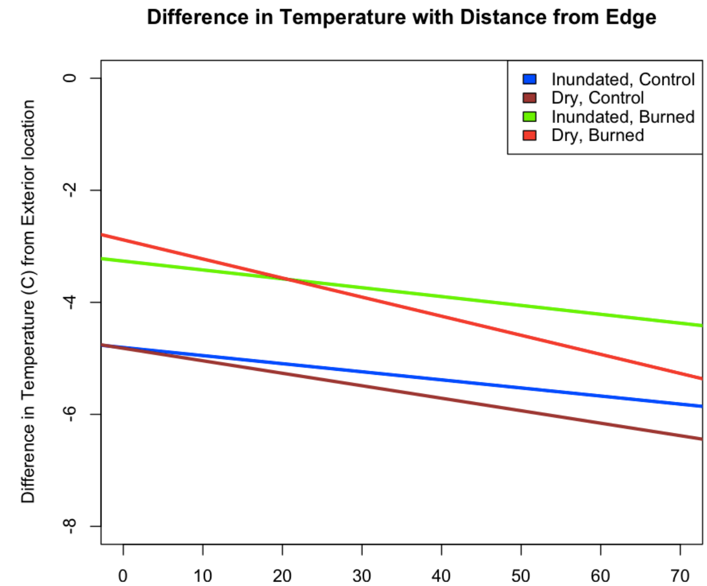

Figure 3-8. Regression models of normalized difference in relative humidity readings from exterior locations by edge distance for different treatments. For equation coefficients and intercepts, see Table 2.

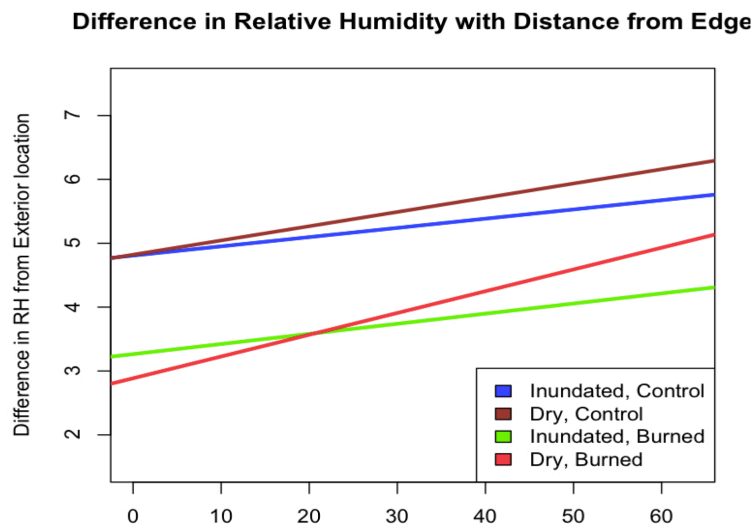

Figure 3-9. Illustration of regression models showing response of vapor pressure deficit (VPD) to increasing distance from dome edge under the four different season/treatment combinations.

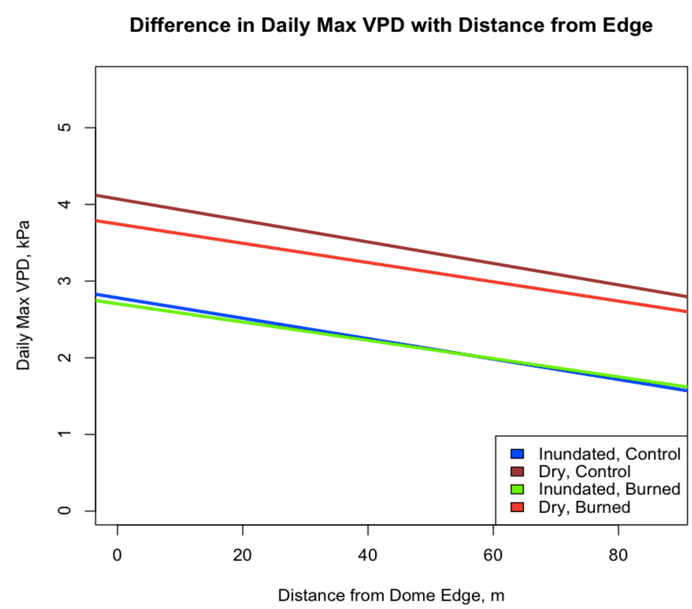

 

Figure 5 (left). In the months following the Deep Fire, interiors of burned cypress domes displayed simplified structure, and enhanced wind and insolation.
Figure 6 (right). By two years following the Deep Fire, understory regrowth in burned domes was vigorous.

Management Implications

During dry periods when water levels retreat, wetland forest patches appear to be subject to the same influence of edge on microclimate as their upland counterparts. In forests where seasonal fluctuations leave wetland forests dry for extended periods (weeks to months), the implications of edge effects and fragmentation for management and conservation are similar to those encountered among upland forests. Even among wetlands that rarely experience desiccation, the occurrence of drought may have detrimental interactive effects with fragmentation on species that rely on conditions attenuated by distance from edge, such as some bromeliads and epiphytic plants (e.g., Muss 2001, Gehrig-Downie et al. 2011, Obregon et al. 2011).

An additional concern involves edge-related fragmentation effects in wetland forests subject to fire. Under dry conditions, wetland forests likely are subject to the same enhanced effects of wildfires when subjected to changes that increase the edge:area ratio, due to an effective decrease in edge distance within the remnant (Cochrane 2001). Numerous studies on the effects of fragmentation on microclimate, as well as dedicated studies concerning the interactive effects among fragmentation, structure, and fire effects (e.g., Cochrane and Schulze 1999), led to the development of positive-feedback models of fragmentation and fire (Lindenmayer et al. 2009). This positive-feedback model describes logging, fragmentation, or other activities that simplify the structure of a forest patch, as leading to increases in fire severity, intensity, or frequency; changes in the fire regime help to maintain clearer understory and sparser overstory that further enhance favorability of microclimate for promoting fire behavior. In this study, the positive feedback model predicted increased temperature and decreased humidity following fire. Contrary to expectations, findings appeared to contradict the positive-feedback model of fragmentation and fire-promoting microclimate conditions. Instead, post-fire changes to cypress domes appear neutral in their potential effects on the behavior of recurrent fire, or (in the case of increased RH) somewhat negative. Negative fire feedbacks have been observed in

Amazonian forests (Balch et al. 2008), but are more likely due to changes in fuels than in microclimate as suggested by the findings of this study.

Further measurements to describe changes to vegetation structure, nutrient cycling, and productivity may elucidate the mechanisms behind the findings concerning post-fire changes in microclimate in cypress domes. Meanwhile, continued observations will improve our understanding of the dynamics of post-fire changes in edge influence on microclimate in these wetland forest patches, while detailed monitoring of hydrologic conditions and additional parameters will enable the modeling of microclimate in wetland forest patches under a variety of hydrologic conditions. These efforts are expected to improve the ability of resource managers to maintain the value of these valuable communities under predicted future scenarios of greater variability in climate and precipitation regimes.

Relationship to Other Recent Findings

These findings of hydrologic and edge effect on microclimate patterns relate to two additional studies conducted simultaneously in Big Cypress National Preserve:

1. **Smoldering combustion and ground fires: ecological effects and multi-scale significance**

Swamps, peatlands, and other wetland ecosystems can store vast amounts of carbon in organically-derived peat soils. Wildfires during severe droughts can produce smoldering combustion in these soils, releasing large quantities of carbon to the atmosphere and causing dramatic changes at the local scale due to plant mortality and hydrologic effects. I studied variation in moisture content and carbon loss from smoldering combustion in soils from pondcypress (*Taxodium distichum* var. *imbricarium*) swamps in Florida USA. In a lab study, soil moisture content near the surface (upper 10 cm) did not predict vertical depth of soil combustion. Mass loss of organic carbon from soil profiles was, however, negatively related ($P < 0.01$). I also studied spatial variation in soil moisture, as a predictor of potential soil combustion, at a range of distances from edges of cypress-swamp patches. A weak, but significant ($P < 0.01$), positive relationship exists between distance from edges and upper-layer soil moisture, indicating that some inhibitive effect on smoldering may be present proceeding toward the centers of larger swamp patches. Conservative estimates of SOC content in cypress peats (approximately 41% by mass, compared to a figure of 50% sometimes used in such studies) indicate substantial potential for soil carbon loss (over 4 kg m^2) from wildfires in cypress swamps. This initial study on smoldering of cypress peats also makes recommendations for future efforts to study ground fires in these regionally important ecosystems

2. **Evidence of biogeomorphic patterning in a low-relief karst landscape**

(with Danielle L. Watts, Matthew J. Cohen, James B. Heffernan, Daniel L. McLaughlin, Jon B. Martin, David A. Kaplan, A. Brad Murray, Todd Z. Osborne, and Leda N. Kobziar)

Patterned landscapes are evidence of biotic control on geomorphic processes, emerging in response to coupled ecosystem processes acting at different spatial scales. Self-reinforcing processes at local scales expand patches, while self-inhibiting processes, operating at distance, impose limits to expansion. Strikingly regular landscape pattern is evident in Big Cypress National Preserve (BICY) in southwest Florida, wherein isolated forested wetland depressions (cypress domes) appear evenly distributed within a mosaic of short-hydroperiod marshes and pine uplands. In this setting, patterning expressed as variation in bedrock elevation is likely induced by variable carbonate dissolution. Our model of landform development invokes a local positive feedback between water storage/exchange in wetland depressions and production of organic-derived acidity. A distal inhibitory feedback arises as the volume of water delivered to the wetland from the local catchment is reduced as wetland area expands. Despite compelling visual evidence for biogeomorphic patterning in this karst setting, the diagnostic features of patterning have not been obtained. To test the hypothesis that apparent patterning is regular and indicative of underlying biotic control, we measured surface elevation, vegetation communities, sediment thickness and spatial arrangement. Observations from classified imagery and ground-based measurements indicate strong spatial overdispersion of cypress domes, supporting the hypothesis that these features result from self-organizing, scale-dependent feedback processes. While bedrock elevations were clearly bimodal, also suggesting strong patch reinforcement mechanisms, soil-surface elevations had weaker bimodality or unimodal distributions. These distributions of landform elevation indicate “smoothing” of surface morphology by sediment transport or reprecipitation and organic matter production. Finally, we observed significant negative autocorrelation of bedrock elevations at characteristic wetland spacing, suggesting the presence of distal inhibitory feedbacks. Together, these findings support the diagnosis of regular landscape patterning and offer insights into the underlying mechanisms, which include divergent ecosystem-controlled dissolution of bedrock as well as the obscuring influence of regional erosion/deposition processes.

Future Work

Further measurements to describe changes to vegetation structure, nutrient cycling, and productivity may elucidate the mechanisms behind the findings concerning post-fire changes in microclimate in cypress domes. Meanwhile, continued observations will improve our understanding of the dynamics of post-fire changes in edge influence on microclimate in these wetland forest patches, while detailed monitoring of hydrologic conditions and additional parameters will enable the modeling of microclimate in wetland forest patches under a variety of hydrologic conditions. These efforts are expected to improve the ability of resource managers to maintain the value of these valuable communities under predicted future scenarios of greater variability in climate and precipitation regimes. Additionally, a study begun soon after the 2013 Huckabee Fire, which burned through the same area studied in this project that experienced the 2009 Deep Fire, will test hypotheses concerning fire feedbacks to future fire severity, and will determine whether factors influencing fire-caused mortality among pondcypress trees change following an unusual wildfire in desiccated cypress domes only four years following a severe dry-season wetland fire.

Deliverables

A number of deliverables have resulted from this project. While the table below summarizes major deliverables anticipated in the original proposal, a more comprehensive list is included with citation information. One additional manuscript remains in preparation and we anticipate submission in the near future, probably October 2013.

Deliverable	Status
Journal article	Completed (3)
Ph.D. Dissertation	Completed
Workshop for Managers	Completed
Oral presentation at 2011 Big Cypress Research Symposium	Completed
Discussion with fire and resource managers on study implications	Completed
Oral Presentation, 2012 AFE Int'l. Fire Ecology & Mgt. Congress	Completed
Final report to JFSP; also disseminated to Big Cypress Fire Mgt.	Completed

List of deliverables resulting from or related to this project

Peer-reviewed publications:

Watts, A. C. and L. N. Kobziar. 2013. Smoldering combustion and ground fires: ecological effects and multi-scale significance. Fire Ecology 9. doi: 10.4996/fireecology.0901.

Watts, A. C. 2013. Organic soil combustion in cypress swamps: moisture effects and landscape implications for carbon release. Forest Ecology and Management 294C: 178-187. doi: 10.1016/j.foreco.2012.07.032.

Watts, A. C., L. N. Kobziar, and J. R. Snyder. 2012. Fire reinforces structure of pondcypress (*Taxodium distichum* var. *imbricarium*) domes in a wetland landscape. Wetlands 32: 439-448. doi: 10.1007/s13157-012-0277-9.

Extension publications:

Watts, A. C. 2013. Smoldering combustion in organic soils. Article, National Park Service Fire Program RxFx Newsletter, Spring 2013 issue.

Watts, A. C. and L. N. Kobziar. 2012. Smoldering combustion in organic soils: peat and muck fires in the southeastern US. Research Synthesis 2012-9, Southern Fire Exchange.

Watts, A. C. and L. N. Kobziar. 2012. Cypress mortality following wildfires: information and recommendations for fire and natural resource managers. Fact Sheet 2012-4, Southern Fire Exchange Information Briefs.

Watts, A. C. and L. N. Kobziar. 2012 University of Florida Graduate Research Reveals Challenges to Managing Fire in Dry Wetlands. Article, Conserved Forests Extension, Outreach, and Research (CFEOR) Consortium Newsletter.

Watts, A. C. 2012. The Wildfire Ecology of Wetland Landscapes. Article, National Park Service Fire Program RxFx Newsletter, Spring 2012 issue.

Manuscripts in preparation:

Watts, A. C., T. A. Martin, and L. N. Kobziar. Hydrology and fire regulate edge influence on microclimate in wetland forest patches. (to be submitted to *Landscape Ecology*, Fall 2013)

Presentations and workshops (selected):

Watts, A. C. Wetland fires and smoldering combustion in organic soils: recent findings and future research directions. Invited seminar, North Florida Prescribed Fire Council, 13 March 2013, Lake City, FL.

Watts, A. C. Fire ecology in the southeastern United States: overview of issues and recent research in Florida. Invited seminar, Missoula Fire Sciences Laboratory, 28 February 2013, Missoula, MT.

Watts, A. C. and L. N. Kobziar. Determinants of smoldering in cypress landscapes: landscape factors and implications for carbon release. Invited presentation, 4th Fire Behavior and Fuels Conference, International Association of Wildland Fire, 18-22 February 2013, Raleigh, NC.

Watts, A. C. Wildfire and landscape ecology research in a wetland mosaic. Invited seminar, Desert Research Institute, 11 February 2013, Reno, NV.

Watts, A. C. Wildfire effects on forest structure and soils in Big Cypress National Preserve, Florida. Invited webinar, Southern Fire Exchange, 5 October 2012 (online).

Watts, A. C. Wildfire ecology of a wetland landscape. Invited seminar, School of Natural Resources and Environment Fall Seminar Series, 11 September 2012, University of Florida, Gainesville, FL.

Watts, A. C. Smoldering combustion in subtropical wetland ecosystems. Invited presentation, International Workshop on Smoldering Fires in the Earth System, 27 July 2012, University of Edinburgh, UK (Organized by Imperial College, London).

Watts, A. C., L. N. Kobziar, and T. A. Martin. Scale-Dependent Microclimate Effects of Wetland Wildfire. Invited presentation, 9th INTECOL International Wetlands Conference, 3-8 June 2012, Orlando, FL.

Watts, A. C. L. N. Kobziar, T. Z. Osborne, and J. R. Snyder. Smoldering Cypress Swamp Soils: Moisture Effects and Implications for Forest Structure. Invited presentation, 9th INTECOL International Wetlands Conference, 3-8 June 2012, Orlando, FL.

Watts, A. C. Wildfire ecology in a wetland landscape: structural, functional, and geomorphic considerations. Seminar, National Wetlands Research Center, 19 December 2011, Lafayette, LA.

Watts, A. C., L. N. Kobziar, J. R. Snyder, and T. A. Martin. Feedbacks to structure and microclimate from large drought fires in wetland landscapes. Presentation, Exploring the Mega-fire Reality: Forest Ecology and Management conference, 14–17 November 2011, Tallahassee, FL.

References Cited

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