FIRE'S EFFECTS ON SOIL AND WATER QUALITY OF TRADITIONALLY LONGLEAF PINE DOMINATED WATERSHEDS*:* A Holistic Review

By

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TABLE OF CONTENTS

Abstract of Report Presented to the Graduate School
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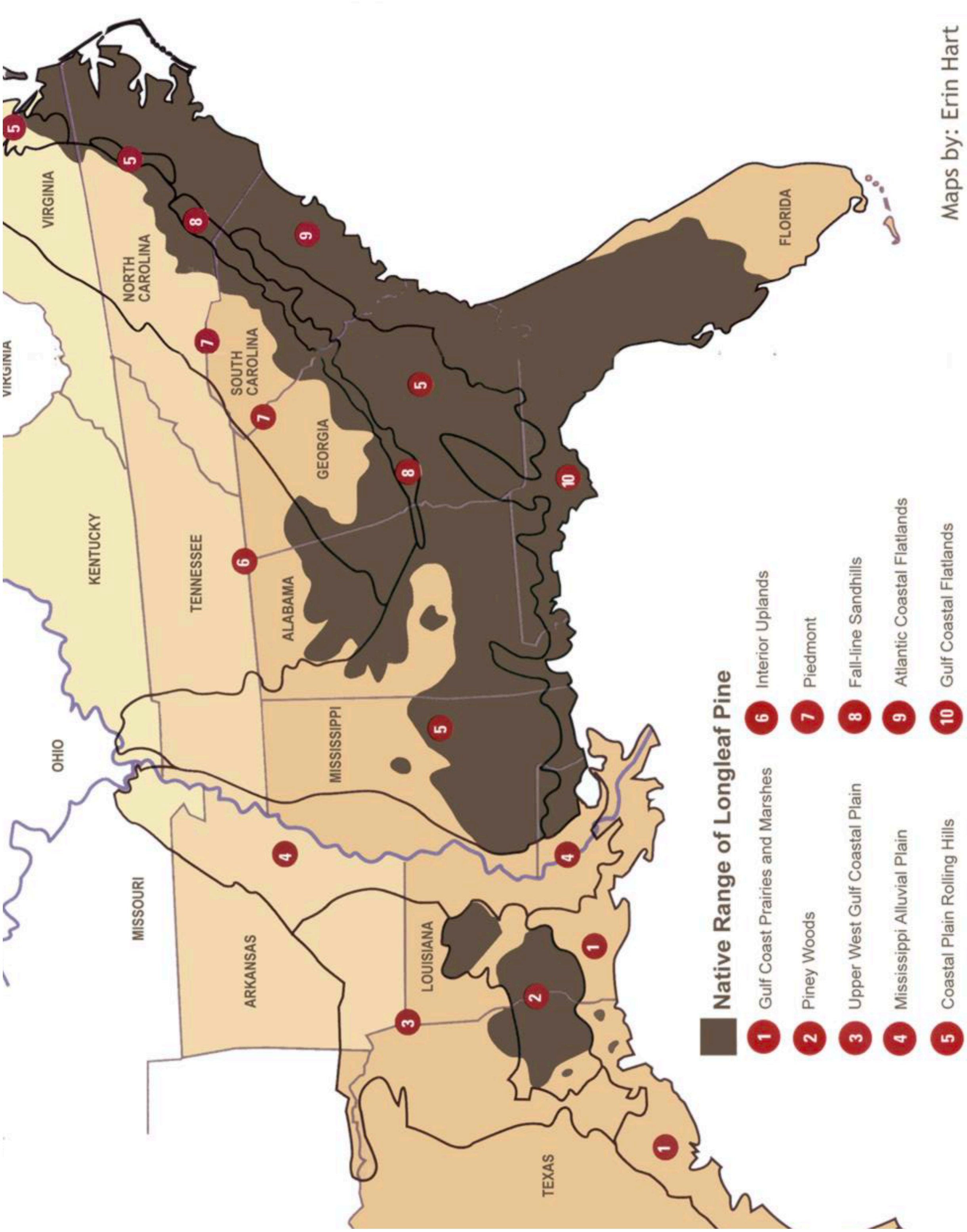
Fire is unequivocally one of the most influential forces on our planet, frequently playing the roles of a renewer, a cleanser and a source of destroyer. It behaves as if there is an intellect and has several of the characteristics of a living organism and as such effects its surrounding in manners suitable of our envy in how it changes the environment around it or more aptly the environment that it interacts with. Prior to the influence of European settlers in North America the Longleaf Pine ruled the ecosystems of the Southern and Eastern portions of what is now the United States. Nearly 37 million hectares or 91.5 million acres of various savannas, piedmont regions, swamps and to near mountainous regions were home to *Pinus palustris.* Longleaf pine forests evolved over millennia with fire as the primary influencer of this evolution. How fire effected the soil and water cycle is a story still being written today. This paper will discuss how fire effects soil and water quality of what were traditionally Longleaf Pine dominated watersheds.

INTRODUCTION

Prior to the influence of European settlers in North America the Longleaf Pine (LLP) (*Pinus palustris*) ruled the ecosystems of large portions of the Southern and Eastern United States (SE-USA). Nearly 37 million hectares or 91.5 million acres of various savannas, piedmont regions, swamps and to near mountainous regions were home to Longleaf pine (Figure I-1). Today only about five percent (1.9 million hectares or 4.7 million acres) of the range exists (ALRI, 2022), this up from a low point of 3.2 million acres. The ability to provide fresh drinking water is a critical ecosystem service of those remaining forests, for many households in the Southeastern United States. About 32 percent of the Southeastern United States' total annual water supply originates on state and private forest lands and another 3.4 percent on National Forest System land (Hallema & Friley, 2016). This critical ecosystem service, provided by watersheds in traditional Longleaf pine forests, requires a broad understanding of land management practices particularly prescribed and naturally occurring fires.

OBJECTIVES

The objectives of this paper are to introduce some basic concepts pertaining to fire regimes associated with longleaf pine watersheds. While numerous published papers and other sources provide conflicting observations and data; this paper hopes to bring some clarity to the how and why for such contradictions. To do so this author intends to explain some of the multitude of facets associated with fires' effects on soil and water quality within LLP watersheds. Lastly, this paper is intended to synthesize the interconnectivity of the trophic effects of fire on LLP watersheds.



Maps by: Erin Hart

Figure I-1

CHAPTER 1

FIRE GENERALITIES

1.1) Regional History

Longleaf pine (*Pinus palustris*) ecosystems are considered to have evolved with fire, in a pseudo symbiotic relationship, prior to the arrival of Europeans to North America. Since the arrival of European settlers, the fire regime has changed continuously due to agricultural and urbanization practices. These modifications in longleaf's range have allowed for an infinite number of fuel and environmental variations thus requiring the application of specified generalities while discussing fire characteristics.

Jose, et al., (eds.), note that even though lightning was and, in some cases, still is the predominant causation of fire with the Longleaf's range, pre-European settlement, additionally Native Americans also used fire as an environmental control tool. Various sources reviewed indicate that significant fires occurred primarily during the growing season on an average of 1-3 years. These fires could cover millions of acres and were contained in their roaming movement by bodies of water and areas that had been previously devoided of surface fuels. As terrain changed from coastal plains and flatlands to rolling hills and uplands the forest's moisture regime and terrain most likely had a significant influence of the range and severity of these fires reducing both spacial and temporal occurrences.

1.2) Fire Characteristics

The Boy Scout Handbook (2019) states that to have a fire you must have three things: fuel, heat, and oxygen. Other sources refer to a fire's needs as a tetrahedron adding continuous chemical reaction to the base three requirements; still, additional books and papers talk about various fire paradigms. This chapter intends to cover fire characteristics in depth enough to provide the basics required to understand how fire effects soil and water characteristics within a watershed.

> "Fire can mean a fire in grass, or in, leaves, or in herbaceous plant growth, in forest debris, or even in the crowns of trees. It can travel slowly, quietly, and be as gentle as the whisper of a breeze; or it can travel with tremendous speed…It can be so cool that one can put his hand under it without discomfort, or its heat can be so intense as to nearly consume one." (Komarek, 1962**)**.

It is generally accepted that there are three types of forest fires: ground, surface, crown; however, there are four other subsets that need to be discussed as well. Each of these four is derived from a regime of temperature and speed that the fire moves through an area. These four subsets are: Hot/Fast, Hot/Slow, Cool/Fast and Cool/Slow (Figures 1-1, 1-2, 1-3). The importance of these four pertains to how temperature duration effects soil temperature, heat saturation, and the amount of biomaterial consumption both above and below the soil surface. Firm accepted standard rules for temperatures and durations as the speed of the fire do not exist, neither in its travel and rate of material consumption. Temperature has the same open-ended definition; however, for hot vs. cold fires this paper uses an accepted delineation of 300^{o}C. This delineation is based on noted field values for creation of water repellency, destruction of soil organic materials, and temperatures as they relate to biota, both flora and fauna. Speed for the purposes of this paper shall be loosely defined in seconds to periods of less than 5 minutes for consumption rates as a FAST fire versus times greater than 5 minutes to days of conductive and radiant heating beyond the consumption of surface and above ground fuels (e.g., logs and limbs that are supported above ~6 inches of the soil or water surface).

Figure1-1. growth likely to create Fast/Cool burn regime

Figure1-2. growth likely to create Slow/Cool burn regime

Figure 1-3. growth and surface fuel likely to create Slow/Hot fire regime
Arrows denote locations of logs and significant surface fuel in foreground of photo.
Additionally, under growth is hardwood and shrub growth.

1.3) LLP Dominant vs Mixed Hardwood Forests

Fire regimes within the Longleaf pine's range are as varied as the watersheds and ecosystems in which these trees reside in. From coastal plains to the flatlands with gently rolling hills LLP dominated with sparse hardwoods except in steep heads and near water sources. Transitioning into uplands with less sandy soils, oaks, maples, and American Chestnut (*Castanea dentata*) became evermore present, as did a transition from grasses to a woodier understory. This transition changed the fire regime due the increased moisture holding capacity of the duff created from greater volumes of deciduous leaves decaying as compared to the pine needle duff of the lowlands.

1.3.1) LLP Dominated Forests

Traditionally LLP dominated forests have been primarily grassy understories dominated with wiregrasses (*Aristida stricta*) in the northern portions or blue stem (*Schizarium maritimum*, *Andropogon spp.*) (Miller et. al., 2018; UT Austin 2022) combined with other bunch grasses in the southern and more coastal areas, and mixes of herbaceous materials and small woody shrubs. These understories dominated traditional ranges where there were large open areas with LLP rising to the sky above, as LLP growth tends to like significant space between other trees. Areas along the Gulf Coast, south of the Cody Escarpment were filled with Sand Post Oak (*Quercus margaretta.*) that tended to only grow to height of about 20ft. These forests were home to flowing surface fires that moved rapidly based on the flow of winds and terrain, spending minimal amount of time consuming biomaterial. It is not uncommon to find plants like Saw Palmetto (*Serenoa repens*) to have its leaves only partially consumed by rapidly moving fires. In those areas that ground fire became a more dominating fire type, fire temperatures still remain relatively low due to the amount and type of duff material. Variations along the forest floor' however, created pockets of increased fuel load subsequently increased heating duration and thereby significantly increased higher temperatures to deeper within the soil profile. It should be noted that sandier soil types dominate the coastal plains that were dominated by primarily LLP stands.

1.3.2) LLP and Mixed Hardwood Forests

Notable in figure I-1, movement from coastal regions into the piedmont and upland areas that become the Appalachian Mountains and westward movement into the swamps and alluvial plains of the Mississippi Valley. In both cases watersheds change from areas dominated by open grasslands dominated by LLP to mixed stands of oak and other hardwoods to a large-scale area dominated by cypress and tupelo in the wetter areas of the western range, predominately west of the Mobile Bay area. Significant variations in duff content and burning characteristics of the surface fuels should be expected due to variations in material density and volume.

With fire suppression, mixed forests also changed from cleared understories to forests with a significant understory of woody growth and decreased herbaceous species presence. Fuel loads altered drastically with increased surface fuel leading to fire heights that more frequently entered into the crown of the forest. These forests can also be associated with fires of extreme severity similar to the wildfire that devastated the Great Smoky Mountains in 2016 or the fires in western Florida, ranging from 2018 through 2021, after hurricane Michael.

CHAPTER 2

FIRE'S EFFECTS ON SOIL

Andrey S. Zaitsev et al. (2015) states, "A poll conducted among soil ecologists who actually studied forest fires revealed that more than 50% of the findings about fire effects on soil ecosystems are unlikely to ever be published." Understanding there may be significant gaps in published knowledge, should be considered, numerous research projects that appear to contradict one another on the amounts and severity of nutrient loss, creation and destruction of water repellency, biotic response, and so on. It must especially be considered that site specific conditions play a key role in how individual fires affect watershed characteristics.

The topic of Bulk Density will come up often in this chapter and it should be understood that soil density can vary as result of fire and biotic responses and that these changes are subjective in both temporal and spatial measurement. Whereas bulk density can be objectively measured, the how, when, and where measurements are taken play a significant part in the outcome of those measurements. E.g. a BD measurement take after two fires in a short period of time may show increasing BD; however, after plant regrowth and recolonization of insects a temporary increase in BD very well could be found to have returned to prefire conditions.

Bulk density plays several important roles in the soils of longleaf pine water sheds. In the confines of this paper BD is a key factor pertaining to water infiltration and percolation into ground water flow. Recovery of, and in specific cases reintroduction of, plant and mycorrhizal species can depend on pore spaces and soil solution percentages (saturation percentage of available pore space).

2.1) Hydrophobia/Water Repellency

A side effect of prescribed, or naturally occurring, fires is the creation of hydrophobic characteristics within the soil profile. Conversely in some cases it can also mean the destruction of naturally occurring hydrophobic tendencies. Numerous laboratory studies of this phenomenon have been accomplished; however, only a handful of studies have been performed in-situ, , though these in-situ studies were not performed in LLP ecosystems. To this end wherever possible those studies performed in-situ will be presented here with supporting evidence from laboratory studies used to fill knowledge gaps. Understandably, the need exists for more study in the field with varying temperature and temporal regimes over a varying spacial study areas throughout the Southeastern United States.

Hydrophobic characteristics of soil are created by the rapid burning and vaporization of organic materials on and/or within soils. Plants and plant detritus containing waxes, aromatic oils and resins from *Pinus spp.* are the most common sources. These materials move into or within the soil profile due to the temperature gradient, this continues until the molecules of organic material cools sufficiently bonding with soil materials (DeBano.1981/2000). Soil moisture and oxygen content are noted to be key factors in the severity of the development or in some cases destruction, of water repellant compounds in the soil profile (Cawson et al., 2015).

The severity of post fire soil hydrophobia is controlled by the factors of 1) overall fire severity; 2) vegetation quantity and type; 3) soil texture; 4) soil moisture, prefire, and 5) time since fire (Huffman et al., 2001). Review of literature and field experience show that prefire management could be a significant controlling factor as well. Prefire mechanical removal of mid-story and invasive pines, in conjunction with other evergreen species, has the opportunity to reduce a large quantity of volatile organic compounds associated with water repellency of soils post fire.

Laboratory experimentation indicates the destruction of water repellency at high temperatures, e.g., greater than 280°C (DeBano, 2000) or 310–340°C, over a five-minute duration (Doerr et al., 2004). Cawson et al., (2015) reported a possible explanation for this discrepancy as the duration of heating. He states that most laboratory-defined temperature thresholds are derived from durations of at least five minutes, e.g., 30 min (Varela et al., 2005), 5–40 min (Doerr et al., 2004), 20 min (DeBano, 1981) and 40min (Zavala et al., 2010) whereas heating durations in his in-situ study were much shorter averaging across all sites of 6 seconds for surface temperatures exceeding 200°C. At shorter heating durations temperature thresholds for changes to water repellency are likely to have been much higher. A second potential explanation is that oxygen deprivation during the burn affected the development of the water repellant characteristics. Bryant et al. (2005) found that temperature thresholds for the destruction of water repellency were much higher (400 to 510°C instead of 210 to 340°C) when oxygen was depleted, which is hypothesized to occur during Slow/Hot burning regimes.

Soils are generally poor conductors of heat and lend to lower temperatures as depth increases. Bulk density (BD) and soil moisture levels are a significant contributor to maintaining thermal transfer properties beyond just the soils' mineralogical make up (Campbell et al., 1995). Keeping this in mind, fire duration becomes a key factor. Heating duration is solely due to the amounts and types of fuels available. In the case of a fast-moving surface fire, the duration of heating will be minimal; however, areas with significant duff build up, areas with increased fuel loads from downed limbs, fire suppressed or anthropogenically located woody fuel sources (e.g., wind rows and slash burning piles) heating temperatures and durations can last for days and in some cases weeks (Figure 2-1).

Figure 2-1.
Arrow indicates a hot spot on bottom of fallen LLP, six (6) days after the initial fire was set by Ft Rucker environmental management foresters.

2.2) Minerology & Erosion

Alcaniz et al. (2018) cites several studies from various locations throughout the world, that indicate there is little to no change in soil texture in fire of less than 500°C. He notes that there are some anecdotal notes of temporary increases in sand within sandy loams; returning to normal, however, after 7 days. Cawson (2016) notes that in their field studies at Mt. Cole that there was a notable increase in water repellency in the sandy soil. More field study is needed to determine the causal factors, while taking into account pore space and the ability for VOCs compounds to enter those spaces before cooling and creating a hydrophobic layer on the sandy particles. These factors also may be associated with the larger surface areas and variations of sand particles creating individually hydrophobic grains that would enhance rill erosion .

Alcaniz et al. (2018) also notes decreases in clay in coarse loamy soils; however, additional studies sited show very little change in clay contents and others show no change in soil texture after a prescribed fire in the western United States. DeBlano (1990) and Albalasmeh et al. (2012) discuss the stability of soil aggregates as having significant impact on soil organic matter and water retention capability. Destruction of organic material and living roots may in fact increase the VOCs within the soil profile. Once again these conditions and effects are dependent on the severity of the fire.

Bulk density is a matter of conjecture at this point and appears to be dependent on fire severity as much as the constituents of the soil. Several post fire studies indicated increased soil densities for which the authors have indicated various reasons but most studies pertaining to the area of this paper noted increases in soil organic matter after 12 years of prescribed fires due to proliferation of plant root mass (Brye, 2006). Further investigation into this should be highly encouraged as bulk density combined with water repellency leads to increased erosion possibilities.

Creation of water repellant properties after fire is a significant consideration for causal factors in post fire erosion. Increases rill and rain drop splash erosion (Cawson et. al., 2015) can be significantly dependent on the severity of the water repellency, bulk density, physical disruption and the amount of fine root material remaining in the O and A layers of the near surface soil. Spatial variability, due to the overall area of unburnt surface fuels and plant biomass, of hydrophobic characteristics and temporary changes in BD from the loss of fine root materials will have a distinct impact on slope erosion. Maintaining a physically intact forest floor and promoting rapid vegetation recovery is critical to minimizing the magnitude and duration of sediment transport (surface erosion), sediment delivery (suspended solids) and postfire water quality variability (Elliott and Vose 2006, Clinton and Vose 2007).

2.3) Nutrient Changes

Cater & Foster (2003) quote in their introduction N. L. Christensen (1987), ‘‘The literature on fire is a bit like the holy scripture; by careful selection of results, one can ‘‘prove’’, for example, that fire increases, decreases, or has no effect on nutrient availability, or that fire results in considerable or negligible loss of nutrient capital from the ecosystem’’.

Nitrogen – N

The effect of fire on N availability has continually been of interest since N availability is one of the primary limiting factors to ecosystem productivity. The USDA in several of their publications note that there were no substantial increases or decreases in total N after a prescribed fire. After a meta-data review, Carter et.al. (2004) concluded there was no significant increase in total N; however, significantly higher levels of NH_4^+ had been noted in several studies without increases in NO_3^- for up to 12 months following slash fires. Added soil moisture and leaching from rainfall events and/or immobilization due nitrifying bacterial interactions may have led to increased soil NO_3^- with reductions in NH_4^+. After repeated fires N levels were noted to be below those of fire suppressed areas and those areas burned on much longer interval (Cater et. al. 2004). I surmise this is due to the reduced fuel loads and losses of N over time in the form of volatile organic compounds (VOCs) in a gaseous state during fire events.

As with carbon levels N levels should be expected to decline in areas where fire is being reintroduced. This reduction for the most part is due not to losses from a bulk source volatilization but from repeated removal of the duff layers preventing natural nutrient cycling.

Phosphorus – P

After a fire ,“The particulate fraction, a fine ash, of P, can be concentrated 50-fold and returns to the soil surface rather quickly. This results in redistribution within, rather than a loss from the stand or ecosystem (Cook, 1994).”

Phosphorus is an element of significant concern as it is directly associated with leaching into ground and surface waters, after terrestrial events. This leaching and accumulation lead to eutrophication and other associated problems. P is typically considered to soil immobile; however, water-soluble organic phosphorus compounds (e.g., livestock manure) can provide excesses of organic P. In the Southeastern United States this is not the norm, but some chicken manure is sometimes used in silviculture and is commonly used in agricultural endeavors, that may exceed soil solution carry capacities with or without fire interaction.

As large portions of what was longleaf dominated area has now become agriculturally managed areas, it must be noted that regardless of crop types and intervals, phosphorous will react differently than in forested areas. The premise of this paper is to discuss fires’ effects on soil and water properties; however, it should be considered that during restoration processes additional P may need to be added in calcareous soils that are also high in iron and aluminum. Large areas of this soil type can be found in lower Alabama, Georgia and Mississippi. Shuai Zang et al. (2021) notes that most of the P fertilizer applied to crop production is unavailable to plants because it is fixed in the soil by sorption or precipitation with Calcium (Ca), Iron (Fe) and Aluminum (Al) oxides depending on the soil pH and/or redox condition. The P fixed in a given soil can in turn be mobilized, depending on the changes in soil properties influenced by soil management practices. Use of fire has been noted to have the effect of changing soil pH levels dependent on severity and preexisting soil qualities and values. Additionally, the Zang paper notes that the organic carbon and ammonium (NH_4^+) can act as electron donors in the Fe(III) reduction reaction as reported in previous studies by (Wang et al., 2018; Yang et al., 2012). In their studies where the mineral fertilizer coupled with manure, mineral fertilizer with manure and straw, and manure coupled with straw treatments, soil Fe (II)/Total Fe ratios were significantly greater while electron accepting capacity was lower by 37–49.3% than those in the mineral fertilizer treatment (control) (Zang, 2021).

Restorative, prescribed, and to a larger extent wildfire releases large amounts of nutrients into the atmosphere, but unlike nitrogen compounds, phosphorus compounds ($PH_2O_4^-$ & PHO_4^{-2}) remain in a solid form. This is determined by the amount of plant material and duff that is consumed. The particulate fraction, a fine ash, of P can be concentrated as it returns to the soil surface. This could result in redistribution both within and downstream of a fire effected watershed due to enriched sediment transport. It should be considered that although fire may remove some P from the soil system, P volatilizes at such a high temperature (774°C) that losses due to burning are most likely minimal (DeBano et al. 1998).

Carbon – C

Fire effects on carbon-C need to be considered in three primary constituents: organic carbon, inorganic, hydrocarbons (discussed in section 2.1).

CO_2 is an inorganic form of C known to be a byproduct of fuel consumption, particularly through lower temperature combustion. This form of inorganic carbon is lost as a gaseous byproduct primarily from combustion of foliar materials and woody fuels that contain moderate high levels of moisture (e.g., rotting logs). Carbon losses as CO_2 can be considered complete losses from the soil profile as this C form does not readily return to the soil profile in its precombustion form as organic material. Photosynthetic transference into organic forms will in time occur and with plant death the carbon cycle will normally return this carbon to the soil profile.

Biochar material, created from incomplete/anoxic organic material combustion, is a mix of organic and inorganic carbon material. Little has been published providing in depth knowledge of how biochar effects soil quality in the long term but has been noted in some published material to have an effect on soil CO emissions. Biochar has also been shown to have some level of water holding characteristics in soil. Particulate ash found after fire events is considered by some sources to be organic carbon based due to the material of origin other sources contend that is inorganic.

Severity of the fire in both temperature and duration plays a key role in the effect on organic material in the soil profile. Temperatures above 48°C (refer to Table 2-4) begin to destroy plant material temperatures, above 200°C are known to break down organic compounds. The carbon materials' fate is determined by factors such as soil moisture, components and temperature gradients. Those organic carbons that become volatilized readily with typically be off gassed or undergo conversion to hydrocarbons associated with water repellency. The loss of organic carbon via any route is a significant issue as carbon becomes a limiting factor in biological functions, water holding capacities, and plant nutrient uptake .

2.3.1) Slash Burn Soil and Nutrient Concerns

It is not likely that the majority of natural or prescribed fires affect changes to N and P forms due to lower soil temperatures below 100°C. Slash burns (Figure 2-2) create soil temperatures, in the top 10cm, have been noted to be 100-200°C frequently and have been noted to exceed 500°C with prolonged durations.

Figure 2-2. Slash pile (preburn) consisting of limbs stump and root systems. Approximately 3m x 8m x 5m in size.

Creech (2009) states that although nutrients such as P, K, Ca, Mg, and NO_3^- were higher in log shadows than the surrounding savanna (characteristics which would be expected to encourage revegetation) C:N was high and mineral N was low, suggesting that strong N-limitation was evident. It should be noted that further investigation found N not to be a significantly limiting factor (refer to section 2.4.3). It is probable that with these significantly higher temperatures that changes in cation exchange capacities will be altered particularly in clayey soils. It has been additionally concluded that as most studies are conducted in the short term, post fire, that increases in nutrient levels will decline as herbaceous species repopulate watersheds (Creech, 2009). It should however be considered that sterilization of soil in log shadows of slash burn piles will be significantly more severe and longer lasting than that of Slow/Hot prescribed or wildfire regimes due to concentrated application of heat over time. This sterilization will likely prolong any herbaceous reestablishment leading to the need for more study on the long-term effects on soil quality post slash burn events.

2.4) Biota

Research on the effects of forest fires pertaining to soil fauna started nearly a century ago (Heyward and Tissot, 1936); however, it is unfortunate that the sum of the studies dedicated to the impact of wild and prescribed fires on soil organisms remains sparse. Those that are available tend to lean towards specific species rather than maintaining a holistic view, most likely due to the difficulty in setting up precise methodology for collecting and measuring data sets both spatially as well as temporally.

We will consider certain generalities to be present throughout the variety of soil and forest types and conditions within the LLP's range: 1. pH increases postfire, for at least short periods of time making nutrients more available for uptake, 2. Cool/Fast fires with low severity of surface organic material have little effect on soil biota, 3. In cases of soil organic material destruction, organic C will be the limiting factor even greater than N or P for biota reestablishment. The ever-present exceptions to these generalities are ever-present and must be considered.

2.4.1) Meso and small macrofauna (mites, worms, insects)

Regardless of where in the LLP ecosystem you study, aeration of the soil is a function primarily of meso (.1-2mm) and small macrofauna. To that end, they are probably the most likely contributor to preventing increased bulk density in soils that are exposed to repeated fires that remove large sums of root material either directly or because of plant mortality. These species are also significant in the breakdown of soil organic material and are key in maintaining aeration of the upper portion of the A and the O horizons

Research by Heyward and Tissot, (1936) in LLP watersheds is to date the broadest individual data set available. Research data from several locations and soil types indicate increased mortality as fire severity increases. They make the hypothesis that in forests burned annually in these areas, soils would be devoid of small species incapable of rapid locomotion. In contrast this was found to be untrue attributed to soil temperatures seldom exceeding 80-90°C. Perhaps quoting Heyward and Tissot (1936) directly would best summarize this concept:

> “The A_O horizon of unburned areas contained approximately five times as many microfaunal forms as the ground cover of burned areas. The top 2 inches of mineral soil of unburned areas contained eleven times more such animals than the corresponding soil depth from burned areas.
>
> “In general, the same microfaunal groups were found in soils protected from fire as in soils exposed to periodic fires, although the total number in each was different.”

2.4.1.1) *Solenopsis invicta*

The red imported fire ant (*Solenopsis invicta*) builds mounds in nearly any type of soil, but prefers open, sunny areas such as pastures, meadows and cultivated fields. Soil moisture and bulk density appear to be key factors in mound location and numbers. Personal observations lead me to the belief that even though *S. invicta* can be found in landscaping pine straw, *S. invicta* tend to avoid soils with densely matted pine duff. Research into this observation is recommended particularly if the casual factor is due to decreased pH and/or elevated terpene levels associated with decaying pine-needle based duff.

The National Park Service’s Fort Smith, AK website has posted “Fire ant mounds can extend into the ground 20' deep or more,”. This is the extreme depth that has been noted during this author’s research; however, the average from numerous non-peer reviewed sourced material is a maximum depth of approximately 8 feet. It has been thought that the disturbance of prescribed burning encouraged their spread; however numerous university studies contradict that idea. *S. invicta* may actually be temporarily deterred due to increased bulk density and decreased soil moisture. Due to soil heating depth in all but the most severe fires, it can be concluded that the depth of the colonies are not disturbed by fires either.

One final thought on *S. invicta* is that even with the issues and species competition created by this highly invasive species, the size and vast multitude of their colonies provides significant aeration and decreased bulk density into any soil they inhabit.

2.4.1.2)

The most rounded and complete information pertaining to meso and small macrofauna comes from research completed at the Tall Timbers Research Center circa 1936 by Heyward and Tissot. The Heyward and Tissot data indicated eradication of numerous species reductions in species quantities postfire in comparison to areas with fire suppression or in frequent fires. Surface and near surface dwelling species of mites, insects and Family *Lumbricidae* were noted to be the most effected by fire. This can be attributed to the proximity and relative durational heating from various fire regimes. Morbidity levels varied primarily from soil temperature peak levels along with duration of exposure at depth within the soil profile (Table 2-1,2,3) and to a lesser degree soil moisture content and type

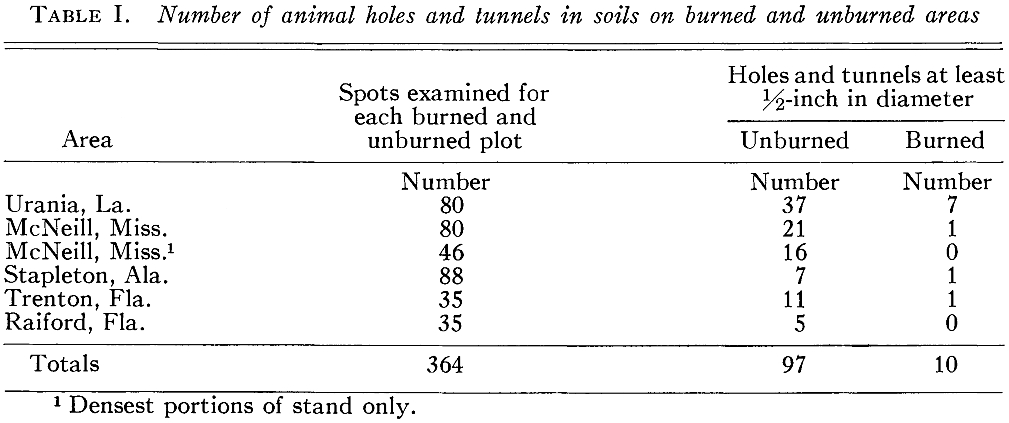


TABLE I. *Number of animal holes and tunnels in soils on burned and unburned areas*

Area	Spots examined for each burned and unburned plot	Holes and tunnels at least ½-inch in diameter	
		Unburned	Burned
	Number	Number	Number
Urania, La.	80	37	7
McNeill, Miss.	80	21	1
McNeill, Miss.[1]	46	16	0
Stapleton, Ala.	88	7	1
Trenton, Fla.	35	11	1
Raiford, Fla.	35	5	0
Totals	364	97	10

[1] Densest portions of stand only.

Heyward &Tissot, 1936

2.4.2) Macrofauna (moles, voles, gopher tortoise, etc...)

To a far lesser extent than mesofauna and small macrofauna, larger macrofauna (e.g., moles and burrowing rodents and reptiles) play their part in soil manipulation. There activities relate to cycling of soils during their digging and cycling of plant detritus in and below the A horizon as they create and line their nests.

Moles (primarily: *Scalopus aquaticus*) and pocket gophers (*Geomys pinetis)*, in particular, create subsurface flow channels encouraging ground water infiltration and flow within the A and B horizons. It is unclear as to long term effects of high severity fires (Slow/Hot), but lower severity fires (Fast/Cool and Slow/Cool)) appear to have little or no effect on populations. Moles dig there tunnels just below the surface as they hunt for insects and larva; however, they also dig deeper tunnels ranging from 7cm as deep as 100cm (Blakely & McPeake) thus allowing them to escape to cooler levels in the soil profile (Figure 2-3).

TABLE II. *Soil microfauna from burned and unburned areas*[3]

Animals	Unburned		Burned	
	A_0 horizon	0–2″ mineral soil	Ground cover	0–2″ mineral soil
	Number	Number	Number	Number
Acarina (mites)[4]	5,415	4,719	1,107	143
Acarina (ticks)	2	0	0	0
Araneida (spiders)	41	5	12	2
Chernetidia (pseudoscorpions)	4	0	2	3
Thysaneura (bristletails)	4	46	2	4
Protura	0	1	0	1
Collembola (springtails)	1,092	10	188	3
Orthoptera (roaches)	3	1	0	1
Isoptera (termites)	16	2	0	0
Psocoptera (psocids)	20	0	16	1
Thysanoptera (thrips)	310	0	65	1
Hemiptera (true bugs)	21	3	19	0
Lepidoptera (moths)	1	0	1	1
Coleoptera (beetles)	48	17	16	10
Coleoptera (larvae)	45	39	18	20
Hymenoptera (ants, mostly)	350	136	53	240
Diptera (two-winged flies)	75	51	31	15
Insecta (larvae and pupae, order undetermined)	100	0	6	0
Isopoda (pill-bugs)	2	1	0	0
Chilopoda (centipedes)	15	5	0	0
Diplopoda (millipedes)	5	2	0	3
Annelida (earthworms)	6	52	3	13
Mollusca (snails)	1	0	0	0

[3] Figures based on 4 sq. ft. of A_0 horizon or ground cover and 2 sq. ft. mineral soil except those for Trenton and Adrian areas, which are based on 3 and 1½ sq. ft., respectively.

[4] Number of mites estimated by means of a sampling device consisting of a glass dish with 25 ruled squares each, 1 cm. on a side.

Heyward & Tissot, 1936

TABLE III. *Total soil microfauna for individual study areas*

Study Areas	Unburned		Burned	
	A_0 horizon	0–2″ mineral soil	Ground cover	0–2″ mineral soil
Trenton, Fla.	4,019	30	36	20
Adrian, Ga.	134	0	25	1
Urania, La.	220	181	90	192
McNeill, Miss.	1,281	3,783	103	78
Stapleton, Ala.	830	906	913	83
Mt. Dora, Fla.	86	9	0	0
Bartow, Fla.	53	16	15	14
Lake Butler, Fla.	182	31	256	46
Raiford, Fla.	771	134	101	27
Totals	7,576	5,090	1,539	461

Heyward & Tissot, 1936

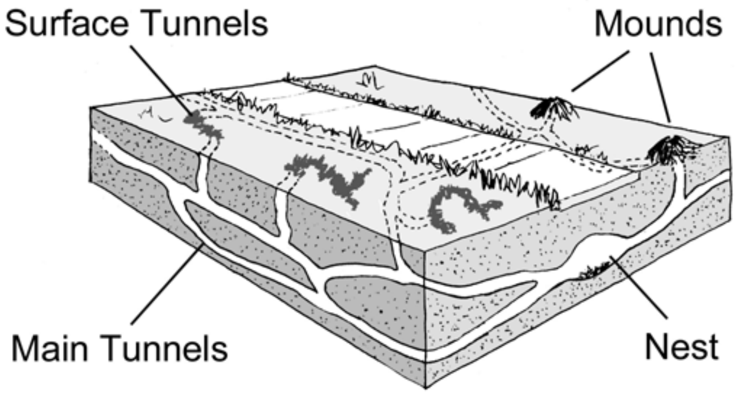


Figure 2-3. Mole's underground burrowing consists of exit mounds, surface and subsurface tunnels and nesting areas. University of Arkansas, FSA9095

Voles (*Microtus spp*.) populations were noted to decline post fire (Simkin & Michener, 2005). This is most likely due to the loss of food sources as they, unlike their mole cousins, are vegetarian in nature. It should also be considered that removal of vegetation during surface and ground fires would also destroy their nesting sites.

The gopher tortoise, to a greater extent than moles, are keystone species that digs significant burrows in the sandy soils of coastal plains and coastal rolling hills. Simkin and Michener (2005) note that there is a decline in numbers of active burrows found. Perhaps this is due to decreases in food sources although tortoise remains have been found on Fort Rucker post fire indicating that perhaps distance from their burrow is in part a casual effect for decreased numbers. Due to the size and depth of gopher tortoise burrows they act as significant water catchments in some areas either from flooding or rain deluges that occur during the summer month within their native range. Even with compacted soils associated with the creation of these burrows, over time abandoned burrows collapse create depressions with decreased bulk densities.

2.4.3) Rhizosphere

Volumes have been written indicating the benefits of mycorrhizal fungi and nitrogen fixing bacteria, I have no intention of beleaguering that point. Pertaining to effect of fire soil moisture prior to the event and temperature vs. duration are the most important factors to the survival of soil microorganisms. Surface fires have a significantly lower effect on soils in this case as the heating is less severe and has minimal direct impact on destruction of hyphae within the O layers. Increases in fire severity and consumption of surface fuels directly impact microbial mortality. Soil heating increases the mortality; however, soil moisture or more aptly the lack of moisture mitigates this issue. The USDA (2005) notes that soil microorganisms are most active in moist soils and that studies have indicated decreases in mortality as moisture decreases as can be noted in Table 2-4. This decrease in mortality can be attributed to not only decreases in metabolic activity but to decreasing heat transfer via soil moisture.

Creech (2009) noted that in some species (e.g., *Aristida stricta*) that Arbuscular mycorrhizal (AM) was not normally associated with root systems. AM spores were additionally noted throughout LLP forests and that even cases of significant fire scarring AM and other microbes may have been protected by the water holding capacity of previous char material. This rapid regrowth of wiregrasses combined with high nutrient availability, postfire, leading to rapid recolonization of AM and *Nitrosomonas spp*. bacteria could be attributed to the lack of surges in nitrogen and other nutrients within postburn soils.

Soil type most be considered in this as well. Soil moisture influences heat transfer within the soil profile, but soil minerology and type directly affect the rate and duration of heat transfer. Sandy soils with their increased pore space heats faster near the surface but transfer of heat decreases rapidly and is transferred back into the atmosphere more rapidly after the heat source is removed. Denser clayey soils tend to be slower to heat but also tend to hold heat due to the prolonged dispersion rate.

It should be mentioned that fungi combined with other organic material are thought to cause hydrophobic characteristics in the most superficial layers of soils (Cawson et al., 2016).

Biological component	Temperature °F	°C	Reference
Plant roots	118	48	Hare 1961
Small mammals	120	49	Lyon and others 1978
Fungi—wet soil	140	60	Dunn and others 1975
Fungi—dry soil	176	80	Dunn and others 1975
Nitrosomonas spp. bacteria—wet soil	176	80	Dunn and DeBano 1977
Nitrosomonas spp. bacteria—dry soil	194	90	Dunn and DeBano 1977

Table 2-4—Mortality threshold temperatures for key biological organisms. Excerpt created from USDA Forest Service RMRS-GTR-42-vol. 4. 2005

2.4.4) Flora

When most speak of fire and plants it is from the aspect of removal and destruction of plant material, but perhaps it is best to speak of it as a maintainer of ecosystems, especially from the perspective of LLP habitat fire suppression encouraging an invasion of a woody plant species that not only shade out herbaceous species but decrease ground water reserves in an environment that evolved throughout periods of drought and deluge. Pre-European settlement herbaceous plants and grasses ruled the understory of the majority of the Longleaf's range. Excluding areas that have been developed as urban areas and those that are primarily agrarian, fire suppression has shifted the forest understory to woody shrubs and understory trees making native plants rare aside from all but the most resilient. Most of those rare plants are herbaceous perennials that depend on frequent natural fire. More than half (65%) occur in moist LLP habitats (i.e., seasonally wet flatwoods and savannas, depressions, shrub bog ecotones, seepage slopes, pond margins), although many (45 species, 24.2% of the total) occur in a more typical mesic-dry upland habitats (Walker 1993, Glitzenstien et. al., 2001).

Beyond the symbiotic relations of soil microorganisms in nutrient uptake, the destruction of above ground plant material leaves sequestered C and other minerals in the remaining roots and as new herbaceous plants and grasses emerge, they uptake available soil nutrients (e.g., N, P, K in their various forms) reducing excess soil nutrient loads created by burning of above ground plant material. It has been hypothesized that burning increases N_2 fixation by legumes, which compensates for the N losses due to burning (Cater and Foster, 2003). Legumes are known to fix N within their root structure, but further study is needed to determine if this actually compensates for fire losses of N within the soil profile (i.e., the O and A layers).

As this is a holistic review, fire is native to and directly affects soil and water quality; however, new species of flora have been introduced to the realm of the Longleaf pine. Species within LLP ecosystems have evolved due to fire and grow at rates that tolerate the heat and destruction/renewal associated with periodic burning. When new species are introduced the fire paradigm can shift, sometimes drastically, and those introduced species may invade the niche of native species. Cogon grass (*Imperata cylindrica*) for example is one of these species and it grows faster and denser than native wiregrass and bluestem species. Additionally, unverified information indicates that fire temperatures are higher in areas invaded by the dense growth of *I. cylindrica*, and with a root system that can grow to depths of 4 feet (~120 cm) this species can alter ground water flow and nutrient levels within watersheds it has invaded.

CHAPTER 3

FIRE'S EFFECTS ON WATER QUALITY

It would appear at first that a fire would have little direct effect on water other than deposition of ash and perhaps a slight increase in surface temperature due to convective and/or radiant heating; contrary to this, fire can have significant effects on water quality beyond temporary temperature increases. Water quality and quantity post fire can vary from only slight deviations in chemical biological and sedimentation to disastrous effects. These effects are both directly and indirectly related to the effects on soil and consumption of plant materials.

Use of fire as a restorative method for LLP watersheds is a must for multiple reasons, many of which deal with increases in hydrolic connectivity and increases in available water quantities. LLP watersheds have been known for high water quality and quantity due in part to the grassland savanna understory and lack of woody/shrub flora taking up large volumes of water from the available ground water supply. It is important to realize that even with possible increases in erosion that can lead sediment transferred to riparian flow, a grassy understory that rapidly recovers from fire can decrease sediment displacement and increases percolation leading to long term increases in ground water supplies. The greatest benefit of fire in the LLP watershed is removal of plant biomass and significantly reducing the leaf area index, thereby decreasing transpiration and in turn loss of available ground water.

3.1) Sedimentation

As discussed in Chapter two of this manuscript, issues associated with water repellency and subsequently erosion plays a key factor in sediment contamination to both surface and stream flow. Fire severity, although a significant factor, is secondary to issues of soil type, slope, compaction, and significance of rainfall events. It should also not be overlooked that sediment transport is not only natural but necessary within watersheds. The extreme of this is the Mississippi River Delta, without sediment transport there would be no delta or the ecosystem functions associated with it. Anne Spafford, of North Carolina State University, describes in several of her lectures that precipitation events in the Southeastern United States are in the form of either drought or deluge. When the issue of sediment transport is discussed, it should be considered that in LLP watersheds that timing of both drought and deluge, as compared to the recency of a fire event, will significantly affect the volume of sedimentation transported into stream flows.

This sediment may be transported long distances or may be rapidly deposited altering the flow of streams and rivers. Regardless of the initial distance, unless other physical factors such as streambed debris or anthropogenic structures hold the sediment, significant flow events will reintroduce finer sediment back into the water column ending in final catchments downstream. Whether the catchment is a lake or bay, tertiary effects may be noted for long temporal durations even if the effects are minimal. Anthropogenic catchments, such as reservoirs controlled by dams have been known to be completely filled with fine through course sediment deposits (Figure 3-1 & 3-2)

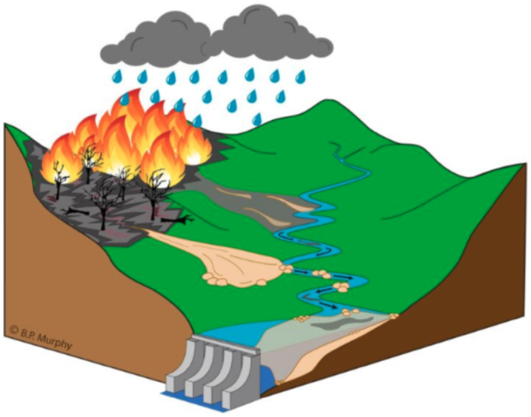


Figure 3-1
Bredan Murphy, Utah State

Figure 3-2. Matilija Dam, on the Ventura River Basin, California, is nearly completely filled with sediment. When constructed in 1947, the dam was 190 ft high and impounded a volume of 7,000 ac-ft; by 2015 it was reduced to 400 ac-ft. Photo credit: P. Jenkin.

Figure 3-2 is an extreme example of this event. Conversely in LLP watersheds this is not likely in all but the steepest and most upland regions. To date, research for this paper has provided no examples of significant sedimentation build up in catchments in LLP watersheds; contrary to this, rivers in portions of the coastal plains have been noted to have become un-navigable due to extreme sedimentation. Upper portions of the Choctawhatchee river are now sediment laden, albeit this is more associated with agricultural practices than residue sediment directly from fire enhanced erosion.

It is commonly accepted that riparian buffers have substantial impacts on reducing water quality degradation due to fine and to a lesser extent course sediment transport. Fire in and of itself, may negate any natural or designed herbaceous buffers; nevertheless, the sediment that is eventually deposited into the channels, following a fire, changes the physical and chemical characteristics of the water flowing from the burned watershed (USDA, 2005).

It should be mentioned that as compared to wildfires, prescribed burns create less sedimentation problems, this is largely due to the decreased vegetation destruction within the watershed and the effects on the physical properties of soil leading to erosion during rain and wind events. The primary standards for suspended sediment concentration and turbidity with respect to drinking water are written in terms of turbidity (U.S. Environmental Protection Agency 1999). Turbidity is the measurement of the depth of which light, particularly sunlight, can penetrate water. The USDA recognizes that this is an area that requires more study due in part to the rapidly changing conditions of streamflow and the variability of measurement techniques. Factors affecting turbidity include the increase of chemical compounds such as tannic acid and ash, but also include reductions in light transference based on carrying capacity of fine silts and clay material washed into stream flows during surface flow events.

3.2) Nutrient Variations

It was my original intent to cover nutrient variations similar to that of Chapter 2, the extremes in variation from rainfall event, soil types and severity effects of the fires themselves make it is near to impossible to provided concise data. It should be expected that as surface and ground flows increase initially that there will be a spike in nutrient loads from ash or enriched sediment transport. Numerous articles and studies reviewed in the process of this paper have significantly varied results from extreme nutrient loading to decreased nutrient loads in stream flows. The USDA (2005) and Richter et al. (1983) agree in that over time there is no significant degradation to water quality due to long term increases in nutrient loads.

Perhaps the best way to look at C, N and P increases, in stream flows and catchments, is that the majority of these compounds are being transported during initial surface flow events after fires and that what little is transported by percolation and seepage carbon that is in a mineralized form. Surface flow nutrient levels, in most literature reviewed, and witnessed after controlled burns at Fort Rucker, Alabama, are largely due to the amounts of ash being transported via run off. These ashy nutrient loads are in the form of organic material being transported by surface flow primarily from duff material not fully consumed during combustion. Potassium (K) and Phosphorous (P) typically being soil immobile elements will temporarily be mobile in the form of ash, with increased soil moisture from small rain events with little surface flow and distributed primarily through infiltration reenters the soil and once again become soil immobile or taken up by reemerging plant growth and mycorrhizal organisms.

The Battle & Golladay (2003) study has stated that there are less dramatic changes in water quality of streams for prescribed fires versus wildfires (see also DeBano et al., 1998) additionally Richter et al. (1982) found that prescribed burns did not significantly alter water quality of streams located on the Coastal Plain in South Carolina. The Battle & Golladay (2003) study indicated that even low intensity prescribed fires are capable of altering water quality of wetlands in Southwestern Georgia, and that it is the scorching of soils that is most responsible for changes in water chemistry. Understanding the variances in nutrient release in various fire regimes is critical. In cases of traditional longleaf pine-bunchgrass forest fires there would be minimal nutrient releases; whereas reintroduction of fire to long suppressed areas and in the slash burning cases studied by Creech (2009), the volume of biomass and duration and level of soil heating would be more likely to seen in what Battle and Golladay (2003) described.

Mercury - Hg

It should also be noted that there are some significant concerns about mercury (Hg), because it biomagnifies up food chains in aquatic ecosystems (U.S. Environmental Protection Agency, Office of Research and Development 2002). Approximately 100 percent of mercury stored in plant-based fuels is emitted into the atmosphere, 85 percent of which is elemental mercury and 15 percent particulate mercury (Friedli and others 2003). The USDA (2012) states that further investigation is required in this area, but bioaccumulation and mercury cycling does not appear to be affected by fires. Studies in Canada, by Kelly et. al. (2006) and Garcia and Carignan (1999, 2000, 2005), show mixed results in areas of burned watersheds and those remaining unburned. The increases in mercury found in fish have varying levels, from no significant increase to 500 percent increases (Carignan et al., 2000). Based on those studies, mercury levels are hypothesized to be species dependent and are not unilaterally caused by releases during fire events.

Two particular points on water quality should be noted. While there have been numerous studies on LLP restoration, there is very little information available on its restorative effects on the forest water and carbon (C) balance. The linkage between watershed-scale LLP restoration and ecohydrological-biogeochemical processes are important regional issues pertaining to water resources and C sequestration (Amatya et. al., 2019). Further the natural or prescribed use of fire in controlling under growth reduces the need for the use of chemical spraying as a primary means of control. This in turn may significantly reduce herbicidal residue in available ground and surface water, situationally.

CHAPTER 4

FIRE’S EFFECTS ON DEPRESSIONAL AND PEAT WETLANDS

Forest and riparian wetlands are unique in their response to the effect of fire and as they are both a result of ground water table variations for most, and stream flow levels for others. Water and soil quality in and surrounding wetlands pose a distinctive challenge in describing, due to its distinctive anaerobic nature. Reviewed literature indicated only a few studies have been accomplished towards understanding the processes on forest depressional wetlands (e.g., Kirkman et al., 2012 and Battle & Golladay, 2003).

4.1)Wetland Characteristics

For the purposes of this paper wetlands will be limited to depressional wetlands, and peatland; consequentially, excluding wetlands dominated by Cypress species (*Taxodium spp.*). Due to the significant fluctuations in nutrients and hydrologic variations riparian and coastal wetlands will additionally not be discussed in much depth. It should however, be considered that regardless of the type and location of wetlands that it is commonly accepted that they will at some point become sinks for debris and enriched sediment effected by fire, erosion, and agricultural events higher in the watershed. Hydrologically active, those with constant or predominantly active inflows/outflows from the wetlands will have significantly different characteristics from more isolated and/or landlocked types of depressional and peat wetlands.

The majority of these depressional wetlands are characterized by poorly drained high-water table soils due to both low topographic relief and sites (Amatya, 2004) that experience natural, and in some cases anthropogenic, ground water flows or seeps. The majority of the outflow (surface runoff and subsurface flow/drainage) from these watersheds, are derived from saturated areas where the water is either at the surface or a near surface water table is present. In other words: outflow is dependent upon the vertical position (relative to the surface soil layer in the wetland) of the water table (hydroperiod), which is driven by rainfall, ground water flow, and evapotranspiration (ET). To a lesser extent it is also dependent upon soil and vegetation type and seasonal dynamics (e.g., temperature, wind and cloud cover); thus, through interactions with vegetation and soils, specific location hydrology plays a significant role for various wetland functions (Amatya, et.al. 2019).

4.2) Nutrient Cycling

The slow decomposition of wetland biomaterial creates peat that act as a nutrient sink but can in turn create nutrient deficient soils. In the case of fens and bogs within watersheds, but not directly tied to stream flow, and in some cases pocosins, fire during periods of lower water levels act as a necessary part of nutrient cycling by burning peat and other biomaterial thus releasing sequestered nutrients. The degree to which fire influences overall nutrient balances within depressional wetlands is not well understood. In general, fire consumes much aboveground biomass and litter, increasing the rate of nutrient turnover; however, the type of vegetation, soils, timing of rainfall, intensity of fire, and hydrologic regime also influence nutrient turnover and availability. In the case of peat wetlands, hydroperiod can also play a significant role. During periods of decreases water tables and decreased inflow exposed layers of peat are subject to Fast/Hot fires of dry organic material while moister material may smolder for days and weeks and may actually become charcoal or biochar, as has been found in the bogs located on Anniston Army Depot, Alabama. Wilbur and Christensen (1983) found that following fire events in shrub-bog wetlands, considerable enrichment of nutrients occurred, including Mg, K, PO_4^-, NH_3^-, and NO_3^-.

Wilbur and Christensen (1983) state that it was unclear as to whether the increase in nitrate in burned peat was a consequence of ash addition, reduced plant uptake, or changes in rates of nitrification and denitrification. Nutrient volatilization associated with fires that consume vegetation in herbaceous wetlands with mineral soils may result in losses of N and C due to gaseous volatilization from combustion, but little loss of P, similar to that reported in adjacent upland longleaf pine/wiregrass forests (Boring, et al. 2004).

4.2.1) Heavy Metals/Pesticides

Due to lack of significant outflow, heavy metals and pesticides will build up in depressional wetlands. With certain types of pesticides, fire can decrease build ups through heat degradation of the specific compounds; conversely, fire has the ability to release some pesticide compounds intact from organic material that has accumulated in peatlands. In other wetland situations, bio-remediation, through plant and microbial uptake plays a part in reducing pesticide and heavy metal leaching into ground water.

4.2.2) Upland Fire Influences

Upland fires may be significant in providing a nutrient bolus that serves to enhance the nutrient availability within various depressional wetlands. The amount of nutrients and enriched sediment transported into wetlands postfire can be presumed to be dependent on several factors such as nutrient solubility, timing and volume of rain postfire, catchment area of the watershed and wetland, when the burn occurred (i.e., growing season versus cool season dormancy), intensity of the burn (e.g., Slow/Hot versus Fast/Cool fires) and severity of the burn (i.e., volume of fuel consumed).

4.3) Riparian and Coastal Wetlands

Though this paper does not directly discuss the effects of the wetland/fire interaction on riparian and costal wetland systems, it should be noted it is commonly accepted and has been discussed in various literature that wetlands have the distinct ability to mitigate enriched sediment's effects on riparian and estuarian nutrient levels and overall water quality. Even though depressional wetlands are usually separated from riparian flows, these wetlands act as sinks reducing or as least slowing enriched sediment and nutrient leaching inflows into watershed stream flow and transport to riparian and coastal ecosystems. This is particularly true in the case of fire enhanced spikes of mineralized nutrients being carried by surface flows as well.

> "Hydrologic fluxes of N, P, S, and basic cations, from burned pine litter to ground and stream waters, are not likely to have appreciable impacts on water quality in the Atlantic and Gulf Coastal Plain." Richter et al. (1983).

CONCLUSION

Whether the data is from a USDA-GTR or a scientific, peer reviewed papers (e.g., Richer et al., 1983) it is reasonable to say that fire does not significantly affect water or soil quality in LLP watersheds. There are of course specific contradictions to this statement that tend to be both spatially and temporally limited. In fact, areas where watersheds ,worldwide, are restored to more frequent fires, and with reestablishment of native grasses, water quality and quantity have been seen to improve. This is in part due to reduced loses from ET, increased infiltration rates, and decreased sediment transport losses. This is true in respect to decreases in soil and nutrient losses from wind and water erosion, as well.

Significantly more research needs to be accomplished, regionally, to determine specific or at least more confined effects of fires on soil and water quality. Due to the extremes in soil moisture and minerology throughout the traditional range of Longleaf pine, it is impossible to draw specific conclusions or develop widespread Best Management Practices to ensure enhance and/or reestablish high degrees of soil and water quality. Since the perception of fire is so individual and every fire is its own beast with its own personality; perhaps the only true conclusion to this manuscript is that, as scientists study and publish specific pieces on the effects of fire, that we as a community should consider a more holistic approach to experimentation and observations of fire on watershed processes.

Glossary: derived primarily from https://www.fs.fed.us/nwacfire/home/terminology.html

Bog - A type of peat wetland that receives water and nutrients from atmospheric precipitation

Duff - The layer of decomposing organic materials lying below the litter layer of freshly fallen twigs, needles, and leaves and immediately above the mineral soil.

Fen - A type of peat wetland that receives significant water and nutrients from a ground source of water.

Fire, crown - The movement of fire through the crowns of trees or shrubs more or less independently of the surface fire.

Fire, surface - A fire burning in vegetation that is predominantly grass but may include brush, fern and small palms: fire remains primarily above the duff layer

Fire, ground - A fire burning that is predominantly in direct contact with the soil horizons (e.g., Duff material burning)

Fire Severity - will refer to the downward energy dispersal, which determines the consumption of the forest floor and heat transference into the soil profile

Fire, slash - fire built for the purpose of disposing of large quantities of waste wood material created from activities such as clear cutting, wood removal, due to large tree fall events (e.g. Large areas of downed trees from hurricanes), restoration or conversion events (e.g., conversion from forest to agriculture , industrial or residential)

Fuel - Combustible material. Includes vegetation, such as grass, leaves, ground litter, plants, shrubs and trees, that feed a fire.

Hydroperiod – the time a soil is saturated or flooded, and results from water table movements caused by distinct seasonal changes in the balance between inflows and outflows of a particular wetland.

Litter - Undecomposed or only partially decomposed organic material that can be readily identified (e.g., plant leaves, twigs, etc.)

Peat - organic material that is deposited under water-soaked conditions as a result of incomplete decomposition

Peatland – Any type of peat covered terrain with an accumulation of at least 20-40cm of peat within the top 80cm of the soil profile in the US and Canada or 30cm in Europe. Most abundant and wide spread of all wetland types.

Pocosin – An upland swamp or wetland bog with a sandy-loam and peat soil, dominated by woody shrubs. Formed by accumulation of organic material resembling a black muck. They occur predominantly in the SE-USA along the Atlantic coastal plain from Virginia to Northern Florida and occur in broad low-lying shallow basins. Soil is nutrient deficient and highly acidic.

Rill erosion - occurs as runoff water begins to concentrate in small channels or streamlets. Rill erosion carries mostly fine-textured, small particles and aggregates. These sediments will contain higher proportions of nutrients.

Sediment - A naturally occurring material (e.g., litter, soil particles, ash) that may be broken down by the process of weathering or erosion and is subsequently transported by wind or water

Sediment, enriched/enrichment - process of preferential movement of fine particulates carrying high concentrations of adsorbed pollutants or nutrients

Soil quality - 1) a measure of the capacity of soil to perform necessary functions…there is no single measurement for soil quality (ag.tennessee.edu); 2) How well a soil does what we want it to do. More specifically…the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality and support human health and habitation (USDA-NRCS).

Water quality - A measure of the suitability of water for a particular use based on selected physical, chemical, and biological characteristics e.g. swimming, drinking, aquatic habitat (derived from USGS & NOAA definitions)

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BIOGRAPHICAL SKETCH

Robert Mason is a UH-72 Maintenance Test Pilot working for SkyQuest Aviation, supporting operational and training activities of the United States Army Aviation Center, Fort Rucker, Alabama. Robert retired from the Army in 2010 after 23 years of service including six combat deployments throughout the Middle East. He has a combined 35 years of military aviation experience and has been recognized for superior performance during numerous CONUS assignments and particularly during overseas combat deployments. While serving in the United States Army Mr. Mason specialized in Army Safety and served in positions from small units to serving at the Army's Safety Center, where he aided in the development of numerous aviation safety courses and worked with the 1995 BRAC (base realignment and closure) commission. When the Army expanded the role of the safety officer, the Department of the Army added environmental safety and hazardous material management to the list of required duties. Mr. Mason managed environmental programs and developed training programs to ensure EPA and host nation environmental laws and policies where complied with while maintaining unit readiness. Recently Robert has worked with the Department of Public Works, Environmental Division, Ft. Rucker Alabama, aiding in the review of the 2017 Integrated Natural Resources Management Plan and assisting in NEPA mandated environmental surveys that affected Alabama Power Company/Ft. Rucker solar power projects. Mr. Mason received his B.S. in Plant and Soil Science with a minor in Biology (Cum Laude) from Texas Tech University and is working on a Master of Science degree in Soil and Water Science, from the University of Florida. He has also completed a graduate certificate program at Texas A&M, in Sustainable Military Land Management. Since 2019 Robert has been working with youth in the Florida Panhandle area as a Merit Badge Counsellor for the Boy Scouts of America.