Fire and Soil in Florida: A Review

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Introduction

All across Florida, from uplands to lowland marshes, fire is naturally occurring and has been a historically present driver of many natural communities (Stys et al., 2017). Soil too is a defining attribute of ecosystems. Indeed, the relationship between fire and soil – and their effect on natural ecological communities – is multifaceted. Together they form a circular relationship of causes and effects (Certini, 2014).

In some situations, fire is responsible for maintaining the uppermost soil layer via the removal of excess organic materials. Frequent burning of longleaf pine forests can maintain O horizon layers at a proper level for preferred longleaf pine (*Pinus palustris*) root growth (Coates et al., 2017). Without fire, the organic layer would become too thick and eventually select-out these pines. In a constructed treatment wetland in Central Florida, fire is periodically used to remove organic matter build up that would otherwise prevent hydrologic flow through the system (White et al., 2008). As a system specifically designed with flow through the system in mind, maintaining hydrochannels is crucial and most efficiently done utilizing prescribed burning.

In other situations, fire's role is to maintain the area for certain plant and animal species. Without fire, a sandhill system could become overgrown with shrubs and oaks, and turn into a xeric hammock (FNAI, 2010). Fire is also needed to maintain systems for fauna, some of which help shape the soil via their burrowing activities (Neary et al., 1999). Too little fire and they will migrate due to lack of proper habitat or could possibly be killed from a severe wildfire due to fire suppression and fuel build-up (Neary et al., 1999).

We also utilize fire to maintain the ecosystem for a particular animal: humans. We purposefully burn forests, prairies, and marshes for a vast number of reasons: reducing fuel, controlling vegetation, improving grazing land, managing insects and disease, clearing land for agriculture, maintaining accessibility to wilderness areas, and maintaining habitat for wildlife (which we benefit from via their intrinsic value) (Waldrop and Goodrick, 2012). As we do this, though, we must understand and learn to predict how else fire will affect systems. The scope of this paper is to discuss the many effects that fire has on the backbone of ecosystems: soil.

Fire– Fire is one of the ways in which nature has traditionally shaped ecosystems – it occurs naturally everywhere on Earth, except for the Arctic and Antarctica (Pereira et al., 2018b). As early as the Native Americans, humans had discovered the usefulness of prescribed burning and used it often (Waldrop and Goodrick, 2012). As far back as 1,300 years ago they were utilizing fire to clear brush for farming and to maintain grasslands and pine communities for hunting and improved landscape visibility (Fowler and Konopik, 2007). Humans used fire as a management tool throughout the arrival of European settlers, then throughout the formation of this country, up until about 1890 AD when the United States Forest Service began promoting fire suppression in response to the destruction of forests from wildfires and logging practices (Fowler and Konopik, 2007). Around 1940 AD, Southeastern United States land managers began introducing prescribed fire programs (Fowler and Konopik, 2007) as we began to – again – realize the importance of fire (FDACS, 2012; Waldrop and Goodrick, 2012). With very active burn programs across the state, Florida is now one of the leading states in the union for the number acres burned each year (Melvin, 2012).

The topic of prescribed fire is especially timely in Florida due to explosive population growth, resulting in residential areas pushing closer and closer to historically forested – and therefore burned – sites (FDACS, 2012). Suppression of fire in an ecosystem due to nearby residences can be problematic, as that ecosystem was likely created and/or is dependent on continued fire (Brenner et al., 2010). Florida has 46 unique above water and ground surface (non-lacustrine, -marine, -riverine, nor -subterranean) ecological communities (FNAI, 2010) and their burn requirements vary from frequent to not-at-all burning [1].

Florida Natural Community	**Fire Frequency**
Upland Pine	Frequent, 1-3 yrs
Dry Prairie	Frequent, 1-2 yrs
Sandhill	Frequent, 1-3 yrs
Seepage Slope	Frequent, 1-3 yrs
Wet Prairie	Frequent, 2-3 yrs
Mesic Flatwoods	Frequent, 2- 4 yrs
Floodplain Marsh	Frequent, 3 yrs
Pine Rockland	Frequent, 3-7 yrs
Marl Prairie	Frequent, 2-10 yrs
Wet Flatwoods	Frequent, 2-10 yrs
Slough Marsh	Frequent, 3-10 yrs
Glades Marsh	Frequent, 3-10 yrs
Up. Mixed Woodland	Occasional, 2-20 yrs
Scrub	Occasional, 5-30 yrs
Scrubby Flatwoods	Occasional, 5-15 yrs
Shrub Bog	Occasional, 10-20 yrs
Upland Glade	Irregular intervals
Basin Swamp	Rare to occasional
Strand Swamp	Rare to occasional
Mesic Hammock	Rare to occasional
Basin Marsh	Influenced by fire from surrounding communities
Depression Marsh	Influenced by fire from surrounding communities
Up. Hardwood Forest	Influenced by fire from surrounding communities
Dome Swamp	Influenced by fire from surrounding communities
Slough	Influenced by fire from surrounding communities

[1] *Sources: FNAI, 2010; Saddler, 2014*

Fire suppression creates a public safety concern, as excessive amounts of fuel can accumulate and eventually burn when lightning strikes (FDACS, 2012). This is further amplified during times of drought (Brenner et al., 2010). Because of this, Florida has made ongoing prescribed fire programs a priority on public lands (FDACS, 2012).

Soil– Soil health is crucial to terrestrial life; it provides the framework for nutrient cycling, water cycling, microbial activities, plant growth, and fauna shelter and proliferation (Neary et al., 1999). The Earth's influences (climate, organisms, parent material, topography) along with the passage of time have worked to shape soil for billions of years (Bockheim et al., 2014). But now, we recognize that humans have also made enough of an impact via the transportation of materials and alteration of nutrients and water to be considered in that category as the sixth soil forming factor. Anthropogenically influenced soils are recognized in taxonomy at the suborder level, subgroup level, and in epipedon designations (Bockheim et al., 2014). It is also suggested that fire impacts a strong enough influence on soil to be considered the seventh soil forming factor (Certini, 2014; Pereira et al., 2018b). Others suggest that fire could simply be included with 'humans' as the sixth soil forming factor. However, fire is not exclusively a human's tool and – as stated before – has been shaping natural communities long before us (Certini, 2014; Stys et al., 2017).

Besides some of the more well-known results of forest fires (reducing fuel for potential wildfires, managing vegetation, and maintaining acceptable habitat for plant and animal species, controlling insects and disease, aesthetics), there are other, less obvious effects that this intense heat has on an ecosystem (Waldrop and Goodrick, 2012). Regarding soil, fire can affect structure, nutrient content, fertility, organic matter content, and can lead to erosion/run off (Waldrop and Goodrick, 2012). But these effects can easily be forgotten or overlooked because some of them occur below the soil surface and are invisible to the naked eye (Certini, 2014).

While some of the effects from fire *are* noticeable the implications of them are not. For example, fire can result in the addition of ash and char residues on the ground. The "unseen" effect is the potential change in soil pH and nutrient content due to the residues (Munoz-Rojas et al., 2016).

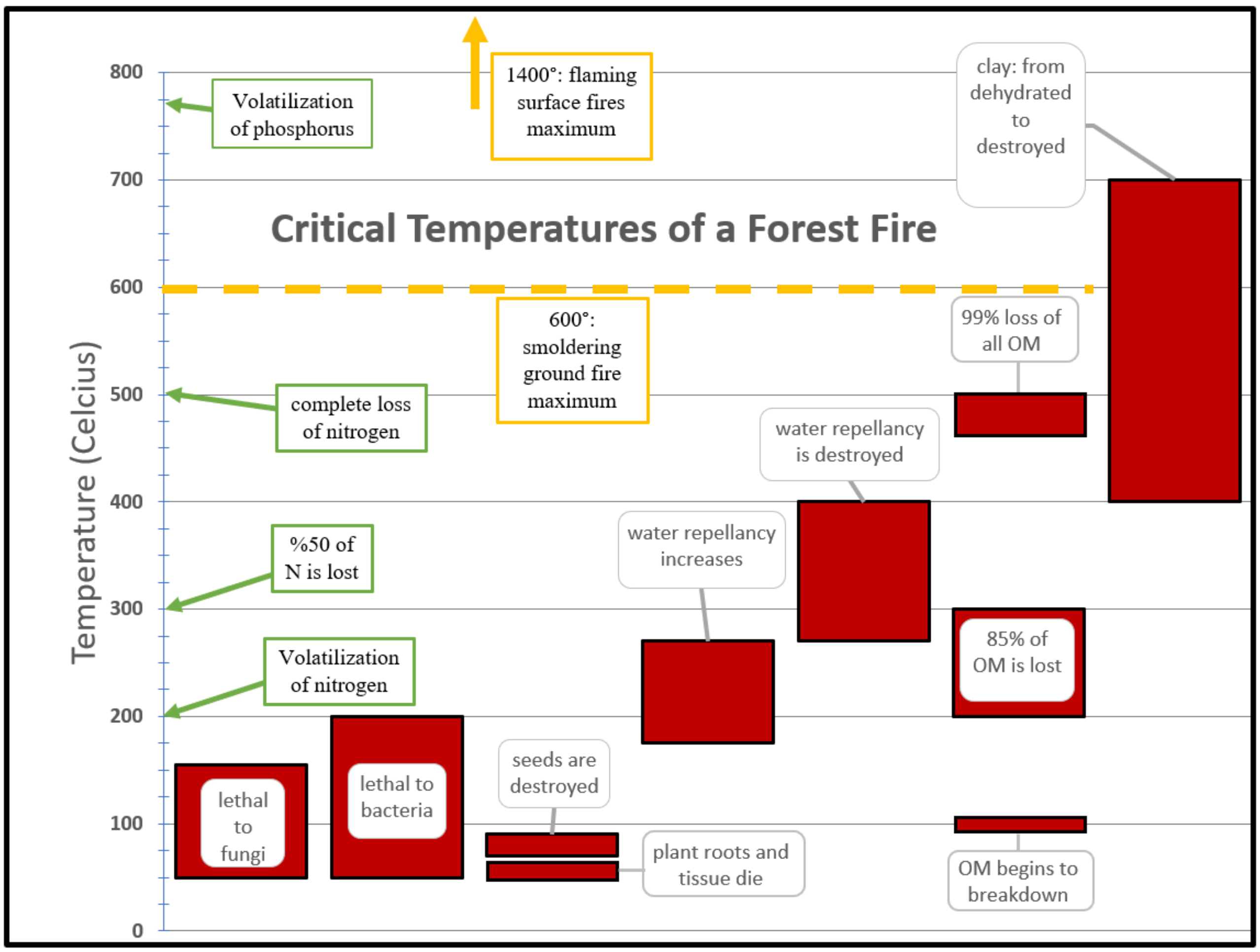
The length of time that fire continues to have an impact on the soil cay vary greatly. Some effects of fire can be most pronounced soon after fire and will lessen as time progresses (Munoz-Rojas et al., 2016). Natural versus disturbed land is an important factor to consider in this assessment. When comparing a burn in a natural marl prairie versus a burn in a nearby similar – but disturbed – prairie, Medvedeff et al. (2013) found differences in the length of time it took for some post-fire readings to reverted back to pre-fire.

Wild vs. Prescribed Fire

Heat and Intensity– Even though we have implemented prescribed fire tactics in part to prevent wildfires, it is impossible to fully escape from the potential of wildfire occurrences. Wildfires can reach much higher temperatures and can quickly devastate forests, personal property, and lives (Irfan, 2018). A proper prescribed fire prescription includes accounting for precipitation, humidity, wind speed and direction, timing/season, current temperature, and state of vegetation (Ottmar, 2014; Saddler 2014). Without this planning, wildfires can consume greater amounts of fuel than a prescribed fire, which can lead to a more intense and fast moving fire. The difference between a prescribed fire and a wildfire – and thereby the severity and extent of the fire –plays a large role in how the soil is affected. These can mean different temperatures, the depth at which heat reaches, and rate of movement across the landscape.

High severity fires can degrade the soil due to volatilization of nutrients and destruction of biological entities. In contrast, a lower severity fire can be valuable to soil health (Pereira et al., 2018b).

Temperatures– There is an overall positive correlation between an increase in fire temperature and changes in soil physical properties and soil organic matter [2] (Wieting et al., 2017). Some fire temperatures are not high enough to cause changes in the soil. Nitrogen, however, is quickly volatized, even at low temperatures [2].



[2] *Sources: Neary et al., 1999; Busse and DeBano, 2005; Knoepp et al., 2005; Doerr et al., 2009; Waldrop and Goodrick, 2012*

Temperatures reached in the soil also have implications on the resulting soil structure (DeBano et al., 2005). While ash and char produced from a fire can have some benefits on the soil, residues from a high severity fire can be problematic: they tend to be finer textured and can clog pores spaces and create an impermeable layer at the soil surface, resulting in reduced water infiltration and increased run-off potential (Pereira et al., 2018b).

Peak temperatures of a fire only reach about the top 2 cm of soil (Certini, 2014), and the depth those temperatures reach is important to how the soil and its constituents are affected (Clement et al. 2010). As you look deeper into the soil past 2 cm, the temperature increases from fire is lessened. Just 2 cm deeper is enough for a temperature drop of half compared to the surface (Carrington, 2010). This is important to seed germination, as seeds can be stimulated by a slight temperature increase, but too close to the surface and they could be destroyed, and too deep means the new growth cannot reach the soil’s surface (Carrington, 2010).

Land Management– A great deal of planning goes into drafting a prescribed fire plan. The season in which a particular ecosystem is burned is important to plant health (Saddler, ed., 2014). And while plant health is often the top concern to prescribed fire managers, different seasons of the year also mean different soil moisture content, total organic carbon, and microbial biomass (Ginzburg and Steinberger, 2012).

One may expect that certain systems would never need fire, but they actually may depend on it [1]. Even dome swamps – around which some have erroneously constructed fire breaks in the past – require periodic fire to keep peat layers and certain trees at bay (FNAI, 2010).

Run-off potential is always a concern. For example, in a treatment wetland – a area designed specifically for eventual run-off – precautions need to be taken post-fire to contain or isolate the burned zone due to nutrient release (White et al., 2008). Length of time of nutrient release is an important factor as well – an increased period of phosphorus release due to fire can last longer than the same for nitrogen (White et al., 2008).

Some areas that have been fire suppressed for long periods of time have an overabundance of fuel accumulation and require 'assistance' in order to properly burn. In this case, there are some chemical and mechanical options available. However, if mechanical chopping and herbicides are going to be used in areas in dire need of restoration, they should always be used in conjunction with fire and only until a normal fire regime is established (Menges and Gordon, 2010).

Proper land management is important not only in planning prescribed fires and preventing wildfires, but also in the way in which areas with wildfires are remediated (Pereira et al., 2018b). Proper management (such as mulching after a fire to prevent erosion) can minimize some of these negative effects (Pereira et al., 2018b). Implementing mechanical removal of trees and spraying herbicides before a fire are not optimal since they can be detrimental to the soil (Saddler, 2014). Nitrogen-containing and ammonium based fire retardants are common in the management of wildfires but can result in contamination of soil and surrounding water bodies (Neary et al., 2005). And even though a prescribed fire may be less intense than a wildfire, it can still have implications of erosion and potential run-off (Stoof et al., 2015). In areas where heavy machinery will be used, mulching is a good way to offset that likeliness (García-Orenes et al., 2017).

Often times when faced with a wildfire, land managers will be forced to clear cut a fire line in an attempt to gain control of the situation. However, this is not always possible with a smoldering fire, which burns deep enough that it can actually pass underneath a cut fire-line

(Watts and Kobizar, 2013). Clear cutting lines also increases the possibility invasive plant introduction, which – coupled with changes in nutrient content and vegetative structure – could promote invasive plant establishment (Smith et al., 2001). The resulting invasive plants can alter fire patterns too. In the Everglades – in areas where fire does not normally reach a canopy height – an infestation of invasive exotic climbing ferns (*Lygodium spp.*) can bring fire into tree tops (Richardson, 2008).

Nutrients

Nutrient availability in the soil is heavily affected by the pH of the soil, which can change due to fire (Knoepp et al., 2005). During a fire, organic matter combustion results in releases of hydroxyl molecules, increasing the pH of the soil (Munoz-Rojas et al., 2016). This change in pH is critical to elemental availability for uptake by plants (Johnston, 2004). In fact, at some pH levels, elements that are normally harmless in a neutral environment can become dangerous to plants and/or animals (Johnston, 2004).

Pre-fire site conditions – baselines – play a major role in nutrient cycling. As phosphorus is often a limiting nutrient (Hendricks et al., 2002), pre-fire phosphorus levels can influence post-fire nitrogen cycling (Liao et al., 2013). Hendricks et al. (2002) found that frequent (every 1-3 years) burning of longleaf pine (*P. palustris*) – wiregrass (*Aristida beyrichiana)* dominated systems were benefited through the mineralization of phosphorus, thus contributing to the mineralization of nitrogen and decomposition. In contrast, Lavoie et al. (2014) found no difference in soil nutrients between longleaf pine systems that had been regularly burned versus fire suppressed. Lavoie et al. (2014) suggest their findings are due to longleaf pine soil’s resistance to fire and/or fire suppression.

Residue (ash and char) remaining after a fire can have an impact on nutrients remaining and released back into the system. These residues can release excess amounts of nutrients, increasing the nutrient content of the soil (Ginzburg and Steinberger, 2012). The composition of these residues – and therefore what is eventually released by them – is dependent on the plant material, current nutrient loads, burn temperature, and burn severity (Qian et al., 2009).

Higher temperatures will result in less nitrogen and phosphorus remaining in residues since these volatize at lower temperatures than other nutrients [2] (Qian et al., 2009). After organic matter, soil nitrogen has the lowest temperature threshold for chemical transformation of the soil constituents: 414F/200C [2].

The cation exchange capacity (CEC) of the soil is also affected by the soil's temperature. A decrease in CEC will decrease the soil's ability to adsorb solutes and lead to the loss of soluble nutrients (Knoepp et al., 2005). As the temperature rises, organic matter is susceptible to breakdown at lower temperatures than clay, therefore a CEC influenced by organic matter is going to be affected before a CEC influenced by clay (Knoepp et al., 2005). The clay is also generally more protected from the heat as it is often located deeper in the profile than organic matter (Knoepp et al., 2005).

Smoldering Fires

Being generally located close to or at the soil's surface, organic matter is extremely vulnerable to fire (Knoepp et al., 2005). Soil and roots in a currently–wet wetland area are generally protected by their saturation (Smith et al., 2001). However, when wetland organic soils dry out, they develop water repelling characteristics (Wieting et al., 2017). When they burn, the result is a smoldering ground fire characterized by organic matter combustion (Smith et al., 2001). Actually, organic soils do not even have to be completely dry to combust, and current surface soil moisture will not necessarily determine the depth of combustion (Watts, 2013).

While a flaming surface fire can be showy and 'obvious', a smoldering fire is much more discreet. It is a lower temperature fire but can last considerably longer (Watts and Kobizar, 2013). Water repellency will continue to increase as heating of the soil continues (Wieting et al., 2017). This extended length of time allows the fire to reach greater depths than a flaming surface fire (DeBano et al., 2005). As the ground fire progresses and destroys tree roots, empty channels are left, allowing more oxygen to reach greater depths and "feed" the fire (Watts, 2013). The

[3] *Evidence of the amount of organic material that can be removed during a fire. Photograph from Watts, 2013.*

greater depths that a ground fire can reach make extinguishing the fire difficult (Watts and Kobizar, 2013), which means a costly and difficult wildfire to battle (Brenner et al., 2010).

Oxidation (when drained) and fire are main causes of global peat loss (Scheidt et al., 2000), which in turn results in major losses of carbon from the soil (Watts, 2013). In contrast to the dozens or hundreds of years a layer of peat has taken to accumulate on the soil's surface, it can be destroyed in a matter of a few minutes [3].

Emissions from smoldering peat fires can vary depending on the make-up of the peat itself (i.e., carbon content, moisture, and chemical structure) (George et al., 2016). Most of the carbon released during organic soil combustion is lost as CO_2 or CO (Watts, 2013). In a cypress swamp, Watts (2013) found that pre-fire soil moisture content was a good indicator of the amount of soil carbon that would be released. In their laboratory experiments, George et al. (2016) discuss the range of hazardous air pollutants released from peat fires: polycyclic aromatic hydrocarbons (such as retene, methylfluorene, phenanthrene) and volatile organic compounds (propylene, benzene, acetaldehyde). Smoldering fires can also release particulate matter, which is harmful to human and animal health if inhaled (Watts and Kobizar, 2013). Haze can also result, which is also problematic to human and animal health and disrupts visibility/transportation (Hu et al., 2018).

Due to the lower severity and lack of open flames, smoldering fires will not reach as high of temperatures – generally an upper limit of 600° Celsius (Neary et al., 1999). They also move relatively slow compared to a flaming forest fire – as slow as .5 meter in a week (Neary et al., 1999).

Microbes

Soil microbes play a role in the formation of soil (Bockheim et al., 2014) and are responsible for decomposition, mineralization, and nitrogen cycling (Busse and DeBano, 2005). And just as fire plays a role in the selection of plant species tolerant to and benefiting from it, some soil microbes have also adapted to survive in this environment (Busse and DeBano, 2005). Also similar to plants, the temperature endured during a fire is critical – microbes that can withstand higher temperatures and a loss of soil moisture have the advantage (Medvedeff et al. 2013).

The changes in microbial communities following fire can have long lasting implications. Oliver et al. (2015) found that frequent (2-3 year interval) burning of Alfisols and Ultisols resulted in a soil fungal community distinct from unburned plots. They also suggest that it may take ten years or more of fire suppression to revert those soil fungal communities back to their pre-fire status. Disturbance after fire – such as using heavy machinery – can increase the amount of time microbial communities take to recover (García-Orenes et al., 2017). Post-fire recovery can be greatest during the summer season, when the re-vegetation rate is highest and dissolved organic carbon content in the soil recovers (Ginzburg and Steinberger, 2012). Because of how these communities are reshaped post-fire, soil fungal and bacterial communities can be good indicators of the soil's overall ability to recover following a fire (Munoz-Rojas et al., 2016).

The soil microbial community is heavily influenced by nutrients in the soil (Ginzburg and Steinberger, 2012). After a fire, they can also be influenced by the resulting ash and char (Medvedeff et al., 2013). These residues can influence water repellency/infiltration and available nutrients (Muñoz-Rojas et al., 2016), both of which effect the soil microbial community.

As stated previously, fire can result in a change in pH. This change also affects microbial communities. Fungi generally prefer an acidic environment, versus bacteria which generally enjoy slightly alkaline environments (Johnston, 2004).

Erosion & Run-off

The simple removal of vegetation and plant litter from the soil surface that occurs during fire can have devastating erosional implications (Stoof et al., 2015). The soil no longer contains roots for stabilization or leaf litter that acts as a protective cover. Heavy wind and rains post-fire and before vegetation can regrow can be especially detrimental to soils, and areas with steep slopes are even more vulnerable (Pereira et al., 2018b). In some instances, land managers choose to salvage downed trees after a fire for logging. Salvage logging – especially when heavy machinery is involved – can be highly destructive to post-fire soil (García-Orenes et al., 2017). Heavy machinery can create divots that contribute to erosion or compact the soil and contribute to run-off. In some instances, ash residues from a low severity fire (in contrast to residues from high heat, as discussed previously) can act as a protective cover for the soil and aid in erosion prevention (Pereira et al., 2018b).

Sand, silt, and clay particles that constitute soil are joined by organic matter and arranged into structural aggregates, which can then be destroyed by high intensity heat (Neary et al., 1999). This breakdown in structure means a decrease in porosity and an increase in bulk density, resulting in reduced water infiltration and increased run-off (DeBano et al., 2005). And, as stated previously, residues from high heat fires can be a very fine texture and actually clog soil pores, leading to increased run-off (Pereira et al., 2018b).

Another cause of run-off is water repellency, which is already a normal state in some soils, but can still be amplified by fire (Doerr et al., 2009). Water repellency can occur when a layer of hydrophobic organic compounds group at the soil's surface and orient with their hydrophobic poles pointing outwards towards the soil pore space (Doerr et al., 2009; Neary et al., 1999).

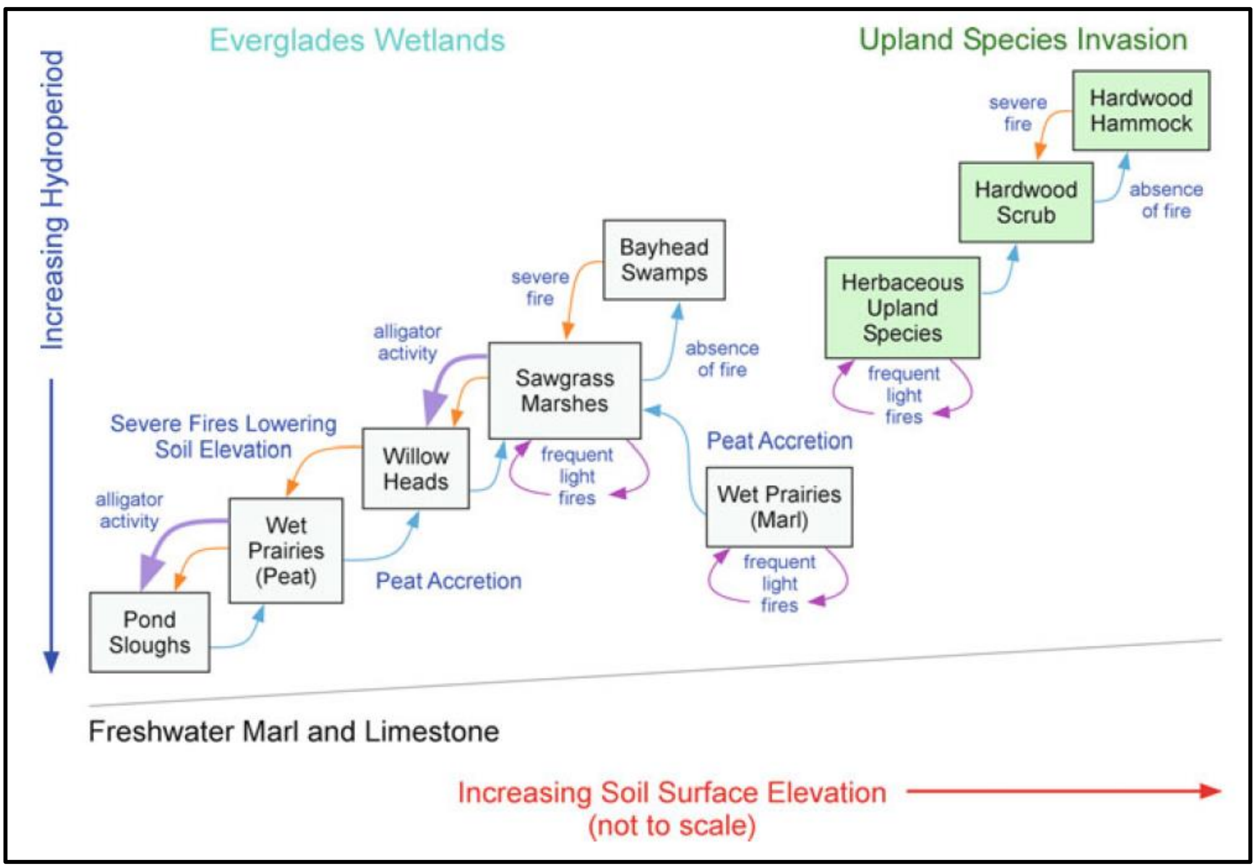
When the soil has a high moisture content, risk of erosion is sometimes decreased (Hosseini et al., 2016). Fire, however, generally decreases soil moisture content, and it can be slow to recover (Ginzburg and Steinberger, 2012). Recovery is highly variable and depends on climate, topography, and previous soil attributes. It can take anywhere from a few months to a few years for soil to revert to pre-fire moisture conditions (Doerr et al., 2009; Stoof et al., 2015).

Florida Everglades

Being that it is one of the largest freshwater marshes in the world, the Florida Everglades is an important natural resource (Scheidt et al., 2000). Historically, the Everglades has been a phosphorus-limited system, but due to agricultural practices, soils there are now subjected to much higher nutrient elevations (especially phosphorus) (Scheidt et al., 2000; Richardson, 2010).

Human altered hydrology – artificial drainage for agriculture purposes – has been devastating to organic soils in the Everglades. Muck soils can dry out to the point of causing severe combustion fires (Richardson, 2008). High intensity fires can also destroy Sawgrass (*Cladium jamaicense*) (a dominant plant species) seeds, preventing the post-fire succession that would naturally take place (Richardson, 2008).

Without human influence, fire partners with drought to maintain the natural hydrologic cycles of the Everglades (Richardson, 2010). As peat accumulates on the soil's surface, the elevation of the area will slowly rise (Richardson, 2010). But even small elevation changes can alter hydrologic flow. At a higher elevation, the amount of time a soil remains inundated is decreased, and eventually progressively upland and less wetland plants will establish (Richardson, 2010). For example, without fire, a slough may eventually become a wet prairie [4]. At those higher and dryer elevations, wildfires are more likely (Richardson, 2010). Fire will then remove the topmost organic layer from the soil and lower the overall elevation of the ground surface, reverting to the original state [4].



[4] *Illustration of hydroperiod cycles in the Everglades. Image from Richardson, 2010.*

Fire has been used in the Everglades by humans to manage Cattail (*Typha domingensis*) – which is native but can form an invasive monoculture (Richardson et al. 2008). Using fire every 3-5 years, Cattails are removed, allowing for Sawgrass to re-establish. Heat from fire activates Sawgrass seeds, which can establish in these wet areas with little nutrients (Richardson, 2010).

Peat– Peat is a major soil constituent found in the Everglades, and peat loss is a key concern: 50% of the total historic Everglades wetlands have already been lost due to anthropogenic drainage (Scheidt et al., 2000). In 1946, Florida had roughly 2,240,000 acres of peat – about 1.9 million of which occurred in the Everglades (Davis, 1946). Even at that time, the Everglades had seen a great decrease in the amount of peat due to anthropogenic drainage and the resulting wildfires (Davis, 1946). Since then, there have been further decreases in the amount of peat soils in the Everglades as agricultural practices continue (Scheidt et al., 2000).

Smith et al. (2001) found that wild peat fires in the Everglades resulted in a decrease in total carbon, total nitrogen (both due to volatilization), and organic phosphorus; they saw increases in total calcium and inorganic phosphorus. Increases in total phosphorus was a result of the physical reduction of the soil. The authors conclude that there are similar changes in nutrient content in both surface and peat fires, but changes from the peat fires are much more drastic due to the severity of those fires.

Astiani et al. (2018) discuss how smoldering fires in peatland can cause significant losses of carbon from the soil in the form of CO_2. They point out that these emissions can be lingering, taking months to dwindle down.

Marl– Marl is another major soil type found in the Everglades (Scheidt et al., 2000) and is often underlaying peat soils (Davis, 1946). In a low-phosphorus marl prairie, the addition of char (with phosphorus) increased nitrogen mineralization and nitrification (Liao et al., 2013).

In a similar area, Clement et al. (2010) found that wildfire can indirectly affect phosphorus nutrient cycling. They found that high fire temperatures caused the conversion of goethite to maghemite – goethite naturally adsorbs phosphorus, therefore removing goethite can disrupt the phosphorus cycle in the soil. The fire may also have caused the phosphorus that was already adsorbed onto the goethite to be released as the goethite was transformed (Clement et al., 2010).

Future Needs

Even with knowledge of current moisture content, humidity data, weather forecasts, and current vegetative conditions, it can still be difficult to predict where and when a wildfire will occur. In fact, studies conducted post-fire are often at a loss as to the exact site conditions prior to the fire (Smith et al., 2001). With so many pre-fire conditions to consider, it can be difficult to determine which factors influenced the fire (Ginzburg and Steinberger, 2012). Further study on multiple fire parameters in a multitude of ecosystem and soil types would benefit us. This is not such an easy task, though, as there is an endless list of combinations of variables and ecosystem types to consider.

Changes in soil nutrients due to fire is one area to focus on. While many researchers have found changes to soil nutrients post-fire (Ginzburg and Steinberger, 2012; Liao et al., 2013; Qian et al., 2009), not all have (Lavoie et al., 2014). The crucial importance of soil nutrients and the differences in these findings illustrate why this is a topic to study further.

In many situations (not just concerning fire and/or soil), longer-term studies would be helpful. Specifically regarding the combination of fire and soil, it would be beneficial to discover how long the effects of fire last. Similar to the question of nutrient changes, this can be an easy question to ask, but a difficult one to carry out.

The state of Florida has made it a priority (as part of its strategic plan) to work with research institutions to better understand all effects of prescribed fire (FDACS, 2012). Here in Florida, fire management is especially crucial in the Everglades (Liao et al., 2013) and an important tool for its future (Richardson et al., 2008). With large amounts of organic soils in Florida that are susceptible to smoldering combustion – and in the Everglades in particular – a good understanding of the relationship between fire temperatures and water repellency and – thereby – erosion and run-off potential is critical (Wieting et al., 2017).

However, across the US, a lack of training and resources is the biggest hurdle to overcome in prescribed fire programs (Melvin, 2012). Perhaps addressing this issue on a global scale would help convince land managers and government officials of the importance of maintaining natural areas with prescribed fire and of preventing wildfires (Janzen et al., 2011). Communication and education are always areas that need improvement in soil science (Janzen et al., 2011). Perhaps – at the very least – recent major wildfires (Irfan, 2018) will garner people's attention on the issue of responsible prescribed forest fires, constructing residences in historically fire-maintained areas, and the contribution of climate change to the frequency of wildfires. Getting citizens and new scientists involved and passionate for the cause is priceless (Janzen et al., 2011).

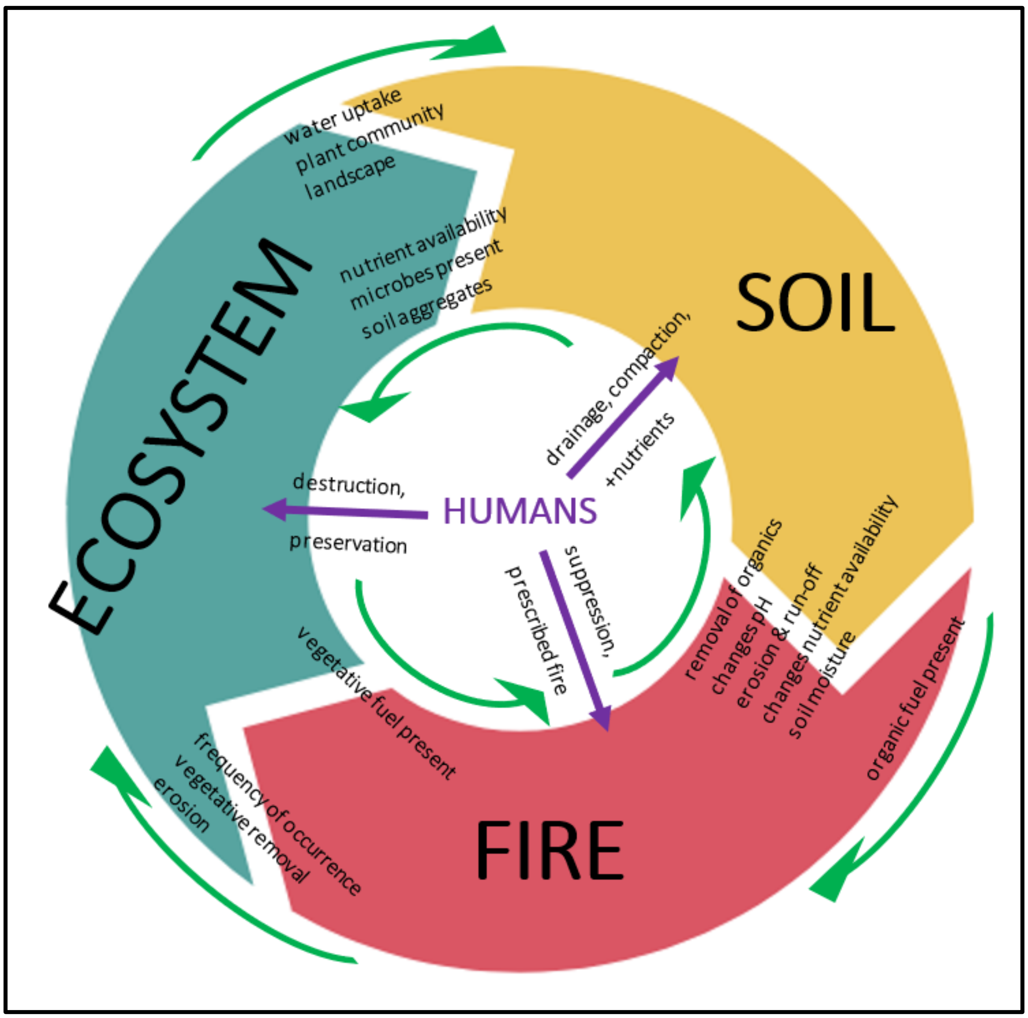
Human altered hydrology has already made once-wet peatlands dry and more susceptible to fire (Davis, 1946). Our changing climate is estimated to bring changes in precipitation and weather patterns, which may lead to more potential drought situations (Stys et al., 2017). During a time of drought, organic soils can develop water repellency (Wieting et al., 2017), and when those soils experience smoldering combustion, the result can be the most difficult forest fire to conquer (Watts and Kobizar, 2013). An increase in smoldering ground fires is a particular problem regarding carbon sequestration since soil is the Earth's largest terrestrial carbon sink (Pereira et al., 2018a), with organic soils alone making up roughly 20% of the Earth's total terrestrial carbon (Watts, 2013).

In general, all forest fires result in methane release into the atmosphere (Medvedeff et al., 2015). Further understandings of forest fuel combustion are necessary to estimate the amounts of other greenhouse gasses and harmful contaminants that could/are being released (Ottmar, 2014; Medvedeff et al., 2015). Perhaps we could also adopt better land management/agricultural methods for sequestering carbon in the soil and plants on a global scale, and thereby offsetting some of these emissions (Janzen et al., 2011).

Climate change also brings about altered weather/precipitation patterns and more extreme weather events, which may mean the parameters for prescribed fire could change (Stys et al., 2017). It is possible that current methods in use for prescribed fire planning may need to be updated in the future as we attempt to adapt to the changing climate.

Conclusion

Just as you could say with all aspects of soil quality and management: there is a complex web of interactions taking place and many factors to consider when planning prescribed fires or remediation following a wildfire [5]. Some of the variables involved in the soil's response to fire are: prior land management, the severity of the fire, post-fire management, post-fire weather, type of ash/char residue produces, fire temperature, topography, and hydrology (Pereira et al., 2018b). The resulting soil can have altered nutrient contents and pH, increased water repellency, reduced soil moisture and organic matter, or be at risk of erosion and/or run-off. While fire is often either prescribed for land management, utilized for agricultural clearing, or suppressed for human's residential building desires, it should not be forgotten that soil (the mainstay in our natural communities) is also heavily influenced by fire.



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(Courtesy Miami Herald)

Fire in the Everglades burning peat, April 1944. Such fires occur frequently during the dry season and destroy some of the dry, surface peat. If the Everglades were more generously flooded such fires could be reduced and the peat saved.

Photograph from David, 1946.