Journal of Environmental Management 249 (2019) 109360

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Utilizing fossilized charcoal to augment the Everglades National Park Fire History Geodatabase

Ginger Tiling-Range[a], Thomas J. Smith III[b], Ann M. Foster[b], Joseph M. Smoak[c,*], Joshua L. Breithaupt[d]

[a] Jamison Professional Services c/o NOAA, National Marine Fishery Service, Southeastern Regional Office, 263 13 Ave South, St. Petersburg, Florida 33701, USA
[b] Wetlands and Aquatic Research Center, U.S. Geological Survey, 7920 NW 71st Street, Gainesville, FL 32653, USA
[c] Environmental Science, University of South Florida, St. Petersburg, Florida 33701, USA
[d] Biology Department, University of Central Florida, Orlando, FL 32816, USA

ARTICLE INFO

Keywords:
Fire ecology
Wetlands
Estuarine
Lead dating
Florida
USA

ABSTRACT

Everglades National Park (ENP) has been documenting fire events since 1948, and these data have been incorporated into an ESRI geodatabase. According to this geodatabase, 757,078 ha of wetlands burned from 1948 to 2011. The main type of vegetation that has burned is comprised of palustrine and estuarine wetlands. However, there are areas in ENP that are comprised of these wetlands that have no documented fire events. We examined fossil charcoal in soil cores and found evidence that fires did indeed occur in some of these areas. Sites of known fires were used to validate the fossil charcoal method. The abundance of fossil charcoal in soil cores from six locations in ENP was measured. Two of the cores were taken from areas with well-documented fire events and four cores where taken from areas with no documented fire events. Three of the cores were dated using ^{210}Pb geochronology. The initial goal was to determine if fires had gone undetected or undocumented in the geodatabase with the ultimate goal being to demonstrate the usefulness of this approach to augment the geodatabase and therefore enhance our understanding of fire ecology in ENP.

1. Introduction

The Everglades is a subtropical ecosystem in Florida, USA, which spans nearly two million acres and includes numerous habitats such as cypress swamps, mangroves forests, wet prairies, sawgrass marshes, and pinelands (Gunderson and Loftus, 1993). It is also the home to an abundance of wildlife such as hundreds of bird species, the endangered manatee, the endangered Florida Panther, bottlenose dolphins, alligators, and crocodiles (Brown et al., 2006; Junk et al., 2006; The Everglades; www.nwf.org/Educational-Resources/Wildlife-Guide/Wild-Places/Everglades). Fire has historically been influential in shaping the Everglades ecosystem (Smith et al., 2015). The relationship among hydrology, soil formation, and fire is a critically important for the persistence of the biotic components of the Everglades (Smith et al., 2013; Beckage, 2005). As a result, Everglades National Park (ENP) has been at the forefront of National Park Service (NPS) fire policy development since the inception of the park in 1947. Everglades National Park was the first to allow prescribed burns and one of the first to develop a fire management plan (Taylor, 1981). The information recorded about these fires has been incorporated into an ESRI geodatabase (Smith et al., 2015). The significant role that wildfire has on the landscape makes the availability of this data in a readily useable format vital for many park planning and operational functions, including ongoing fire management activities, fire ecology studies as well as addressing a variety of resource management issues.

Because of the important role of fire in the Everglades ecosystem (Gunderson and Snyder, 1994; Beckage et al., 2003), fire records for ENP from 1948 to 1979 were compiled by Taylor (1981) to review fire history and management practices, revealing that approximately 353,476 ha of the terrestrial component of ENP burned from 1948 through 1979. From 1980 to 2011, ENP continued to add fire event data to the geodatabase and, based on these data, approximately 403,601 additional hectares have burned, making for a cumulative total of 757,077 ha burned in ENP from 1948 to 2011 (Taylor, 1981) (Fig. 1). The burned areas primarily represent two general land cover types: 80 percent is classified as palustrine wetlands and 19 percent is classified as estuarine wetlands. The remaining one percent is comprised of 13 additional land cover classifications (Rutchey et al., 2006). In addition, the records reveal areas within ENP that have no reports of being burned during the last 60 years.

* Corresponding author.
E-mail address: smoak@mail.usf.edu (J.M. Smoak).

https://doi.org/10.1016/j.jenvman.2019.109360
Received 25 June 2018; Received in revised form 26 July 2019; Accepted 2 August 2019
Available online 09 August 2019

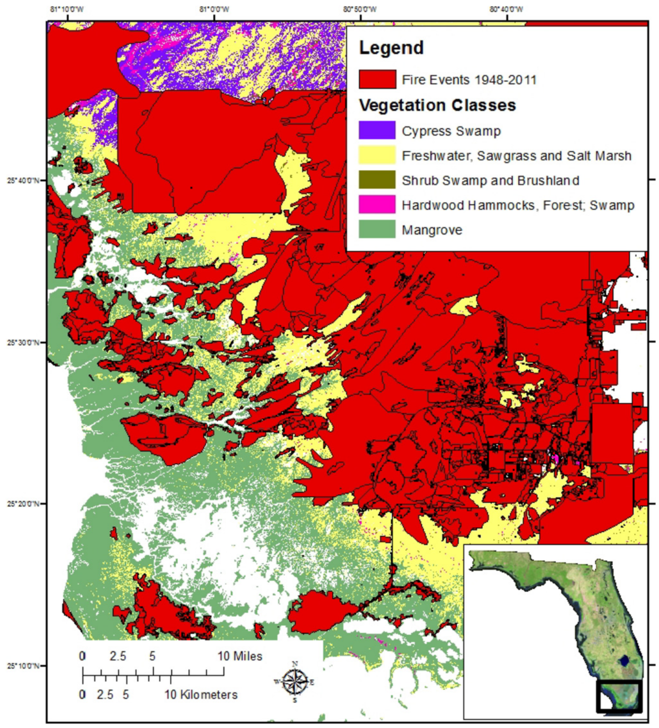

Fig. 1. Fire events shown in red and wetlands in ENP that have no documented fire events. Base map shows vegetation classification of the unburned areas. Base map is modified from Florida Fish and Wildlife Conservation Commission Fl_veg03 map.

Since these unburned areas are comprised of the same land cover types as that of the burned areas (Fig. 1), we hypothesized that additional areas have burned without being documented. Fossil charcoal in soil cores was used as a proxy for past fire events to test the hypothesis.

Charcoal was first recognized as a fire proxy in pollen slides by Inversen in 1941 (Whitlock and Larsen, 2001). Since that discovery, charcoal in sediment has been utilized in many studies as a means of establishing historic fire events (Leys, 2015; Power et al., 2008; Mueller et al., 2014; Adolf et al., 2017). Here soil cores from sites of known fires (i.e., recorded in geodatabase) were used to validate the approach and once validated we propose this as a means to augment the fire history within the existing database.

Fire history is often reconstructed using many different methods such as stand ages, fire scars, dendrochronology, fossil charcoal presence or absence in sediment, chemical signatures, and written and administrative records. Charcoal which forms due to incomplete combustion (280–500 °C) of plant material during a fire event can be deposited in soil, washed into lakes, or transported via air to other locations downwind of the fire. Charcoal is relatively inert and is well preserved in sediment, making its presence useful for fire history reconstruction. Factors such as vegetation type and moisture content, fire size, duration, and intensity play significant roles in the type of charcoal produced and the distance it can be transported (Patterson et al., 1987; Whitlock and Millspaugh, 1996; Pisaric, 2002). How charcoal is deposited into surrounding soils is a factor of particle size and characteristics of the fire itself (Clark et al., 1998). During a fire, charcoal is ejected into the atmosphere by thermal drafts generated during the fire. The height to which the charcoal is elevated and its ultimate distance to deposition is a factor of heat level, wind direction, particle size, and wind speed (Lynch et al., 2004). Charcoal particles have different aerodynamic behaviors based on diameter size class (Clark, 1988). Large charcoal particles are heavier and tend to move shorter distances than smaller sized charcoal. Hence, the size of charcoal particles decreases as the distance from the fire source increases (Patterson et al., 1987). Charcoal particles with sizes ranging from 130 to 150 μm can be easily lifted and transported in the smoke plume. Conversely, particles larger than 150 μm can be lifted but generally are not transported as far as smaller, lighter particles (Clark, 1988). Many studies have been conducted regarding transport of charcoal, all with varying ranges of

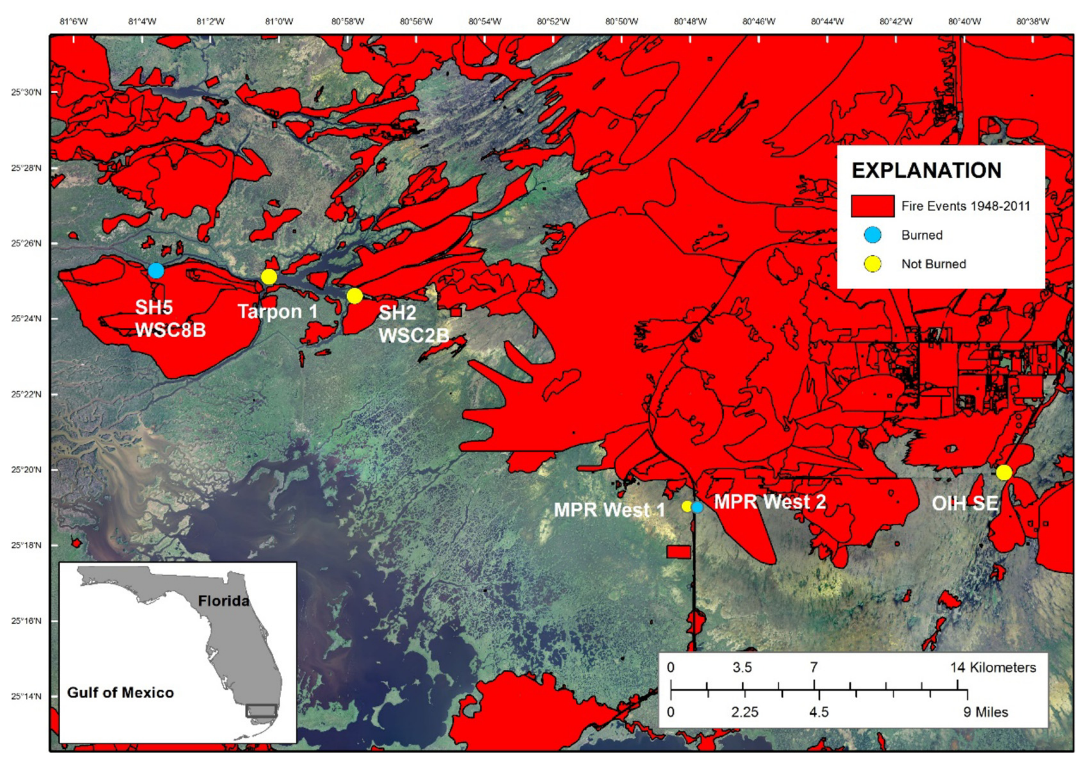

Fig. 2. Location of six soil cores taken for charcoal analysis in ENP. Note that two of the cores (blue dots) are located in areas with historically-recorded fires and the other four cores (yellow dots) are located in areas with no historical record of burning. The base map is a mosaic of 2004 DOQQs.

transport, and a Gaussian Plume Model predicts that particles greater than 1000 μm are deposited close to the fire, whereas particles less than 100 μm can travel beyond 100 m (Whitlock and Larsen, 2001).

2. Methods

There are several methods to detect charcoal, though there is no established methodology for analyzing fossil charcoal. Early studies analyzing charcoal involved counting charcoal fragments on pollen slides. Newer methods include thin sections, sieving, chemical extraction, combustion, and image analysis (Whitlock and Larsen, 2001). Due to the nature of our cores (peat and marl) and existing laboratory capabilities, charcoal was examined using a stereomicroscope.

Six soil cores were collected from ENP (Fig. 2) using a Russian Peat corer and processed at 2 cm intervals for charcoal abundance. Sediment collected in the Russian Peat Corer was transferred to half-sectioned 50-cm PVC tubes. These tubes were sealed in plastic and labeled according to the site location name. Four of the cores were taken from areas that have no record of fire (SH2M2/WSC-2B, Tarpon 1, MPR West 1, OIH SE) and two cores were taken from areas with well-documented fire history (SH5/WSC-8B, MPR West 2). Sites SH2M2/WSC-2B, Tarpon 1 and SH5/WSC-8B are coastal marsh communities surrounded by mangrove forests, and sites MPR West 1 and OIH SE are freshwater marl prairies dominated by marsh communities. For charcoal analysis, two cubic centimeters (cm^3) of sediment were subsampled from the breadth of the sample interval down all six cores. Each subsample was placed into a 400 ml beaker and placed under a fume hood. To remove organic material that obscured visualization of charcoal from the peat samples (SH2M2 WSC2B, SH5 WSC8B and Tarpon 1), 200 ml of 20% Hydrogen peroxide (H_20_2) was added to beakers containing the peat subsamples under the fume hood and placed on a hot plate at 50 °C. These samples were left in the solution until the organics were no longer visible and charcoal was easily visualized. To remove calcite marl that obscured visualization of charcoal (MPR West 1, OIH SE and MPR West 2), 200 ml of 1 Normal Hydrochloric acid (1N HCl) was poured into beakers containing the marl/peat subsamples and placed on a hot plate at 50 °C. These samples were left in the solution, under a fume hood, until the marl was no longer visible. Following the 1N HCl treatment, the subsamples (MPR West 1, OIH SE and MPR West 2) were placed in 200 ml of 20% H_20_2 on a hot plate at 50 °C to remove the remaining organic material. These samples were left in the solution until the organics were no longer visible and that charcoal was easily visualized. After all six samples were treated with H_20_2 or HCl, the samples were sieved through 250, 125, and 63 μm (μm) sediment sieves. The resulting sieved material was then placed in petri dishes, labeled according to core identification (ID), depth and sieve size, then placed under a fume hood to dry for two to three days. These methods were modified from the methods of Clark (1982), Huber and Markgraf (2003), Patterson et al. (1987), and Rhodes (1998).

To grade charcoal abundance, a grid was created which was placed under a Petri dish and the number of charcoal particles in each grid cell was visualized and counted using a stereomicroscope (Fig. 3). We classified charcoal into three size classes: small (63–125 μm), medium (125–250 μm) and large (> 250 μm) and inferred that an abundance of large charcoal represents an in situ or local fire event. To establish core chronologies, ^{210}Pb dating was conducted on three peat cores (SH2M2/WSC-2B, SH5/WSC-8B, and Tarpon 1) following the methods described in Smoak et al. (2013) and Breithaupt et al. (2014). Gamma activities were measured using an intrinsic germanium well detector and a multichannel analyzer. Activity for ^{210}Pb was measured using the 46.5 keV peak and ^{226}Ra by using ^{214}Pb (351.9 keV peak) as its proxy (Appleby et al., 1988). Dates have been calculated following the Constant Rate of Supply (CRS) model. The locations of the sediment cores and historic fire events were compared using ArcGIS, with two of the six cores taken from locations where historic fire events had been previously documented.

3. Results

SH5/WSC-8B and Tarpon 1 have the largest amount of large charcoal particles compared to all the other cores (Fig. 4). The SH5/WSC-8B core is from a site that has a well-documented fire history, and this core was also dated using ^{210}Pb. High amounts of large charcoal occur at 0–2 cm, 4–6 cm and at 10–11 cm down core. Based on the ^{210}Pb CRS Model, the large charcoal peak at 0–2 cm represents years 2006–2013 and corresponds to the Harney River and Harney River RX Fires. At the 2–4 cm interval, the ^{210}Pb age corresponds to 1993–2006. During this time, there were two fire events, the HarneyS2, and Harney RVR Fires, based on the Fire Geodatabase. However, there is not a substantial peak of large charcoal at this depth. The charcoal peak at 4–6 cm represents years 1976–1993 which corresponds to the documented Graveyard Fire. Finally, the charcoal peak at 6–10 cm corresponds to years 1941–1976. This charcoal peak chronicles the Harney River Fire.

The Tarpon 1 site has no documented fire events according to the Fire Geodatabase (Fig. 2). However, according to our charcoal abundance analysis, large charcoal particles increase steadily from 6-8 cm to 10–12 cm depth intervals (Fig. 4). The ^{210}Pb CRS Model indicates that this large charcoal peak occurred between 1948 and 1964.

The SH2M2/WSC2B site had a moderate amount of large charcoal particles at 4–6 cm (Fig. 4). However, there are no documented fire events at this site according to the Fire Geodatabase (Fig. 2). Based on the ^{210}Pb CRS Model results, a fire event occurred between 1950 and 1980 at SH2M2 site.

The MPR West 1 site had a moderate amount of medium and large charcoal particles at 4–6 cm. Moreover, this site has no documented fire history (Fig. 2). Unfortunately, ^{210}Pb dating was not performed on MPR West 1; we, therefore, cannot assign a date to the fire event at 4–6 cm.

Visual inspection of charcoal was problematic in our mixed marl/peat cores (MPR West 1, MPR West 2 and OIH SE) due to residue that remained in the petri dishes after processing, possibly a result of the two-step chemical treatments of H_2O_2 and HCl making charcoal identification questionable. MPR West 2 and OIH SE cores had an insignificant amount of large and medium charcoal (Fig. 4). Despite the absence of large charcoal in the MPR West 2 core, the Flamingo Wells Fire in 2004 is documented in the Fire Geodatabase (Fig. 2). OIH SE has no record of fire and no significant amount of charcoal was found in this core (Fig. 2). Lead-210 dating was not performed on these cores.

4. Discussion

Fire plays an important role in the ecology of the Everglades in that it influences the hydrology, soil formation, and biotic components of the ecosystem (Smith et al., 2013; Beckage, 2005). Due to the importance of fire in the Everglades, the ENP has been documenting fire events since the 1940s and has been at the forefront of fire management. ENP was the first to allow prescribed fires (Taylor, 1981). Consequently, these fire events have been recorded in an ESRI geodatabase.

At the SH-5/WSC-8b site, fire is well documented. Peaks in large charcoal abundance can be correlated with documented fire events based on ^{210}Pb CRS Model results (Fig. 4). However, at the 2–4 cm interval, which was dated at 1993–2006, there are two recorded fire events in the fire geodatabase, the Harneys2 and Harney RVR Fires, but there are only small amounts of large charcoal in this interval. This finding could indicate that these fires were small and/or short-lived, resulting in little deposition of large charcoal particles.

At Tarpon 1, there is no documentation of fire. However, large charcoal particles increase from 6 to 8 cm down to 10–12 cm (Fig. 4). We suggest that this may represent a large fire event or multiple fires over time. Based on ^{210}Pb CRS Model results the peak in large charcoal particles at 8–10 cm occurred between 1948 and 1964. These dates are within the date range of the Fire Geodatabase and may represent a fire event that was not documented in the geodatabase.

The SH2M2/WSC-2b site has no documentation of fire events in the

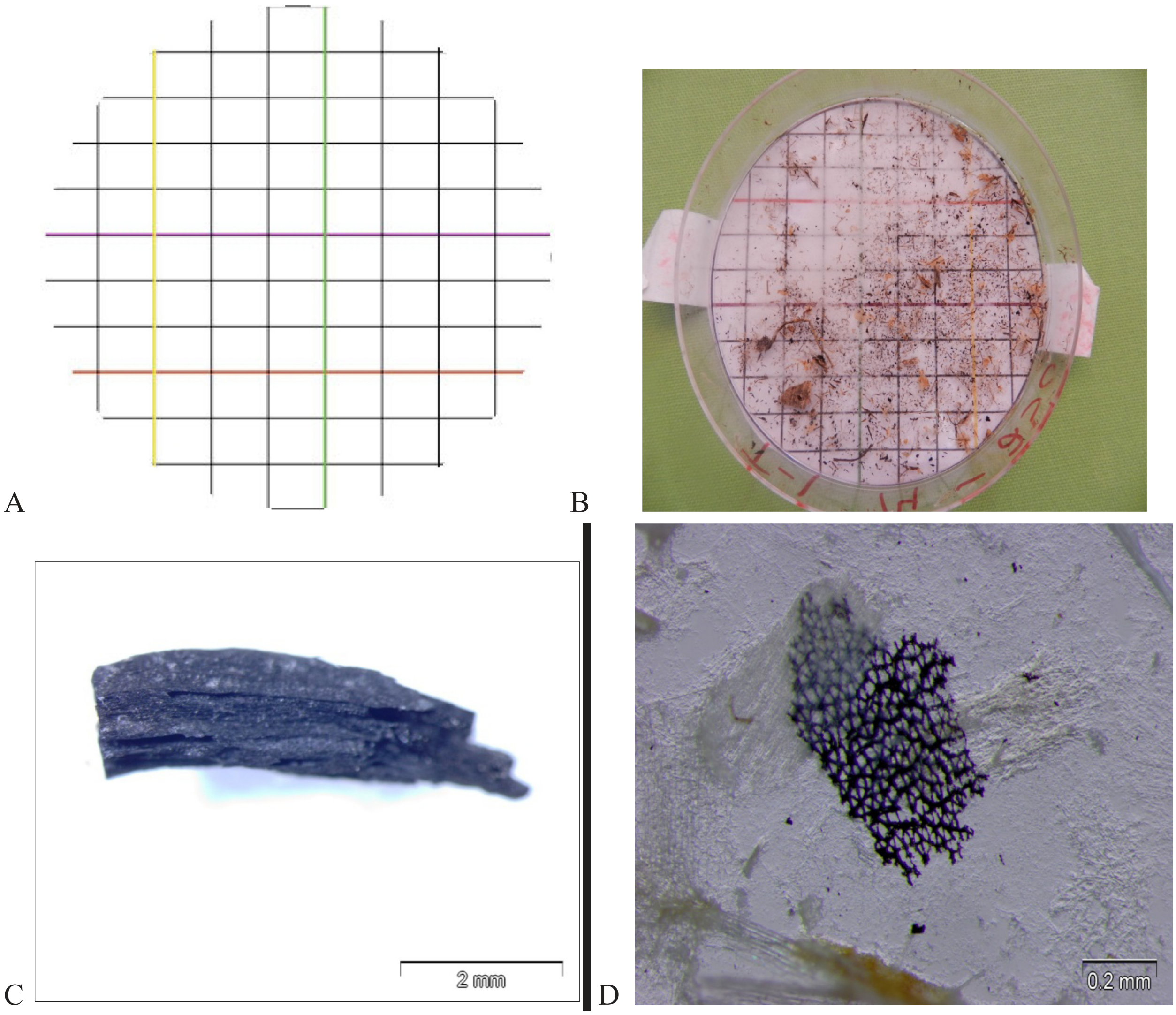

Fig. 3. Sample grid, Petri dish, and charcoal examples. A. Grid used for counting charcoal. B. Grid placed under a Petri dish with charcoal. C. and D. Examples of charcoal particles.

Fire Geodatabase. Contrary to that finding, we found large charcoal particles at a depth of 4–6 cm. This interval was dated between 1950 and 1980 using the ^{210}Pb CRS Model (Fig. 4). We hypothesize that this represents a local or small fire that was not observed and therefore not recorded in the Fire Geodatabase.

At the MPR West 2 site, a fire occurred in 2004 according to the Fire Geodatabase. However, there is very little charcoal throughout this core (Fig. 4), which raises the question of why this fire event was not recorded in the sediment as a charcoal layer. We hypothesize that this fire may have been too small or short-lived to create a significant charcoal layer or that the fire was mispresented in the Fire Geodatabase.

The SH5/WSC_8b, SH2/WSC-2b and Tarpon 1 cores were all highly organic peat cores and these organics were easily oxidized using 20% H_20_2 rendering these sediments useful for charcoal visualization. Conversely, the MPR West 2, MPR West 1 and OIH SE cores were a mix of peat and marl. Consequently, these cores required further processing to dissolve the carbonate in addition to bleaching of the organics. After the preprocessing was completed, we noticed that these samples had a residual substance in the petri dishes making charcoal visualization and counting difficult. Moreover, no charcoal was identified in the 0–2 cm and 11–12 cm intervals in the OIH SE core due to the residue mentioned above. We hypothesize that the two-step process (soaking in HCl and H_20_2) may have physically and chemically altered the charcoal, making its identification problematic in marl/peat soils.

Using fossil charcoal along with ^{210}Pb dating in peat soils appears to be a promising tool in fire history reconstruction. In this study, we were able to identify fire events based on fossil charcoal that was documented in the Fire Geodatabase. Moreover, we also identified possible fire events that were not documented in the Fire Geodatabase based on large charcoal abundance. Based on these findings, the Fire Geodatabase does have some data gaps. This study can only assess the fires missing from the database at these six sites, however, the findings at these sites suggest that many other areas may have had undocumented fires. The implications of these findings (i.e., a more complete record) could aid land managers in implementing better fire data collection and management. Conversely, in the absence of the information presented here, assuming that an area has not burned historically, when in fact it has, could lead to flawed management practices.

By using fossil charcoal analysis along with ^{210}Pb dating we can help in filling in the data gaps for the Fire Geodatabase. Unfortunately, charcoal analysis in mixed peat and marl sediments may not allow for fine-scale fire history reconstruction. One disadvantage to this sampling method is the coarseness of the temporal record in regards to deposition of sediment and charcoal. Based on Fig. 4, we can see that 2 cm of sediment can represent a relatively large time span. Thus, establishing a

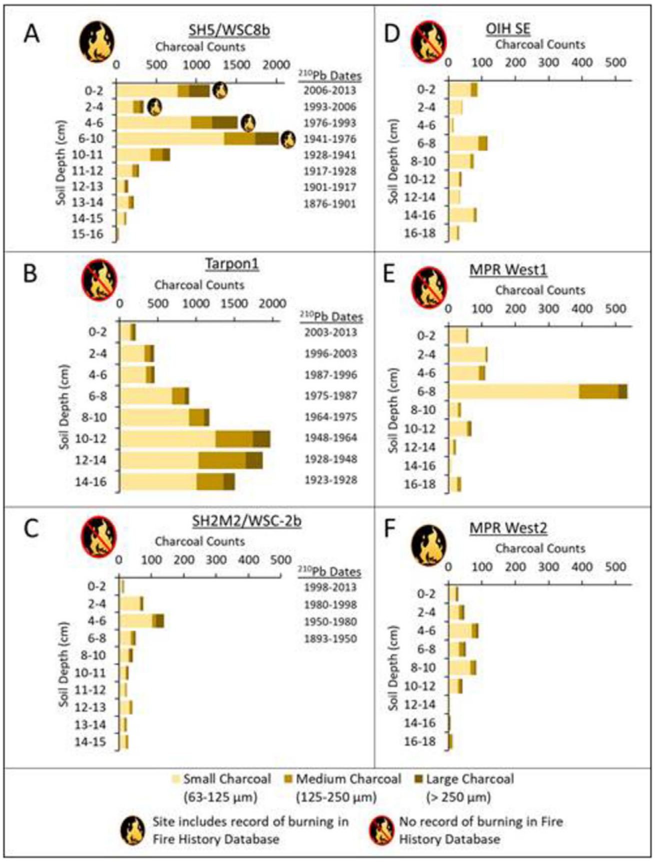

Fig. 4. Charcoal counts by size class and depth for locations with and without a record of fire occurrence in the Everglades National Park Fire History Geodatabase. Panels A, B, and C include ^{210}Pb dates for soil depth intervals. For Panel A (SH5/WSC8b), recorded fires occurred in 2006 and 2011 (Harney River RX), 2001 and 2005 (Harneys2, Harney RVR), 1990 (Graveyard), and 1949 (Harney River). For Panel F (MPR West 2), a recorded fire occurred in 2004 (Flamingo Wells Fire). Note larger x-axis scale for panels A and B.

fine-resolution time scale is difficult in these environments. Additional investigations are needed to refine methods and examine how different types of fires (e.g., peat vs. surface, natural vs. anthropogenic) (Smith et al., 2001; Slocum et al., 2007) produce charcoal and how charcoal is transported and preserved in the soil record. Wildfire is an important factor in the Everglades landscape and ecology. As such a complete fire record is crucial to understanding ecological functioning within the park and vital to ongoing fire management.

Acknowledgments

The research reported here was supported by a number of sources including, the USGS′ Great Everglades Priority Ecosystems Studies program and the Climate and Land Use Change program. We thank N. Aumen and D. Willard, respectively. K. Balentine, K. Comparetto, P. Nelson, M. Tupaq, and K. Whelan assisted with collecting the cores. J. Snyder, and two anonymous reviewers provided helpful comments on the manuscript. This material was developed in collaboration with Florida Coastal Everglades Long-Term Ecological Research program under U.S. National Science Foundation Grant No. DBI-0620409 and supported by the U.S.National Science Foundation under Water, Sustainability & Climate grant EAR-1204079 to J.M. Smoak. JLB was funded under STAR Fellowship Assistance Agreement no. F13B20216 by the U.S. Environmental Protection Agency (EPA). This manuscript has not been formally reviewed by EPA. The views expressed are solely those of the authors, and EPA does not endorse any products or commercial services mentioned in this publication. The use of trade, firm or product names if for descriptive purposes only and does not imply endorsement by the U.S. Government.

References

Adolf, C., Wunderle, S., Colombaroli, D., Weber, H., Gobet, E., Heiri, O., van Leeuwen, J., et al., 2017. The sedimentary and remote-sensing reflection of biomass burning in Europe. Glob. Ecol. Biogeogr. 27 (2), 199–212.

Appleby, P.G., Nolan, P.J., Oldfield, F., Richardson, N., Higgitt, S.R., 1988. 210Pb dating of lake sediments and ombrotrophic peats by gamma essay. Sci. Total Environ. 69, 157–177.

Beckage, B., Platt, W.J., Slocum, M.G., Panko, B., 2003. Influence of the El Nino southern oscillation on fire regimes in the Florida Everglades. Ecology 84 (12), 3124–3130.

Beckage, B., Platt, W.R., Panko, B., 2005. A climate-based approach to the restoration of fire-dependent ecosystems. Restor. Ecol. 13 (3), 429–431.

Breithaupt, J.L., Smoak, J.M., Smith III, T.J., Sanders, C.J., 2014. Temporal variability of carbon and nutrient burial, sediment accretion, and mass accumulation over the past century in a carbon platform mangrove forest of the Florida Everglades. J. Geophys. Res.: Biogeosciences 119 (2032), 2048.

Brown, M.T., Cohen, M.J., Bardi, E., Ingwersen, W.W., 2006. Species diversity in the Florida Everglades, USA: a systems approach to calculating biodiversity. Aquat. Sci. 68 (3), 254–277.

Clark, J.S., 1988. Particle motion and the theory of charcoal analysis: source area, transportation deposition and sampling. Quat. Res. 30, 67–80.

Clark, J.S., Lynch, J., Stocks, B.J., Goldammer, J.G., 1998. Relationships between charcoal particles in air and sediments in west-central Siberia. Holocene 8 (1), 19–29.

Clark, R.L., 1982. Point count estimation of charcoal in pollen preparations and thin sections of sediments. Pollen Spores XXIV (3–4), 523–535.

Gunderson, L.H., Loftus, W.F., 1993. The Everglades. Biodiversity of the Southeastern United States: Lowland Terrestrial Communities. pp. 199–255.

Gunderson, L.H., Snyder, J.R., 1994. Fire Patterns in the Southern Everglades. Everglades, the Ecosystem and its Restoration. St. Lucie Press, Delray Beach, FL, USA, pp. 291–305.

Huber, U.M., Markgraf, V., 2003. European impact on fire regimes and vegetation dynamics at the steppe-forest ecotone of southern Patagonia. Holocene 13 (4), 567–579.

Junk, W.J., Brown, M., Campbell, I.C., Finlayson, M., Gopal, B., Ramberg, L., Warner, B.G., 2006. The comparative biodiversity of seven globally important wetlands: a synthesis. Aquat. Sci. 68 (3), 400–414.

Leys, B., Brewer, S.C., McConaghy, S., Mueler, J., McLauchlan, K.K., 2015. Fire history reconstruction in grassland ecosystems: amount of charcoal reflects local area burned. Environ. Res. Lett. 10. https://doi.org/10.1088/1748-9326/10/11/114009.

Lynch, J.A., Clark, J.S., Stocks, B.J., 2004. Charcoal production, dispersal, and deposition from the Fort Providence experimental fire: interpreting fire regimes from charcoal records in boreal forests. Can. J. For. Res. 34 (8), 1642–1656.

Mueller, J.R., Long, C.J., Williams, J.J., Nurse, A., McLauchlan, K.K., 2014. The relative controls on forest fires and fuel source fluctuations in the Holocene deciduous forests of southern Wisconsin, USA. J. Quat. Sci. 29, 561–569. https://doi.org/10.1002/jqs.2728.

Pisaric, M., 2002. Long-distance transport of terrestrial plant material by convection resulting from forest fires. J. Paleolimnol. 28, 349–354. https://doi.org/10.1023/A:1021630017078.

Patterson, W.A., Edwards, K.J., Maguire, D.J., 1987. Microscopic char coal as a fossil indicator of fire. Quat. Sci. Rev. 6, 2–23.

Power, M.J., Marlon, J., Ortiz, N., Bartlein, P.J., Harrison, S.P., Mayle, F.E., et al., 2008. Changes in fire regimes since the Last Glacial Maximum: an assessment based on a global synthesis and analysis of charcoal data. Clim. Dyn. 30, 887–907. https://doi.org/10.1007/s00382-007-0334-x.

Rhodes, A.N., 1998. A method for the preparation and quantification of microscopic charcoal from terrestrial and lacustrine sediment cores. Holocene 8 (1), 113–117.

Rutchey, K., Schall, T.N., Doren, R.F., Atkinson, A., Ross, M.S., Jones, D.T., Madden, M., Vilchek, L., Bradley, K.A., Snyder, J.R., Burch, J.N., Pernas, T., Witcher, B., Pyne, M., White, R., Smith III, T.J., Sadel, J., Smith, C.S., Patterson, M.E., Gann, G.D., 2006. Vegetation Classification for South Florida Natural Areas. 2006-1240. U.S Department of Interior, U.S. Geological Survey Open-File Report 2006-1240. Ref Type: Report.

Slocum, M.G., Platt, W.J., Beckage, B., Panko, B., Lushine, J.B., 2007. Decoupling natural and anthropogenic fire regimes: a case study in Everglades National Park, Florida. Nat. Area J. 27 (1), 41–56.

Smith, S.M., Newman, S., Garrett, P.B., Leeds, J.A., 2001. Differential effects of surface and peat fire on soil constituents in a degraded wetland of the northern Florida Everglades. J. Environ. Qual. 30 (6), 1998–2005.

Smith III, T.J., Foster, A.M., Tiling-Range, G., Jones, J.W., 2013. Dynamics of mangrove-marsh ecotones in subtropical coastal wetlands: fire, sea-level rise, and water levels. Fire Ecology 9 (1), 66–76.

Smith III, T.J., Foster, A.M., Jones, J.W., 2015. Fire History of Everglades National Park and Big Cypress National Preserve, Southern Florida. U.S. Geological Survey Open-File Report 2015-1034, pp. 86. https://dx.doi.org/10.3133/ofr20151034.

Smoak, J.M., Breithaupt, J.L., Smith III, T.J., Sanders, C.J., 2013. Sediment accretion and organic carbon burial relative to sea-level rise and storm events in two mangrove forests in Everglades National Park. Catena 104, 58–66.

Taylor, D.L., 1981. Fire History and Fire Records for Everglades National Park, 1948- 1979. South Florida Research Center Report T-619. National Park Service Ref Type: Report.

The Everglades, https://www.nwf.org/Educational-Resources/Wildlife-Guide/Wild-Places/Everglades.

Whitlock, C., Larsen, C., 2001. Charcoal as a Fire Proxy. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Whitlock, C., Millspaugh, S.H., 1996. Testing the assumptions of fire history studies: an examination of modern charcoal accumulation in Yellowstone National Park, USA. Holocene 6, 7–15. https://doi.org/10.1177/095968369600600102.