Project Title: Do Annual Prescribed Fires Enhance or Slow the Loss of Coastal Marsh Habitat at Blackwater National Wildlife Refuge?

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I. Abstract

The rate of estuarine marsh loss at Blackwater NWR has been high (up to 2,000 ha) during the past 80 years because the vertical buildup of the marsh surface has lagged behind the local rate of relative sea-level rise. In this mineral sediment-poor estuary, marsh vertical development is driven primarily by the accumulation of plant matter in the soil (roots and rhizomes). Thus any activity that affects plant productivity can affect the ability of these marshes to keep pace with sea-level rise. Blackwater NWR has employed an annual prescribed fire regime since the 1970's to achieve multiple management objectives. However, the influence of annual burning on plant production and marsh elevation dynamics is unknown. The Refuge Manager has stated, "Our most critical science need is to know if an annual return fire interval adversely or positively affects marsh elevation, and whether fire is contributing to or slowing the loss of marsh habitats." We addressed this concern through manipulative experiments in field plots with varying burn return frequencies (annual, 3-5 years, 7-10 years, and no burn control) established by the refuge in 1998.

Key findings: Annual burning significantly increases above- and below-ground plant production over the other three treatment regimes. There was a consistent pattern of other effects of annual burning but they were not statistically significant. The pattern includes annually burned marshes having the lowest surface accretion, root zone subsidence, shallow subsidence, and elevation deficit (i.e., lagged behind the relative sea-level rise rate less than the other treatments). Annual burning has a strong positive influence on plant production, which is a critical component of marsh vertical development in this mineral sediment-poor estuary. Yet, we cannot say unequivocally that annual burning increases the elevation and thereby the sustainability of the marshes at Blackwater NWR. However we can say that annual burning does not pose an additional risk to long-term sustainability of the marsh habitats there, compared to the other treatment regimes.

II. Background and Purpose

This project was conducted at Blackwater National Wildlife Refuge (BNWR), which is part of the Chesapeake Marshlands National Wildlife Refuge Complex. More than 2,000 hectares of tidal marshes at BNWR and the adjacent Fishing Bay Wildlife Management Area (FBWMA) have been lost during the past century because marsh vertical development has not kept pace with sea-level rise. At BNWR, marsh vertical development occurs primarily through soil organic matter accumulation because very little mineral sediment comes into the system. Thus any action that affects plant growth can directly affect the ability of the marsh to keep pace with sea-level rise. For example, severe grazing of marsh plants by herbivores (e.g., nutria, muskrat, snow and Canada geese), in particular the nutria, likely was an important contributor to past marsh loss by its effects on plant growth. Because of the threat to marsh sustainability, the nutria population was eradicated from the refuge by 2005. Fire also affects the accumulation of plant organic matter in the soil, but the magnitude and direction (i.e., positive or negative) of its effects are not fully known. Land managers at BNWR and FBWMA have a management dilemma. They manage ~ 4,450 hectares of tidal marsh with annual prescribed fires to reduce hazardous fuel conditions, promote rare and endangered species, and enhance habitat for wildlife. Yet, using fire to improve the wildlife value of the marsh habitats may be contributing to their destruction if fire negatively affects plant growth and organic matter accumulation in the soil. Understanding the relationship between fire, organic matter accumulation, and marsh sustainability is important in recognizing the limits and consequences of fire as a management tool in these coastal marshes.

This research addressed the following data gap identified by the manager at BNWR: *Does the annual prescribed fire regime adversely or positively affect marsh elevation, and does it contribute to marsh loss at BNWR*? We experimentally determined how annual prescribed burns affect soil organic matter accumulation and surface elevation trends in the marshes. Our data were used to identify key processes controlling elevation, and how annual burning affects these processes, and, ultimately, marsh elevation change. Also, we assessed the risk that annual burns pose to long-term marsh sustainability by integrating the accretionary processes data into an inundation model that forecasts the fate of the marsh to sea-level rise. This modeling framework allows us to forecast ecosystem change and provide important feedback to managers; enabling adaptive shifts in burn strategies for the sustainable management of the marshes. Lastly, we assessed the effect of fire return frequency (annual, 3-5 years, and 7-10 years) on marsh fuel loads, because the managers will need to understand the fuel load and potential wildfire consequences for switching to a less frequent burn schedule if annual burns prove to be detrimental to marsh sustainability. Knowledge provided by this study will reduce the managers' uncertainty regarding the impacts of their prescribed burn schedule on marsh stability and will have direct implications for the further application of the Fire Management Plan at BNWR and the trade-offs between fuel reduction and marsh sustainability. Furthermore, improving our understanding of marsh elevation dynamics may lead to more effective management of the 1.2 million hectares of estuarine and 600,000 hectares of marine wetland habitat in the National Wildlife Refuge system.

III. Study Description and Location

Study Site & Experimental Design

The Blackwater National Wildlife Refuge (BNWR) near Cambridge, MD is located on the eastern shore of Chesapeake Bay on the Delmarva Peninsula in an area of low elevation and relief (Fig. 1). The current rate of relative sea-level rise (RSLR) in Cambridge, MD on the Choptank River is 3.52 mm y^{-1} (NOAA tide gauge 8571892, www.tidesandcurrents.noaa.gov). RSLR is the combined effect of both sea level and land level changes. The marsh is brackish and co-dominated by *Spartina patens* and *Schoenoplectus americanus*, often mixed with *Distichlis spicata*. *Spartina alterniflora* occurs along the marsh edge and in low-lying areas. This marsh is typical of brackish marshes found along the eastern and Gulf coasts of the United States. *Schoenoplectus americanus*, commonly called Olney three-square, has high value for wildlife and is the species of highest management concern to the refuge. Prescribed fire is typically used to enhance growth of Olney three-square.

This study was designed around an existing experimental prescribed burning framework established by BNWR in 1998 (Fig. 1). The experimental design consisted of 3 blocks with 4 burn treatments (Table 1). Within each treatment level – block combination we installed 3 surface elevation tables (SET). Each SET plot consisted of a deep rod SET benchmark driven to refusal (~ 12 – 24 m) and four shallow benchmarks driven to the depth of the root zone around each deep rod SET benchmark, which allowed us to determine the relative contribution of the root zone versus deeper subsurface soil processes to surface elevation (Cahoon et al. 2002b). Accretion marker horizon (MH) plots were located around the SETs. BNWR staff conducted burns from December to March following a prescription used since 1970 of temperature, humidity, winds, and soil moisture that ensured a surface burn with 5 – 10 cm of vegetative stubble remaining. In addition to the annual burn treatments, the following sites were burned according to the BNWR prescription schedule over the course of this study: in Unit 1 the 3-5 Year and 7-10 Year treatments were burned in 2007; and in Units 2 and 3 the 3-5 Year treatments were burned in 2008.

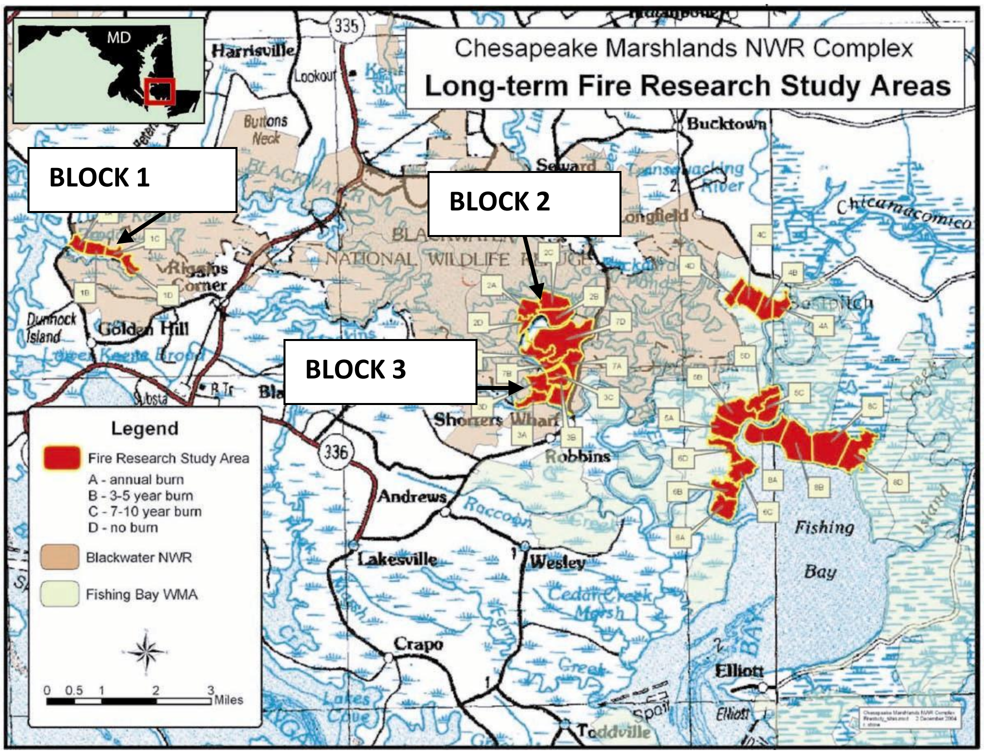

Figure 1. Locations of long-term fire research study areas at BNWR (indicated by block labels) and Fishing Bay WMA. Field sampling was conducted in blocks 1, 2, and 3 on BNWR. Field sampling was not conducted in the red areas around FBWMA shown on the right of the figure.

Table 1. Experimental design.

Factor	Sample Size
Blocks	3
Treatments within each Block	4
SETs within each Treatment	3
Total Sample Size	36

Block = Parcel of land in which all burn treatments are applied once

Treatment = burn treatments (e.g., annual burn, no burn, 3-5 year burns, 7-10 year burns)

SET = SET benchmark plot, each plot includes a deep rod and shallow benchmark

Marsh Elevation Dynamics

Changes in marsh elevation were measured using a SET- MH technique (Cahoon et al. 2002a, 2002b), making it possible to quantitatively determine high precision (1-2 mm) changes in marsh surface elevation, separate the contributions of surface and subsurface processes to surface elevation, calculate shallow subsidence (Cahoon et al. 1995), and to partition shallow subsidence between shallow (root zone) and deeper (below the root zone to > 10 m) portions of the soil profile (Cahoon et al. 2002a, 2002b) using benchmarks of different depths. Vertical accretion (i.e., sediment deposition and erosion) was measured to the nearest mm from cryogenic cores taken through a soil MH laid on the marsh surface at the beginning of the study (Cahoon & Turner 1989). Surface elevation change and changes in elevation associated with the root zone were measured using deep rod SET and shallow benchmark SETs, respectively (Cahoon et al. 2002a, 2002b). SET measurements incorporate the surface processes measured from the MH plus the subsurface processes occurring between the MH and the base of the SET benchmark. The collective influence on surface elevation of these subsurface processes (i.e., root growth and decomposition, sediment compaction, and shrink/swell from water flux), which is called shallow subsidence, is calculated by subtracting elevation from accretion (Cahoon et al. 1995) (Fig. 2). SET and MH measurements were conducted 3 times annually (spring, summer, and fall) during 2006-2009 in each of the experimental plots.

Standing crop

Samples for peak standing crop were harvested annually during the height of the growing season (August-September). Within each plot, both live and dead standing material and litter were harvested from randomly selected duplicate sub-plots (0.1 m^2 diameter). Harvested samples were sorted by species and tissue type (live, dead) and were processed within 2 weeks of collection. Stem counts and height of the tallest individuals (n=6) for each species also were recorded. Samples were then dried at 70^{o}C to constant mass and weighed. Ground plant samples were analyzed for C and N content according to Aspila et al. (1976).

Belowground tissue accumulation

Annual rates of belowground tissue accumulation for each site were determined using an implanted mass technique (e.g., McKee et al. 2007). In the fall of each year, duplicate ingrowth bags (dia = 5 cm, l = 30 cm) constructed from mesh material and containing sphagnum peat were inserted into pre-cored holes in the marsh surface within each experimental plot. Sphagnum peat was used to provide a standardized organic substrate with a bulk density similar to that of the marsh sediment (e.g., McKee et al. 2007). Bags were retrieved after ~1 y and divided into three 10-cm sections to provide depth profiles of belowground tissue accumulation. Samples were sorted into live and dead tissues as well as into 3 classes: fine roots (dia<2.5 mm); coarse roots (dia>2.5 mm); or rhizomes. No attempt was made to sort root and rhizome material by species.

Tissues were then dried at 70°C to constant mass and weighed. Annual belowground production (g m^{-2} y^{-1}) was calculated by summing live and dead root biomass over both diameter classes and all three depths for each bag.

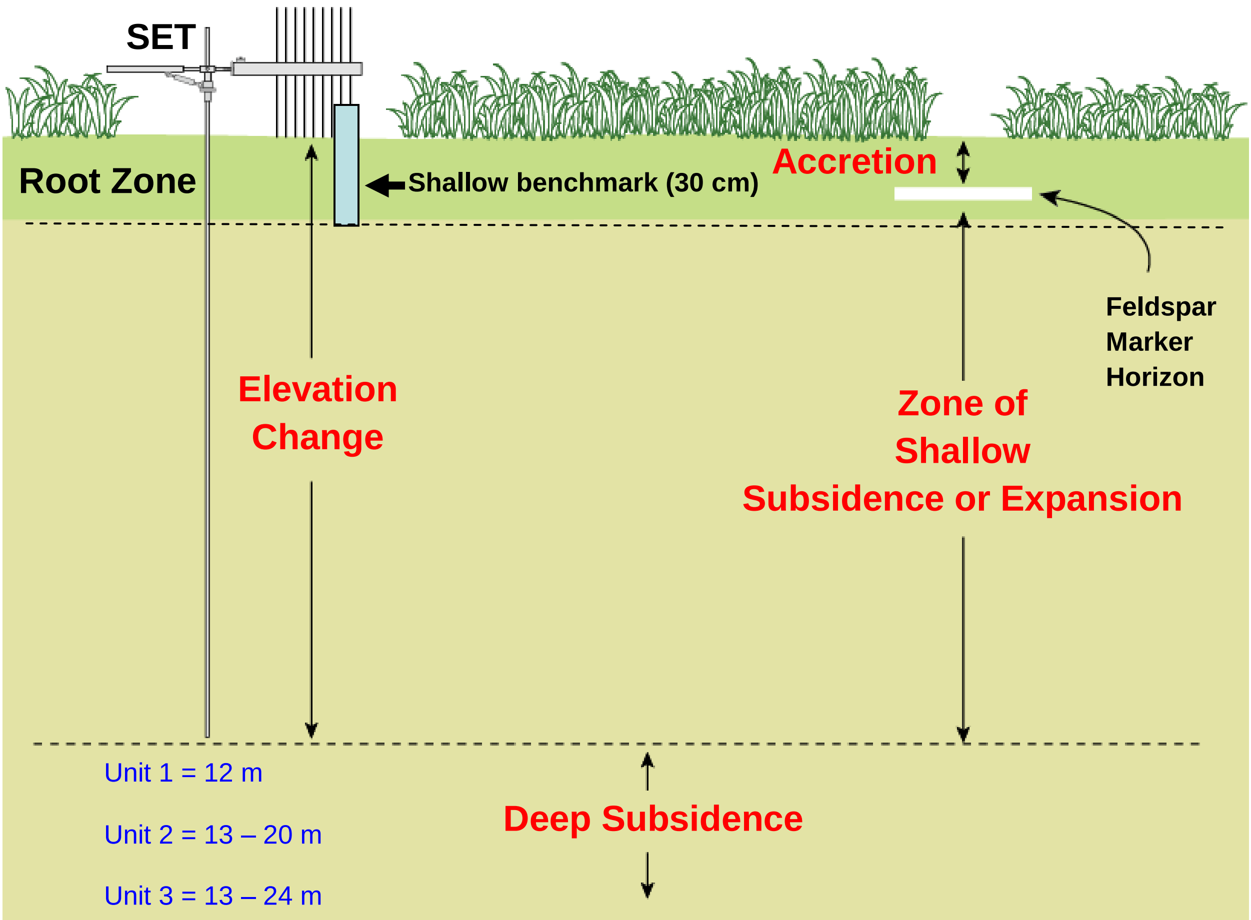

Figure 2. Diagram showing the portions of the soil profile measured by deep and shallow Surface Elevation Table (SET) benchmarks and marker horizon techniques. Shallow subsidence or expansion is calculated as accretion minus elevation change. Root zone subsidence or expansion is calculated as elevation change minus the readings from the shallow benchmark, which represent the processes (deep) occurring between the bottoms of the two benchmarks. Deep subsidence is determined from tide gauge data. See text for detailed explanation.

Statistical Analyses

The experimental design of this study is considered a complete fixed block: each of three blocks (burn units at Blackwater 1-3) contained all four burn treatments (annual burn, 3-5 year burn frequency, 7-10 year burn frequency, and the no-burn control) with no replication of treatment zones within each block. Therefore, there were a total of 12 block-by-treatment combinations. Within each combination, there were three SET plots: at each plot, the SET device occupied four fixed positions repeatedly over time, each 90 degrees apart. Within each position, nine fixed position measurements of sediment surface elevation were made. These elevation data were expressed as cumulative elevation change for each individual pin location (1-9) within each position the instrument occupied (4) at each benchmark plot, since the start of the study. A linear regression was fitted for each pin. Pins 1-7 generally corresponded to the wetland sediment surface; pins 8 and 9 generally landed on a capped shallow pipe which had been inserted about 30 cm into the soil at the start of the study. The slopes for pins 1-7 were therefore averaged separately from pins 8 and 9. The latter would integrate only sub-root zone processes (down to the depth of the SET benchmark), whereas the former would integrate all soil processes with respect to the bottom of the mark. The shallow pipe would be expected to be insensitive to elevation dynamics within the top 30 cm of soil. Therefore, by subtracting the average slope from pins 8 and 9 from the average slopes of pins 1-7, an estimate of vertical processes within the top 30 cm of the soil could be estimated. For each position occupied within each SET benchmark plot, three elevation change estimates were made: total elevation change, root zone change, and sub-root zone change. These three rates were averaged over the four positions within each plot.

Three feldspar marker horizon plots were established at each SET plot according to Cahoon and Turner (1989), and were sampled repeatedly over time using cryogenic techniques (Cahoon et al. 1996), yielding cumulative accretion for each marker surface. Simple linear regressions were calculated for each surface, and then averaged to the SET plot. Estimates of linear trends in shallow subsidence (Cahoon et al. 1995) were estimated by subtracting the average elevation change slopes from accretion slopes at the SET plot level:

$$SS = Accr - SET$$

Where: SS = Shallow subsidence

$Accr$ = Accretion over feldspar marker horizons

SET = Surface elevation change from SET instrument

The four linear trajectory estimates (accretion, total elevation change, shallow subsidence, root zone and deep elevation change) were averaged over the three replicate SET plots within each block * burn treatment combination.

The elevation of a wetland sediment surface with respect to local water levels has been shown to exert some control over sediment deposition and the resulting vertical processes (e.g., Stoddart et al. 1989). Elevations of the marsh surface at each SET plot was obtained using real-time kinematic GPS (RTK), with a minimum of 15 sec observations for each of at least four points within each SET plot. The base station was established on a 2005 height modernized National Geodetic Survey deep rod mark (PID DH8216). RTK elevations were expressed with respect to the North American Vertical Datum of 1988 (NAVD88). Mean sea level was assumed to be relatively constant across the three burn units within the Blackwater Refuge, so elevations with respect to NAVD88 were assumed to be adequate proxies for expressing differential inundation and sedimentation potential across the study area.

An analysis of covariance was used to determine the presence of a burn treatment effect for each vertical process, using the average elevation of the SET plots as a covariate (SAS Proc Reg, SAS Institute Inc. 2002). Only one slope was specified (elevation effect): the default intercept was the control no-burn treatment and the intercept adjustors corresponded to the three other burn treatments. Therefore, the adjustors correspond to comparisons between the burn treatments and the control.

IV. Key Findings

When interpreting these data and the importance of the findings, there are two issues that must be kept in mind. First, the burn treatments installed in 1998 represent a release from annual burning pressure for the 3-5 year, 7-10 year and control treatments because the entire marsh had been burned annually beginning in the 1970's up to 1998. In addition, this means that the annually burned marsh had been burned for more than 30 consecutive years by 2009, although the records for Unit 1 go back only to the 1980's. In contrast, the fire regime for the other treatment marshes had been implemented for only 11 years by 2009, following two decades of annual burning (1970's to 1998). The findings presented herein must be interpreted in this context. Second, there were underlying physical differences among the different blocks in this study, the most important of which was site elevation, which influences both hydroperiod (flooding patterns) and plant productivity. Therefore, site elevation was used as a covariate in our statistical analyses.

A. Accretion, root zone subsidence, and shrink-swell of sediments below the root zone are the primary drivers of elevation change in the marshes at Blackwater NWR.

Several processes that occur within the top 15 m of the marsh substrate can influence vertical development and subsequently elevation change. They are surface accretion, root zone subsidence, root zone expansion, shrink-swell of the substrate below the root zone, and subsidence (e.g., compaction) of the substrate below the root zone but above the base of the SET benchmark. Not all of them occur in every wetland, and for those that do occur they often differ in their impact on elevation. In addition, the process that dominates wetland vertical development often varies among and within wetland types and settings. Our sampling methods were designed to measure different portions of the top 15 m of the substrate (surface, root zone, and below the root zone to the base of the SET benchmark, referred to as the deep zone) so we could quantify the influence (rate and direction) of any of these processes, should they occur at Blackwater NWR. Our data indicate that the processes most influencing the rate of marsh vertical development at Blackwater NWR are surface accretion, root zone subsidence, and shrink-swell of sediments below the root zone. We also calculated shallow subsidence in each treatment marsh in order to calculate a revised rate of relative sea-level rise. Estimates of relative sea-level rise derived solely from tide gauges provide estimates of deep subsidence only, and do not include any subsidence that occurs in the upper portion of the marsh profile measured by the SET-MH approach (Rybczyk and Cahoon 2002). Adding the rate of shallow subsidence to the deep subsidence estimate yields the revised rate of relative sea-level rise (Rybczyk and Cahoon 2002).

There are positive trends in surface accretion in all treatments (mean = 5.9 - 9.7 mm y^{-1}) indicating there was limited, if any, surficial erosion occurring. Given that there is little mineral sediment input to these marshes, the source of sediments accumulating on the surface most likely comes from litter falling from the plants and the breakup of the marshes as their elevation becomes too low relative to local sea level. The death of the vegetation and disintegration of the root mat releases the bound sediments and organic matter for redistribution throughout the system. There are negative trends in root zone elevation change in all treatments (< -1 to -6 mm y^{-1}) indicating that root zone subsidence or collapse is occurring. There is no evidence of root zone expansion. Lastly, shrink-swell of the substrate below the root zone is evident for marshes located along the Blackwater River (Units 2 and 3), which had the thickest peat layers. The shrink-swell is related to seasonal changes in river discharge and stearic changes in water levels of Chesapeake Bay, and masks our ability to estimate subsidence below the root zone. Shrink-swell in the deep zone does not have an important influence on long-term elevation trends. Shallow subsidence ranged from 1.7 mm y^{-1} in the annually burned marsh to 5.9 mm y^{-1} in the control marsh.

B. Annual burning stimulates plant growth.

Annual burning stimulates plant growth, resulting in greater stem densities and above- and belowground production (dry weight) compared to all other treatments. The means for these variables from the other three treatment marshes were similar and not statistically different. The annually burned marsh had up to 50% greater live peak standing crop (443 ± 24 vs. 290 ± 31 g m^{-2}, $p < 0.06$), up to 100% greater stem density (3,518 ± 357 vs. 1,589 ± 236 stems m^{-2}, $p<0.02$), up to 100% greater root production (122 ± 10 vs. 58 ± 8 g m^{-2} y^{-1}, $p<0.0002$), and up to 83% greater total belowground production (243 ± 34 vs. 133 ± 32 g m^{-2} y^{-1}, $p=0.15$). The increase in stem density occurred in both dominant plant species (*Spartina patens* and *Schoenoplectus americanus*). The increase in aboveground production in annually burned marsh was related to an increase in total plot production. There was no significant increase in production of either dominant species. Belowground production was not sorted by species.

There are several possible mechanisms by which annual burning could improve conditions for plant growth. They include rapid mineralization of organic matter resulting in increased soil nutrient content (i.e., a fertilization effect), increased insolation (sunlight) reaching the marsh surface and the emerging shoots in the spring as a result of removal of dead standing plants (i.e., less shading), increased soil temperatures in the spring as a result of increased insolation that could stimulate root activity, or any combination of these or other factors.

C. Annual burning reduces plant litter standing crop and fuel loads.

Annual burning removes standing dead biomass from the marsh surface every winter, resulting in a significantly lower litter standing crop (38 ± 6 g m^{-2}, $p<0.0001$) compared to all other treatment marshes. There was no significant difference in litter standing crop, or fuel load, among the 3-5 year, 7-10 year, and control treatment marshes, the means for which were 208 ± 38 g m^{-2}, 175 ± 29 g m^{-2}, and 216 ± 22 g m^{-2}, respectively.

D. Annual burning did not significantly influence marsh vertical development. However there was a consistent pattern in the annually burned marshes: they had the lowest rates of surface accretion, root zone subsidence, shallow subsidence, revised relative sea-level rise, and elevation deficit compared to the other treatment marshes.

<u>Surface accretion</u>: There is a trend for surface accretion in the annual burn treatment marsh (5.9 ± 1.5 mm y^{-1}) to be slower than all other treatment marshes (6.9 ± 2.3 mm y^{-1}, 8.4 ± 0.8 mm y^{-1}, and 9.7 ± 1.8 mm y^{-1} for the 3-5 year, 7-10 year, and control treatments, respectively), but the model was not significant ($F = 7.13$, 9 df, $p=0.1289$) and all comparisons among treatment means were not statistically significant ($p>0.05$). The rates of accretion for all treatments are greater than the estimated rate of relative sea-level rise (3.52 mm y^{-1}) as indicated by the NOAA tide gauge located in Cambridge, MD.

Root zone subsidence: There is a trend for root zone subsidence to be lower in the annually burned marsh (-0.4 ± 1.2 mm y^{-1}; rate is not different from zero) than in the other treatment marshes (-2.5 ± 0.7 mm y^{-1}, -4.3 ± 1.2 mm y^{-1}, and -6.2 ± 1.0 mm y^{-1} for the 3-5 year, 7-10 year, and control treatments, respectively), but the model was not significant (F= 2.39, 9 df, p=0.33) and all comparisons among treatment marshes were not statistically significant (P>0.20). We hypothesize that the increase in root production and total belowground production contributed to the reduction in root zone subsidence in the annually burned marsh.

Shallow subsidence and revised relative sea-level rise rate: There is a trend for shallow subsidence in the annual burn treatment marsh (1.7 ± 1.2 mm y^{-1}) to be slower than all other treatment marshes (3.4 ± 1.2 mm y^{-1}, 3.3 ± 1.2 mm y^{-1}, and 5.9 ± 1.2 mm y^{-1} for the 3-5 year, 7-10 year, and control treatment marshes, respectively), but the model was not significant (F = 2.52, 9 df, p=0.32) and all comparisons among treatment means were not statistically significant (P>0.58). The revised rate of relative sea-level rise is lowest in the annually burned marsh and highest in the control marsh (5.2 mm y^{-1}, 6.9 mm y^{-1}, 6.8 mm y^{-1}, and 9.4 mm y^{-1} respectively in the annual, 3-5 year, 7-10 year, and control marshes).

Marsh elevation gain: Total elevation change in the annually burned marsh (4.0 ± 1.5 mm y^{-1}) was virtually identical to that in the other treatment marshes (3.9 ± 1.4 mm y^{-1}, 5.0 ± 1.3 mm y^{-1}, and 3.8 ± 0.6 mm y^{-1}, p=0.79) (F = 1.34, 9 df, p=0.50), despite experiencing the lowest rate of root zone subsidence. We hypothesize that the lower litter and surface accretion rates in the annually burned marsh offset any reduction in root zone subsidence. The rate of elevation change in all treatment marshes was lower than the revised relative sea-level rise rate (see above).

E. Given the already high level of risk from sea-level rise on marsh survival at Blackwater NWR, annual burning does not pose an additional risk to long-term sustainability of the marsh habitats.

Marsh vulnerability to sea-level rise is determined by comparing the rate of marsh elevation gain to the revised relative sea-level rise rate. If the rate of marsh elevation gain is less than the revised relative sea-level rise rate then an elevation deficit exists (revised RSLR > Elevation gain = elevation deficit) and the marsh elevation gradually becomes lower relative to sea level until it eventually becomes totally submerged. An elevation deficit exists in all treatment marshes. Although the size of the deficits in the different treatment marshes are not statistically significantly different, there is a trend for the deficit in the annually burned marsh to be smaller than for all other treatment marshes (1.2 mm y^{-1} compared to 3.0 mm y^{-1}, 1.8 mm y^{-1} and 5.8 mm y^{-1} for the 3-5 year, 7-10 year, and control treatment marshes, respectively).

V. Management Implications

We present a monitoring approach for evaluating the effect of prescribed fire on marsh vulnerability to sea-level rise that can be adopted at other refuges and management agencies. The key findings have important implications for managing the marsh at Blackwater NWR. However, there are some caveats that must be considered before modifying management practices based on these findings. First, this is a short-term study based on monitoring of only three fire and two growing seasons. A longer term record based on continued sampling may provide additional insights into the effects of annual burning on marsh elevation. Second, this study was performed on a single refuge. So extrapolating these findings to other refuges, especially ones with different geomorphic settings and tide ranges, in lieu of collecting site-specific data, is not advised. Third, the key findings and management implications described herein assume that the nutria eradication and control program will continue at the refuge. Nutria herbivory has a direct and severe impact on marsh plant growth. Any increase in nutria herbivore activity could influence negatively the marsh elevation trajectories across all treatment marshes. In particular, vegetation in the annually burned marsh may be the preferred food of a revitalized nutria population given the robust productivity there. Lastly, since the entire marsh was burned annually from the 1970's to 1998, the burn treatments installed in 1998 represent a release from annual burning pressure for the 3-5 year, 7-10 year, and control treatment marshes; and a 30-year record of annual burning pressure for the annual treatment marsh. The findings must be interpreted in this context.

A. Accretion, root zone subsidence, and shrink-swell of sediments below the root zone are the primary drivers of elevation change.

We have identified the key processes driving elevation change in the marshes at this refuge. Future land management practices that increase mineral sediment inputs into this mineral-sediment poor system could benefit the marsh. If there are no feasible means for increasing natural sediment inputs to enhance vertical development, the refuge could evaluate artificial means for introducing additional mineral sediments onto the marsh surface (e.g., thin-layer deposition of dredged material) to raise marsh elevations relative to sea level. Another issue for refuge managers is marsh plant productivity; root production might be used as another means of enhancing marsh vertical development.

B.C. D. Annual burning significantly stimulates plant growth; significantly reduces litter standing crop and fuel loads; and does not significantly influence marsh vertical development.

Annual burning has both negative and positive effects on marsh vertical development. Thus any management decision to use or not to use an annual burning regime will require an evaluation of trade-offs. The significant reductions in litter standing crop caused by annual burning likely contribute to the slower (albeit not significantly) surface accretion rates in that treatment marsh. On the positive side, annual burning increases plant production, which has a direct benefit to wildlife using the marsh for food and habitat. In addition, the increase in belowground production in the annually burned marsh apparently contributes to the non-significant trend for a lower rate of root zone subsidence and shallow subsidence. So if the practice of annually burning the marsh is stopped, then surface accretion, root zone subsidence, and shallow subsidence will increase with the net effect likely being an increase in the revised relative sea-level rise rate and decreased sustainability for these marshes. In addition, the wildlife value of the habitat will be diminished, and the fuel loads and likelihood of wildfires will increase.

E. Given the already high level of risk from sea-level rise on marsh survival at Blackwater NWR, annual burning does not pose an additional risk to long-term sustainability of the marsh habitats.

Elevation deficits exist within all treatment marshes. Thus none of the habitats are sustainable for the long-term at current revised relative sea-level rise rates and especially at projected accelerated rates of rise during the coming century. Given that the annually burned marshes have significantly greater plant production and the lowest (albeit not significantly lower) elevation deficit of 1.2 mm y^{-1}, future management actions might be focused first on these treatment marshes. In particular, any actions that can be taken to increase surface accretion or further increase soil organic matter accumulation in these marshes could reduce the elevation deficit further.

VI. Relationship to Other Recent Findings and Ongoing Work on This Topic

<u>Recent findings</u>: In the first study to investigate the influence of fire on marsh elevation dynamics, Cahoon et al. (2004) reported that a prescribed burn reduced root zone collapse in a *Spartina patens*-dominated marsh at McFadden NWR in Texas where the vegetation had been killed by prolonged flooding. The prescribed burn also enhanced the rate of elevation recovery and recolonization by *S. patens* over the two years following the killing flood. The mechanism driving the enhanced elevation trends and recovery was an increase in the volume of soil organic

matter. The increase in organic matter volume appeared to be related to increased root growth, but the potential for decreased root decomposition in the burned marsh could not be ruled out. These results are similar to our findings of increased plant growth and decreased root zone collapse in the annually burned marsh at Blackwater NWR.

Ongoing work: There are three ongoing studies of prescribed fire effects on marsh plant growth and elevation dynamics. The first two studies described below are using the same suite of methods as we used in this study to evaluate marsh elevation dynamics in response to fire. The third is investigating the mechanisms by which prescribed fire induces increased plant growth and carbon storage in the soil. These studies will provide information on a new marsh setting (Gulf Coast), environmental factor (nutrient enrichment), and burn treatment duration (< 10 years).

Our US Geological Survey colleagues, Drs. Karen McKee and James Grace, have been carrying out an investigation of the effects of prescribed fire on marsh elevation dynamics at McFadden NWR in Texas, where prescribed burning is conducted every 2-3 years. The investigation includes a fertilization treatment to evaluate the interactive effects of fire and nutrient enrichment on marsh elevation dynamics.

Guntenspergen and Cahoon have established a separate investigation in Units 7 and 8 at Blackwater NWR and the adjacent Fishing Bay Wildlife Management Area. These new units were established in 2004 to provide additional replicates to the refuge and wildlife management area sampling designs. Unit 7 is located adjacent to Units 2 and 3 along the Blackwater River and Unit 8 is adjacent to Units 5 and 6 along the Transquaking River. Thus this investigation is evaluating the marsh response to fire treatments that have been in effect for only 6 years. The investigation is comparing only the annually burned and control treatment marshes, and includes a fertilization treatment to evaluate the interactive effects of annual fire and nutrient enrichment on marsh elevation dynamics.

Dr. Brian Needelman and his graduate students at the University of Maryland are evaluating the mechanisms by which fire enhances plant growth and possibly carbon sequestration. See Section IV B above (Annual burning stimulates plant growth) for a description of these proposed mechanisms. Dr. Needelman and his graduate students have implemented manipulative field experiments adjacent to our field plots in order to investigate the effects of rapid mineralization (i.e., fertilizer effect), increased insolation, and increased soil temperatures on plant growth and carbon storage in the soil. Preliminary findings indicate increased growth in annually burned plots is related to canopy removal and the associated effects of increased insolation and soil temperatures, and is not related to a fertilizer effect.

VII. Future Work Needed

Monitoring of elevation responses in all treatment marshes should continue for the long-term to confirm the nature of the process controls on marsh elevation. A minimum of a 2-3 year record is needed to provide a meaningful trend in elevation change from the SET – MH method. We currently have the minimum record length. In addition, a long-term (e.g., multi-decadal) record will integrate the interactive effects of low-frequency environmental drivers such as hurricanes.

To date, there are only two locations (McFadden NWR, Texas and Blackwater NWR, Maryland) where the effects of prescribed fire on marsh elevation dynamics have been evaluated. Both sites possess microtidal to nontidal astronomical tidal ranges and very low mineral sediment supplies. Investigations need to be carried out in additional geomorphic settings with differing tidal ranges and sediment supplies to determine if the marsh elevation responses to prescribed fire are applicable across the broader range of settings where prescribed fire is applied. At the very least, the project should be expanded into the Fishing Bay Wildlife Management Area, where prescribed fire is conducted and the treatment plots were also established in 1998. FBWMA has a higher tidal range and greater sediment load. Thus it would be interesting to see how this different physical setting interacts with fire to influence marsh elevation dynamics.

VIII. Deliverables Crosswalk Table

Proposed	Delivered	Status
Website	http://www.pwrc.usgs.gov/blackwaterburn/	Completed
Annual reports	Summary of progress in each year of the project	Completed for 2007 and 2008
Final report	Summary of project findings and management options	Completed
Workshop	Workshop with managers to disseminate and discuss findings and management options	Tentatively scheduled for May 3, 2010.
Publications	(1) At least one (1) manuscript prepared and submitted to a journal for peer review; (2) at least one summary publication (e.g., fact sheet) prepared for managers	(1) In progress (2) In progress

IX. Literature Cited

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Stoddart, D.R., D.J. Reed, and J.R. French 1989. Understanding salt-marsh accretion, Scolt Head Island, Norfolk, England. Estuaries 12(4):228-236

X. Additional Reporting

A. Input into Findings Database (available from www.firescience.gov)

B. Digital Photo Library (Photos available on CD)

C. Completed Deliverables (available on CD and entered into the citation database at www.firescience.gov)

D. Deliverables Citation Database (items entered into the JFSP Citation Database through March 31, 2010)

Final Report

Cahoon, D. R., Guntenspergen, G., Baird, S., Nagel, J., Hensel, P., Lynch, J., Bishara, D., Brennand, P., Jones, J., and Otto, C. 2010. Do Annual Prescribed Fires Enhance or Slow the Loss of Coastal Marsh Habitat at Blackwater National Wildlife Refuge? Final Project Report (JFSP Number: 06-2-1-35). March 31, 2010. Beltsville, MD

Website

Marsh Elevation Response to Prescribed Burning at Blackwater NWR. Research Project Website. http://www.pwrc.usgs.gov/blackwaterburn/

Knowledge Transfer Workshops and Advisory Meetings

Guntenspergen, G. and Cahoon, D. 2007. Processes affecting coastal wetland surface elevation at Blackwater NWR. Chesapeake Marshlands National Wildlife Refuge Complex, Fourth Annual Science Meeting, March 8, 2007.

Cahoon, D. and Guntenspergen, G. 2008. Marsh elevation response to prescribed burning at Blackwater NWR: preliminary data. Blackwater Technical Advisory Meeting, February 5, 2008, Blackwater NWR.

Cahoon, D.R. and Guntenspergen, G. 2009. Marsh elevation response to prescribed burning at Blackwater National Wildlife Refuge. Chesapeake Marshlands National Wildlife Refuge Complex, Sixth Annual Science Meeting, March 18, 2009.

Cahoon, D.R. and Guntenspergen, G. 2009. Marsh elevation response to prescribed burning at Blackwater National Wildlife Refuge: preliminary data analyses and interpretations. Blackwater Fire Advisory Meeting with refuge staff and FWS regional representatives, June 3, 2009.

Cahoon, D.R. and Guntenspergen, G. 2010. Marsh elevation response to prescribed burning at Blackwater National Wildlife Refuge. Chesapeake Marshlands National Wildlife Refuge Complex, Seventh Annual Science Meeting, March 17, 2010.

Professional Presentations and Invited Talks

Cahoon, D. R. Climate effects on wetland elevation dynamics. 19th Biennial Conference of the Estuarine Research Federation, Rhode Island Convention Center, 4-8 November 2007, Providence, RI.

Cahoon, D. R. Patterns and processes of coastal wetland surface elevation responses to sea-level rise. TIGS Symposium 2008, "Adaptation Strategies for Climate Change". February 26-28, 2008, Honolulu, Hawaii. Page 12 in program abstracts.

Cahoon, D.R. Climate change, sea-level rise, and coastal marsh elevation: dynamic process interactions determine marsh survival and management options. The Wildlife Society 16th Annual Conference, Sept. 20-24, 2009, Monterey, California, USA.

Cahoon, D.R. and Guntenspergen, G. Effects of prescribed burning on marsh elevation and vulnerability to sea-level rise. Coastal and Estuarine Research Federation, 20th Biennial Conference, 1-5 November, 2009, Portland, OR, USA

Deliverables in Preparation

Journal article: Effects of prescribed fire on marsh vulnerability to sea-level rise.