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ABSTRACT The Currituck National Wildlife Refuge (CNWR) in North Carolina is inhabited by feral horses (*Equus caballus*), feral pigs (*Sus scrofa*), and white-tailed deer (*Odocoileus virginianus*). The impact of these species on the vegetation of CNWR is unknown. To assess impact, we created two replicate exclosure plots within maritime forests, brackish marshes, and maritime grasslands. An electric fence divided each habitat into two sections: including or excluding horses. On each side of the electric fence within each habitat, we sampled three different 5×5 m plots (i.e., 36 plots). The first was a fenced exclosure 3 m high, the second a fenced exclosure raised 1 m above the ground and extended to 3 m, and the third, a control, was not fenced. Within plots, we created two 1 m transects, and randomly selected and tagged grasses, forbs, shrubs, and trees. We measured the distances from base to tip of herbs and from branching point to terminal bud in shrubs. We used a linear model to analyze plant growth rate. We used a length ratio adjusted by the number of days as the response variable. Out of 1,105 tagged plants, we detected 87 disturbances; 80 where horses were present and 7 where horses were excluded. Overall, horses were responsible for 84% of disturbances. Most disturbances occurred in brackish marshes on *Schoenoplectus pungens*. We detected a significant effect of exclosure treatment on plant growth rate where horses were present ($p = 0.035$), but not where they were excluded ($p = 0.32$).

Key words: Currituck National Wildlife Refuge, feral horses, feral pigs, habitat conservation, nonnative wildlife, vegetation impacts, white-tailed deer, wildlife conservation

INTRODUCTION Feral horses (*Equus caballus*), feral pigs (*Sus scrofa*), white-tailed deer (*Odocoileus virginianus*), cattle (*Bos* spp.), sheep (*Ovis* spp.), and goats (*Capra* spp.) all have the potential to negatively impact the vegetation in grass-shrub communities and salt marshes and may lead to a decrease in annual above-ground plant growth (Wood et al. 1987). Furthermore, nonnative feral pigs and feral horses alter plant and wildlife diversity in plant communities (Levin et al. 2002, Seimann et al. 2009). At Shackleford Banks, North Carolina, salt marshes were heavily impacted by nonnative ungulates including horses, cattle (*Bos* spp.), sheep (*Ovis* spp.), and goats (*Capra* spp.) (Wood et al. 1987). On Assateague Island, feral horses affected the natural growth competition between *Spartina alterniflora* Loisel, and *Distichlis spicata* (L.) Green in salt marsh communities (De Stoppelaire et al. 2004).

Few natural communities of coastal barrier islands are fully intact, and overgrazing by wildlife (e.g., feral horses, feral pigs, and white-tailed deer) is of particular concern (Schafale and Weakley 1990, Rheinhardt and Rheinhardt 2004). Feral horses have been shown to alter the composition of entire communities through grazing and trampling. In estuarine communities, the diversity of fishes and birds was greater in ungrazed plots compared to plots grazed by horses (Levin et al. 2002). A simulated removal of *Spartina alterniflora*, a grass species often consumed by horses, resulted in reduced fish survival (Levin et al. 2002). Grazing can decrease the rate of succession from grassland habitats to

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scrub-shrub habitats, and can inhibit maritime forests from expanding (Wood et al. 1987). LIDAR surveys showing topographical differences in grazed and ungrazed plots indicate that horses led to a decrease in dune elevation, while ungrazed plots increased in elevation (De Stoppelaire et al. 2004). Feral horses may limit maximum plant height (Seliskar 2003, Rheinhardt and Rheinhardt 2004, Freedman et al. 2011) and preferential grazing by horses exerts pressure on palatable plant species, contributing to the alteration of species presence or abundance in salt marshes (Furbish and Albano 1994). In addition to grazing, horse trampling can impact fragile barrier island vegetation (Turner 1987, Rheinhardt and Rheinhardt 2004). Simulation studies on Cumberland Island National Seashore, Georgia, demonstrated that horse trampling had a greater impact than grazing alone (Turner 1987), as the trampling of soft, damp soil can degrade soil structure (Jensen 1985). Also, tidal freshwater marshes may experience significant horse disturbances in the spring when new plants are just beginning to flush (Rheinhardt and Rheinhardt 2004).

Feral pigs can impact vegetation as various plant structures (i.e., roots, bulbs, tubers, leaves, fruits, and seeds) compose the majority of the diet of feral pigs (Everitt and Alaniz 1980, Chimera et al. 1995, Adkins and Harveson 2006, Cuevas et al. 2010). In forest understories, species with diaspores greater than 250 mg were twice as abundant in the absence of feral pigs, indicating that feral pigs may have an effect on plant species composition (Siemann et al. 2009). Soil alterations by feral pigs can alter the native and exotic species composition and affect plant ground cover biomass (Cushman et al. 2004). Pig rooting behavior can lead to increases in tree root exposure and to decreases in soil nutrients, ground cover, and habitat suitability for some wildlife species (Singer et al. 1984).

Grazing and browsing by white-tailed deer can decrease local plant species survivorship, growth, and reproductive success (Boerner and Brinkman 1996, Waller and Alverson 1997, Ruhren and Handel 2003). Areas with larger white-tailed deer populations have lower plant species diversity within forest, wetland, and savannah sites (Urbanek et al. 2012). White-tailed deer grazing within maritime forests has the potential to negatively impact maritime forest regeneration. On the Outer Banks in particular, grazing, combined with increasing development, may accelerate maritime forest degradation (Sherrill et al. 2010). Furthermore, preferential browsing by high numbers of white-tailed deer has been linked to an increase in exotic plants (Eschtruth and Battles 2009).

From 2000 to 2010, the resident human population of Currituck County increased from about 18,000 to 23,500 (30%) (US Census Bureau 2010). Annual tourism to the Currituck National Wildlife Refuge (CNWR) adds an additional 25,000 visitors (US Fish and Wildlife Service [USFWS] 2008). Increases in human populations and property development may reduce the available habitat for wildlife, potentially resulting in increased grazing impacts in the remaining habitat (USFWS 2008).

In 2007, a management plan signed between the Corolla Wild Horse Fund, the County of Currituck, the North Carolina Coastal Reserve and National Estuarine Research Reserve (Department of Environment and Natural Resources), and the CNWR mandated that no more than 60 horses be present in the Currituck Outer Banks (Currituck National Wildlife Refuge 2007). The management plan called for the adoption, relocation, or use of horse fertility contraceptives to maintain the target population level. However, a recent aerial survey counted at least 121 horses on or in close proximity to the CNWR (M. Hoff, Currituck National Wildlife Refuge Manager, pers. comm.). In January 2013, Congressman Walter Jones reintroduced the Corolla Wild Horse Protection Act (H.R. 126), which, at the time of this publication, is awaiting review by the US House of Representatives. This legislation would require a minimum population of 110 horses and would allow for the introduction of horses from the Cape Lookout National Seashore to increase horse herd genetic diversity (US House of Representatives 2013, H.R. 126).

Management of wild horses has become controversial. While some groups support the protection of horses (e.g., Corolla Wild Horse Fund Inc. 2012), others view the horses as exotic species that compete with native species (e.g., USFWS 2008). Furthermore, although feral horses, feral pigs, and white-tailed deer have had documented negative impacts on plant communities, the effects at CNWR are unknown. Therefore, our objective was to quantify vegetation impacts by wildlife within different habitats at CNWR by determining number of disturbanc-

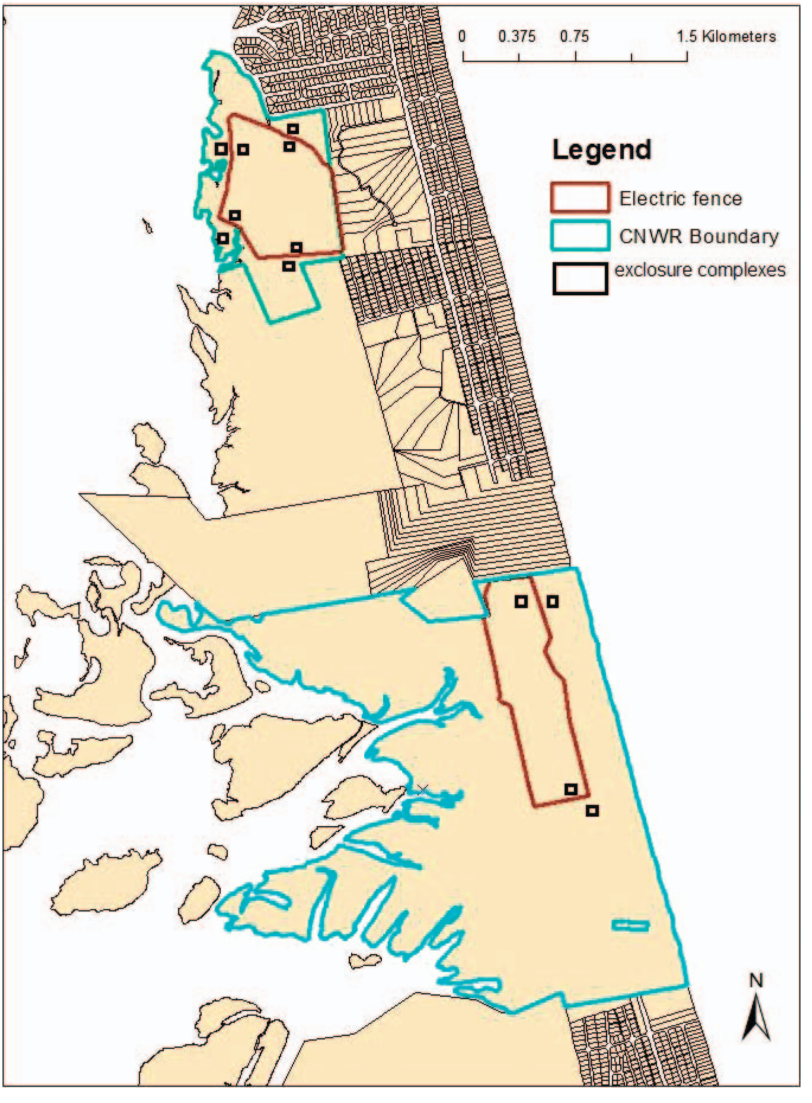

Figure 1. Currituck National Wildlife Refuge Station Landing Marsh Unit and Swan Island Unit, Currituck National Wildlife Refuge, North Carolina, 2010–2012.

es, overall biomass change, and plant daily growth.

MATERIALS AND METHODS

Study Area

The CNWR is an 1,850 ha refuge on North Carolina's Outer Banks barrier islands (Figure 1). The refuge is located 1.2 km north of Corolla in Currituck Co., North Carolina, and is composed of a variety of habitats, including evergreen maritime forests, fresh and brackish marshes, dune grasses, maritime dry and wet grasslands, and maritime shrub swamps (Schafale and Weakley 1990, USFWS 2008). The refuge serves to protect native wildlife, which may include threatened, endangered, or protected species such as piping plovers (*Charadrius melodus*), bald eagles (*Haliaeetus leucocephalus*), loggerhead sea turtles (*Caretta caretta*), and leatherback sea turtles (*Dermochelys coriacea*) (USFWS 2008). Also, the CNWR is used for hiking, bird watching, photography, and waterfowl and feral pig hunting. No trails, paved

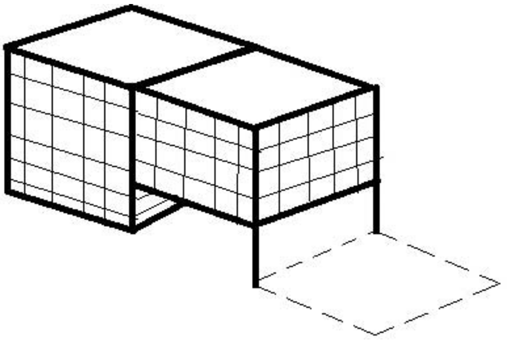

Figure 2. Three different 5 × 5 m plots; the first was a fenced exclosure 3 m high, the second a fenced exclosure raised 1 m above the ground and extended to 3 m, and the third, a control, was not fenced, Currituck National Wildlife Refuge, North Carolina, 2010–2012.

roads, or facilities are available within the refuge, and visitors may only enter the refuge on foot (USFWS 2008).

Experimental Design

In winter 2010, we established sampling sites in evergreen maritime forests, brackish marshes, maritime wet grasslands, and maritime dry grasslands. Within each habitat, an electric fence divided the area into two sections: one with horses and one without. Feral pigs and white-tailed deer were present in both sections. The electric fence to the north and all exclosure plots were erected in 2010; the electric fence further south was installed in 1994 (Figure 2). On each side of the electric fence within each habitat, we established three different 5 × 5 m plots (Figure 2). The first plot (complete exclosure) was a fenced exclosure 3 m high that excluded all focal wildlife species. The second plot (i.e., raised exclosure) was a fenced exclosure, raised 1 m above the ground and extended to a height of 3 m, allowing feral pigs and white-tailed deer to enter but not horses. The third plot (i.e., the control) was not fenced and marked only by boundary stakes. We created two replications for the brackish marsh and maritime forest habitats and one replication for the maritime wet grassland and maritime dry grassland habitats for a total of 12 sampling locations, which included 24 fenced exclosure plots and 12 unfenced control plots. Within each plot, we created two randomly placed 1 m transects. Within each transect, we randomly selected individuals from multiple possible plants of the same species by assigning each a color, and then drawing straws to determine which individual would be tagged. We made species diversity comparable for tagged plants by selecting prevalent species within a given habitat, thereby making all exclosures within a habitat comparable. We modified methodology of Siemann et al. (2009) and randomly selected and tagged branches of shrubs within an exclosure. We randomized branches to tag in the same manner as was done within the transects. All selected plants were tagged with numbered zip ties; herbaceous species were tagged at the base of the plant, woody species were tagged on particular branches. The total area represented by our combined 5 × 5 m plots was 900 m^2, which represents 0.049% of the total refuge size. Within these plots, the combined length of our sampled transects was 72 m.

Data Collection and Analyses

From May 2010 until May 2012, we collected monthly measurements on tagged plants including distance from base to tip of herbs and distance from branching point to terminal bud on woody plants in order to quantify grazing and browsing intensity. We recorded clear signs of wildlife disturbances that led to length reduction or disappearance of tagged plant (e.g., horse trampling, grazing or browsing with hoof marks present in the area, fecal piles, digging indicative of pigs, deer beds, and deer bite marks).

Past exclosure research has shown differential effects of animal disturbance on habitat and plant species (Seliskar 2003, De Stoppelaire et al. 2004, Freedman et al. 2011). Therefore, we compared plant disturbances between the sections where horses were excluded and those where horses were present. We collected data on the number of disturbances on tagged plants, and calculated the percentages of plants that were disturbed by wildlife for each side of the electric fence. Additionally, we examined which habitats experienced wildlife disturbances, how many disturbances occurred in each habitat, which plant taxa were most impacted, and the wildlife species responsible for the disturbances.

To determine plant growth rate, we only considered measurements collected in the growing season in a given year. We defined the starting point for the growing season as the first interval of growth for the particular plant and the ending point as first frost of the fall. Data for individuals with fewer than two observations

Table 1. Number of disturbances in the presence and absence of horses within three habitats, Currituck National Wildlife Refuge, North Carolina, 2010–2012

	Horses Present	Horses Absent	Total
Maritime forest	26	5	31
Brackish marsh	36	1	37
Maritime grassland	18	1	19
Total	80	7	87

within a growing season were omitted. Data on tagged plants that were browsed or shortened by natural events were included only if at least two undisturbed measurements were available prior to the event within the season. We excluded data from the maritime wet grassland for this analysis because of sampling problems (i.e., flooding). We used two separate one-way ANOVAs to compare growth rates among exclosure treatments where horses were present and where horses were excluded. If significant, we used a Tukey's HSD to determine differences among exclosure treatments. We used R 3.0 for these analyses (R Core Team 2012).

We calculated the total shoot length reduced due to wildlife disturbances by subtracting the length measurement at the date of the disturbance from the previous length measurement. To provide context of the significance of this disturbance to individual plants, we compared average length reductions to documented standard taxonomic maximum and minimum heights for the given plant taxa (Radford et. al 1968, Smith 2002). The calculations were as follows:

1. (total length reduction we calculated) / ([number of tagged individuals of a species disturbed] × [maximum known length of plant])
2. (total length reduction we calculated) / ([number of tagged individuals of a species disturbed] × [minimum known length of plant]).

RESULTS We tagged 1,105 plants: 288 in maritime forests, 492 in brackish marshes, and 325 in maritime grassland habitats. We detected 87 disturbances: 80 where horses were present, and 7 where horses were excluded (Table 1). We detected 37 disturbances in brackish marshes, which amounted to 42.5% of all disturbances found (Table 1). Among all habitats, we documented 18 plant taxa that experienced disturbances; 15 disturbances impacted *Schoenoplectus pungens* (Vahl) Palla, a common brackish marsh species, and 7 impacted *Vaccinium* spp. (Table 2). Fifty-nine disturbances (68% of all disturbances) impacted facultative, facultative wetland, or obligate wetland species. Of the disturbances to *S. pungens*, 60% were attributed to horses ($n = 9$), 13% to deer ($n = 2$), and 27% were due to unknown causes ($n = 4$). Overall, horses were responsible for 83% ($n = 72$) of all documented disturbances, white-tailed deer were responsible for 9% ($n = 8$), and 8% ($n = 7$) were due to unknown sources. We detected a significant effect of treatments on plant growth where horses were present ($F = 5.14$, $df = 2{,}421$ $p = 0.0063$); the raised exclosure ($p = 0.004$) and the complete exclosure ($p < 0.04$) were significantly different from the control, the complete exclosure was similar to the raised exclosure ($p = 0.60$). No differences were detected where horses were excluded ($F = 1.11$, $df = 2{,}406$, $p = 0.33$) (Figure 3).

The total length reduction for *S. pungens* was 4.43 m and the range of reduction was between 39.4% and 100% loss in biomass (Smith 2002). We detected a total length reduction of 0.59 m for *Vaccinium* spp., which indicated a biomass loss between 2.4% to 12.5% (Radford et al. 1968).

DISCUSSION The presence of feral horses can lead to significant impacts on vegetation and habitat structure (Jensen 1985, Turner 1987, Seliskar 2003, De Stoppelaire et al. 2004, Rheinhardt and Rheinhardt 2004, Freedman et al. 2011). Our study demonstrated a marked increase in disturbances where horses were present compared to areas where they were excluded. Additionally, horses may have been responsible for six of the seven disturbances in the excluded area due to a two-week power outage. We detected few disturbances from white-tailed deer and none from feral pigs.

Our results indicated that treatment had a positive effect on growth of vegetation on the side of the fence where horses were present. A similar study focusing on the vegetation of primary sand dunes showed significant differences in plant growth measurements inside and outside of exclosures (Seliskar 2003). However, in our study, treatments were located in areas where horses were present and excluded. No significant treatment effect was detected where horses were excluded, suggesting that horses were primarily responsible for the plant growth

Table 2. Number of wildlife disturbances by plant taxon and the Southeast wetland indicator status, Currituck National Wildlife Refuge, North Carolina, 2010–2012

Taxa	Number of Disturbances	Wetland Indicator Status (Southeast)[a]
Schoenoplectus pungens	15	OBL
Unknown grass	13	
Vaccinium spp.	7	FACU, FACW
Juncus spp.	6	FACW, OBL
Typha spp.	6	OBL
Distichlis spicata	5	FACW+
Rhynchospora spp.	5	FACW, OBL
Spartina patens	5	FACW
Baccharis halimifolia	4	FAC
Dichanthelium spp.	4	FACU, FAC
Eupatorium spp.	3	FACU, FAC, FACW
Carex spp.	2	FACU, FAC, FACW, OBL
Chasmanthium spp.	2	FACW−
Sagittaria lancifolia	2	OBL
Centella asiatica	1	FACW
Hydrocotyle spp.	1	FACW, OBL
Iva frutescens	1	FACW+
Pinus taeda	1	FAC

[a]OBL: Obligate wetland, almost always is a hydrophyte, rarely located in uplands;.FACW: Facultative wetland, usually a hydrophyte but occasionally found in uplands; FAC: Facultative, commonly occurs as either a hydrophyte or nonhydrophyte; FACU: Facultative upland, usually in nonwetlands but occasionally in wetlands; UPL: Obligate upland species; almost always occurs in nonwetlands.

The positive sign indicates that taxon is more frequently located in wetlands. The negative sign indicates less frequently (USFWS 1988). When a taxon was not identified to species, wetland indicator statuses were taken from all species known to exist in the Outer Banks.

differences. Future monitoring of exclosures and control plots would be useful to further document these differences.

Some of our electric fences and all of the exclosures were created only months before monitoring began and, prior to that time, horses, pigs and white-tailed deer had access to the entire refuge and likely impacted vegetation throughout the refuge. Past studies have shown that *S. pungens* decreased in total biomass and in growth when the rhizomes of mother and daughter clones were cut and a complete year was necessary after the cutting was discontinued for the effects to cease (Poor et al. 2005), suggesting that a full year is necessary for this species to recover. Vascular plants may take several years to recover after a period of intense herbivory (Henry and Gunn 1991, Manseau et al. 1996, Crête and Doucet 1998, Hansen et al. 2007). Despite the short time period between the end of the fence construction and the start of our sampling, we documented significant differences in plant growth between treatments in areas where horses were present. This is remarkable because the vegetation in horse-excluded sections likely had not fully recovered when sampling began. Additionally, our exclosure plots accounted for less than 1% of the entire refuge. Therefore, it is likely that we only captured a small part of the overall impact from horses and only a fraction of difference to be expected as the area's exclusion history lengthens.

Other studies documented horse impact on various marsh habitats including salt marshes, tidal freshwater marshes (Furbish and Albano 1994, Rheinhardt and Rheinhardt 2004), grasslands (Rheinhardt and Rheinhardt 2004, Freedman et al. 2011), and sand dunes (Seliskar 2003, De Stoppelaire et al. 2004). Although many habitats may be impacted by wildlife, marshes may be particularly susceptible to degradation as marsh soil is soft and easily affected by trampling (Jensen 1985). In our study, brackish marshes received the highest number of disturbances of all three habitat types. *Schoenoplectus pungens* received the highest number of disturbances of all plant taxa monitored. We believe that loss of biomass should be considered when making further management decisions. Demographic studies may be useful in modeling the impact on *S. pungens*, and the overall impact on marsh species diversity and abundance over time.

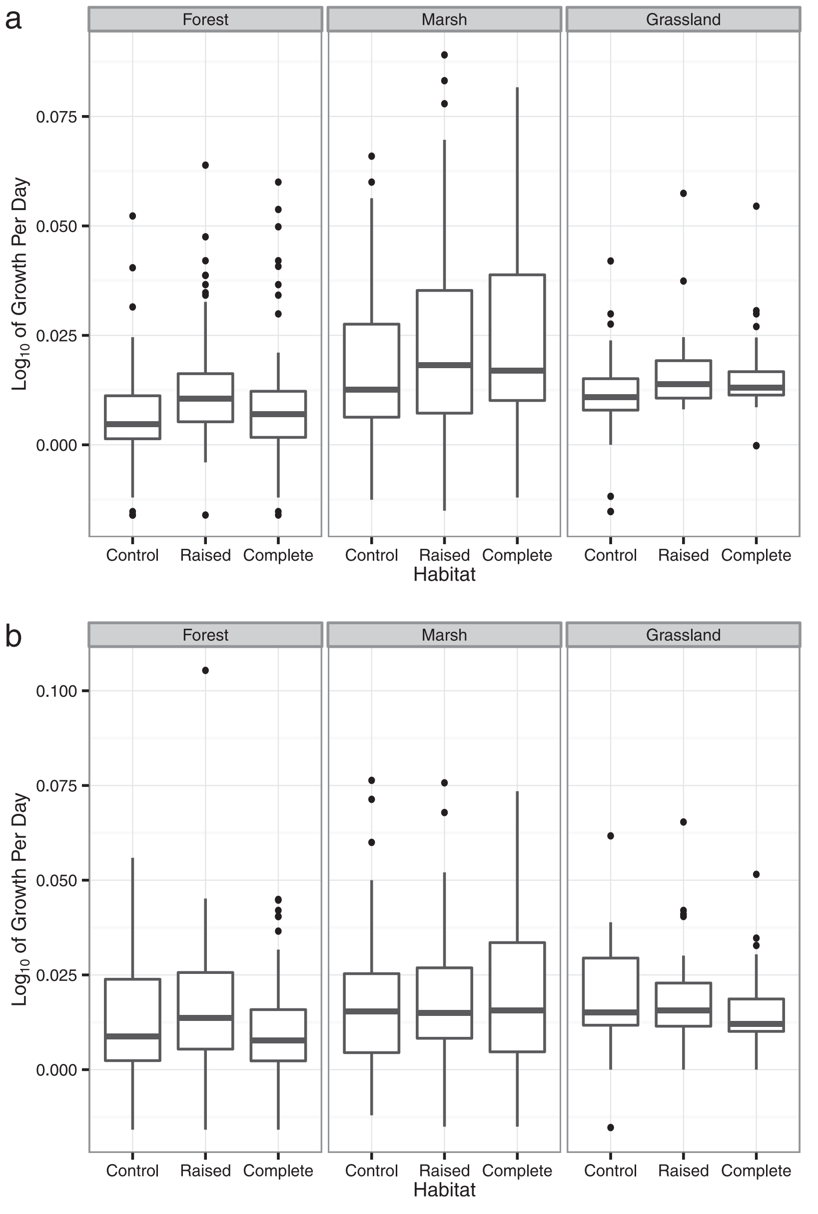

Figure 3. Comparison of daily growth in forest, brackish marshes, and grassland habitats for control plots, raised exclosures and complete exclosures where (a) horses were present, effects of treatments are significantly different ($F = 5.73$, $df = 2$, $p = 0.0035$); (b) horses were excluded, effects of treatment were similar ($F = 1.14$, $df = 2$, $p = 0.32$), Currituck National Wildlife Refuge, 2010–2012.

Overall, the number of disturbances was low when considering the total number of tagged plants, which has raised questions about how likely horses are to use the land in close proximity to our exclosures. Horses are known to have defined home ranges and groups of horses may spend months or years within these boundaries (Miller 1983, McCort 1984). Seasonal changes that affect food quality and water availability may contribute to movements of horses within their home ranges and to the habitats used in a given season (Miller 1983, McCort 1984). Hence, focal horse studies would be valuable in elucidating horse habitat use, distribution, movements, and activity budgets on CNWR. Additionally, there is a lack of research documenting ungulate behavior in the presence of fences, especially in areas large enough for wildlife to avoid structures altogether. Demographic data are needed so that trends can be modeled. In the future, cameras may be useful in monitoring wildlife to determine if exclosures are altering horse, pig, or white-tailed deer behavior. Also, human dimension studies may provide a more complete picture about how local residents and tourists view the horses.

SUMMARY Where horses were present, we documented a negative impact to plants and their growth rates. Brackish marshes received the highest number of disturbances. *S. pungens*, a prevalent marsh species, experienced the highest number of disturbances and, when disturbed, lost up to 100% of its biomass. Based on our research, we recommend that exclosure plots and electric fences be maintained and monitored in all habitats, and that additional efforts be made to exclude horses from brackish marshes wherever possible.

Although our study was conducted over a short time period and our study area represented less than 1% of the refuge, we were able to document differences in plant growth between treatments in areas where horses were present. Further, we believe we only captured a small part of the overall impact from horses. We believe the number of disturbances by horses and effect of horses on plant growth would likely increase with an increase in horse population levels. Conversely, we would anticipate a decline in the number of disturbances and effect of horses on plant growth if the horse population were reduced. Additionally, we believe that many tourists are interested in simply catching a glimpse of the horses, and, like other areas containing populations of free roaming horses, high population levels may perpetuate the view of these animals as nuisances (Rubenstein 2001). Therefore, we recommend decreasing the number of horses to reduce habitat damage and to ensure that sightings are appreciated by the public and viewed as a novelty.

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