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SHORT COMMUNICATION

Nutria Grazing Preference as a Function of Fertilization

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Abstract In Louisiana, subsiding wetlands frequently receive diverted fresh river water, which contains nutrients, stimulates vegetative growth, and may increase vertical accretion via vegetative growth. When river water is introduced, varying nutrient and salinity concentrations are produced. These varying conditions within marshes probably influence the feeding habits of herbivorous animals because of a preference for vegetation high in nutrients and low in salinity. Nutria (*Myocastor coypus*), a large introduced rodent, can negatively affect wetlands. We speculate that, driven by a biological need for nitrogen, nutria may affect treated wetlands more than untreated wetlands. Therefore, we sought to determine if wild-captured nutria preferred fertilized versus unfertilized plants of the following species: *Panicum hemitomon* Schult., *Sagittaria lancifolia* L., and *Spartina patens* (Aiton) Muhl. Nutria showed a significant preference for fertilized over non-fertilized samples, potentially caused by nutrient-driven increases in the nitrogen concentrations of fertilized plants, changes in the carbon to nitrogen ratio within plant tissue, and the universal animal need for biologically available nutrients to maintain homeostasis. Preliminary findings may partially explain observations of reduced plant abundance where elevated levels of nutrients are introduced to nutrient-limited wetlands, possibly necessitating a re-examination of proposed diversion implications and focusing nutria control efforts in such places.

Keywords Herbivory · Diversion · Nutrient · Nitrogen · Fertilization · Wetland

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Introduction

Since their introduction to Louisiana in the 1930s, nutria have significantly affected coastal vegetation (Shaffer et al. 1992, Grace and Ford 1996, Evers et al. 1998, Shaffer et al. 2009). They are voracious grazers (Baroch and Hafner 2002) and reports of private and public land damages are widespread (LDWF 2007). Nutria populations in coastal Louisiana are limited neither by the seasonal droughts or extended frosts of their indigenous South American steppe habitat (Ehrlich 1967), nor constrained by a fixed breeding season (Atwood 1950). Consequently, the species is capable of extremely rapid population growth and by the early 1950s the statewide population estimate was 20 million animals (Carter et al. 1999, Baroch and Hafner 2002, Jojola et al. 2005, LDWF 2007). Although a viable commercial trapping industry historically took advantage of large nutria populations, by the 1980s pelt prices were greatly reduced and trapping diminished (Jojola et al. 2005). Coastal land damage increased as nutria populations exploded in the wake of weakened controlling pressures, with an aerial survey in 2001 estimating more than 83,000 acres damaged by nutria (Marx et al. 2003, Jojola et al. 2005). In 2002, the Louisiana Department of Wildlife and Fisheries instituted the Coastwide Nutria Control Program (CNCP) (Marx et al. 2003, Jojola et al. 2005, Dedah et al. 2010), a geographically targeted harvest incentive program, offering US$4/nutria tail (US$5/tail beginning in 2006) (Dedah et al. 2010). Within 5 years of the CNCP implementation, herbivory damage decreased by 50 % statewide and annual nutria harvests increased from 24,683 to 375,683 animals (Scarborough and Mouton 2007); after the 2011–2012 trapping season, 354,354 nutria were harvested and vegetation surveys found affected coastal marsh reduced to 1,129 acres (Hogue and Mouton 2012).

Robust wetland systems are vital to the sustainability of coastal human populations because they provide habitat to numerous wildlife and plant species, support an economically valuable recreation industry, and render important ecological functions such as storm surge protection and wastewater filtration (Day et al. 1995, Spalding and Hester 2007). Although the CNCP has increased control over herbivory and its associated wetland destruction, marsh loss is estimated at 42.9 km^2 yr^{-1} and predicted to continue (Couvillion et al. 2013), thus remaining an important issue in coastal Louisiana. Therefore it is of interest that certain wetland management practices may affect vegetation palatability to herbivores, thus altering risk of herbivory.

For example, there currently is an increasing emphasis on restoration methods which include re-establishing connectivity between the Mississippi River and its floodplain by diverting water from the river into the surrounding marsh (Lane et al. 1999, Lane et al. 2006, Hyfield et al. 2008). In addition to beneficial fresh water and mineral sediments, Mississippi River water also contains nutrients from such anthropogenic sources as upstream agricultural runoff of animal manure, eroded soils, pesticides and fertilizers (Goolsby et al. 1999). Although levels of suspended nutrients are relatively low, high river volume transports a correspondingly high nutrient load to affected wetlands. For example, while nitrate levels passing through the Caernarvon diversion into Breton Sound range from 1 to 2 mg N L^{-1}, maximum allowable flow is 280 $m^3 s^{-1}$, and yearly total N loads are approximately 10 g N m^{-2} yr^{-1} (Lane et al. 1999, 2004, Mitsch et al. 2005).

Many emergent wetlands offset local subsidence and global sea-level rise with vertical accretion via vegetative production (Nyman et al. 2006), and vegetative production in wetland systems may be positively affected by nutrient input and lowered salinity (Merino et al. 2010, Morris et al. 2013). However, there also is evidence that marsh herbivores prefer lower salinity habitats over higher salinity habitats (Nyman et al. 1993) and that wetland herbivores prefer vegetation with higher nitrogen content over vegetation with lower nitrogen content (Alisauskas et al. 1988). Thus, herbivory may have a greater effect on marshes within the low salinity, nutrient-rich end of the spectrum.

Wetlands directly northwest of Lake Cataouatche, Louisiana, have received nutrient-rich Mississippi River water via the Davis Pond diversion since 2002, and Four Mile Marsh, within the Joyce Wildlife Management Area, has been the site of secondarily treated municipal effluent from the city of Hammond, Louisiana, since fall 2006. Both sites are examples of nutrient enriched wetlands that support nutria populations which have affected surrounding marsh since nutrient inputs began (Lundberg et al. 2011, Baker, personal communication 2012). Consequently, we sought to test the hypothesis that nutria selected vegetation within a species grown in higher nutrient concentrations over vegetation within that species grown in lower nutrient concentrations. The *ex situ* implication of this research is that if the presence of high nutrient levels potentially influences the feeding habits of nutria, it is then possible that increased herbivory may in turn degrade wetlands most affected by river diversions and assimilation wetlands.

Methods

We collected *Panicum hemitomon* Schult., *Sagittaria lancifolia* L., and *Spartina patens* (Aiton) Muhl, plants that are all identified as dominant species within their marsh type, eaten by nutria in the wild and representative of nutria habitat across a salinity range. *P. hemitomon*, which historically made up over 25 % of freshwater marsh vegetation and 9 % of total Louisiana wetlands (Chabreck 1970), was grazed considerably by nutria in exclosures in Terrebonne Parish (Holm Jr et al. 2011). We gathered it from an unnamed freshwater marsh outside Houma, LA. *S. lancifolia* is the most widespread fresh-brackish marsh plant in the northern Gulf of Mexico, can constitute a large part of nutria diet (Linscombe and Kinler 1997) and was gathered along the northern shore of Lake Cataouache, east of the Davis Pond diversion outflow and outside of its influence. *S. patens*, widely dominant in brackish marshes within the brackish marsh salinity limit of nutria habitat (Baroch and Hafner 2002, Jojola et al. 2005), is palatable to nutria under certain circumstances (Chabreck 1981, Wilsey et al. 1991) and was gathered within Rockefeller Wildlife Refuge in Chenier, LA.

Plant samples were transported to the Louisiana State University greenhouse, where they were transplanted immediately into 15 cm, open-flow plastic pots using landscaping sand substrate. Potted plant samples were placed within 6 individual 2 m diameter plastic wading pools, such that each pool contained 30 pots, and each plant species occupied two pools. In determining appropriate nutrient fertilization rates, it was decided that the importance of maximizing difference in treatments outweighed that of approximating previously established loading rates. One pool of each plant species was then fertilized at 0.9 g N m^{-2} d^{-1} with Miracle-Gro All Purpose Plant Food (Scotts Miracle-Gro Products, Marysville, OH) for a period of 68 d with a final total loading of 61.9 g N m^{-2}, resulting in 30 fertilized and 30 non-fertilized samples of each species. Samples were observed daily for yellowing leaves, browning of leaf margins, excessive algal blooms, or other indications that nutrient concentrations were approaching toxic levels. We temporarily suspended nutrient additions when nutrients appeared to be causing toxicity. We supplied all pools with municipally sourced fresh water, maintained at just below sediment level and constantly circulated by Mini-jet 404 submersible pumps (Marineland United Pet Group, Blacksburg, VA) to ensure homogeneity of nutrient concentrations.

From 10 June 2010 to 27 June 2012, seven adult nutria were live-trapped in the artificial ponds of the Louisiana State University aquaculture center with three Havahart large one-door easy set traps (Woodstream Corporation, Lititz, PA) using sweet potato fragments as bait in obviously nutria-grazed areas. The nutria were housed in two 4 m × 2.5 m pens in the Louisiana State University Veterinary Medicine Center and fed a diet of sweet potatoes and commercial rodent chow by employees of the Veterinary Medicine Center. Individual nutria were identified by colored plastic neck collars and medical attention was administered on an as-needed basis.

Feeding trials were conducted nightly when nutria are believed to feed most often. Individual plant-pot samples were removed from growing pools 24 h prior to the trial and weighed 24, 12 and 0 h before the trial to account for water loss. One fertilized and non-fertilized sample of that particular trial's target species was placed in a 4 m × 2.5 m trial pen, the 15 cm pots set 0.5 m away from three walls and each other at the end of the trial pen. The 15 cm pots were set within standard concrete blocks to prevent overturning but still allow nutria to mimic natural foraging. An individual nutria was then removed from the holding pens, introduced into the trial pen and left overnight for a period of 12 h, after which the plant-pot samples were immediately weighed again. The nutria were not starved before the trials, and the location of the fertilized and unfertilized pots was alternated randomly before each trial to minimize habitual feeding. Pre- and post-trial plant mass was used as an indicator of damage; actual material ingested was not measured because potential marsh damage could include indirect vegetative destruction as well as consumption. Pre- and post-trial plant mass loss was calculated as percent mass lost in an effort to reduce bias; for example, larger plants might lose more raw mass than smaller plants. One nutria died in captivity after only two trials, and those trials were discarded. Five remaining nutria were each offered a choice of fertilized and unfertilized samples of each plant species three times over 54 d, from July 27 to September 21, 2012. One remaining nutria was offered the same choice of fertilized and unfertilized *S. lancifolia* and *S. patens* over the same time period but not *P. hemitomon* because by this time, our *P. hemitomon* samples had become senescent and no longer useable.

Initial analysis of residuals in the raw data indicated that the data were not normally distributed, which we attribute to a small sample size. A log transformation greatly improved normality, and we then modeled percent plant loss as a function of the fixed effects of fertilization and plant species, measured in percent mass lost over the course of each trial, analyzed as a two-way ANOVA using nutria as a random effect in PROC MIXED (SAS Institute, Inc., Cary, NC). Results were then back-transformed and presented with the 95 % lower confidence interval (LCI) and upper confidence interval (UCI) in parentheses. All research was conducted in accordance with Animal Welfare Act regulations, the United States Department of Agriculture, Animal and Plant Health Inspection Service, and the Louisiana State University Agricultural Center. The Louisiana State University Division of Laboratory Animal Medicine's Institutional Animal Care and Use Committee approved the study protocols, under which the animals were ultimately euthanized.

Results

Fertilization had a significant effect on the percent mass of vegetation lost through nutria herbivory ($F_{1,4}=36.8$, $P<0.0001$) in all plant species (Fig. 1). Across the three plant species, fertilized vegetation experienced an overall mean mass loss of 79.4 % (LCI 63.1, UCI 100.0), as compared to 9.3 % (LCI 7.4, UCI 11.7) in unfertilized vegetation. The mean carbon content of fertilized plant samples was 42.9 % (0.6), the mean nitrogen content was 2.2 % (0.2), and the mean C:N was 19.8. The mean carbon content of unfertilized plant samples was 44.4 % (0.3), the mean nitrogen content was 0.91 % (0.1), and the mean C:N was 48.8.

Species also had a significant effect on the percent mass of vegetation consumed by nutria ($F_{2,\ 3}=9.5$, $P=0.0008$). The mean percent mass lost by *S. patens* was significantly less than the other two species (Fig. 1). *S. lancifolia*, which had a mean C:N of 18.0, experienced the greatest consumption with a mean mass loss of 50 % (LCI 39.8, UCI 63.1). This was followed by *P. hemitomon*, which had a mean C:N of 35.3 and had a mean mass loss of 31.6 % (LCI 25.1, UCI 39.8). *S. patens*, which had a mean C:N of 41.1, experienced the least reduction and had a mean mass loss of 10 % (LCI 7.9, UCI 12.6). In our fertilized samples, nutria did not greatly differentiate between *S. lancifolia* and *P. hemitomon*, but there was significant difference in percent mass lost between these species and *S. patens*. Nutria consumed more *S. lancifolia* and *P. hemitomon* than fertilized *S. patens*, even as fertilization lowered the mean C:N of *S. patens* to slightly below that of *P. hemitomon*. As the mean C:N was quite close in fertilized samples of *P. hemitomon* and *S. patens* (25.3 and 24.8, respectively), the distinction between the two species may lie in N:P ratios of 7.4 and 5.7, respectively (Table 1).

In the log transformed model, the species-fertilization interaction term was not significant ($F_{2,\ 3}=1.5$, $P=0.24$). In non-transformed raw data, fertilized *P. hemitomon* was reduced by a mean of 11.1 % (3.4) and unfertilized by 0.9 % (3.0). Fertilized *S. lancifolia* was reduced by a mean of 12.0 % (2.8) and unfertilized was reduced by 3.0 % (2.7). Fertilized *S. patens* was reduced by 5.8 % (2.9) and unfertilized was reduced by 0.19 % (3.1). Order of preference of plants consumed, in both fertilized and unfertilized samples, was *S. lancifolia*, *P. hemitomon*, and *S. patens*.

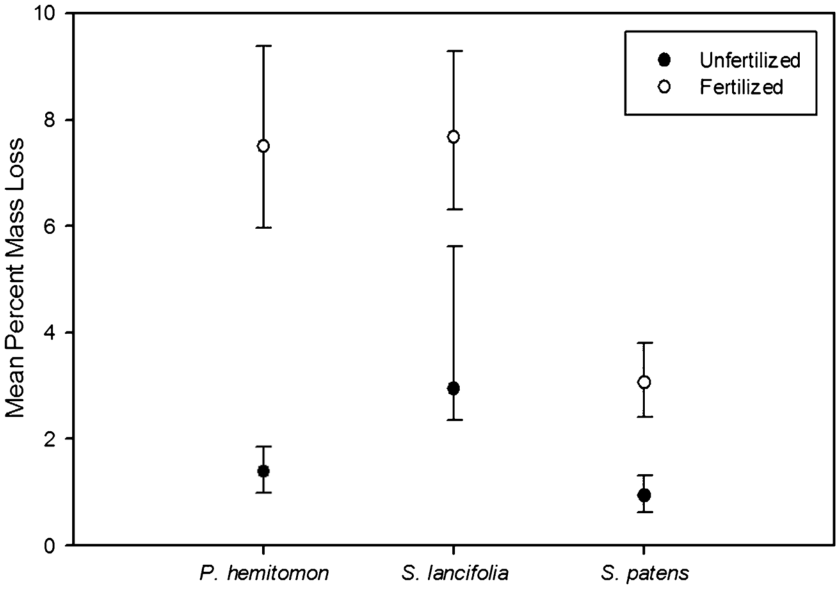

Fig. 1 Mean percent mass loss of fertilized and unfertilized plant samples with one standard error of the mean, plotted by species

Discussion

Animals require nitrogen and phosphorous to maintain growth, reproduce, and survive (White 1978, Mattson 1980); therefore grazing animals select vegetation containing the highest relative source of these elements within a fixed intake (Gurchinoff and Robinson 1972, Westoby 1974, White 1978, Mattson 1980). Our experimental results, in which nutria caused significantly greater percent mass loss to fertilized versus unfertilized samples of *P. hemitomon*, *S. lancifolia*, and *S. patens*, are consistent with previously researched behavior. By increasing the concentration of biologically available nutrients in the tissues of fertilized plants, the ratio of carbon to nitrogen and carbon to phosphorus dropped significantly and the palatability of those plants to nutria rose. As carbon is generally in excess in terrestrial systems (Elser et al. 2007) and N and P limit consumers bodily homeostasis (Anderson et al. 2005), these ratios may provide a means of assessing the relative desirability of varied vegetation.

As noted earlier, nutria consumed more *S. lancifolia* and *P. hemitomon* than fertilized *S. patens*, even as fertilization lowered the mean C:N of *S. patens* to slightly below that of *P. hemitomon*. Higher N:P is typical of the fresher marsh (Baroch and Hafner 2002, Ngai and Jefferies 2004) that makes up the majority of nutria habitat, and observed lack of interest in *S. patens* despite relatively high N levels may reflect a lesser relative nutritional importance of P to N in our controlled trials.

Percent mass lost in unfertilized samples followed similar C:N and C:P trends. While nutria inhabit and feed extensively in both fresh and fresh-brackish marsh (Linscombe and Kinler 1997, Holm Jr et al. 2011), abundance data indicate their general preference is for fresher marsh vegetation over more saline (Kinler et al. 1998). Preference is defined as the selection of certain habitats independent of availability (Silvy 2012), and this preference is potentially due to the decreasing availability of biologically accessible N in saline environments (Baroch and Hafner 2002, Ngai and Jefferies 2004). As in fertilized samples, *S. lancifolia* had both the lowest C:N and C:P; nutria may have consumed more of it because it supplied necessary nutrients most efficiently.

Our findings support previous research showing that the palatability of certain food sources to various grazing herbivores can be affected nutrient addition. In examining the interactions of plant carbon, nutrient balance, and herbivory, Bryant (1987) observed that snowshoe hares (*Lepus americanus*) prefer fertilized over unfertilized feltleaf willow (*Salix alaxensis*). Similar results also were observed by

Table 1 Mean nutrient concentrations of fertilized and unfertilized plant species reported in percent content of carbon, nitrogen, and phosphorous with respective sample standard deviations of the mean included in parentheses

Fertilized						Unfertilized				
Species	C	N	P	C:N	N:P	C	N	P	C:N	N:P
P. hemitomon	44.98 % (1.26)	1.78 % (.69)	.24 % (.06)	25.27	7.42	44.7 % (.87)	.75 % (.17)	.09 % (.03)	59.60	8.33
S. lancifolia	38.23 % (1.11)	2.88 % (.53)	.51 % (.08)	13.27	5.65	41.9 % (.06)	1.58 % (.19)	.24 % (.03)	26.54	6.58
S. patens	43.38 % (1.20)	1.83 % (.13)	.32 % (.12)	24.80	5.72	46.7 % (1.28)	.41 % (.06)	.05 % (.02)	113.90	8.2

Hartley et al. (1995), in which Orkney voles preferentially grazed Sitka spruce (*Picea sitchensis*) seedlings with increased N concentrations. Morris et al. (2002) found that *Spartina alterniflora* that had been treated with additional N was preferentially consumed by rice rats (*Oryzomys palustris*).

Shaffer et al. (2009) and McFalls et al. (2010) observed that nutria significantly reduced biomass of fertilized plots in which herbivory was allowed, and Lundberg et al. (2011) observed nutria first and in large numbers in zones nearest the nitrogen-rich effluent inflow while examining a wastewater treatment wetland. However, because Lundberg et al. (2011) did not ascertain whether nutria presence nearest the nutrient source was merely a result of increased vegetation growth and did not include an unfertilized control, their observations, while informative, are inconclusive. Similarly, Shaffer et al. (2009) and McFalls et al. (2010) noted that, with fertilization, vegetation biomass increased only in exclosures where herbivory was absent, suggesting but not isolating the effects of nutrient addition to nutria feeding preference. Wilsey et al. (1991) concluded that N content affected nutria preference among plant species, while our research extends their conclusions to address nutria preference within plant species as well.

We believe the distinction that the nutria made among our samples was based on the chemical content. Because chemical content of vegetation can change with factors such as season and plant life stage, both at the stand and individual plant level, it is possible that associated herbivory also would vary. For example, research shows that while vegetation incorporates N at higher levels early in the growing season (Harper 1971, Valiela et al. 1976, Tobias 2010), by maximum growth the C:N ratios began to increase, regardless of previous nutrient input or the ultimate size of the plant; C:N ratios of fully grown fertilized and unfertilized plants trend toward comparable concentrations (Patrick and DeLaune 1976). Additionally, as water volume is greatly seasonally variable (Hyfield et al. 2008), elemental ratios within diversion-managed marsh vegetation are likely in constant flux. Tobias (2010) also showed that C:N, within fixed nutrient supplies, can vary with salinity. Therefore, depending on localized pre-existing background conditions, herbivory may be asymmetrically distributed within an affected area.

In practical terms, our nutrient loading fell between the rates of secondarily treated municipal wastewater (0.21 g^{-2} d^{-1}) entering the Joyce Wildlife Management Area in Hammond, La, (Lundberg et al. 2011) and the most nutrient-rich Santa Ana river water (5.75 g N m^{-2} d^{-1}) entering a treatment wetland in the Prado Basin CA, prior to groundwater recharge (Reilly et al. 1999). Therefore, our experimental nutrient levels reflect current conditions in some areas and so are useful for inferring effects in the wild.

Nutria herbivory is a widely studied problem in the Mississippi Delta, and as such, successful measures have recently been enacted to minimize it (Scarborough and Mouton 2007, Hogue and Mouton 2012). However, a correlation between increased fertilizer concentrations and preferential feeding habits has implications for both current nutria management and wetland restoration efforts. For example, the nutria harvest program currently limits the area in which hunters can take advantage of financial incentive to keep animal numbers low; an awareness of the connection between nutrient influx and increased herbivory might necessitate a reexamination of the geographical targets of the program. Additionally, a more complete assessment of the risks and benefits of treating wetlands with nutrient infused water might further inform current commentary on wetland restoration methods. For example, in assessing the efficacy of three Mississippi River diversions in post-Katrina restoration, Kearney et al. (2011) noted that vegetation disturbance in zones closest to the diversions was noticeably greater than reference areas, however they did not include the possibility of nutrient-induced herbivory in their analysis. By identifying areas at greater risk of a nutrient-induced herbivory, such as sites of agricultural runoff, sewage treatment outflows, and river diversion sources, selective assessment and management can better address a restrictive hindrance to restoration efforts.

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