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SHORT COMMUNICATION

Non-Destructive Estimation of Aboveground Biomass in Sawgrass Communities of the Florida Everglades

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Abstract The preservation, restoration, and management of ecologically sensitive wetland plant communities, such as found in the Florida Everglades, require methods to reliably and non-destructively assess their health and performance. The pin-intercept method is a technique commonly used in grasslands for non-destructively estimating aboveground plant biomass. In this study, we developed an algorithm for the estimation of aboveground sawgrass biomass using coupled pin-intercept and harvest methods at A.R.M. Loxahatchee National Wildlife Refuge. Our data illustrates a positive relationship between aboveground biomass and the frequency of pin-intercepts as well as leaf area for sawgrass (*Cladium mariscus*). This pin-intercept method will serve as an effective, reliable tool for conservation and land management efforts in graminoid-dominated wetlands.

Keywords Pin-intercept method · Non-destructively sampling · Carbon · Net primary production

Introduction

Wetlands like the Florida Everglades provide critically important ecosystem services including wildlife habitat, water filtration and storage, and carbon sequestration (Zedler and Kercher 2005). In particular, the Florida Everglades recharges the Biscayne aquifer, the primary source of fresh water for high-population areas of south Florida (Lodge 2004), making it incredibly important not only ecologically, but socially and economically. Approximately 50 % of the historic Everglades remain intact (McPherson et al. 1976) due to human disturbances such as urban and agricultural development (Birnhak and Crowder 1974), nutrient pollution (Childers et al. 2003), fire suppression, species invasion, and water management (White 1994) degrading or destroying vast expanses of the Everglades. As a result, the Comprehensive Everglades Restoration Plan was enacted in 2000 to restore the Everglades watershed, making it the largest restoration initiative in the United States (www.evergladesplan.org). A number of state and federal agencies are conducting research and monitoring activities to better understand the drivers of the Everglades structure and function to inform restoration and management decisions. Given the logistic and funding constraints of these research and monitoring efforts, there is a need for rapid, non-destructive methods for quantifying key ecosystem metrics.

Plant biomass is often used to evaluate ecosystem function for land management (Guo and Rundel 1997), as it can provide a straight-forward metric of plant community health as well as standing fuel load for fire management decision-making. Biomass data collection methods are traditionally obtained by physically clipping and collecting the vegetation, which can have several negative consequences. Destructive clipping is time consuming and labor intensive, limiting the extent and frequency of sampling. Additionally, harvesting of biomass may not be feasible or permissible in remote locations or protected areas, particularly biodiverse ecosystems with rare or threatened species. Hence, a more efficient, non-destructive method for estimating biomass and productivity is highly useful for wetland monitoring and assessment.

The pin-intercept method is an inexpensive method for estimation of aboveground biomass requiring little training or equipment, and it can be assessed repeatedly or at high spatial frequency. This method has been used frequently in graminoid-dominated ecosystems such as terrestrial grasslands (Bråthen and Hagberg 2004; Glatzle et al. 1993). By relating standing plant biomass to the frequency of

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intersections between leaves and a vertical pin extending through the plant canopy within a set of reference plots, a predictive algorithm can be generated for estimating aboveground biomass in future plots without the need for destructive harvesting (Jonasson 1988; Tadmor et al. 1975).

In this study, we developed a regression algorithm for estimating standing biomass and leaf area in communities dominated by sawgrass (*Cladium mariscus* (L.) Pohl ssp. *jamaicense* (Crantz) Kük) in the Florida Everglades to aid in ecosystem monitoring in this ecologically sensitive wetland landscape.

Methods

Study Area

This study was conducted at Arthur R. Marshall Loxahatchee National Wildlife Refuge (the Refuge henceforth) located in Boynton Beach, FL and managed by the U.S. Fish and Wildlife Service and the South Florida Water Management District. The Refuge (aka Water Conservation Area 1) is approximately 60,000 ha located in the northern section of the Everglades wetlands, and it is most closely representative of conditions in the historic northern Everglades marshes. Like the majority of the freshwater Everglades, the landscape of the Refuge is a mosaic of raised tree islands, emergent ridges, and inundated sloughs. Sawgrass dominated ridges comprise approximately 70 % of the Everglades (McPherson et al. 1976) and account for approx. 25 % of the Refuge land cover. These communities are primarily a monoculture of sawgrass (approx. 93 % ground cover) with mixed low abundance species in the understory (e.g., *Pontederia cordata, Rhynchospora tracyi, Utricularia* spp.; Jordan et al. 1997).

Sampling Method

We collected pin-intercept frequencies and destructively harvested aboveground biomass from 26 randomly located 1-m^2 plots in sawgrass-dominated communities (defined by having ≥50 % sawgrass cover) of the northern Refuge. Within each plot a 6.4 mm dia., 2.13 m tall pin (tent pole) was dropped through the vegetation canopy vertically at a 90° angle to the water surface in 15 random points throughout the plot. The number of contacts made between the pin and intersecting vegetation was recorded and were partitioned among major physiognomic groups; graminoid (grasses and sedges), woody (broadleaf perennial with woody stem), or herbaceous (broadleaf forbs). All vegetation contacts were included, regardless of whether or not the plants were rooted within the plot, to best approximate standing biomass per unit area.

Following pin-intercept sampling, the aboveground biomass was harvested from each plot. Vegetation within the plot was clipped at the waterline and stored in plastic bags before being transported to the lab for processing. Out of concern for damaging plant meristematic tissue and compromising vegetation recovery in the Refuge, the vegetation was clipped at the waterline, which was consistent and unbiased across the sample plots (approx. 10–15 cm water depth). As a result, our biomass values represent a conservative minimum biomass for expanded aboveground foliage. The biomass was separated by plot into the three groups (graminoid, woody, and herbaceous), and cumulative leaf area was measured for each plot using a high through-put leaf area meter (LI-3300; LiCor, Inc., Lincoln, NE), after which the biomass was dried at 60 °C until constant dry mass was achieved. The relationship between the mean number of pin-intercepts and aboveground biomass or total leaf area per plot were assessed for the total plot data and individually for each of the three groups (e.g., graminoid pin-intercept frequency vs graminoid biomass) using linear regression (PROC REG, SAS v9.3; SAS Institute, Cary, NC), with the y-intercept defined to meet the origin (i.e., no pin-intercepts = no aboveground biomass).

Results

We found a significant positive relationship ($F_{1,25}$=330.5, p<0.001, r^2=0.93) between the intercept frequency and total aboveground biomass (Fig. 1). Total aboveground biomass (B_A; kg m^{-2}) was significantly predicted by the mean intercept frequency per pin ($\bar{I}$) by the equation:

$$B_A = 0.095\left(\bar{I}\right)$$

Pin frequency and biomass of herbaceous or woody functional groups was not significantly related to functional group biomass or total aboveground biomass, indicating strong influence of graminoid species (primarily sawgrass) on the overall regression. Leaf area (ln transformed) was strongly related to the mean intercept frequency (Fig. 2; $F_{1,22}$=50.19, p<0.001, r^2=0.70), with a mean plot leaf area of 2.02 m^2 m^{-2} (Table 1).

Discussion

Our results suggest the pin-intercept method is an effective, low-cost, minimally invasive, long term monitoring metric for restoration and management of wetlands like the Everglades. The pin-intercept method could be used to monitor net primary production, ecosystem health, and fuel loading for fire management regimes, providing an estimate of sawgrass community biomass in a fraction of the time and effort required for

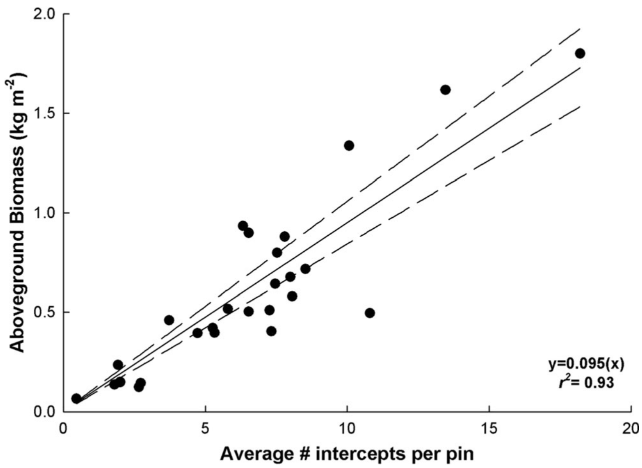

Fig. 1 Relationship between the total aboveground biomass (destructively harvested) and the mean frequency of interception per pin (slope = 0.095±0.005) across all sample plots (n=26). *Dashed lines* indicate 95 % confidence interval boundaries of the regression (*solid line*)

destructive harvesting. Additionally, because the vegetation within the plots is untouched, it is possible to monitor in-situ changes in biomass over time within permanent plots, thereby eliminating many of the confounding variables that limit assessments of community response over time or under changing environmental conditions (Willis and Birks 2006).

Compared to other methods of nondestructive biomass estimation (e.g., tiller length algorithms, spectral reflectance correlations), the pin-intercept method requires fewer measurements per plot (Daoust and Childers 1998) and is not as sensitive to ambient conditions at the time of sampling (i.e., time of day; see Whitbeck and Grace 2006), increasing the flexibility and reducing time requirements of sampling. Additionally, this method can be used on a smaller scale than remote sensing methods (Yan et al. 2013), and does not

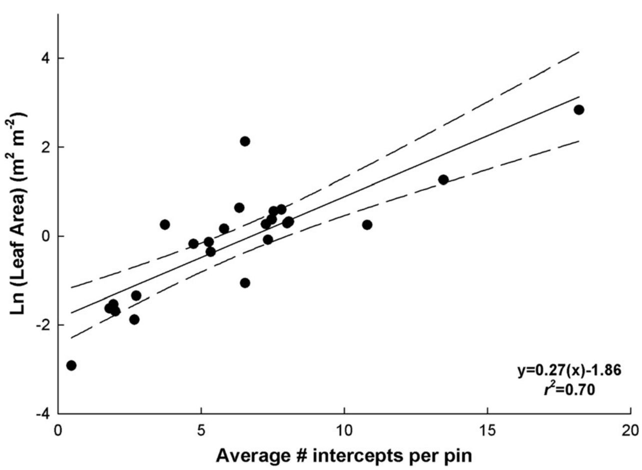

Fig. 2 Relationship between log-transformed total plot leaf area and the mean frequency of interception per pin across all sample plots (n=24). Leaf area data was missing for two plots, which were excluded from the analyses. *Dashed lines* indicate 95 % confidence interval boundaries of the regression (*solid line*)

Table 1 Mean (± SE) aboveground biomass, pin-intercept frequency (plot total and mean per pin), and leaf area across all plots (n=26) and separated by major plant functional groups

	Biomass	Intercept Frequency		Leaf Area
	(g m^{-2})	Plot	Pin	(m^2 m^{-2})
Total	608.3±86.3	98.3±11.4	6.6±0.8	2.02±0.36
Graminoid	577.7±86.5	96.8±11.5	6.5±0.8	2.01±0.36
Herbaceous	1.3±0.4	0.6±1.4	<0.1	0.01±0.02
Woody	29.3±48.1	0.9±2.2	<0.1	–

require any expensive equipment (e.g. ceptometer) or software while providing comparable if not better estimates of standing biomass than light penetration, visual obstruction, or leaf area index methods (Whitbeck and Grace 2006). Biomass data may also provide greater insight than vegetation cover data (Newman et al. 1998), as it represents the stature and health of the vegetation and reflects the quality of environmental conditions supporting productivity rather than just the spatial frequency of species.

Herbaceous and woody plants were relatively scarce in our plots, having occurred in 38 and 54 % of plots, and accounted for 0.21 and 4.82 % of the total biomass of all of the plots, respectively. However, these groups were only detected by pin-interceptions in 19 % of plots in which they occurred. Herbaceous and woody physiognomic groups also yielded inconclusive correlations between their pin frequency and biomass. This may be contributed in part to the scarcity of these groups, as sites were chosen for being dominated by sawgrass with at least 50 % of the cover being composed of sawgrass. However, it may also be due to differences in morphology between these groups. Graminoid species grow long, lean, relatively uniform leaves, whereas herbaceous and woody species are more irregular in shape, and are likely branched. The uniformity of graminoids versus the other physiognomic groups makes them much easier to measure using a pin-intercept method. Woody and herbaceous groups might be better adapted to other methods using different phenometric techniques for biomass estimation (Daoust and Childers 1998).

The pin-intercept method is an effective, non-destructive method for estimating and monitoring aboveground biomass and leaf area in graminoid-dominated wetlands like the Everglades. While site or taxa-specific validation and calibration of the predictive equations may be required, the method provides for rapid and repeated assessment of site conditions over extended temporal and spatial scales while minimizing ecosystem impact, making it well-suited for monitoring or ground-truthing, as well as resource inventory and research, particularly toward achieving the objectives for Everglades restoration.

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