ESTIMATION OF ABOVE-GROUND BIOMASS IN A HURRICANE-IMPACTED COASTAL PLAIN FOREST [1]

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Abstract. This paper describes one phase of a long-term study on the role of fire in post-hurricane forest plant community dynamics. Two years after Hugo but prior to initiation of fire regime treatments, the biomass complex within the 75-ac study area on the heavily damaged Santee Experimental Forest in South Carolina was assessed using a variety of techniques to establish pre-burn data baselines. Overall, downed woody debris comprised the largest biomass component at 57.8% of the total, followed by forest floor (16.3%), living residual trees (15.0%), dead residual trees (8.1%), and regeneration layer vegetation (2.8%). Detailed quantitative pre-treatment descriptions characterize biomass distribution and document variation in post-hurricane vegetative structure and fuel characteristics, and will permit assessments of nutrient pool variation among treatment plots. These baselines will allow for more sensitive testing and evaluation of fire effects on the development of plant communities following devastating hurricanes.

Introduction

Hurricane Hugo's profound impact on the Francis Marion National Forest in South Carolina has presented the rare opportunity to formally study plant communities as they develop following what is arguably the most severe of natural disturbance factors in the southeastern United States: the combination of strong winds from hurricanes and subsequent wildfires in heavy fuels. This combination has almost certainly been a highly influential force in the evolution of plant species and community successional patterns, and a driving factor in the development of coastal plain landscapes. However, little documentation of the ecological processes involved in this interaction have to date been reported in the literature.

One part of a current research effort (Van Lear 1990, Van Lear and Myers 1992) investigating the role of fire in hurricane-devastated coastal plain forest plant communities has involved the detailed description of the biomass complex of the study area. Measurement and description of post-hurricane/pre-fire biomass components will allow for evaluation of such phenomena as nutrient redistribution and vegetation change following the implementation of burning treatments. One objective of this paper is to document post-Hugo stand conditions and to characterize biomass distribution of forest stands in which the fire-regime treatments are to be applied.

Characterizing post-hurricane forest structure and biomass becomes a difficult sampling problem. Forests severely damaged by windstorms and abetted by two growing seasons of early successional vegetative development are chaotic and highly variable assemblages of both living and dead plant material. Empirical description of the quantity of biomass and nutrients in various biomass components has required the use of both standard and improvised techniques. Thus, a second objective of this paper is to report on methods herein employed to describe the post-hurricane biomass complex.

Study Area

This research is being conducted at two sites on the Santee Experimental Forest (SEF) within the Witherbee Ranger District of the Francis Marion National Forest (FMNF). The FMNF is located in the Lower Terraces of the Coastal Flatwoods Region, a part of the Flatlands Coastal Plain Province in South Carolina (Myers et al. 1986). Soils are mostly moderately well drained to somewhat poorly drained, and include Craven, Duplin, Lenoir, and Wahee soil series. These are soils with slow to moderately slow permeability and seasonally high water tables (Long 1980).

Both of the two study sites on the SEF were natural, unevenage mature pine stands prior to Hurricane Hugo, with the oldest trees exceeding 150 yrs in age. Stand records indicate loblolly (*Pinus taeda* L.) and longleaf (*Pinus palustris* Mill.) pine were the predominant overstory species, comprising

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stands for decades, except for four small wildfires that burned in parts of both sites in the 1960's (USFS Witherbee R.D. Fire Atlas). Various species of hardwoods, notably the oaks (*Quercus* spp.), sweetgum (*Liquidambar styraciflua* L.), and blackgum (*Nyssa sylvatica* Marsh.), had become well-established in the under- and mid-stories, and were beginning to encroach into the overstory.

Fifteen, 5-ac burning plots, each surrounded by a wide (30 ft) firebreak, comprise the treatment areas in this study. A randomized complete block design was utilized with three blocked replicates of five treatment plots. Four burning regimes plus an unburned control constitute the five treatments, which were assigned at random for each block of five plots. Biomass and structure of vegetation, living and dead, was characterized prior to burning for each treatment plot. Biomass summaries will be presented here on an average per ac basis by treatment (3 reps combined) rather than on a plot by plot basis.

Biomass Categories and Estimates

Five distinct biomass categories were recognized which collectively comprised the vegetative complex of the hurricane-impacted forest two years following Hugo. These five biomass categories are: the regeneration layer (RL), forest floor (FF), downed woody debris (DWD), living residual trees (LRT), and dead residual trees (DRT). Empirical description of each of these components required specialized and, in some cases, improvised sampling methods.

Regeneration Layer

This biomass component consisted of living vegetation, both woody and herbaceous, much of which has developed in the two years following the hurricane-induced removal of the canopy. The regeneration layer (RL) was defined to include trees and shrubs less than 1-in dbh, woody vines, graminoids, forbs, and ferns. These six lifeform groups were arranged in a diverse assemblage of species associations and developing plant communities across the 75-ac study area.

It was subjectively observed prior to sampling that there was considerable variation in quantity and vegetative makeup of RL biomass within the study area. Nutrient content per unit weight of biomass can also vary greatly from one type of vegetation to another. Because of this perceived variation in amount and form of RL biomass, stratification was considered appropriate to decrease sample size, given the constraints of time, manpower, and funds available for this phase of the study.

A stratification procedure was developed that combined identification and estimation of unit area dry weight of Regeneration Layer Cover Types (RLCT) with measurement of area occupied by cover types within each plot. By combining RLCT weight per unit area with an estimate of cover type area, RL biomass and its composition in terms of lifeform plant assemblages for each pre-burn plot could be estimated. Weight per unit area was determined for each RLCT from destructive (ground) samples, and cover type area was measured on low-level helicopter-obtained aerial photography of each plot, a technique similar to that suggested by Helms and Shain (1981). This method increased sampling efficiency by reducing variability of stratified clip plots, resulting in a smaller sample size for obtaining acceptable weight estimates for each RLCT.

Eight rectangular (6.6 ft x 9.8 ft) quadrats were located in each of the five photo-identifiable RLCT's, and monumented with 5-ft conduit driven 1.5 ft into the ground. Four samples of each cover type (n=20) were placed in dormant season burn plots while the other 20 samples were located in growing season burn plots, allowing regeneration layer development comparisons between these two levels of the season-of-burn main effect. One half (3.3 ft x 9.8 ft) of each clip plot was sampled prior to initial fire treatments in late October-early November of 1991. The remaining unclipped plot-half was reserved for post-burn sampling in 1992 and 1993. Bormann (1953) described the advantages of using rectangular (long/narrow) plot shapes in uneven, discontinuous, and variable vegetation.

All herbaceous and woody plants less than 1-in dbh rooted in the plot were cut at or as near as possible to the groundline, and separated into the six previously-described lifeform groups. Vegetation was placed into separate paper bags by group, labeled, and returned to the lab for dry weight determination. Estimates for dry weight per unit area (T/ac) for each RLCT were obtained from the average of eight oven-dry sample weights, based on the composite weight of all plants clipped on each destructive sample plot. Thus, each RLCT pre-burn biomass estimate is based on 258.7 ft^2 of clipped plot area. Separation of RLCT destructive biomass samples into plant lifeform components allowed for determination and description of pre-burn plant community composition based on biomass proportions (Table 1).

Estimation of area covered by each RLCT for each plot was achieved by dot grid counts on aerial photographs. Photos were obtained on October 16, 1991 using hand-held 35-mm cameras and color slide films (400 ASA) during low-level (500 ft above land surface) helicopter flights over the study areas. Plots were framed within separate, nearly-vertical exposures using zoom lenses so that plot firebreaks were as close as possible to image borders. Accurate photo-interpretation of plots was possible with the high resolution slide images enlarged by projection. Corrections for photo scale distortion resulting from tilt were made by the use of rectified dot grid transparencies mounted in the same frames with color slide plot images. Rectified grids were constructed optically in the lab by photographing tilted dot grids drawn on white paper at a density of four dots per in^2.

For each plot, the total number of dots falling in each of the five RLCT's was counted. That proportion of dots per type to total dots per plot was calculated and used as an estimate for the proportion of area in each plot covered by each cover type. Table 2 presents area estimates for cover types in each of the five treatment areas.

As a check on this method of determining area in cover types from aerial photo interpretations and dot counts, an independent area estimate was made based on a set of 480 ground samples. Thirty-two cover type ground samples (3.3 ft x 9.8 ft) were systematically located in all 15 treatment plots. Each sample was given one of the five RLCT names based on its vegetative makeup. That proportion of ground samples (X/32) in each RLCT was taken as an estimate for the proportion of area in the treatment plot occupied by each RLCT, in the same manner as with the aerial photo procedure.

A simple correlation analysis was performed for the two methods of area estimation. While correlation was expectedly imperfect, the scatter diagram (Fig. 1) and high coeffecient of determination ($r^2 = 0.7598$) shows that there is a strong relationship between the estimates of the two methods. Since a statistically significant ($F = 230.95$; $df = 73$) relationship resulted from this analysis, it can be inferred that the two methods yield similar estimates of area in cover types. The aerial technique with its greater sampling intensity (n=2401) is less apt to exclude smaller areas of relatively rare cover types, while the ground method has obvious advantages for correctly identifying vegetative assemblages and assigning cover type names. Aerial photo area estimates were ultimately used to calculate both regeneration layer and forest floor biomass for this project. Overall, regeneration layer biomass averaged 2.3 T/ac across the 75-ac study area (Table 3).

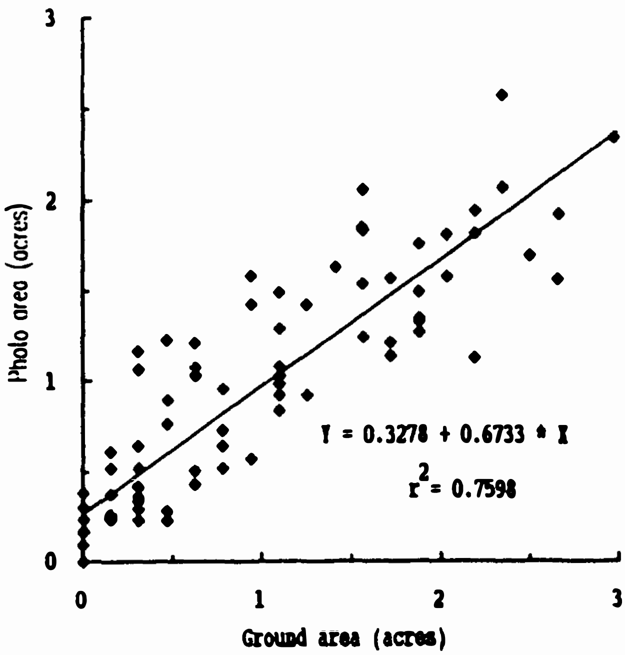

Figure 1. *Correlation of photo and ground RLCT area estimates.*

Forest Floor

Forest floor (FF) biomass was assessed by methods similar to those used in regeneration layer biomass description. High variation in characteristics of the forest floor across the study area were anticipated and assumed to be related in part to vegetation characteristics. To minimize sample sizes while still obtaining representative estimates for forest floor biomass and nutrient content, sampling was stratified by RLCT. One 0.672 ft^2 composite (litter + fermentation layer + humus) sample was collected from one of 48 possible random locations within each of the 40 clipped regeneration layer plots described above. All organic material excluding dead woody material visible on the litter surface was removed, placed in paper bags, labeled, and returned to the lab for drying, processing in a hammer mill, determination of mineral content, and storage for later nutrient content assays. Mineral fraction of samples was determined by the method of Hesse (1974).

Forest floor weight estimates were calculated for each RLCT based on the average of the eight samples per cover type. Area factors for RLCT's already established (Table 2) were used to determine

Table 1. *Dry weight of lifeform components comprising five regeneration layer cover types (RLCT), prior to burning and two growing seasons following Hurricane Hugo.*

Plant Lifeform	Regeneration Layer Cover Type				
	Pine	Herb.	Hwd.	Mixed	Shaded
	dry wt. - tons/acre				
Trees	1.97	0.25	1.38	0.72	0.25
Shrubs	0.49	0.07	1.53	0.47	0.39
Woody Vines	0.07	0.04	0.29	0.21	0.08
Graminoids	0.60	1.77	0.25	0.58	0.13
Forbs	0.40	0.13	0.03	0.24	0.04
Ferns/Moss	0.01	0.00	0.01	0.00	0.00
Total	3.54	2.26	3.49	2.22	0.89

Table 2. *Area in regeneration layer cover types (RLCT) estimated from aerial photos, summarized by treatment area.*

Treatment Area	Regeneration Layer Cover Type					Treatment Total
	Pine	Herb.	Hwd.	Mixed	Shaded	
	acres					
A	1.045	0.832	4.605	5.755	2.762	15
B	1.808	1.075	4.978	4.168	2.972	15
C	1.798	1.315	3.685	5.130	3.072	15
D	0.435	1.682	3.540	4.360	4.982	15
E	1.158	2.158	4.590	4.480	2.615	15
Total	6.242	7.062	21.398	23.892	16.405	75

Table 3. *Pre-burn regeneration layer (RL) biomass distribution, two growing seasons following Hurricane Hugo.*

Treatment Area	Regeneration Layer Cover Type					Total
	Pine	Herb.	Hwd.	Mixed	Shaded	
	dry wt. - tons/acre					
A	0.25	0.13	1.07	0.41	0.16	2.02
B	0.42	0.16	1.16	0.62	0.18	2.54
C	0.42	0.20	0.86	0.76	0.18	2.42
D	0.10	0.25	0.82	0.65	0.29	2.12
E	0.27	0.32	1.07	0.66	0.15	2.48
Mean	0.29	0.21	1.00	0.62	0.19	2.32

dry weight biomass estimates for the forest floor in each of the 15 treatment plots (Table 4). Overall, forest floor biomass averaged 13.7 T/ac across the 75-ac study area.

Downed Woody Debris

The planar intersect method described by Brown (1974) was employed to estimate pre-burn dry weight of wood and bark contained in down and dead trees and other downed woody material (DWD). Eight sampling planes were established on each 5-ac treatment plot using the permanent measurement points already in place as plane origins. A subset of the 16 points per plot was chosen by random selection of either the even- or odd-numbered stations. Compass bearings for sampling planes were also randomly selected from one of the three remaining cardinal or semi-cardinal directions not already used for plant cover measurement. Thus, eight samples per

Table 4. *Pre-burn forest floor (FF) biomass distribution, two growing seasons following Hugo.*

Treatment Area	Regeneration Layer Cover Type					Total Biomass
	Pine	Herb.	Hwd.	Mixed	Shaded	
	dry wt. - tons/acre					
A	0.93	0.31	5.55	4.48	2.70	13.98
B	1.62	0.40	6.00	3.24	2.91	14.17
C	1.61	0.49	4.42	3.99	3.00	13.52
D	0.39	0.63	4.27	3.39	4.87	13.56
E	1.04	0.81	5.53	3.49	2.56	13.42
Mean	1.12	0.53	5.15	3.72	3.21	13.73

plot (24/treatment area) were established for downed woody material biomass assessment.

Variable-length sampling planes were utilized to achieve high sampling efficiency. Long planes (50 ft) were used for the larger (3+ in), less-frequently-occurring pieces of DWD, while shorter transects were used for the numerous small pieces. Woody material 0-1 in diameter at the point of plane-intersection was measured on 6-ft planes, while 12-ft planes were used for material 1-3 in diameter. End-points of transects were marked with flagging and aluminum pins placed in the ground to facilitate reestablishment and remeasurement of sample planes after burning.

Table 5 summarizes quantities and variation in DWD distribution, by size class, for the five treatment areas. Given the severity of damage and the large size of trees in these stands prior to Hugo, it is not surprising that DWD represented the largest of the five components of aboveground biomass in the hurricane-impacted forest. Overall, DWD averaged 48.7 T/ac across the 75-ac study area. Variation was moderate, ranging from a low average of 41.8 T/ac for the three plots (15 ac) in treatment C to a high of 56.2 T/ac for treatment B.

Residual Living and Dead Trees

Biomass in living residual trees (LRT) and standing, dead residual trees (DRT) was quantified for each plot using tree measurements of dbh and total height obtained from fixed-radius plot samples. These tree data were used to estimate total aboveground biomass in living and dead residual trees in conjunction with published biomass equations for estimating wood and bark in the total tree (Clark and Taras 1976; Phillips 1981; Saucier and Clark 1985; Taras and Clark 1977). Each treatment plot was "cruised" using sixteen 1/20-ac circular plots with centers at the 240 monumented sampling points previously described. All trees 3.0-in dbh and larger, dead or alive, rooted within these plots were tallied for species, dbh, total height, and condition (vertical, leaning, downed, top-broken, etc.). In addition, 32, 1/200-ac samples per treatment plot (n=480) were established at monuments and at monument mid-points in which the above measurements were taken for trees and large shrubs 1.0 - 2.9-in dbh. Using information from these inventories, woody biomass descriptions were compiled in tabular form for each of the fifteen 5-ac plots.

The majority of trees in the hurricane area had abnormal form, with tops blown out or broken off, limbs removed from crowns to varying degrees, and (with hardwood species) two years of vigorous regrowth in the form of epicormic, limb, and basal sprouts. Equations generally used dbh and total height to predict whole-tree biomass. Trees with crowns completely removed (e.g. the numerous dead standing pine boles typical of the hurricane-impacted forest area) were measured for total height of that portion of stem remaining, and equations for dbh and merchantable height were used to estimate biomass of wood and bark, on a dry-weight basis.

The many published whole-tree equations are not designed to predict biomass in trees with wind-damaged crowns. Thus, the accuracy of the biomass predictions for the damaged residual forest stand may be in question. However, the alternative to the use of existing equations was to destructively sample many trees of many species, a prohibitively expensive and time-consuming task. Since the quantities of biomass estimated in this study are used primarily as a means for comparing effects of various burning treatments on the redistribution of nutrients, the method is defensible and valid. It is the repeatability of the measurements and estimates that is most important in this application, and not estimate accuracy. Tables 6 and 7, respectively, summarize distribution of LRT

Table 5. *Pre-burn downed woody material (DWM) biomass distribution, two growing seasons following Hugo.*

Treatment Area	0-3" size class			3"+ size class		Total Biomass
	0-.25"	.25-1"	1-3"	sound	rotten	
	dry wt. - tons/acre					
A	0.66	1.92	6.22	38.39	2.66	49.85
B	0.59	2.95	6.28	45.57	0.82	56.21
C	0.63	2.52	7.27	31.39	0.03	41.84
D	0.75	2.03	5.64	39.50	2.49	50.41
E	0.47	1.83	4.94	37.10	1.02	45.36
Mean	0.62	2.25	6.07	38.39	1.40	48.73

Table 6. *Pre-burn living residual tree (LRT) biomass distribution, two growing seasons following Hugo.*

Treatment Area	Species Group					Total Biomass
	Pine	Oaks	Sweetgum	H-Hwd	S-Hwd	
	dry wt. - tons/acre					
A	4.62	3.49	0.94	0.33	1.73	11.11
B	4.62	6.42	0.45	1.08	0.54	13.11
C	6.20	3.02	0.80	0.57	1.38	11.97
D	7.50	4.40	0.57	2.11	1.20	15.78
E	3.92	4.33	1.32	0.29	1.42	11.28
Mean	5.37	4.33	0.82	0.88	1.25	12.65

Table 7. *Pre-burn dead residual tree (DRT) biomass distribution, two growing seasons following Hugo.*

Treatment Area	Pine		Hardwood		Total Biomass
	Trees	Snags	Hard	Soft	
	dry wt. - tons/acre				
A	1.52	6.53	0.54	0.02	8.61
B	1.43	3.30	1.04	0.03	5.81
C	0.16	4.79	0.51	0.08	5.54
D	2.56	4.09	1.28	0.04	7.98
E	1.64	4.00	0.27	0.14	6.06
Mean	1.46	4.54	0.73	0.06	6.80

and DRT biomass. In Table 7, the term "snags" refers to dead pines whose crowns were completely broken out by strong wind, leaving only the standing boles.

Distribution of Biomass

Total aboveground dry biomass across the study area averaged 84.2 T/ac (Table 8). This quantity is similar to estimates from other studies for total forest biomass in natural, 60+-year-old southern pine and mixed pine-hardwood forests (Knight and McClure 1981). Downed woody debris comprised the largest (57.8%) component, by weight, of biomass in the hurricane-devastated forest. This finding was expected in view of the severity of Hugo's impact and the extensive windthrow and stem breakage of many large trees. The regeneration layer represented the smallest (2.8%) biomass component, but required the most effort for valid quantification because of its variability and the diversity of plant forms comprising it. This effort was considered worthwhile, since RL biomass is high in nutrient content relative to the other more woody biomass components (Van Lear et al. 1988), and because these plants represent the seed

Table 8. *Pre-burn aboveground biomass distribution for five treatment areas two growing seasons post-Hugo.*

Treatment Area	RL	DWM	FF	LRT	DRT	TOTAL
	dry wt. - tons/acre					
A	2.02	49.85	13.98	11.11	8.61	85.57
B	2.54	56.21	14.17	13.11	5.81	91.84
C	2.42	41.84	13.52	11.97	5.54	75.29
D	2.12	50.41	13.56	15.78	7.98	89.85
E	2.48	45.36	13.42	11.28	6.06	78.60
MEAN	2.32	48.73	13.73	12.65	6.80	84.23
PERCENT	2.8	57.8	16.3	15.0	8.1	100.0

sources and rootstocks that will play important roles in the colonization of the sites following burning treatments.

Conclusions

The biomass quantification phase of this study demonstrated that in the chaotic, complex structure of hurricane-devastated but rapidly regenerating forests, a combination of standard and improvised techniques is necessary for assessing forest attributes. On the Santee Experimental Forest after Hurricane Hugo, downed woody debris was the largest component of total biomass (57.8 %), followed by the forest floor, living residual trees, dead residual trees, and the regeneration layer. Baseline data have been collected and summarized which thoroughly describe pre-treatment conditions of stand structure and biomass distribution, allowing for subsequent assessment of nutrient pools. These baselines will enable burning treatment effects to be documented and analyzed in an on-going study of the interactive effects of hurricanes and fire on the development of forest plant communities.

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