TECHNICAL NOTE

Patterns of Urban Forest Debris from the 2004 and 2005 Florida Hurricane Seasons

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ABSTRACT

Urban tree debris generation and damage resulting from seven hurricanes during the 2004 and 2005 Florida hurricane seasons was analyzed using a random sample of communities in highly affected counties. Woody debris amounts, rates, and costs for cleanup were quantified, as were the spatial patterns of damage across the state. Average debris volume per mile of street segment was 488 cubic yards, and cost of removal and disposal averaged $21.50 per cubic yard. Urban forest structure, community characteristics, and hurricane severity influenced debris and cost results. Spatial analyses indicated that debris results were clustered into northwest and southeast areas of the state, which represent two distinct ecoregions in Florida. Although southeastern Florida had much higher costs per cubic yard than the northwest, the debris volume per road mile was higher in the northwest portion of the state. On a per-mile basis, Hurricane Ivan was responsible for the greatest debris volume, and Hurricane Katrina was the most expensive. These results can be used to help communities plan for hurricane response and management activities and to estimate potential damage to their urban forest resource.

Keywords: emergency management, i-Tree, ordinary kriging, debris removal costs, urban forest management, wind damage

Hurricanes Charley, Jeanne, Frances, and Ivan during 2004 and Dennis, Katrina, and Wilma during 2005 generated an unprecedented amount of urban forest debris in Florida. These hurricane events also presented substantial challenges to city and county officials in terms of posthurricane response to damage and removal of debris. Quantifying urban forest debris can be important for prehurricane planning and posthurricane response, but few published data exist for landscape-level vegetation debris generation in urban areas after hurricanes. Estimates of posthurricane vegetation debris amounts and costs are particularly important for justifying reimbursement funds requested from the Federal Emergency Management Agency (FEMA) by communities during the recovery operation.

As part of the posthurricane emergency management process, local and regional governments recorded their hurricane damage profiles and accounted for tree debris removal amounts and costs. This accounting is documented at the community level in sections of the FEMA Project Worksheet reports (PWs), which itemize vegetation and construction/demolition debris amounts and costs of cleanup, as well as hurricane damage related to hazard tree pruning and removal. Project Worksheets are categorized by the type of hurricane damage and include vegetation debris data. Additional data, such as hazard tree prunings and removal reimbursements, can also be obtained using categories A and G in the PWs. Because debris is brought to the street right-of-way for disposal, PWs in this study represent urban forest damage at the community and landscape levels. Using existing FEMA PWs, US Forest Service land cover data, and methods from Escobedo et al. (2009), we analyzed posthurricane vegetation debris, urban forest characteristics, and patterns of damage across the state of Florida for a sample of communities affected during the 2004 and 2005 Florida hurricane seasons.

Methods

FEMA posthurricane debris and cost data were compiled from a random 10% sample of 680 PWs from hurricane-affected communities following methods outlined in Escobedo et al. (2009). Project Worksheets quantified total tree debris and damage in cubic yards and were compiled by communities requesting public monetary assistance for hurricane damage. Of the 68 randomly selected communities with PWs, we excluded those from public entities (e.g., counties, tribes, official departments, hospitals) and others with insufficient data. This resulted in a sample of 43 communities affected by the seven hurricanes in 2004 and 2005 across the state of Florida. Urban forest cover characteristics for sampled communities were obtained using state urban and community forest land cover data provided by the US Forest Service (David Nowak, US Forest Service, Northern Research Station, Mar. 31, 2008). Tree density was estimated from methods outlined in Escobedo et al. (2009). Street segment lengths used for estimating debris volume per road mile were derived using i-Tree's Sample Street Segment Generator (i-Tree 2008) and the US Census Bureau's TIGER/Line data (US Census Bureau 2004). Reported costs are in 2004 and 2005 dollars and have not been adjusted or normalized to 2009 costs.

Descriptive statistics were used to characterize urban forest cover and debris results. In addition, we explored regional and local patterns of urban forest debris generation across Florida using geostatistical techniques based on the Universal Transverse Mercator (UTM) location of the community. Using the SAS procedure PROC VARIOGRAM (version 9.2; SAS Institute, Inc. 2006),

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Table 1. Descriptive statistics (mean ± standard error) for a random 10% sample of communities affected during the 2004 and 2005 Florida hurricane seasons. Communities generating less than 50 cubic yards per mile for individual hurricanes are not included.

Hurricane (knots)[a]	City	Tree cover (%)[b]	Trees per acre[c]	Developed land[b]	Tree cover in developed areas[b]	Year 2000 Population density[b] (no./mile²)	Vegetation debris (cu yd/mile)
				..........(%)..........			
Charley	De Land	34	33.7	63	19	1,317	86.4
(65–130)	Orange City	41	39.8	57	18	1,091	187.4
	Oviedo	43	42.5	47	14	1,739	1,396.3
	Port Orange	28	9.3	66	16	1,855	973.4
Frances	Atlantic Beach	26	33.3	71	27	3,584	160.9
(55–85)	Daytona Beach Shore	30	10.0	41	13	1,093	245.4
	Debary	40	38.9	46	19	853	475.6
	Deltona	28	27.8	68	16	1,943	388.2
	Edgewater	33	11.1	63	21	1,872	374.8
	Fort Pierce	10	3.2	81	5	2,545	276.6
	Gulf Port	11	11.0	94	9	4,422	97.5
	Palm Beach Gardens	23	7.7	38	8	630	164.9
	Palm Springs	3	0.9	96	2	7,261	699.8
	Tampa	22	23.4	78	11	2,707	122.8
Ivan	Destin	15	19.3	85	13	1,477	696.5
(105)	Fort Walton Beach	18	23.5	95	17	2,683	1,131.1
	Gulf Breeze	45	57.9	46	27	1,192	3,204.5
Jeanne	Belle Glade	4	1.3	72	2	3,206	236.4
(105)	Belle Isle	31	30.4	63	25	2,873	633.8
	Clearwater	10	10.4	91	6	4,302	99.6
Dennis	Destin[d]						119.1
(105)	Fort Walton Beach[d]						714.3
	Gulf Breeze[d]						1,190.5
	Mary Esther	26	33.4	81	18	2,635	182.9
Katrina	Gulf Breeze[d]						137.7
(70)	North Lauderdale	9	3.0	89	5	8,319	54.5
	Pembroke Pines	7	2.3	75	4	4,466	128.6
Wilma	Atlantis	13	4.4	92	11	1,463	1,573.9
(105)	Belle Glade[d]						1,225.2
	Golf	20	6.9	94	19	277	2,142.9
	Greenacres	6	1.9	96	4	5,918	316.5
	Lauderdale Lakes	4	1.2	95	3	8,832	512.3
	Opa-locka	2	0.8	95	1	3,452	796.0
Northwest Florida average		26.9 ± 2.5	27.4 ± 3.31	70.0 ± 3.9	16.3 ± 1.32	2,328 ± 1,247	522.7 ± 149.6
Southeast Florida average		9.7 ± 1.8	4.22 ± 1.46	80.1 ± 4.7	6.3 ± 1.46	4,517 ± 3,097	447.9 ± 132.1

[a] Maximum sustained wind speeds at land fall obtained from National Hurricane Center (2004, 2005).
[b] Source: David Nowak, US Forest Service, Northern Research Station, March 2008.
[c] Tree density determined using methods from Escobedo et al. (2009, p. 101).
[d] Cities affected by separate 2004 and 2005 hurricanes.

semivariograms were estimated to quantify the spatial continuity of vegetation debris generated per street mile of the affected communities. Based on the spatial location of the data, semivariograms showed the variability among data points as the distance between them increased, as well as identified regional patterns of debris generation. Ordinary kriging, a generalized least-squares interpolation in which the local mean is unknown and constant over the area of study (Goovaerts 1997), was used to spatially display results across the eastern halves of Palm Beach and Broward counties. This region is one of the most urbanized portions of Florida, and because of the large number of community-specific observations in this area, we were able to produce a localized interpolation map reflecting the pattern of debris generation at a landscape scale.

Results and Discussion

Urban forest characteristics and vegetation debris per street mile by hurricane are presented in Table 1. Escobedo et al. (2009) indicated that the amount of debris generated was affected by urban forest characteristics such as landscape-level tree cover, tree density, amount of tree cover in urbanized areas, and the amount of urbanized (e.g., developed) land. The spatial analysis of debris volume data performed for this study also indicated that debris results were clustered into northwest and southeast areas of the state, which represent two regional climate and vegetation associations of Florida: the humid temperate domain (outer coastal plain mixed forest province in northern Florida) and the humid tropical domain (the Everglades province in the southern third of the state) (Bailey et al. 1994).

On average, 447.9 (standard error, ±132.1) cubic yards per mile per community was generated in the southeastern third of the state, at an average cleanup cost per cubic yard of $27.70 (standard error, ±$3.52) during the two hurricane seasons (Figure 1). Although southeastern Florida had much higher and more variable costs per cubic yard than the northwest, the debris volume per mile of 522 cubic yards (±149.6) was higher in the northwest portion of the state, with variability similar to that of southeast Florida. Calculated on a per-road-mile basis, Hurricane Ivan was responsible for greater debris volume, but because of the low sampling intensity for this storm ($n = 3$), variability in the data was greater. Katrina was the most expensive and the most variable, in terms of cost per cubic yard of storm debris.

The robust variogram shown in Figure 2 indicates the patterns of variability in debris (left axis, cubic yards) and cost (right axis, $) for the 2004 and 2005 Florida hurricane seasons as the distance

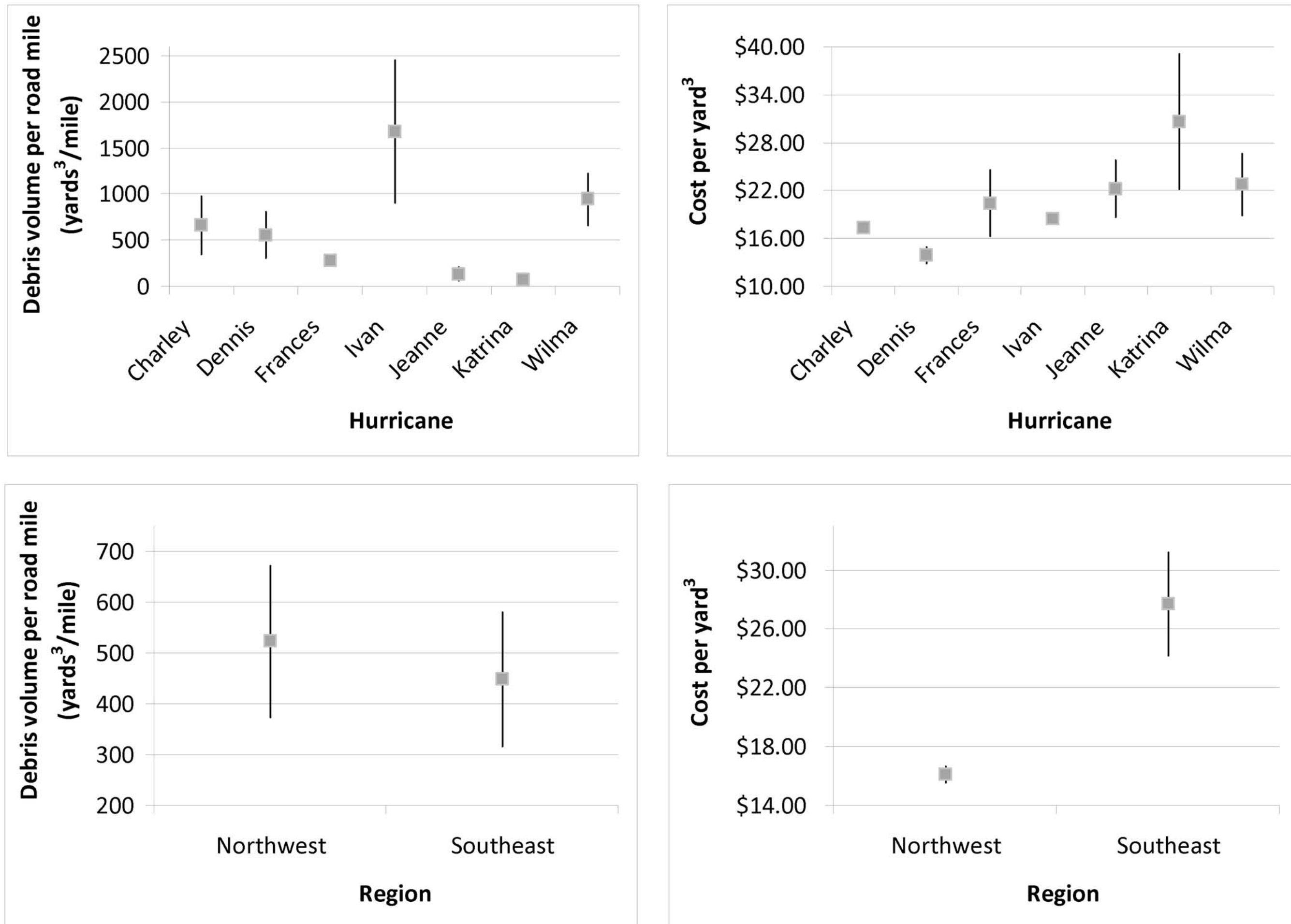

Figure 1. Average debris volume per road mile (cubic yards/mile) and average costs per unit volume ($/cubic yard), ± standard error, for Florida by named hurricane (2004–2005 season) and by region.

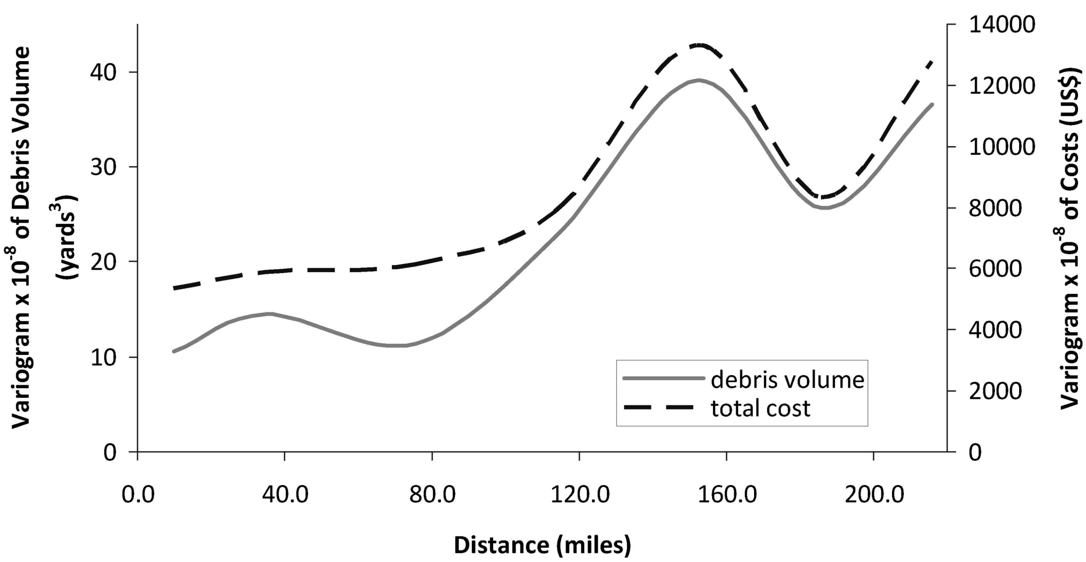

Figure 2. Robust variogram × 10^{-8} for debris volume (cubic yards) and costs ($) for Florida during the 2004–2005 hurricane seasons.

between sampled communities increased. The shapes of these curves are very similar, indicating similar trends in variability over distance. The results for debris volume and costs were locally consistent, as indicated by the shallow curves, signifying a high degree of spatial autocorrelation of both debris volume and cost at distances <100 miles (Figure 2). In addition, as distance between samples increased beyond approximately 100 miles, the curves both became steeper, indicating that variability between observations became greater. The

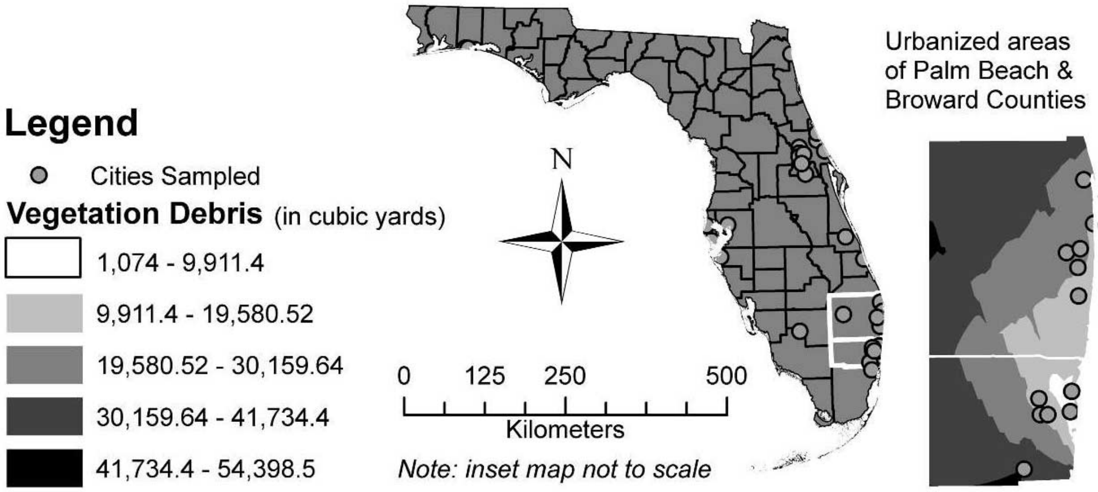

Figure 3. Interpolation of hurricane debris generation for the eastern, urbanized halves of Palm Beach and Broward counties, Florida, during the 2004 and 2005 hurricane seasons.

variogram analysis implies that there was strong spatial continuity at locations <100 miles apart, that hurricane effects were localized (e.g., hurricane paths), and that debris generation was similar within these affected areas.

Ordinary kriging results display the interpolation estimates of hurricane debris generation across the eastern, urbanized halves of Palm Beach and Broward counties (Figure 3). Using the community-specific values of debris generated from the sampled PWs and UTM locations, ordinary kriging gave the debris generated over the sampled area, assuming a constant trend over space. Figure 3 shows that debris volume in the urbanized portions of Palm Beach and Broward counties was greater as the distance from the ocean increased. Although this may seem counterintuitive, it is indicative of the relationship between community tree cover and debris generation reported in Escobedo et al. (2009); although many communities on the coast sustained higher winds than those inland, the high tree density of inland communities strongly affected debris generation rates.

Conclusions

The clustering of debris data along northwestern and southeastern portions of the state typifies Florida's regional vegetation and climate differences and supports the characterization of urban forest types and hurricane effects into two zones: the northwest and southeast portions of the state. Urban forest structure, community characteristics, and hurricane severity at the landscape level also affected debris and cost results. Communities in Florida are prone to hurricanes; as a result, they require urban forest damage and debris information to assist in predisaster planning and hurricane tree debris and damage assessment following a hurricane (Escobedo et al. 2007). Debris and cost results from this analysis could assist in accounting and possibly in requesting reimbursement funds from the federal government as part of recovery operations. These results can also be used to adjust community-specific inputs for urban forest storm damage assessments, protocols, and debris estimation models.

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