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Rapid Assessment of Change and Hurricane Impacts to Houston's Urban Forest Structure

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Abstract. A subsample of 332, 0.06-hectare plots measured during 2001–2002 in Houston, TX, U.S., were relocated and measured in 2008 following Hurricane Ike. These 37 re-measured plots provide a unique opportunity to explore the effects of urbanization and hurricanes on the forest structure of coastal urban forests. Statistical analyses of growth, mortality, and in-growth were conducted using plot- and tree-level factors. In total, 305 trees were re-measured, of which 195 (63.9%) still remained on-site and 110 (36.1%) had been removed. Ninety-seven (31.8%) of these trees were determined to be removed due to urbanization and 13 trees (4.3%) were removed due to hurricane impacts. Results show an overall annual net loss in tree numbers and an increase in tree density during the analysis period. Average annual mortality and in-growth rates were 3.9% and 5.3%, respectively. Growth rates were significantly influenced by land cover type, tree stem diameter, crown width, and percent dieback ($P < 0.05$). Overall, Hurricane Ike resulted in the removal of 4.3% of all trees measured, with removal occurring on six (16%) of the 37 re-measured plots. These initial findings could be used to understand changes in forest structure in coastal urban areas, improve estimates of carbon sequestration, and develop management goals.

Key Words. Emergency Management; Hurricane Damage; Urban Forest Growth; Urban Forest Mortality.

Urban forests are subject to various factors that alter the amount and type of structure and produce changes in the provision of ecosystem services such as aesthetics, shading, pollution removal, and carbon sequestration (Nowak et al. 1990; Kuo 2003; Nowak et al. 2004; Texas Forest Service 2005; Escobedo et al. 2010). While urbanization and land cover change often produce gradual changes, natural disturbance events, such as hurricanes and ice storms, cause immediate damage, resulting in dramatic changes to the urban ecosystem. While both types of change often give rise to long-term modifications in forest structure and composition through mortality and species replacement, hurricanes detrimentally affect urban forest structure (Zhao et al. 2010), have immediate and substantial effects to infrastructure (e.g., debris removal, hazards to property and human life, restoration needs), and contribute to emissions of carbon through degradation of downed trees and debris (McNulty 2002; Duryea et al. 2007a; Duryea et al. 2007b; Escobedo et al. 2009).

Annual urban tree mortality has been the subject of relatively few scientific studies in North America. In a limited number of studies tree mortality has been shown to be related to tree condition, size, and management practices. Street tree size and condition in Syracuse, NY, U.S., were found to influence annual mortality rates with higher mortality in large trees (5.4%) and trees with crown deterioration (6.4%) (Nowak 1986). Another street tree study in Boston, MA, U.S., reported that mortality averaged 9% over a ten-year period and depended on tree planting methods (Foster and Blaine 1978). In Oakland, CA, U.S., annual mortality of newly planted street trees averaged 19% over a two-year period (Nowak et al. 1990), with lower tree mortality next to single family housing and rapid transit stations and higher mortality in proximity to apartments, green spaces, and areas with low socio-economic status and high unemployment. Water and nutrient stress, and soil properties are also a common factor in urban tree mortality (Gilbertson and Bradshaw 1985).

Previous studies have used re-measurement of permanent plots to understand changes in urban forest structure (Jo and McPherson 1995; Nowak et al. 2004). In Baltimore, MD, U.S., two-year plot re-measurements yielded annual tree mortality and net change in the number of live trees of 6.6% and -4.2%, respectively, with the lowest mortality reported in medium to low-density residential land use areas and the highest mortality on industrial lands (Nowak et al. 2004). Tree health, size, and species also affected tree mortality; smaller tree sizes were more significantly related to mortality than was poor tree health.

Tree growth in urban areas is variable even among the same tree types due to different land uses, cultural practices, soil properties, site conditions, and disturbances (Nowak et al. 2004). In Chicago, IL, U.S., growth rates for urban trees in residential areas were determined using annual diameter increment measurements from core samples and were found to be 1.09 cm per year for hardwood trees and 0.51 cm per year for softwood trees (Jo and McPherson 1995). Comparable growth rates for forest-grown hardwood trees in Indiana and Illinois averaged 0.38 cm per year (Smith and Shifley 1984). Park trees in New York City were reported to have annual growth rates of 0.61 cm/year (deVries 1987). Although Jo and McPherson (1995) reported that individual urban tree growth in their study was affected by poor rooting conditions, air pollution, heat, and severe pruning, their annual growth rates were nearly twice as those reported by Smith and Shifley (1984) for forest-grown hardwood species. As mentioned earlier, this discrepancy in hardwood tree growth rates might be a result of the spatial heterogeneity of urban forest structure and open-grown conditions of urban trees (Zhao et al. 2010).

In the southeastern U.S., urban tree growth has been studied on a species level with emphasis on live oaks (*Quercus virginiana* Mill.), a historically important common species and a large component of total biomass by species in the region. In a study of parking lots in Florida, Grabosky and Gilman (2004) found that growth, in terms of canopy radius and height, declined as nonpaved surface area was reduced for Chinese elm (*Ulmus parvifolia* Jacq.), Sycamore (*Platanus occidentalis* L.), Shumard oak (*Quercus shumardii* Britton), and laurel oak (*Quercus laurifolia* Michx.); but not live oak. Templeton and Putz (2003) report that laurel oak growth rates in the Gainesville, FL area were 1.3 cm/yr. Information on tree growth and mortality is commonly being used for estimates of urban forest carbon sequestration (Nowak and Crane 1998; Escobedo et al. 2010).

In 2008, following Hurricane Ike in Houston, TX, a subsample of 332, 0.06-hectare circular plots originally measured during 2001–2002, were relocated and measured. In total, 37 permanent urban forest plots in Houston were re-measured to analyze the effects of Hurricane Ike on urban forest cover, mortality, and debris generation from urban trees, and to examine urban forest structure change over time in terms of growth and in-growth rates. These permanent plots, originally measured during November 2001 through May 2002, were assessed for hurricane debris generation but also provide a unique opportunity to explore changes in the city's urban forest structure over a seven-year period and assess the influences of Hurricane Ike and urbanization on both tree and plot level characteristics. The study authors define urbanization as processes (e.g. increased impervious surfaces, new buildings, roads, and other human influences) associated with urban development and land cover/use change (Texas Forest Service 2005).

Specifically, this study: 1) evaluated the effects of urbanization on tree numbers, basal area, mortality, and in-growth; 2) examined the impacts of Hurricane Ike on urban forest structure; and 3) determined annual growth rates for the most common species by diameter size class found in Houston, TX. Results can be used to understand temporal changes in urban forest structure and to estimate growth and mortality rates used increasingly in urban forest carbon sequestration assessments in the Gulf Coast of the United States.

MATERIAL AND METHODS

Plot Selection

In 2001, the Texas Forest Service established 332 plots using a systematic, random sampling design across an eight county region in the Houston area. During the 2001-2002 analysis, 2,010 trees were measured on 162 (49%) plots; the remaining plots contained no trees. On September 13, 2008, Hurricane Ike made landfall on Galveston Island at 2:10 a.m. Central Daylight Time as a strong category two hurricane on the Saffir-Simpson Hurricane Scale with 177 kph winds and a central pressure of 952 mb (Berg 2009). Its broad size and long fetch across the Gulf of Mexico created one of the most devastating storm surges to affect the coasts of upper Texas and Louisiana in the last 150 years (Berg 2009). Following Hurricane Ike, a subsample of 37 plots or, 23% of the original 2001 plots with trees, were re-measured to assess the effects of Hurricane Ike on urban forest structure and tree debris generation. Plots were selected for re-measurement using the following criteria (Figure 1):

1. Plots with at least one tree taller than 6.09 meters and in close proximity to residential buildings;
2. Plots with at least one tree taller than 6.09 meters, and closest and farthest from the storm track;
3. Plots severely affected by storm surge were eliminated from the sample; and
4. Plots with no access or safety concerns, and approved access by the Texas Forest Service and homeowners.

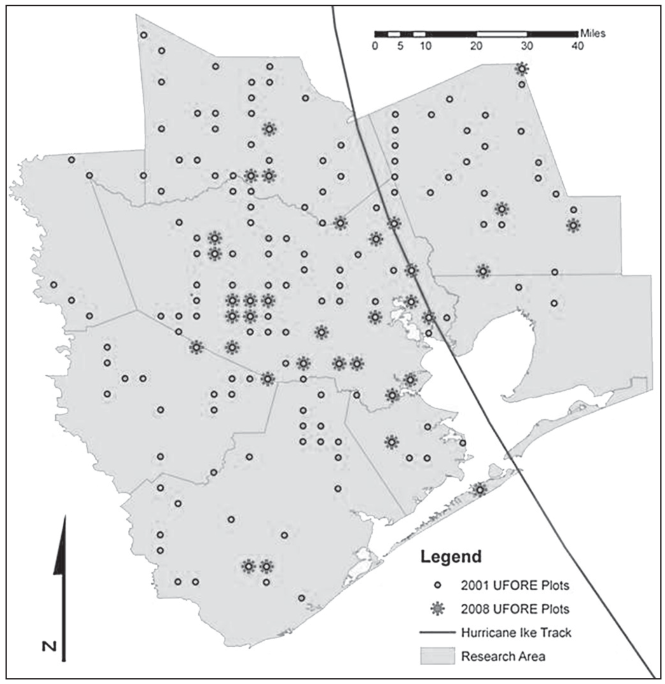

Figure 1. Distribution of plots measured in 2001 in Houston, TX, highlighting plots re-measured in 2008 and their proximity to the track of Hurricane Ike.

Field Measurements

Modified Urban Forest Effects (UFORE/ECO) field measurement methods from Nowak and Crane (1998), Zhao et al. (2010), and data from the 2001 sample were used along with additional measurements for hurricane damage and debris generation to re-measure the 37 selected re-measurement plots. Using original data and maps from the 2001–2002 UFORE/ECO sampling, each plot center was re-located using GPS coordinates and reference object distance and direction measurements. Once the perimeter for the 0.06 hectare plot was established, individual trees with DBH greater than 12.7 cm at the time of the original measurement in 2001-2002 were re-located and re-measured with the aid of original field data measurements, site and aerial photos from 2001, and Google Earth® maps from 2008. New trees with DBH greater than 12.7 cm were also measured.

The following data were collected for each tree on the plot: species (DBH; cm), total and crown base height (m), crown width in two directions (m), percent dieback, and crown light exposure using methods outlined in Bechtold (2003), Nowak et al. (2004), and Zhao et al. (2010). Percent tree cover, percent crown damage, percent missing foliage, and the amount of damage caused by other trees or wind were estimated ocularly using methods outlined in the i-Tree Storm manual (i-Tree 2009). Recently removed trees, as indicated by fresh stumps and saw dust on-site, were assumed to have been downed and/or removed as a result of Hurricane Ike. Measurements of debris amounts, notes on existing land use and visual observation of hurricane damage by trees, or wind to nearby buildings were also collected and are being used for a parallel study. For this analysis, original land covers were condensed into the following four: Woody Wetlands (WW); Developed Open Space (DO); Developed Low Intensity (DL); and Developed High Intensity (DH). Developed Low and High Intensity represent more urbanized land covers in the study area.

Matching 2001–2002 and 2008 Plots and Individual Trees

Sample data from 2001–2002 and the 2008 post-Hurricane Ike measurements were merged and trees present in both samples were matched. Trees were considered matched if 2001–2002 and 2008 tree measurements had the same direction and distance to plot center, same species and had a net increase in DBH. Annual DBH growth increments (cm/yr) were calculated by subtracting the 2001–2002 measurement from the 2008 and dividing by the years since measurement. Re-measurements using tree diameter tapes at breast height can differ from actual tree growth due to measurement error and changes in tree physiology (Avery and Burkhart 1983; Pastur et al. 2007). In addition, changes in the height of mulch and litter below a tree can change the location of the breast height measurement resulting in subsequent measurements taken at different heights. Although tree core increments are used to more precisely measure tree growth, in urban tree studies, tree coring is not practical due to tree aesthetics or liability issues associated with coring trees on private properties. While this study's method may lead to more measurement error than coring, the study auhors believe this issue to be negligible over the time period of this study; furthermore, this approach has been used in other urban forest structure studies (Nowak et al. 2004).

Since the DBH threshold in the 2001–2002 measurements was 12.7 cm, in-growth of a newly established tree into the population or trees was indicated by the presence of a tree with DBH > 12.7 cm in the 2008 measurement that was not originally measured in 2001–2002. Thus, in-growth as defined in this study indicates either a newly planted tree on the plot or that a small tree on the plot grew to the DBH threshold of 12.7 cm. If a previously measured tree was either removed, dead, or downed due to reasons other than Hurricane Ike, it was considered absent from the plot re-measurement. For this study, absence and in-growth were considered the same as mortality and recruitment, respectively; it was assumed that no trees were moved (e.g., replanted from outside the plot to inside the plot), or vice-versa.

Statistical Analyses

Statistical analyses of growth, mortality, and in-growth were conducted using the following plot level factors from the 2001–2002 measurements: land cover type, trees per acre, basal area per acre, and percent impervious groundcover. Tree level factors used in the analysis were: species, percent foliage, percent dieback, DBH, and crown light exposure from the 2001–2002 measurements.

Mortality and in-growth models were developed for this analysis using the plot-level mortality and in-growth data, respectively, as the dependent variables. A generalized linear model was fit using the SAS procedure PROC GLIMMIX (SAS 2006) assuming a negative binomial distribution for the response and plot-level characteristics as predictor variables.

Due to the frequency of near zero growth data values, growth rate values were transformed using a square root function to the reduce the variance and enable the modeling assumption of normally distributed and homoscedastic residuals to be met. Growth rates were modeled using a general linear mixed model with the SAS procedure PROC MIXED (SAS 2006) with both plot and tree level characteristics as predictor variables. A random effect was included to account for correlations between trees on the same plot. A Kenward-Rogers adjustment was made to the degrees of freedom to better reflect the effect of autocorrelation on the denominator degrees of freedom (Littel et al. 2006).

The model results were examined using information criteria and *P*-values associated with each independent value. A type I error level of 0.05 and the Akaike's information criteria (AIC) with second order correction (AICC) were used to eliminate nonsignificant effects and their interactions. The AICC is a small sample bias-corrected version of the AIC fit statistic which measures the goodness of fit of an estimated statistical model. It is a relative measure that quantifies the tradeoff between bias and variance in a model. A model with lower AIC gives more evidence that the model arose from the data. While the absolute values of AIC are not meaningful in and of themselves, a difference of two units of AIC between competing models is usually taken to indicate a meaningful difference between them (Burnham and Anderson 2002). The final models for growth, in-growth, and mortality included only significant effects and also had the lowest AICC values, indicating substantial evidence that the data arose from this model.

RESULTS

Change in Urban Forest Structure

When comparing trees within the 37 matched plots, there was an overall loss of an estimated nine trees and 0.24 square meters per ha of basal area per year. These re-measured plots contained 305 trees, of which 195 (63.9%) were matched and 110 (36.1%) were removed. Ninety seven (31.8%) of these trees were removed due to urbanization effects and 13 trees (4.3%) were removed due to hurricane effects. Plots in 2008 contained a total of 245 trees where 195 trees remained from the previous measurement and 50 were new trees. Overall, the net change in number of live trees was an annual loss of 2.9%. Figure 2 indicates that the average percent change for all tree density measurements (e.g., basal area, trees per acre, and tree cover) decreased over time when comparing plots that were matched through re-measurement. A comparison between 2008 plots with original 2001 plots in terms of overall density is not possible, because the post-hurricane plot selection criteria in 2008 targeted plots that contained trees only. Figure 3 shows annual plot density (e.g., number of trees/hectare) by land cover type. Plots on DL land cover showed an average annual increase in tree density while plots on WW land cover decreased over time.

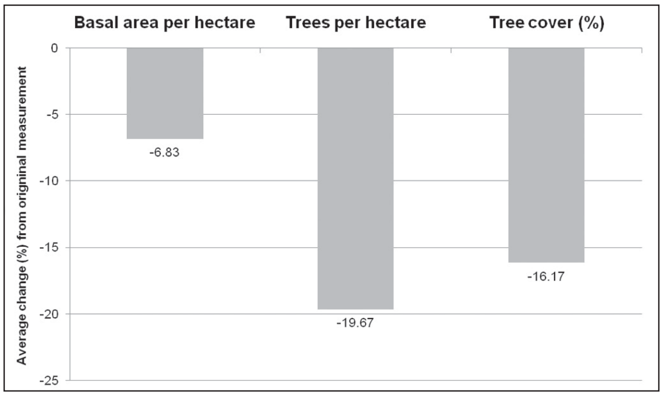

Figure 2. Comparison of average percent change in basal area (m2/ha), trees per hectare (# trees/ha), and tree cover from 2001 to 2008 for all 37 matched plots following Hurricane Ike in Houston, TX.

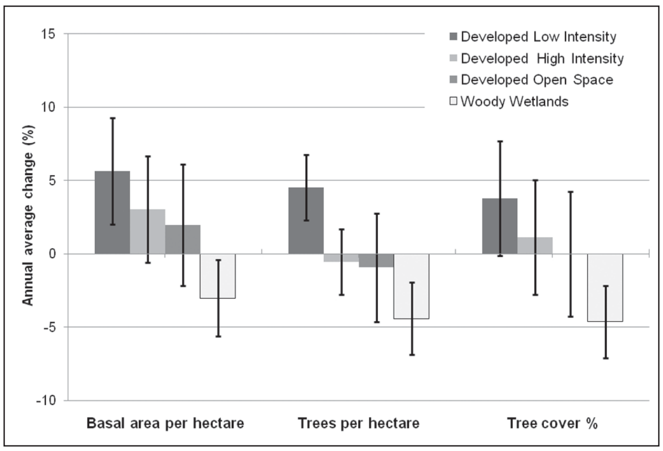

Figure 3. Percent average annual change in basal area, tree density, and tree cover by land use/cover type in Houston, TX, between 2001 and 2008.

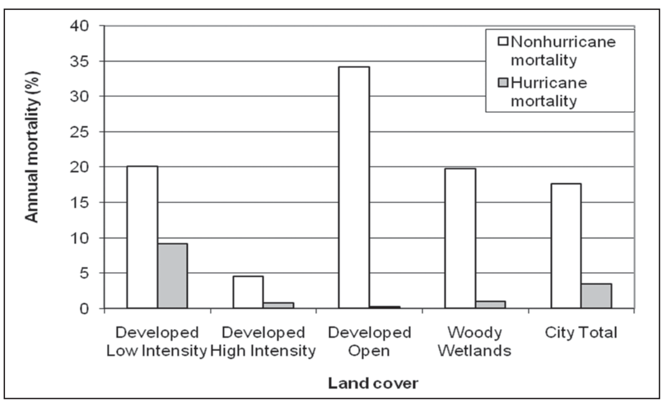

Figure 4. Average nonhurricane and hurricane mortality rates for 37 re-measured plots by land cover type in Houston, TX, between 2001 and 2008.

Mortality, In-growth, and Growth Models

The overall average annual mortality and in-growth rates were 4.7% and 2.4%, respectively. Average non-hurricane and hurricane mortality rates per hectare are shown in Figure 4 by land cover. Nonhurricane changes were mostly in the DO land cover category, while hurricane-induced mortality was largest in DL land cover.

Two competing mortality models are shown in Table 1. These models indicate that land cover and trees per hectare significantly influenced mortality at $P < 0.05$. The model with trees per acre had a lower AICC, indicating more evidence that the data arose from this model; the competing model is of interest since it does not rely on field data. The highest mortality occurred in DO land covers, followed by WW, then DL and DH. The only significant differences between land covers were found between the DO and DH land cover categories. Mortality increased as trees per hectare increased.

Only land cover was found to be significant in predicting in-growth of trees in Houston. As in the mortality model, more new trees occurred in the DO land cover. This was followed by DL, WW, then DH land covers. As with the mortality model, the only significant differences were found between the DO and DH land cover categories.

Due to the limited amount of tree mortality that could be attributed to Hurricane Ike, only a descriptive analysis of hurricane-caused tree mortality was possible. While developed low intensity (DL) land covers had more hurricane losses on a tree per hectare basis, 7 of the 13 hurricane removed trees were found in the WW land cover type. Figure 4 indicates—with the exception of WW—hurricane mortality increased with increasing rates of development. Only 29 trees located on 10 plots had trees with more than 25% of the tree crown damaged and tree crown defoliation was estimated to average 25% of total crown density across all measured trees. Only three plots had visual evidence of direct damage to residential or commercial buildings from trees.

Growth rates were influenced by land cover type, initial DBH, crown width, and percent dieback ($P < 0.05$; Table 1). The highest growth rates were found in DO, then DL and DH land cover types, while lower growth rates were found in WW plots. Growth was significantly lower in WW as compared to all other land cover categories. Growth rates increased as crown width increased, and decreased as DBH and dieback increased. The top four species in terms of growth were live oak, southern red oak (*Quercus falcata* Michx.), loblolly pine (*Pinus taeda* L.), and American elm (*Ulmus americana* L.) (Table 2). These were not, however, the most prevalent species; loblolly pine, water oak (*Quercus nigra* L.), sweet gum (*Liquidambar styraciflua* L.), and Chinese tallow (*Triadica sebifera* L.) were the most prevalent, accounting for 63% of the trees in the sampled plots.

DISCUSSION

Mortality and overall net loss of trees during the analysis period were less than reported in a similar study in Baltimore, MD (Nowak et al. 2004). In addition, the 4.3% tree mortality from Hurricane Ike was much lower than would be predicted for the minimum percent urban forest loss, as defined by Duryea et al. (2007a), using the polynomial relationship reported from eight hurricanes across several wind speeds (Duryea et al. 2007a; Duryea et al. 2007b). For example, according to this relationship, Hurricane Georges with the same maximum sustained winds as Ike (177 km/hr) resulted in 13% tree mortality in Puerto Rico (Duryea et al. 2007b). Differences might be due to different climate, a comparatively smaller sample size in this study and/

Table 1. Tests of fixed effects for growth, mortality and in-growth models for Houston, TX's urban forest.

Effect	Num DF	Den DF	F value	Pr > F
Annual Growth Rate Model				
Effect	Num DF	Den DF	F value	Pr > F
Land cover	3	187	6.66	0.0003
DBH 2001	1	187	6.49	0.0116
Crown width	1	187	8.35	0.0043
% Dieback	1	187	9.47	0.0024
Mortality Model 1 (AICC= 141)[z]				
Effect	Num DF	Den DF	F value	Pr > F
Land cover	3	33	3.79	0.0193
Mortality Model 2 (AICC= 132)				
Effect	Num DF	Den DF	F value	Pr > F
Trees per hectare	1	35	16.3	0.0003
In-growth Model				
Effect	Num DF	Den DF	F value	Pr > F
Land cover	3	33	3.45	0.0277

[z] Low AICC indicates better model; DF, Degrees of Freedom.

Table 2. Top four species ranked by highest growth rates and frequency in Houston, TX.

Rank	Common name	Species	Average growth rates (cm/yr)	SE
By Growth Rate				
1	Live oak	*Quercus virginiana*	1.22	0.25
2	Southern red oak	*Quercus falcata*	0.94	0.44
3	Loblolly pine	*Pinus taeda*	0.90	0.18
4	American elm	*Ulmus americana*	0.81	0.15
By Frequency				
1	Loblolly pine	*Pinus taeda*	0.90	0.18
2	Water oak	*Quercus nigra*	0.57	0.09
3	Sweet gum	*Liquidamber styraciflua*	0.44	0.10
4	Chinese tallow	*Triadica sebifera*	0.65	0.21

or the selection criteria used to measure the 2008 plots. Most importantly, Duryea et al. (2007a) only sampled trees along rights-of-way (e.g., transportation land cover/use), whereas the authors of the current study sampled several land cover/uses.

The highest growth rates found in the new study were on developed open space land cover. But this rate was not significantly different from the other developed land cover categories (DL and DH) in the study. However, significantly lower growth rates were found in WW. Also, measures of tree density decreased in WW and increased in DL during the analysis period. These results might have been influenced by a single plot in the WW land cover category where a loss of all 22 trees occurred due to land clearing activities in 2008. Greater sampling intensity would likely have improved growth, mortality, and in-growth models using tree- and plot-level characteristics. However, due to post-hurricane access and safety issues, this was not possible.

A study limitation is the time lag in tree mortality measurements immediately following Hurricane Ike, which more than likely affected the results. It is also probable that trees might have been removed in anticipation of hurricane landfall. Thus, the study authors could not determine if a tree was removed as a direct result of hurricane impacts or removed for other reasons. Unfortunately, safety, access, homeowner privacy, and logistical concerns following the hurricane delayed sampling. Recent tree removals and damaged trees were determined, however, and were thus associated with pre and post-Hurricane Ike impacts with relative certainty.

Despite this, in general the authors found that with the exception of WW hurricane mortality increased with increasing urbanization as defined by comparing WW to urban DL and DH land covers. Greater hurricane severity was experienced on the eastern portion of Hurricane Ike as expected (Berg 2009), and resulted in greater damage and debris in the WW plots located in this area. In addition, debris on WW plots was likely not removed during post-hurricane debris removal activities. Similar findings of increased tree mortality with increasing development and hurricane severity have been reported by Duryea et al. (2007a) and Escobedo et al. (2009), who found increased tree damage and debris in areas characterized by open-grown, single trees and communities with low tree density. Observations indicated that severe tree damage to standing trees was not common, finding only three plots that indicated visible evidence of direct tree damage to buildings on or near the measured plots.

Results are within the range of other studies of mortality and growth of urban forests. To compare this study's results to existing studies, mortality and growth data were arranged according to the diameter size classes reported in Nowak et al.(2004) (Table 3). Nowak et al.'s (2004) mortality rates were determined similarly by the remeasurement of 200 permanent plots sampled randomly across different land cover types in Baltimore, MD. Table 3 can be used to facilitate comparisons with existing growth, mortality, and biomass values used in the various urban forest structure-function models such as the UFORE/ECO model that is increasingly being used to assess carbon sequestration by southeatern U.S urban forests (Escobedo et al. 2010).

Table 3. Percent annual mortality and annual growth rates by diameter size class.

DBH (cm)	Houston 2001–2008 mortality and growth		Nowak et al. (2004) mortality
	Percent annual mortality (N)	Average annual growth rate (cm/yr) (N)	Percent annual mortality (N)
0–7.6	0 (0)	0 (0)	9 (528)
7.7–15.2	12 (21)	1.01 (14)	6.4 (267)
15.3–30.5	5.1 (48)	1.03 (110)	4.3 (201)
30.6–45.7	6.8 (28)	0.43 (46)	0.5 (109)
45.8–61.0	6.7 (11)	0.62 (19)	3.3 (62)
61.1–76.2	4.8 (2)	0.47 (6)	1.8 (28)
>76.2	0 (0)	0 (0)	3.1 (33)

N, sample size

CONCLUSION

From 1992 to 2000, forest land cover types declined by 17% and the Texas Forest Service (2005) reports that this equated to a loss of more than 10 million trees per year. As such, it is assumed that the current findings measured the changes due to urbanization, and hurricanes to a lesser degree, that have affected tree growth and mortality in Houston. Land cover was shown to significantly affect mortality, in-growth, and growth rates, as exemplified by growth rates being higher in urban developed areas as opposed to non-urban land covers with more natural forest structure. This might explain the discrepancy between the current findings and those of Jo and McPherson (1995) and Smith and Shifley (1984) mentioned in the literature review. Plots with a structure resembling more natural, closed canopy-like, forest conditions (e.g., woody wetland) had the lowest growth rates and were similar to those reported in Smith and Shifley (1984). Mortality and ingrowth were influenced by land cover, with significantly higher rates in more intensive developed land cover (DH) versus those of low development (DO). Mortality also had a significant relationship with tree density, increasing as trees per hectare increased. Growth decreased as crown condition deteriorated (crown width decreased as dieback increased) highlighting the effect of spacing on urban tree growth. In general, hurricane mortality increased with increasing rates of development and might indicate increased urban forest damage and debris in urban areas characterized by open-grown, single trees and urban land covers with low tree density, which corroborates findings from Escobedo et al. (2009).

Currently, most urban forest and hurricane literature focuses on tree species characteristics' resistance to hurricane force winds (Duryea et al. 2007a; Escobedo et al. 2009) and urban forest structure change in temperate urban forests (Nowak et al. 2004). It is hoped that results from this study can be used to better assess changes in structural characteristics in urban forests of the U.S. Gulf Coast region and to better understand landscape level effects of hurricanes on urban forests and debris generation. A concurrent study is using this data to analyze hurricane effects on tree debris generation and urban forest structure effects on hurricane winds and building damage. Using this approach of re-measurement permanent plots could be useful in future research to measure actual change in urban tree biomass, generation of green waste from pruning and tree removal activities, and to explore the effects of socioeconomics, urban morphology, and land use change on urban forest structure, function, and ecosystem services. Urban forest structure and function models, such as the i-Tree UFORE/ECO and STREETS models, are being used throughout the southeastern U.S. (i-Tree 2009). However, many of the algorithms used are from natural forest and urban tree growth studies from northern or western U.S. regions (Nowak 1994; Nowak and Crane 2002). Results from this study could be used to verify and better adjust growth and mortality algorithms in these models.

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Résumé. Un sous-échantillonnage parmi les 332 places-échantillons de 0,02 hectare chacune mesurées en 2001-2002 à Houston au Texas ont été localisées à nouveau et remesurées en 2008 à la suite de l'ouragan Ike. Ces 37 unités d'échantillonnage remesurées à nouveau ont constitué une occasion unique pour explorer les effets de l'urbanisation et des ouragans sur la structure de la forêt côtière urbaine. Des analyses statistiques de croissance, de mortalité et de croissance des sujets existants ont été faites au moyen de divers facteurs. Au total, 305 arbres ont été remesurés parmi lesquels 195 (63,9%) étaient encore existants et 110 (36,1%) ont été enlevés. Quatre-vingt-dix-sept (31,8%) de ces arbres ont été enlevés en raison de l'urbanisation et 13 arbres (4,3%) l'ont été en raison des impacts dus à l'ouragan. Les résultats ont permis d'établir une perte annuelle nette en nombre d'arbres et un accroissement de la densité en arbres durant la période d'analyse. Les taux de mortalité annuelle moyenne et de croissance des sujets existants ont été respectivement de 3,9% et 5,3%. Les taux de croissance ont été significativement influencés par le type de couvert au sol, le diamètre de tige des arbres, la largeur des cimes et le pourcentage de dépérissement (p < 0,05). Globalement, l'ouragan Ike a occasionné la perte de 4,3% de tous les arbres mesurés, avec des pertes survenus dans six (16%) des 37 unités d'échantillonnage remesurées. Ces découvertes initiales pourraient être utilisées dans la compréhension des changements au niveau de la structure des forêts en milieux côtiers urbains, pour améliorer l'estimation de la quantité de carbone séquestrée et pour développer des objectifs de gestion.

Zusammenfassung. Eine Teilprobe von 332 0,02 Hektar Flächen, die während 2001-2002 in Houston, Texas, gemessen wurden, wurden in 2008 nach dem Hurrikan Ike wieder ausfindig gemacht und erneut gemessen. Diese 37 erneut vermessenen Flächen liefern eine einmalige Gelegenheit, die Auswirkungen von Urabnisierung und Windsturm auf die bewaldeten Küstenregionen zu erkunden. Statistische Analysen von Wachstum, Sterberate und Einwachsen wurden anhand von Flächen und Baumlevelfaktoren gemessen. Insgesamt wurden 305 Bäume erneut gemessen, von denen 195 (63,9%) am Standort verblieben und 110 (36,1%) entfernt wurden. Siebenundneunzig (31,8%) dieser Bäume mussten aufgrund von Urbanisierungen entfernt werden und dreizehn (4,3%) wurden wegen Sturmschäden entfernt. Die Resultate zeigen einen allgemeinen jährlichen Rückgang der Stückzahl und einen Zuwachs an Baumdichte während des Analysezeitraums. Die durchschnittliche jährliche Sterberate und Einwachsrate lag bei 3,9 % bzw. 5,3 %. Die Wachstumsraten waren signifikant beeinflusst durch den Bedeckungstyp, Stammdurchmesser, Kronenbreite und dem Prozentsatz des Zurücksterbens (P < 0,05). Insgesamt führte der Sturm Ike zu einer Entfernung von 4,3 % aller gemessenen Bäume, die auf sechs (16 %) der 37 re Flächen standen. Diese ersten Ergebnisse können dazu verwendet werden, ein besseres Verständnis für die Veränderungen in der Forststruktur von küstennahen, urbanen Regionen zu bekommen, die Schätzungen der Kohlenstoffbindung zu verbessern und Managementziele zu entwickeln.

Resumen. Una submuestra de 332, 0.02-hectáreas de parcelas medidas durante 2001-2002 en Houston, TX, U.S., fueron reubicadas y medidas en 2008 luego del huracán Ike. Estas 37 parcelas proporcionan una oportunidad única para explorar los efectos de la urbanización y los huracanes en la estructura del bosque de las zonas costeras urbanas. El análisis estadístico de crecimiento y mortalidad fueron conducidos usando factores de parcelas y árboles. En total, 305 árboles fueron medidos, de los cuales 195 (63.9%) permanecen áun en el sitio, y 110 (36.1%) han sido removidos. Noventa y siete (31.8%) de estos árboles fueron determinados para ser removidos debido a la urbanización, y 13 árboles (4.3%) fueron removidos debido a los impactos del huracán. Los resultados muestran una pérdida neta total en número de árboles y un incremento en la densidad de árboles durante el período de análisis. La mortalidad promedio anual y las tasas de rebrote fueron 3.9% y 5.3%, respectivamente. Las tasas de crecimiento fueron significativamente influidas por el tipo de cobertura del terreno, el diámetro del tallo, amplitud de la corona, y porcentaje de muerte regresiva (P < 0.05). En resumen, el huracán Ike resultó en la remoción de 4.3% de todos los árboles medidos, en seis (16%) de las 37 parcelas. Estos encuentros iniciales podrían usarse para entender los cambios en la estructura del bosque en las áreas costeras urbanas, mejorar las estimaciones del secuestro de carbono y desarrollar objetivos de manejo.