Hurricane Katrina's Carbon Footprint on U.S. Gulf Coast Forests

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Forests recovering from land use, the expansion of woody vegetation, and other ecological processes produce a net terrestrial CO_2 sink of ~1 to 2 Pg C year^{-1} (*1*). The United States contributes an estimated 0.30 to 0.58 Pg C year^{-1} to this global sink, with 26 to 33% being actively sequestered in forest trees (*2*). Changes in the strength and sign of this sink over the coming decades are difficult to predict, but as secondary forests mature the sink strength is likely to diminish (*3*). Another process that can diminish the terrestrial carbon sink is an increase in disturbance frequency and intensity (*4*), which transfers biomass from live to dead respiring pools and shifts the stem distribution toward smaller average tree size and lower biomass stocks (*5*). Here, we quantify hurricane Katrina's carbon impact on Gulf Coast forests by using a synthetic approach combining detailed field investigations, remote sensing image analyses, and empirically based models for regional scaling.

To develop spatially explicit maps of hurricane forest impacts, we used spectral mixture analysis (SMA) (*6*, *7*) on Landsat imagery to quantify per-pixel fractional abundance of green vegetation (GV), nonphotosynthetic vegetation (NPV: wood, dead vegetation, and surface litter), soil, and shade for seasonally matched Landsat 5 images captured before and after the storm. The fractional change in NPV (ΔNPV) from 2003 to 2006 provided a quantitative measure of the change in dead vegetation associated with Katrina. A subset for the Pearl River basin was stratified by ΔNPV to generate disturbance classes, and forest inventory plots were randomly established across the entire ΔNPV disturbance gradient (Fig. 1A). In each plot, tree mortality and damage, species composition, and biomass loss were quantified.

A strong correlation between Landsat-derived ΔNPV and field-measured tree mortality and damage (fig. S1) enabled development of tree mortality and damage maps from the Landsat imagery. Next, a second scaling function was generated by comparing Landsat- and MODIS-derived ΔNPV. With the high temporal frequency and large spatial dimension of MODIS imagery, the Landsat-MODIS scaling provided an assessment of hurricane disturbance across the entire impact region (Fig. 1B). To carry out this scaling, we generated distribution functions for stem density and tree biomass from our forest inventory plots and additional U.S. Forest Service data. A Monte Carlo model was developed to estimate stem density, biomass distribution, mortality, and damage for all forested pixels in the MODIS scene (fig. S2) affected by Katrina. Statistically evaluated minimum and maximum values for key model parameters were used to estimate prediction error intervals (table S1). Nominal runs of the model predicted mortality and severe structural damage to 320 million large [>10-cm diameter at breast height (DBH)] trees (range from 290 to 350) with a total biomass loss of 105 Tg C (1 Pg = 1000 Tg) (range from 92 to 112), an amount equivalent to 50 to 140% of the net annual U.S. carbon sink in forest trees (*2*).

Methods for calculating the contribution of forest trees to the terrestrial carbon sink include summing tree recruitment and growth and subtracting mortality (*2*). Although carbon in coarse woody debris (CWD) from tree mortality and damage is not immediately respired to the atmosphere, this CWD pulse largely represents committed future CO_2 emissions (*5*). Although subsequent forest recovery from disturbance can offset CO_2 emissions from decomposing CWD, a sustained increase in disturbance intensity or frequency (or both) will reduce forest tree carbon stocks and ultimately cause ecosystems to act as a net CO_2 source (*8*). If a warming climate causes more extreme events and greater storm intensity (*4*), elevated forest tree mortality will increase CWD production, resulting in higher ecosystem respiration and a potentially important positive feedback with elevated atmospheric CO_2.

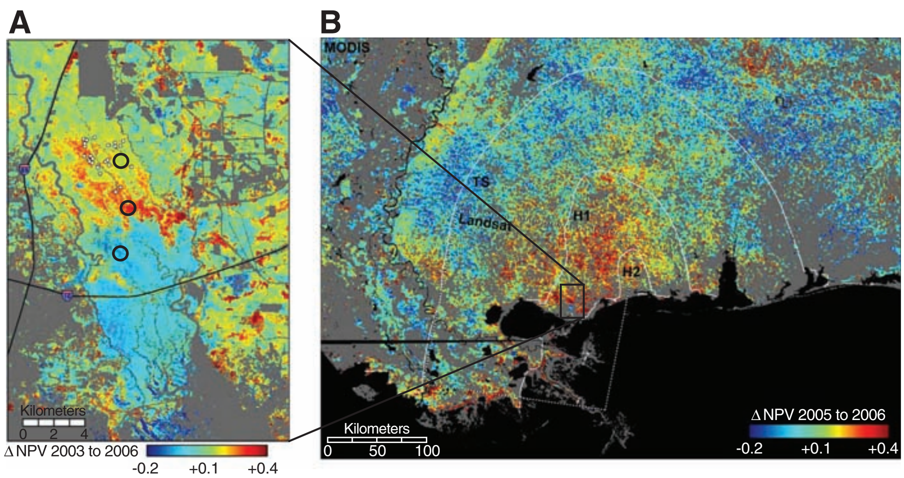

Fig. 1. (**A**) Pre- to posthurricane change in the NPV fraction (ΔNPV) on a Landsat 5 subset for the Pearl River basin (Louisiana-Mississippi state line) provided a quantitative measure of disturbance intensity. By using this map, we established forest inventory plots (white markers) across the disturbance gradient. Open black markers represent (top) moderately resistant, infrequently flooded, bottomland hardwood forest; (middle) minimally resistant, frequently flooded, bottomland hardwood forest; and (bottom) highly resistant, flooded, cypress-tupelo swamp forest. (**B**) MODIS-derived ΔNPV from 2005–2006 provided regional estimates of tree mortality and biomass loss across the entire impact region. Isotachs (white lines) represent tropical storm (TS), category 1 (H1), and category 2 (H2) wind fields (*9*).

References and Notes

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References

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