Investigating the effect of hurricane disturbance on fire activity in tropical forests: a GIS-based approach.

Percival Cho[1], Alan Blackburn[1], Jos Barlow[1]

[1]Lancaster Environment Centre, Lancaster University, Lancaster LA1 4YQ, UK.
Tel. (44)1524510221
Email, p.cho@lancs.ac.uk

Summary: Hurricanes and wildfires are important agents of forest disturbance in Central America, although it is not known whether there are links between them. Here we demonstrate the effect of hurricane disturbance on fire prevalence combining remote sensing and GIS analyses. We collated MODIS fire hotspots for the eleven year period 2001-2011 in which two hurricanes struck the Central American country of Belize. We evaluated fire activity by comparing fire hotspots in hurricane affected forests with activity in similar but unaffected forests. We found that fire activity was substantially and significantly higher in hurricane affected forests after controlling for various factors, including rainfall.

KEYWORDS: Hurricanes; Tropical forests; Central America; Fires; MODIS

1. Introduction

Hurricanes are an annual occurrence in Central America, frequently causing major disturbance to tropical broadleaf forests (Brokaw and Walker, 1991; Tanner, Kapos and Healey, 1991). Hurricane force winds cause full and partial tree blowdown which input large quantities of debris in the form of branches, whole crowns and logs (Brokaw and Grear 1991; Boose, *et al.*, 1994; Lugo 2008). This level of damage occurs over large spatial scales covering tens of thousands of hectares (Vandermeer, *et al*., 2000). The disturbance is thought to encourage an increase in tree diversity (Vandermeer, *et al.*, 1996; Burslem, *et al*., 2000; Vandermeer, *et al.*, 2000), but at the same time can cause significant disruption to habitat for large vertebrate fauna and avifauna (Waide, 1991; Tossas 2006).

Habitat disruption can be intensified when other disturbance activities follow hurricane damage, such as salvage logging and fires. Fire prevalence and intensity are thought to increase in hurricane damaged ecosystems (Myers and van Lear, 1998). It is hypothesized that the combination of hurricane and fire in synergy leads to significant compositional and structural changes in coastal ecosystems (Myers and van Lear, 1998). The basis of this hypothesis rests on the assumption that hurricanes increase fire activity and intensity in affected ecosystems but the only evidence supporting this comes from fire-adapted ecosystems of the Gulf and south-eastern coast of the US (Lui, *et al.*, 2008). Hurricanes occur across the Caribbean and north-Atlantic, so there is also the possibility that hurricane and fires occur in synergy to shape past, present and future ecosystem composition and structure elsewhere in the region.

Central America's forests are highly fragmented and the larger contiguous blocks are usually bordered by agricultural lands (Ray, *et al.*, 2006) or open pine savannah, which are typically burnt annually during the dry season from February to May (Billings and Schmidtke, 2002). Agricultural and savannah fires frequently encroach into broadleaf forests but, in Belize, typically do not spread beyond a few metres (Kellman and Meave, 1997). The increase in downed wood caused by hurricanes coupled with the proximity to agricultural lands (a source of fire) is thought to pose serious risk to hurricane affected forests (Chavez and Patterson, 2007). Not only can the natural processes of direct regeneration and recruitment which occur after hurricanes (Boucher, *et al.*, 1994) be stifled by fire, but animal and bird species can be displaced from large areas of their range (Askins and Ewert, 1991; Wiley and Wunderle 1993). The Central American isthmus is straddled by a large network of protected areas which forms a biological corridor for many endangered species and links populations from Mexico to Argentina (Kaiser 2001). Fires pose serious risk for the integrity of this biological corridor and for the biodiversity found within (Ray, *et al.*, 2006).

Hurricanes are expected to increase in frequency and intensity due to climate change (Holland and Webster 2007). In addition, drier conditions during the dry season are expected in the tropics (Mahli and Wright 2004), and this can facilitate the conditions which promote fire in broadleaf forests. Furthermore, forest fragmentation results in high perimeter to area ratio and presents greater risk for fire encroachment from adjacent agricultural lands. Given these assumptions, it is thus necessary to investigate the link between hurricanes and fires to determine if indeed a synergy exists and if so what factors besides fuel inputs are at play.

The aim of this study was to determine whether hurricane affected forests are subject to increased fire activity using an extensive dataset of MODIS fire pixel locations collected over the past eleven years, in conjunction with geospatial datasets for forest cover and hurricane damage. This study will adopt a spatially explicit approach using GIS analysis.

2. Methods

This study utilized ArcGIS 10 (ESRI). Fire activity data was obtained from the University of Maryland's FIRMS system (Davies, *et al*., 2009) in ESRI shapefile format for the period January 1, 2001 to August 24, 2011 and contained all active fire detection points based on the gridded fire product (NASA/University of Maryland, 2002). A complete treatment of the fire activity data and the algorithm it is based on are given in Justice, *et al.* (2002) and Giglio, *et al.* (2003).

A list of all hurricanes which occurred during the period 2001 to 2011 (the date range of the MODIS fire product) was compiled (Table 1). This study focussed strictly on forest types not naturally prone to fire which excluded dry tropical forests. The remaining study sites were moist or wet forests affected by hurricane Iris (2001), Felix (2006), and Richard (2010) (Table 1). Of these, forest cover and hurricane damage data were readily available for Iris and Richard, only. Although data for Felix were requested from the relevant authorities in Nicaragua, it has not yet been obtained.

Table 1. Major hurricanes to affect Central America's tropical forests

Year	*Hurricane*	*Strength*	*Country*	*Tropical Zone*
2001	Iris	Category 4	Belize	Moist
2005	Wilma	Category 4	Mexico	Dry
2005	Emily	Category 4	Mexico	Dry
2007	Felix	Category 5	Nicaragua	Moist/Wet
2007	Dean	Category 5	Mexico	Dry
2010	Richard	Category 1	Belize	Moist

Forest cover data for Belize was obtained from Cherrington, *et al.* (2010) in raster format and was converted to shapefile format for the analysis. The dataset included forest cover obtained from analysis of Landsat imagery for various periods during 1980 to 2010. Although hurricane Iris occurred in 2001, the forest cover dataset corresponding to the year 2010 was used in order to exclude fires in areas which were converted to non-forest after 2001. This meant that a certain number of fires which occurred in forests that were later converted to non-forest between the time of the hurricane and 2010 were not counted as such and were ignored in the analysis. We did not expect that this would bias our results toward fewer fires in unaffected forest because the rate of deforestation was not expected to be different between affected and unaffected forests given the relatively compact spatial arrangement of each study area (Figure 1).

The hurricane damaged area for hurricane Richard was based on analysis of ALOS-PALSAR and ASTER imagery and was obtained from CATHALAC/SERVIR (2010) in shapefile format. The damage area for hurricane Iris was determined by aerial survey immediately after the storm (Meerman, 2001) and was included in the study in shapefile format. For both studies, the definition of the hurricane damage area was similar as it entailed the detection and delineation of all areas showing distinct visual and spectral differences compared to conditions before the hurricane and to areas known to be unaffected, based on foliage removal/discolouration and/or percent of visible ground.

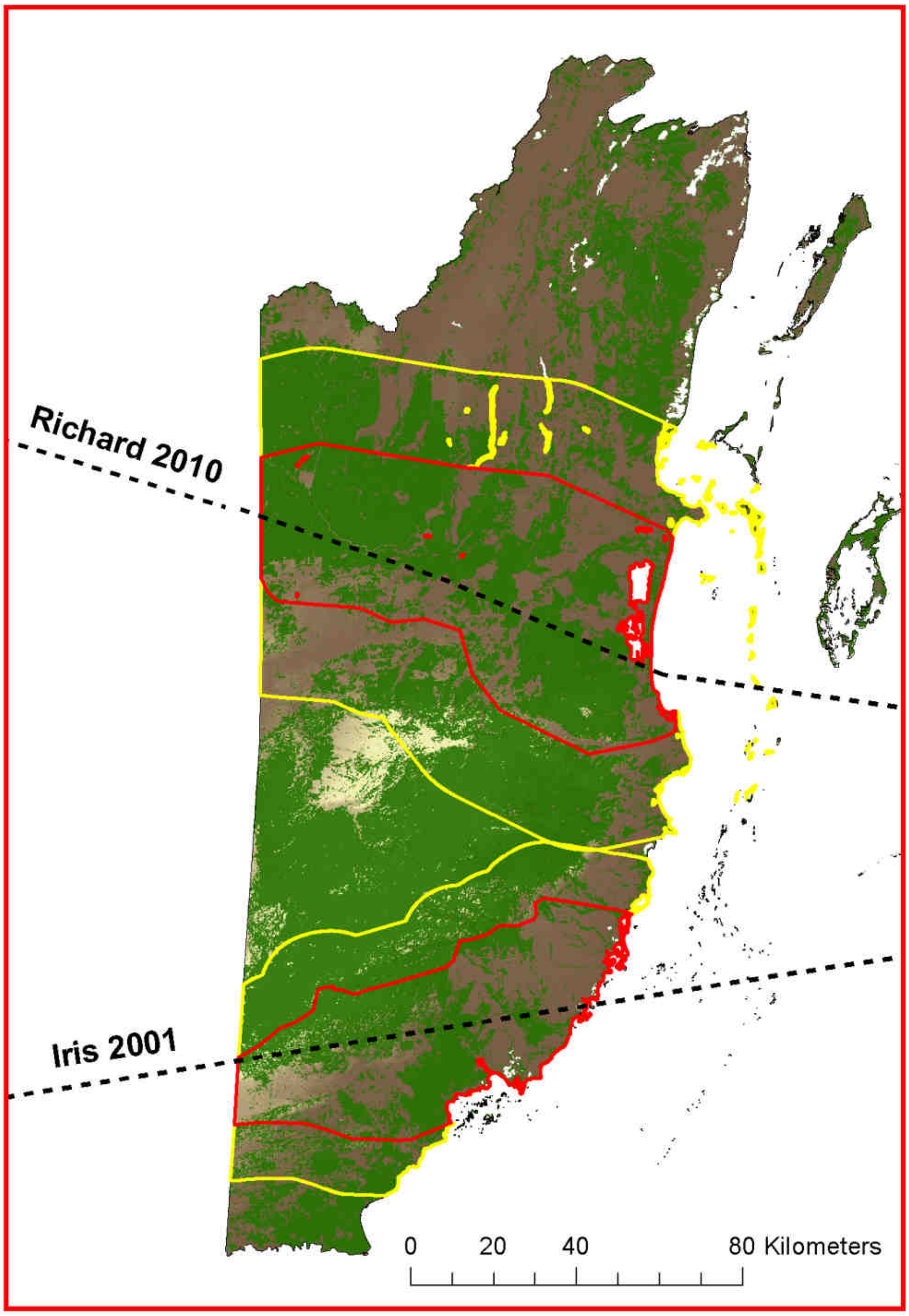

Figure 1. Spatial composition of the study area. Green areas indicate the broadleaf forest cover of Belize (Cherrington, *et al*., 2010). Red outline indicates the hurricane-affected forest areas and yellow outline indicates the unaffected forest areas used in our analysis. Thick dashed lines indicate approximate hurricane tracks.

We expanded a buffer of half the width of the hurricane damaged area on both the northern and southern extent in an effort to obtain a sample of unaffected forest of equal area. This process was repeated iteratively until the area of unaffected forests roughly equalled the area of affected forest after which we clipped the forest cover dataset to the study areas and calculated the resulting area (Table 2).

Table 2. Area in hectares of hurricane affected and unaffected forests included in the study.

Year	*Hurricane*	*Affected Forests (ha)*	*Unaffected Forests (ha)*	*Ratio (Approx.)*
2001	Iris	112,141	110,509	1:1
2010	Richard	196,976	195,290	1:1

We then applied an internal buffer of 1 km width to reduce the area of all forest polygons in order to reduce any bias resulting from the 1 km resolution of the MODIS fire pixel location data. It is important to reduce this bias because it could confound the results through the erroneous inclusion of fire pixels at the non-forest/forest periphery in forests when in actuality they occurred in non-forest, and vice versa. Another potential bias could result from unequal distribution of non-forest/forest periphery between affected and unaffected forests. This was controlled for by the elimination of all forest fragments less than 100 hectares from the analysis.

We calculated the number of fires detected per 1000 km^2 per month during the dry season months of April and May, and normalized and standardized this variable across affected and unaffected area for both hurricanes and across all years in the study period in order to facilitate comparison. We compared the results to dry season rainfall over the study period using long-term rainfall data for Belize (Baker, *et al.*, 1994)

3. Results and Discussion

We found that fire activity over the entire study period was substantially higher in hurricane affected forests as compared to unaffected forests (Figure 2). We tested this using a Wilcoxon Signed-Rank test for hurricane Iris and found that the difference was statistically significant at the p=0.05 level (Table 3). We also found that the effect was not constant in all post-hurricane years and that the variation in annual fire activity in hurricane affected forests was closely related to dry season rainfall patterns (Figure 3). More importantly, dry season rainfall had no effect on fire activity in unaffected forests, suggesting that hurricane damage does increase fire activity in broadleaf forest but only when dry seasons were unusually dry.

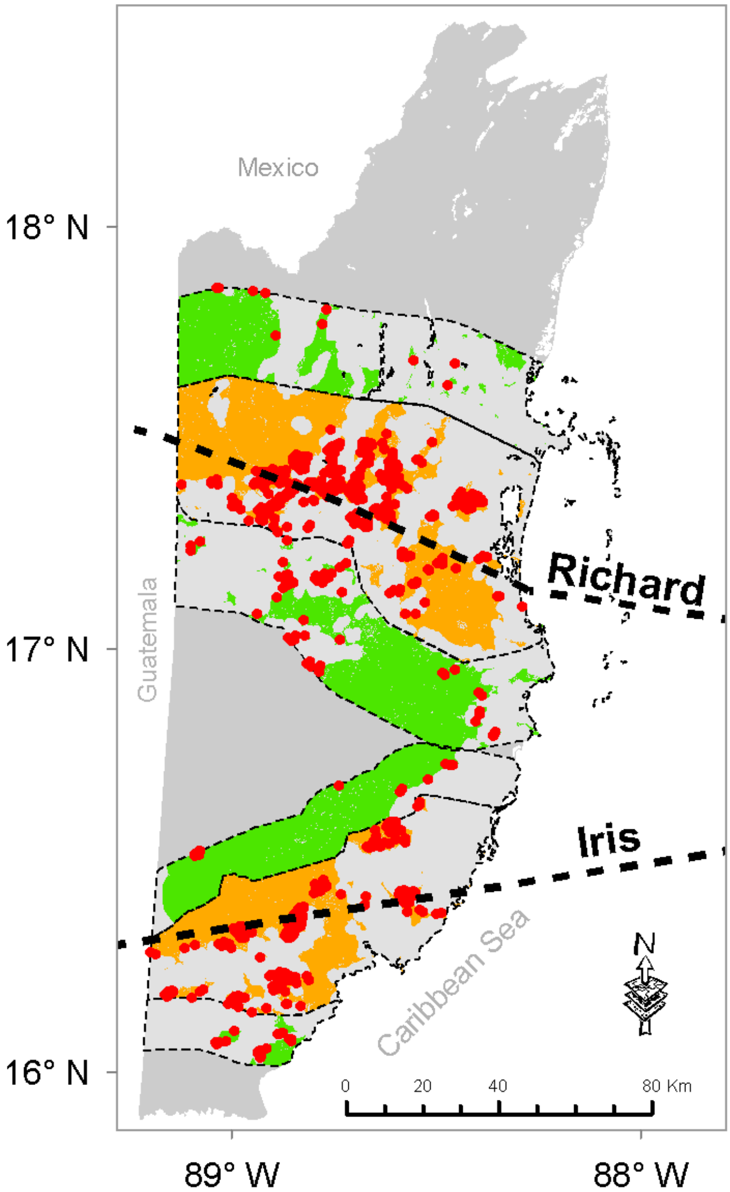

Figure 2. Total fire detections in the study area. Red dots indicate MODIS fire pixel location in hurricane-affected (orange) and unaffected (green) forests. Thick dashed lines indicate approximate hurricane tracks. Thin dash lines indicate the spatial constraint used to define affected versus unaffected forests. For hurricane Richard, the number of fire pixels in affected (n=406) and unaffected (n=73) forests corresponds to the 2011 dry season only. For hurricane Iris, fire pixels in affected (n=259) and unaffected (n=43) forests represents cumulative detections during dry seasons for the period 2002-2011.

Table 3. Results of a Wilcoxon Signed-Rank test of difference between mean fire activity (detections/1000 km^2/month) in affected vs. unaffected forests.

Year	*Hurricane*	*Status*	*Period*	*Months*	*N*	*W*	
2001	Iris	Affected Unaffected	2011 2011	Apr-May Apr-May	2 2	n.a.	n.a.
2010	Richard	Affected Unaffected	2001-2011 2001-2011	Apr-May Apr-May	22 22	374	0.002

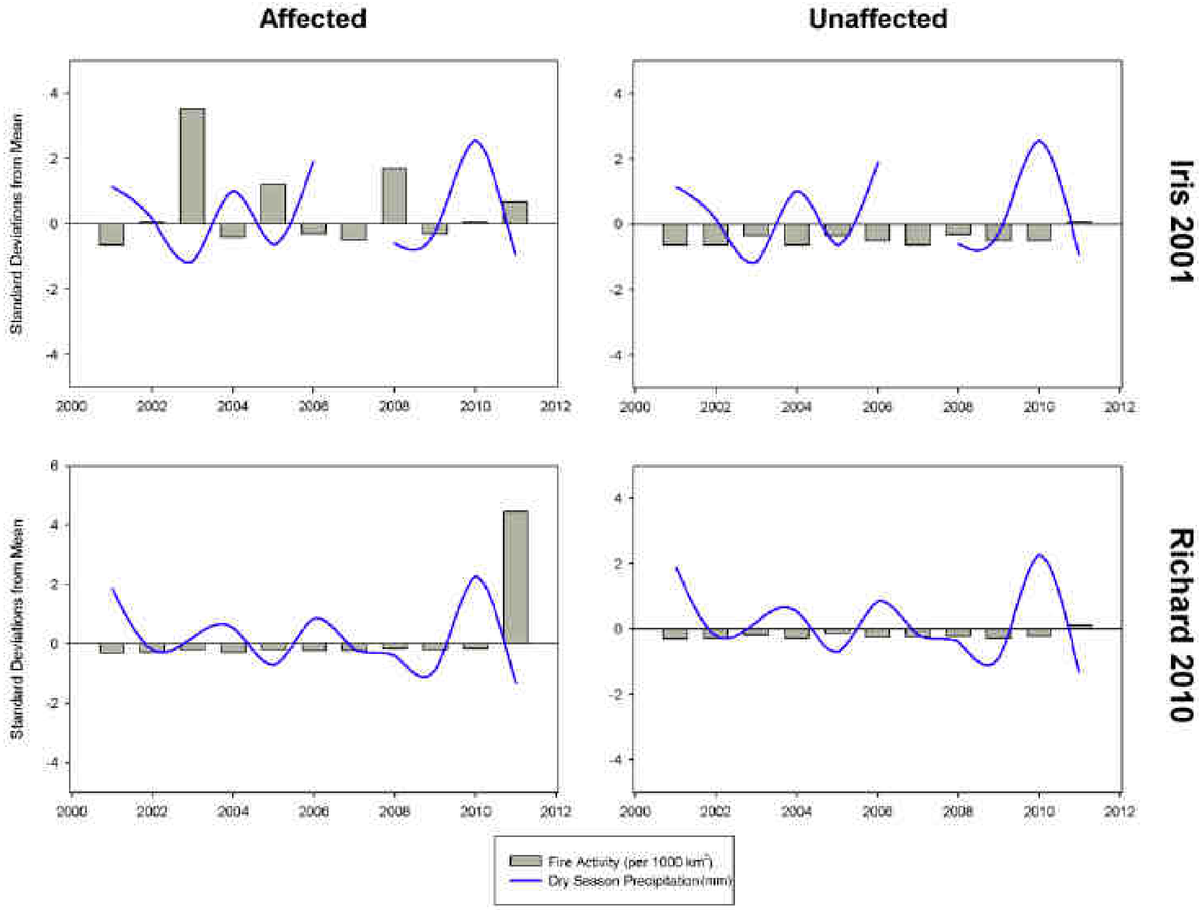

Figure 3. Results showing standardized values of fire activity and dry season rainfall across the study period in affected and unaffected forests. Dry season rainfall mean was taken over the 50 year period 1960-2011 for the Richard study area and for the Iris study area it was taken over the 30 period from 1976-2006. Where the dry season was drier than average or anomalous, as in years 2003, 2005 and 2008, we see higher than average fire activity, but more importantly we only see this pattern in hurricane affected forests.

4. Conclusions

The findings of this study are important because they demonstrate a clear link between hurricane damage and increased fires in broadleaf forests that are not normally subject to fire activity, and where most species have very little or no evolutionary resilience to heat stress. The results suggest that hurricane disturbance facilitates increased fire activity but only when dry season conditions are drier than normal. In a region where hurricanes are an annual occurrence and predicted to increase in frequency, a hurricane-fire synergy could have dire consequences for tropical forests and biodiversity.

5. Acknowledgements

The authors would like to acknowledge CATHALAC/SERVIR for providing the forest cover and hurricane damage datasets used in this study. Long-term rainfall data was kindly provided by the Hydrology and Meteorology Department of Belize and Jan Meerman of Belize Tropical Forest Studies. In addition, a large portion of the dataset of historical rainfall and temperature for the study area was sourced from NOAA NCDC Global Historical Climate Network.

6. References

Askins R A and Ewert D N (1991). Impact of hurricane Hugo on bird populations on St. John, US Virgin Islands. *Biotropica*, 23(4a), 481-487.

Baker C B, Eischeid J K, Karl T R, and Diaz HF (1994). The quality control of long-term climatological data using objective data analysis. Dallas, TX: Preprints of AMS Ninth Conference on Applied Climatology, January 15-20, 1995.

Billings R F and Schmidtke P J (2002). Central America southern pine beetle / Fire management assessment. [pdf] USA: USDA. Available at: < http://www.fao.org/forestry/9316-084ee8938d876b19c18e41110ef6dcf8e.pdf>

Boose E R, Foster D R and Fluet M (1994). Hurricane impacts to tropical and temperate forest landscapes. *Ecological Monographs*, 64(4), 370-400.

Boucher D H, Vandermeer J H, Mallona M A, Zamora N and Perfecto I (1994). Resistance and resilience in a directly regenerating rainforest: Nicaraguan trees of the Vochysiaceae after Hurricane Joan. *Forest Ecology and Management*, 68, 127-136.

Brokaw N V L and Grear J S (1991). Forest structure before and after hurricane Hugo at three elevations in the Luquillo Mountains, Puerto Rico. *Biotropica*, 23(4), 386-392.

Brokaw N V L and Walker L R (1991). Summary of the effects of Caribbean hurricanes on vegetation. *Biotropica*, 23(4), 442-447.

CATHALAC/SERVIR (2010). Forest damage caused by hurricane Richard. [jpeg] City of Knowledge, Panama: CATHALAC/SERVIR/NASA. Available at: <http://www.servir.net/images/desastres/2010-10-21_TT_Richard/bz_hurricane_richard_forest_damage_v3.jpg>

Chavez L and Patterson H (2007). Emergencies causing higher fire risks: hurricane Felix in Nicaragua. *The 5th international wildland fire conference*. Sun City, South Africa 9-13 May 2011. Available at: < ftp://ftp2.fs.fed.us/incoming/wo_fam/Wildfire2011%20Conference.SouthAfrica/Wildfire2011%20e-programme/Programme%20contents/Wildfire2011%20Conference%20Papers/Wildfire2011%20Conference%20Papers/Conference%20Papers/Herbert%20Patterson.pdf>

Cherrington E, Eck E, Cho P, Howell B, Hernandez B, Anderson E, Flores A, Garcia B, Sempris E and Irwin D (2010). Forest cover and deforestation in Belize: 1980-2010. [pdf] City of Knowledge, Panama: Cathalac SERVIR/NASA. Available at: <http://www.servir.net/servir_bz_forest_cover_1980-2010.pdf>

Davies D K, Ilavajhala S, Wong M M and Justice C O (2009). Fire Information for Resource Management System: Archiving and Distributing MODIS Active Fire Data. *IEEE Transactions on Geoscience and Remote Sensing,* 47(1), 72-79.

ESRI (2011). ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute.

Giglio L, Descloitres J, Justice C O and Kaufman Y (2003). An enhanced contextual fire detection algorithm for MODIS. *Remote Sensing of Environment,* 87, 273-282.

Holland G J and Webster P J (2007). Heightened tropical cyclone activity in the North Atlantic: natural variability or climate trend? *Philosophical Transactions of the Royal Society A,* [online] doi:10.1098/rsta.2007.2083

Justice C O, Giglio L, Korontzi S, Owens J, Morisette J T, Roy D, Descloitres J, Alleaume S, Petitcolin F and Kaufman Y (2002). The MODIS fire products. *Remote Sensing of Environment,* 83, 244-262.

Kaiser J (2001). Building a case for biological corridors. *Science*, 293, 2199.

Kellman M and Meave J (1997). Fire in the tropical gallery forests of Belize. *Journal of Biogeography*, 24, 23-24.

Lugo A E (2008). Visible and invisible effects of hurricanes on forest ecosystems: an international review. *Austral Ecology*, 33, 368-398.

Mahli Y and Wright J (2004). Spatial patterns and recent trends in the climate of tropical rainforest regions. *Philosophical Transactions of the Royal Society London B,* 359, 311-329.

Meerman J (2001). A first assessment of damage to terrestrial ecosystems in southern Belize as caused by hurricane Iris of October 8, 2001. [pdf] Belize: BENCO. Available at: < http://biological-diversity.info/Downloads/damage%20assessment%20Iris_sm.pdf>

NASA/University of Maryland (2002). MODIS Hotspot / Active Fire Detections. Data set. MODIS Rapid Response Project, NASA/GSFC [producer], University of Maryland, Fire Information for Resource Management System [distributors]. Available on-line [http://maps.geog.umd.edu]

Ray D K, Welch R M, Lawton R O and Nair U S (2006). Dry season clouds and rainfall in northern Central America: Implications for the Mesoamerican Biological Corridor. *Global and Planetary Change*, 54, 150-162.

Tanner E V J, Kapos V and Healy J R (1991). Hurricane effects on forest ecosystems in the Caribbean. *Biotropica*, 23(4), 513-521.

Tossas A G (2006). Effects of hurricane Georges on the resident avifauna of Maricao State Forest, Puerto Rico. *Caribbean Journal of Science,* 42(1), 81-87.

Vandermeer J, de la Cerda I G, Boucher D, Perfecto I and Ruiz J (2000). Hurricane disturbance and tropical tree species diversity. *Science*, 290(5492), 788-791.

Waide R B (1991). Summary of the response of animal populations to hurricanes in the Caribbean. *Biotropica*, 23(4a), 508-512.

Wiley J W and Wunderle J M (1993). The effects of hurricanes on birds, with special reference to Caribbean islands. *Bird Conservation International*, 3, 319-349.

8. Biography

Percival Cho is a 3rd year PhD student at the Lancaster Environment Centre. His research interests are tropical forests and hurricane disturbance. His research is focussed on the use of long-term forest plot data and remote-sensing to study the effect of hurricane disturbance on tree diversity and carbon budget of tropical forests.

Alan Blackburn is a senior lecturer at Lancaster University who focuses on developing remote sensing and GIS techniques for ecological and environmental applications.