Forest Ecology and Management xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Abiotic and biotic changes at the basin scale in a tropical dry forest landscape after Hurricanes Jova and Patricia in Jalisco, Mexico☆

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A R T I C L E I N F O

Keywords:
Enhanced Vegetation Index
Environmental monitoring
Small mammals
Tropical dry forest
Water quality

A B S T R A C T

Given the current evidence of global change, extreme events are projected to be more frequent and intense. At a river basin scale, the immediate effects of hurricanes include changes in soil properties, vegetation structure and composition, and water volume and quality, which lead to changes in species distribution and community structure. The goal of this study was to identify key abiotic and biotic elements for monitoring hurricane events at the river basin scale by linking databases of vegetation cover, small mammal diversity and water quality between 2010 and 2016. Abiotic parameters and biotic communities were monitored in a tropical dry forest (TDF) landscape on the coast of Jalisco, Mexico after two major events: Hurricanes Jova (2011) and Patricia (2015). Three zones (1-upper, 2-middle and 3-lower basin) adjacent to the TDF were analyzed along the Cuitzmala River catchment areas before and after the events. We used the Enhanced Vegetation Index (EVI) as a proxy for vegetation greenness and the diversity index of a small mammal community of rodents and bats as indicators of terrestrial habitat quality, and Fecal Coliform (FC), Fecal Enterococci (FE), and Electrical Conductivity (EC) as indicators of the river-water condition. During the years of hurricanes (2011 and 2015) there was a decrease in the EVI and small mammal diversity, as well as changes in the concentration of FC, FE and EC. The main effects associated with the two hurricanes were observed in the lower basin where hurricanes made landfall and the forest had been converted to other land uses. The EVI, communities of small mammals, and abiotic and biotic water conditions were responsive to the effects of hurricanes and can thus be useful for a long-term ecological monitoring program at the basin scale. This program would allow a faster evaluation and response to future extreme meteorological events. Our results could be implemented through the Urban and Environmental Plans at the state level (*Ordenamiento Territorial del Estado de Jalisco*), through the regulation of sustainable agricultural and livestock techniques, and by educating local populations of the effects of extreme meteorological events.

1. Introduction

Given the current evidence of global change, it is predicted that extreme climatic events will likely occur more frequently and/or will be more intense (Goodess, 2013; IPCC, 2012; Levy and Patz, 2015). The effects of these extreme events depend on the spatio-temporal scale under which they are studied as well as their magnitude and frequency (Gillespie et al., 2006; Mallin and Corbett, 2006; Vandecar et al., 2011).

Hurricanes can increase the availability of habitat for organisms, promote species distribution shifts, increase the variability in ecosystem processes and landscape heterogeneity, alter the direction of ecological succession, change the composition and structure of natural

☆ Part of the Special Issue "Resilience of tropical dry forests to extreme disturbance events: An interdisciplinary perspective from long-term studies".

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http://dx.doi.org/10.1016/j.foreco.2017.10.015
Received 31 May 2017; Received in revised form 6 October 2017; Accepted 8 October 2017

communities, and promote ecological reorganization (Lugo, 2008). These effects can be exacerbated by land-use change, affecting terrestrial and aquatic systems (Erb, 2012; Baker, 2003). The environmental and socioeconomic characteristics of the ecosystems will define their response to the effect of meteorological events such as hurricanes.

Species assemblages after these events may result in communities dominated by secondary forests and invasive species, which may alter the functioning of socio-ecosystems. On the other hand, the risk of being affected by an extreme event is 80 times higher in a developing than in a developed country because of the lack of infrastructure, risk reduction and emergency preparedness (Levy and Patz, 2015).

The immediate effects of hurricanes are related to changes in soil properties, vegetation cover, water volume, and water quality, which in turn affect forest structure and composition (Wang et al., 2010). However, the magnitude of these changes is generally reported at the local scale. Therefore, there is a gap of knowledge on the impacts of hurricanes at broader spatial scales (Steyer et al., 2013), such as watersheds and river basins. Impacts of hurricanes at large scales can affect also human populations, but they are not limited to human-made infrastructure, as they can alter productive systems such as crops and livestock production and increase the exposure to infectious and non-infectious diseases (Khan et al., 2015).

Several studies have used remote sensing to estimate the damage caused by hurricanes and to observe recovery processes in different ecosystems including tropical dry forest (TDF) (Gillespie et al., 2006; Rodgers et al., 2009). There is scarce information on the recovery of TDFs after extreme events such as high-intensity hurricanes (Imbert and Portecop, 2008), especially along the Mexican Pacific coast where this vegetation type predominates. The Enhanced Vegetation Index (EVI) represents a proxy for plant cover and productivity but for a broader damage evaluation it is necessary to consider other biological groups (Steyer et al., 2013). For example, it is expected that populations of nectarivores, frugivores, and seed eaters will be affected by the high hurricane winds that strip flowers, seeds, and fruits (DeGraaf and Miller, 1996). The most representative vertebrate taxa belonging to these trophic groups are rodents and phyllostomid bats. These are the most abundant and diverse groups among vertebrates in the TDF; they occupy all vegetation layers and provide diverse ecosystem services (*e.g.*, pollen and seed dispersal). Therefore, these vertebrates are considered excellent habitat-quality indicators (Istomin, 2009).

At the river basin scale, water microbiological parameters are also good indicators of habitat quality because water is an integrating element of many ecological processes in ecosystems. The alteration of water parameters, such as biomass of phytoplankton or concentration of contaminants as well as the composition of microorganisms and physico-chemical elements, have also been recognized as good tracking features of habitat quality. However, since rivers are highly dynamic systems it is difficult to identify long-term negative changes in water quality (Burkholder et al., 2004), and therefore multi-year data are needed for a better assessment of water quality.

Our interdisciplinary research group monitored the Cuitzmala River basin over a 10-year period. During this period, two strong hurricanes hit the region: Hurricane Jova in October 2011, classified as category 3 (Saffir-Simpson Hurricane Wind Scale), made landfall on the Jalisco coast as a category 2 hurricane (Brennan, 2012), and Hurricane Patricia in October 2015, classified as category 5 (Saffir-Simpson scale), hit the coast near the Cuitzmala River mouth as a category 4 (Kimberlain et al., 2016). Both hurricanes passed through the *Sierra Madre Occidental* region, causing significant damage to native vegetation and croplands. These two events provided a unique opportunity to evaluate the response of abiotic and biotic elements in the Cuitzmala River basin. The goal of this study was to identify key abiotic and biotic elements for monitoring hurricane events at the river basin scale by linking databases of vegetation cover, small mammal diversity and water quality between 2010 and 2016. We predict at a basin scale EVI will change significantly, and as a result there will be a modification of the species assemblages and as well as an impact in water quality parameters. By integrating information generated by different disciplines such as ecology, veterinary medicine, and spatial analysis oriented towards the conservation of tropical areas, we aim to acquire a better understanding of the effects of hurricanes at larger scales, which is fundamental for the development of management strategies designed to reduce socio-ecosystem vulnerability.

2. Materials and methods

2.1. Study site

The Cuitzmala River basin is located on the Pacific Coast in the state of Jalisco, Mexico. The landscape matrix is comprised of the TDF, one of the major vegetation types, wetlands in the lowlands, agricultural fields, and grasslands used for cattle raising (Sánchez-Azofeifa et al., 2009; CIGA, 2008). The basin belongs to the Hydrologic Region RH-15, covering an approximate area of 1096 km^2 (Meléndez, 1999). The study area includes: zone 1 from 2400 to 1000 masl, zone 2 from 1000 to 200 masl, and zone 3 from 200 masl to sea level within the basin (Cotler et al., 2002), including the Southern and Eastern portions of the Chamela-Cuixmala Biosphere Reserve (Ceballos et al., 1999).

The most important feature of the climate is its seasonality, with a rainy season from June to October and a dry season from November to June (Bullock, 1986; García-Oliva et al., 2002). There is a high diversity of flora and fauna, including > 1200, 400 and 2000 species of plants, vertebrates, and insects, respectively (Ceballos and Miranda, 2000; Lott, 2002; Lott and Atkinson, 2002). The predominant vegetation at the selected sampling sites is TDF mixed with agricultural land in the lowlands and riparian vegetation (Fig. 1). Except for the vegetation index, all sampling was performed after Hurricane Jova in 2011 and Hurricane Patricia in 2015, as soon as it was possible to access the study sites. Due to limited accessibility to study sites, the number of samples obtained during hurricane event periods was lower than for years when hurricanes did not occur.

2.2. Vegetation monitoring

To identify changes in the vegetation cover associated with the passage of Hurricanes Jova and Patricia, a series of values from the Moderate Resolution Imaging Spectro radiometer (MODIS)-EVI were assembled and analyzed. The MODIS-EVI product (MOD12Q1) consisted of 16-day composite vegetation images with a resolution of 250 m, which were downloaded from the Oak Ridge National Laboratory (ORNL), Distributed Active Archive Center (DAAC), of the National Aeronautics and Space Agency (NASA) Website (https://modis.ornl.gov/fixedsite/) (ORNL-DAAC, 2008). ArcGIS version 10.2 (ESRI) software was utilized to process and analyze MODIS-EVI data. Two-thousand meter wide buffers, from the point located in the center of the riverbed along a six-kilometer section of the river, were used to extract the main statistics (*e.g.* the mean and Standard Deviation [SD]) of EVI values inside of each buffer. Then, mean EVI values were obtained during October 16 to October 31 in 2011, 2010, 2012, 2013, 2014, 2015 and 2016.

2.3. Monitoring of small mammal communities

Small mammals were captured in sites of the TDF adjacent to the river. Rodents were captured at three selected sites per zone separated by 400 m each one, employing 100 Sherman traps per site, covering the buffer area described previously. Each trap was baited with peanut butter, oats, and vanilla essence, during three consecutive nights in October 2010, 2011, 2014, and 2015 fieldwork seasons. Bats were captured at two sites in natural corridors adjacent to the river per zone separated from each other by at least 10 km, in 2011, 2014, and 2015 with five mist nets (5 × 9 m) per site, which were opened at dusk and