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Hurricane impact on biogeochemical processes in a tropical dry forest in western Mexico

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ABSTRACT

Extreme climatic events (ECEs), such as hurricanes, significantly affect biogeochemical processes and their intensity is predicted to increase. We documented the immediate and short-term consequences of the impact of Hurricane Jova on such processes in primary undisturbed tropical dry forest at the Estación de Biología Chamela. Data from our long-term study in five contiguous small watersheds were used to provide perspective to the hurricane effects. Carbon (C), nitrogen (N) and phosphorus (P) concentrations and fluxes were measured in runoff, litterfall and surface litter prior to and after the impact of the hurricane. Dissolved organic P (DOP) and C (DOC) concentrations in runoff in October 2011 (hurricane landfall), were 96% and 33% greater than the mean concentrations of previous months (July–September 2011). Nutrient fluxes were 10 (DOC), 3 (DON) and 15 (DOP) times greater than the mean fluxes of previous months. N and P concentrations in litterfall collected a few days after the hurricane were not different from pre-disturbance values, but P concentrations were much greater a few months after disturbance. Nutrient fluxes from vegetation to soil due to Jova represented 42% (N) and 30% (P) of the mean annual N and P litterfall fluxes in the period 2010–2012. Surface litter P concentrations, but not N, were very high at the end of the dry season following Jova. In addition, N and P stocks at this time were about 40% higher than the mean stocks in May of the other years of study. Both, litterfall and surface litter P returned to average values about a year after the hurricane. Litterfall P use efficiency, but not N, decreased after hurricane impact. Mean residence time of organic matter and N were similar and did not respond to hurricane disturbance, whereas P residence time was lower and decreased after the hurricane. Overall, our results indicate that hurricane Jova can be identified as an ECE. The return to pre-disturbance values within a year after the event suggests a high degree of short-term biogeochemical resilience in this forest. Variables related to N were resistant (no change) to the impact of Jova and to rainfall variability, but those related to P were highly responsive, quickly recovering to pre-disturbance and long-term dynamics. The P response to the hurricane and its relevance in the ecosystem are discussed in terms of long-term forest productivity and resilience under a scenario of increasing extreme hydrometeorological events.

1. Introduction

In the context of current global environmental changes, extreme climatic events (ECEs) can be considered as infrequent disturbances with a variety of ecosystem level consequences (Smith, 2011). Changes in the incidence and intensity of ECEs and other disturbances may significantly affect global biogeochemical processes such as the C, N and P cycles (Bahn et al., 2014; Reichstein et al., 2013; McLauchlan et al., 2014). It has been suggested that the common definition of ECEs using statistical climatological criteria should be complemented by the type of ecosystem response, extreme or not, to such an event (Reichstein et al., 2013). Therefore, from an ecological perspective, an ECE can be defined as a statistically rare event or unusual climatic period which pushes ecosystem structure or function beyond the typical or normal limits of ecosystem behavior (Smith, 2011).

The type of disturbance and the ecological response usually

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determine the ecosystem recovery pathway, which is known as resilience. According to Hodgson et al. (2015) ecosystem resilience includes two components: (a) resistance, the ability not to change substantially in structure or function in response to disturbance, and (b) recovery, the return path or trajectory to the ecosystem state prior to disturbance. Understanding ecosystem resilience is relevant not only for ecological science, but also to develop management strategies directed to the recovery and maintenance of ecosystem services. The ecosystem response to ECEs may be especially important under the predicted higher intensity of tropical cyclones (Elsner et al., 2008; Knutson et al., 2015).

Among ECEs, high intensity hurricanes can have severe impacts on ecosystems and on human settlements. Hurricanes and typhoons have been considered frequent disturbances to ecosystem dynamics both in the Caribbean and in the Pacific oceans (Tanner et al., 1991; Xu et al., 2004; Wang et al., 2013; Shiels et al., 2014). Several studies in these regions have documented the ecosystem biogeochemical changes after hurricane impact, e.g. litterfall nutrient fluxes or groundwater and stream chemistry (Lodge et al., 1991; McDowell et al., 1996; Herbert et al., 1999; Lin et al., 2003; Xu et al., 2004; Van Bloem et al., 2005; Lin et al., 2011; Wang et al., 2013; Silver et al., 2014; McDowell and Liptzin, 2014). In the case of Mexico, much of our knowledge about hurricane impacts on ecosystems derives from studies on the Atlantic coast and the Gulf of Mexico, such as those that have impacted the Yucatan peninsula (Whigham et al., 1991; Gutiérrez-Granados et al., 2011; Vandecar et al., 2011). Very few studies have documented hurricane impacts and ecosystem recovery on the Pacific coast of Mexico (e.g. this special issue), where a high percentage of the country's tropical dry forests occur. Nine hurricanes category 2 and higher have impacted the coast of Jalisco since 1949 (Blake et al., 2009) and it was only recently that two made landfall in the Chamela-Cuixmala region: Jova (category 2) in 2011 and Patricia (category 4 upon landing) in 2015. A deeper understanding of the ecological consequences of hurricane impact should aid the definition of better management strategies for coastal tropical ecosystems in Mexico.

The objective of this study is to document the impact of Hurricane Jova on biogeochemical processes in primary tropical dry forest (TDF) in the Chamela region, western Mexico. We aim to determine if Hurricane Jova can be defined as an ECE and if the Chamela TDF was resilient to Jova by analyzing biogeochemical variables measured prior (long-term data), during and after hurricane impact. To accomplish this we measured nitrogen (N) and phosphorus (P) concentrations and fluxes in runoff and litterfall and in surface litter and calculated integrative measures of ecosystem response (i.e. residence times and litterfall nutrient use efficiency). When possible, we used pre-hurricane data from our long-term study to provide perspective to the biogeochemical effects of Jova in this tropical dry forest ecosystem. The contribution of long-term research to the understanding of ecological processes, disturbances, and ecosystem resilience has been widely recognized (Strayer et al., 1986; Turner et al., 2003; Likens, 2004; Hughes et al., 2017). Also, a baseline prior to the natural disturbance has recently been proposed as a needed reference to document the degradation or recovery of ecosystem functions (Kotiaho et al., 2016).

2. Materials and methods

2.1. Study area

The study was conducted at the long-term ecological research site of the Chamela-Cuixmala Biosphere Reserve (hereafter, Chamela), in the Pacific coast of Mexico (19°29′N; 105°03′W). The landscape is dominated by low hills (< 300 m elevation) with steep slopes (> 20°) (Cotler et al., 2002). Soils are young, shallow (0.5–1 m depth), predominantly sandy loams, and classified as Typic Ustorthents (USDA system). Average annual temperature is 25.6 °C (1980–2015) with small fluctuations among years (standard deviation of 3.4 °C). Monthly mean minimum and maximum temperatures are 16.4 °C (March) and 32.6 °C (August), respectively. Mean annual rainfall is 800.4 mm (1983–2015), with 87% falling between June and October, and with September (215 mm) as the wettest month on average (data from the meteorological station at Chamela, IBUNAM and the "Watershed Project", UNAM). Rainfall is highly seasonal, with a highly variable annual precipitation regime (annual range from 366 to 1329 mm), which contrasts with the small variation in mean annual temperature. Only 6% of rainfall events are > 50 mm, but these events, associated with hurricane activity, deliver 42% of the total precipitation (Maass and Burgos, 2011; Maass et al., this issue).

The dominant vegetation type is a highly diverse undisturbed tropical deciduous forest (1149 vascular plants), with trees 4–15 m tall and a well-developed understory (Lott and Atkinson, 2002). Forest phenology is markedly seasonal and most species drop their leaves during the dry season each year (Bullock and Solís-Magallanes, 1990). Lott (2002) lists 227 tree species within the Chamela-Cuixmala Reserve, 23% of which belong to Fabaceae, the most important family.

2.2. Field design

Five small contiguous watersheds (Ws I to V; 12–28 ha each) have been gauged for long-term ecological research since 1982 in Chamela (Sarukhán and Maass, 1990; Martínez-Yrízar et al., this issue). Three permanent plots were established along an altitudinal gradient in Ws I. Watersheds II to V included only one permanent plot at the middle position. Each plot was 2400 m^2 (80 × 30 m), with its long axis perpendicular to the stream channel, and covers both slopes of the watershed (generally North- and South-facing slopes). Thus, each slope includes a 1200 m^2 (40 × 30 m) sub-plot, which is divided into 10 × 10 m quadrats.

2.3. Runoff sampling

Coshocton wheels were used to sample the surface runoff at the base of each watershed, which was stored in polypropylene containers (50 L capacity), when storms were strong enough to result in runoff (see Maass et al., this issue) during 2011. Water was collected and kept in amber-colored Nalgen bottles, transported to the laboratory at the field station and filtered with Whatman filters 0.45 µm. Two ml of concentrated sulfuric acid (0.2 ml of acid per 100 ml of water) were added for preservation within two hours of collection. Samples were stored at 4 °C before transportation to the laboratory for nutrient determinations. Runoff volumes were measured with a water level recorder at the weir of each watershed (see Maass et al., this issue).

2.4. Litterfall sampling

Since 1982, fine litterfall has been collected monthly during the dry season and bi-weekly during the rainy season, in 24 litter traps per plot (see Martínez-Yrízar et al., this issue). Fine litterfall samples consisted of all fine dead plant material accumulated in the litter traps (i.e. leaves, reproductive structures and small woody debris ≤1 cm in diameter). Dead branches > 1 cm in diameter were discarded. Litterfall samples were dried at 80 °C for 72 h. In this study, we included samples from the plots in the middle position in each of the five watersheds, collected between July 2010 and June 2013. These represent three phenological years, each starting in July (the month of the rainy-season leaf flush) of a given year to June of the following year (Anaya et al., 2012). To describe in more detail the hurricane impact on litterfall, the litter from six random litter traps per plot was sorted out into two components only in the October 2011 collection date (two weeks after Jova); these are referred to as leaf (blades, petioles, raquises and reproductive structures) and woody (all branches ≤ 1 cm in diameter) litterfall.