Chapter 7
Natural and Human Induced Disturbance in Vegetation

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Abstract The present chapter analyses natural and human disturbance which impacted the vegetation of the Yucatán Peninsula. The relevance of the slash-and-burn system is outlined, a system used for many centuries, and the relevance of fire in this practice. Slash-and-burn and fires provide information about the present structure and composition of the tropical forests of the Yucatán Peninsula. Several seral stages are identified, which agree well with seral stages recognized by modern Maya farmers. In relation to natural disturbance, we analyze the influence of hurricanes and their immediate and general effects on the vegetation and related fauna. Hurricanes and droughts are relevant agents of disturbance, as hurricanes cause considerable structural damage to forests and contribute to the accumulation of large quantities of dry biomass. This biomass can act as fuel for large forest fires. We discuss the natural dynamics that have characterized the vegetation of the Yucatán Peninsula through time, showing that it is a resilient ecosystem.

Keywords Composition change • Fire • Hurricanes • Maya farmers • Milpa • Perturbation • Succession • Structural damage • Tropical forest • Wildlife

7.1 Introduction

The vegetation of the Yucatán Peninsula has been subject to the pressures of natural and human-mediated disturbance for a long time. Paleoecological evidence shows that human influences have been a key factor for the last 3500 years (Islebe et al. 1996; Leyden et al. 1998), when Maya culture began to emerge. The

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G.A. Islebe et al. (eds.), *Biodiversity and Conservation of the Yucatán Peninsula*,
DOI 10.1007/978-3-319-06529-8_7

demographic peak in the late Classic period (300–900 AD) forced the Maya to develop advanced agroforestry systems. To fulfill the needs of a burgeoning population, agricultural areas increased during the Maya Classic period (Flannery 1982; Siemens 1978; Gómez-Pompa et al. 1987). The vegetation provided additional uses (Barrera et al. 1976; Folan et al. 1979). Lambert and Arnason (1982) suggested that the present floristic composition of tropical forests in the Yucatán Peninsula is tied to agroforestry practices of the ancient Maya, considering the abundance of arboreal species such as breadnut or Maya nut (*Brosimum alicastrum* Sw.), guaya (*Talisia oliviformis* [H.B.K.] Radlk) and sapodilla (*Manilkara zapota* [L.] P. Royen), among other species. The presence of many pyramids and other structures that are covered by vegetation in the tropical forests of the Maya realm is evidence that forests established in former agricultural areas and ceremonial centers after 900 AD. Population reduction continued until the Spanish conquest and establishment of Mexico as a country (de Landa 1566/1982; Hammond 1982). However, over the last 170 years, the vegetation of the Yucatán has been placed under enormous pressure of a different nature and intensity. With the steady increase in population, shifting cultivation increased (Read and Lawrence 2003; Dalle et al. 2011), based on an ancient system that has been used for millennia until the present.

From 1850 onwards, large areas of forests were cleared to plant *henequén* (*Agave fourcroydes* Lem.) for the production of rope fiber and a traditional Mexico alcoholic beverage, *Licor del henequén*. For more than a century, henequen plantations were the main agricultural activity and source of revenue for the State of Yucatán. Between 1890 and 1945, exploitation of sapodilla latex for *chicle* production was an important economic activity, mainly in the States of Campeche and Quintana Roo. This was a sustainable activity, which helped to maintain the forest in good condition for conservation purposes. When demand for chicle declined, timber extraction became the main forest activity, causing the near-extinction of *caoba* or Honduran mahogany (*Swietenia macrophylla* King) and Spanish cedar (*Cedrela odorata* L.). More recently and since the early 1970s, extensive animal husbandry and sugar cane production has expanded across the Yucatán Peninsula, converting large forested areas into crop or pasture lands. The Yucatán Peninsula can be further characterized as a hurricane-sensitive region, given that it is influenced by two major hurricane areas, i.e., the eastern Caribbean and the Atlantic region, the latter being an area under regular hurricane influence. During the period between 1871 and 2013, about 50 hurricanes hit the eastern coast, while 45 hurricanes passed by the Yucatán Peninsula (Jáuregui et al. 1980; NOAA 2015; Fig. 7.1). These metereological phenomena are the main agents of natural disturbance in the Yucatán Peninsula, and experienced an increase in number and intensity since the 1980s, which is driven by a changing climate due to increased greenhouse gas concentrations in Earth's atmosphere.

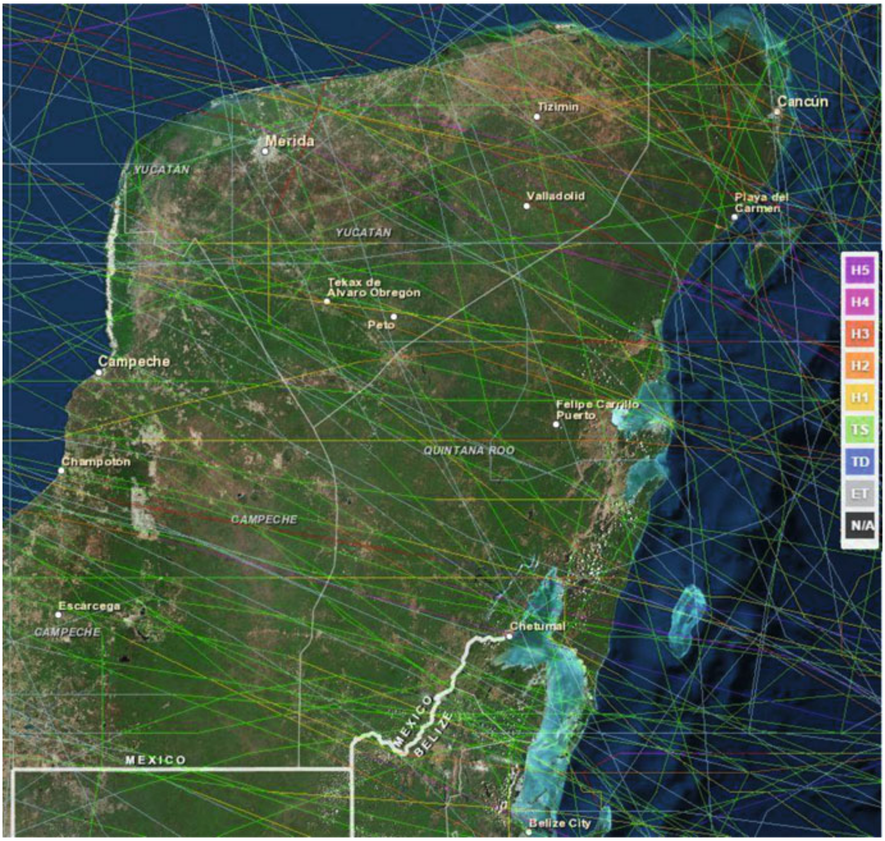

Fig. 7.1 Hurricane incidence between 1843 and 2013, based on NOAA database. http://www.coast.noaa.gov/hurricanes/*H5* hurricane 5 on Saffir-Simpson scale, *H4* hurricane 4 on Saffir-Simpson scale, *H3* hurricane 3 on Saffir-Simpson scale, *H2* hurricane 2 on Saffir-Simpson scale, *H1* hurricane 1 on Saffir-Simpson scale, *TS* tropical storm, *TD* tropical depression

7.2 Importance of Fire as Disturbance Agent in Vegetation

The application of fire in the Yucatán Peninsula continues to be the common practice of Maya farmers, who use the slash-and-burn system to manage their *milpas* (fields of corn, bean and squash, among other crops; Toledo et al. 2008). Detailed knowledge of milpa management and *cosmovision*, understanding the world, is provided by Atran (1993), and by Ford and Nigh (2009). In local communities, burning is performed by organized groups, which establish *guardarrayas* (fire control strips) to prevent fires from extending to nearby areas. Fire control strips are important, given that prescribed fires occasionally burn out of control and can potentially cause large-scale forest fires. Thus, it is not surprising that most forest fires are detected during months with low levels of precipitation

(April, May and June; 87 % of all fires) After hurricanes strike the forest, large forest fires can develop due to the large quantities of fallen leaves, branches and trees that accumulate on the ground, and which act as a natural fuel. These fires can cover hundreds or thousands of hectares of forest (López-Portillo et al. 1990).

In comparing areas that were affected by fires during hurricane impacts versus areas where fires occurred without hurricanes from 1993 to 2004, 123 reported fires damaged 97,560 ha of forest, compared to 8132 ha that were damaged by fire alone (CONAFOR 2005). It should be mentioned only two hurricanes that were reported in 1995 (Roxanne and Opal) affected *ca*. 700,000 ha of forest. Due to effective fire prevention at that time, only 2200 ha were damaged (less area than the average area for the previous hurricane-free period). In a second case (1975), Hurricane Carmen (1974) caused forest fires, which damaged 97,655 ha, while forest fires that were incurred by the effects of Hurricane Gilbert (1989) damaged more than 135,000 ha (López-Portillo et al. 1990). In most cases, the causes of fires were that they were not controlled during slash-and-burn operations. Tropical forests of the Yucatán Peninsula are ecosystems that are sensitive to the effects of fire, but some species may respond positively to the presence of fire. Alternatively, fire is a disturbance that plays a role in favoring certain species and habitats, such as Honduran mahogany (Snook and Negreros-Castillo 2004) and associated species. Although fires are one of the main agents that have shaped the present tropical forest communities of the Yucatán Peninsula (Sánchez-Sánchez and Islebe 2002), their impacts and dynamics have not been well documented. In an early study by Pérez (1980) regarding the climate and forest fires in Quintana Roo, he discussed the ecological and economic aspects of fire, mentioning that its notable effects included reducing forest diversity and changing ecological conditions of the areas where fires develop. Damage of woody products, which could be commercially valuable, range from simple burns to the destruction of adult trees and the additional damage that is caused to trees by insects and diseases as a consequence of their exposure to fire. Some researchers, such as Gómez-Pompa et al. (2003) and Dickinson et al. (2001), mention that fire can irreversibly damage younger trees and juveniles, causing the disappearance of forests over the long-term. The damage that fires cause to soil, upon which tree species depend for their growth (Urquiza-Haas et al. 2007; Vargas et al. 2008), reduces vegetation cover temporarily. Soil is exposed to the action of wind and water, thereby accelerating processes of soil erosion and degradation (Castellanos et al. 2001). Microclimate is also influenced, an effect that might be difficult to detect in early stages; if fires are more frequent, changes become more noticeable (Allen and Rincon 2003).

In 1989, a year after Hurricane Gilbert, a long dry period caused several fires that affected large areas of northern Quintana Roo. About 130,000 ha of tropical forest burned. In analyzing the effects of burning on tropical forest, López-Portillo et al. (1990) conducted preliminary assessments of the 1989 fires. These authors report that the fires exerted differential effects on the vegetation, creating a mosaic of varying degrees of disturbance. Areas of disturbance were classified as: (1) superficial damage, where only the herb and shrub layer was affected; (2) intermediate damage, where some trees were burned along with the herbs and shrubs; and

(3) complete damage, where intense fires affected all vegetation layers, including the canopy. In the assessment, 28,200 ha were recorded as suffering complete damage, 33,500 ha experienced intermediate damage, and 46,300 ha had superficial damage. Concerning the regeneration of plant species, a comparison between sampling sites (hurricane-impacted sites vs hurricane- and fire-impacted sites), the following results were obtained: at the hurricane sites, only 46 % of all recorded species grew from seeds, while the rest were classified as resprouters; and 12 % of the species recovered from seeds and sprouts. Frequency per square meter was 48.6 %. In the sites that were affected by both hurricanes and fire, only resprouting was observed. Cover estimate in the herb layer was 14.8 %, which was 70 % less than the exclusively hurricane-damaged sites. The authors noted that burned tree and palm species presented 86 % of the species found in the fire-damaged areas. Survival was calculated at 33.5 %, including those individuals that were capable of resprouting from the base of the trunk. The tallest trees suffered the highest mortality, but there were survivors in all diameter classes. In the burned areas, the number of individuals was reduced by nearly 50 % compared to the hurricane damaged area; however, the range of life-forms (trees, shrubs, and vines) remained constant. Most species corresponded to the tree layer, and of these, a substantial fraction (25 %) were canopy species common to less disturbed forests of Quintana Roo. Considering these results and the known recovery of forests after slash-and-burn practices, we could consider that forests have developed a high degree of resilience. However, the occurrence of repeated forest fires in the burned areas of 1989 and the shortening of fallow periods have caused an interruption in the natural successional process and favored conditions for the wide dispersal of bracken fern (*Pteridium aquilinum* [L.] Kuhn), which is common in disturbed tropical forest areas (Schneider 2006; Schneider and Fernando 2010). At present, areas invaded by this fern present one of the main risks of forest fires. Detailing the role of fire in forest structure and dynamics of the Yucatán Peninsula is crucial, particularly forest fires that occur over large areas, as these cause the greatest damage on both ecological and economic scales. Also, large forest fires threaten ecosystem services and continuity of forests in the region. Due to climate change, an increase in fires is expected in the future, as forests will likely be more sensitive to drought events (Valdez-Hernández et al. 2014). Hardesty et al. (2005) pointed out that alteration of the fire regime in these ecosystems is the main threat and that such changes will affect conservation of key species, and rare and threatened species.

7.3 Slash-and-Burn Systems, and Maya Nomenclature of Different Seral Stages of Tropical Forest

In the Yucatán Peninsula, the main economic activity of Maya farmers is milpa-based agriculture, an ancient practice which is based on shifting cultivation and traditional techniques that have been known for the last 4000 years (Ucan-Ek

Table 7.1 Maya nomenclature on seral stages

Maya terminology	Milpa type
Sak'aab kool (kool: step away)	Recently abandoned milpa, early succession
Hubche' (hub: tangle; che': stick, tree)	Early succession, 1–5 years post-disturbance
K'ambal hubche' (k'ambal: mature)	Succession, 5–10 years post-disturbance
Ka'anal hubche' (Ka'anal: tall)	Succession, 10–15 years post-disturbance
Kelemche' (kelem: strength)	Succession, 15–30 years post-disturbance
Ka'anal k'aax (k'aax: tropical forest)	Old-growth forest, >30-years-old

et al. 1984; Hammond 1982). This system consists of felling tropical forest in areas of 0.5–3 ha or more (Sánchez-Sánchez and Islebe 2002). Trees that have specific uses for forestry, fodder, religious purposes, shade or fruit crops are frequently excluded from the felling process. This use is part of a strategy considering the holistic use of a various species (Toledo et al. 2008). Gómez-Pompa (1987) suggested the possibility that Maya nut, sapodilla, *zapote prieto* or black sapote (*Dyospiros digyna* [J.F. Gmel.] Perrier), mamey sapote (*Pouteria sapota* [Jacq.] H.E. Moore and Stearn), cainito (*Chrysophyllum cainito* L.), pawpaw or soursop (*Annona* sp.), and *pimenta* or allspice (*Pimenta dioica* [L.] Merr.) were remnants of ancient silvicultural practices of the Maya culture, which could explain their presence and dominance.

Local farmers give specific names to various stages of milpa-based agriculture (Table 7.1).

First-year milpa is called *milpa* (*ch'akbe'en*) and offers the greatest yield. The second year of sowing is called *cañada* (*sak'aab*) and results in lower yields. After the second yield, the field is abandoned to natural succession; vegetation regeneration depends upon certain factors, which are determined by previous management practices. After nearly 30 years, vegetation recovers and the process of slash-and-burn is repeated with the sowing of new *milpas*. The fallow period is known as *barbecho* and is a factor critical for the functioning of the system. Dalle et al. (2011) noted the danger of degradation if the fallow period is shortened to just 4 or 5 years. Gómez-Pompa (1987) concluded that in isolated conditions and at low population densities, these agroforestry systems function well. Maya nomenclature, which defines the seral stages of this system, have been described for the Yucatán Peninsula by Flores and Ucan (1983) and Gómez-Pompa (1987) and is consistence with field observations.

A study by Sánchez-Sánchez et al. (2007) analyzed a successional sequence in northern Quintana Roo that compared tree species in different seral stages (Table 7.1), including *Ka'anal k'aax* (mature forest >70-years-old), *K'ambal hubche'* (5-year-old slash-and-burn), *Ka'anal hubche'* (15-year-old slash-and-burn), and *Kelemche'* (20-year-old slash-and-burn), together with plots subjected to fires (2-year-old, 13-year-old). They found that mature tropical forest had the highest number of species (72), while the lowest number of species (40) was recorded in the 13-year-old fire-successional stage plot. In this study, the distance between the sampling plot and surrounding vegetation was ≤50 m for the 13-year-old successional stage. Floristic richness is lower where fire has been the main cause of disturbance, while floristic richness after 5 years is relatively high in the slash-and-burn system (Valdez-Hernández et al. 2014). Sánchez-Sánchez et al. (2007) and Valdez-Hernández et al. (2014) have noted that differences in numbers of recorded species in the milpa were related to management practices implemented by local farmers. This management included opening the forest canopy, while protecting useful arboreal species, and making fire breaks to protect vegetation from fires. These actions favor mainly vegetative regeneration, the establishment of seeds from remaining trees, and recruitment of propagules from nearby areas. Sánchez-Sánchez et al. (2007) recorded 62 species in a 20-year-old plot, which was just ten species less than the number recorded in mature forest >60-years-old.

In the study described above, the regeneration of slash-and-burn could be classified as a form of auto-succession, where rapid re-establishment of the floristic composition is achieved by two effective mechanisms of regeneration: resprouting by remaining vegetative structures that are resistant to fire, and recruitment of germinants from the soil seed bank that can survive fire, such as like *Sabal yapa* C. Wright ex Bec, thatch palm (*Thrinax radiata* Lodd. ex Schult. and Schult. f.) and Mexican silver palm (*Coccothrinax readii* H.J. Quero). The latter three palm species are characteristic of northern Quintana Roo (Quero 1992). Seeds are also brought in by dispersal nearby areas. Thus, two types of dispersal operate in these forests, *i.e*., resprouting and seed dispersal, observations that consistent with those of similar forest types (López-Portillo et al. 1990; Valdez-Hernández et al. 2014). With respect to dominant plant families, the Fabaceae is the most important family, followed by the Myrtaceae, Rubiaceae, Euphorbiaceae and Sapotaceae (Ceccon et al. 2002; Sánchez-Sánchez and Islebe 2002; Snook and Negreros-Castillo 2004; Vandecar et al. 2011; Dupuy et al. 2012; Valdez-Hernández et al. 2014). Many species in these families are heliophytes, hence it is not unusual to find them as components of mature forest, including false tamarind (*Lysiloma latisiliquum* [L.] Benth.), *mata ratón* (*Gliricidia sepium* [Jacq.] Kunth ex Walp.), glassywood or *ronrón* (*Astronium graveolens* Jacq.), Spanish cedar (*C. odorata*), *pochote* (*Ceiba aesculifolia* [Kunth] Britten & Baker F.), and caimitillo (*Chrysophyllum mexicanum* Brandegee ex Standl). Of all of the described seral stages, farmers prefer *Ka'anal k'aax* (old-growth forest >30-years-old) in which to apply slash-and-burn. However, mature forest stands are hard to find, so farmers will apply slash-and-burn to younger seral stages, or even to mature *hubche'ob*. The total available area of *ejidos* is limited, while continual population growth is observed. The traditional strategy of management appears to have reached some limits, which could cause a severe ecological imbalance (Dalle et al. 2011). This response is frequently observed in the central parts of Quintana Roo, where a large proportion of Maya farmers live.

The *Hampea trilobata*-*Metopium brownei*-*Bursera simaruba* plant community (Sánchez-Sánchez and Islebe 2000), which is distributed in the east-central region of the peninsula between Tulum and Carrillo Puerto, has abundant *che che'en* or black poisonwood (*M. brownei* Roxb.) and *S. yapa*, which are both fire resistant, together with gumbo-limbo or *chaca* (*Bursera simaruba* [L.] Sarg.) and tzitzilché (*Gymnopodium floribundum* Rolfe), which are abundant species in secondary vegetation. This community has low canopy heights of 12–15 m, suggesting that it may be in early successional stages of 8–10 years. The resulting lack of advanced successional areas prompts farmers to use these early successional forests for milpa with consequent lower yields (Dalle et al. 2011).

7.4 Importance of Hurricanes as Factors of Disturbance in Vegetation of the Yucatán Peninsula

Hurricanes are considered to be among the most dangerous and destructive natural phenomena, due to the strength of their winds (up to 300 km/h), heavy rainfall and heavy flooding. The flat relief of the Yucatán Peninsula increases its vulnerability to hurricanes, as it favors the inland advance of these storms. There is no substantial variation in elevation or presence of mountain barriers that would slow or impede wind flow (Jáuregui et al. 1980; Wilson 1980; Whigham et al. 1991; Sánchez-Sánchez and Islebe 1999, 2000; Boose et al. 2003; Sánchez-Sánchez et al. 2007). Over the past 60 years, the most destructive hurricanes in the region were Janet and Hilda (1955), Behula (1967) and Carmen (1974). One of the most destructive hurricanes of the 1980s was Gilbert, with wind speeds of more than 280 km/h and maximum gusts of 350 km/h. Minimum pressure in the eye of the hurricane was 886 millibars (88.6 kpa, lowest value ever recorded); the storm was catalogued as a category five hurricane following the Saffir-Simpson scale (Jáuregui et al. 1980). After Gilbert, the peninsula was struck more frequently by strong hurricanes. Between 1990 and 2005, nine major hurricanes caused severe damage; 2005 was an important year as three hurricanes that made landfall, Emily, Stan and Wilma (Saffir-Simpson scale 4), caused the most destruction (Sánchez-Sánchez et al. 2007; Bonilla-Moheno 2012). In 2006, no hurricane was recorded, but Hurricane Dean entered southern Quintana Roo as a category five storm in 2007 (Islebe et al. 2009). The destructive effects that hurricanes have on vegetation in the wider Caribbean area have been detailed in a series of studies by Webb (1958), Craighead and Gilbert (1962), Dittus (1985), Brokaw and Grear (1991), Walker (1991), Imbert and Portecop (2008) and Zimmerman et al. (2014). Few detailed analyses of hurricanes and their biological effects or evaluations of biodiversity exist (Tanner et al. 1991; Zimmerman et al. 1996; Vandecar et al. 2011). The most detailed analysis is still that of Whitmore (1989), who conducted research in the Solomon Islands. A special volume on hurricane effects on vegetation (Lodge and McDowell 1991) emphasized that hurricanes are disturbances that are capable of changing processes in an ecosystem on both a short- and a long-term basis, and though the periodicity of hurricane impacts seems low (years or decades), those processes are shorter than the life cycle of the canopy or ecosystem. Lodge and McDowell (1991), therefore, considered that cyclones or hurricanes have profound effects on population dynamics, soil development and nutrient cycling over relevant temporal and evolutionary scales across most of the Caribbean region. In the case of the Yucatán Peninsula, the first description of a hurricane was provided by the Roman Catholic Bishop of Yucatán, Diego de Landa, who wrote in 1566:

> a wind came . . . it became stronger, converting into hurricane . . . and this wind caused the fall of all trees, . . . and the earth remained without trees, and the present trees seem to have been planted at the same time, as watching them from higher ground, they all look they have been cut by the same scissor (de Landa 1566/1982).

Detailed effects of hurricanes on the Yucatán Peninsula have not been evaluated until recently by Rodríguez et al. (1989), Sánchez-Sánchez and Herrera (1990), Olmsted et al. (1990), Whigham et al. (1991), Sánchez-Sánchez and Islebe (1999, 2002), Boose et al. (2003), Sánchez-Sánchez et al. (2007) and Bonilla-Moheno (2012). The first five studies refer to the effects of Hurricane Gilbert on the vegetation of northern Quintana Roo. Sánchez-Sánchez et al. (2007) and Bonilla-Moheno (2012) refer to damage caused by Hurricanes Wilma and Emily. Most of the studies describe the major kinds of damage incurred to the vegetation, such as falling trees, defoliation, and accumulation of plant biomass on the ground. Sánchez-Sánchez and Islebe (1999) provide a detailed description of the damage that the tropical forest suffered following a category five hurricane. These authors compare post-hurricane data with previous structural and compositional data of Sánchez-Sánchez (1987). The tree and shrub layer experienced 100 % defoliation by the hurricane, while the herb layer was completely covered with leaves and twigs. The quantity of fallen leaves was about 4.5 Mg/ha dry mass. Whigham et al. (1991) report a much higher value one month after Hurricane Gilbert, *viz*., 1500 g/m^2 (15 Mg/ha). These litterfall data, when combined with adverse climatic conditions that are incurred by drought and the use of slash-and-burn, suggests a debris load that more than sufficient to fuel large-scale fires (a total of 135,000 ha; López-Portillo et al. 1990). With respect structural damage, mean canopy height (between 3 and 8 m) height decreased by 6 %, while the upper canopy decreased by 9 % (between 8.1 and 16 m). The reduced canopy height of tropical forests is clearly related to hurricane activity (Sánchez-Sánchez and Islebe 1999; Islebe et al. 2009). Given that hurricanes are recurring events, they periodically prune the canopy, which incurs a higher energetic cost to trees, explaining the delay in growth.

Whigham et al. (1991) report a tree mortality of 12.6 % (182 out of 1447) for a tropical forest in northern Quintana Roo 2 years after hurricane Gilbert. A 33 % decrease in the number of individuals and a 12 % decrease in basal area were observed. Of all of the fallen trees, 96 % belonged to small diameter classes (class 1 = 3–10 cm). This contrasts with the findings of Walker (1991), who worked in El Valle, Puerto Rico, and reported for that the tallest and larger diameter classes were uprooted or their trunks were split. Trees with large diameters that are located in tropical forest near the Caribbean coast are well rooted and, therefore, more resistant to strong winds. Sánchez-Sánchez and Islebe (1999) report that even though most trees of diameter class > 20 cm remained standing, most accrued damaged to their branches, 100 % exhibited damage to secondary branches, and 55 % received damage to their main branches. Damage at branches additionally caused the release of vines and epiphytes. Damage also varied along the main stem: 50 %, middle parts of the trunk; was 15 %, tree base; and 35 % at root level. The understory lost 51 % of all individuals and cover was decreased by 70 %. Diversity of species and the floristic composition did not change substantially, given that five months after disturbance, only four new secondary species were recorded in the understory. A study of 40 species of secondary vegetation of 15 years of age, after being damaged by Hurricane Wilma in 2005, showed that foliar recovery was extremely rapid (Sánchez-Sánchez et al. 2007). Foliar recovery of the different seral stages took only two months and seven days. Species in the Fabaceae showed the greatest capacity for response, probably due to their deciduous character, making those species more competitive. Greater knowledge is required regarding the response of plant communities and individual species to catastrophic events, such as strategies of recovery, time to recovery, species mortality, adaptations developed by species to resist, and relevance to restoration and aspects of forestry.

7.5 Hurricanes and Habitat Affectation of Vertebrates

The effect of disturbance on habitat and its consequences on the fauna has been poorly studied, despite the close relationship of habitat, organisms that occupy the habitat and their changing abundances (Ramírez-Barajas et al. 2012a). In tropical forests, a large number of tree species are present that produce fruits and attract frugivores as a strategy for seed dispersal (Fleming et al. 1987; Chapman et al. 1994; Milton 2008). Habitat quality can be measured in terms of the availability of fruits or tree species that are of potential use to frugivores. The deterioration of the habitat can be used as base line to analyze the relationship between ecosystem health and faunal abundance. In the Yucatán Peninsula, there is a long history of hurricanes, which have caused damage of variable strength, but few studies have evaluated the effect of these disturbances on biodiversity and ecosystems. In 2007, Hurricane Dean made landfall as a category five storm according to the Saffir-Simpson scale. To evaluate the effect of this hurricane on the vegetation, Ramírez-Barajas et al. (2012b) sampled a total 20,000 m^2 in plots that were located along a gradient from high to low damage. The results of their study indicated that 40–56 % of all trees at a distance of 40 km from the hurricane center were damaged, which was progressively reduced to 1 % damage at 120 km from the hurricane center. The diversity of tree species was assessed and the number of species quantified based on traditional ecological knowledge of hunters and farmers who older were 18 years and old; 65 % of all tree species were reported as sources of food (leaves, flowers, seeds, fruits) for vertebrate herbivores and omnivores. Nine large vertebrates were sampled and their relative abundance was estimated by means of an abundance index of tracks along the same gradient of damage (Ramírez-Barajas et al. 2012a, b). Percentage vegetation damage was negatively correlated with faunal abundance, particularly with herbivores ($F_{1,18} = 24.72$; $P < 0.0001$; Pearson $r = -0.76$). The abundances of frugivores such as the Central American agouti *Dasyprocta punctate* and the paca *Cuniculus paca* ($F_{1,18} = 6.7$; $P < 0.01$; Pearson $r = -0.52$;), together with frugivore browsers such as the white-tailed deer *Odocoileus virginianus* and brocket deer *Mazama* sp. ($F_{1,18} = 8.5$; $P = 0.009$; Pearson $r = -0.57$), exhibited significant decreases with increasing damage to the vegetation. Vertebrates that depended most upon the vegetation as a food source were the most affected, while abundances of species with omnivorous feeding habits did not significantly respond to damage, despite a weak negative correlation for some species, *e.g.*, great curassow *Crax rubra* and ocellated turkey *Agriocharis ocellata* (Pearson $r = -0.19$) and for some, a positive correlation for white-nosed coati *Nasua narica* and collared peccary *Tayassu tajacu* (Pearson $r = 0.25$), and nine-banded armadillo *Dasyprocta punctata* (Pearson $r = 0.26$). In the case of carnivorous vertebrates that were present in the area (i.e., jaguar *Panthera onca*; puma *Puma concolor*; ocelot *Leopardus pardalis*; margay *Leopardus wiedii*; and hog-nosed skunk *Conepatus semistriatus*), Hernández-Díaz et al. (2012) report a weak relationship between abundance and the degree vegetation damage. Although those species are associated with large forest-covered areas (Emmons 1988), they can be found in a wide variety of habitats (Emmons 1988; Villa-Meza et al. 2002; Trolle and Kery 2003; Dillon and Kelly 2007). These species are considered opportunistic carnivores, as their diets include more than 20 prey species (Konecny 1989; Farrell et al. 2000; Villa-Meza et al. 2002). Unlike the other species that have been previously discussed, it was expected that carnivore abundances would not respond negatively to changes in habitat that were caused by hurricanes. Changes reflect other aspects of biology and ecology, including adjustments to diet according to the availability or behavior of prey species and the availability of shelter and habitat use (Hernández-Díaz et al. 2012).

7.6 Conservation Outlook

Land use change is part of the natural history of the Yucatán Peninsula, whether it be at millennial scales (Carrillo-Bastos et al. 2010) or with respect to recent land use changes (Turner et al. 2001). The insufficient time that is given for fallow land to recover is one of the main challenges, which lies beyond understanding of ecological knowledge of tropical forests of the Yucatán Peninsula, and requires holistic conservation approaches. Conservation strategies should involve fauna, as a key element to habitat functioning. Conversion to secondary forests changes carbon sequestration by more than 30 % and nutrient cycles are out of balance (Eaton and Lawrence 2009). So, effective conservation measures must consider resilience of forests and alternative land use practices to guarantee future biodiversity.

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