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Managing the invasion of guava trees to enhance carbon storage in tropical forests

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ABSTRACT

Tropical forests account for a substantial percentage of the world's carbon stocks, but the consequences to carbon storage of the rapid invasiveness of the guava tree in these forests is not known. Two different forest management strategies are practiced in a tropical forest in western Kenya: (1) a protection strategy where human entry is prohibited except for minimalistic human presence (e.g., research activities); and (2) a conservation strategy where human access to the forest and its resources are permitted. We assessed the effects of these management strategies and different levels of disturbance caused by the legacy effects of legal logging activities and the contemporary effects of unauthorized harvesting of forest products on the abundance of guava and non-guava trees and carbon storage in both plant biomass and soil in this forest. We found that guava trees were less likely to thrive and carbon storage in plants and soils was similar in sites with minimal disturbance under both the protection and conservation strategies. However, as disturbance increased, whether by the historical or contemporary effects of human activities, guava trees were more likely to thrive and carbon storage in plants shifted from non-guava trees to guava trees, but without an effect on more stable soil carbon. We conclude that regulations should be strictly enforced to prevent all logging activity, but the conservation strategy would provide similar effects on both forest plant and soil carbon to the protection strategy, while providing benefits to the surrounding community who rely on the forest for cultural and spiritual nourishment.

1. Introduction

Tropical forest ecosystems play an important role in the global carbon cycle (Martin et al., 2013), accounting for 37% of the estimated 1150 Gt of carbon residing in forest ecosystems (Mahli et al., 2002). Tropical forests have undergone a series of natural and anthropogenic disturbances leading to fragmentation and an estimated annual loss in area of about 1 million km^2 globally (Herold et al., 2011) and 25,000 km^2 $year^{-1}$ in the humid tropics (Kim et al., 2015). These disturbances create gaps or open spaces that invasive species use to gain entry, occupy, and eventually colonize the forests (Joshi et al., 2015) as they are able to survive, reproduce, and spread unaided at high rates (van Wilgen et al., 2000; Kawawa et al., 2016a).

Most of the carbon in tropical forests is stored in living plant biomass, unlike boreal and temperate forests in which a greater proportion is stored in the soil and in peat bogs (Mahli et al., 2002). Nevertheless, soil organic carbon (SOC) represents a significant pool of C (Scharlemann et al., 2014; Baccini et al., 2017) in these forests, acts both as a source and sink for carbon dioxide and other greenhouse gases (Barančíková et al., 2010; Stockmann et al., 2013; Lal et al., 2015; Baccini et al., 2017), and has longer residence times compared to carbon stored in biomass (Duarte-Guardia et al., 2018). The amount of SOC in any ecosystem depends on the interaction between litter production and decomposition processes (Post et al., 1982). In general, forest disturbances reduce the amount of SOC (Liao et al., 2015). However, incidences have been documented where invasive plants are more productive than co-occurring native species (Blumenthal et al., 2009; Peltzer et al., 2010) and influence SOC through littering and decomposition in addition to carbon stored in their biomass. Therefore, invasive species may increase the carbon storage potential of forests.

The only equatorial forest remaining in Kenya is Kakamega Tropical Forest, which has undergone a series of disturbances since it was

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gazetted as a Trust Forest in 1933 (Miao, 2008). Logging was practiced in all areas of the forest from 1933 until 1986, a period during which there was massive clearing of the forest for timber and other commercial uses. The largest disturbances occurred along the edges of the forest that were catalyzed in part by the increasing human population surrounding the forest (Vuyiya et al., 2014; Kawawa, et al., 2016b). These disturbances have encouraged proliferation of invasive species including the guava (*Psidium guajava L.*) tree (KIFCON, 1994; Joshi et al., 2015). The guava tree is known to extensively colonize, suppress and eventually out-compete other plants and trees in areas in which it has been introduced (Morton, 1987; Chapla and Campos, 2010). It is an invasive species in many parts of the world (Kawawa et al., 2016a) because of its ability to produce numerous seeds that remain viable for a long time and that are dispersed by avian and mammalian vectors (Kawawa et al., 2016a, 2016b). Although logging has since been largely controlled, cases of illegal logging continue to be reported (Kokwaro, 1988; Bleher et al., 2006; Tsingalia and Kassily, 2010; Ouma et al., 2011; Mutiso et al., 2013; Vuyiya et al., 2014).

The Kenya Wildlife Service (KWS) and Kenya Forest Service (KFS) are tasked with the management of different portions of the Kakamega Tropical Forest. Both Services have categorized the guava tree as a threat to biological diversity (Vuyiya et al., 2014). Their focus is to eliminate or reduce the spread of guava trees but each agency employs different management strategies to achieve this purpose. KWS employs a strict protection strategy in the northern parts of the forest, restricting entry of people except for tourism and research purposes (Kohli et al., 2006). On the other hand, KFS employs a conservation strategy in the southern parts of the forest that permits monitored human access to the forest and its resources; communities living adjacent to the forest are allowed limited access for collecting woody debris for firewood, grass harvesting, and grazing on traditional lands (Tsingalia and Kassily, 2010).

The activities supported by the different forest management strategies are expected to result in different rates of guava tree invasion, with higher rates in the conservation than protection strategy. Increased abundance of the relatively lower story and smaller basal area guava tree may lead to decreases in local plant biomass carbon. Similarly, guava leaf litter contains both allelopathic properties that reduce the density of understory plant growth of native and non-native species in the forest (Kawawa et al., 2016b), and antifungal and antimicrobial properties that inhibit decomposition into soil (Biswas et al., 2013; Mailoa et al., 2014), leading to decreases in SOC. However, few studies have attempted to understand the carbon storage potential of guava trees in tropical forests (Rathore et al., 2018).

This study provides empirical evidence of the effects of guava tree invasions on carbon storage in both plants and soils, and investigates the carbon storage potential of guava and non-guava trees under different forest management strategies and across different levels of disturbance. We hypothesized that (1) forest management strategies that allow greater human access (the conservation strategy) will result in greater guava tree abundance that in turn lowers soil carbon storage compared to management strategies that restrict human access (the protection strategy), and (2) forest carbon storage in plants and soils decreases with increased disturbance levels related to tree removal that results in the opening of areas to invasion and the regeneration of guava trees.

2. Materials and methods

2.1. Study area

Kakamega Tropical Forest is located in western Kenya at 0°8′ and 0°24′N and between 34°46′ and 34°57′E (Fig. 1). The forest covers 240 km^2 with altitudes ranging from 1250 to 2000 m above sea level on the easternmost remnant of the great Lowland Guineo-Congolean rainforest that once stretched across the middle of Africa but has since become fragmented in the last century by humans (KIFCON, 1994). The region experiences a hot and wet climate, with a mean temperature of 25 °C and an annual precipitation of 1500–2000 mm, and a dry season between December and March (Glenday, 2006; Mitchell et al., 2006). The forest has over 400 plant species including 112 tree species (Otuoma et al., 2016). Soils in the forest are heavily leached Acrisols of low fertility and acidic clay loams and clays (pH < 5.5) that overlay gneiss, basalt, phenolite and gold-bearing quartz vein rocks (KIFCON, 1994).

The forest's vegetation comprises: a disturbed primary forest; secondary forests in different stages of succession; indigenous, mixed indigenous and exotic monoculture plantation forests; and both natural and man-made glades (Tsingalia and Kassily, 2010). Closed canopy old-growth natural forest stands are dominated by evergreen tree species (e.g., *Funtumia Africana* Benth. Strapf., *Strombosia scheffleri*, *Trilepisium madagascariense* DC, *Antiaris toxicaria* Lesch., *Ficus exasperate* Vahl., *Croton megalocarpus L.* and *Celtis gomphophylla*) (Glenday, 2006; Lung and Schaab, 2006). The main invasive plant in the interior of the forest is the guava tree (*Psidium guajava L.*), with the invasive species of *Solanum mauritianum* and *Lantana camara* occuring only at the edge of the forest (Obiri et al., 2002). Local communities depend on the forest for limited and authorized access to firewood (Tsingalia and Kassily, 2010), medicinal plants, thatching grass, and grazing in the grassland patches within the forest (Vuyiya et al., 2014). Illegal logging and unauthorized charcoal burning and hunting of small mammals are still prevalent in the forest (Tsingalia and Kassily, 2010).

2.2. Sampling design

Eighteen sites were selected in the Kakamega Tropical Forest – two forest management strategies (protection and conservation) and three disturbance levels (control, low, and high) with three replicate sites for each combination of forest management strategy and disturbance level (Fashing and Gathua, 2004). The disturbance levels were partitioned by the area and intensity of historical and contemporary logging activity. Control sites included remaining stands of primary forests. Low disturbance sites included areas of old, middle and young secondary forest as well as mixed indigenous and plantation forests which have undergone minimal disturbances arising mainly from logging but also tourism activities such as the establishment of trails. High disturbance sites included conditions similar to low disturbance sites although over a greater area and with higher intensity, but also frequent disturbances caused by authorized and unauthorized human activities within the forest. A modified Gentry method (Gentry, 1982; Boyle, 1996), where long parallel transects of individual plots at equal distances are positioned, was used to collect data. Two parallel transects 500 m long and 10 m wide were laid 50 m apart at each site from the site's edge toward its center. Each transect consisted of a series of three 10 m × 10 m quadrats placed at 250 m intervals. Three 1 m × 1 m subplots were randomly established at least 5 m apart in each of the 10 m × 10 m quadrats. Sampling was conducted between August and December 2016.

2.3. Abundance

Guava and other trees with a circumference ≥ 3 cm at breast height measured at 1.3 m were counted in each quadrat. For each site, counts per square meter in each quadrat were averaged and then scaled to hectares to give estimates of abundance in units of stems ha^{-1}.

2.4. Plant biomass estimation

Aboveground biomass (AGB) (dry weight, kg) of each tree was determined through a non-destructive allometric equation developed for moist tropical trees (Chave et al., 2005):