Forest Ecology and Management 354 (2015) 149–159

Contents lists available at ScienceDirect

Forest Ecology and Management

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

Coupled human-natural regeneration of indigenous coastal dry forest in Kenya

David W. MacFarlane [a,*], Andrew T. Kinzer [b], John E. Banks [c,d]

[a] Department of Forestry, Michigan State University, East Lansing, MI 48840, USA
[b] A Rocha Kenya, Watamu, Kenya
[c] University of Washington-Tacoma, Tacoma, WA 98402, USA
[d] Department of Zoology, National Museums of Kenya, Nairobi, Kenya

ARTICLE INFO

Article history:
Received 1 April 2015
Received in revised form 16 June 2015
Accepted 18 June 2015
Available online 27 June 2015

Keywords:
East Africa
Zanzibar-Inhambane
Tropical dry forest
Restoration
Azadirachta indica

ABSTRACT

Remaining fragments of East African coastal dry forests contain very high levels of endemic species and are in critical need of conservation and restoration. Little is known about natural regeneration dynamics of these forests, or the potential for human action to aid recovery of lost structures and functions after deforestation/degradation. Here, data and analyses are presented from long-term monitoring plots in a 20 year-old forest restoration project in Gede, Kenya, in a fragment of Zanzibar-Inhambane (ZI) regional forest mosaic. Study results provided previously unavailable indigenous tree species growth rates and human-assisted forest regeneration rates for ZI forests and highlighted issues relevant to conserving and regenerating remnants of coastal dry forest throughout East Africa. Enrichment plantings accelerated recovery of indigenous tree species diversity and increased species density above natural levels. A strategy of inter-planting within existing natural regeneration, including leaving large relic trees, accelerated regrowth of the forest, but the main beneficiary of the strategy was exotic *Azadirachta indica*, which came to dominate significant areas. Analyses indicated that *A. indica*, which produces insecticidal compounds, was significantly altering the structure of arthropod communities; flying to ground-dwelling arthropod ratios were higher where *A. indica* made up a higher proportion of above-ground woody biomass. Management strategies appear to be mostly restoring indigenous forest structures, despite continued casual illegal tree cutting and invasion by *A. indica*. Analysis of illegally harvested trees highlighted the important role of indigenous tree species as a source of ecosystems services to local people; an important consideration for forest conservation planning worldwide.

1. Introduction

Tropical dry forests are among the most degraded and threatened of tropical ecosystems and there is an urgent need to better understand how coupled human-natural processes can work to conserve and restore them (Vieira and Scariot, 2006). While there have been intensive studies of tropical dry forest dynamics, they have been concentrated in certain places (e.g., Costa Rica, Janzen, 1988) and there is comparatively little data on tropical dry forests in many regions of the world (Tarrasón et al., 2010). In particular, there is a relative scarcity of knowledge regarding regenerative capacity of indigenous tropical forest communities, in response to both natural and anthropogenic disturbances (Chazdon, 2003).

Some of the most vulnerable tropical dry forests may be the remaining fragments of East African coastal dry forests (Burgess and Clarke, 2000), which are part of the Zanzibar-Inhambane (ZI) regional forest mosaic ecoregion (White, 1983); this coastal forest belt once stretched from Somalia to Mozambique. This ecoregion is listed among the 200 most outstanding and representative areas of biodiversity globally (WWF, 2014), part of the Swahilian Regional Centre of Endemism (Burgess and Clarke, 2000). ZI forests include globally important areas for bird conservation and provide habitat for many species of invertebrates, butterflies, large and small mammals, including three globally threatened mammals (Burgess et al., 1998). Many of these forests also have high social value; e.g., a significant number are sacred Kaya forests of the Mijikenda (Kibet and Nyamweru, 2008). Though they contain high levels of endemic species and have been identified as key areas for conservation, little is known about the natural growth rates and regeneration dynamics of ZI forests, or about how to restore and sustain them after degradation.

Recent reviews suggest a need to evaluate forest restoration efforts with respect to both the human and natural components

* Corresponding author.
E-mail address: macfar24@msu.edu (D.W. MacFarlane).

http://dx.doi.org/10.1016/j.foreco.2015.06.026
0378-1127/

of specific forest ecosystem types (Lamb et al., 2005; Chazdon, 2008) and caution against measure of success that attempt to restore forests to a "putative natural state" (Stanturf et al., 2014). This raises important questions for forest managers regarding the relative role of natural regeneration in a global "Anthropocene" (Paquette and Messier, 2009), where anthropogenic process are becoming increasingly dominant. Remnants of ZI forest in Kenya have been estimated to hold more than 50% of Kenya's rare tree species, but are generally small and isolated from each other, embedded in a matrix of farmland, savannah-woodland and thicket (summing to only about 660 km^2 nationwide, Burgess et al., 1998). Though these remnants have some capacity to regenerate themselves, human assistance may be necessary to allow them to retain their indigenous tree species, in the face of exotic and invasive species that have been widely introduced into the landscape, and a continued dependence by local people on wood for lighting and domestic energy production (especially charcoal, WRI, 2007) and poles and timber for home building (Dahdouh-Guebas et al., 2000). Though Kenya's Vision 2030 plan for national development sets a target of increasing forest cover to 10% of the land area (Ogweno et al., 2009), most restoration efforts have been comprised of planting exotic plantations on deforested lands (e.g., Pellikka et al., 2009), with some more limited efforts to plant indigenous species (e.g., Farwig et al., 2008). So, there is a critical need to quantify the regenerative capacity of remaining remnants of indigenous forest and understand the potential for human action to help sustain them over time.

Here, we present the results of a study of coupled human-natural regeneration processes in a fragment of ZI forest in Kenya, where a forest restoration project was established two decades ago. Our broad objectives were to quantify productivity and community dynamic processes resulting from natural regeneration and indigenous species enrichment plantings that employed multi-species mixtures and varied the level of existing vegetation. The latter included retention of an exotic, invasive tree species, *Azadirachta indica*, which we hypothesized could alter community dynamics. We also wanted to quantify human-assisted regeneration rates for ZI forests and establish baseline growth metrics for the large number of tree species, indigenous to East African dry forests, which were planted as part of the restoration effort. Specifically, we examined: (1) the survival and growth of the enrichment plantings and their relative contribution to restoring forest structure and biodiversity, (2) the impact and implications of illegal harvesting on the restoration effort, (3) the relative contribution of natural regeneration to restoring forest structure and biodiversity, and (4) the influence of invasive *A. indica* on forest structure, biodiversity and productivity and on the composition of forest arthropod communities. The latter were chosen because arthropod (especially insect) diversity and abundance are increasingly being used as bio-indicators for environmental change and degradation (Thomas, 2005; Nichols et al., 2007).

2. Methods and materials

2.1. Study area

A restoration project was established in 1992 in an isolated 44 ha fragment of ZI forest at the Gede National Monument (GNM), in Kenya, located at Latitude −3.31° and Longitude 40.01°, at about 20 m altitude above sea level. The climate consists of two rainy seasons annually, which are highly variable in length and intensity from year to year, but the long rains most typically last from March to June and the short rains come in October and November (Roberston et al., 2002). The extended dry periods between the rains and close proximity to the equator create natural conditions for tropical dry forest (Burgess and Clarke, 2000). The GNM itself contains the ruins of a thirteenth-century stone city, a historic site for endemic Swahili culture, which is surrounded by the forest. The perimeter of the GNM was fenced in 1991 to limit casual cultivation, cutting of trees and firewood collection by people from surrounding villages, which contributed to forest clearing and degradation.

The objectives of the original restoration project are explained in Robertson et al. (2002) whom initiated indigenous species enrichment plantings in 1992 to restore a deforested/degraded portion of the forest. Species were selected as being indigenous to Gede or found at other collection sites, but thought likely to be indigenous to Gede. About 45% of materials were wild seedlings collected from the remaining GNM Forest and the other 55% were grown in the nursery from propagated cuttings or seed sources (84% were sourced from Gede NM). Ease of propagation and attractiveness to frugivores were also considered as species selection criteria. Trees were planted from 1992 through 1995, during the long rainy season, in holes about 25 cm depth and at least 1 m apart. Compost was placed in the bottoms of holes and trees were staked. Initial plot maintenance was carried out to keep newly planted trees clear of weeds and vines. Plantings were given water during dry periods up to a year after planting (about 7 l once or twice a week). The average initial height of planted trees was 1 m.

The site was divided into a grid of 400 m^2 monitoring plots, with 1 m buffer paths around them. About half of the plots were in open areas without woody regeneration, with the rest set in areas with some significant woody vegetation already established (small trees and shrubs that seeded into cleared areas); a few plots had a few larger relic trees at the time of planting. In plots with patches of existing woody vegetation, planting was carried out around naturally regenerating seedlings and saplings and trees were planted around relic trees. Roberston et al. (2002) called this planting strategy "copse" planting and hypothesized that it may have some benefits in terms of providing initial ground cover for planted trees. Initial vegetation was not measured, but it was noted that larger remnant trees were mainly *Xylopia parviflora*, *Trichilia emetica*, *Dalbergia melanoxylon* and the exotic *A. indica*. Seedlings and saplings of *A. indica* and the exotic shrub, *Lantana camara* were considered to be weedy invaders at the site.

2.2. Vegetation data collection

In 2012, twenty-nine of the original thirty-two monitoring plots were selected for re-measurement; three of the original plots were cleared for an apiary. A complete census of remaining planted trees on each monitoring plot was conducted, using a stem map describing the location of each planted tree on each plot. A census of non-planted woody plants with any stem with a diameter at breast height (DBH) ⩾ 2.5 cm, measured 1.3 m above ground, was also conducted. If multi-stemmed, the diameters of all stems were recorded.

For each planted tree, the following data were recorded: (1) species, (2) DBH, to nearest 0.1 cm, (3) total tree height (nearest 0.1 m), meaning the height above ground to the highest living point on the tree (live leaf or bud), and (4) a tree status was recorded as live, dead, missing or illegally harvested, the latter meaning the main stem had been cut; in this case stem diameter was recorded at stump height. Trees were also assigned to one of five canopy classes (CC):

1. Suppressed (S) – All parts of the tree's crown are below that of surrounding trees.
2. Mostly Suppressed (M) – Most of tree's crown is below crowns of surrounding trees, but the highest parts extend into gaps in the canopy of taller competitor's.