Forest Ecology and Management 369 (2016) 155–160

Contents lists available at ScienceDirect

Forest Ecology and Management

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

Effects of reduced-impact selective logging on palm regeneration in Belize

Boris Arevalo[a], Jair Valladarez[b], Shahira Muschamp[b], Elma Kay[c], Alex Finkral[d], Anand Roopsind[e,*], Francis E. Putz[e]

[a] Friends for Conservation Development, Chi-Ha Street, San Jose Succotz, Cayo District, Belize
[b] University of Belize, Faculty of Science and Technology, Department of Biology, Belmopan, Belize
[c] University of Belize Environmental Research Institute, Price Centre Road, Belmopan, Belize
[d] The Forestland Group, Chapel Hill, NC 27514, USA
[e] Department of Biology, University of Florida, Gainesville, FL 32611-8526, USA

ARTICLE INFO

Article history:
Received 23 December 2015
Received in revised form 17 March 2016
Accepted 18 March 2016
Available online 26 March 2016

Keywords:
Arecaceae
Biodiversity
Forest disturbance
Forest management
Tropical silviculture

ABSTRACT

To assess the impacts of a low-intensity selective timber harvest on a palm community in Belize, we mapped logging infrastructure (i.e., roads, log landings, skid trails, and stumps) and measured palm regeneration 1 year after a timber harvest carried out using reduced-impact logging (RIL) practices. We sampled palms across a gradient of increasing harvest impact severity from areas not directly affected by logging, in felling gaps, on secondary and primary skid trails, and on log landings. We used generalised linear mixed-effect models fitted in a Bayesian framework and applied a non-metric multi-dimensional scaling of the ecological distances between sites to evaluate differences in palm seedling regeneration density and species composition, respectively. The harvest of an average of 2.5 trees ha^{-1} caused 0.4% of the forest to be converted to log landings, 0.7% and 3.6% to roads and skid trails, and 2.3% to felling gaps, which left 93.0% of the 350 ha harvest block with no direct impacts of logging. The difference in abundance and species composition of palm regeneration in unlogged areas compared to felling gaps and skid trails was small, but log landings had markedly lower densities. These results highlight that the impacts of selective logging are minor at least where harvest intensities are low and RIL practices are employed. If further reductions in canopy opening and soil disturbance are desired, we recommend that logs be cable-yarded (i.e., winched) the final 20 m to skid trails instead of driving to the tree stumps. We estimate that implementation of this practice would reduce total skid trail coverage from 3.6% to 2.9% and overall forest disturbance from 7.0% to 6.3%. However, further reductions in disturbance might be inimical to the maintenance of palms and will certainly not favour regeneration of light-demanding commercial timber species (e.g., *Swietenia macrophylla*).

1. Introduction

Published assessments of the impacts of selective logging on tropical forests mostly focus on invertebrate and vertebrate species (e.g., Berry et al., 2010; Burivalova et al., 2014), with fewer studies on plants (but see Cannon et al., 1998; Duah-Gyamfi et al., 2014; de Avila et al., 2015) and fewer yet where reduced-impact logging (RIL) practices were employed (but see Bicknell et al., 2014). To help sustain timber yields, minimize carbon emissions, and reduce adverse impacts on biodiversity, RIL methods are advocated for selective logging of tropical forests (Putz et al., 2008). Given that RIL and other silvicultural interventions unavoidably and purposefully change forest structure and composition, it is important to document the responses of plant taxa not directly targeted for extraction. Here we focus on the impacts of RIL on palms (Arecaceae) across a gradient of micro-environmental conditions created by selective logging in a lowland tropical forest in Belize.

Palms are geographically widespread, ecologically diverse, and often critical for the maintenance of ecosystem functions, wildlife populations, and local livelihoods (e.g., Balick and Beck, 1990; Goodman et al., 2013). Furthermore, palm resilience to disturbance is well documented for fire-maintained ecosystems (Abrahamson, 1999; Anderson et al., 1991), but not for logged forests. Palms may also be disproportionately prone to damage during selective logging operations given their lack of both taproots and large

* Corresponding author.
E-mail address: aroopsind@ufl.edu (A. Roopsind).

http://dx.doi.org/10.1016/j.foreco.2016.03.040
0378-1127/

diameter structural roots; these characteristics render them easy to topple and hence are often not avoided when roads and skid trails are opened. Palms that have emerged from the establishment growth phase and have their apical meristem above the ground are killed if pushed over (Henderson and Tomlinson, 1991); if palm-rich areas are preferred by heavy equipment operators, infrastructure installation may reduce recruitment by killing reproductively mature individuals (Darrigo et al., 2016). In contrast, palms that are still in the establishment growth phase during which their apical meristem is below-ground generally survive trampling, mowing, burning, or any other activity that kills their above-ground parts (note that stilt-rooted palms do not pass through an establishment growth phase and hence lack the capacity to re-sprout after being top-killed). Given the potential susceptibility of large palms and resilience of small ones, it is not clear how palms fare in areas subjected to selective logging.

In this study we mapped and measured the effects of low-intensity selective RIL on forest structure and palm regeneration in Belize. We categorized disturbances by intensity of surface soil disruption (i.e., compaction and movement by heavy equipment) and changes in understory light conditions. We expected that higher intensities of disturbance favours palms over other plant growth forms because palms tolerate compacted soils (Emilio et al., 2014) and, as seedlings, they readily recover from above-ground disturbances. At the same time, we also expected that low intensity RIL impacts would, overall, be restricted in their distribution and therefore have minimal impacts on palm regeneration (Schwartz et al., 2014). By assessing both the spatial extent of forest management activities and their impacts on palm regeneration in a hurricane-prone forest, we explore the response of the most abundant plant family in the neotropics (ter Steege et al., 2013) to low-intensity selective logging.

2. Methods

2.1. Site description

The study was conducted on the 42,301 ha Laguna Seca property of the Yalbac Ranch and Cattle Corporation in Orange Walk District, Belize (17°15′N, 89°04′W). The area is characterized by lowland, broad-leaved, moist forest on gently rolling karstic topography (~88 m asl) with shallow soils over limestone. The annual average precipitation is ~1400 mm, with a pronounced dry season from February to May. Over the past 5000 years, hurricanes made landfall in central Belize about once per decade (McCloskey and Keller, 2009), but with increased sea surface temperatures, hurricane frequencies and intensities are expected to increase (Knutson et al., 2010). Deforestation rates in Belize between 1980 and 2010 averaged only 0.61% per year, (9650 ha year^{-1}; Cherrington et al., 2010), but this rate recently increased substantially due to deforestation for industrial agriculture (Cherrington et al., 2012) and includes a clearing in excess of 10,000 ha immediately adjacent to the studied forest (personal observation, all authors).

This Forest Stewardship Council (FSC) certified forest is managed under a long-term license that permits selective logging with RIL practices on a 40-year rotation. Commercial trees 45–90 cm DBH (stem diameter at 1.3 m) are harvested at an average intensity of 2.7 trees ha^{-1} (2.9 m^3 ha^{-1}). The principal harvested species are *Swietenia macrophylla* (mahogany), *Calophyllum brasiliense rekoi* (Santa Maria), *Manilkara zapote* (sapodilla), and *Lonchocarpus castilloi* (cabbage bark). Palms present in the study area include the subcanopy (up to 10–20 m tall) species *Cryosophila stauracantha*, *Sabal mauritiiformis*, *Guassia maya* and *Attalea cohune*, two understorey species (*Bactris mexicana* and *Chamaedorea oblongata*), and one liana (*Desmoncus orthacanthus*; all species hereafter referred to by their generic names).

2.2. Data collection and analysis

Data were collected in March 2015 in a 350 ha area that was logged in February–May 2014. Palm seedlings (i.e. individuals with no above-ground stem and leaves <1 m long; no fully stilt-rooted species occur in the study area) were counted in randomly located 2 × 20 m plots across a five-class gradient of disturbance severity in 11 separate harvest areas. In each of the 11 areas we sampled a log landing, a primary skid trail used to yard ⩾2 logs, a secondary skid trail used to yard only one log, a felling gap, and an area of undisturbed forest within the logged area hereafter referred to as 'not affected directly area' (NADA). The average distance between the 11 harvest areas was 800–1000 m, with log landings used as our point of access to the other logging disturbance categories. Skid-trail plots were parallel with and in the centres of skid trails at random locations. NADA plots were randomly located at distances of 25–35 m from the edge of the nearest skid trail or logging gap. Palm seedling data were collected within the 40 m^2 plots, while non-palm woody plant seedlings (<1 m tall), which were much more abundant, were subsampled in five circular 1 m radius subplots located at 5 m intervals along the central axis of each main plot. Relative abundance of palm regeneration was calculated as the sum of all palm seedlings across species relative to the total woody plant regeneration (palm and non-palm woody seedlings). Percent canopy cover was measured at 1 m above the ground with a spherical densiometer (Lemmon, 1956) at 5 and 15 m along each of these transects.

We used the rstanarm package (Gabry and Goodrich, 2016) in R (R CORE TEAM, 2010) to fit generalized linear mixed-effects models in a Bayesian framework to quantify the effects of logging on the abundance of palm regeneration. The model results presented were fitted with a negative binomial distribution to account for the large proportion of zeros in the dataset. Palm species were treated as random effects and logging disturbance as fixed effects. Models with random intercepts and slopes for species across disturbance categories did not converge and were discarded. We report the mean and 95% credible intervals for the effect size of different logging disturbances based on draws from our posterior distribution.

We also estimate the ecological distance between all pairs of plots using the Bray–Curtis method for the species-specific palm abundance data, ignoring non-palm woody regeneration. We apply a non-metric multidimensional scaling (NMDS) to display the rank-order of distances between sites in a two-dimensional unconstrained ordination space. We included a weighted average species score on the ordination plot to allow for interpretation that sites closer to a species would be expected to have high abundance of that species, whereas sites that are farther away are expected to have lower abundance. We preformed these analysis with the Vegan package in R (Oksanen et al., 2010).

We extrapolate our plot level data on the impacts of logging on palm seedling density to the entire 350 ha 2014 logging area in which the locations of all log landings, roads, skid trails, and felled tree gaps were mapped with a GPS. We used the average areas of log landings (1225 m^2) and felling gaps (90 m^2) along with the average widths of roads (7 m) and skid trails (3.4 m) to calculate the proportion of the forest directly affected by logging and to portray those changes on a stylized map of 25 ha (Fig. 1). The map represents actual roads, skid trails, and log landings, as well as the spatial locations of all harvested trees. To visualize the felling gaps, we assigned at random to each tree stump mapped one of the 31 felling gaps we measured and mapped in the field.