Underproductive agriculture aids connectivity in tropical forests.

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Abstract

Establishing connectivity in tropical lowland forests is a major conservation challenge, particularly in areas dominated by agriculture. Replanting schemes have been widely utilized as a method for reconnecting once contiguous forest patches. However, these approaches require funds for both initial planting and subsequent site maintenance. Furthermore, identifying sites for habitat rehabilitation schemes is difficult and may require purchasing of land, sometimes at great expense. Underproductive, often unprofitable, areas of agriculture have the potential to aid in re-establishing forest connectivity via natural forest regeneration. We identified an area of natural forest regrowth, previously cleared for agriculture and abandoned due to high levels of flooding. We assessed the structural regrowth of this forest after a 17-year period, and examined its efficacy as corridor habitat for Bornean elephants. Regrowth areas had re-established tree canopy areas similar to that of adjacent forest, as well as a randomly selected site of uncleared forest. Flooding in the area hampered the regrowth of some sections of the site; however, ~79% of the site exhibited canopy coverage. Aboveground carbon levels have returned to 50% those of uncleared forests, with flooding resulting in areas of reduced vegetation regeneration. Elephants have shown increasing usage of the regenerated forest, suggesting that the area has regenerated its suitability as elephant corridor habitat. We have shown that what would traditionally be thought of as low-quality, flood-prone areas for habitat restoration can be a useful, cost-effective tool for wildlife corridor management. We propose that natural regeneration of reclaimable, underproductive agriculture has the potential to play a key role in lowland tropical forest connectivity, reconnecting now isolated populations of endangered Bornean elephants.

1. Introduction

Tropical forests are primary targets for land conversion due to their high agricultural productivity potential (Hansen et al., 2013). South East Asia, in particular Malaysia, is currently experiencing among the highest rates of forest conversion globally (Achard et al., 2014; Hansen et al., 2013; Pfeifer et al., 2016), and this is largely fueled by the rapid expansion of the palm oil (*Elaeis guineensis*) industry (Gaveau et al., 2016). The island of Borneo has experienced some of the heaviest conversion levels in the region (Achard et al., 2002), with some 18.7 million hectares of old-growth forest cleared across the island between 1973 and 2015 (Gaveau et al., 2014). Of these cleared areas, approximately 23-25% were converted to oil palm plantation within five years (Gaveau et al., 2016).

Oil palm trees produce the highest yields when cultivated in lowland coastal terrain, and require a near-constant water supply (Basri Wahid et al., 2005). However, flooding and standing water within plantations creates a poor growth environment, and areas with periodic flooding may become less productive or even unprofitable, to continue to cultivate (Abram et al., 2014; Sumarga et al., 2016; Woittiez et al., 2017). Lowland forests exhibit higher rates of agricultural conversion (Sodhi et al., 2004), which is particularly important because these areas are associated with high levels of biodiversity (Curran et al., 2004). Therefore, their large-scale conversion to agriculture poses a severe threat to the continued functionality of lowland forest ecosystems, as well as the overall biodiversity of a region (Meijaard and Nijman, 2003; Scriven et al., 2015).

Lack of connectivity caused by high instances of poorly planned land-use change is one of the greatest challenges in modern conservation (Dobson et al., 1997). Reclamation of underproductive agricultural lands represents a major opportunity for restoring once contiguous forest. Complete, or enrichment, replanting schemes generally utilize dozens of native species to quickly establish canopy coverage and encourage faunal repopulation (Bowen et al., 2007; Parotta and Knowles, 1999). These methods are, however, costly both in terms of initial outlay, as well as site maintenance (Brancalion et al., 2012; Zhou et al., 2007). Without enrichment planting, forests are unlikely to reach the level of complexity of old growth forests (Chazdon, 2008). Studies such as Aide et al. (2000) in Puerto Rico, have suggested that enrichment planting may be necessary to achieve community composition in line with old growth forests. Despite this finding, small remnant forest fragments can provide natural seed dispersal capabilities to aid in the natural reconnection of forested fragments (Turner and Corlett, 1996).

Borneo is at the forefront of land conversion for oil palm plantations, with approximately 1.43 million ha cultivated in the Malaysian state of Sabah alone (Abram et al., 2014). The Kinabatangan floodplain is among the largest floodplains in Borneo, providing ideal land for the cultivation of oil palm. This has led to large-scale land clearance and planting (Ancrenaz et al., 2004). Clearance for large estates has often led to the removal of forested areas that would subsequently prove unsuitable for later cultivation. Abram et al. (2014) conducted a study throughout the Kinabatangan to identify areas that were currently being cultivated with low, or even unprofitable yields, and found that almost 16,000 ha (oil palm in Kinabatangan floodplain totals ~250,000 ha) were deemed to be commercially redundant and thus represent significant opportunities for reclamation, or natural successional regeneration.

Reforestation of agriculture, and its potential use in corridor re-establishment, is a crucial recovery tool in sustaining biodiversity levels throughout the tropics. Re-establishing corridor systems and restoring patch connectivity provides the most feasible method of ensuring long-term survival of large mammals in tropical systems, especially for forest-restricted species that range farther and require large home ranges. Bornean orang-utans (*Pongo pygmaeus*) and Bornean elephants (*Elephas maximus borneensis*), for example, have been shown to rely heavily on existing corridor systems, both in terms of population dynamics and genetic diversity (Alfred et al., 2012; Goossens et al., 2005). Bornean elephants in particular range over many kilometers, heavily utilizing highly productive agricultural areas (Alfred et al., 2012). The Kinabatangan floodplain supports a population of ~300 individuals out of an estimated total population of between 1100-3600 individuals (Alfred et al., 2010; Estes et al., 2012). Enhancing connectivity in such an important habitat for this endangered species has become an essential requirement to ensure the continuity of both the elephant population and a burgeoning local ecotourism industry (Hai et al., 2001).

Herein, we examine whether allowing secondary forests to regenerate naturally on abandoned oil palm plantation could provide a cost-effective method of enhancing habitat connectivity for Bornean elephants. We also explore the efficacy of this particular reclaimed forest area as elephant corridor habitat. The main objectives of the study were to 1) examine natural forest regrowth structure and compare against representative intact forest throughout the study site; 2) investigate levels of flooding that initiate oil palm abandonment and its implications for future agricultural reclamations; 3) discuss the value of natural regeneration as a tool for tropical forest connectivity and its use as a corridor by the endangered Bornean elephant.

2. Materials and Methods

2.1 Study Site

The study site (N5.551166, E117.890413) is located in "Lot 5" of the Lower Kinabatangan Wildlife Sanctuary (LKWS). The study region, a large tropical, lowland floodplain, consists of a mosaic of degraded, logged forest and agriculture. Both large- and small-holding agriculture are present in the vicinity; however, both largely focus on oil palm cultivation. Land conversion peaked in the area during the 1970s and 80s, and remnant forest fragments are largely under governmental protection (Goossens et al., 2005), although fragments now exhibit varying levels of connectivity, with complete isolation of several of the LKWS lots. Using data from Gaveau et al. (2014), we determined that the study site had been selectively logged, initially, between the years of 1990 and 1995. Subsequent land clearance for oil palm development was carried out in 1999 and the title transferred to the Sabah Forestry Department in 2000 (M. Martin, pers. comm.). The edge of the cleared area was identified by the remnants of a large drainage ditch visible in the digital elevation model. Clearance was carried out in accordance with Sabah state law which requires the maintenance of a riparian buffer zone (Sabah Land Ordinance, 2010). Numerous forest replanting schemes have occurred within the study region, with Davison & Prudente (2001) representing the largest. This project involved planting within several kilometers of the study site.

2.2 Airborne LiDAR

The study area was mapped in April 2016 using discrete-return airborne Light Detection and Ranging (LiDAR) by the Carnegie Airborne Observatory-3 (Asner et al., 2012). Three-dimensional structural information of aboveground vegetation and terrain were acquired through the use of a custom-built LiDAR subsystem, onboard the CAO (Asner et al., 2012). Precision three-dimensional positions and orientations for CAO sensors were captured using the Positioning System-Inertial Measurement Unit (GPS-IMU) subsystem, this allows for precise positioning of ground-based LiDAR observations. Data collected for this study were were taken from an altitude of 3600 m above ground level, with a scan angle of 36° and a side overlap of 30%. Flights were conducted at a velocity of 150 knots and utilized a LiDAR pulse frequency of 150 kHz, which yielded a mean point density of 3.20 laser shots per m^2. Vertical error was estimated at 7 cm root square mean area (RSME) and horizontal error at 16 cm RMSE.

A 'cloud' of LiDAR data was produced through a combination of LiDAR laser ranges and embedded GPS-IMU data (Asner et al., 2007), determining 3-D laser return locations. Where elevation is relative to a reference ellipsoid, the LiDAR data cloud consisted of a number of georeferenced point elevation estimates. The 'lasground' tool packaged in the LAStools software package (Rapidlasso, Gilching, Germany) was used to process LiDAR data points, detecting which laser pulses penetrated the canopy volume and reached the ground. These points were subsequent used to interpolate a raster digital terrain model (DTM). A further digital surface model (DSM) was created using interpolations of all first-return points, which included canopy top and, bare ground where only ground returns were detected. Disparities between DTM and DSM vertical difference yielded a digital canopy model (DCM). Spatial resolutions of 2 m for both ground elevation and woody canopy height models were derived.

2.3 Bornean elephant GPS tagging

Data from eight Bornean elephants carrying Global Positioning System (GPS) collars as part of a wider home ranging behavior study, were utilized to assess corridor movement behavior. These were the only individuals that utilized the study area within the entire GPS collaring dataset. Throughout this study individuals were GPS tagged using units produced by Africa Wildlife Tracking (AWT, Pretoria, South Africa). GPS units recorded location points every 2 hours throughout the tracking period. All eight individuals tracked were female and thus their movements were likely indicative of herd movement, compared to often solitary males. The mean tracking period of individuals utilized within this study was 677.63 (±192.04) days, with a minimum of one and maximum of three individuals being tracked at any given period between 2010 and 2016.

2.4 Analysis

The LiDAR data were analyzed using both QGIS (Quantum GIS Development Team, 2017) and R statistical software (R Core Team, 2000). Top-of-canopy Height (TCH) was derived from a LiDAR-derived canopy height model (CHM) created by calculating the difference between ground and canopy digital elevation models. Such features as the number of trees per hectare and crown area, were identified using the R package "ForestTools" (Plowright, 2017). A minimum tree height threshold of 4 m was selected to exclude all understory vegetation from the analysis. Quantification of canopy coverage was carried out in QGIS, with gaps identified using crown areas isolated using ForestTools. Digital elevation models (DEM) also produced by the LiDAR mapping were analyzed using the "Raster" package (Hijmans et al., 2016). DEM data were also analyzed using QGIS to identify areas of potential flooding and swamp forest. 1-way Analysis of Variance (ANOVA) tests were performed to assess the variation between regrowth and extant forest fragments. A linear regression was utilized to examine the relationship between the tree counts and site elevation above sea level.

A randomly-selected forest area of equal size was delineated to provide representative habitat variables for the study region. This site provides an assessment of areas within the study region that are likely to have been selectively logged but not having been previously cleared. Selection of a comparison site involved the creation of a buffer along the northern bank of the Kinabatangan River, and 100 randomly generated locations along the buffered zone. A random number generator was then used to select the location of the comparative site. A site of equal size and shape was selected to provide the truest comparative representation of forest in the area. The site was located six km upriver of the study site. Analysis of the comparative site was performed as above to assess standard habitat traits across degraded, un-cleared forest.

Aboveground carbon density (ACD) was calculated for the entire state of Sabah by combining LiDAR TCH models and satellite imaging data (Asner et al. *under revie*w). These data were calibrated using field plots ranging in size from 0.28 ha to 1.0 ha throughout Sabah (Coomes et al. 2017). These ACD estimates were examined across 0.5 m elevations throughout the study site. A linear regression was performed to ascertain the relationship between ACD and site elevation-linked flooding potential.

Due to fluctuations in occurrences in elephant presence between years, data for both regrowth and riparian habitats uses were converted to proportions of overall elephant presence per year. A linear regression was subsequently performed to assess whether a significant trend in habitat use occurred throughout the sample period.

3. Results

The area of regrowth forest (N5.41476; E118.02571) totaled 65.44 ha, bordered by an additional 25.49 ha of remnant intact riparian vegetation. There was approximately a 17-year interval between the clearance of forest (1999) and the LiDAR mapping of the study site (2016). The regrowth area was abandoned after clearance due to high flooding probabilities, as well as presence of standing water (M. Martin, pers. comm.). A total of 16.5 ha (25.21%) of the regrowth forest were deemed to be at risk of flooding through the use of elevation data, being located at below riverbank elevation (Fig. 1). We checked these flood risk areas in the field to examine the efficacy of our flood modelling.

Figure 1. Study region DEM fitted with contours depicting meters above sea level. Differences in elevation resulting from historic irrigation ditches become apparent. Areas less than riverbank elevation were deemed to be susceptible to flooding and permanent swamp.

Over the 17-year regrowth period, cleared forest regenerated total canopy coverage of 51.68 ha (79.0%), whilst remnant, riparian vegetation had an overall canopy cover of 22.24 ha (87.4%). Mean total crown areas across habitat types were similar. However, the slightly higher mean crown areas displayed by regrowth forest tended towards significance ($p=0.06$) (Fig. 2). Differences in tree height significantly differed between habitat types ($p<0.001$), with new growth trees being significantly shorter than the riparian corridor.

Figure 2. Comparisons of a) crown area (m^2) and b) tree canopy height (m) between forest types.

Tree numbers per hectare in the regrowth area were statistically lower than those in the extant forest ($p<0.001$) (Fig. 3a). There was a positive correlation between site elevation and number of trees present in 25 m grids ($p=0.013$) (Fig. 3). This suggests that flooding had a negative impact on tree regrowth and accounts for the lower numbers of trees per hectare found within the regrowth site.

Figure 3a. Tree numbers by 25 m grid across the study site b. Terrain ruggedness analysis, clearly displaying irrigation network dug for agriculture c. Tree height with clear demarcation between cleared and un-cleared sites d. DEM of site showing areas of potential flooding.

Mean ACD values for the regrowth and riparian sites were 23.37 Mg C ha^{-1} and 45.30 Mg C ha^{-1}, respectively. This equates to an approximated ACD of 51.59% over the 17-year period, since clearance. The riparian site is likely to have been selectively logged in the past; however, this ACD value is unlikely to represent true historical carbon stocks of the area. A positive correlation ($p<0.01$) between increasing elevation and ACD showed that flooding hampered the re-establishment of those areas of regrowth site that were at lowest elevations (Fig. 4).

Figure 4. Aboveground Carbon Density (ACD) of the study site against elevations above sea level in 0.5 m increments.

The comparative site (N5.40860; E118.00016) covered the same number of hectares, and was orientated across similar distances from the riverbank, whilst ensuring random selection of overall location. The random site exhibited higher levels of canopy coverage for both the "cleared" and riparian corridor comparative sites (92.47% and 94.98%, respectively). There were also fewer areas considered as potential swamp forest, 9.71 ha (14.83%) for regrowth zone and 1.99 ha (7.8%) for the riparian habitat.

Table 1. Habitat summary statistics for both the study site and comparative site.

	Trees Per ha	Mean Canopy Area (m^2)	Canopy Coverage (%)	Swamp forest (%)
Study Site				
Regrowth area	227.43	34.72	78.97	25.21
Riparian area	291.95	34.26	87.25	16.37
Comparative Site				
"Regrowth area"	263.17	35.91	92.47	14.84
"Riparian area"	220.52	40.29	94.98	7.81

This indicates that the original study site is broadly speaking wetter than a random location within the study region. This could partially account for the lower number of trees per hectare, as well as the lower canopy coverage, present in the regrowth forest.

The study area forms part of the corridor actively utilized by Bornean elephants and links LKWS lots 5 and 7. The regeneration of the regrowth plot has enhanced the width of this corridor providing additional habitat for these elephants (Fig. 5). Analysis of elephants traversing this corridor over a six-year period provided evidence of an increasing trend in elephant usage of the regrowth site ($p=0.017$). This suggests that, as the area recovered, and canopy cover was restored, elephants used this additional habitat more frequently (Fig.5). The increasing use of the site by elephants suggests that despite low-ACD and significantly shorter trees, the site can be used for corridor purposes, even for a large mammal.

Figure. 5. Bornean elephant movements across both the regrowth and riparian study sites over a six-year period, with each point denoting an elephant location.

4. Discussion

We found that under-productive oil palm can be reclaimed and, without restoration, provide suitable corridor habitat for endangered Bornean elephants. We also found that largely flooded forest, once restored, can provide important connectivity habitat; this is of increased importance when considering reconnecting once contiguous lowland dipterocarp forests. Our findings have implications throughout the tropics, where productive lowland forests are being converted for agriculture at an increasing rate, as well as for the creation of plantations, of which, portions are producing unprofitable crop yields. The findings also examine reclamation of these areas as increased connectivity for elephants in a habitat crucial to the population's survival.

The LKWS, consisting of degraded forest with varying connectivity, is a prime example of how an increasing number of tropical, lowland floodplains will look in the future. With extremely high levels of ecosystem productivity, paired with agricultural desirability, those floodplains that are yet to experience widespread conversion will come under encroachment pressure over the next decade. The LKWS thus provides a model ecosystem for tropical lowlands across the globe, with it retaining high levels of biodiversity, despite the sanctuary containing only ~ 28,000 ha of forest, across 10 lots (Abram et al., 2014). Abram et al. (2014) determined that 15,810 ha of oil palm planation throughout the sanctuary were, at that time, commercially redundant, providing a strong case for reclamation and the potential for assisted habitat restoration. This provides a financial incentive for existing plantations to engage in forest regeneration. Despite the fact that flood-prone forest, once regenerated, produce lower ACD than surrounding areas (Fig. 4), over a relatively short time frame (17 years), we have found that naturally regenerating canopy coverage is equivalent to those areas that were not cleared (Fig. 2). In addition, we have demonstrated that corridor habitat suitability is obtainable without enrichment restoration. This has wide-reaching fiscal prioritization implications for future replanting and management schemes.

The study site, at the time of clearing, retained a narrow riparian corridor (~100 m) that would have likely aided the diversity of saplings during the initial recovery phase. During this study we do not, however, examine the species composition of the regrowth forest, rather its broader structural characteristics and suitability for wildlife use. No intervention forest regeneration of agricultural land has been explored as a means of regeneration, for example in Africa (Chapman & Chapman, 1999), and the Caribbean (Aide et al., 2000). Chapman and Chapman (1999) showed that naturally regenerating forests were more frequently utilized by birds, but that these areas seemed less suitable for large mammals. In this study, we suggest that in instances where fiscal constraints exist or the habitat is, broadly speaking, wetter, that a hands-off approach to restoration can have acceptable results, leading to active corridor utilization.

In this case study, we identified that a flooding potential of 25.1% of total land area of the regrowth site was cause for abandonment of the study site (Fig. 1). Whilst this by no means represents the upper, nor the lower bounds, of potential abandonment thresholds, it does provide an insight into the drivers of decision making by plantation managers. This figure could be used as a starting point to identify areas for potential reclamation, based on agricultural productivity levels. Whilst these flooded areas, having undergone 17 years of natural regeneration, provide incomplete canopy coverage of ~78%, this is enough to encourage the increased use by large herbivores (Fig. 5).

The major value of the study site, despite being a relatively small area for wildlife, is through its ability to expand narrow corridors and to provide validation for future planning where even a narrow corridor, such as was present at this site, may no longer exist. We demonstrated increasing tendencies of elephants to pass through the regrowth area as regeneration progressed (Fig. 5). As all of the individuals tracked were females, these points are, in fact, likely to be indicative of the movement of several family groups, rather than sole individuals. This compounds these movement trends, and places increased importance on its regeneration. Figure 5 also suggest that at no point do the herds cut through oil palm, over a six-year period. The lack of movement through agriculture demonstrates the value of even "low quality", low ACD, habitat restoration. This could provide further impetus for plantation managers to reforest underproductive areas, providing additional corridor habitat and thus mitigating human-elephant conflict. Identifying forested areas as key elephant habitat can provide a mandate for current policy reinforcement or reform, given the species charismatic nature.

Whilst this study examined only one site, this sites ability to enhance existing corridors within a highly fragmented, vulnerable ecosystem, represents a valuable gain in forest connectivity. Covering just over 65 ha, the restricted nature of the study site means that future studies need to identify additional areas of natural regrowth. Furthermore, these LiDAR data represent just one temporal insight into how regrowth is occurring within the site. Further studies should aim to identify more sites and chart regrowth throughout the regrowth process, using this methodology. This has the potential to provide additional evidence of the value of natural regrowth forests for connectivity. In order to restore connectivity to once contiguous forest, working with increasingly small areas of forest, such as the study site, is going to prove increasingly important in restoring patch connectivity.

To conclude, we suggest that natural regeneration can be a productive connectivity tool in instances where financial, or habitat traits prevent enrichment planting schemes from occurring. Furthermore, these areas can, within a short timeframe provide corridors usable by even the largest of forest dwelling animals.

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7. Appendices

Appendix A. Above ground carbon (ACD) map of the study site. Displaying substantially higher carbon densities in the regrowth forest than in regrowth forest.