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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).

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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; Parrotta 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 and 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 geo-referenced 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