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# 1 Underproductive agriculture aids connectivity in 2 tropical forests.

3  
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17 Key Words: restoration ecology; elephants; oil palm; wildlife corridors; Borneo; Sabah

18

## 19 Abstract

20 Establishing connectivity in tropical lowland forests is a major conservation challenge,  
21 particularly in areas dominated by agriculture. Replanting schemes have been widely utilized as  
22 a method for reconnecting once contiguous forest patches. However, these approaches require  
23 funds for both initial planting and subsequent site maintenance. Furthermore, identifying sites  
24 for habitat rehabilitation schemes is difficult and may require purchasing of land, sometimes at  
25 great expense. Underproductive, often unprofitable, areas of agriculture have the potential to aid  
26 in re-establishing forest connectivity via natural forest regeneration. We identified an area of  
27 natural forest regrowth, previously cleared for agriculture and abandoned due to high levels of

28 flooding. We assessed the structural regrowth of this forest after a 17-year period, and examined  
29 its efficacy as corridor habitat for Bornean elephants. Regrowth areas had re-established tree  
30 canopy areas similar to that of adjacent forest, as well as a randomly selected site of uncleared  
31 forest. Flooding in the area hampered the regrowth of some sections of the site; however, ~79%  
32 of the site exhibited canopy coverage. Aboveground carbon levels have returned to 50% those of  
33 uncleared forests, with flooding resulting in areas of reduced vegetation regeneration. Elephants  
34 have shown increasing usage of the regenerated forest, suggesting that the area has regenerated  
35 its suitability as elephant corridor habitat. We have shown that what would traditionally be  
36 thought of as low-quality, flood-prone areas for habitat restoration can be a useful, cost-effective  
37 tool for wildlife corridor management. We propose that natural regeneration of reclaimable,  
38 underproductive agriculture has the potential to play a key role in lowland tropical forest  
39 connectivity, reconnecting now isolated populations of endangered Bornean elephants.

40

## 41 **1. Introduction**

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

51

52 Oil palm trees produce the highest yields when cultivated in lowland coastal terrain, and require  
53 a near-constant water supply (Basri Wahid et al., 2005). However, flooding and standing water  
54 within plantations creates a poor growth environment, and areas with periodic flooding may  
55 become less productive or even unprofitable, to continue to cultivate (Abram et al., 2014;  
56 Sumarga et al., 2016; Woittiez et al., 2017). Lowland forests exhibit higher rates of agricultural

57 conversion (Sodhi et al., 2004), which is particularly important because these areas are  
58 associated with high levels of biodiversity (Curran et al., 2004). Therefore, their large-scale  
59 conversion to agriculture poses a severe threat to the continued functionality of lowland forest  
60 ecosystems, as well as the overall biodiversity of a region (Meijaard and Nijman, 2003; Scriven et  
61 al., 2015).

62

63 Lack of connectivity caused by high instances of poorly planned land-use change is one of the  
64 greatest challenges in modern conservation (Dobson et al., 1997). Reclamation of  
65 underproductive agricultural lands represents a major opportunity for restoring once contiguous  
66 forest. Complete, or enrichment, replanting schemes generally utilize dozens of native species to  
67 quickly establish canopy coverage and encourage faunal repopulation (Bowen et al., 2007;  
68 Parotta and Knowles, 1999). These methods are, however, costly both in terms of initial outlay,  
69 as well as site maintenance (Brancalion et al., 2012; Zhou et al., 2007). Without enrichment  
70 planting, forests are unlikely to reach the level of complexity of old growth forests (Chazdon,  
71 2008). Studies such as Aide et al. (2000) in Puerto Rico, have suggested that enrichment planting  
72 may be necessary to achieve community composition in line with old growth forests. Despite this  
73 finding, small remnant forest fragments can provide natural seed dispersal capabilities to aid in  
74 the natural reconnection of forested fragments (Turner and Corlett, 1996).

75

76 Borneo is at the forefront of land conversion for oil palm plantations, with approximately 1.43  
77 million ha cultivated in the Malaysian state of Sabah alone (Abram et al., 2014). The  
78 Kinabatangan floodplain is among the largest floodplains in Borneo, providing ideal land for the  
79 cultivation of oil palm. This has led to large-scale land clearance and planting (Ancrenaz et al.,  
80 2004). Clearance for large estates has often led to the removal of forested areas that would  
81 subsequently prove unsuitable for later cultivation. Abram et al. (2014) conducted a study  
82 throughout the Kinabatangan to identify areas that were currently being cultivated with low, or  
83 even unprofitable yields, and found that almost 16,000 ha (oil palm in Kinabatangan floodplain  
84 totals ~250,000 ha) were deemed to be commercially redundant and thus represent significant  
85 opportunities for reclamation, or natural successional regeneration.

86

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

101

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

110

## 111 **2. Materials and Methods**

### 112 *2.1 Study Site*

113 The study site (N5.551166, E117.890413) is located in “Lot 5” of the Lower Kinabatangan  
114 Wildlife Sanctuary (LKWS). The study region, a large tropical, lowland floodplain, consists of a  
115 mosaic of degraded, logged forest and agriculture. Both large- and small-holding agriculture are

116 present in the vicinity; however, both largely focus on oil palm cultivation. Land conversion  
117 peaked in the area during the 1970s and 80s, and remnant forest fragments are largely under  
118 governmental protection (Goossens et al., 2005), although fragments now exhibit varying levels  
119 of connectivity, with complete isolation of several of the LKWS lots. Using data from Gaveau et al.  
120 (2014), we determined that the study site had been selectively logged, initially, between the  
121 years of 1990 and 1995. Subsequent land clearance for oil palm development was carried out in  
122 1999 and the title transferred to the Sabah Forestry Department in 2000 (M. Martin, pers.  
123 comm.). The edge of the cleared area was identified by the remnants of a large drainage ditch  
124 visible in the digital elevation model. Clearance was carried out in accordance with Sabah state  
125 law which requires the maintenance of a riparian buffer zone (Sabah Land Ordinance, 2010).  
126 Numerous forest replanting schemes have occurred within the study region, with Davison &  
127 Prudente (2001) representing the largest. This project involved planting within several  
128 kilometers of the study site.

129

## 130 *2.2 Airborne LiDAR*

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

142

143 A 'cloud' of LiDAR data was produced through a combination of LiDAR laser ranges and  
144 embedded GPS-IMU data (Asner et al., 2007), determining 3-D laser return locations. Where  
145 elevation is relative to a reference ellipsoid, the LiDAR data cloud consisted of a number of geo-

146 referenced point elevation estimates. The 'lasground' tool packaged in the LAStools software  
147 package (Rapidlasso, Gilching, Germany) was used to process LiDAR data points, detecting which  
148 laser pulses penetrated the canopy volume and reached the ground. These points were  
149 subsequent used to interpolate a raster digital terrain model (DTM). A further digital surface  
150 model (DSM) was created using interpolations of all first-return points, which included canopy  
151 top and, bare ground where only ground returns were detected. Disparities between DTM and  
152 DSM vertical difference yielded a digital canopy model (DCM). Spatial resolutions of 2 m for both  
153 ground elevation and woody canopy height models were derived.

154

### 155 *2.3 Bornean elephant GPS tagging*

156 Data from eight Bornean elephants carrying Global Positioning System (GPS) collars as part of a  
157 wider home ranging behavior study, were utilized to assess corridor movement behavior. These  
158 were the only individuals that utilized the study area within the entire GPS collaring dataset.  
159 Throughout this study individuals were GPS tagged using units produced by Africa Wildlife  
160 Tracking (AWT, Pretoria, South Africa). GPS units recorded location points every 2 hours  
161 throughout the tracking period. All eight individuals tracked were female and thus their  
162 movements were likely indicative of herd movement, compared to often solitary males. The  
163 mean tracking period of individuals utilized within this study was 677.63 ( $\pm 192.04$ ) days, with a  
164 minimum of one and maximum of three individuals being tracked at any given period between  
165 2010 and 2016.

166

### 167 *2.4 Analysis*

168 The LiDAR data were analyzed using both QGIS (Quantum GIS Development Team, 2017) and R  
169 statistical software (R Core Team, 2000). Top-of-canopy Height (TCH) was derived from a LiDAR-  
170 derived canopy height model (CHM) created by calculating the difference between ground and  
171 canopy digital elevation models. Such features as the number of trees per hectare and crown  
172 area, were identified using the R package "ForestTools" (Plowright, 2017). A minimum tree  
173 height threshold of 4 m was selected to exclude all understory vegetation from the analysis.  
174 Quantification of canopy coverage was carried out in QGIS, with gaps identified using crown  
175 areas isolated using ForestTools. Digital elevation models (DEM) also produced by the LiDAR

176 mapping were analyzed using the “Raster” package (Hijmans et al., 2016). DEM data were also  
177 analyzed using QGIS to identify areas of potential flooding and swamp forest. 1-way Analysis of  
178 Variance (ANOVA) tests were performed to assess the variation between regrowth and extant  
179 forest fragments. A linear regression was utilized to examine the relationship between the tree  
180 counts and site elevation above sea level.

181

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

191

192 Aboveground carbon density (ACD) was calculated for the entire state of Sabah by combining  
193 LiDAR TCH models and satellite imaging data (Asner et al. *under review*). These data were  
194 calibrated using field plots ranging in size from 0.28 ha to 1.0 ha throughout Sabah (Coomes et al.  
195 2017). These ACD estimates were examined across 0.5 m elevations throughout the study site. A  
196 linear regression was performed to ascertain the relationship between ACD and site elevation-  
197 linked flooding potential.

198

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

203

204 **3. Results**



205 The area of regrowth forest (N5.41476; E118.02571) totaled 65.44 ha, bordered by an additional  
206 25.49 ha of remnant intact riparian vegetation. There was approximately a 17-year interval  
207 between the clearance of forest (1999) and the LiDAR mapping of the study site (2016). The  
208 regrowth area was abandoned after clearance due to high flooding probabilities, as well as  
209 presence of standing water (M. Martin, pers. comm.). A total of 16.5 ha (25.21%) of the regrowth  
210 forest were deemed to be at risk of flooding through the use of elevation data, being located at  
211 below riverbank elevation (Fig. 1). We checked these flood risk areas in the field to examine the  
212 efficacy of our flood modelling.

213  
214  
215 Figure 1. Study region DEM fitted with contours depicting meters above sea level. Differences in  
216 elevation resulting from historic irrigation ditches become apparent. Areas less than riverbank  
217 elevation were deemed to be susceptible to flooding and permanent swamp.  
218

219  
220 Over the 17-year regrowth period, cleared forest regenerated total canopy coverage of 51.68 ha  
221 (79.0%), whilst remnant, riparian vegetation had an overall canopy cover of 22.24 ha (87.4%).  
222 Mean total crown areas across habitat types were similar. However, the slightly higher mean  
223 crown areas displayed by regrowth forest tended towards significance ( $p=0.06$ ) (Fig. 2).  
224 Differences in tree height significantly differed between habitat types ( $p<0.001$ ), with new  
225 growth trees being significantly shorter than the riparian corridor.

226  
227  
228 Figure 2. Comparisons of a) crown area ( $m^2$ ) and b) tree canopy height (m) between forest types.  
229

230  
231 Tree numbers per hectare in the regrowth area were statistically lower than those in the extant  
232 forest ( $p<0.001$ ) (Fig. 3a). There was a positive correlation between site elevation and number of  
233 trees present in 25 m grids ( $p=0.013$ ) (Fig. 3). This suggests that flooding had a negative impact  
234 on tree regrowth and accounts for the lower numbers of trees per hectare found within the  
235 regrowth site.

236  
237 Figure 3a. Tree numbers by 25 m grid across the study site b. Terrain ruggedness analysis,  
238 clearly displaying irrigation network dug for agriculture c. Tree height with clear demarcation  
239 between cleared and un-cleared sites d. DEM of site showing areas of potential flooding.  
240

241  
242 Mean ACD values for the regrowth and riparian sites were  $23.37 \text{ Mg C ha}^{-1}$  and  $45.30 \text{ Mg C ha}^{-1}$ ,  
243 respectively. This equates to an approximated ACD of 51.59% over the 17-year period, since

244 clearance. The riparian site is likely to have been selectively logged in the past; however, this ACD  
 245 value is unlikely to represent true historical carbon stocks of the area. A positive correlation  
 246 ( $p < 0.01$ ) between increasing elevation and ACD showed that flooding hampered the re-  
 247 establishment of those areas of regrowth site that were at lowest elevations (Fig. 4).

248  
 249  
 250 Figure 4. Aboveground Carbon Density (ACD) of the study site against elevations above sea level  
 251 in 0.5 m increments.  
 252

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

259

260 **Table 1.** Habitat summary statistics for both the study site and comparative site.  
 261

	Trees Per ha	Mean Canopy Area (m <sup>2</sup> )	Canopy Coverage (%)	Swamp forest (%)
<b>Study Site</b>				
<i>Regrowth area</i>	227.43	34.72	78.97	25.21
<i>Riparian area</i>	291.95	34.26	87.25	16.37
<b>Comparative Site</b>				
<i>“Regrowth area”</i>	263.17	35.91	92.47	14.84
<i>“Riparian area”</i>	220.52	40.29	94.98	7.81

262

263

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

267

268 The study area forms part of the corridor actively utilized by Bornean elephants and links LKWS  
 269 lots 5 and 7. The regeneration of the regrowth plot has enhanced the width of this corridor  
 270 providing additional habitat for these elephants (Fig. 5). Analysis of elephants traversing this  
 271 corridor over a six-year period provided evidence of an increasing trend in elephant usage of the  
 272 regrowth site ( $p = 0.017$ ). This suggests that, as the area recovered, and canopy cover was

273 restored, elephants used this additional habitat more frequently (Fig.5). The increasing use of the  
274 site by elephants suggests that despite low-ACD and significantly shorter trees, the site can be  
275 used for corridor purposes, even for a large mammal.

276  
277  
278  
279  
280  
281

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.

## 282 **4. Discussion**

283

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

292

293 The LKWS, consisting of degraded forest with varying connectivity, is a prime example of how an  
294 increasing number of tropical, lowland floodplains will look in the future. With extremely high  
295 levels of ecosystem productivity, paired with agricultural desirability, those floodplains that are  
296 yet to experience widespread conversion will come under encroachment pressure over the next  
297 decade. The LKWS thus provides a model ecosystem for tropical lowlands across the globe, with  
298 it retaining high levels of biodiversity, despite the sanctuary containing only ~ 28,000 ha of  
299 forest, across 10 lots (Abram et al., 2014). Abram et al. (2014) determined that 15,810 ha of oil  
300 palm plantation throughout the sanctuary were, at that time, commercially redundant, providing  
301 a strong case for reclamation and the potential for assisted habitat restoration. This provides a  
302 financial incentive for existing plantations to engage in forest regeneration. Despite the fact that  
303 flood-prone forest, once regenerated, produce lower ACD than surrounding areas (Fig. 4), over a  
304 relatively short time frame (17 years), we have found that naturally regenerating canopy  
305 coverage is equivalent to those areas that were not cleared (Fig. 2). In addition, we have

306 demonstrated that corridor habitat suitability is obtainable without enrichment restoration. This  
307 has wide-reaching fiscal prioritization implications for future replanting and management  
308 schemes.

309

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

320

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

329

330 The major value of the study site, despite being a relatively small area for wildlife, is through its  
331 ability to expand narrow corridors and to provide validation for future planning where even a  
332 narrow corridor, such as was present at this site, may no longer exist. We demonstrated  
333 increasing tendencies of elephants to pass through the regrowth area as regeneration progressed  
334 (Fig. 5). As all of the individuals tracked were females, these points are, in fact, likely to be  
335 indicative of the movement of several family groups, rather than sole individuals. This

336 compounds these movement trends, and places increased importance on its regeneration. Figure  
337 5 also suggest that at no point do the herds cut through oil palm, over a six-year period. The lack  
338 of movement through agriculture demonstrates the value of even “low quality”, low ACD, habitat  
339 restoration. This could provide further impetus for plantation managers to reforest  
340 underproductive areas, providing additional corridor habitat and thus mitigating human-  
341 elephant conflict. Identifying forested areas as key elephant habitat can provide a mandate for  
342 current policy reinforcement or reform, given the species charismatic nature.

343

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

354

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

359

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361

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376  
377

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## 487 7. Appendices

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489

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

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