Determining the numbers of a landscape architect species (*Tapirus terrestris*), using footprints

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Background. As a landscape architect and a major seed disperser, the lowland tapir (*Tapirus terrestris*) is an important indicator of the ecological health of certain habitats. Therefore, reliable data regarding tapir populations are fundamental in understanding ecosystem dynamics, including those associated with the Atlantic Forest in Brazil. Currently, many population monitoring studies use invasive tagging with VHF or satellite/GPS collars. These techniques can be costly and unreliable, and the immobilization required carries physiological risks that are undesirable particularly for threatened and elusive species such as the lowland tapir.

Methods. We collected data from one of the last regions with a viable population of lowland tapir in the south-eastern Atlantic Forest, Brazil, using a new non-invasive method for identifying species, the Footprint Identification Technique (FIT).

Results. We identified the minimum number of tapirs in the study area and, in addition, we observed that they have overlapping ranges. Four hundred and forty footprints from 46 trails collected from six locations in the study area in a landscape known to contain tapir were analyzed, and 29 individuals were identified from these footprints.

Discussion. We demonstrate a practical application of FIT for lowland tapir censusing. Our study shows that FIT is an effective method for the identification of individuals of a threatened species, even when they lack visible natural markings on their bodies. FIT offers several benefits over other methods, especially for tapir management. As a non-invasive method, it can be used to census or monitor species, giving rapid feedback to managers of protected areas.

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18 **Abstract**

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20 *terrestris*) is an important indicator of the ecological health of certain habitats. Therefore,

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23 monitoring studies use invasive tagging with VHF or satellite/GPS collars. These techniques can

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32 analyzed, and 29 individuals were identified from these footprints.

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36 over other methods, especially for tapir management. As a non-invasive method, it can be used

37 to census or monitor species, giving rapid feedback to managers of protected areas.

38

Introduction

39

40   One of the key ecological processes that maintain the health status of tropical forests is

41   seed dispersal (Boissier et al. 2014). Vertebrates can disperse between 45% and 90% of woody

42   species seeds and mammals are important dispersers in warmer forests (Almeida-Neto et al.

43   2008). The lowland tapir, *Tapirus terrestris* (Linnaeus, 1758), a remaining species of the

44   Pleistocene megafauna in South and Central America (Simpson 1980; Eisenberg 1981), is a large

45   selective browser (180-300 kg), and an important vertebrate seed disperser because it can

46   disperse large-seeded species over long-distances (Dirzo & Miranda 1991; Galetti et al. 2001;

47   O'Farrill et al. 2012; Bueno et al. 2013).

48   In Brazil, lowland tapir populations are decreasing at an alarming rate due to habitat

49   destruction and fragmentation, illegal fires (Chiarello 2000a; Michalski & Peres 2007), hunting

50   (Chiarello 2000b; Peres 2000) and road kill (Medici & Desbiez 2012; Souza et al. 2015),

51   especially in the Atlantic Forest and Cerrado ecosystems. Consequently, the lowland tapir is

52   listed as Vulnerable in the IUCN Red List of Threatened Species (Naveda et al. 2008), and in the

53   Brazilian list of Threatened Species (Instituto Chico Mendes de Conservação da Biodiversidade

54   2016). In the Atlantic Forest, tapirs are considered as Endangered (Medici et al. 2012).

55   The disappearance of frugivores such as tapirs from disturbed tropical forests can reduce

56   the recruitment and survival of plant species, threatening forest regeneration (Boissier et al.

57   2014). Thus, tapirs can be considered a landscape architect and a major indicator of ecological

58   health of landscapes (Bueno et al. 2013; O'Farrill et al. 2013; Giombini et al. 2016).

59   Understanding tapir population dynamics is therefore crucial to the health of Brazilian Atlantic

60   Forest ecosystems.

61   Gatti et al. (2011) and Medici & Desbiez (2012) estimated that a lowland tapir population

62 is considered genetically stable in the Atlantic Forest if it consists of at least 200 animals at all

63 times over a 100-year period. However, only three areas currently have a population of more

64 than 200 individuals in the Atlantic Forest (Medici et al. 2012), the Serra do Mar forest complex,

65 the State Park of Rio Doce and the Linhares/Sooretama forest complex. If no conservation

66 intervention is taken to protect the species in the Atlantic Forest, it is predicted that the

67 remaining populations will disappear in 33 years (Medici et al. 2012). Without reliable

68 information on demographics, developing a strategy for sustaining free-ranging tapir populations

69 will be impossible (Foerster & Vaughan 2002). However, while lowland tapir population

70 censusing and monitoring is essential, it is a difficult task because tapir are mostly crepuscular

71 and nocturnal (Oliveira-Santos et al. 2010; Wallace et al. 2012; Cruz et al. 2014).

72   Classical studies of tapir population censusing and monitoring include individual

73 counting by direct sightings (Fragoso 1987; Glanz 1990), scat surveys (Naranjo & Cruz 1998;

74 Flesher 1999; Ramírez 2013), footprint counts (Naranjo & Cruz 1998; Flesher 1999; Naranjo &

75 Bodmer 2007), line transect sampling (Naranjo & Cruz 1998; Naranjo & Bodmer 2007; Medici

76 2010; Wallace et al. 2012), the use of high technology such as camera traps (Wallace et al. 2012;

77 Carbal-Borges et al. 2014; Mejía-Correa et al. 2014; Tobler et al. 2014) and VHF/GPS collars

78 (Foerster & Vaughan 2002; Medici 2010). However, the research costs and duration have often

79 hampered the implementation of these methods. Nevertheless, many facets of wildlife research

80 demand the recognition of individual animals (Alibhai et al. 2008). For tapirs, each of these

81 methods has disadvantages. For example, adult tapirs do not have natural coat patterns that can

82 easily distinguish an individual during a census or in a camera trap image and to fit a tag or

83 radio-collar, it is necessary to capture and immobilize a tapir, which comes with ongoing

84 expenses and risks to animal and researcher.

85   A new cost-effective and non-invasive method for identifying endangered species is the

86   Footprint Identification Technique (FIT) (Alibhai et al. 2008; Jewell & Alibhai 2013; Jewell et

87   al. 2016; Alibhai et al. 2017), which is capable of identifying at the individual, sex and age-class

88   levels from digital images of footprints of certain species. It is considered a cost-effective

89   method because of the low investment for fieldwork combined with high accuracy in individual

90   identification (Gusset & Burgener 2005; Jewell 2013; Pimm et al. 2015; Jewell et al. 2016). In

91   this way, footprints can serve as an alternative to natural coat patterns or body marks for those

92   species whose foot is of sufficient complexity to create a footprint with individual characteristics.

93   The technique proved to be effective with footprints of black rhino (*Diceros bicornis*) (Jewell &

94   Alibhai 2001) and white rhino (*Ceratotherium simium*) (Alibhai et al. 2008). FIT has

95   subsequently been adapted for several other species, including Amur tiger (*Panthera tigris* ssp.

96   *altaica*) (Gu et al. 2014), cougar (*Puma concolor*) (Jewell et al. 2014; Alibhai et al. 2017), brown

97   bear (*Ursus arctos*) (Petridou et al. 2008), cheetah (*Acinonyx jubatus*) (Jewell et al. 2016), panda

98   (*Ailuropoda melanoleuca*) (Li et al. 2018), Bengal tiger (*Panthera tigris* ssp. *tigris*), polar bear

99   (*Ursus maritimus*) and Baird's tapir (*Tapirus bairdii*) (Jewell & Alibhai 2013). In 2007, the

100   method was tested for the first time for the lowland tapir in the Atlantic Forest (Medici 2010).

101   This study is an attempt to census one of the last regions with a viable population of

102   tapirs in the southeastern Atlantic Forest – the Linhares-Sooretama forest complex in the state of

103   Espírito Santo, Brazil. This population survives in a forested area of about 50,000 ha. FIT

104   methodology has the potential to census tapir populations and help implement species

105   management and conservation strategies, especially for disturbed tropical ecosystems dependent

106   on frugivores for maintenance. Thus, determining tapir distribution and numbers accurately is a

107   major challenge for tropical ecologists.

108

Material & Methods

Study area

111   We performed the study in the Private Natural Heritage Reserve Recanto das Antas

112 (*Reserva Particular do Patrimônio Natural Recanto das Antas*, in Portuguese, hereafter

113 "RPPNRA") and adjacent private areas to the reserve (Fig. 1). The RPPNRA is a private

114 protected area of 2,212 hectares owned by Fibria Celulose S.A., a Brazilian company, located in

115 the Linhares-Sooretama forest complex, north of the state of Espírito Santo, Brazil. It is

116 contiguous with the 27,858 ha Sooretama Biological Reserve and the 22,711 ha Vale Natural

117 Reserve. The RPPNRA is located at the coordinates 19°5' south latitude, 39°58' west longitude,

118 and mostly consists of discontinuous primary vegetation, interposed by extensive eucalyptus and

119 papaya plantations, cabruca (cacao trees planted in the shade of thinned native forest), seringal

120 (rubber tree culture) and smaller amounts of coffee plantations and cattle pastures, which are not

121 part of the reserve (Centoducatte et al. 2011). Unpaved roads used for eucalyptus harvesting and

122 transportation also cross the area.

123   The study site is situated in an area of Barreiras Formation (Tertiary sediments, or

124 "tabuleiros"), where the vegetation is part of the Ombrophilous Forest Region of the Lowlands

125 (Instituto Brasileiro de Geografia e Estatística 1987), also known as the Tabuleiros Atlantic

126 Forest (Rizzini 1997). The Tabuleiros Forest of Linhares and Sooretama region is considered of

127 high biological importance for the conservation of the biodiversity (Conservação Internacional

128 do Brasil et al. 2000), a priority area for the conservation of medium- and large-sized mammals

129 (Galetti et al. 2009) and part of the UNESCO World Heritage Discovery Coast Atlantic Forest

130 Reserves.

131

Collection of footprints

133   The lowland tapir, an ungulate from the order Perissodactyla, whose toes are surrounded

134   by a hoof, has four digits on the forefeet, representing anatomical digits 2, 3, 4 and 5. The

135   smallest one (the fifth digit) appears only in footprints impressed in soft ground (Ballenger &

136   Myers 2001). The hind feet have only three digits (anatomical digits 2, 3, and 4), and they each

137   appear in the footprint (Medici 2011). Tapirs, like many terrestrial large mammals, typically

138   register the hind foot in the impression left by the front foot when they are walking (Jewell &

139   Alibhai 2001; Elbroch 2003; Alibhai et al. 2008; Jewell et al. 2016).

140   Footprint surveys were performed on 17 dirt (unpaved, soft surface) roads, which

141   represent the main dirt roads crossing the study area. The total length of surveyed roads was

142   35,118 meters. One road was visited at least once in each field survey. We chose dirt roads

143   because (1) tapirs use them frequently, (2) the roads cross many different types of habitat,

144   including forest and agriculture land, and (3) we had easy access to them. Because lowland tapirs

145   are active mostly between dusk and dawn (Oliveira-Santos et al. 2010; Wallace et al. 2012; Cruz

146   et al. 2014), our surveys were done early in the morning and in the late afternoon, when there

147   was sufficient light for photography. The availability of footprints of tapirs on roads also

148   depended to some extent on the weather. The quality of footprints was sometimes reduced when

149   the weather was too dry because footprint impressions were not held so well by the substrate,

150   and when it rained footprints were lost. The footprint identification technique requires well-

151   defined clear footprints, generally obtained from animals walking at a relaxed pace so we used

152   only undistorted footprints in this study.

153   We collected sets of digital images of footprints from wild lowland tapirs, as follows,

154 following the WildTrack FIT protocol (Alibhai et al. 2008; Jewell et al. 2016). First, we

155 identified a trail (an unbroken series of footprints made by the same animal) of footprints left by

156 an individual (Fig. 2A). Left hind footprints were used for the analysis following the protocol

157 given in Alibhai et al. (2008). For each footprint image, a scale (in centimeters) was placed to the

158 left and bottom of it, and a slip was placed alongside one of the rulers with the date, name of the

159 road, UTM coordinates, collector and footprint code (Fig. 2B). Each day, every trail and

160 footprint received a unique code. Photographs were taken at high resolution (2248 X 4000 pixels

161 or higher), from directly overhead (although FIT can work quite effectively at 1600 X 1200).

162 To avoid the risk of collecting a footprint more than once, we obliterated each footprint

163 after taking the photos. We carried out ten fieldwork sessions of three to five days duration

164 during 10 months between March 2014 and June of 2015 in the study area. To enable a more

165 detailed analysis of the minimum number of tapirs in the area, we arbitrarily divided the study

166 area into six locations based on distribution of footprint trails (A-F; Fig. 1). The subdivision of

167 locations allowed a comparison of the number of trails and the number of animals in different

168 areas. Maps were designed in ArcMap 10.1 (®Esri). The farthest distance between two areas was

169 6,297 meters (area C and E), the smallest distance was 1,110 meters (area A and B), while the

170 average distance among the areas was 3,290 meters (Table 1).

171 We received permission to conduct fieldwork in our study area from SISBIO/Instituto

172 Chico Mendes de Conservação da Biodiversidade (number 32565-5), according to the Brazilian

173 laws.

174

175 **Analysis**

176 The identification of individuals using FIT is based on the morphometrics of the footprint

177 (Alibhai et al. 2001; Alibhai et al. 2008; Jewell et al. 2016; Alibhai et al. 2017). Because each

178 species has a unique foot anatomy, FIT algorithms are designed to be species specific. Each

179 species FIT algorithm defines the footprint measurements that allow the software to discriminate

180 between individuals for that species (Alibhai et al. 2017). The lowland tapir algorithm was

181 developed by S.K. Alibhai and Z.C. Jewell (Document S1, Document S2) and Medici (2010)

182 through the collection of a training-set database of footprint photographs from known individual

183 captive tapir (Table S1). Randomized holdback trials using the FIT algorithm with the training

184 set gave accuracies of 90% for the predicted number of individuals (for more details about the

185 FIT algorithm, see Jewell et al. (2016) and Alibhai et al. (2017)). The FIT software home-page,

186 feature extraction page and footprint variable extraction are shown in Fig. 3A, B. The training-

187 set library of 426 images from 36 captive individuals was used to extract the algorithm for

188 individual identification of tapirs using FIT (Alibhai et al. 2001; Alibhai et al. 2008; Medici

189 2010; Jewell et al. 2016; Alibhai et al. 2017). To census the unknown tapir population in this

190 study, we then applied this previously-derived algorithm to the analysis of new footprint images

191 collected from our study area.

192   Prior to the statistical analysis, we uploaded each footprint image into Gimp 2.8.14

193 software to optimize color contrast and crop the images. Each image was then rotated to a

194 standardized orientation using the FIT add-in in JMP Pro 12 (SAS). Fifteen anatomically-based

195 landmark points on a tapir footprint were prior chosen that could be repeated in other studies and

196 clearly identified (Alibhai et al. 2008; Jewell et al. 2016). Using FIT software, these landmark

197 points were then manually placed on each footprint image using cross-hair guidelines to

198 minimize bias (Fig. 3B, C). From these fifteen landmark points, FIT script defined a further set

199 of seven derived points, geometrically constructed from the set of landmarks points (Jewell et al.

200 2016). From the 15 landmark points and seven derived points, a total of 121 measurements

201 (distances, angles, and areas) were generated for each tapir footprint.

202   This full set of measurements (the 'geometric profile'; Table S2) was taken to include all

203 those that might prove useful in discriminating between footprints (Fig. 3B, C). The set of

204 measurements of all the tapir footprints constituted the dataset upon which all FIT analyses were

205 performed (Alibhai et al. 2008; Jewell et al. 2016). A full step-by-step video account of the

206 footprint identification technique is reported in Jewell et al. (2016).

207   FIT is based on a comparison of sets of footprints (trails) where each trail is an unbroken

208 set of footprints made by one individual. The comparison is made using a customized robust

209 cross-validated pair-wise discriminant analysis. Where trails were composed of more than 10

210 footprints, they were randomly divided into sub-trails each consisting of 5-8 footprints. For

211 example, trail 8214 was divided into three sub-trails arbitrarily – A8214A, A8214B & A8214C –

212 with the prefix (A) denoting the location of the trail in the study area (see Fig. S1), and the

213 suffixes A, B and C represent the three sub-trails (see Jewell & Alibhai 2001; Alibhai et al. 2008;

214 Jewell et al. 2016). The sub-trails from a single unbroken trail were named 'self' sub-trails for

215 purposes of classification. Sub-trails from different trail sets were named 'non-self' sub-trails.

216 This enabled the comparison of self sub-trails and non-self sub-trails during FIT analysis.

217   For the whole study area (7,900 ha), we analyzed the data at several different scales: (A)

218 We used all the sub-trails to identify the number of individuals in the entire study area (pooled

219 data), (B) we analyzed the data for each location (A-F) separately and we summed that data to

220 identify the number of individuals and (C), we paired the locations and once again compared the

221 pooled data with summed data. Doing so, we were able to identify if one or more tapirs were

222 visiting more than one location. Finally, using the data from the six different locations (A to F),

223   we tested the relationship between the numbers of trails and tapir population estimates. Images

224   were processed in JMP data visualization software.

225

226   **Results**

227   We collected a total of 547 footprint images from 48 trails with an average of 11.40

228   footprints per trail, but after discarding some poor quality images we used 440 footprints from 46

229   trails in the analysis (an average of 9.57 footprints per trail). The minimum number of usable

230   footprints in a trail was 4 and maximum was 23. The data were subjected to FIT analysis which

231   generates a cluster dendrogram giving a prediction for the estimated minimum number of

232   individuals and the relationship between sub-trails (Jewell et al. 2016). For the whole study area,

233   FIT gave an estimate of 29 different individuals for pooled data (Fig. 4A, B). We then analyzed

234   the data for each of the six locations and the summed estimate for all six locations was 35

235   individuals. Finally, we compared the pooled and summed estimates for different combinations

236   of locations (Table 2). All pooled estimate values were either equal to or lower than summed

237   values. Location A had the most tapirs identified (n=12; see Fig. S1), whereas locations C and D

238   (see Fig. S2) had only one individual identified (Table 2). Locations A and E combined

239   represented more than 65% of total individuals identified in the study area (Table 2; Fig S1 and

240   Fig. S3). FIT identified six and seven individuals for the locations B and F, respectively (see Fig.

241   S4 and Fig. S5).

242   The difference between the pooled (29) and summed (35) estimates indicates that six

243   individuals appeared in more than one area during the study period (Table 2). For example, three

244   individual used the closest sites A+B (1,110 m apart). One individual visited the sites A+E

245   (1,567 m apart), three tapirs were recorded visiting the sites B+F (3,868 m apart) and two

246 individuals used the sites A+F (4,494 m apart). The other sites, when combined, did not indicate

247 any individuals visiting more than one area.

248   Finally, although the data were limited to just six different locations (A to F), we

249 examined the relationship between the number of trails (predictor variable x) and the tapir

250 population estimate (response variable y) for each location (Fig.5). The regression was highly

251 significant (y = 1.24 + 0.62x, R^2 = 0.9660, p <0.001).

252

253 **Discussion**

254   We have demonstrated a practical application of FIT as a means of monitoring the health

255 of the Atlantic Forest of Brazil, through an assessment of the numbers of an indicator species, the

256 lowland tapir. In the 10 months over which this census was conducted, we identified at least 29

257 different individuals of lowland tapir in the RPPNRA and surroundings. The study suggested that

258 tapirs in the RPPNRA might have overlapping ranges and that FIT could identify that the some

259 individuals visited more than one location.

260   Lowland tapirs exhibit extensive home range overlap (Noss et al. 2003; Medici 2010). In

261 our study, we estimated that at least six different individuals shared the same areas. In addition,

262 we found evidence to suggest that they moved long distances within the study area. Lowland

263 tapirs can easily traverse low-quality and non-natural habitats, moving through the landscape

264 matrix in between patches of forest, including eucalyptus and agriculture fields (Noss et al. 2003;

265 Medici 2010; Centoducatte et al. 2011). In our study area, a landscape composed basically of

266 agriculture, eucalyptus forest, pasture, and secondary patches of Tabuleiro Forest, we identified

267 footprints of the same individuals in at least two sites, from 1,110 to 4,494 meters apart. This

268 result indicates that the landscape matrix in the RPPNRA area provides a certain level of

269   functional connectivity that allow tapirs to mediate, considerably, the gene flow of many plant

270   species since they have a key role in the dispersion of many seeds (Tobler et al. 2009; Bueno et

271   al. 2013; O'Farrill et al. 2013; Giombini et al. 2016). This ability of tapir to travel among

272   heterogeneous habitats, dispersing seeds over distances is essential for plants that depend on long

273   dispersion to survive (Giombini et al. 2016).

274   FIT offers several substantial benefits over other monitoring methods, especially those

275   that are invasive to the study species (Alibhai et al. 2017). First, footprints of tapirs are easy to

276   find and very abundant. With appropriate weather conditions and substrates, and a moderate

277   sampling effort, footprints can be used effectively for censusing tapir populations. The RPPNRA

278   and its surroundings have more than 70 dirt roads, and all the roads used for this study (a total of

279   17) were visited by lowland tapirs at least once. Most of these unpaved roads have a good

280   substrate for footprints and trails (e.g., sand or clay substrate). They are located in different parts

281   of the studied area, covering different habitats, and footprint trails found were mostly long and

282   well defined. Also, it is likely that tapirs use dirt roads more frequently than off roads (e.g. Di

283   Bitetti et al. 2014). In our study area, footprints of tapir are more visible and frequent in those

284   unpaved roads than in other areas inside the forest, such as game trails. To find a footprint or a

285   long trail of footprints in the forest is a difficult task, especially because of the great amount of

286   litter that cover the forest floor.

287   Second, an invasive method (i.e. immobilization and capture) carries a small risk of

288   individual mortality, and it is possible that immobilization itself may negatively impact on

289   female fertility (Alibhai et al. 2001). In addition, instrumented animals may exhibit changed

290   behavior that is not representative of the population as a whole, and therefore poses questions

291   about resulting data reliability (Jewell & Alibhai 2013; Jewell 2013). Third, a systematic FIT

292   survey can be carried out in a relatively short period of time depending on personnel and

293   resources. Fourth, FIT projects can employ local trackers' expertise to locate tapirs and other

294   species' footprints, supporting the local people and their valuable traditional knowledge. Lastly,

295   FIT can be used alongside camera-trapping or line transects as a powerful addition to the

296   monitoring toolbox. An additional finding was the significant relationship between the numbers

297   of trails and the estimated uniquely identified individuals of tapir that suggests that this could be

298   used as an effective method for estimating tapir numbers by simply counting the number of

299   trails. However, we believe that this needs to be validated in different study sites to include

300   detection probabilities before it is employed as a useful index for tapir censusing as it is likely to

301   be influenced by sampling procedure.

302

303   **Conclusions**

304   This is the first census survey attempt using footprints for the Tabuleiros Forest, and we

305   will continue to apply the FIT method to census populations and individuals over time in the

306   RPPNRA and surrounding areas. We hope that this will form the basis of a long-term study that

307   we can replicate in nearby sites to estimate the species population, and determine its status and

308   viability in the Linhares-Sooretama forest complex region.

309   The FIT software can be made available free of charge (www.wildtrack.org), and sits as

310   an add-in to JMP statistical analysis software which is available commercially (www.jmp.com).

311   We help non-profits and other groups with demonstrable need to apply for a Friends of JMP free

312   annual license. We offer in-situ FIT training workshops for users on request and usually hosted

313   in conjunction with a local partner.

314   Research with this type of methodology is needed to improve our ability to manage and

315   conserve tapirs. This technique is able to rapidly provide data on the numbers and distribution of

316   a key seed-disperser species, from footprints alone. A non-invasive and low-cost method, like

317   FIT, is essential to collect data on populations of threatened species, and provide those data to

318   managers of protected areas. Our surveys within a heterogeneous landscape, such as the

319   RPPNRA, with the identification of a minimum of 29 tapir individuals, confirms the

320   conservation value of this area as a stronghold for populations of *Tapirus terrestris*.

321

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327

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Approximate distances (in meters) between sampling sites.

Study area is located in the Private Natural Heritage Reserve Recanto das Antas and surroundings, Espírito Santo, Brazil. In bold are the smallest and farthest distances between two sites. See map in Fig. 1 for sites reference.

	A	B	C	D	E	F
A	0					
B	**1110**	0				
C	6130	4245	0			
D	2893	1837	3872	0		
E	1567	2547	**6297**	2370	0	
F	4494	3868	4203	1860	2058	0

Number of lowland tapirs identified in one or more sites using the Footprint Identification Technique (FIT).

Study area is located in the Private Natural Heritage Reserve Recanto das Antas and surroundings, Espírito Santo, Brazil. See map in Fig. 1 for sites reference. Estimates of numbers of lowland tapirs are for summed data. Pooled data are in parenthesis.

Location	# of footprints	# of trails	# of subtrails	# of footprints per subtrail	Estimated # of tapirs
A	150	16	23	5-8	12
B	71	9	10	6-8	6
C	20	2	4	5	1
D	20	2	4	5	1
E	99	10	15	5-8	8
F	80	7	12	6-8	7
TOTAL FOR STUDY SITE	**440**	**46**	**68**	**5-8**	**35 (29)**
A+B	221	25	33	5-8	18 (15)
A+C	170	18	27	5-8	13 (13)
A+D	170	18	27	5-8	13 (13)
A+E	249	26	38	5-8	20 (19)
A+F	230	23	35	5-8	19 (18)
B+C	91	11	14	5-8	7 (7)
B+D	91	11	14	5-8	7 (7)
B+E	170	19	25	5-8	13 (13)
B+F	151	16	22	6-8	13 (10)
C+D	40	4	8	5	2 (2)
C+E	119	12	19	5-8	9 (9)
C+F	100	9	16	5-8	8 (8)
D+E	119	12	19	5-8	9 (9)
D+F	100	9	16	5-8	8 (8)
E+F	179	17	27	5-8	15 (15)

Figure 1

Survey sites for lowland tapir footprints.

Location of the main survey sites (A-F) used for lowland tapir footprints survey in the Private Natural Heritage Reserve Recanto das Antas and surroundings, Espírito Santo, Brazil. Cartographic base source: Protected areas - Cadastro Nacional de Unidades de Conservação (2015); Political boundaries – Instituto Brasileiro de Geografia e Estatística (2001; 2005). Datum: WGS 1984. Coordinate system/projection: UTM 24S.
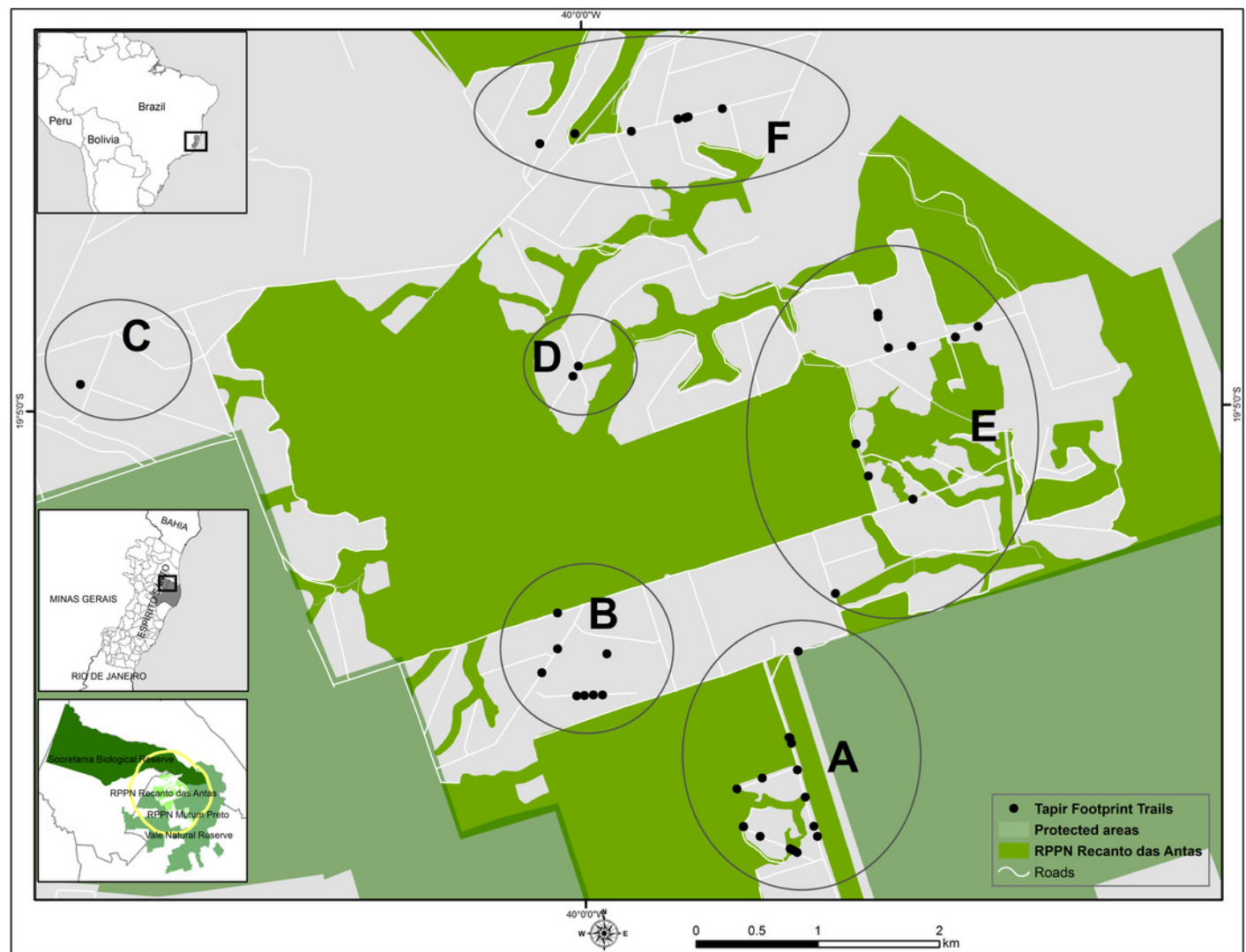
Figure 2

Lowland tapir trail and footprint.

(A) Trail of lowland tapir (*Tapirus terrestris*) along a dirt road. Photo credit: Danielle O. Moreira. (B) Lowland tapir left hind footprint photo collected during footprint surveys. Photo credit: Cristina J. da Cunha.

Figure 3

Footprint Identification Technique (FIT).

(A) Main menu window for lowland tapir in FIT. (B) Feature extraction window in FIT for lowland tapir. (C) Footprint image after processed using FIT script. Landmark points are in black and derived points in yellow. Image and photos credits: Danielle Moreira/ Andressa Gatti/ WildTrack.

Figure 4

Dendrogram generated by FIT algorithm predicting the minimum number of lowland tapir (*Tapirus terrestris*) for the studied area.

(A) The first panel of the dendrogram shows 14 tapirs identified. (B) The second panel of the dendrogram shows more 15 tapirs identified. Surveys ranged from location A to location F (see Fig. 1 for sites references) in the Private Natural Heritage Reserve Recanto das Antas and surroundings, in Espírito Santo, Brazil. Each letter represents a location; a number represents a trail; a number and letter, a sub-trail; and the colors represent one individual.
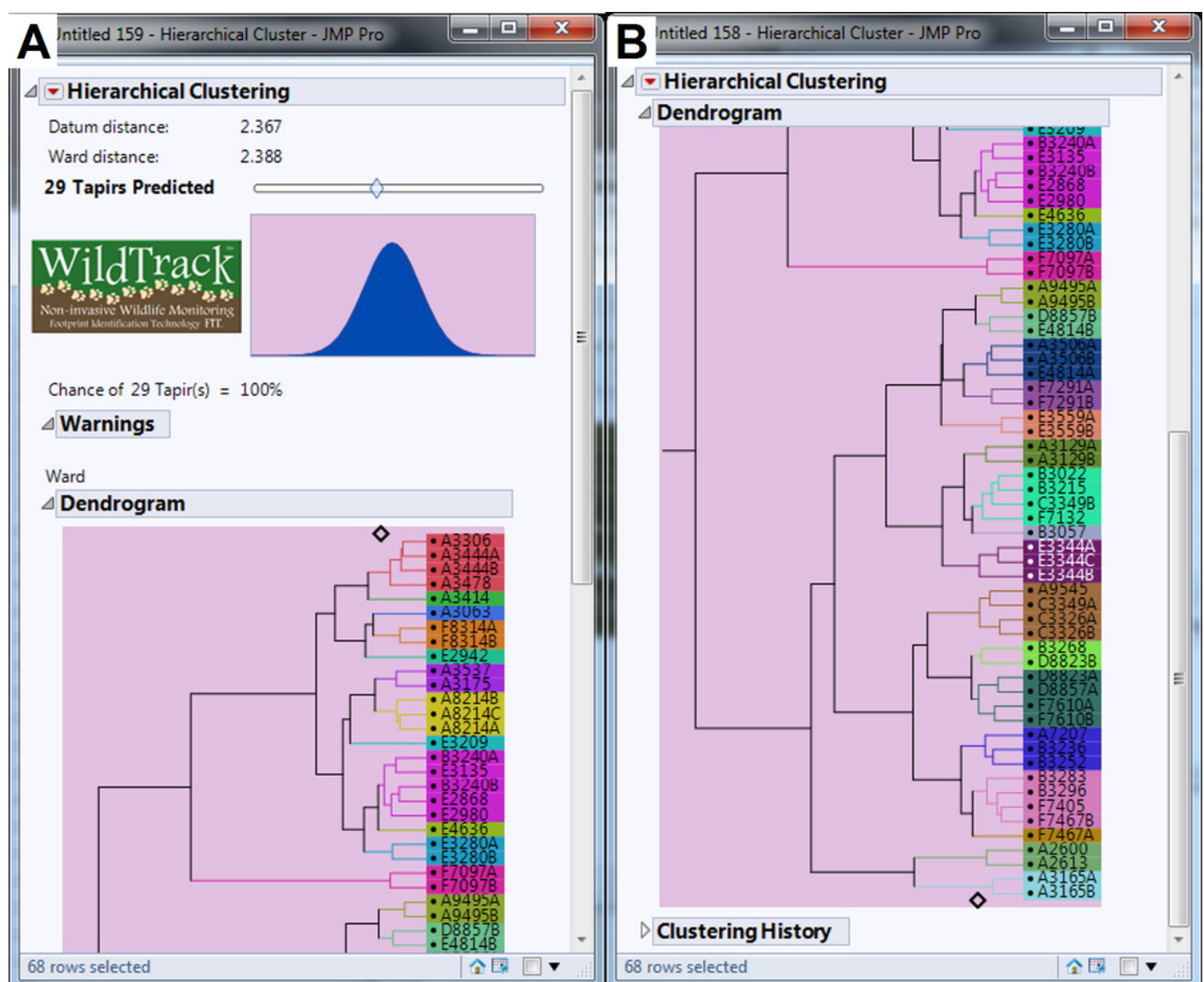
Figure 5

Relationship between numbers of trails and estimated number of unique individuals of lowland tapirs as determined by FIT in the study site.

The figures for numbers of trails are derived from the different locations (A to F) using separate locations and combinations of locations. Where locations were combined for the analysis, pooled estimates of tapir numbers were used.