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1   **Local habitat and landscape influence predation of bird nests**

2   **on afforested Mediterranean cropland**

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ABSTRACT

Afforestation programs such as the one promoted by the EU Common Agrarian Policy have contributed to spread tree plantations on former cropland. Nevertheless these afforestations may cause severe damage to open habitat species, especially birds of high conservation value. We investigated predation of artificial bird nests at young tree plantations and at the open farmland habitat adjacent to the tree plantations in central Spain. Predation rates were very high at both tree plantations (95.6%) and open farmland habitat (94.2%) after two and three week exposure. Plantation edge/area ratio and development of the tree canopy decreased predation rates and plantation area and magpie (*Pica pica*) abundance increased predation rates within tree plantations, which were also affected by land use types around plantations. The area of nearby tree plantations (positive effect), distance to the tree plantation edge (negative effect), and habitat type (mainly attributable to the location of nests in vineyards) explained predation rates at open farmland habitat. We conclude that predation rates on artificial nests were particularly high and rapid at or nearby large plantations, with high numbers of magpies and low tree development, and located in homogenous landscapes dominated by herbaceous crops and pastures with no remnants of semi-natural woody vegetation. Landscape planning should not favour tree plantations as the ones studied here in Mediterranean agricultural areas that are highly valuable for ground-nesting bird species.

Keywords: Artificial nests, Farmland habitat, Land use types, Magpie abundance, Pine plantations

1. Introduction

A significant amount of abandoned cropland, low productive cropland and pastureland has been converted into tree plantations in the last few decades, and ca. 7% of the total forest land in the world are tree plantations at present (FAO, 2011). Different afforestation programs have contributed to the spread of such tree plantations at the regional level. Thus, the Common Agricultural Policy (CAP) has favoured the conversion of farmland into tree plantations in the European Union since 1992 by means of a scheme of aid for forestry measures in agriculture (EEC Council Regulation No. 2080/92), which has resulted in the afforestation of > 8 million ha to date (European Commission, 2013a, 2013b). Further, afforested cropland is expected to increase in the near future in countries such as Spain due to subsidies to afforestation of extirpated vineyards (Spanish Agrarian Guarantee Fund, 2012). This afforestation program pursues both societal and environmental benefits, including control of erosion, prevention of desertification, regulation of the water regime, and increasing the fixation rate of carbon dioxide. However, whereas tree plantations provide a number of benefits (Rey Benayas et al., 2007), they may have noticeable effects on biological communities, as it has been exemplarily shown with birds (Shochat et al., 2001; Santos et al., 2006; Bremer and Farley, 2010; Felton et al., 2010; Lindenmayer et al., 2010; Rey Benayas et al., 2010).

Agro-ecosystems are important for maintenance of bird diversity in Europe, especially for species of conservation concern (BirdLife International, 2004). The Directorate-General for Agriculture and Rural Development (2012), using *the common farmland bird index* as "a barometer of change for the biodiversity of agricultural land

in Europe", shows a decline in these bird populations of ca. 20% between 1990 and 2008 (see also Gregory et al., 2005; Butler et al., 2010; Guerrero et al., 2012). Cropland afforestations in southern Europe are mostly based on coniferous species such as *Pinus halepensis* and *P. pinaster*, and are an example of novel and hybrid ecosystems sensu Hobbs et al. (2009). These plantations may cause damage to open habitat species, especially birds, by replacing high quality open farmland habitat and increasing risk of predation (Díaz et al., 1998; Cresswell, 2008; Reino et al., 2009). Predation has both direct and indirect effects on bird populations (Batáry and Báldi, 2004), the latter related to the avoidance of use of habitats that are perceived as risky (Murcia, 1995) or fecundity reduction (Bonnington et al., 2013). Besides hindering the persistence of established ground-nesting bird populations, predation may impede the colonization of the new afforested habitat by bird species (Murcia, 1995; Lindenmayer and Fischer, 2006).

Tree plantations act as sources of generalist predators of various types, including rodents, lagomorphs, feral cats, dogs, and corvids (Andren, 1992; Pita et al., 2009; Reino et al., 2010; Suvorov et al., 2012). These generalist predators usually have very low densities at treeless open habitats, but thrive in mosaic habitat landscapes where they exhibit an exploratory behaviour (Andren, 1992; Pita et al., 2009; Reino et al., 2010). Particularly, predation by corvids is enhanced in humanized landscapes where they attain high densities (Jokimaki et al., 2000; Newson et al., 2010), and Salek (2004) experimentally showed that the presence of magpie (*Pica pica*) nests increased predation rates on bird eggs. Accordingly, Castilla et al. (2007) attributed in part the relatively low predation on Red-legged Partridge (*Alectoris rufa*) eggs at Mediterranean fallow fields to the low presence of magpies due to their capture by humans. Magpies

are strongly attracted by trees in deforested landscapes for nesting, and this phenomenon is highly noticeable at relatively small and isolated tree plantations in Mediterranean cropland afforestations.

This study aimed to investigate the predation of bird eggs set on artificial nests at young (< 20 yr) tree plantations established on former cropland and at the open habitat adjacent to such tree plantations in a farmland and woodland Mediterranean mosaic. We hypothesized that nest predation will be affected by both (1) the features of local breeding habitat and (2) the features of landscape −namely proportion of land use types- surrounding local habitat. At tree plantations, we predicted that (i) a reduced area and a high edge-area ratio will favour permeability to predators and hence increase nest predation rates and (ii) magpie abundance and predation rate will be positively correlated. At open farmland habitat adjacent to tree plantations, we predict that predation rates will be influenced by (i) plantation area (positive effect), (ii) distance from plantation (negative) and (iii) magpie abundance (positive).

Our experimental study sheds light on the risk of nest predation at Mediterranean landscapes that have been subjected to afforestation projects of former cropland, and provides insights for impact assessment and management of such projects at the local habitat and landscape scales.

2. Methods

2.1. Study area

Field work was carried out in afforested cropland and open farmland located in Campo de Montiel (La Mancha natural region, southern Spanish plateau, 38º41'53''N,

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106 2º51'54"W, **Figure S1 in Supplemental Material**). The study area spreads on ca. 440

107 km^2 with altitude ranging between 690 and 793 m a.s.l. The climate is continental

108 Mediterranean with dry and hot summers and cold winters. Mean annual temperature

109 and total annual precipitation in the area during the last 30 years were 13.7 °C and 390

110 mm, respectively (Agencia Española de Meteorología, 2012). These figures were

111 16.6°C and 359.9 mm in 2011 and 15.8ºC and 362.9 mm in 2012, when our nest

112 predation experiments took place (Junta de Castilla-La Mancha, 2013).

113   The area is a representative mosaic of different crops, pastures and semi-natural

114 or planted woody vegetation that are characteristic of large areas in Mediterranean

115 landscapes. Croplands were mostly occupied by herbaceous crops (wheat and barley)

116 and permanent woody crops (olive groves and vineyards). Natural vegetation consisted

117 of holm oak (*Quercus rotundifolia L.*) woodland and riparian forests that have been

118 mostly extirpated from this region. Until 1992, woodland cover was restricted to open

119 holm oak parklands, usually grazed by sheep and goats. Major land use changes in the

120 last 20 years are the abandonment of herbaceous cropland and vineyard extirpation and

121 their subsequent afforestation with the native Aleppo pine (*Pinus halepensis* Mill.)

122 alone or mixed with holm oak and (*Retama sphaerocarpa* (L.) Boiss) (Rey Benayas et

123 al., 2010). These tree plantations are noticeably dominated by pines as they establish

124 better and grow faster than the other planted species.

125

126 *2.2. Selection of tree plantations for predation experiments*

127 The constraints associated with each habitat type, namely tree plantations and open

128 farmland adjacent to tree plantations, prevented homogeneous experimental designs and

6

sampling methods, and consequently data from the different experiments were not

directly analysed together (see below). Thus, we run two independent experiments of

bird nest predation, (1) at tree plantations and (2) on open farmland. First, all tree

plantations in the study area were located using both orto-photos (Geographic

Information System of Farming Land, 2010; hereafter SigPac) and Google Earth®, and

were later verified in the field. We found 99 tree plantations on former cropland that

took place in 1992 or later. Only tree plantations > 0.78 ha were selected for the

predation experiments to take advantage of bird survey plots of this size in the study

area. In addition, a target tree plantation for the experiment on adjacent farmland had to

be placed at least 2-km away from another plantation to avoid that experimental nests

associated with a given tree plantation were affected by another tree plantation.

Following these criteria, we finally selected 30 tree plantations for the experiment at

tree plantations and 38 tree plantations for the experiment on farmland adjacent to the

tree plantations, with 20 plantations that were used in both experiments (**Figure S1 in**

Supplemental Material).

2.3. Survey of magpie abundance

We recorded the abundance of magpie as a potential nest predator in the studied tree

plantations and open farmland habitat adjacent to such plantations. At every tree

plantation, magpies were surveyed using point-count stations (Bibby et al., 2000)

lasting 10 minutes in May 2011. The point-counts were located at the centre of each tree

plantation. All auditory and visual contacts were recorded, but only those within a 50 m

radius (0.78 ha; **Figure S2 in Supplemental Material**) were used in subsequent

analyses, in order to increase the probability of detection. Every point-count station was

153 surveyed by two censuses in different days, one within the first 4 h in the morning and

154 another in the afternoon beginning 3 h before sunset. We used the average of the two

155 counts as a measure of magpie abundance. The same trained person conducted all the

156 censuses (JSS-O) on nearly windless (wind speed <3 m s^{-1}) and rainless days.

157   The open farmland habitat adjacent to 38 tree plantations was also surveyed for

158 magpie abundance by means of one line transect of 400-m length and 200-m width in

159 may 2012 (**Figure S2 in Supplemental Material**). Again, all censuses were conducted

160 by the same well trained field ornithologist (JSS-O) on windless (wind speed < 3 m s-1)

161 and rainless days. We employed two different census methods and years for sampling

162 magpie relative abundance according to the limitations imposed by the size of pine

163 plantations, where transects were not possible due to their small area. Nevertheless, this

164 is not a concern in this study as the aim is not to compare magpie abundance inside *vs*

165 outside plantations, but to relate the relative abundance of magpies to nest predation

166 within plantations and outside plantations, separately.

167   Other corvid species were disregarded as key predators of artificial nests because

168 they were very scarce in the study area (the Carrion Crow, *Corvus corone*, was detected

169 at only one open farmland adjacent to tree plantations, and other species such as the Jay,

170 *Garrulus glandarius*, or the Raven, *C. corax*, were not observed in the study area).

171

172 *2.4. Nest predation experiments*

173 The two nest predation experiments used quail (*Coturnix coturnix*) eggs that were layed

174 on exposed artificial wicker nests (two eggs at each artificial nest; see below details on

175 egg placement). All eggs had the same origin (i.e., supplier), were washed and then

176 dried at air temperature before being used for the field experiments (Vander Haegen and

177 DeGraaf, 1996; Conner and Perkins, 2003; Piper and Catterall, 2004), and were handled

178 with gloved hands to minimize human scent (Whelan et al., 1994).

179   The artificial nests at tree plantations and on open fields near plantations were

180 not placed on the same date due to limitations inherent to the organization of the field

181 work, which included a number of tasks, and considering the timing of agricultural

182 activities in the study area (e.g., ploughing). Nevertheless, the data for the two

183 experiments were analysed separately and were never directly compared.

184   We considered an artificial nest as predated when the eggs were either absent or

185 damaged, excluding from analyses those artificial nests that were ploughed or trampled

186 (42 and 7, respectively, on open farmland and neither at tree plantations). Types of

187 predators could not be distinguished for the eggs that were removed from the artificial

188 nests which, in turn, were most of them (see Results). Nevertheless, unidentified

189 predation events were probably attributable to small corvids (Schaefer, 2004) such as

190 magpies considering their ability to store large items of food and to steal and remove

191 eggs from nests (Henty, 1975; Groom, 1993; Perrins, 1998). We were able to

192 distinguish predation by rodents (by their characteristic bites and, sometimes, faeces)

193 and by corvids (by their characteristic pecks) from some fresh egg remains, whereas for

194 the largest part of predated eggs with fresh remains we could not distinguish the source

195 of predation. However, this issue is not a problem for the aims of this study since we

196 were interested in the effects of tree plantations on overall predation risk rather than in

197 the identification of predator assemblages.

198 *Experiment 1.- Predation at the tree plantations.* This experiment was run at 30

199 plantations in the spring of 2011, which averaged 5.6 ± 7.2 ha and ranged between 1.5

and 36.5 ha. The artificial nests with two quail eggs each were placed at two different positions (i.e. one nest on the ground and another nest on pine branches) at 25-m intervals along an *a priori* line spanning from the edge (0 m) to the centre of the plantation (**Figure S2 in Supplemental Material**), in May 22-25. The height above the ground for those nests located on branches was estimated using a measuring tape. The line where both on-ground and on-branches artificial nests were placed covered at least 50 m (i.e. three nest locations at 0, 25, and 50 m from the plantation edge), whereas the maximum length of that line from the plantation edge was 225 m that included ten nest locations (average was 70.8 m and sd = 38.9). Total sample size was 230 nests, 115 located on the ground and 115 located on branches. We visited the nests in two occasions, 7-9 days (May 31 and June 1) and 15-18 days after they were placed (June 9-11), counting the number of eggs that had been removed. Artificial nests were not checked more often in order to reduce the effect of the observer on predation and to preserve nest concealment (e.g., Major and Kendal, 1996).

Experiment 2.- Predation on open farmland adjacent to tree plantations. This experiment was run at 38 plantations in the spring of 2012. Each artificial wicker nest was baited with two treated quail eggs (see above) and was placed on the ground along an *a priori* 300-m line; this line spanned at 25-m intervals from the plantation edge (0 m) until 150 m away from such edge, and then at 50-m intervals until 300 m (i.e., nine nests at 0, 25, 50, 75, 100, 150, 200, 250, and 300 m; **Figure S2 in Supplemental Material**). The artificial nests were placed on May 4-9. Total sample size was 342 nests. We took note of the habitat type where each nest was situated, considering five habitat categories (olive groves, vineyard, abandoned cropland and pastures, semi-natural woody vegetation, and dry herbaceous cropland). We checked the nests for egg

224   predation in two occasions (in May 15-22 and in May 27-June 1, 11-14 days and 21-23

225   days after the nests were placed), following the same protocol presented in Experiment

226   1.

227

228   *2.5. Local habitat and landscape features*

229   In each of the 46 tree plantations where experiments 1 and 2 took place, we

230   characterized variables related to vegetation structure, area, edge/area ratio, and

231   landscape surrounding the tree plantation (**Table S1 in Supplemental Material**).

232   Vegetation structure at each surveyed plantation was characterized in one 25-m radius

233   plot (**Figure S2 in Supplemental Material**). We directly measured or estimated by eye,

234   after previous training, the following structural features of the vegetation: percentage

235   cover of chamaephytes, shrubs and trees, average height of chamaephytes, shrubs and

236   trees, and number of trunks <5, 5-10, 10–20, 20–40 and >40cm in diameter at breast

237   height (dbh). Additionally, we estimated percentage cover of herbs and bare soil and

238   measured the average height of the herb layer in one concentric 10-m radius plots within

239   the 25-m radius plot (**Figure S2 in Supplemental Material**) due to perceptual

240   limitations when carrying out visual estimations. Vegetation structure was sampled by

241   the same observer (JSS-O) to avoid inter-personal bias in vegetation measurements. We

242   also measured area and edge/area ratio using ArcGIS 10.0 (ESRI Inc.). Edge/area ratio

243   was calculated as the quotient between the length of the edge (in m) and the square root

244   of the plantation area (in m^2).

245   Land use types were identified by means of land use layers taken from SigPac

246   (see source above) and were analysed with ArcGIS 10.0. We distinguished 14 land use

247 types: streams, rivers and lagoons, roads and rural tracks, urban areas and scattered

248 buildings, semi-natural woodland, dried-fruit orchards, orchards, waste lands, olive

249 grove, pastures with scattered trees, scrubland, pasture land, dry herbaceous cropland,

250 vineyard, and vineyard with olive trees. To characterize landscape surrounding the tree

251 plantations for Experiment 1, the percentage of area of each land use types was obtained

252 in 1-km buffer-rings centred at each forest plantation (**Figure S2 in Supplemental**

253 **Material**). To characterize landscape for Experiment 2, the proportion of land use types

254 was measured as above at 600 m x 600 m squares that included the 300-m transects in

255 farmland habitat were the artificial nests were set (**Figure S2 in Supplemental**

256 **Material**).

257

258 *2.6. Statistical analysis*

259 The two experiments of nest predation were analysed independently. We used

260 predation incidence obtained from the first checking date as most artificial nests were

261 predated within the first 7-14 days after they were placed on the field (see Results).

262 We looked at the correlation among the independent variables of our models

263 (see below). Most correlations were not significant. Moreover, the VIF figures (variance

264 inflation factor) for predictors in the analyses were very low (<1.75). Particularly, the

265 shared variance between magpie abundance and other explanatory variables was usually

266 very low (as measured by the coefficient of determination R^2): (a) Within tree

267 plantations: log area 0.03; edge/area ratio <0.001; PC1 vegetation 0.14; PC2 vegetation

268 0.04; and PC1 land use 0.08; (b) On open farmland habitat: log area 0.09; pine height

269 <0.001; and PC1 land use 0.03.

270   Two statistical approaches were carried out for each experiment. First, we

271   analysed the predation of each individual nest using a binomial response variable

272   (predated-1, non-predated-0) by means of a Generalized Linear Mixed Effects Model,

273   with the study location (the plantation or the farmed fields outside the plantation) as a

274   random factor and the position of the nests as fixed effects. Additionally, we analysed

275   global predation rates at the tree plantations and on open farmland by means of a

276   generalized Poisson regression model. This model considered the whole sample of

277   artificial nests at each location. Predictor variables described the characteristics of the

278   plantations, the density of the magpie and the landscape structure around each study

279   location.

280   *Experiment 1.*- A Generalized Linear Mixed Model was applied to the predation of each

281   individual nest at tree plantations using a binomial response variable (predated-1, non-

282   predated-0; logit link function). The plantation was included as a random factor and the

283   position of the nests were the fixed effects (distance of each artificial nest to the

284   plantation edge and height of artificial nests above the ground). The continuous

285   predictor variables were standardized to mean $= 0$ and sd $= 1$ in order to obtain

286   standardized regression coefficients. Statistical significance was estimated using a

287   robust approach with quasi-ML standard errors (Lindsey, 2004) after correcting for

288   overdispersion ($\phi = 0.82$).

289   We also used a Generalized Linear Model based on a Poisson distribution (with

290   the log-link function) for analysing the number of predated nests, with the total number

291   of artificial nests placed at each plantation as an offset. This model was applied to

292   analyse the effects of six predictor variables, namely tree plantation area (log-

293   transformed), plantation edge/area ratio, magpie abundance, two components related to

vegetation structure, and a principal component related to landscape features (see below). Statistical significance of the standardized regression coefficients of the predictor variables was estimated using a robust approach with quasi-ML standard errors after correcting for overdispersion ($\phi = 0.72$).

We performed two different principal components analyses (PCA), one on vegetation structure variables within tree plantations and another on land use types surrounding the plantations, to obtain synthetic and independent environmental gradients that may affect nest predation.

Experiment 2.- A Generalized Linear Mixed Model was applied to the predation of each individual nest on farmland habitat using a binomial response variable (predated-1, non-predated-0; logit link function). The plantation was included as a random factor and the position of the nests were the fixed effects (distance of each artificial nest to the nearest plantation edge and a factor describing the location in six different habitat categories). The continuous predictor variables were standardized to obtain standardized regression coefficients. Statistical significance was estimated using a robust approach with quasi-ML standard errors after correcting for overdispersion ($\phi = 0.36$).

Additionally, we used another Generalized Linear Model based on a Poisson distribution (with the log-link function). The response variable was the number of predated nests placed at each transect, with the total number of artificial nests as an offset. Predictor variables were: area of the nearby tree plantation (log-transformed), average tree height of the nearest plantation, magpie abundance on the farmed field transect, and the principal component related to landscape features (see below). The continuous predictor variables were standardized in order to obtain standardized

318 regression coefficients. Statistical significance of the standardized regression

319 coefficients of the predictor variables was estimated using a robust approach with quasi-

320 ML standard errors after correcting for overdispersion ($\phi = 0.43$).

321 For this experiment we carried out another PCA on land use type categories

322 measured at 600 m x 600 m squares.

323 Out of the 342 nests placed in total for the experiment, 40 nests were not found,

324 seven were trampled, and 42 were located on cropland fields that were ploughed. All

325 artificial nests at five out of the 38 tree plantations that were initially selected for

326 Experiment 2 were lost due to ploughing or trampling.

327 Statistical analyses were carried out using GRETL 1.9.14 (Cottrell and

328 Lucchetti, 2007) for generalized linear models and STATISTICA 10 (StatSoft, 2011)

329 for principal components analyses.

330

331 **3. Results**

332 *3.1. Dominant environmental gradients*

333 The first component on vegetation structure variables within tree plantations (51.2% of

334 total variance) defined a gradient of increasing development of the tree canopy, as it

335 opposed tree cover (factor loading = 0.897), tree height (0.816) and number of trunks >5

336 cm in dbh (0.852) to shrub height (-0.724) and cover (-0.523) and herb height (-0.656).

337 The second component on vegetation structure variables (20.1% of the total variance)

338 was associated with the development of the shrub layer; it opposed shrub cover (0.727)

339 and height (0.602) to herb cover (-0.611). The first component on land use around tree

340 plantations (36.3% of the total variance) opposed olive groves (0.964) and semi-natural

woodland (0.718) to roads and rural tracks (-0.842), vineyard (-0.766) and dry herbaceous cropland (-0.637).

For land use type categories measured at 600 m x 600 m squares on open farmland habitat, the first component (14.8% of the total variance) opposed semi-natural woodland (0.644) and pastures with scattered trees (0.626) to dry herbaceous cropland (-0.715).

3.2. Predation rates and magpie abundance

Overall predation rates were very high at both the tree plantations and adjacent open farmland (**Figure 1**). 81.2% and 88.4% of the predated artificial nests were observed at tree plantations and on open farmland habitat, respectively, by the first counting, one to two weeks after being set. Only 4.4% and 5.8% of artificial nests at tree plantations and on open farmland habitat, respectively, were left un-predated two to three weeks after the start of the experiment (**Figure 1**).

All artificial nests at 12 (40%) tree plantations were predated by the first counting, and all artificial nests were left un-predated at only one tree plantation. On open farmland habitat, all artificial nests were predated in 21 (58.3%) transects by the first counting. The maximum number of artificial nests left un-predated in a transect by the first counting was 85.7%.

Of the total nests, 74.2% at tree plantations and 79.2% on open farmland were removed and, consequently, their source of predation is unknown. Predation by rodents at tree plantations and on open farmland were, respectively, 1.7% and 2.3%, whereas

363 5.2% and 6.9%, respectively, showed evidence of predation by corvids, namely magpie

364 as the nearly exclusive corvid species present around and in plantations.

365   Mean magpie abundance at the 30 tree plantations was 1.37 birds per ha (sd =

366 1.87, range = 0-6.41), whereas it averaged 0.11 birds ha^{-1} (sd = 0.18, range =0-0.63,

367 n=38) at open farmland near tree plantations.

368

369 *3.3. Nest predation at tree plantations*

370 The Generalized Linear Mixed Model analysing the predation probability of artificial

371 nests at tree plantations showed substantial differences among plantations, but distance

372 of artificial nests to the plantation edge and height of nests above the ground did not

373 show any significant effect on nest predation (**Table 1**).

374   The Generalized Linear Model (Poisson distribution) of the number of predated

375 nests at tree plantations, using the total number of artificial nests placed at each

376 plantation as an offset (**Table 2**), revealed positive effects of tree plantation area and

377 magpie abundance (**Figure 2**), and negative effects of edge/area ratio, development of

378 the tree canopy (first PC of vegetation structure variables), and relative amount of tree

379 crops and woodland in the landscape (first PC of land use type variables).

380

381 *3.4. Nest predation on open farmland adjacent to tree plantations*

382 The Generalized Linear Mixed Model analysing nest predation of individual nests on

383 open farmland adjacent to tree plantations resulted in significant effects of the three

384 predictors (**Table 3**). There were important differences among the 33 open farmland

385 sites adjacent to tree plantations (random factor). Distance of nests to the nearest edge

386   of tree plantations had a negative effect on predation risk (i.e., lower predation risk at

387   longer distances from plantations). The habitat type where artificial nests were placed

388   had also a significant effect, mainly attributable to the location of nests in vineyards that

389   increased the probability of predation.

390   The Generalized Linear Model (Poisson distribution) of the number of predated

391   nests on open farmland adjacent to tree plantations, using the total number of artificial

392   nests placed outside plantations as an offset, showed only a significant effect of the

393   nearby plantation area, global predation risk on open farmland being higher around

394   larger tree plantations. Mean height of nearby tree plantations, magpie abundance and

395   the relative amount of tree crops and woodland in the landscape (first PC of land use

396   variables) did not show any significant effect on nest predation **(Table 4)**.

397   The area of the tree plantations for predated (n = 224) and non-predated (n = 29)

398   artificial nests were (mean $\pm$ se) 6.4 $\pm$ 0.48 ha and 3.1 $\pm$ 0.24 ha, respectively. Predated

399   and non-predated artificial nests were on average at a distance of 121.0 $\pm$ 6.38 m and

400   144.0 $\pm$ 20.75 from the tree plantations, respectively, and the modal values

401   corresponded to a distance of 50 m for predated nests and 300 m for non-predated nests.

402

403   **4. Discussion**

404   Overall, we found that predation of artificial bird nests at young tree plantations

405   established on former cropland and at adjacent open farmland habitat in a

406   Mediterranean mosaic located in central Spain was (1) very high at both habitats, (2)

407   influenced by local habitat features, and (3) influenced by landscape context. However,

408   we obtained different results for specific variables that were hypothesized to affect

409   predation rates inside and outside the investigated tree plantations (i.e. area, edge/area

410   ratio, distance to edge, and magpie abundance).

411   The use of artificial nests to test predation rates is controversial due to factors

412   that are not controlled with respect to real nests, and several studies have demonstrated

413   that artificial nests do not estimate nest predation rates on natural nests precisely (Burke

414   et al., 2004; Faaborg, 2004; Thompson and Burhans, 2004; Villard and Part, 2004).

415   Thus, artificial nests can reveal where birds would never choose to nest as opposed to

416   where their nests would suffer relatively high predation rates. Also, nest predation is

417   only one of demographic parameters and thus this study provides only a partial view of

418   the ecological relationships in the studied landscape.

419

420   *4.1. High predation rates on artificial nests*

421   Nest predation was very high and quick at both the tree plantations and adjacent open

422   farmland habitat (>80% in less than two weeks after the start of our experiments). These

423   rates are among the highest reported in the scientific literature (data and references in

424   **Table 5**). Previous published figures of nest predation rates at tree plantations average

425   59.5% with a range of 23-94% (**Table 5a**). Similarly, nest predation rates for natural

426   forest fragments are usually high (mean = 66.4%, range = 38.9-88.0%; **Table 5b**) but

427   lower than in our tree plantations (95.6%). Other studies that have assessed nest

428   predation rates at open habitat adjacent to tree plantations or natural forest fragments

429   reported figures that average 60.0% (range = 13.7-100%; **Table 3c**), which are

430   substantially lower than our 94.2% predation rate. However, comparisons of these

431   figures with the figures obtained in our study should be cautious due to the different

432   experimental designs across studies. In an experiment that used eggs of red-legged

433   partridge located at Holm oak woodland patches in Central Spain, Castilla et al. (2007)

434   reported a predation rate of 38.9% after a 2-week exposure.

435   We attribute the high predation rates in our study to the following three

436   phenomena. First, our tree plantations were overall very small (mean size of 5.7±6.7

437   ha), which make nests easily accessible to predators in general even at the largest

438   plantations (Ford et al., 2001; Chalfoun et al., 2002). Second, they were located in an

439   agricultural and highly humanized landscape, which may favor predation by a number

440   of animals such as rodents, hares, feral cats and dogs (Danielson et al., 1997; Jokimäki

441   et al., 2005; Pangau-Adam et al., 2006). Also, short vegetation −such as that in the

442   fields surrounding the studied plantations- is usually associated with very high predation

443   rates (Beja et al., 2014). And third, they were a very attractive habitat for magpies, a

444   documented powerful nest predator (Andren, 1992; Roos, 2004; Suvorov et al., 2012)

445   that was particularly abundant in our study area (Sánchez-Oliver et al., 2013).

446

447   *4.2. Factors affecting predation rates*

448   Nest predation at tree plantations increased with larger plantation area and abundance of

449   magpies and with a lower edge-area ratio and development of the tree layer, whereas

450   nest predation on open farmland habitat was higher if nearby tree plantations were of

451   large area and nests were located at closer distances from the plantations.

452   The small size and homogeneity of the studied tree plantations and the high

453   predation rates explain why distance to edge and average height above the ground of

454   individual nests did not have any effect on predation rates at tree plantations. However,

455 a shorter distance to edge of the tree plantation may enhance predation on the open

456 farmland habitat because nests are closer to the source of predators (Batáry and Báldi,

457 2004; Reino et al., 2010) such as magpies. Lack of association between magpie

458 abundance and nest predation on open farmland makes unclear if magpies are or not a

459 major predator in open habitats, an issue that should be tested by using cameras to

460 identify the actual predators.

461   Predator identification in our experiments was relatively unsuccessful as the

462 proportion of eggs that disappeared was high (>74%) and, unfortunately, egg shell

463 observation did not provide enough information to determine the main sources of

464 predation. However, we detected a positive relationship between nest predation rates

465 and magpie abundance inside tree plantations, which points to relevance of nest

466 predation caused by magpies. Magpies have a high capability of exploring relatively

467 new habitats and are prone to nesting in the most developed plantations (> 3 m in

468 height) that we surveyed in our mostly deforested study area (Carrascal et al., 2014).

469 Andren (1992) found predation rates of bird nests in forest fragments by this corvid that

470 ranged between 7.2% and 35.7%. As most of the studied tree plantations are of a

471 rectangular shape, low edge-area ratios mean larger plantations, which may function as

472 a refuge habitat and harbour a higher abundance of magpies and other generalist

473 predators of bird nests such as domestic carnivores (Virgós et al., 2002; Barea-Azcón et

474 al., 2006; Pita et al., 2009; Fandos et al., 2012).

475   The higher predation rates at tree plantations with lower tree development may

476 be explained by the facts that these plantations are newer habitats that call more the

477 attention of exploring predators (Virgós et al., 2002) than older plantations and,

478 additionally, they are more open and thus artificial nests are more visible (Suvorov et

479 al., 2012). The same influence of low vegetation cover can be related to the higher

480 predation risk suffered by artificial nests located at vineyards outside tree plantations, a

481 heavily anthropized habitat with no vegetation at ground level due to agricultural

482 practices that eliminate the natural herbaceous layer that may compete for water and

483 nutrients with grapevines.

484   Finally, we found significant landscape effects on nest predation at both the tree

485 plantations and the surrounding open farmland habitat. Other studies have found

486 relationships between landscape context and nest predation rates (Huhta et al., 1996;

487 Bayne and Hobson, 1997). In our study, nest predation in tree plantations was higher in

488 landscapes with higher proportion of herbaceous crops and pastures and lower

489 proportion of woody crops and semi-natural woodlands. This finding supported by

490 correlational evidence hints at the importance of semi-natural vegetation for

491 conservation of ground-nesting birds in vast open farmed fields (Santos et al., 2006;

492 Zuria et al., 2007; Ludwig et al., 2012). However, some open farmland birds may have

493 strong negative reactions to woody habitats, either natural or planted, and they may also

494 increase the abundance of generalist predators (Pita et al., 2009; Reino et al., 2009 and

495 2010). Deforested landscapes with a high proportion of herbaceous crops favour also

496 the abundance of lagomorphs, which can predate on eggs (Reino et al., 2010). In

497 general, tree plantations in open, deforested, and homogenous landscapes are better

498 attractors and refuges of predators than tree plantations in more heterogeneous

499 landscapes where there is more availability of habitat with trees (e.g. Andren, 1992).

500

501

5. Conclusion

Our experiments on predation rates at young afforestations of Mediterranean cropland and adjacent open farmland hint local habitat and landscape features that are indicators of predation risk for bird nests. We conclude that predation rates on artificial nests were particularly high and rapid at or nearby large plantations, with high numbers of magpies and low tree development, and located in homogenous landscapes dominated by herbaceous crops and pastures with no remnants of semi-natural woody vegetation. Thus, the studied tree plantations should not be favoured, and even be extirpated, in agricultural landscapes that are highly valuable for ground-nesting bird species and open farmland bird communities (Traba et al., 2006; Sánchez-Oliver et al., 2013). We recommend assessments of real nest predation risk following afforestation in agricultural landscapes to fully understand and, consequently, reduce its impacts on biodiversity, particularly on ground-nesting birds.

524 manuscript. All authors of this manuscript do not have any conflict of interest to

525 declare.

526

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728

729 **Table 1.** Results of the Generalized Linear Mixed Model (binomial distribution with

730 logit link function) analysing the effects on nest predation of distance to edge of tree

731 plantations and height above ground of individual artificial nests located in 30 tree

732 plantations on former cropland (random factor). p: statistical significance was estimated

733 using a robust approach with quasi-ML standard errors. Significant predictor variables

734 at p<0.05 are emboldened. Beta (β): standardized partial regression coefficients; se:

735 standard error of beta.

	df	β	se	p
Distance to plantation edge (m)	1	*-0.207*	0.305	*0.496*
Height above ground (m)	1	*-0.257*	0.223	*0.250*
Plantation (random factor)	**29**			***<<0.001***

736

737

738

739 **Table 2.** Results of the Generalized Linear Model (Poisson distribution with log-link

740 function) analyzing the effects of six predictor variables on the number of predated

741 artificial nests at 30 tree plantations on former cropland. The total number of artificial

742 nests placed at each plantation was used as an offset of the model. p: statistical

743 significance was estimated using a robust approach with quasi-ML standard errors.

744 Significant predictor variables at $p<0.05$ are emboldened. Beta (β): standardized partial

745 regression coefficients; se: standard error of beta.

	df	β	se	p
Area (ha; log-transformed)	**1**	*0.127*	**0.055**	*0.021*
Edge/area ratio	**1**	*-0.153*	**0.061**	*0.012*
Magpie abundance (no. individuals)	**1**	*0.169*	**0.061**	*0.006*
PC1 Vegetation structure	**1**	*-0.085*	**0.043**	*0.050*
PC2 Vegetation structure	1	*0.075*	0.041	*0.066*
PC1 Land use types	**1**	*-0.165*	**0.063**	*0.009*

746

747

748 **Table 3.** Results of the Generalized Linear Mixed Model (binomial distribution with

749 logit link function) showing the effects of predictor variables on predation of artificial

750 nests on open farmland adjacent to 33 tree plantations (random factor). p: statistical

751 significance was estimated using a robust approach with quasi-ML standard errors.

752 Significant predictor variables at $p<0.05$ are emboldened. Beta (β): standardized partial

753 regression coefficients for continuous predictors and for the dummy variables built with

754 the levels of the factor habitat types.

	df	β	se	p
Distance to edge (m)	**1**	*-1.122*	**0.363**	*0.002*
Habitat types where nests were placed:	**5**			*0.003*
Olive groves		*0.632*	0.701	*0.368*
Vineyard		***8.440***	**0.433**	***<0.001***
Abandoned cropland and pastures		*0.656*	0.948	*0.489*
Semi-natural woody vegetation		*-0.575*	0.650	*0.376*
Dry herbaceous cropland		*0.988*	0.800	*0.217*
Plantation (random factor)	**32**			***<<0.001***

755

756

757 **Table 4.** Results of the Generalized Linear Model (Poisson distribution with log-link

758 function) analysing the effects of predictor variables on the number of predated artificial

759 nests on open farmland adjacent to 33 tree plantations. The total number of artificial

760 nests in each open farmland habitat was used as an offset of the model. p: statistical

761 significance was estimated using a robust approach with quasi-ML standard errors.

762 Significant predictor variables at $p < 0.05$ are emboldened. Beta (β): standardized partial

763 regression coefficients; se: standard error of beta.

|	df	β	se	p
Plantation area (ha; log-transformed)	**1**	*0.052*	**0.024**	*0.030*
Average tree height in plantations (m)	1	*-0.017*	0.036	*0.641*
Magpie abundance (no. individuals)	1	*0.016*	0.031	*0.602*
PC1 Land use types	1	*-0.061*	0.039	*0.116*

764

765

Table 5. Review of nest predation rates at (a) tree plantations, (b) forest fragments and

767   (c) open habitat adjacent to tree plantations or forest fragments. The mean and range of

768   predation rates and the mean ± sd of exposure days for the three habitat types (i.e. a, b

769   and c) have been calculated by the authors of this study on the basis of the referred

770   studies.

| Habitat type	Landscape context	Mean (range) predation rate (%)	Mean no. exposed days (±sd)	References
a) Tree plantations		59.5 (23.0-94.0)	12±2	
Conifer plantations	Sub-boreal forest	83.7 (64.7-94)	10	Pedersen et al. 2009
		23.0	14	Vander Haegen & DeGraaf 1996
		41.2 (36.7-45.8)	13	Carignan & Villard 2002
b) Forest fragments		66.4 (38.9-88.0)	11±4	
Forest fragments	Boreal agricultural	88.0	7	Andren 1992
Oak forest fragments	Mediterranean agricultural	87.5	8	Santos & Tellería 1992
		38.9	14	Castilla et al. 2007
Fagus forest fragments	Eurosiberian agricultural	41.7	14	Ludwig et al. 2012
Cloud forest fragments	Andean agricultural	48.9	15	Arango-Vélez & Kattan 1997
Rainforest fragments	Tropical pastures	71.9	9	Estrada et al. 2002
c) Open habitat adjacent to tree plantation or forest fragments		60.0 (13.7-100)	10±3	
Forest fragments	Boreal agricultural	99.0	7	Andren 1992
		41.0	14	Vander Haegen & DeGraaf 1996
Tree plantations and Oak forest fragments	Mediterranean agricultural	49.0	15	Reino et al. 2010

		13.7	14	Castilla et al. 2007
		50.0	8	Santos & Tellería 1992
Fallow	Template forest	86.5	14	Conner & Perkins 2003
Rainforest fragments	Pastures with tropical rainforest remnant	79.0	9	Estrada et al. 2002
Clearing	Turkey Oak forest	24.0	7	Purger et al. 2004

771

772 **Figure 1.** Percentage of predated artificial nests by the first counting and by the second

773 counting and of non predated nests at tree plantations (Experiment 1) and on adjacent

774 open farmland habitat (Experiment 2).
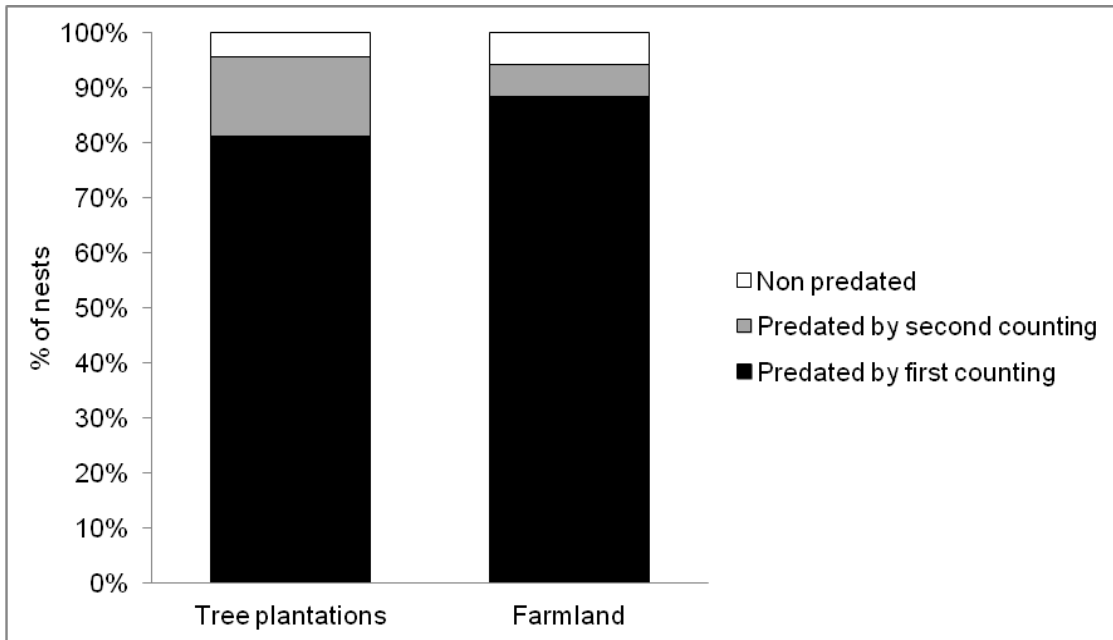
775

776　**Figure 2.** Partial residual plot of the influence of magpie abundance on predation

777　intensity of nests at 30 tree plantations on former cropland. The residual plot shows the

778　relationship with magpie abundance given that the other independent variables are also

779　in the model, therefore partialling out their effects (see **Table 2** for more details).
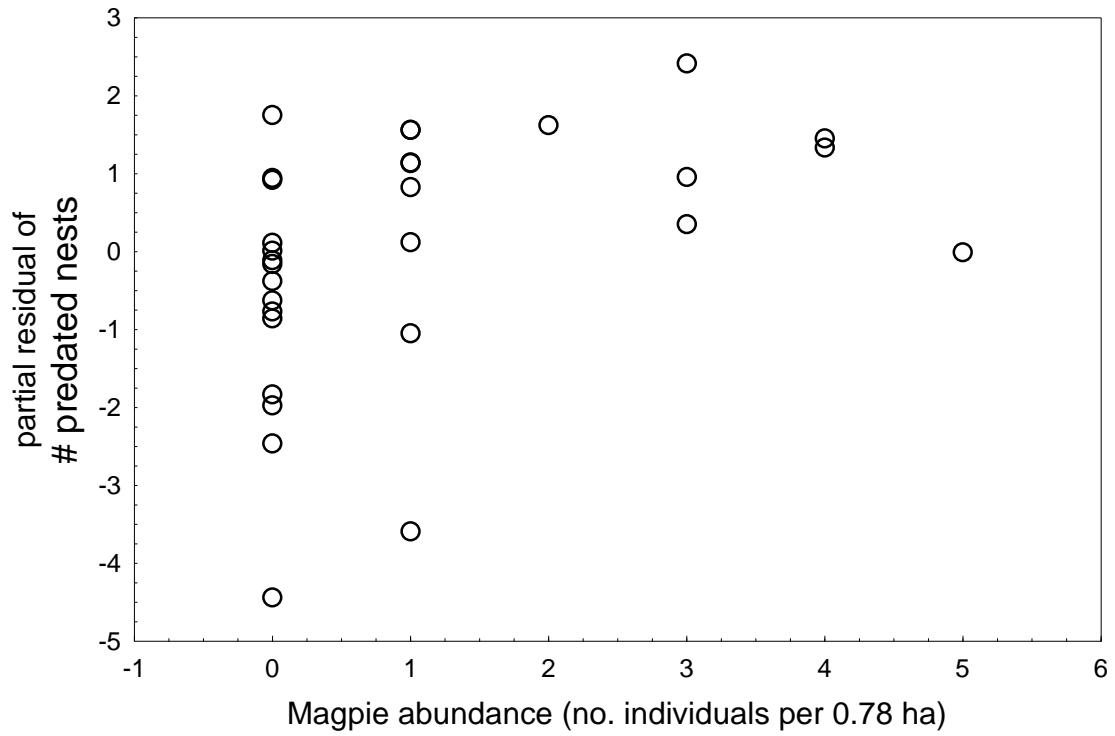

780

Sánchez-Oliver *et al*. Local habitat and landscape influence predation of

bird nests on afforested Mediterranean cropland

Supplemental On-line Material

Figure S1. Location of the study area in central Spain within the Ciudad Real province

and distribution of the tree plantations on former cropland that were used to investigate

nest predation at the tree plantations (Experiment 1), on open farmland adjacent to tree

plantations (Experiment 2) and at both habitat types.
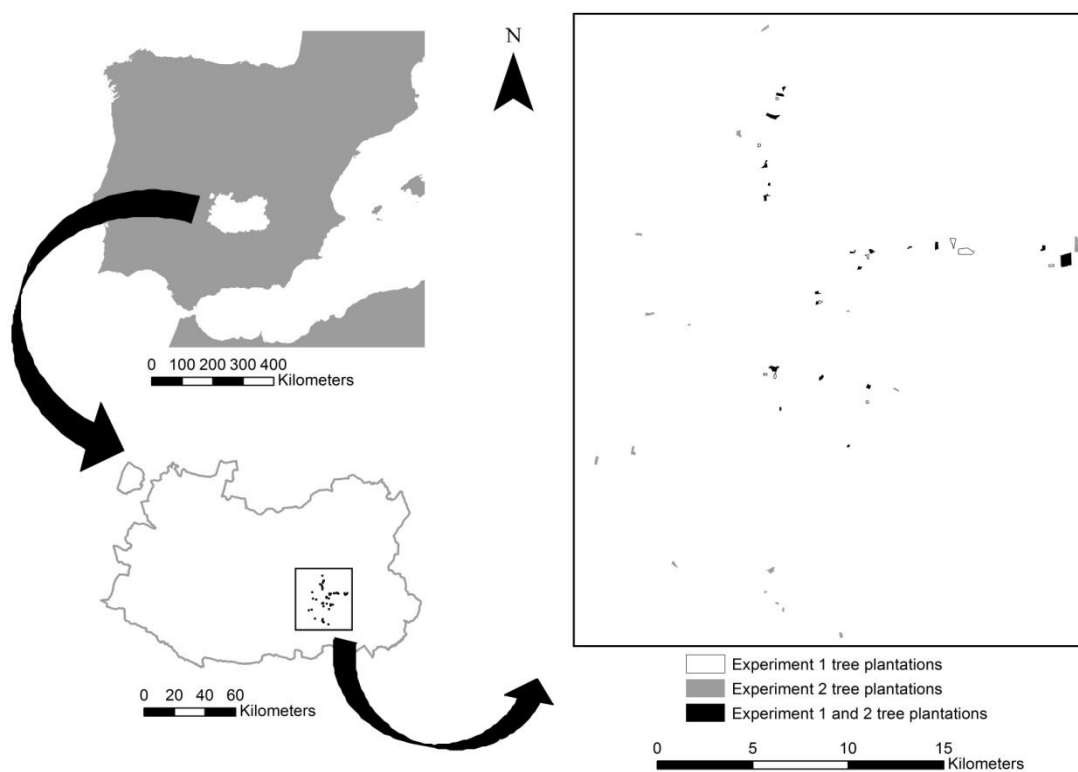
Figure S2. Sketch of the experimental design and associated surveys that were used to investigate nest predation at tree plantations and on adjacent open farmland.
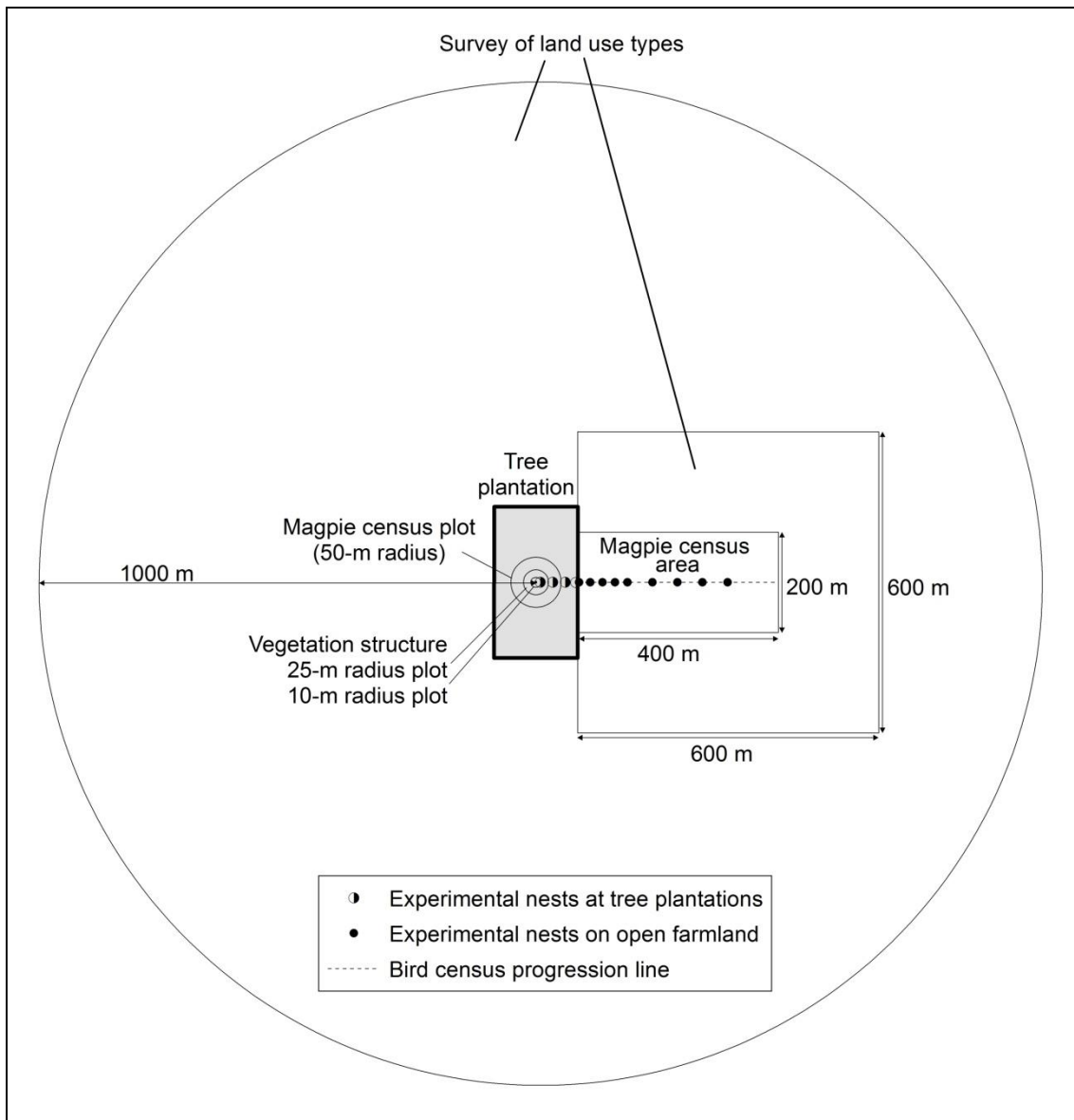
Table S1. Mean, standard deviation (sd) and range (min/max) of the local habitat and landscape variables describing the characteristics of the 30 and 36 studied tree plantations for experiments 1 and 2, respectively. Note: all artificial nests at two out of the 38 tree plantations that were initially selected for Experiment 2 were lost due to ploughing or trampling.

Experiment 1	mean	sd	min	max
Characteristics of tree plantations				
Area (ha; log-transformed)	1.3	0.8	0.4	3.6
Edge/area ratio	4.7	0.6	4.0	6.2
Position of artificial nests				
Distance to edge (m)	35.4	19.4	25.0	112.5
Height above ground (m)	0.9	0.3	0.4	1.6
Vegetation structure				
Cover of tree layer (%)	36.1	25.5	2.2	100.0
Pine height (m)	3.6	1.6	0.9	7.2
No. Of pine trunks >5 cm dbh	69.7	51.5	0.0	185.0
Cover of shrub layer (%)	6.1	9.8	0.0	46.2
Height of shrub layer (m)	1.3	1.1	0.0	3.3
Cover of herbaceous layer (%)	38.5	37.3	0.0	100.0
Height of herbaceous layer (m)	0.3	0.3	0.0	1.0
Percentage of land use types				
Streams, rivers and lagoons	1.1	1.3	0.0	4.1
Roads and rural tracks	6.7	3.3	0.0	12.0
Urban areas and scattered buildings	2.2	1.9	0.0	7.4
Semi-natural woodland	4.8	5.4	0.3	25.2
Dried-fruit orchards	0.7	3.1	0.0	16.9
Orchards	1.3	1.5	0.0	5.4
Waste lands	7.0	4.1	0.0	14.8
Olive groves	13.6	19.0	0.0	71.2
Pastures with scattered trees	0.4	1.7	0.0	9.4
Scrubland	13.1	7.8	0.0	29.5
Pasture land	1.1	3.4	0.0	19.1
Dry herbaceous cropland	19.0	8.2	0.0	40.4
Vineyard	25.8	12.1	1.0	47.8
Vineyard with olive trees	3.0	3.9	0.0	10.6

Experiment 2	mean	sd	min	max
Characteristics of tree plantations				
Area (ha; log-transformed)	1.4	0.8	0.3	3.6
Average pine height (m)	3.6	1.4	1.0	6.4
Percentage of land use types				
Streams, rivers and lagoons	0.2	0.5	0.0	2.4
Roads and rural tracks	2.3	2.4	0.0	13.7
Urban areas and scattered buildings	0.4	0.6	0.0	2.3
Semi-natural woodland	0.9	2.2	0.0	9.4
Dried-fruit orchards	1.0	2.3	0.0	9.9
Orchards	0.2	0.8	0.0	4.5
Waste lands	1.3	2.6	0.0	13.0
Olive groves	17.1	14.9	0.0	57.4
Pastures with scattered trees	1.8	5.0	0.0	22.9
Scrubland	0.6	1.7	0.0	11.5
Pasture land	8.7	12.4	0.0	60.0
Dry herbaceous cropland	33.8	27.3	0.6	96.6
Vineyard	29.5	24.4	0.0	82.0
Vineyard with olive trees	0.9	2.7	0.0	10.6

Habitat type where nests were placed	% of nests	No. of nests
Olive groves	17.4	45
Vineyard	17.4	45
Abandoned cropland and pastures	32.4	84
Semi-natural woody vegetation	10.0	26
Dry herbaceous cropland	19.7	51
Waste lands, roads and rural tracks	3.1	8