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Medium-term response of breeding Blue Chaffinch *Fringilla teydea teydea* to experimental thinning in a *Pinus canariensis* plantation (Tenerife, Canary Islands)

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We studied the medium-term response of the endemic Blue Chaffinch *Fringilla teydea teydea* to experimental thinning in a *Pinus canariensis* plantation on the island of Tenerife during breeding season. Distance Sampling method was applied to line transects, and habitat preferences were modelled by means of univariate regression trees. The density was 1.70 birds/ha (1.09 to 2.68 95%CI) in thinned areas and 0.56 birds/ha (0.33 to 0.97 95%CI) in unthinned areas. The Blue Chaffinch densities peaked in thinned areas where the density of trees with Diameter at Breast Height of <25 cm was between 10.5 and 16.5 trees/plot (r = 25 m) and the cover of *Adenocarpus* shrubs was ≤82.5%. Thinning had added heterogeneity into the stand structure at least in terms of lowering the basal area of small pine trees and increasing the understorey cover of *Adenocarpus* shrubs, with average cover being 37.15% in thinned and only 1.40% in unthinned areas. Our results justify the silvicultural thinning of 2844 hectares of pine plantation on the summit of Gran Canaria as a means of increasing the density of the endangered Gran Canaria Blue Chaffinch (*Fringilla teydea polatzeki*).

1. Introduction

The Blue Chaffinch *Fringilla teydea* is endemic to the Canary Islands (Fig. 1). Two races have been described and supported genetically (Snow & Perrins 1998, Pestano *et al.* 2000). The nominate *F. t. teydea* inhabits pine forests (*Pinus canariensis*) of Tenerife, whereas *F. t. polatzeki* is restricted to the pine forests of Gran Canaria. Although the total population size of *F. t. teydea* is within reasonable thresholds (Garcia-del-Rey 2002, Garcia-del-Rey & Cresswell 2005), *F. t. polatzeki* is on the brink of extinction, having faced a significant decline during the last 20 years. The latter also became extinct from the humid pine forest fragment in Tamadaba Natural Park in 1990, and a shift in their distribution towards suboptimal sites, i.e., a high-density *Pinus canariensis* plantation at La Cumbre, has been detected after the intense fire of 2007 (authors' pers. obs.). The total population size after the fire has been estimated at less than 150 individuals in the wild (S. Sanchez, Colectivo Ornitologico de Gran Canaria).

The life history of the Blue Chaffinch is interesting. The species shows marked sexual size dimorphism in plumage colouration and biometrics (Garcia-del-Rey & Gosler 2005) and produces clutches of only 1–3 eggs on both islands (Garcia-

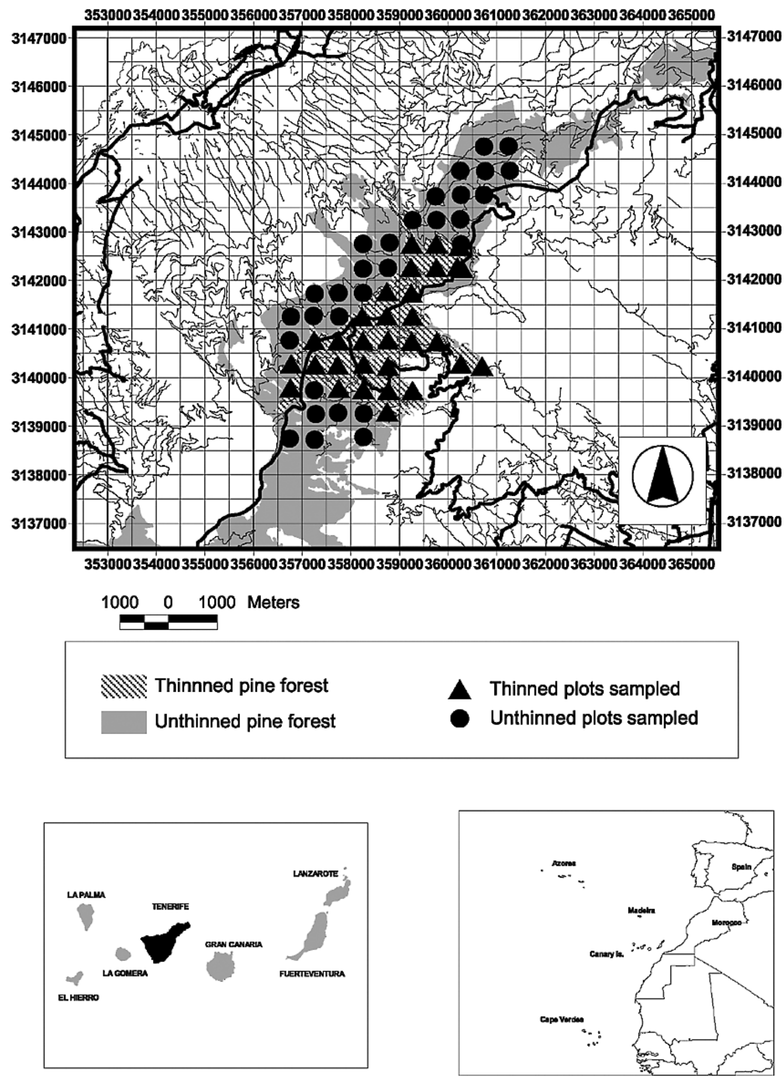

Fig. 1. Location of the study site in the *Pinus canariensis* forest plantation of Tenerife, Canary Islands.

del-Rey 2008, Rodríguez & Moreno 2008). During nesting, females forage mainly on branches whereas males usually forage on the ground (Garcia-del-Rey 2002), and during winter individuals tend to select sheltered mature-forest sites for feeding on pine seeds (Garcia-del-Rey *et al.* 2009b). Post-fire surveys on Tenerife suggest that the species is most abundant in areas with low canopy fire severity, i.e., with greener vegetated micro-sites only affected by fire from 0% to 50% (authors' unpubl. data).

Pine forests of the Canary Islands are partly of planted origin, but generally these forests have been little commercially utilized. Between 1945 and 1983 a total of 7,280 hectares of pine forest were densely planted on Tenerife in order to restore the original pine-forest area (del Arco *et al.* 2006). On the island of Gran Canaria only, 2,844 hectares were planted at a similar density. Although plantations in Gran Canaria mainly consist of *Pinus canariensis* as the constituent species, other exotic pines, such as *P. radiata*, *P. pinea* and *P halepensis* have been used as well. Today, pine stands of the Canary Islands are not managed for timber production, but instead the Canarian authorities intend to 'naturalize' these plantations in order to improve the biodiversity in these areas. The effects of silvicultural thinning on breeding birds have generally been found to enhance habitat heterogeneity, and consequently plant diversity and bird species richness, abundance and diversity increase (Degraaf *et al.* 1991, Hayes *et al.* 2003, Thompson *et al.* 2003, Hagar *et al.* 2004, De la Montana *et al.* 2006). However, negative or no detectable effects of thinning have been occasionally reported (Christian *et al.* 1996, Lohmus 2004, Calladine *et al.* 2009).

On Tenerife, 575 hectares (60%) of plantations were experimentally thinned in 2002, providing an opportunity to study the effects of thinning on Blue Chaffinch. The aims of the present study were three-fold. (1) To describe the medium-term response of *F. t. teydea* to moderate or high intensity of silvicultural thinning on the island of Tenerife. (2) To compare the present results with other experiments undertaken elsewhere, with special attention to the Mediterranean region. (3) To evaluate the appropriateness of this silvicultural management in improving the situation of the Gran Canarian race of the Blue Chaffinch (*F. t. polatzeki*).

2. Material and methods

This study was conducted on the volcanic island of Tenerife, Canary Islands, in the Natural Park of "Corona Forestal" (Fig. 1). The climate of this island is Mediterranean with mild winters and warm summer months. The rainy season tends to begin in October and end in February, but sometimes it continues until April (Marzol-Jaén 1984). The monospecific *Pinus canariensis* forest ranges from 700 to 2,300 m a.s.l. and the dominant understorey vegetation, when present, is *Chamaecytisus proliferus* and *Adenocarpus foliolosus* at low altitudes, and *Adenocarpus viscosus* at higher altitudes. For detailed descriptions of the vegetation, see Ceballos & Ortuño (1976).

2.1. Habitat characteristics

Habitat type was characterized at vegetation-point stations (25-m radius), placed 100 m apart along 500-m transects for each bird-inventory plot (see below), by measuring 12 variables plus longitude and latitude. Tree percentage cover was estimated using a spherical convex densiometer (Lemmon 1956, 1957) coinciding with north, south, east and west. The number of pine trees belonging to three classes of trunk diameter at breast height (DBH; T1 = DBH >50 cm; T2 = DBH 25–50 cm; T3 = DBH <25 cm) were counted visually (trees/plot, i.e., within $r = 25$ m). The percent covers of *Myrica faya*, *Erica arborea*, *Adenocarpus* sp., *Chamaecytisus proliferus* and grasses were visually estimated. The number of pine seeds and the number of first-year seedlings were counted in 1 m × 1 m plots at each point station. The basal area was measured with a Bitterlich relascope (Bitterlich 1990), and a Geographic Positioning System (GPS) unit (Garmin 12) was used to obtain longitude and latitude. All measurement values were averaged for every 500-m transect.

2.2. Bird survey

A total of 30 bird-survey plots (500 m × 500 m) were systematically placed within the thinned area (575 hectares; thinned forests, thinned stratum). Another 30 plots were similarly placed within unthinned forests (unthinned stratum) adjacent to the area of experimental thinning in order to minimize possible confounding factors, such as altitude and rainfall (Fig. 1). A random, 500 m transect was placed from east to west in each plot unless the orography did not allow this. Transects were seldom placed on trails and dirt tracks, although such transects made up ca. 15% in each stratum. All transects were marked in the field for count-repeating purposes and to obtain higher number of observations.

The census protocol followed Bibby *et al.* (2000) and Buckland *et al.* (2001) with a single observer (first author) walking each transect at a uniform velocity of 1 km/h and counting all birds seen and heard. Distant birds were identified with binoculars, and the distance between bird and observer was measured with a laser range-finder (± 1-m error). The timing of the census was synchronized to coincide with the mean egg-laying stage of the Blue Chaffinch (Garcia-del-Rey 2008), i.e., from mid-April to mid-May. All censuses were undertaken between 7:00 h and 12:00 h in days free of precipitation and with no or only light wind. The response variable (abundance) was calculated as the total number of Blue Chaffinches per transect within 500 m × 25 m (Effective Strip Width) × 2 (Thomas *et al.* 2004), once detectability was accounted for using DISTANCE software (Thomas *et al.* 2004). Hence, a total of 15 km were sampled in the thinned and 30 km in the unthinned stratum. The total number of birds detected per stratum was 65 in thinned and 61 in unthinned, which both are above the minimum, as recommended for reliable estimates by DISTANCE Sampling (Thomas *et al.* 2004).

2.3. Statistical analysis

Basic statistics follow Zar (1998). A nonparametric Mann-Whitney *U* test was used to test differences between thinned and unthinned forests. During the initial data exploration collinearity was examined using Spearman rank correlation tests and pair-plots of the explanatory variables. Cross-correlations greater than 0.75 were considered important and the other correlated variable was randomly removed. Moran's *I* index and a permutation test (Zuur *et al.* 2007) were used to test for spatial auto-correlations. In order to reduce the dimensionality of the data a multivariate partial Principal Component Analysis (PCA) was carried out on the untransformed explanatory variables, with latitude and longitude as covariables.

To model the influence of the collected habitat characteristics on Blue Chaffinch abundance (response variable), a univariate regression tree was performed (Chambers & Hastie 1992, De'ath & Fabricus 2000). Regression trees can identify the most important variables among the collected ones, and their thresholds may provide crucial information, for example, for selecting appropriate management strategies. Other advantages of regression trees over other methods are that the analysis is not affected by transformations of the explanatory variables (Zuur *et al.* 2007), and the technique also minimizes many other problems associated with stepwise regression (Whittingham 2006). The analysis is based on repeated partitions of observations into two homogeneous groups based on the values (orders) of an explanatory variable. The following criteria were adopted: (1) apply minimum split criterion = 5, (2) always start with the default complexity parameter of 0.001,

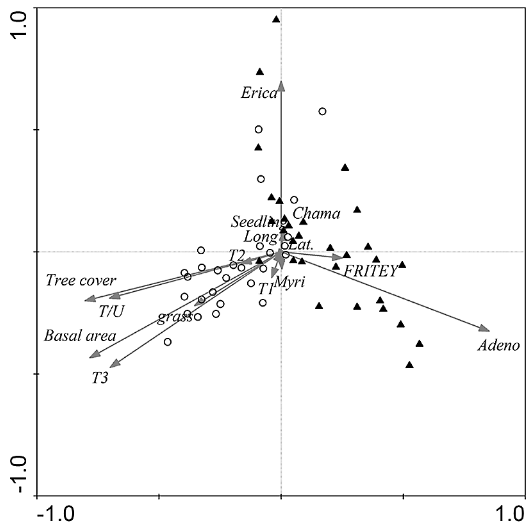

Fig. 2. Partial Principal Component Analysis biplot. Triangles = thinned, circles = unthinned forests. Explanatory variables are shown as vectors.

and (3) apply severe pruning only when minimum deviance explained is lost. The predictive power of the obtained regression tree was evaluated by means of cross-validation using 10 random sampling iterations, allowing selection of the optimal regression tree size and avoiding complex, suboptimal 'trees' (Zuur *et al.* 2007).

The analyses were done using Brodgar 2.5.6 software (www.brodgar.com) in R (www. r-project.org), except that CANOCO 4.5 (ter Braak & Smilauer 1998) was used to generate a correlation biplot of the partial Principal Component Analysis (PCA).

3. Results

3.1. Habitat characteristics

The descriptive statistics of the explanatory variables measured in the two strata (thinned or unthinned) are presented in Table 1. Mann-Whitney *U* tests showed significant differences between the strata in tree cover (U = 58.00, p = 0.001), T2 (U = 277.00, p = 0.003), T3 (U = 169.50, p = 0.001), *Adenocarpus* cover (U = 117.50, p = 0.001) and basal area (U = 68.00, p = 0.001). Tree cover, T3 and basal area had lower mean values in thinned than in unthinned forests,

Table 1. Descriptive statistics for the habitat characteristics measured in thinned (n = 30) and unthinned (n = 30) vegetation-point stations. * $p < 0.01$. Mean = mean value, SE = Standard error of the mean, Min = minimum and Max = maximum value.

	Thinned stratum				Unthinned stratum				Total			
	Mean	SE	Min	Max	Mean	SE	Min	Max	Mean	SE	Min	Max
Tree cover (%) *	52.82	3.02	28	88	86.03	2.5	38	100	69.42	2.91	28	100
Trees with DBH > 50 cm (T1)	0	0	0	0	0.04	0.02	0	1	0.02	0.01	0	1
Trees with DBH 25–50 cm (T2) *	0.15	0.08	0	2	0.29	0.06	0	1	0.22	0.05	0	2
Trees with DBH < 25 cm (T3) *	18.05	1.49	4	33	39.52	3.66	10	72	28.78	2.41	4	72
% *Myrica faya*	1.67	1.66	0	50	1.07	0.58	0	11	1.37	0.87	0	50
% *Erica arborea*	15.05	4.31	0	90	25.67	4.92	0	90	20.36	3.31	0	90
% *Adenocarpus* sp. *	37.15	6.1	0	100	1.4	0.69	0	19	19.28	3.83	0	100
% *Chamaecytisus proliferus*	1.00	0.84	0	25	0.03	0.02	0	1	0.52	0.42	0	25
% Grass	0.4	0.33	0	10	2.83	1.54	0	38	1.61	0.79	0	38
No. *Pinus canariensis* seeds	0.00	0.00	0	0	0.00	0.00	0	0	0.00	0.00	0	0
No. first year seedlings	0.34	0.18	0	5	0.16	0.05	0	1	0.25	0.09	0	5
Basal area of trees (m2/ha) *	10.1	0.68	4	19	25.88	1.97	5	48	17.99	1.46	4	48

whereas an opposite was found for *Adenocarpus* cover. Note that no mature trees were observed in the thinned forests (T1 with DBH >50 cm) and only one was found in the unthinned stratum. However, the mid-sized trees, i.e., T2 with DBH 25–50 cm, were more abundant in the thinned forests.

3.2. Density and abundance of the Blue Chaffinch

The permutation test ($p = 0.161$) and Moran's test ($I = 0.089$) indicated that the spatial auto-correlation of Blue Chaffinch counts was not significant. The density, abundance and 95% confidence inter-

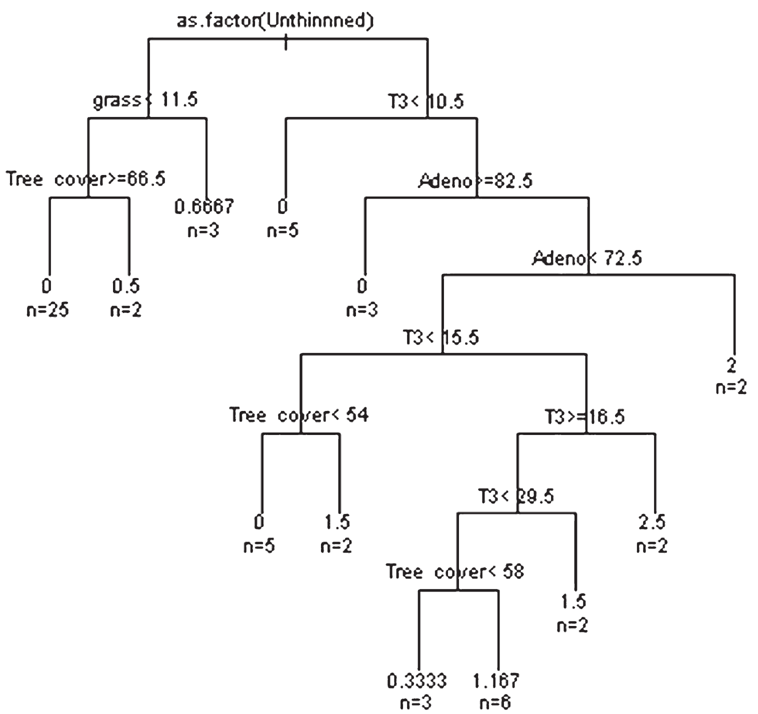

Fig. 3. Regression tree for the abundance of the Blue Chaffinch *Fringilla teydea*. If a given statement is true, follow the left branch, and if false follow the right branch. The numbers at the bottom of each terminal branch show mean abundance and the number of observations falling into a given end branch.

Table 2. DISTANCE models fitted to the untruncated detection distance by stratum in an ascending order according to Akaike's Information Criterion corrected for small samples (AICc; lower values indicate more reliable models). The thinned stratum was 575 and the unthinned stratum was 1729 ha. Density = individuals/ha, Abundance = the total number of individuals, ESW = the effective strip width (in m).

Model type	Density	95%CI	Abundance	95%CI	ESW	AICc
Thinned stratum						
Hazard-rate (cosine)	1.86	1.05–3.31	1070.0	601.0–1904	17.92	437.61
Hazard-rate (polynomial)	1.86	1.05–3.31	1070.0	601.0–1904	17.92	437.61
Negative exponential (cosine)	1.87	1.26–2.79	1079.0	724.0–1608.0	17.76	437.98
Negative exponential (polynomial)	1.87	1.25–2.79	1079.0	724.0–1608.0	17.76	437.98
Half-normal (cosine)	1.57	1.09–2.27	904.0	626.0–1305	21.0	439.66
Half-normal (polynomial)	1.19	0.86–1.65	689.0	499–952	27.80	443.07
Weighted average	1.70	1.09–2.68	982.0	629.16–1547	20.0	438.98
Unthinned stratum						
Negative exponential (cosine)	0.58	0.37–0.91	1016.0	655.0–1578.0	23.31	424.74
Negative exponential (polynomial)	0.58	0.37–0.91	1016.0	655.0–1578.0	23.31	424.74
Hazard-rate (cosine)	0.61	0.29–1.27	1064.0	514.0–2199.0	22.28	425.18
Hazard-rate (polynomial)	0.61	0.29–1.27	1064.0	514.0–2199.0	22.28	425.18
Half-normal (cosine)	0.58	0.37–0.90	1005.0	645.0–1566.0	23.0	426.24
Half-normal (polynomial)	0.41	0.28–0.58	710.0	496.0–1017.0	33.30	427.35
Weighted average	0.56	0.33–0.97	980.0	580.0–1690.0	24.60	425.57

vals for thinned and unthinned strata are presented in Table 2. Thinned forests supported 1.70 birds/ha (1.09 to 2.68 95%CI) and the unthinned forests supported 0.56 birds/ha (0.33 to 0.97 95%CI). This average difference of 1.14 birds/ha between thinned and unthinned strata was significant (U = 6079.5, p = 0.0001). The effective strip width (ESW) was 20.0 m for thinned and 24.60 m for unthinned forests. The total abundance for thinned forests was 982.0, with the 95%CI varying between 629.16 and 1547.0. A similar total abundance was found for unthinned forests that actually covered a three times larger area (575 versus 1 729 ha): 980.0 birds with 95%CI varying between 580.0 and 1690.0.

3.3. Habitat associations

Initial data exploration revealed a significant correlation between basal area and T3 (r_s >0.75). Basal area was subsequently removed from the univariate analysis but not from PCA. Axis 1 in the PCA biplot reflects a gradient from sites with high tree density (left) toward pure shrub sites dominated by *Adenocarpus* (right). Axis 2 apparently reflects *Myrica-Erica* woodlands. Note that tree cover, basal area and T3 were inter-correlated and, along with *Adenocarpus*, were also the most important explanatory variables in this analysis.

The regression tree for the abundance of the Blue Chaffinch accounted for 78% of the original variability (Fig. 3; basal area removed due to collinearity, see above). The most influential explanatory variable was the factor habitat type /thinned/unthinned stratum). In thinned forests, the maximum abundance of the Blue Chaffinch was found at sites with the number of small pine trees (DBH <25 cm) ranging between 10.5 and 16.5 trees/plot and *Adenocarpus* shrub cover ≤82.5%. Conversely, Blue Chaffinch densities were lowest at unthinned sites with herbaceous grass cover <11.5% and tree cover ≥66.5%.

4. Discussion

This study demonstrates how a forested area can become more heterogeneous in structure through silvicultural thinning operations in the medium term. Removal of trees increases the amount sunlight that reaches the forest floor and permits the remaining trees to grow faster and larger, and in turn to produce more cones (Ceballos & Ortuño 1976). This process results in higher seed production and the formation of a dense shrub layer, thereby increasing local plant-species richness and the appearance of *Pinus* seedlings, although these seedlings do not always become mature trees (Arévalo & Fernández-Palacios 2008). Such structural change has been observed elsewhere (Newton 2007).

Our results support the view that Blue Chaffinches significantly increase in density if the forest in question is thinned (Table 2). Other studies on the response of breeding birds to thinning in coniferous forests support this view (Siegel & DeSante 2003, Luck & Korodaj 2008). We observed the maximum density of Blue Chaffinches at sites with the density of small trees (DBH <25 cm) was between 10.5 and 16.5 trees/plot and the *Adenocarpus* sp. cover was equal to or lesser than 82.5%. The structure of thinned forests had thus become more heterogeneous through an increasingly dense understorey of *Adenocarpus* shrubs. In spring, this shrub produces a high density of caterpillars that are exploited for nestling food by forest passerines (Garcia-del-Rey 2003), including the Blue Chaffinch (authors' pers. obs.). However, 100% understorey cover may not be ideal for the focal species, as its abundance was influenced by shrub cover of 82.5% or less.

We conclude that thinning can be considered an important driver of the Blue Chaffinch abundance in pine plantations (see also Goodale et al. 2009). According to the present results, on the summit of Gran Canaria, a reduction of tree density in pine plantations probably improves the heterogeneity of these forests and can increase Blue Chaffinch abundance and the pine seed crop available, at least in the medium term.

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Kanarianpeipon keskipitkän aikavälin vaste kokelliseen harvennukseen kanarianmännyn istutusmetsiköissä

Tutkimme kanarianpeipon (*Fringilla teydea*) keskipitkän aikavälin pesimäkautista vastetta kokeelliseen metsänharvennukseen kanarianmännyn (*Pinus canariensis*) istutusmetsiköissä Teneriffan saarella. Sovelsimme etäisyys-näytteenottotekniikkaa linjalaskenta-aineistoon, ja mallinsimme elinympäristöjen suosimista yhden riippuvan muuttujan regressiopuilla. Harvennetuissa metsiköissä kanarianpeipon tiheys oli 1,70 (1,09–2,68, 95 % luottamusväli) ja harventamattomissa 0,56 (0.33–0.97) yksilöä/ha. Laji oli runsain sellaisissa harvennetuissa paikoissa, joissa pienikokoisen (rinnankorkeusläpimitta <25 cm) puuston määrä oli 10,5–16,5 puuta näytealalla (r = 25 m) ja *Adenocarpus*-pensaiden peittävyys enintään 82,5 %.

Harventaminen oli selvästi lisännyt metsiköiden rakenteellista vaihtelua ainakin siten, että pienten mäntyjen pohjapinta-ala oli alempi ja *Adenocarpus*-pensaiden peittävyys korkeampi, ollen 37,15 % harvennetuissa ja vain 1,40 % harventamattomissa metsiköissä. Tuloksiemme valossa suosittelemme Gran Canarian ylängön 2 844 istutusmäntyhehtaarin harventamista keinona nostaa uhanalaisen Gran Canarian kanarianpeipon alalajin (*Fringilla teydea polatzeki*) kannankokoa.

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