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Seedling dispersion and population structure of rosewood *(Aniba rosaeodora Ducke)* in Ucayali, Peru

Jorge M. REVILLA-CHÁVEZ[1,2,*], Lyanna H. SÁENZ-RAMÍREZ[2], Antony C. GONZALES-ALVARADO[4], Alex J. ALVAREZ-GARCÍA[6], Jorge A. MORI-VÁSQUEZ[5], Alexandre M. SEBBENN[1,3]

[1] Universidade Estadual Paulista, School of Engineering, CP 31,15385-000, Ilha Solteira - SP, Brazil

[2] Instituto de Investigaciones de la Amazonía Peruana (IIAP), Yarinacocha - Ucayali, Peru

[3] Instituto Florestal de São Paulo, CP 1322, 01059-970, São Paulo - SP, Brazil

[4] Universidade Federal do ABC, Centro de Ciências Naturais e Humanas, 09606-045, São Bernardo do Campo - SP, Brazil

[5] Universidad Nacional de Ucayali, Facultad de Ciencias Forestales y Ambientales, Pucallpa - Ucayali, Peru

[6] Universidad Nacional Intercultural de la Amazonía Peruana, Yarinacocha - Ucayali, Peru

* Corresponding author: jrevilla@iiap.gob.pe

ABSTRACT

Aniba rosaeodora is a valuable species of the Amazon, being extensively logged to extract linalool - a secondary metabolite that fixes cosmetic perfumes, which has led to its overexploitation and near extinction. Forest conservation and management efforts are hampered by insufficient knowledge about the distribution of *A. rosaeodora* seedling and population structure. Therefore, in the present study we sought to understand these patterns in a central-eastern tropical forest in the Peruvian Amazon, where seed dispersal result mainly from barochory and zoochory. The average distance of seedlings from their seed trees was 18.3 ± 9.3 m, with a maximum of 44 m from the seed tree, and the emergent population structure was 53.4% seedlings; 12.2% saplings; 27% stems and 7.4% adult trees, fitting the Weibull model (shape 2.1; scale 20.2). In selected plots, we observed population density ranging from 7 to 3.3 ind ha^{-1}, with a low presence of adult trees (0.5 ind ha^{-1}). Trees with diameters > 20 cm were grouped in clusters of 2 to 5 individuals, with a Morisita index of 1.97 in the F-distribution (p > 0.05) and were spaced on average 97 to 110 m apart. Our analysis indicated that the population was unsustainable, with a high probability of co-ancestry, as indicated by the exponential (R^2 = 0.98) and Liocourt's quotient (q = 1.5–3). Nevertheless, the area holds significant potential for the conservation of the species' genetic resources.

KEYWORDS: forest, Amazon, population density, population structure, seedling dispersion

Dispersión de plántulas y estructura poblacional de palo rosa (*Aniba rosaeodora* Ducke) en Ucayali, Perú

RESUMEN

La *Aniba rosaeodora* es una especie valiosa del bioma amazónico, talada para extraer linalol, un metabolito secundario fijador de perfumes cosméticos, llevándola a su sobreexplotación, y cerca de su extinción. Mas, los esfuerzos de conservación y manejo forestal se dificultan por el insuficiente conocimiento sobre la distribución de las plántulas y estructura poblacional de *A. rosaeodora*. Por lo tanto, en el presente estudio buscamos conocer estos patrones, en un bosque tropical centro oriental en la amazonia peruana, donde la dispersión de semillas se produce principalmente por barocoria y zoocoria alcanzando una distancia media de 18,3 ± 9,3 m, con una máxima de 44 m desde el árbol semillero, y una estructura poblacional emergente de 53,4% plántulas; 12,2% brinzales; 27% fustales y 7,4% árboles adultos, lo que se ajusta al modelo de Weibull (forma 2,1; escala 20,2). En parcelas seleccionadas observamos que la densidad varía de 7 a 3,3 ind ha^{-1}, con una baja presencia de árboles adultos (0,5 ind ha^{-1}). Los árboles con diámetros > 20 cm se agruparán en núcleos de 2 a 5 individuos, con un índice de Morisita de 1,97 en la distribución F (*p > 0,05*), y se encontraban espaciados en promedio entre 97 y 110 m. La población presenta una recuperación insostenible en el área de estudio, con alta probabilidad de coancestría, según el ajuste al modelo exponencial de Meyer (R^2 = 0,98) y al coeficiente de Liocourt (q = 1,5–3). No obstante, el área posee un potencial significativo para la conservación de los recursos genéticos de la especie.

PALABRAS CLAVE: bosque, Amazonía, densidad de población, estructura de la población, dispersión de plántulas

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INTRODUCTION

One of the most valuable native tree species in the Amazon biome is *Aniba rosaeodora* Ducke (Lauraceae family), or rosewood. The species has been overexploited for decades to extract linalool, a secondary metabolite valued in the cosmetic industry as an excellent perfume fixer (Amusant *et al*. 2015; Amusant *et al*. 2016; Giongo *et al*. 2017). Overexploitation has led to the decline of both populations and oil production, with the consequent genetic erosion of *A. rosaeodora* natural populations, putting the species at risk of extinction in heavily exploited areas (May and Barata 2004) and leading to its inclusion on the IUCN list of threatened species (Barstow 2021). Although linalool is present in all parts of the tree, its yield for oil extraction is 1.4 and 2.4% from wood and leaf biomass, respectively. Oil has been primarily extracted from the wood (Araújo *et al*. 1971; Teles and Mouchrek 2022) which implies the destruction of the tree and consequently its death, this has led to an increase in research for the extraction of oils from the leaves.

Aniba rosaeodora flowers' are pollinated by insects, its seeds are dispersed by zoochory, mainly by mammals and birds, particularly parrots and toucans (Araujo 1967; Spironello *et al*. 2004), who after feeding on its pulp and digesting them, transport the seeds to different locations and distances in the forest randomly. Reproduction begins when individuals reach about 10 cm in diameter at breast height (DBH) (Spironello *et al*. 2003). However, several studies have shown that seed production in these individuals is scarce, intermittent, and of low viability (Spironello *et al*., 2021). Moreover, studies in Amazonian plantations indicate that although young trees grow at moderate rates, they do not reach stable reproductive capacity or contribute effectively to regeneration until they exceed 25 cm in diameter at breast height (DBH) (Perea-Gonzales, 2022; Fernández-Silva, 2023). Therefore, early sexual maturity does not guarantee functional maturity, as it does not significantly contribute to natural regeneration and population sustainability (Condit, 1995). In adulthood, individuals can reach up to 30 m in height and 2 m in DBH (Kubitzki and Renner 1982); in Ucayali, Peru, trees have been reported in natural populations with approximately 25 cm in DBH and a maximum total height of 26 m (Gutierrez *et al*. 2023; Revilla-Chávez *et al*. 2024).

Trees have a straight and cylindrical trunk, yellowish or reddish-brown bark that easily separates into large plates, and a narrow, oval crown. The species occupies the intermediate or upper stratum of the forest canopy and occurs in Brazil, Colombia, Ecuador, French Guiana, Guiana, Peru, Suriname, and Venezuela (Kubitzki and Renner 1982). It is found in both dry and moist forests, with a preferred habitat on plateaus and streams (Kubitzki and Renner 1982). Population density is generally low, ranging from two (Loureiro *et al*. 1979) to 27 trees/ha (Mitja and Lescure 1996) for trees with DBH > 10 cm in *terra-firme* forests north of Manaus, Brazil. Near to Manaus, the density for DBH > 20 cm ranged from 0.12 to 0.16 trees ha^{-1} (Alencar and Fernandes 1978). The spatial distribution of adult trees on those sites was clustered in groups (five to eight trees), with spacing among trees ranging from 50-100 m and 300-400 m between groups (Alencar and Fernandes 1978).

The natural regeneration of *A. rosaeodora* is irregular and infrequent. The recruitment of seedlings generally occurs near to seed trees, from seeds dispersed by barochory. Previous studies have shown the occurrence of juvenile individuals in the area surrounding about 70% of seed trees, with approximately 50% of these juveniles distributed within a radius of four to 10 m, and no individual beyond 23 m (Araujo 1967; Mitja and Lescure 1993; Mitja and Lescure 1996; Santana 2000). Seed dispersal also occurs by zoochory (Araujo 1967), an important aspect of seed dispersal as it influences the genetic and population structure of tree species (Dick *et al*. 2008; Ellstrand 2014). However, these processes are affected by forest overexploitation and the spatial fragmentation of remaining stands, which can lead to reductions in gene flow and seed dispersal between populations (Braga & Collevatti 2011; Tambarussi *et al*. 2015), giving rise to generations of seedlings that are increasingly related to the nearest seed tree (Manoel *et al*., 2017). Seed dispersal is a fundamental element of natural regeneration that ensures the sustainability of forest resources over time when it occurs in a random and complex manner (Rodríguez & Mandujano 2007; Calama *et al*. 2017). This phenomenon determines the potential area of recruitment of new individuals and establishes the foundation for subsequent processes, which are influenced by the tree's genetics, age, position in the forest canopy, among other factors (Campoe *et al*. 2013). Therefore, the species may have a reduced dispersal capacity due to environmental factors, resulting in limited numbers of seeds reaching the soil. During dispersal, seed predation is one of the main causes of mortality in the tree's reproductive cycle (Norden 2014; Muñoz 2018). *A. rosaeodora* can lose up to 60% of its seed viability, with approximately 50% of the mortality associated with insect infestations (Spironelo *et al*. 2003) and viability can be affected by severe inbreeding processes (Sebbenn *et al*. 2011; Sant'Anna *et al*. 2013).

Anthropogenic interventions can alter the structural dynamics of forests that have developed under natural processes, whose regeneration is typically characterized by an inverted "J"-shaped distribution of seedlings, juveniles, and adults, along with a sigmoidal growth pattern (Rasal *et al*. 2012). The inverted "J"-shaped curve can be modeled by the negative exponential function of Meyer (1952), where a high R^2 indicates minimally disturbed forests (Alder, 1980). At the same time, Liocourt's quotient (q) has been used to estimate the balance between successive diameter classes in various forest species. Typical values (1.3 to 2.5) indicate sustained regeneration, while deviations suggest possible disturbance

(Liocourt 1898; Silva *et al.* 1984). Moreover, the Morisita index (1959) has been used in various studies to classify the spatial distribution of trees, providing insight into genetic connectivity within the population (Morisita 1959; Krebs 1999). Likewise, the Weibull model (Weibull 1939) has been used to describe seedling dispersion, given its flexibility to represent asymmetric patterns of dispersion and mortality. This function has proven effective in modeling seedling aggregation near the parent tree, especially under mixed dispersal mechanisms such as barochory and zoochory (Pérez-López *et al.* 2019). Altogether, these indicators are essential for diagnosing the population structure of *Aniba rosaeodora* and guiding effective management and conservation strategies.

Towards this goal, the present study seeks identifying seedling dispersion patterns, density, and population structure dynamics of *A. rosaeodora* in a forest concession, which would contribute to developing strategies for conserving genetic resources for the development of breeding and domestication programs, reducing pressure on forests.

MATERIAL AND METHODS

Study site

We carried out the study in the Forest Concession of the Company LUSH SAC, located in the Iparia district, Province of Coronel Portillo, Ucayali, Peru (between 9º12'7.57"S 74º3'33.01" W, 9º13'18.88" S 74º2'21.05" W, 9º12'8.37" S 74º2'23.05" W, 9º13'18.25" S 74º3'31.02" W). This location is a hot spot of genetic diversity of *A. rosaeodora* occurrence in the department of Ucayali (MINAM 2015; Guizado *et al.*, 2020). The concession is located in a low terrace forest (Btb) and is a transitional zone between tropical humid forest and tropical premontane very humid forest (bh-T/bmh-PT). In this area, the mean annual temperature is 24.9°C and the total mean annual rainfall is 1603.8 mm ha year^{-1} (GRU 2017). We examined the population structure of *A. rosaeodora* in the Permanent Production Forest (Forest Concession) using two different forest plot types.

Plots for evaluating seedling dispersion

Three circular sampling plots (1-D, 2-D, 3-D) of 50 m radius with an area of 0.785 ha each were established, for a total of 2.4 ha. Each one composed of three concentric subplots (Sp1, Sp2, Sp3), treated as nested units forming three rings with a radius of 12.5 m and an area of 0.0491 ha, of 25 meters with 0.1473 ha and of 50 m with an area of (0.5890 ha) respectively, the distance between seedling dispersal plots is 194 m from 1-D to 2-D, 1800 m from 2-D to 3-D, and 1926 m from 3-D to 1-D (Figure 1a, b). Each plot was installed with a seed tree as its central point. Within the plots and subplots, all *A. rosaeodora* individuals were classified by diameter category: seedling and adult, according to MINAM (2015): seedlings: naturally regenerating plants with a height of 30 to 50 cm; saplings: plants with a diameter greater than 5 cm and less than 10 cm at 30 cm from the ground (D30) and one to less than three m in height; stems: plants with a DBH of 10 cm and less than 25 cm, and a height greater than 50 cm; and adults: trees with a DBH greater than 25 cm. The evaluation consisted of counting the number of individuals, measuring height and diameter, and recording their geographic coordinates. Diameter at breast height (DBH) was measured with a measuring tape at a height of 1.3 m above ground level or over 30 cm where the root flanges. Total tree height (H) was measured with a clinometer, from the base of the tree to the apex of its crown.

We calculated the relative abundance of seedlings (n, %), arithmetic mean (mean) of the seedling density per square meter (seedlings m^{-2}), standard deviation (SD_1), coefficient of variation (CV_1), and arithmetic mean distance to seed tree (mean), distance range (range), coefficient of variation (CV_2) per plot, subplot, and for all plots using dynamic tables tools for analysis. Seedling dispersion distance (*D*) was calculated as the Euclidean distance between the central focal tree and each seedling. The Weibbul adjustment was used to model the dispersion distances from seedlings to the seed tree (Weibull 1939; Pérez-López *et al.*, 2019), due to its ability to adjust to asymmetrical dispersal patterns, which are common in species with predominantly barochoric or zoochoric dispersal. Regression models with the highest coefficient of determination (R^2) were selected.

Plots for evaluating population structure

The sample plots were established based on the *A. rosaeodora* population census conducted in the forest concession for three annual cutting plots (ACP) over an area of 823 ha. Three plots were established in areas with the known occurrence of *A. rosaeodora* trees, adapting the methodology of the Flora and Vegetation Inventory of the Peruvian State (MINAM 2015). The total sampling area was 27 ha distributed in three plots (1-E, 2-E, 3-E) of 9 ha (300 x 300 m) each, the distances between population structure assessment plots are 442 m from 1-E to 2-E, 692 m from 2-E to 3-E, and 1430 m from 3-E to 1-E (Figure 1a,c), in an area classified as a critical point for the conservation of genetic diversity (MINAM 2015; Guizado *et al.* 2020). In each plot, the evaluated individuals were georeferenced using UTM coordinates. In addition, the DBH (cm) and individual height (m) for four growth categories were taken: seedlings – naturally regenerating plants with a height of 30 to 50 cm; saplings – plants with diameter > than five and < 10 cm at 30 cm from the ground (D30) and one to < three m tall; stems – plants with 10 >DBH< 25 cm, and height greater than 50 cm; and adults – trees with DBH> 25 cm (MINAM 2015).

Based on the results of the natural regeneration dispersion study, a dispersion map and horizontal population structure of the species was developed. To do so, an area of seedling dispersal around mature trees (trees that produce seeds) was

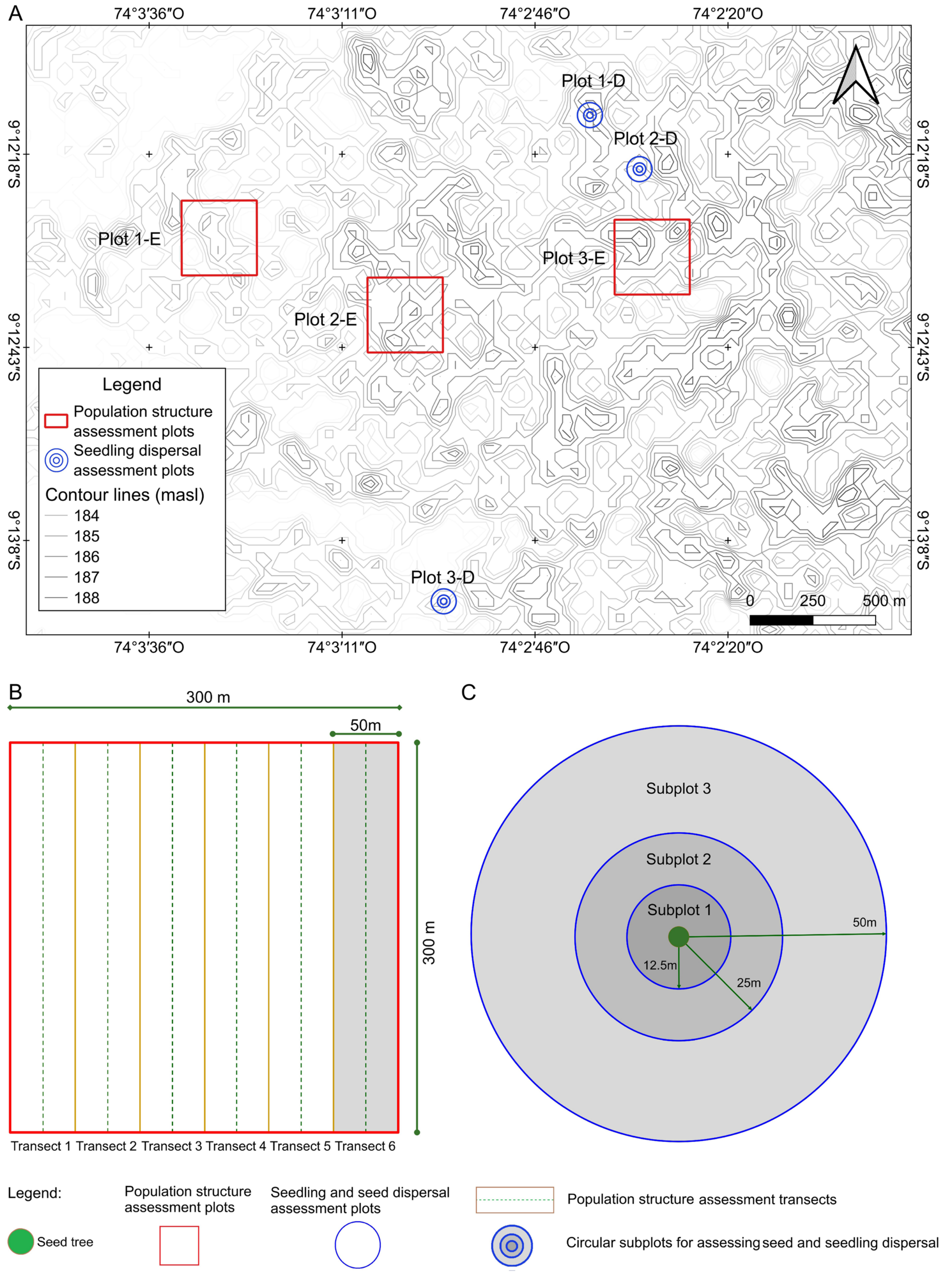

Figure 1. A - Location map of plots for *A. rosaeodora* seedling dispersal (1-D, 2-D, 3-D) and population structure (1-E, 2-E, 3-E) assessments; **B** - Design of plots and strips to evaluate the population structure and distribution of *A. roseadora* seedlings; **C** - Plot design for the evaluation of the dispersal of *A. rosaeodora* plants smaller than 50 cm.

established, considering that the main dispersal processes of *A. rosaeodora* are barochory and zoochory. With the abundance and DBH data, the population density (ind ha^{-1}) of saplings, stems, and adults was determined, and abundance histograms with five diameter classes: 10 (5-15cm), 20 (16-25 cm), 30 (26-35 cm), 40 (36-45 cm) and 50 (46-55cm) were developed to model the normal distribution pattern of the population. This was done by fitting Meyer's (1952) exponential equation: $y=\propto_0 e^{\propto_1 x}$, where y is the estimator of the total number of trees in the diameter class x, expressed by their class mark in centimeters; ∝i, are the model parameters, calculated for the complete sample and for the species. This model helps assess whether the population follows a typical natural regeneration pattern and to detect signs of disturbance or overexploitation.

We determined the population recovery status based on the assumption that abundance in all population classes resembles an inverted J, with adjustment for the Meyer exponential model and the Liocourt coefficient (q_i) (Meyer, 1952) as an indicator of the stability of the diameter classes in the population. For individuals with DBH≥ 5 cm: $q=\frac{N_{d_{max}}}{N_{d_{min}}}$, where q=Liocourt coefficient; $N_{d_{max}}$= number of individuals in the largest diameter class; $N_{d_{min}}$= number of individuals in the lowest diameter class.

For the analysis of dispersion in the population structure, we used the Morisita index (Morisita 1959), applying the following equation:

$$I_\delta = \frac{n\sum x_i(x_i-1)}{n\bar{x}(n\bar{x}-1)} = \frac{n\bar{x}IP}{n\bar{x}-1} \quad \text{and} \quad I_\delta = \frac{n\sum \lambda_i^2}{(\sum \lambda_i)^2}$$

where: =>1 grouped and/or aggregated; =1 aleatory and < 1is regular

We used this index because it allows us to determine whether individuals are distributed in aggregated, random, or uniform patterns, which is essential for understanding ecological processes such as seed dispersal, genetic structure, and habitat use.

Data were processed in Microsoft Office Excel 2019 using pivot tables and R-Studio R 4.0.0 (R Core Team, 2020). The census dispersion and population structure maps were made using the open source software QGIS Desktop 3.34.0 (QGIS Project, 2024).

RESULTS

Seedling dispersion

The mean dispersion distance measured between progenies and seed trees was 18.3 ± 9.2 (SD) m, and a CV of 50% (Table 1, Figure 2 a,b,c). The maximum dispersal distance observed was 44 m (Figure 2 a,b,c and Figure 3a). Seedling density (mean) for all plots was 0.03 seedlings m^{-2} (Table 1).

Seedling dispersal was adjusted to the Weibull model with reference to the seed tree and dispersing animals (Figure 3a). The best fit of the *A. rosaeodora* seedling dispersal data to the Weibull model is within the average shape parameters of 2.09 and an error of 0.12 with a scale of 20.23 for an error of 0.72 and a correlation between shape and scale of 0.31. (Figure 3b).

Population structure

We found a total of 189 individuals of *A. rosaeodora* distributed across the four categories with similar rank order across plots (Tables 2 and 3, Figure 4): 53.4% seedlings; 12.2% saplings; 27% stems and 7.4% adults. The mean population density by diameter class was 3.7 ind ha^{-1} for seedlings, 0.9 ind ha^{-1} saplings, 1.9 ind ha^{-1} stems and 0.5 ind ha^{-1} adult trees (Table 2). We found a mean overall density of 7 ind ha^{-1} (including seedlings). The proportion of the distribution structure by plant class are maintained in the evaluated plots with 1.1 to 5.7 seedlings, 0.6 to 1.1 saplings, 1.4 to 1.9 stems, and 0.4 to 0.6 adults, with a mean of 3.7, 0.9, 1.9, and 0.5 ind ha^{-1} respectively, and a SD of 2.4, 0.3, 0.8, and 0.1 (Table 2). The adjustment of *A. rosaeodora* population abundance per diameter class with the Meyer's (1952) exponential equation showed y = 118.91$e^{-0.9Di}$ and R^2= 0.98 (Figure 3), with Liocourt coefficients (q) ranging from 1.5 to 3.0 (Table 3). The Morisita index for this population was I_δ=1.97, i.e. >1 ($p < 0.05$) indicating an aggregated pattern.

DISCUSSION

Seedling dispersal

We found that most dispersal occurs at small distances from the parent tree (up to 20 m), leading to a high (75%) relative abundance of seedlings up to 12.5 m from the parent. A similar pattern was previously identified by Santana (2000), who reported that 79.27% of seedlings were located between four to 10 meters from the seed tree. The observed seedling dispersal patterns are consistent with two dispersal systems: dispersal over small distances by a barochoric mechanism and dispersal over longer distances by a zoochoric mechanism, potentially by birds (Psittacidae and Ramphastidae families) and the few mammals that feed on the pulp (Araujo 1967; Santana, 2000). Previously, Spironello *et al.* (2003) found that 75% of toucans that ingested the fruits dispersed them at distances greater than 50 m from the seed tree (via regurgitation, 15-30 minutes after ingesting the fruit), while 30% of parrots that ingested the fruits dispersed 40% of the seeds after a few minutes. Although the seedlings in our study reached distances of up to 44 m from the seed tree, likely a result of animal dispersal, the frequencies of large-distance dispersal are low, consistent with Santana (2000).

The general pattern observed here points towards a predominance of short-distance seed dispersal. However, this requires further analysis, preferably based on maternity and paternity tests using genetic markers such as microsatellite loci. Considering that the isolation of overexploited forests favors

Table 1. Seedling abundance (n, %), density (seedlings m^{-2}) and mean distance between seedlings to seed tree (m) for plots, subplots and total for *Aniba rosaeodora* in a forest concession in the Iparia district, Ucayali, Peru.

Plot	Subplot	Abundance		Density (seedlings m^{-2})			Distance to seed tree (m)			
		n	A%	Mean	SD	CV_1 (%)	Mean	SD	Range	CV_2(%)
1-D		150	100	0.02	-	-	17.9	8.3	2.8-42.2	46
	Sp1	37	24.7	0.08	-	-	7.4	3.0	2.8-12.4	17
	Sp2	72	48.0	0.05	-	-	18.9	3.4	13.5-25	19
	Sp3	41	27.3	0.01	-	-	25.6	7.9	26-42.2	44
2-D		29	100	0.00	-	-	20.2	13.1	3.2-44	65
	Sp1	12	41.4	0.02	-	-	7.8	3.8	3-12.5	19
	Sp2	7	24.1	0.00	-	-	18.7	3.5	14.4-24	17
	Sp3	10	34.5	0.002	-	-	36.2	5.7	26.2-44	28
3-D		26	100	0.00	-	-	14.0	6.7	1-27.6	48
	Sp1	9	34.6	0.02	-	-	6.3	4.3	1-12	31
	Sp2	16	61.5	0.01	-	-	17.4	2.6	13.1-24	19
	Sp3	1	3.9	0.0002	-	-	27.6	0	27.6	0
Total summary										
1-D, 2-D, 3-D		205	100	0.03	-	-	18.3	9.2	1-44	50
	Sp1	58	28.3	0.12	0.04	73	7.3	19	1-12.5	47
	Sp2	95	46.3	0.06	0.02	34	18.7	18	13.1-25	76
	Sp3	52	25.4	0.01	0.03	49	30	29	26.2-44	39

n = abundance of individuals per plot, and A% = abundance percentage per area; SD= standard deviation; CV_1= Density variation coefficient (%); CV_2= Distance variation coefficient (%).

endogamous reproduction and that inbreeding offspring rates increase for seedlings closer to the seed tree (Pereira *et al*. 2020), the seedlings likely have greater levels of relatedness with the nearest seed tree (Sebbenn *et al*. 2012; Manoel *et al*. 2017; Manoel *et al*. 2021). These events create a restricted spatial genetic structure, since fragmented habitats present an increase in the deleterious genetic load and reduce heterozygosity, which weakens vigor, fertility, biomass reduction, germination and the capacity to adapt to environmental changes (Dussex *et al*. 2023; Aguilar *et al*. 2019).

Population structure

The total mean population density (including seedlings, saplings, stems and adults) was high (7 ind ha^{-1}), but adult trees had very low density (< 1 ind ha^{-1}). A total population density of 0.547 ind ha^{-1} was found previously in the same area (Gutierrez 2023) and 0.77 ind ha^{-1} (for trees >15cm DBH) in the Tapajós National Forest, Brazil (Carvalho 1983). The difference between the density estimates for the same area may have arisen from the differences in sampling design - plots of 300 x 300 m in areas with known occurrence of *A. rosaeodora* individuals in the present study which increases the probability of detection and tends to overestimate relative density, in contrast to Gutierrez *et al*. (2023), who used randomly placed strip plots of 1000 x 10 m, which are more suitable for characterizing overall communities but could underestimate rare or aggregated species. The sampling design has a decisive impact on the detection and estimation of rare species, especially when they present non-random spatial patterns (Sutherland (2006), Magnusson *et al*. 2013). Another study in the same area found 0.2 ind ha^{-1} (DBH ≤ 10 cm) in 10 x 100 m plots, with an *A. rosaeodora* whole population density of 2.09 ind ha^{-1} (CANDES 2017). Furthermore, the regeneration potential of the species is very heterogeneous - a similar study found that 65% of the species had less than 10 young individuals in their immediate vicinity, while only 5% had abundant regeneration, leading to a high population density of 27 individuals per ha (Mitja and Lescure 1993). Finally, Loureiro *et al*. (1979) reported a density of two individuals per ha. This *A. rosaeodora* population heterogeneity across the Amazon are most likely the result of historical processes of selective exploitation, which drastically reduced the number of adults, leaving young natural populations, while also inducing fragmentation and isolation of populations, limiting gene flow (Guizado *et al*. 2020; Gutiérrez *et al*. 2023).

We detected evidence of a persistent disturbance in the studied population, given by the lack of adjustment of the size-class distribution to the inverted J pattern, as expected in naturally regenerating populations. In regular natural forests, the species respond to multiple ecological and ecophysiological filters (Souza and Jesus 1994), leading to the predominance of younger individuals compared to a low number of individuals with larger diameter; hence the decreasing abundance distribution in the shape of an inverted J. Similarly, it can be verified that the extreme diameter classes where *q* differs appreciably from the rest occur because a large number of individuals of these classes were recently extracted for various reasons (Imaña-Encinas *et al*. 2020).

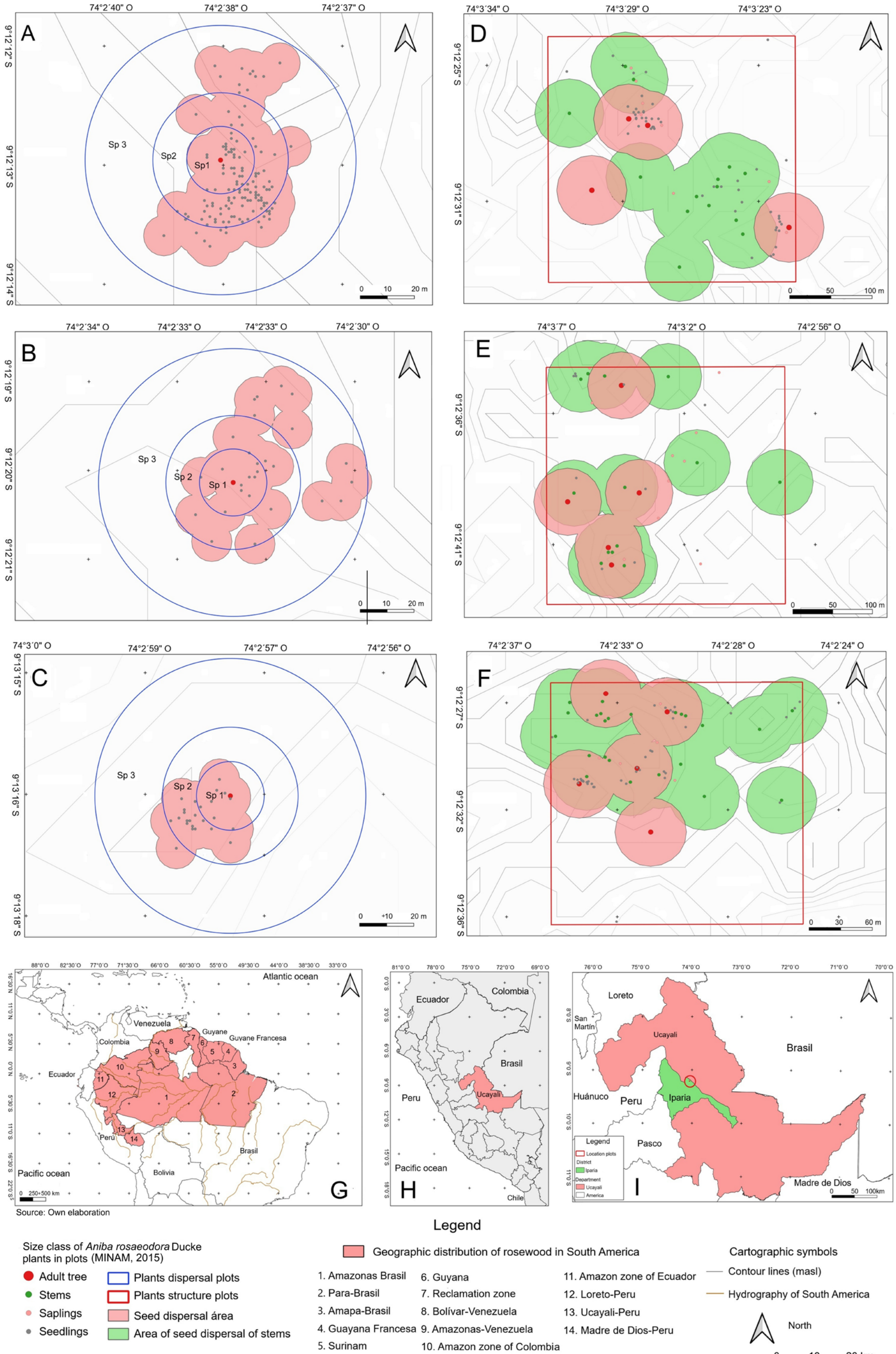

Figure 2. *Aniba rosaeodora* seedling dispersion and population structure by diameter class. **A** - seedling dispersion in the plot 1-D; **B** - seedling dispersion in the plot 2-D; **C** - seedling dispersion in the plot 3-D; **D** - distribution of the population structure in the plot 1-E; **E** - distribution of the population structure in the plot 2-E; **F** - distribution of the population structure in the plot 3-E; **G** - Distribution map in South America, prepared by the authors, based on bibliographic and cartographic records from various institutions and authors; **H** - political location of the department of Ucayali, Peru; **I** - political location of the Iparia district in the Ucayali department of Peru, where the sampling was conducted.

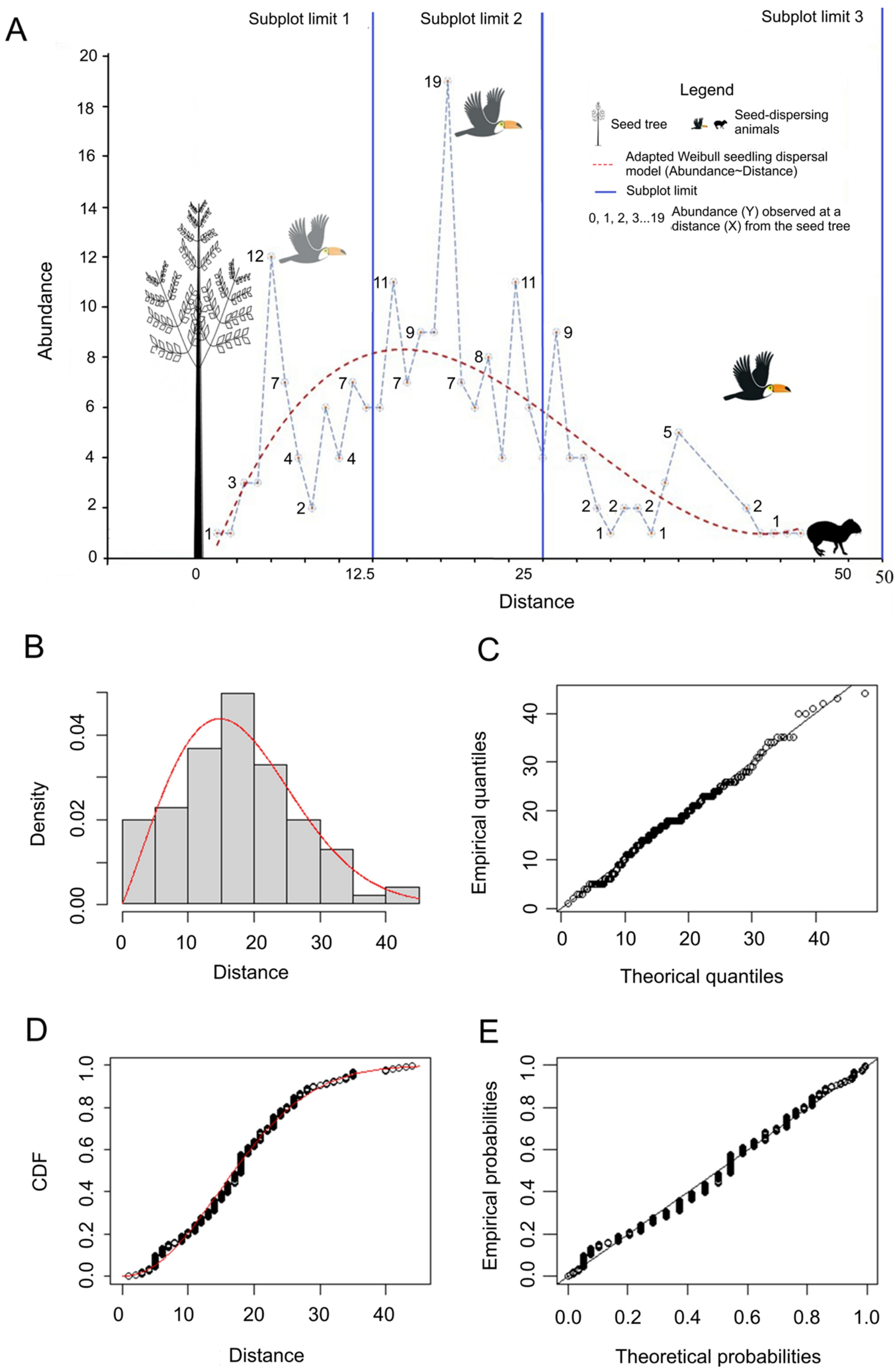

Figure 3. A - Seed and seedling dispersal data for *Aniba roseadora*, adapted to the Weibull model with reference to the seed tree and dispersing animals; **B** - Distribution of plants among size-classes (histogram) adjusted with the Weibull model (Weibull distribution curve); **C** - Q-Q plot for diagnosing differences between the probability distribution of a population from which a random sample has been drawn and a distribution used for comparison; **D** - The cumulative failure distribution (CDF) function; **E** - The probability-probability (P-P) chart.

Table 2. Population structure of *Anita rosaeodora* in a forest concession in the Iparia district of Ucayali, Peru.

Plots/	Abundance		DBH (cm)			H (m)			Density (ind ha^{-1})	
	n	A%	Mean	Range	CV	Mean	Range	CV	Mean	CV
1-E	38	100	13.7	2.5-38	80.4	13.6	0.11-31	70.5	4.2*	24
Seedling	10	26.3	2.8	2.5-3.4	0.1	2.4	0.11-6.2	6.3	1.1	25
Sapling	10	26.3	8.4	5.8-9.9	2.2	12.3	7-17.6	8.3	1.1	25
Stem	13	34.2	15.9	10.3-24	21.0	19.5	13-31	30.6	1.4	22
Adult	5	13.2	29.6	25.1-38	24.4	21.9	12.2-27.2	10.7	0.6	29
2-E	76	100	11.6	1-53.9	139.5	7.5	0.1-31	98.9	8.4*	23
Seedling	51	67.1	2.2	1-4.1	1.1	1.3	0.1-10	6.5	5.7	11
Sapling	8	10.5	7.0	5.5-9.9	2.5	12.8	6.5-16	10.3	0.9	30
Stem	13	17.1	17.0	12-22.8	15.8	21.8	16-31	21.1	1.4	28
Adult	4	5.3	39.0	29-55.9	109.7	29.0	25.3-31	7.3	0.4	32
3-E	75	100	12.9	0.3-36.6	73.3	10.3	0.1-29.8	103.4	8.3*	23
Seedling	40	53.3	2.9	0.3-4.4	1.9	2.0	0.4-11	8.3	4.4	16
Sapling	5	6.7	7.7	5.3-9.2	2.4	12.0	6.34-18	19.1	0.6	31
Stem	25	33.3	15.6	14.4-23.5	18.7	20.5	9-29.8	30.9	2.8	22
Adult	5	6.7	29.0	25.4-36.6	20.3	24.7	17.5-28.4	19.7	0.6	31
Total summary	189	100	12.7	0.3-53.9	96.4	9.8	0.1-31	99	7	16
Seedling	101	53.4	2.5	0.3-4.4	1.3	1.7	0.1-13	7.3	3.7	63
Sapling	23	12.2	7.7	5.3-9.9	2.5	12.4	4.2-18	10.3	0.9	33
Stem	51	27.0	16.0	10.3-24	18.1	20.6	7.4-31	27.9	1.9	41
Adult	14	7.4	32.1	25.1-55.9	59.9	24.9	13.8-31	19.6	0.5	12

n= abundance of seedling, sapling, stem, and adult individuals; A%= abundance percentage per area; H= individual height; DBH= diameter at breast height; CV= coefficient of variation (%); Density= Plant density per hectare (ind ha^{-1}); *density includes seedlings.

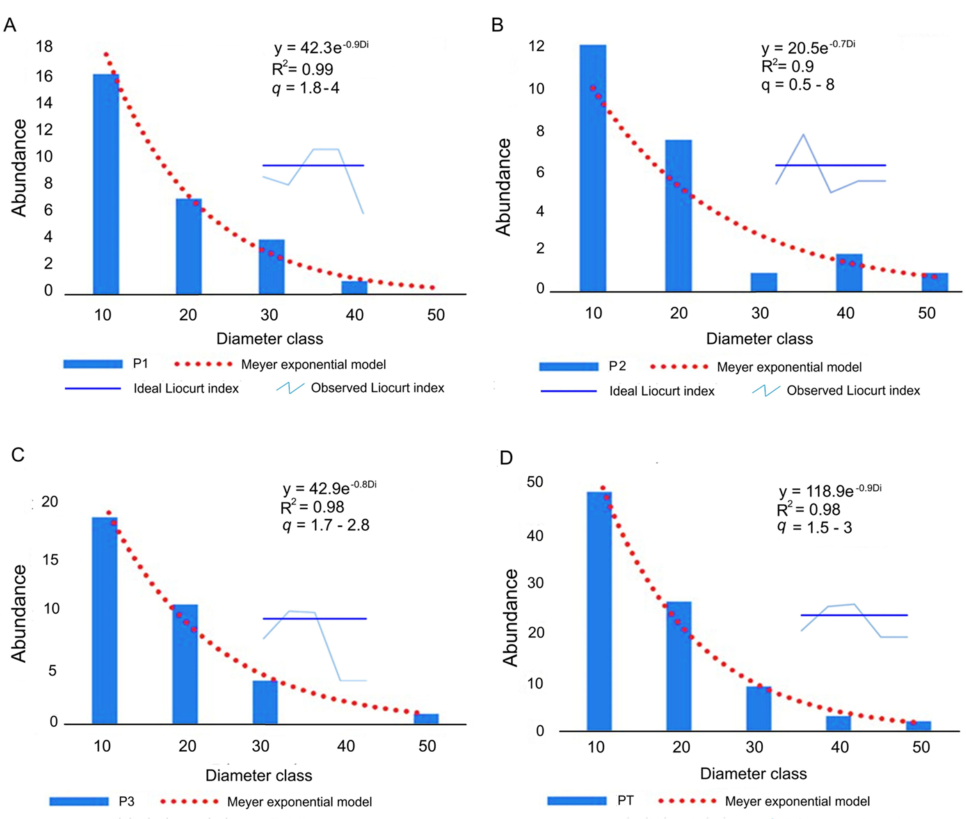

Figure 4. Determination of population recovery potential by the inverted "J" method (Meyer, 1952) and Liocourt (*q*) through the abundance distribution of individuals per diameter class (Di). **A** - Distribution for plot P1; **B** - Distribution for plot P2; **C** - Distribution for plot P3; **D** - Distribution for the sum of the three plots.

Table 3. Regression models applied to determine the status of the sampled *Aniba rosaeodora* population in a forest concession in the Iparia district, Ucayali, Peru.

Class (Di)	P1		P2		P3		PT	
	n (%)	*q1*	n (%)	*q2*	n (%)	*q3*	n (%)	*qt*
10	16 (57.1)	2.3	13 (52)	1.6	19 (54.3)	1.7	48 (54.5)	1.8
20	7 (25)	1.8	8 (32)	8.0	11 (31.4)	2.8	26 (29.5	2.9
30	4 (14.3)	4.0	1 (4)	0.5	4 (11.4)		9 (10.2)	3.0
40	1 (3.6)		2 (8)	2.0			3 (3.4)	1.5
50			1 (4)		1 (2.9)		2 (2.3)	
Total	28 (100)		25 (100)		35		88 (100)	
Equation	$y = 42.3e^{-0.9Di}$		$y = 20.5e^{-0.7Di}$		$y = 42.9e^{-0.8Di}$		$y = 158.2e^{-0.96Di}$	
R^2	0.99		0.9		0.98		0.98	

Di=diametric class; P1, P2, P3 =plots; PT= all plots together; n=number of individuals by diametric class; q1, q2, q3, qt=Liocourt coefficient by plot.

The inverted J pattern, with stable q coefficients is typical of Lauraceae, with high levels of seed and seedling production and high density-dependent mortality, very few individuals reach the adult stage (Cuevas *et al*. 2008). From the observed results we can assume that the impact of *A. rosaeodora* overexploitation persists in the study area. Likewise, it was found that on average there is a significant abundance of individuals located in the outer range of the maximum seed dispersal of the seed tree, which differs from that proposed by Santana (2000). This apparent difference may be due to the presence of early maturing stems that have begun reproductive dissemination, as observed in the field. Thus, a maximum seed dispersal zone per adult tree with a radius of 44 m was identified, within which seedlings and stems were located. For this reason, it is very likely that the observed population structure is the result of the presence of seed trees that are remnants of different harvesting intensities (Alencar and Fernandes 1978; Loureiro *et al*. 1979; Spironello *et al*. 2003). However, this seedling dispersal pattern is potentially dangerous for the sustainability of the species, considering that in this study area the *A. rosaeodora* population is isolated compared to other populations in the Peruvian Amazon (Guizado *et al*. 2020). Overexploited species may present high rates of coancestry within isolated populations, as found for seedlings close to *Swietenia macrophylla* seed trees in an over-exploited tropical forest in Bolivia (Sebbenn *et al*. 2012).

Despite the presence of spatially sparse individuals, the distribution of adult trees was mostly clustered in groups, as determined by the Morisita index. Two to five trees with DBH> 20cm spaced by distances of 97 to 110 m were found. This range is at the upper limit of what was found before, i.e. between 50 and 100 m apart (Alencar and Fernandez 1978). This distance could imply in a decrease of genetic diversity and a loss of alleles as the best phenotypes may have been removed for linalool extraction, resulting in reduced genetic drift due to changes in gene flow as a result of tree selection (Correa *et al*. 2013). Such changes can increase the vulnerability of the species by reducing the genetic foundation for reproduction among fewer individuals or among progenies, thus increasing the coancestry in the population.

CONCLUSIONS

The study of *A. rosaeodora* seedling dispersal and population structure in Ucayali, Peru, indicates that the seedling dispersion pattern is irregular and the population structure does not adhere to species recovery models in tropical forests. These results are likely due to the continuing effects of overexploitation of the species throughout the 20th century. The population density of the study area is heterogeneous, but it is higher than the average obtained in other studies, likely due the placement of plots in an area with the known presence of trees and seedlings of the species. The study population demonstrates characteristics of an isolated population typical of an overexploited species that is at constant risk due to endogamous processes. Because of its isolation, the population in the study area has potential for the conservation and management of the genetic resources of the species.

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REFERENCES

Aguilar, R.; Cristóbal-Pérez, E.J.; Balvino-Olvera, F.J.; Ashworth, L., Lobo, J.A.; Quesada, M. & Rosas, F. 2019. Fragmentation effects on the quality of progeny: A global meta-analysis of 179 plant species. *Global Ecology and Conservation* 20: e00724.

Alder, D. 1980. Forest volume estimation and yield prediction. FAO Forestry Paper 22, FAO, Rome.

Alencar, J.C.; Fernandes, N.P. 1978. Desenvolvimento de árvores nativas em ensaios de espécies. I. Pau-rosa (*Aniba duckei* Kostermans). *Acta Amazonica* 8: 523–541.

Amusant, N.; Beauchène, J.; Digeon, A.; Chaix, G. 2016. Essential oil yield in rosewood (*Aniba rosaeodora* Ducke): initial application of rapid prediction by near infrared spectroscopy based on wood spectra. J. Near Infrared. *Journal of Near Infrared Spectroscopy* 24: 507–515.

Amusant, N.; Digeon, A.; Descroix, L.; Bruneau, O.; Bezard, V.; Beauchène, J. 2015. Planting rosewood for sustainable essential oil production: Influence of surrounding forest and seed provenance on tree growth and essential oil yields. *Bois et Forets des Tropiques* 326: 57–65.

Araújo, V. C. 1967. Sobre a germinação de *Aniba* (Lauraceae). I. *A. duckei* Kostermans (Pau-rosa itaúba). Botânica. Manaus: Inpa, 23. 21 pp.

Araújo, V.C.; Correa, R.G.C.; Maia, J.G.S.; Silva, M.L.; Gottlieb, O.R.; Marx, M.C.; Magalhães, L.M.S. 1971. Óleos essenciais da Amazônia contendo linalol. *Acta Amazonica* 1: 45–47.

Barstow, M. 2021. *Aniba rosaeodora*. The IUCN Red List of Threatened Species 2021: e.T33958A88301381.

Braga, A.C.; Collevatti, R.G. 2011. Temporal variation in pollen dispersal and breeding structure in a bee-pollinated Neotropical tree. *Heredity* 106: 911-919.

Calama, R.; Manso, R.; Lucas-Borja, M.E.; Espelta, J.M.; Piqué, M.; Bravo, F.; Del Peso, C.; *et al*. 2017. Natural regeneration in Iberian pines: A review of dynamic processes and proposals for management. *Forest Systems* 26: eR02S.

Campoe, O.C.; Stape, J.L.; Nouvellon, Y.; Laclau, J.P.; Bauerle, W.L.; Binkley, D.; *et al*. 2013. Stem production, light absorption and light use efficiency between dominant and non-dominant trees of *Eucalyptus grandis* across a productivity gradient in Brazil. *Forest Ecology and Management* 288: 14–20.

CANDES (Consultores Asociados en Naturaleza y Desarrollo S.A.C). 2017. Ministerio del Ambiente. Estudio de las poblaciones de especies de flora silvestre priorizadas “palo rosa” y “Shihuahuaco”. Lima, Perú. 136p.

Carvalho, J.O.P. 1983. Abundância, freqüência e grau de agregação do pau-rosa (*Aniba duckei* Kostermans) na Floresta Nacional de Tapajós. Boletim de Pesquisa 53. EMBRAPA-CPATU, Belém.

Condit, R. 1995. Research in large, long-term tropical forest plots. *Trends in Ecology & Evolution* 10: 18–22.

Correa, E.; Espitia, M.; Araméndiz, H.; Murillo, O.; Pastrana, I. 2013. Variabilidad genética en semillas de árboles individuales de *Tectona grandis* L.f. en la conformación de lotes mezclados en Córdoba, Colombia. *Revista U.D.C.A Actualidad & Divulgación Científica* 16: 379–389.

Cuevas, R.; García, E.; Vázquez, A.; García, J.; Núñez, N. 2008. Estructura poblacional y relaciones ambientales del árbol tropical *Nectandra rudis* (Lauraceae), una especie rara en el occidente de México. *Revista de Biologia Tropical* 56: 247–256.

Dick, C.W.; Hardy, O.J.; Jones, F.A.; Petit, R.J. 2008. Spatial scales of pollen and seed-mediated gene flow in tropical rain forest trees. *Tropical Plant Biology* 1: 20-33.

Dussex, N.; Morales, H.E.; Grossen, C.; Dalén, L. & van Oosterhout, C. 2023. Purging and accumulation of genetic load in conservation. *Trends in Ecology & Evolution* 38: 961–969.

Ellstrand, N.C. 2014. Is gene flow the most important evolutionary force in plants?. *American Journal of Botany* 101: 737-753.

Fernández-Silva, A. 2023. Estrategias de recuperación de especies aromáticas del género *Aniba* (palo rosa) en el distrito de Puerto Bermúdez, Oxapampa, Pasco. Tesis de maestría, Universidad Nacional Agraria La Molina, Lima, Perú, 123p. (https://hdl.handle.net/20.500.12996/5788). Accessed on 31 Jul 2025.

Giongo, J.L.; Vaucher, R.A.; Da Silva, A.S.; Oliveira, C.B.; Mattos, C.B.; Baldissera, M.D.; *et al*. 2017. Trypanocidal activity of the compounds present in *Aniba canelilla* oil against *Trypanosoma evansi* and its effects on viability of lymphocytes. *Microbial Pathogenesis* 103: 13–18.

GRU (Gobierno Regional de Ucayali), 2017. Zonificación ecológica económica base para el ordenamiento territorial de la región Ucayali. Pucallpa. 227p. (https://sinia.minam.gob.pe/sites/default/files/sinia/archivos/public/docs/estudio_de_la_propuesta_de_zee_10.pdf). Accessed on 31 Jul 2025.

Guizado, S.J.V.; Nadeem, M.A.; Ali, F.; Barut, M.; Habyarimana, E.; Gómez, T. P.; Baloch, F.S. 2020. Diversidad genética y estructura poblacional de palo de rosa en peligro de extinción de la Amazonía Peruana utilizando marcadores ISSR. *Acta Amazonica* 50: 204-212.

Gutierrez, H.; Castañeda, R.; Flores, E.; Sotelo-Méndez, A.; Tarazona, G. 2023. Estimación de la densidad y estructura de la población de palo rosa en el Perú y sus implicaciones para su explotación comercial. *Folia Amazonica* 32: e32661.

Imaña-Encinas, J.; Riesco-Muñoz, G.; Antunes-Santana, O.; de Camino, R. 2021. Análisis silvicultural del bosque tropical atlántico a partir de la distribución diamétrica y riqueza florística del arbolado. *Revista Forestal Mesoamericana Kurú* 18: 46–54.

Krebs, C.J. 1999. Ecological methodology. 2nd ed. Benjamin Cummings, Menlo Park, California, USA. 620p.

Kubitzki, K.; Renner, S. 1982. Lauraceae I (*Aniba* and *Aiouea*). *Flora Neotropica* 31: 1–124.

Liocourt, F. 1898. De l’aménagement des sapinières. Bulletin Trimestriel, *Société Forestière de Franche-Comté et Belfort* 4: 396–409.

Loureiro, A.A.; Silva, M.D.; Alencar, J.D.C. 1979. Essências madeireiras da Amazônia. Manaus: CNPq/INPA/SUFRAMA, *Boletim de Pesquisa* 1, INPA/SUFRAMA-MA, 245p.

Magnusson, W. E.; Braga-Neto, R.; Pezzini, F.; Baccaro, F. B.; Bergallo, H. G.; Penha, J.; *et al*. 2013. Biodiversity and integrated environmental monitoring: A handbook for field biologists (1. a ed.). Áttema Editorial, Manaus, Brasil. 352p.

Manoel, R.O.; Freitas, M.L. M.; Furlani Junior, E.; Alves, P.F.; Moraes, M.L.T.; Sebbenn, A.M. 2017. Low levels of pollen and seed flow in a riparian forest fragment of the dioecious tropical tree *Genipa americana* L. *Forestry Research and Engineering: International Journal* 1: 00003.

Manoel, R.O.; Rossini, B.C.; Cornacini, M.R.; Moraes, M.L.; Cambuim, J.; Alcântara, M.A.; *et al*. 2021. Landscape barriers to pollen and seed flow in the dioecious tropical tree *Astronium fraxinifolium* in Brazilian savannah. *Plos one* 16: e0255275.

May, P.H.; Barata, L.E. 2004. Rosewood exploitation in the Brazilian Amazon: Options for sustainable production. *Economic Botany* 58: 257–265.

Meyer, H.C. 1952. Structure, growth and drain in balanced uneven-aged forests. *Journal of Forestry* 50: 85-92.

MINAM (Ministerio del Ambiente), 2015. Guía de inventario de la flora y vegetación. Dirección General de Evaluación, Valoración y Financiamiento del Patrimonio Natural, Lima-Perú. 50p. (https://cdn.www.gob.pe/uploads/document/file/155205/07_guia-a-de-flora-y-vegetacion.pdf?v=1532447513). Accessed on 31 Jul 2025

Mitja, D.; Lescure, J.P. 1993. Etude de la régénération du pau-rosa. In: Lescure, J.P. (Eds) Extractivisme en Amazonie brésilienne. Paris: Ministère de Enviromiement, Repport Final de Convention SOFT, pp. 127–162.

Mitja, D.; Lescure J.P. 1996. Du bois pour du parfum: Le bois de rose doit-il disparaître? In: Emperaire L. (eds.). La forêt en jeu: l' extractivisme en Amazonie centrale. Paris, OSTROM-UNESCO, pp.93-102.

Morisita, M. 1959. Measuring of the dispersion and analysis of distribution patterns. Memoires of the Faculty of Sciences, Kyushu University, *Series E. Biology* 2: 215-235.

Muñoz, J. 2018. Regeneración Natural: Una revisión de los aspectos ecológicos en el bosque tropical de montaña del sur del Ecuador. *Bosques Latitud Cero* 7: 130-142.

Norden, N. 2014. Del porque la regeneración natural es tan importante para coexistencia de especies en los bosques tropicales. *Colombia Forestal* 17: 247–261.

Perea-Gonzales, J.A. 2022. Evaluación del crecimiento y sobrevivencia de *Aniba rosaeodora* "Palo de rosa" de la plantación N° 38 del CIEFOR – Puerto Almendra, Loreto – Perú. Tesis de licenciatura, Universidad Nacional de la Amazonía Peruana, Iquitos, Perú. https://hdl.handle.net/20.500.12737/9264.

Pereira, L.C.; Tambarussi, E.V.; Biliati, M.O.; Martins, K.; Kageyama, P.Y.; Sebbenn, A.M. 2020. Inbreeding depression from selfing and mating among relatives of *Hymenaea courbaril* L. *Forest Ecology and Management* 475: 118414.

Pérez-López, E.; Santiago-García, W.; Quiñonez-Barraza, G.; Rodríguez-Ortiz, G.; Santiago-García, E. & Ruiz-Aquino, F. 2019. Estimación de distribuciones diamétricas para *Pinus patula* con la función Weibull. Madera y Bosques, 25: e2531626.

QGIS Project, 2024. QGIS Desktop 3.34 User Guide, QGIS Association. 1673p. https://docs.qgis.org/3.34/en/docs/developers_guide/index.html

R Core Team, 2020. R: A language and environmental for statistical computing R 4.0.0. R Foundation for Statistical Computing. Vienna, Austria. URL https://www.R-project.org/

Rasal, M.; Troncos, J.; Lizano, C.; Parihuamán, O.; Quevedo, D. 2012. La vegetación terrestre del bosque montano de Lanchurán (Piura, Perú). *Caldasia* 34(1): 1–24.

Revilla-Chávez, J.M.; Sáenz-Ramírez, L.H.; Gonzales-Alvarado, A.C.; García-Soria, D.G.; Sebbenn, A.M. 2024. Allometric models of biomass and essential oils of *Aniba rosaeodora* Ducke in a tropical middle terrace soil forest of Masisea, Ucayali, Peru. *Trees, Forests and People* 16: 100594.

Rodríguez, A.V.; Mandujano, S. 2007. Efectos de la fragmentación sobre la composición y la estructura de un bosque tropical lluvioso Mexicano. In: Harvey, C.A., Sáenz, J.C. (Eds) Evaluación y conservación de biodiversidad en paisajes fragmentados de Mesoamérica 1ª ed. Santo Domingo de Heredia, Costa Rica: Instituto de Biodiversidad, INBio. pp. 179–196.

Sant'Anna, C.S.; Sebbenn, A.M.; Klabunde, G.H.; Bittencourt, R.; Nodari, R.O.; Mantovani, A.; *et al.* 2013. Realized pollen and seed dispersal within a continuous population of the dioecious coniferous Brazilian pine [*Araucaria angustifolia* (Bertol.) Kuntze]. *Conservation Genetics* 14: 601-613.

Santana, J.A.S. 2000. Distribuição espacial da regeneração natural de *Aniba rosaeodora* Ducke (pau-rosa). Revista Brasileira de Ciencias Agrarias 33: 37–48.

Sebbenn, A.M.; Carvalho, A.C.M.; Freitas, M.L.M.; Moraes, S.M.B.; Gaino, A.P.D.S.D.C.; Da Silva, J.M.; *et al.* 2011. Low levels of realized seed and pollen gene flow and strong spatial genetic structure in a small, isolated and fragmented population of the tropical tree *Copaifera langsdorffii* Desf. *Heredity* 106: 134-145.

Sebbenn, A.M.; Licona, J.C.; Mostacedo, B.; Degen, B. 2012. Gene flow in an overexploited population of *Swietenia macrophylla* King (Meliaceae) in the Bolivian Amazon. *Silvae Genetica* 61: 212-220.

Silva, J.N.M.; Carvalho, J.O.P.; Lopes, J.C.A.; Almeida, B.F.; Costa, D.H.M.; Oliveira, L.C.; *et al.* 1984. Growth and yield of a tropical rain forest in the Brazilian Amazon 13 years after logging. *Forest Ecology and Management* 71: 267–274.

Souza, A.; Jesus, R. 1994. *Distribuição diamétrica de espécies arbóreas da Floresta Atlântica: análise de agrupamento Viçosa, MG*: Sociedade de Investigações Florestais (Boletim Técnico, 10), 30 p.

Spironello, W.R.; Sampaio, P.; de T.B.; Ronchi-Teles, B. 2004. Produção e predação de frutos em *Aniba rosaeodora* Ducke var. amazonica Ducke (Lauraceae) em sistema de plantio sob floresta de terra firme na Amazônia Central. *Acta Botanica Brasilica* 18: 801–807.

Spironello, W.R.; Sampaio, P.T.B.; Vieira, G.; Barbosa, A.P. 2003. Ecologia reprodutiva do Pau-rosa (*Aniba rosaeodora* Ducke, Lauraceae) em uma mata de terra firme na Amazônia central. In: Sampaio, P.D.T.-B., Barbosa, A.P., Vieira, G., Spironello, W.R., Ferraz, I.D.K, Camargo, J.L.C, Quisen, R.C. (Eds). Uso e conservação do pau-rosa (*Aniba rosaeodora*) Ducke. INPA, Manaus. p. 69–88.

Spironello, W.R.; Sampaio, P.T.B.; Ronchi-Teles, B. 2021. Produção e predação de frutos em *Aniba rosaeodora* Ducke var. amazonica (Lauraceae) em sistema de plantio sob floresta de terra firme na Amazônia Central. *Acta Amazonica* 51: 185–192.

Sutherland, W. J. (2006). Ecological census techniques: A handbook (2nd ed.). Cambridge University Press. 432p.

Tambarussi, E.V.; Boshier, D.; Vencovsky, R.; Freitas, M.L.M.; Sebbenn, A.M. 2015. Paternity analysis reveals significant isolation and near neighbor pollen dispersal in small *Cariniana legalis* Mart. Kuntze populations in the Brazilian Atlantic Forest. *Ecology and Evolution* 5: 5588-5600.

Teles, R.D.M.; Mouchrek, V. 2022. Análisis térmico del aceite esencial de *Aniba rosaeodora* Ducke por TGA y DSC. Research, Society and Development 11: e3411326085.

Weibull, W. 1939. The phenomenon of rupture in solids. Proceedings of the Royal Swedish Academy of Engineering Sciences, 153: 1-55.

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