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Acacia dealbata Link. Aboveground Biomass Assessment: Sustainability of Control and Eradication Actions to Reduce Rural Fires Risk

Leonel J. R. Nunes [1,*], Catarina I. R. Meireles [2], Carlos J. Pinto Gomes [2,3] and Nuno M. C. Almeida Ribeiro [4,5]

1 PROMETHEUS—Unidade de Investigação em Materiais, Energia e Ambiente para a Sustentabilidade, Escola Superior Agrária, Instituto Politécnico de Viana do Castelo, Rua da Escola Industrial e Comercial de Nun'Alvares, 4900-347 Viana do Castelo, Portugal

2 MED—Mediterranean Institute for Agriculture, Environment and Development, Pólo da Mitra, Universidade de Évora, 7006-554 Évora, Portugal; cmeireles@uevora.pt (C.I.R.M.); cpgomes@uevora.pt (C.J.P.G.)

3 Departamento da Paisagem, Ambiente e Ordenamento, Universidade de Évora, 7000-671 Évora, Portugal

4 ICT—Instituto de Ciências da Terra, Universidade de Évora, Rua Romão Ramalho, 59, 7002-554 Évora, Portugal; nmcar@uevora.pt

5 Departamento de Fitotecnia, Universidade de Évora, 7000-083 Évora, Portugal

* Correspondence: leonelnunes@esa.ipvc.pt

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Abstract: Invasive species are an environmental problem affecting worldwide ecosystems. In the case of *Acacia dealbata* Link., the negative impacts affect the productivity of the forests due to the competition established with native species while contributing to a significant increment in the available fuel load, increasing the risk of fire. In Portugal, chemical and mechanical methods are mostly used in the control of these species. However, the costs are often unsustainable in the medium term, being abandoned before completing the tasks, allowing the recovery of the invasive species. The establishment of value chains for the biomass resulting from these actions was pointed out by several authors as a solution for the sustainability of the control process, as it contributes to reducing costs. However, the problems in quantifying the biomass availability make it challenging to organize and optimize these actions. This work, which started from a dendrometrical analysis carried out in stands of *A. dealbata*, created a model to assess woody biomass availability. The model proved to be statistically significant for stands with trees younger than 20 years old. However, the amount of data collected and the configuration of the settlements analyzed do not allow extrapolation of the model presented to older settlements.

Keywords: *Acacia dealbata* Link; invasive species; control and eradication actions; value chains; sustainability; rural fires

1. Introduction

Acacia dealbata Link. is a species of Australian origin that has shown very aggressive invasive behavior in certain locations in Europe, namely in certain specific habitats and protected areas, such as coastal dunes, riparian zones, natural parks, and other protected areas, but also in agricultural areas or in the borders of forest areas [1–3]. Lorenzo et al. (2010) pointed out human interference, more specifically, soil disturbance and severe fires, as the main causes of the spread of *A. dealbata* in different habitats [4]. The same authors, corroborated by others, also presented the main impacts on ecosystems directly associated with the invasion and prevalence of *A. dealbata* in invaded ecosystems, namely the negative effects on native biodiversity [5–7]. Figure 1 shows the actual distribution of *A. dealbata* in Europe.

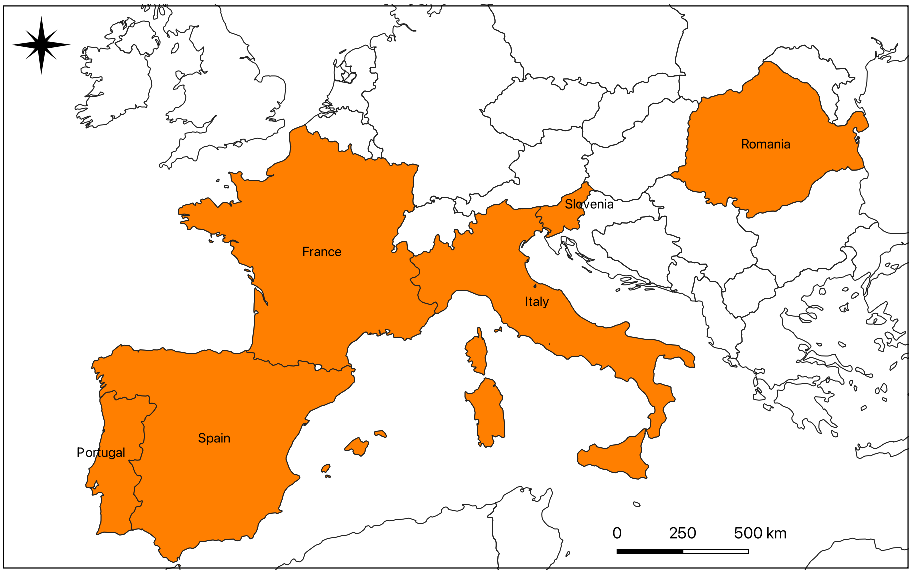

Figure 1. Distribution of *A. dealbata* in Europe (data collected from [8]).

This ability of *A. dealbata* to disperse seems to be related to a set of properties that the species presents, which even allow it to severely interfere with the balance of microorganisms in the soil. This ability, as noted by Lorenzo et al. (2010) allows *A. dealbata* to thrive through changes in microscopic communities. For example, it promotes increased bacterial activity in the soil, which is perhaps more advantageous for the species, while, on the other hand, the authors observed a decrease in fungal activity [9]. The authors also refer to changes in the chemical composition of the soil, which was later confirmed by other works, such as that of González-Munõz et al. (2012), with the authors demonstrating that *A. dealbata* alters the chemical composition of soils, with an increase in the content of nitrogen compounds and a lowering of the pH, contributing to the seeds of other species finding it more difficult to germinate [2]. Allelopathy has also been presented as a competitive advantage that this species presents, not only due to the presence of compounds in the soil that interfere with the development of other species but also due to the passage of rainwater through the foliage of the canopy of the trees. *A. dealbata*, mainly during the flowering period, as presented by Lorenzo et al. (2008), proves the ability of this species to aggressively dominate the space and with a competitive capacity that goes far beyond the ability that native species have [10]. This ability of the leachates of *A. dealbata* had already been reported by Carballeira et al. (1999), who tested the allelopathic capacity of these leachates in the growth of lettuce and concluded that the samples showed very significant toxicity [11].

This set of arguments led to the growing need to find ways to control and eradicate the species, to avoid its growing dispersion in different habitats, putting native biodiversity at risk [12,13]. However, the forms of control employed so far have not shown to be efficient and have not been able to prevent the advance of the species [14]. These control processes focused mainly on chemical and mechanical processes, as indicated by Campbell et al. (1990), who also described the use of controlled fire. This seems, however, not to contribute to the elimination of plants but rather to their recurrence with greater intensity in burnt areas, especially when there were previously adult stands with the capacity to create seed banks in the soil that germinate with great intensity after the use of fire, since *A. dealbata* is a pyrophyte species [15–17].

The possibility of creating value chains with the biomass of *A. dealbata*, as presented by Nunes et al. (2020), seems to be a methodology capable of contributing to the maintenance of control actions for longer periods of time so that pressure is exerted on the species, not giving it the ability to recover and, thus, continue its expansive process [18]. Control actions are often abandoned because of their costs, which often make it impossible to continue the work. The creation of value chains for biomass resulting from the control actions of *A. dealbata* can allow the sustainability of these actions, allowing their continuity. With this objective in mind, it seems to be essential to develop a tool that allows the expeditious quantification of the quantities of biomass available, so that the campaigns for the collection of biomasses can be optimized. They can be used later, for example, to produce firewood for domestic consumption, for incorporation in the production of biomass pellets, or in the production of charcoal [19,20]. Thus, the main objective of the present work is the development of a mathematical model aimed at quantifying the biomass of *A. dealbata* available in each area, for example, using aerial photography, where the various existing stands are delimited, allowing the organization of actions to control and forward the biomass resulting from these actions.

2. Materials and Methods

2.1. Framework and Selection of the Sampling Zone

There are several works that point to examples of protected areas that suffer the invasion of *A. dealbata*. In Portugal, this is a recurrent situation, with this species reaching both the coastal regions and the inland regions of the country, more specifically, for example, in the Peneda-Gerês National Park, or in the Serra da Estrela Natural Park, as shown in the works by Liberal et al. (1999), or Raposo et al. (2021) [14,21]. Thus, to carry out this work, an area located in the Serra da Estrela Natural Park was selected, specifically in the União de Freguesias de Cabeça e Vide, in the municipality of Seia, in the district of Guarda (Figure 2).

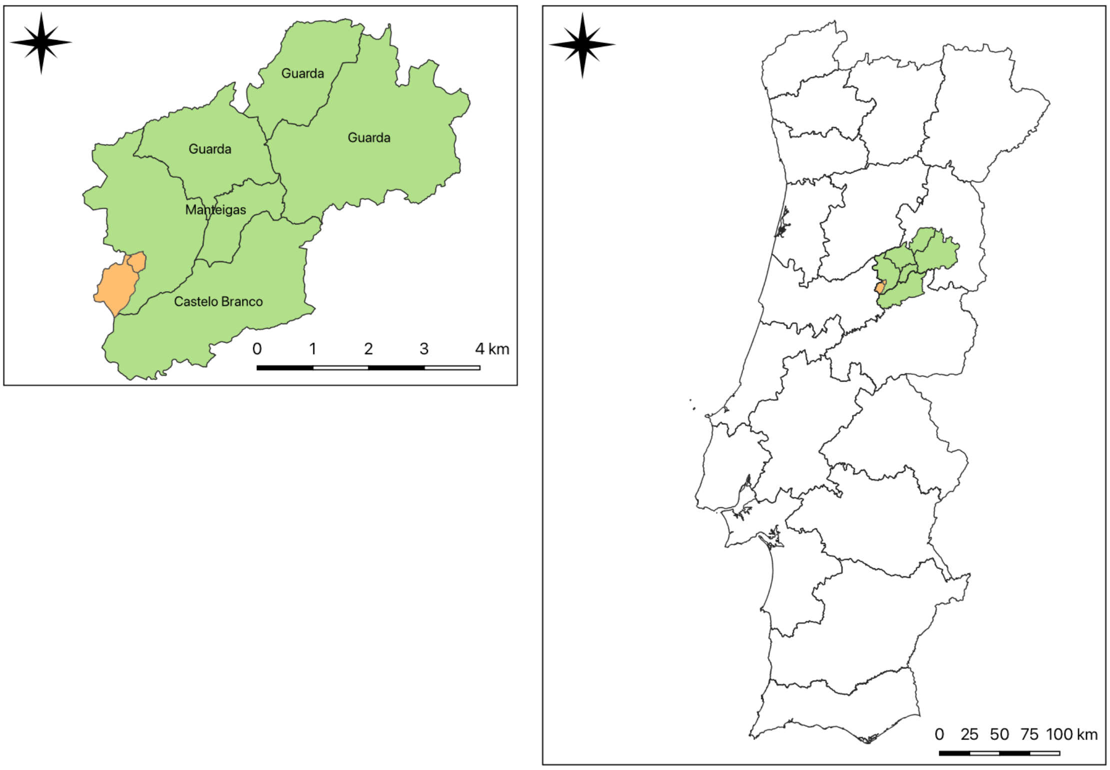

Figure 2. Location of the study area, in the União de Freguesias de Cabeça e Vide, in the municipality of Seia, in the district of Guarda.

Settlements of *A. dealbata* existing in the territory of the area selected for the study were first identified using a satellite image from August 2018, acquired using the Sentinel-2 plugin for QGIS software, version 3.18.1—Zurich. The settlements were later confirmed with on-site visits and delimited using QGIS to assess the area of each one of the settlements. For the data acquisition, one of the settlements was selected, where two circular transepts were established. These two transepts, designated by Parcel 1 and by Parcel 2, were established and selected to collect samples of *A. dealbata* specimens that were representative of existing settlements in the region, including specimens in different stages of development and from different ages. The transepts were established starting from a central point, which served to delimit a circle with a radius of 15 m, corresponding to an area of approximately 710 m^2, within which all existing trees were catalogued, with the collection of the following information: species, distance to the center of the transept (m), direction (°), and diameter at chest height (cm). Table 1 shows the data collected for each of the plots.

Table 1. Data collected in Parcels 1 and 2 (Ad—*Acacia dealbata*; Au—*Arbutus unedo*; Pp—*Pinus pinaster*; n/a—not applicable).

Parcel	Species	Tree nr.	Distance (m)	Direction (°)	Direction (rad)	d_1 (cm)	d_2 (cm)	d_{med} (cm)	Class d_{med}
1	Ad	1	0.73	4	0.0698	4.7	4.8	4.75	5
1	Ad	2	1.8	30	0.5236	5	4.6	4.8	5
1	Ad	3	3.3	5	0.0873	10.6	9.9	10.25	15
1	Ad	4	4.1	5	0.0873	4.4	3.7	4.05	5
1	Ad	5	3.9	10	0.1745	7.1	6.7	6.9	10
1	Ad	6	4.8	60	1.0472	9.7	7.2	8.45	10
1	Au	7	4.5	85	1.4835	n/a	n/a	n/a	n/a
1	Ad	8	3.6	90	1.5708	30.4	31	30.7	35
1	Ad	9	4.5	100	1.7453	6.8	6.8	6.8	10
1	Ad	10	5.1	85	1.4835	4.3	4.2	4.25	5
1	Ad	11	5.1	90	1.5708	5	5.6	5.3	10
1	Ad	12	5.2	97	1.693	4.2	4.1	4.15	5
1	Ad	13	5.2	98	1.7104	6.5	6.8	6.65	10
1	Ad	14	5.2	99	1.7279	3.5	3.5	3.5	5
1	Ad	15	5.6	97	1.693	3.7	3.7	3.7	5
1	Ad	16	5.2	100	1.7453	8.1	8	8.05	10
1	Ad	17	4.4	101	1.7628	5.4	5.6	5.5	10
1	Au	18	4.2	100	1.7453	4.3	4	4.15	5
1	Ad	19	5.1	115	2.0071	14.6	15.2	14.9	15
1	Ad	20	5.3	126	2.1991	12.5	12.2	12.35	15
1	Ad	21	4.2	117	2.042	5.9	5.7	5.8	10
1	Ad	22	5.45	130	2.2689	4.6	4.5	4.55	5
1	Ad	23	5.4	129	2.2515	3.4	3.6	3.5	5
1	Pp	24	5.35	130	2.2689	n/a	n/a	n/a	n/a
1	Ad	25	5.6	138	2.4086	8.2	9	8.6	10
1	Ad	26	5.3	141	2.4609	17.4	16.7	17.05	20
1	Ad	27	5.4	143	2.4958	4.3	4.1	4.2	5
1	Ad	28	5.6	155	2.7053	6.7	6.4	6.55	10
1	Ad	29	5.3	160	2.7925	4.4	4.5	4.45	5
1	Ad	30	5.3	162	2.8274	8.3	8.4	8.35	10
1	Ad	31	2.9	186	3.2463	17.9	18.2	18.05	20
1	Ad	32	3.5	185	3.2289	8.5	8.4	8.45	10
1	Ad	33	1.9	196	3.4208	16.7	16.7	16.7	20
1	Ad	34	2.3	210	3.6652	5.2	5.3	5.25	10
1	Ad	35	1.8	220	3.8397	5.2	4.7	4.95	5
1	Ad	36	1.8	235	4.1015	10.1	10	10.05	15
1	Ad	37	5.4	222	3.8746	16.6	15.2	15.9	20
1	Ad	38	5.0	230	4.0143	3.4	3.3	3.35	5
1	Ad	39	5.6	242	4.2237	13	13	13	15
1	Ad	40	5.3	244	4.2586	22.2	21.6	21.9	25
1	Ad	41	4.1	245	4.2761	11.7	10.8	11.25	15
1	Ad	42	4.0	258	4.5029	4.3	4.4	4.35	5
1	Ad	43	4.8	272	4.7473	4.6	5.2	4.9	5

Table 1. *Cont.*

Parcel	Species	Tree nr.	Distance (m)	Direction (°)	Direction (rad)	d_1 (cm)	d_2 (cm)	d_{med} (cm)	Class d_{med}
1	Ad	44	4.4	290	5.0615	4.5	4	4.25	5
1	Ad	45	4.2	295	5.1487	10.8	10.2	10.5	15
1	Ad	46	3.9	310	5.4105	16.7	17.8	17.25	20
1	Ad	47	3.9	320	5.5851	14.5	16.4	15.45	20
1	Ad	48	4.1	340	5.9341	14.2	15.6	14.9	15
1	Ad	49	5.2	0	0	4.6	4.8	4.7	5
1	Ad	50	5.4	2	0.0349	14.3	15.4	14.85	15
1	Ad	51	5.5	5	0.0873	3.6	3.2	3.4	5
1	Ad	52	5.6	20	0.3491	7.4	8.7	8.05	10
2	Ad	1	3.5	62	1.0821	6.1	6	6.05	10
2	Ad	2	5.3	114	1.9897	10.4	11.5	10.95	15
2	Ad	3	5.3	115	2.0071	10.7	11.3	11	15
2	Ad	4	5.5	116	2.0246	4.4	4.7	4.55	5
2	Ad	5	5.5	120	2.0944	10.4	11.3	10.85	15
2	Ad	6	5.4	123	2.1468	5.8	5.6	5.7	10
2	Ad	7	5.6	138	2.4086	11.9	13.7	12.8	15
2	Ad	8	4.5	150	2.618	6.3	5.9	6.1	10
2	Ad	9	5.0	158	2.7576	14	15.2	14.6	15
2	Ad	10	4.7	165	2.8798	9.7	9.6	9.65	10
2	Ad	11	5.0	165	2.8798	4.6	4.5	4.55	5
2	Ad	12	5.0	168	2.9322	9.1	10	9.55	10
2	Ad	13	5.6	168	2.9322	13.2	12.4	12.8	15
2	Ad	14	1.8	185	3.2289	3.4	3.2	3.3	5
2	Ad	15	1.0	195	3.4034	23.2	20.4	21.8	25
2	Ad	16	1.5	200	3.4907	4.6	4.5	4.55	5
2	Ad	17	3.8	225	3.927	6.4	6.3	6.35	10
2	Ad	18	4.9	227	3.9619	9.3	9	9.15	10
2	Ad	19	3.5	239	4.1713	4	4	4	5
2	Ad	20	1.7	265	4.6251	5.5	6.8	6.15	10
2	Ad	21	4.0	318	5.5501	16.9	19.6	18.25	20
2	Ad	22	4.8	305	5.3233	12.6	14.3	13.45	15
2	Ad	23	5.6	286	4.9916	9	8.5	8.75	10
2	Pp	24	5.0	285	4.9742	n/a	n/a	n/a	n/a
2	Ad	25	5.0	303	5.2883	4.1	4	4.05	5
2	Ad	26	3.7	315	5.4978	8.8	9.4	9.1	10
2	Ad	27	3.4	328	5.7247	6.4	6	6.2	10
2	Ad	28	2.0	323	5.6374	5.7	6.2	5.95	10
2	Ad	29	1.9	323	5.6374	5.3	5	5.15	10
2	Ad	30	4.5	326	5.6898	13.3	12.7	13	15
2	Ad	31	1.8	98	1.7104	7.7	8.8	8.25	10

Subsequently, 20 trees were selected as being representative of all existing diameter classes, defined as shown in Table 2.

Table 2. Diameter classes existing in Parcels 1 and 2.

Diameter Classes	DCH Range (cm)
Class 5	<5
Class 10	5–10
Class 15	10–15
Class 20	15–20
Class 25	20–25
Class 30	25–30
Class 35	30–35
Class 40	35–40

2.2. Samples Preparation

The selected trees were cut, and the following parameters were subsequently measured: trunk height (m), canopy height (m), total height (m), canopy diameter (m), trunk weight (kg), and weight of the branches (kg), which together provide the total weight of the aboveground biomass of each tree (kg). In Figure 3, the different stages of the cutting process and obtaining the measurement data are presented.

(**a**) (**b**)

Figure 3. Steps in the process of sampling with (**a**) cutting and measuring the *A. dealbata* trees and (**b**) weighing the selected specimens.

A section of the trunk near the base was also cut to determine the age of each one of the specimens. These discs were later polished and digitized to allow identification of the growth rings, as shown in Figure 4.

(**a**) (**b**) (**c**)

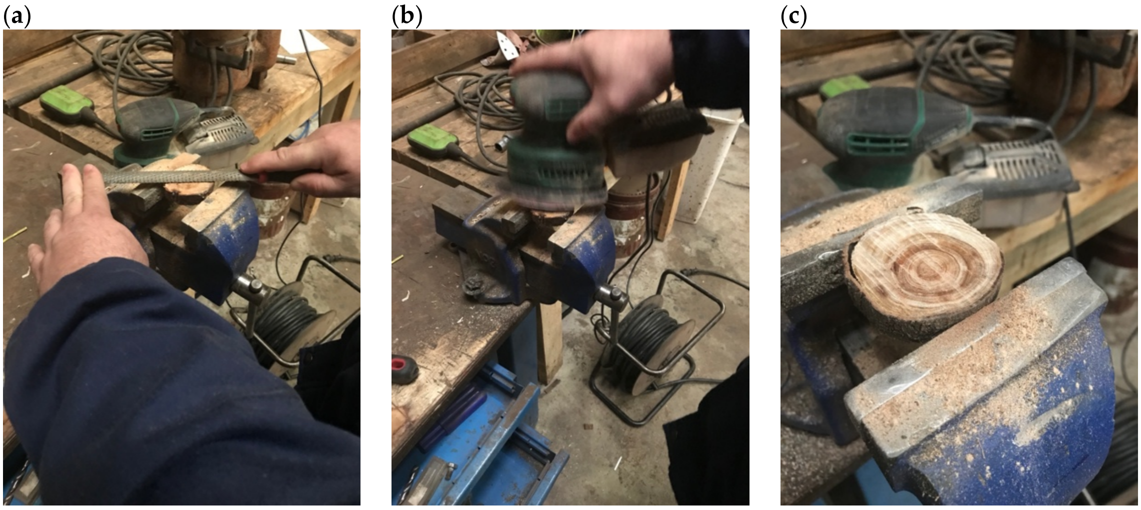

Figure 4. *Cont.*

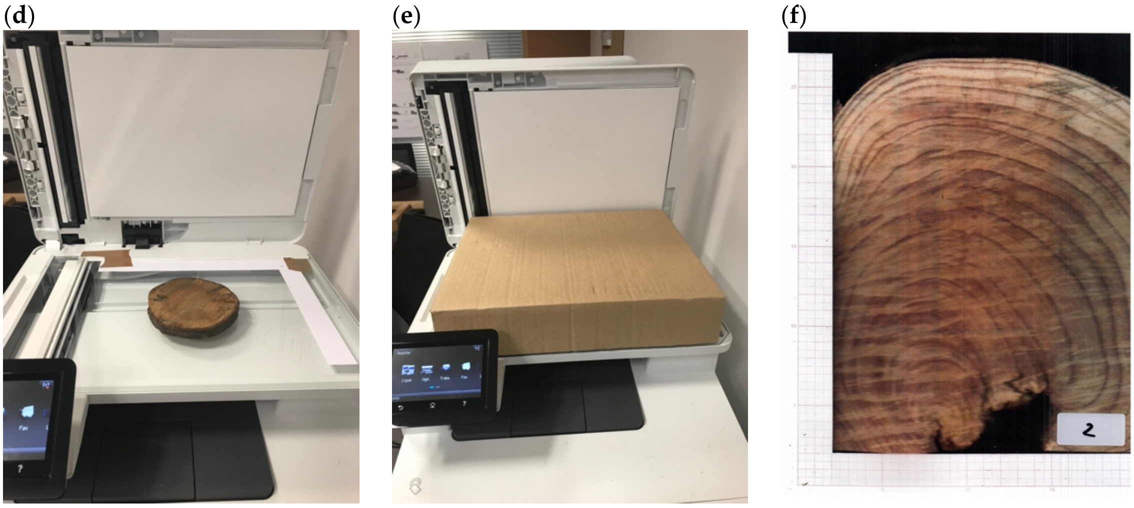

Figure 4. Sequence of the growth ring identification process to determine the age of selected specimens. (**a**) Coarse polishing of the samples, (**b**) fine polishing of the samples, (**c**) final aspect after polishing, (**d**) placing the samples to be digitalized, (**e**) covering the sample to create a dark chamber, and (**f**) digital image of the sample.

2.3. Data Processing and Creation of the Mathematical Model

For the treatment of the obtained data and development of the mathematical model, Microsoft® Excel, version 16.54, and IBM® SPSS Statistics, version 27.0.1.0 (64-bit edition), were used.

2.4. Validation of the Developed Model

After the creation of the mathematical model, it was applied to assess the amount of biomass of *A. dealbata* available in the settlements identified in the União de Freguesias de Cabeça e Vide.

3. Results

3.1. Characterization of the Selected Samples

The results obtained and calculated for the selected samples are shown in Table 3.

From the data obtained by direct measurement, such as height, weight, trunk diameter at chest height, or crown diameter, the area occupied by the crown was also determined, as this is understood to be the factor to be used in the creation of the mathematical model for estimating the biomass of stands. The trunk height parameter (h_t) presented a minimum value of 5.8 m and a maximum value of 17.75 m, with an average value of 13.78 ± 4.5 m. The canopy height (h_c) had a minimum value of 3 m and a maximum value of 11 m, with an average value of 4.0 ± 2.4 m. The total height (h_{total}) presented a minimum value of 8.8 m and a maximum value of 32.7 m, with an average value of 18.19 ± 6.3 m. The crown diameter presented a minimum value of 1 m and a maximum value of 9.5 m, with an average value of 2.3 ± 2.0 m. The diameter at chest height (DCH) had a minimum value of 4.2 cm and a maximum value of 30.7 cm, with a mean value of 9.95 ± 7.2 cm. The trunk weight presented a minimum value of 3.6 kg and a maximum value of 578.9 kg, with an average value of 48.75 ± 142.5 kg. The weight of the branches presented a minimum value of 1.8 kg and a maximum value of 25.5 kg, with an average value of 4.75 ± 9.2 kg. The total weight presented a minimum value of 5.5 kg and a maximum value of 594.8 kg, with an average value of 51.2 ± 149.1 kg. Age presented a minimum value of 5 years and a maximum value of 20 years, with a mean value of 12 ± 3.9 years. The canopy area presented a minimum value of 0.8 m^2 and a maximum value of 70.9 m^2, with an average value of 4.19 ± 15.5 m^2.

Table 3. Data collected and calculated for selected samples.

Parcel	Tree nr.	h_t (m)	h_c (m)	h_{total} (m)	Canopy Diameter (m)	DCH (cm)	Trunk Weight (kg)	Branches Weight (kg)	Total Weight (kg)	Age (years)	Canopy Area (m^2)
1	3	17.3	6.3	23.6	1	10.25	52.5	2.1	54.6	10	0.8
1	5	10.46	4.9	15.36	1	6.9	23.6	5.2	28.8	5	0.8
1	6	10.35	2.85	13.2	2.1	8.45	29.7	3.8	33.5	14	3.5
1	8	16.2	6.7	22.9	9.5	30.7	578.9	15.9	594.8	20	70.9
1	16	12.93	5.54	18.47	2	8.05	45	2.8	47.8	10	3.1
1	17	8.3	3	11.3	2.5	5.5	14.2	4.3	18.5	9	4.9
1	19	14.2	3.7	17.9	4.3	14.9	145.8	21	166.8	12	14.5
1	26	13.8	3.5	17.3	1.2	17.05	223.6	25.5	249.1	14	1.1
1	27	5.8	3	8.8	1.2	4.2	43.5	3.1	46.6	10	1.1
1	29	6.8	3.1	9.9	1.8	4.45	3.6	1.9	5.5	6	2.5
1	30	13.75	9.93	23.68	1	8.35	43.5	2	45.5	9	0.8
1	31	19.6	7.8	27.4	4.8	18.05	267.4	15.5	282.9	16	18.1
1	33	17.75	5.6	23.35	3.8	16.7	205	18.9	223.9	14	11.3
1	37	16.8	3.3	20.1	4.4	15.9	202.3	8.9	211.2	17	15.2
2	9	15.4	4.53	19.93	3.4	14.6	131.2	7.7	138.9	15	9.1
2	10	12.1	3.6	15.7	1.9	9.65	38.9	1.8	40.7	10	2.8
2	11	9	3.5	12.5	1.9	4.55	11	2.6	13.6	9	2.8
2	15	21.7	11	32.7	2.65	21.8	301.7	31.7	333.4	17	5.5
2	21	7.75	2.5	10.25	3.2	5.8	15.6	4.1	19.7	12	8.0
2	30	17.2	4.3	21.5	2.7	21.9	173.9	19.4	193.3	15	5.7

3.2. Mathematical Model for Estimating the Amount of Biomass of A. dealbata

To determine the mathematical model, multiple linear regression was used to verify whether the area of the canopies can be used to estimate the amount of biomass in *A. dealbata* stands. The analysis resulted in a statistically significant model, defined by Equation (1):

$$[F(1,18) = 35.502; p < 0.001; R^2 = 0.645], \quad (1)$$

The canopies area of *A. dealbata* trees ($\beta = 0.815$; $t = 5.958$; $p < 0.001$) can be used as an estimator of the amount of biomass. Equation (2) describes this relationship:

$$y = b_0 + b_1 \cdot x_1, \quad (2)$$

That is, according to Equation (3):

$$W_{bio.est} = 65.753 + 7.858 \times area\_canopy, \quad (3)$$

The use of the t-Student test to compare the mean aboveground biomass weights of *A. dealbata* measured and the weights obtained by using Equation (3) and presented in Table 4, based on hypotheses H1 and H2, indicate that it should choose hypothesis H1, since $p > 0.05$:

H1. *There are no differences between the means of the variables.*

H2. *There are differences between the means of the variables.*

Table 4. Measured and estimated biomass quantities.

Measured Biomass Weight (kg)	Estimated Biomass Weight (kg)
54.6	71.9
288	71.9
33.5	93.0
594.8	622.7
47.8	90.4
18.5	104.3
166.8	179.9
249.1	74.6
46.6	74.6
5.5	85.7
45.5	71.9
282.9	207.9
223.9	154.9
211.2	185.2
138.9	137.1
40.7	88.0
13.6	88.0
333.4	109.1
19.7	129.0
193.3	110.7

Thus, on average, the estimated biomass weight of *A. dealbata* (West. = 150.42, SE = 27.148) is statistically similar to the measured *A. dealbata* biomass weight ($W_{measured}$ = 137.54, SE = 33.341), t(19) = −0.04, $p > 0.05$.

3.3. Application of the Mathematical Model to Estimate the Amount of Woody Biomass in A. dealbata Stands from the União de Freguesias de Cabeça e Vide (Seia, Portugal)

To validate the model, it was applied to determine the amount of available biomass of *A. dealbata* in the territory of the União de Freguesias de Cabeça e Vide. With this objective, the identification of all existing settlements in the territory and their delimitation was carried out in the first phase. For this purpose, satellite photography was used from the same date on which the samples were cut, which was October 2018. A total of 41 settlements of *A. dealbata* were identified, distributed as shown in the Figure 5.

With the areas determined through the delimitation of the *A. dealbata* stands, Table 5 was elaborated, where the calculation of the amount of available biomass was added, using Equation (3). Subsequently, and since it was verified that the woody biomass corresponds to 91% of the total weight of the cut trees, the weight of woody biomass available was determined, as this will be of interest for recovery. Afterwards, the amount of biomass per hectare was determined to be able to make a comparison with the data available in the bibliography and to validate the procedure.

As can be seen from the results presented, the *A. dealbata* stands have the capacity to provide 863.5 tons of biomass, distributed over 12 hectares of land, which corresponds to a production of approximately 72 t/hectare. This result is in line with the result presented by Nunes et al. (2020), where the authors describe a trial where they proceeded to cut the biomass of *A. dealbata* in two previously delimited hectares, with all the cut biomass being weighed, totaling 140 tons [18]. In other words, these authors refer to a production of 70 t/hectare, which were later transported to a biomass pellets production unit for recovery.

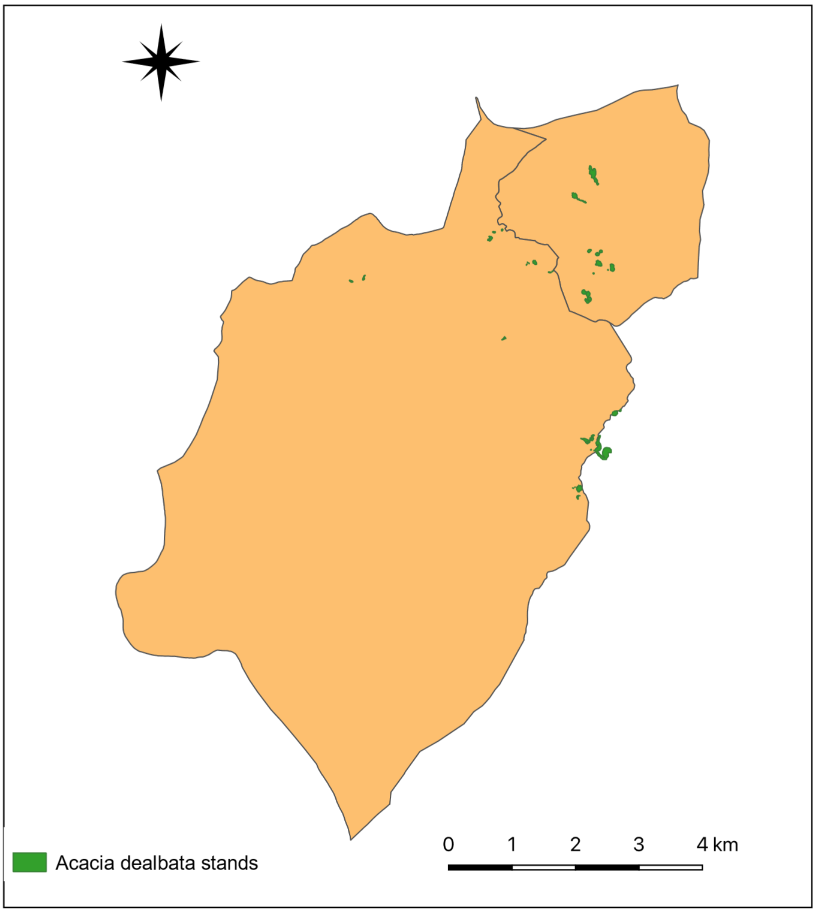

Figure 5. Distribution of *A. dealbata* settlements in the territory of the União de Freguesias de Cabeça e Vide.

Table 5. Area of settlements of *A. dealbata* existing in the territory of the União de Freguesias de Cabeça e Vide.

A. dealbata Stands	Area (m^2)	Aboveground Estimated Biomass (kg)	Aboveground Estimated Biomass (t)	Aboveground Estimated Woody Biomass (t)
1	1961.45	15,478.83	15	14.1
2	2331.7	18,388.25	18	16.7
3	5782.41	45,503.93	46	41.4
4	141.93	1181.04	1	1.1
5	5882.61	46,291.30	46	42.1
6	3701.94	29,155.60	29	26.5
7	3738.36	29,441.79	29	26.8
8	2884.44	22,731.68	23	20.7
9	2673.55	21,074.51	21	19.2
10	280.93	2273.30	2	2.1
11	2779.35	21,905.89	22	19.9
12	5087.1	40,040.18	40	36.4
13	1767.64	13,955.87	14	12.7
14	16,406.28	128,986.30	129	117.4
15	497.65	3976.29	4	3.6
16	138.68	1155.50	1	1.1
17	147.96	1228.42	1	1.1
18	100.73	857.29	1	0.8
19	82.05	710.50	1	0.6
20	1045.57	8281.84	8	7.5

Table 5. *Cont.*

A. dealbata Stands	Area (m^2)	Aboveground Estimated Biomass (kg)	Aboveground Estimated Biomass (t)	Aboveground Estimated Woody Biomass (t)
21	4985.52	39,241.97	39	35.7
22	644.61	5131.10	5	4.7
23	42.34	398.46	0	0.4
24	66.75	590.27	1	0.5
25	6016.9	47,346.55	47	43.1
26	131.66	1100.34	1	1.0
27	122.58	1028.99	1	0.9
28	33,364.1	262,240.85	262	238.6
29	5115.62	40,264.29	40	36.6
30	1360.39	10,755.70	11	9.8
31	1749.83	13,815.92	14	12.6
32	48.47	446.63	0	0.4
33	17.66	204.53	0	0.2
34	898.09	7122.94	7	6.5
35	25.57	266.68	0	0.2
36	1049.3	8311.15	8	7.6
37	1418.66	11,213.58	11	10.2
38	630.92	5023.52	5	4.6
39	830.72	6593.55	7	6.0
40	2943.09	23,192.55	23	21.1
41	1511.1	11,939.98	12	10.9

4. Discussion

Chemical control is, most likely, the most-used method in the control and eradication actions of *A. dealbata*. In fact, there are several references where examples of the use of the most diverse types of chemical compounds for the control of *A. dealbata* are found, namely those where the sensitivity of the species to different herbicide products is analyzed, as can be seen in the work of Delabraze & Valette [22], showing some efficacy of glyphosate, if used in high concentrations, as opposed to several other compounds, such as 2,4-D or fosamine-ammonium, which proved to be completely ineffective. This resistance of *A. dealbata* to chemical attack has led to the use of other processes, namely mechanical methods, such as cutting and peeling acacia trees.

However, any of these methodologies involve costs, both from the perspective of the acquisition of herbicides, as for the labor and means necessary for their application, and mechanical control methods, where it is also necessary to quantify the costs associated with labor and the mechanical means (motor-cutters, chainsaws, heavy equipment, trucks, among others) used in the works. Additionally, there is the need to repeat the actions until the eradication of *A. dealbata* in the area is complete. As previously mentioned, *A. dealbata* has a great capacity for recovery and resilience, being able to return, in a short period of time, to occupying the previously cleaned space. This is especially true if there is a seed bank in the soil, wherein they use the opportunity created by cleaning the vegetation cover so that they can germinate, enjoying direct access to sunlight, since it is a heliophile species. In other words, the control of this species is not limited to an occasional action of applying an herbicide or cutting down stands but rather requires the planning of a set of actions that necessarily have to extend over time, repeatedly, until that they do not germinate any more seeds or regrowth through roots and stumps.

Roughly, the costs associated with cutting a hectare of *A. dealbata* can be around the values shown in Table 6, which were obtained based on the information provided by ICNF (www.icnf.pt, accessed on 8 November 2021) for reference costs for forestry work.

Table 6. Forestry works reference costs map (adapted from www.icnf.pt, accessed on 8 November 2021).

Operation Action	Minimum Value (€/t)	Maximum Value (€/t)
Cut and branches cleaning	10.00	60.00
Retrieval and extraction	10.00	45.00
Transport with loading and unloading	12.00	60.00

The minimum and maximum values depend on the type of operation to be carried out and the conditions under which they are carried out. The important traits are the size of the area where the intervention takes place, the slope, whether heavy equipment is allowed, existence or not of accesses, and existence of other types of vegetation that require a more careful separation. Therefore, the values presented are only indicative of the costs that may be involved in the removal of *A. dealbata* biomass.

Currently, biomass considered residual may reach a value for energy recovery in power stations dedicated to biomass of approximately 15 €/t, placed at the destination. In other words, this value is practically used to transport the biomass to the recovery site, with the cost of cutting and returning it, normally, to be borne by the owner of the land that orders the service. In the case of creating a value chain, where prior planning is carried out, the destination of the biomass and the entire logistical scheme must be considered in order to optimize resources. It will be possible to achieve lower costs associated with operations, and the destinations can be optimized in looking for those that are able to pay more for biomass, such as the biomass pellet industry, domestic firewood users, or charcoal production units. In any of these production units, the purchase price of biomass can reach 35 €/t, depending on the diameter and quantities available for delivery, as consumers often want to have some regularity in raw material deliveries because it is a way to achieve greater homogeneity in the final product and, thus, ensure quality standards.

The biomass of *A. dealbata* has some parameters that can be problematic when used in large-scale combustion processes, as it has, for example, a higher chlorine content than other biomasses, such as *Pinus pinaster*, *Eucalyptus globulus*, or *Quercus* spp., traditionally used in the production of biomass pellets and used as firewood. However, as shown in the works by Nunes et al. (2020) or Nunes et al. (2021), this valorization is possible if the raw material is incorporated in a mixture that dilutes the parameter values that do not comply with the current quality requirements indicated by standards, such as ENPlus® for biomass pellets [18,23]. The creation of value chains can, in some way, contribute to the sustainability of control and eradication actions by allowing for some valorization of biomass while enabling the optimization of processes. This obligatorily reduces costs associated with control and eradication campaigns, increasing pressure on populations, which can be cyclically controlled until eradication.

However, although the applicability of the model presented here indicates good statistical significance, it is worth emphasizing that the model was built from data obtained from trees aged under 20 years. In other words, it is understood that the model can present a good statistical significance in stands younger than 20 years old, but that the same may not be accurate for stands of *A. dealbata* of older ages. This is because the growth of the tree crowns reaches an asymptote and stabilizes while, subsequently, the amount of biomass continues to grow, with the increase in the trunk and branches diameter. As in Portugal, the species of the genus *Acacia* are all part of the list of invasive species presented by Decree-Law no. 92/2019, of 10 July. *A. dealbata* is subjected to frequent control campaigns, and, because of this, it is challenging to find stands with old trees. For this reason, it is not easy to extrapolate the model to settlements of a different type from those found more frequently in Portugal without prior analysis of more data and different-aged stands. In any case, it is an expeditious procedure that can be used to optimize the control processes of the species by quantifying the biomass available in dense and single-species *A. dealbata* stands.

5. Conclusions

Invasive species are species that, not being native to a particular habitat, quickly become naturalized and compete very aggressively with native species, occupying their space and dominating the habitat. This occupation of habitats by invasive exotic species brings in a set of problems, such as the environmental issue, for example, associated with the loss of biodiversity and from an economic perspective, when it is associated with the loss of productivity of the planted forests used for raw materials. The control and eradication of these species is of particular importance, especially when, in a scenario of climate change such as the current one, the growth of these species increases the risk of fires, with Mediterranean-type climate regions being very susceptible to this situation. In Portugal, one of the species that has caused the most alarm is *A. dealbata*, which has occupied a prominent place at the top of forest species invasions. In this way, the development of policies and concerted interventions for its control has been a current practice. However, these actions, normally carried out using chemical and mechanical methods, require a certain temporal continuity, given the resilience of the species, resulting in high costs. For this reason, the creation of value chains for residual biomass resulting from control actions can be a way to contribute to the sustainability of these actions by allowing a reduction in financial losses, allowing the processes to continue to be carried out. This valorization will be more effective the more efficient its organization, planning, and optimization is, given the necessity of the development of expedite numerical tools that allow the quantification of the available biomass in the stands to be controlled so they can be properly programmed for their cut and forwarded to the best option for recovery. The tool presented here, despite some recognizable limitations that are closely associated with the data on the species that are currently available, seems, however, to allow the quantification of the biomass produced by *A. dealbata* stands using easily accessible information. However, since *A. dealbata* stands in Portugal are the target of frequent control actions, it is not possible to extrapolate the results to stands over 20 years of age since this was the maximum age found in the samples used to build the model. Therefore, so the data collection campaign should be continued to improve the model here presented.

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