**DOI:** 10.29298/rmcf.v16i87.1503

Research article

# Biomasa aérea y radicular en etapa de brinzal de *Abies religiosa* (Kunth) Schltdl. & Cham. en Hidalgo

# Aboveground and root biomass in sapling stage of *Abies religiosa* (Kunth) Schltdl. & Cham. in *Hidalgo* state

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Fecha de recepción/Reception date: 16 de julio de 2024.
Fecha de aceptación/Acceptance date: 22 de octubre de 2024.

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**Abstract**

The initial development of the forest is known as sapling. At this stage the regeneration density is high, so the biomass accumulation rate is higher. In this context, the objective of estimating the total biomass storage capacity (aboveground-root) in trees in the initial stage of *Abies religiosa* in *El Chico* National Park, *Hidalgo* state, was raised. Four sampling sites of 100 m$^2$ were established to obtain population density. 52 specimens less than 1.5 m in height and 5 cm in average base diameter were extracted with roots; a high-pressure water backpack sprayer was used to detach the soil from the root; later the plant material was placed in a drying oven at 80 °C until reaching constant weight. Results indicate that the fir trees in the sapling stage formed the basic group (height 6 to 65 cm) with 72.6 % of aboveground biomass and 27.4 % of root biomass, and another developed group (height 68 to 150 cm), with 75.8 and 24.2 % of aboveground and root biomass, respectively. The biomass stored in the fir forest in the sapling stage was 103.6 kg ha$^{-1}$, with potential accumulation of aboveground/root biomass in a 3:1 ratio in canopy gaps, which favored the establishment of natural regeneration. The ratio of root biomass to aboveground biomass in the sapling stage changes with age in *Abies religiosa* trees.

**Key words:** Natural Protected Area, aboveground biomass, root biomass, sapling, fir, natural regeneration.

**Resumen**

El desarrollo inicial del bosque es conocido como brinzal. Etapa en la cual, la densidad de regeneración es alta; por lo que la velocidad de acumulación de biomasa es mayor. En este contexto se planteó el objetivo de estimar la capacidad de almacenamiento de biomasa total (aérea-raíz) en árboles en etapa inicial de *Abies religiosa* en el Parque Nacional El Chico, Hidalgo. Se establecieron cuatro sitios de muestreo de 100 m$^2$ para obtener densidad de población. Se extrajeron con raíz 52 ejemplares menores a 1.5 m de altura y 5 cm de diámetro basal promedio; se utilizó un rociador de mochila de agua a presión con el cual se desprendió el suelo de la raíz;

posteriormente, el material vegetal se depositó en una estufa de secado a 80 °C hasta alcanzar peso constante. Los resultados indicaron que los árboles de oyamel en etapa de brinzal formaron el grupo básico (altura de 6 a 65 cm) con 72.6 % de biomasa aérea y 27.4 % de biomasa radicular; otro grupo desarrollado (altura de 68 a 150 cm), con 75.8 y 24.2 % de biomasa aérea y radicular, respectivamente. La biomasa almacenada en el bosque de oyamel en etapa de brinzal fue de 103.6 kg $ha^{-1}$, con potencial de acumulación de biomasa aérea-raíz en relación 3:1 en claros del dosel, que favorecieron el establecimiento de la regeneración natural. La relación de biomasa radicular, respecto a la biomasa aérea en etapa de brinzal cambia con la edad en los árboles de *Abies religiosa.*

**Palabras clave:** Área Natural Protegida, biomasa aérea, biomasa radicular, brinzal, oyamel, regeneración natural.

# Introduction

Plant biomass is formed by all the organic components within an ecosystem (Litton et al., 2007) and is important as a source of energy, as well as in the storage of carbon (C) and nitrogen (N) (Peichl et al., 2012; Schuler et al., 2017). The capacity of a forest to capture atmospheric carbon tends to decrease with the increase in the age of the trees. It is known that at early or intermediate ages the rate of carbon capture is higher (López-Reyes et al., 2016). In addition, it is related to the rate of accumulation of aboveground and root biomass that forests have with the net growth of trees that are capable of sequestering more $CO_2$ than they emit through respiration. The rate of carbon capture is directly proportional to said growth (Casiano-Domínguez et al., 2018).

Natural Protected Areas (NPA) are intended to conserve, protect and recover natural resources (González et al., 2014; Íñiguez et al., 2014). Such is the case of *El Chico* National Park, which is a provider of important environmental services for the mountainous region of central Mexico and is home to one of the most important relics of *Abies religiosa* (Kunth) Schltdl. & Cham. (fir) (Comisión Nacional de Áreas Naturales Protegidas [Conanp], 2005). This species develops in humid conditions (precipitation greater than 1 000 mm) and in low temperatures (average temperature of 7 to 12 °C), so the increase in the temperature on the planet causes effects, which are manifested in modifications at the molecular, morphological and physiological level that are reflected in negative alterations in its early stages of development (Romahn-Hernández et al., 2020).

The initial development of the temperate forest is known as the sapling stage, which includes trees up to approximately 1.5 m tall and with an average base diameter of less than 5 cm (Aguilar, 2018; Hutchinson, 1993; Ronquillo-Gorgúa et al., 2022). In most temperate climate NPAs, the sapling stage is established during the first rainy period, after gaps are generated in the canopy that allow solar radiation to enter the forest floor (Lara-González et al., 2009). Generally, there are densities of up to 6 100 seedlings ha$^{-1}$ in western exposures (Rodríguez-Laguna et al., 2015) that are reduced over time due to competition for abiotic and biotic factors that thus achieve a gradual accumulation of biomass in the aboveground and root parts of the tree (Bar-On et al., 2018; Ronquillo-Gorgúa et al., 2022).

Studies focused on estimating the accumulation of aboveground biomass in forests (Albers et al., 2019; Oliveira et al., 2018; Pham et al., 2019; Razo et al., 2015), do not consider root biomass (Adame et al., 2017; Addo-Danso et al., 2016; Sochacki et al., 2017). Recent research suggests the need to know point estimates by component of the total forest biomass on a large scale (Bar-On et al., 2018; Djomo et al., 2011; Fu et al., 2017).

The machinery, tools and time to extract adult trees with roots is almost impossible, but the interest in providing information on the root component of young trees allows for complementary information to reach the total biomass stored in the forest. Fragoso-López et al. (2017) estimated the aboveground biomass component through geographic information systems; likewise, the biomass stored on the soil surface, known as necromass (Cortés-Blobaum et al., 2019), is known, so it is necessary to incorporate a part of the root component in this ecosystem. Therefore, the objective of the present research was to estimate the total biomass accumulation capacity (aboveground-root) in *A. religiosa* trees at the sapling stage in *El Chico* National Park, *Hidalgo* state, Mexico.

# Materials and Methods

## Study area

The study was carried out in the NPA *El Chico* National Park, located at the western end of the *Sierra de Pachuca*, *Hidalgo* state, in the Transversal Neovolcanic Axis (Figure 1). It is located between 20°10’10’’ to 20°13’25’’ North and 98°41’50’’ to 98°46’02’’ West, with an area of 2 739 ha, and altitudes between 2 600 and 3 050 m (Conanp, 2005).

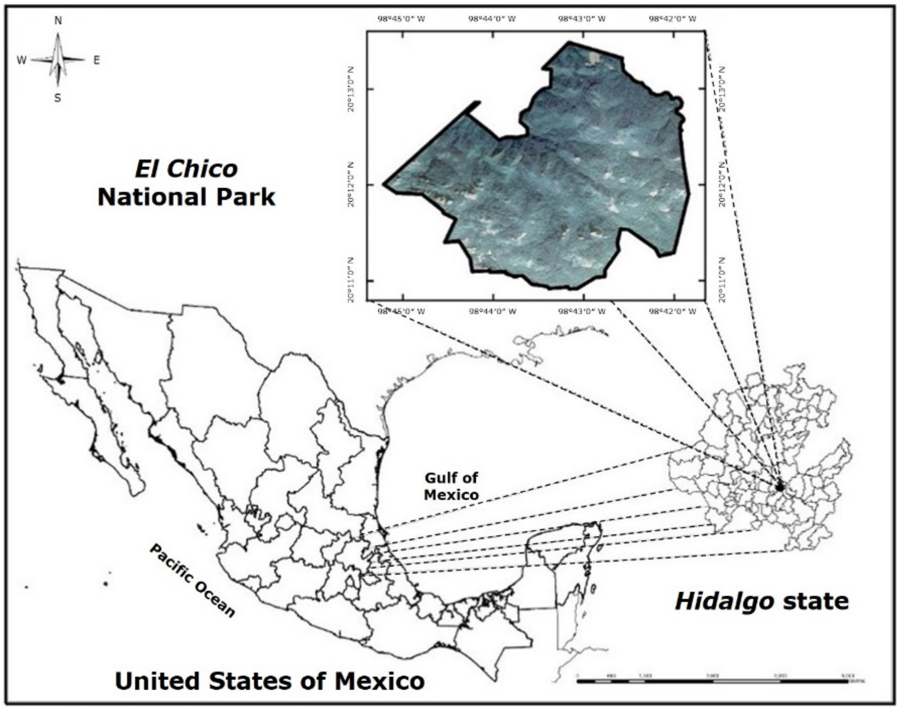


**Figure 1.** Geographic location of *El Chico* National Park, *Hidalgo* state, Mexico.

The climate is temperate-subhumid with summer rains (C(m)(w)b(i0)gw) and mean annual temperature between 12 and 18 °C. The predominant soils are humic Cambisol, dystric Regosol and medium-textured humic Andosol (Conanp, 2005). The largest percentage of vegetation cover (67 %) belongs to the *A. religiosa* forest (Fragoso-López et al., 2017); other important tree species are: *Quercus* spp., *Pseudotsuga macrolepis* Flous, *Taxus globosa* Schltdl. and *Pinus* spp. (Conanp, 2005).

## Tree density in the sapling stage

To determine density, four 100 $m^2$ (10×10 m) plots were established in fir regeneration areas; from which the complete saplings with roots were extracted.

## Tree selection for aboveground-root biomass analysis

Travels were conducted within *El Chico* National Park to identify spaces (clearings) within the forest that were large enough for natural fir regeneration. A total of 52 *A. religiosa* trees at sapling stage were selected, with average heights of 6-150 cm (Ronquillo-Gorgúa et al., 2022), free of mechanical damage, far from roads or gaps with compacted soil, and were completely extracted from the root.

Organic matter was removed from each tree using a rake, then sufficient water was gradually added around the base of the specimen in order to soften the soil and remove it the next day, taking care not to damage the root. A high-pressure water backpack sprayer was used and the direction and depth of each root was followed (one at a time) until the complete extraction of the root system was ensured. A wooden support in the form of a square was implemented, fixed to the ground, which helped to keep the tree in a vertical position; in the middle part of the trunk they were tied with plastic ropes during the entire extraction process, until the root system was completely free.

## Evaluated variables

The total height (cm) from the soil surface to the apex of each tree was measured with a model FCN-3M Truper® tape measure; the base diameter (cm), with a model 14388 Truper® digital vernier with millimetric precision; age was determined by the number of whorls in each individual, since these are produced at a rate of one whorl per year in *Abies* (Lara-González et al., 2009). The complete root system of each specimen was washed and left to air dry in the shade for approximately two hours (Fonseca et al., 2009) and the fresh weight of the entire tree (g) was taken in the field with a model BE16001 Biobase® scale. Subsequently, the aerial and root parts were separated to weigh each component and were placed each in paper bags previously labeled with the sample number and were placed in a model LW-201C GRIEVE® drying oven at 80 °C until reaching constant weight. With this, the average dry weight (g) of each component was calculated and multiplied by the number of fir plants per hectare.

In a first analysis, the variance of the dry weight of the root was determined with the following formula:

$$n = \frac{(t^2 \sigma^2)}{d^2}$$

Where:

$t$ = Standardized value of the error at 5 %, which is equivalent to 1.96

$\sigma^2$ = Variance of the attribute to be evaluated

$d$ = Confidence interval for the quality measured (Zar, 2010).

## Data analysis

With the information from the 52 trees included in the sample, a cluster analysis was performed based on the variables height, dry weight of the whole tree, dry weight of the root and percentage of root biomass, using the Ward method based on Euclidean distances; for this, the Statistica v.10 program was used (StatSoft Inc., 2011). The dry root biomass was contrasted using a t-test for unbalanced samples, before a normality test. For this analysis, the Past program was used (Hammer et al., 2001). And the rest of the attributes were contrasted with parametric or non-parametric paired tests according to the type of data.

# Results and Discussion

The cluster analysis indicated the formation of two groups that are mainly distinguished by smaller size (initial sapling) with a height range of 6 to 65 cm, 0.07 to 0.9 cm base diameter and age of 1 to 8 years, and another of larger size (developed sapling) with a height range of 68 to 150 cm, 0.9 to 2.1 cm base diameter and age of 8 to 12 years. The root biomass data are normally distributed (Anderson-Darling, 0.4669 and 0.3743; $p>0.05$) with 38 individuals of initial sapling and 14 of developed sapling; on the other hand, no significant differences were found between groups of saplings ($t=1.7468$; $p=0.09$), while for height: $t=5.47$ and $p=0.0001$, dry weight of the aerial part: $t=5.435$ and $p=0.0001$, and dry weight of the root: $t=5.482$ and $p=0.0001$.

The organization of two groups is possibly due to the age of the specimens and the differences in the formed and accumulated biomass (Figure 2), in addition to the changes in the formation of roots at early ages, so it is not possible to assume a linear increase throughout the life of the plant.

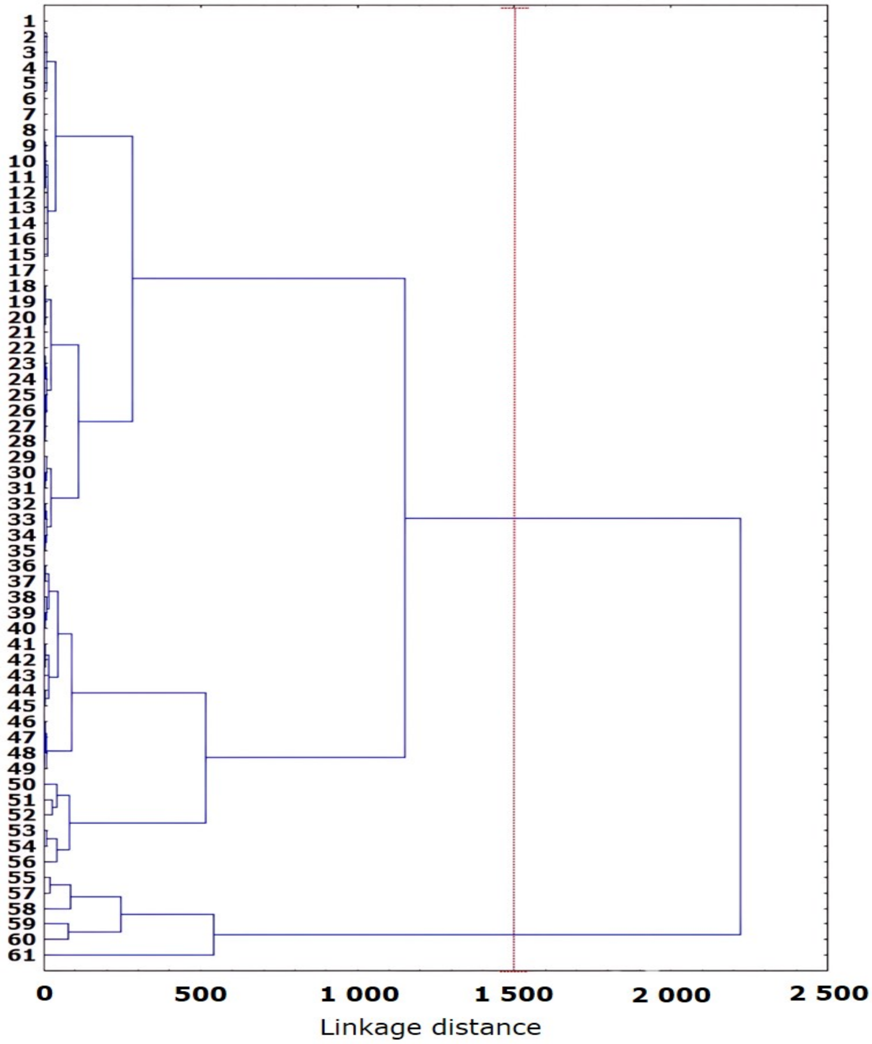


**Figure 2.** Grouping by morphological attributes in *Abies religiosa* (Kunth) Schltdl. & Cham. plants at the sapling stage in *El Chico* National Park, *Hidalgo* state, Mexico.

Some works mention that the proportion of aboveground biomass-root biomass are interdependent, which highlights the importance of the functional balance of both parts (van Noordwijk & Willigen, 1987). However, the growth rate of both elements differs depending on soil water content, biophysical processes, changes in leaf elongation rate, plant stress, crowding and competition, among others (Krizek et al., 1985; Macklon et al., 1994).

## Biomass by component

The results for dry biomass by component indicate that the trees in the initial sapling group have 72.6 % of aboveground biomass and 27.4 % of root biomass (Figure 3), while in the developed sapling group, 75.8 % corresponds to aboveground biomass and 24.2 % to root biomass (Figure 4). It is convenient to consider this rate of change to estimate the amount of Carbon in regeneration areas, especially when the space has a greater abundance of young plants. Previous studies have shown that there is a significant increase of up to five percentage points in root production in restrictive soils (Guerra et al., 2005), which could modify the results obtained if they were compared under conditions with lower soil nutritional quality.

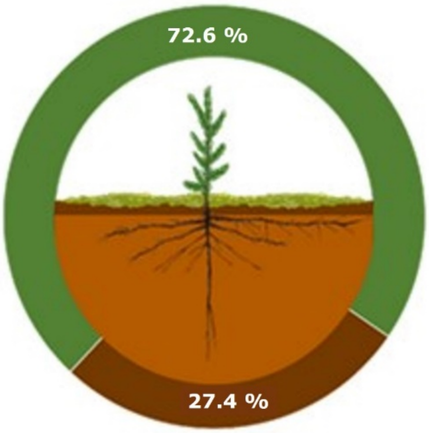


**Figure 3.** Aboveground and root biomass in initial sapling trees (6 to 65 cm tall).

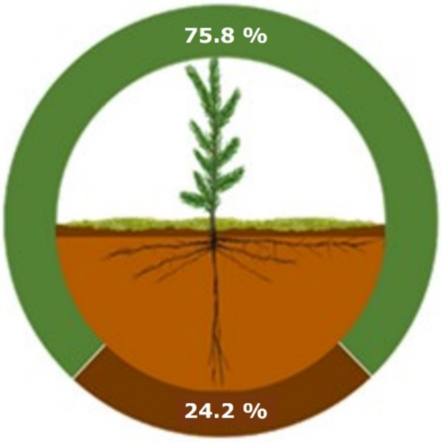


**Figure 4.** Aboveground and root biomass in trees with developed saplings (68 to 150 cm tall).

Several authors estimate that 20 to 40 % of forest biomass is composed of roots (Brunner & Godbold, 2007; Finér et al., 2011; Sochacki et al., 2017); however, this biomass changes according to the species, the climate and the characteristics of the ecosystem in which they grow.

## Accumulated biomass potential

An average regeneration density of 3 925 trees ha$^{-1}$ at the sapling stage was estimated, but this result could be overestimated since the sampling sites were located in clear spaces in the canopy where environmental conditions allowed the establishment of *A. religiosa* regeneration; however, under the canopy of adult trees the density was low due to the low solar radiation that reaches the forest floor and the plants do not regularly establish themselves (Lara-González et al., 2009). Contrasting data by Hernández et al. (2022) with the percentage of dead seedlings under a partially closed canopy was 79 % (*n*=803), while under light gaps it was 70.1 % (*n*=384). And regarding the percentage of live seedlings under a partially closed canopy it was 17.9 % (*n*=182), while in light gaps it was 28.1 % (*n*=154).

On the other hand, the potential of total biomass (aboveground and root) stored in *A. religiosa* at the sapling stage was 103.6 kg ha$^{-1}$ (Figure 5). It is worth noting that the aboveground part-root ratio calculated was 3:1, that is, 3 parts correspond to aboveground biomass and one part to root biomass. This contributes to maintaining organic Carbon (OC) under the soil by inducing its stability through the mineralization process that occurs over time. Xia et al. (2022) mention that the lignin contained in the wood of the roots is a recalcitrant component that stabilizes the OC in the soil for decades, and fir forests have a high lignin content as do pine forests (Avendaño et al., 2009; Leifeld & Kögel-Knabner, 2005).

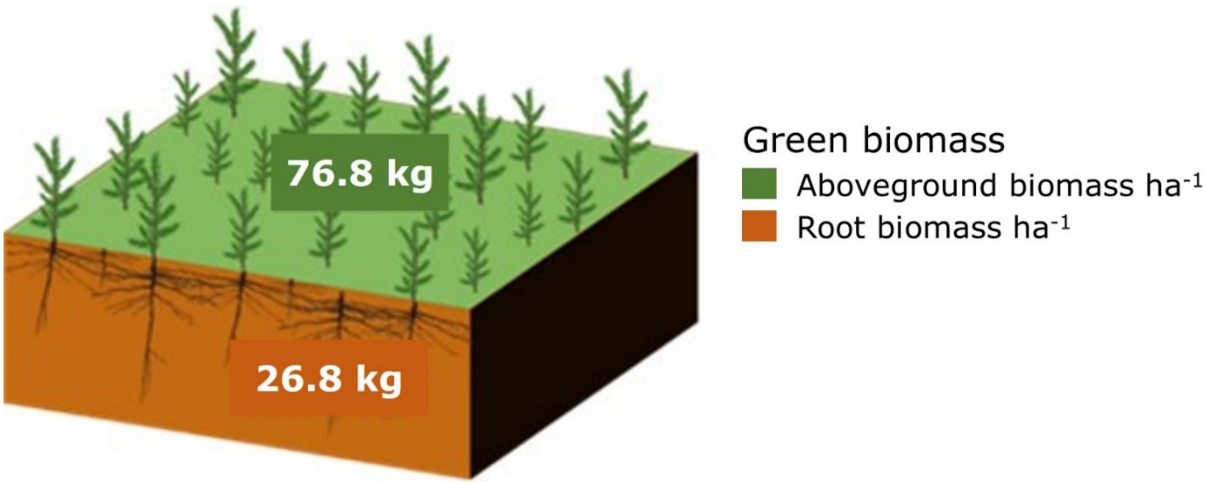


**Figure 5.** Potential storage of aboveground and root biomass per hectare of fir trees at the sapling stage in *El Chico* National Park, *Hidalgo* state, Mexico.

Root competition is greater when they grow with other root structures, so this is a factor that influences their conformation, extension and distribution in the soil and sometimes tends to reduce their depth, design and density (Bolte & Villanueva, 2006; Curt & Prévosto, 2003; Rewald & Leuschner, 2009). In this way, the percentage of root biomass during the growth of *Abies religiosa* in *El Chico* National Park could be reduced.

# Conclusions

*Abies religiosa* forests at the sapling stage have the potential to accumulate aboveground-root biomass in a 3:1 ratio in canopy gaps where conditions allow the establishment of natural regeneration. Small plants aged 1 to 8 years on average store more root biomass in percentage than larger plants aged 8 to 12 years at the same sapling stage. The ratio of root biomass to aboveground biomass at the sapling stage changes with age in *Abies religiosa* trees.

**Acknowledgements**

The authors wish to express their gratitude to the National Council of Humanities, Sciences and Technologies (*Conahcyt*), for the financial scholarship granted to the first author, which allowed this research to be carried out.

**Conflict of interest**

The authors declare that they have no conflict of interest.

**Contribution by author**

Nancy Manzur Chávez: data collection in the field, interpretation of results, structure and writing of the manuscript; Rodrigo Rodríguez Laguna: design of the field format, review and correction of the manuscript; Ramón Razo Zárate: review, design and interpretation of the results and review of the manuscript; Otilio Arturo Acevedo Sandoval: interpretation of the results and review of the manuscript; Pablo Octavio Aguilar: analysis of the field data, interpretation of results, review and writing of the manuscript.

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