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# While clearing the forests: The social–ecological memory of trees in the Anthropocene

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**Abstract** The Anthropocene concept raises awareness of human-induced planetary changes but is criticized for being 'too global'. We examined the social–ecological memory that emerges from people-tree relationships in South American temperate territories, Chile. We integrated dendrochronology (analysis of tree rings of 35 memorial trees; 17 species) with dendrography (participant observation complemented with semi-structured and go-along interviews with 14 interviewees; six women, eight men). We found that assemblages of people–tree relationships reflect marked historical changes in the territory, associated with the historical clearing of forests, which may be imprinted in both tree growth rings and in the social meanings and practices associated with memorial trees. In devastated territories, practices of tree care emphasize interconnectedness, multispecies collaborations, and the blurring of boundaries between humans and other-than-humans. We discuss some of the interdisciplinary and relational insights of our study, which may prove valuable for future research, political agendas, and educational programs in South America and beyond.

**Keywords** Chile · Chthulucene · Complex adaptive systems · Habitat legacy · Oral histories · Temperate forests

## INTRODUCTION

Global environmental change, the erosion of biological and cultural diversity, the widespread of emergent diseases, among many other processes, are considered vast evidence that humanity is transitioning through the Anthropocene (Steffen et al. 2007). This geologic epoch, characterized by human dominance over the Earth's territories, has informed researchers, politicians, citizens, and institutions that these processes are both interconnected and shaping novel social–ecological systems (Smith-Nonini 2017). While people have transformed territories for thousands of years (Ellis et al. 2021), rapid anthropogenic transformations on Earth arose in the Global North and accelerated and spread at unprecedented rates with an epoch/series rank based on a mid-twentieth-century boundary (Zalasiewicz et al. 2017). In the Anthropocene, human societies have increasingly cleared native forests, resulting in social–ecological systems that may conform to the environment, culture, and the availability of technologies of specific territories (Subercaseaux et al. 2020). Although the Anthropocene concept has become a key framework in raising awareness of anthropogenic transformations of the planet, it has been criticized for being 'too global' as it neglects vast differences across regions and situated trajectories of social–ecological systems (Malm and Hornborg 2014; Biermann et al. 2016). Furthermore, critical but also proactive scholars have stressed the need to envision more diverse and cooperative futures that move beyond the dominant narratives of progress and development inherently associated with the Anthropocene concept (Tsing et al. 2017; Latour et al. 2018; Bauer et al. 2019). Instead of accepting a single, all-encompassing geologic epoch, they have advocated for embracing diverse, entangled, and caring narratives about people–forest relationships (Haraway 2016; Tsing 2017).

An outstanding property of social–ecological systems, from which territories can make reorganization possible and rebuild after large-scale disturbances over centuries, is the memory of the complex system. Social–ecological memory refers to the stored experiences and information

(e.g., evolutionary, historical, ecological) of living beings with one another and with their territories (Barthel et al. 2010; Ibarra et al. 2022). Recent studies on the ecological memory of trees indicate that they communicate and transmit experiences to new generations (Tompkins and Bird 2016; Ramírez-Carrasco et al. 2017; Simard 2018), particularly in situations of environmental stress such as forest fires, heatwaves, and other climate crisis-related events (Roces et al. 2022). Recent research on plant physiology suggests that trees can learn to live in devastated conditions (García-Campa et al. 2022) and that their accumulated evolutionary memories may contain the capacity to resist these novel ecosystems (Witzany 2018; Beyhan and Koca 2022). Memory frequently emerges from long-lived system entities like remnant ancient trees, which retain the information of past forest conditions and disturbance events (e.g., clearing, fires) in their growth rings (Briffa 2000; Ibarra et al. 2020b). In the rings of trees, the context of global space–time is graphed, often with accelerated transformations (Rockström et al. 2009), that lead humans to live in territories in ruins (Haraway 2016; Tsing et al. 2017; Latour et al. 2018). For example, tree ring–based long-term reconstructions of central Europe allowed determining the role of climate variability on the demise of the Roman Empire, with associated practical information for present discussions on the political resistance to reduce the effects of climate change in the Anthropocene (Berman et al. 2011).

The south-western margin of South America, where the second largest temperate rainforests in the world occurs, shows a parallel and intimate connection to forces and historical transformations of land cover during the Anthropocene (Fig. 1). Before the arrival of the Spaniards in the sixteenth century, the territory of southern Chile was spatially heterogeneous with large areas of native forests interspersed with patches cleared for agriculture that supported Mapuche Indigenous communities dispersed in the territory (Camus 2006). The seventeenth–nineteenth centuries were characterized by extensive forest loss because of timber extraction for mining operations in both south-central Chile and western North America (Armesto et al. 2010). This period also witnessed the expansion of wheat farming the mid-1800s, a trend driven by the gold rush in California and Australia (Aschmann 1991). Two centuries of intensive deforestation associate with the European colonization of southern Chile (a historical process known as the "Pacification of the La Araucanía"), with long-lasting effects on forest cover and on the displacement and marginalization of Mapuche communities, which persist until today (Armesto et al. 2010; Bengoa 2014). During the second half of the twentieth century, plantations of non-native species expanded exponentially (Klubock 2014), initially related to direct government investment and then through the increasing involvement of the private sector through national policies for trade liberalization and the 1974 passage of Decree Law #701 (Nahuelhual et al. 2012). The latter public policy is generally considered as the main driver of the rapid expansion of Monterey pine (*Pinus radiata*) and southern blue gum (*Eucalyptus globulus*) plantations and large-scale native forest loss in southern Chile (Reyes and Nelson 2014).

In temperate territories of southern Chile, remnant ancient trees play key ecological roles such as carbon sequestration, the maintenance of hydrological and nutrient regimes, and the creation of habitat for biodiversity (Ibarra et al. 2020a; González et al. 2022). Due to their ability to provide both physical products (seeds, lumber, fruits, firewood, flowers, medicines) and intangible benefits (aesthetic and religious character), ancient trees in these southern latitudes have also had material and symbolic importance for humans through generations (Herrmann 2005; Skewes and Guerra 2016; Skewes et al. 2017). These roles are continually unfolding in the contexts of specific social–ecological systems, in which properties of the complex system emerge from localized interactions between trees, people, and their territories (Filotas et al. 2014; Ibarra et al. 2022). Remnant ancient trees are protagonists in the recent history of southern temperate territories, as they have witnessed massive fires, territorial dispossession, logging exploitation and, lately, drought (Gutiérrez 2016).

In this paper, we examined the social–ecological memory that emerges from an assemblage of relations between trees and people in South American temperate territories, Chile. We hypothesized that tree–people relationships reflect marked historical changes in the territory, associated with the clearing of forests, which are imprinted in both tree growth rings and in the social meanings and practices associated with specific tree individuals. For this examination, we used an interdisciplinary and relational approach that has little been used for explicitly assessing the role of trees for a diversity of people with different cultural backgrounds (Ibarra et al. 2022). This approach integrated dendrochronology (analysis of tree rings) with dendrography (semi-structured and go-along interviews during participant observation) to provide in-depth insights into rational and emotional connections between people and trees. Our study shows the usefulness of interdisciplinary and relational approaches for empirical and in-depth evaluation of vivid and longing human–tree relationships for better understanding dynamic social–ecological systems in the Anthropocene.

## MATERIALS AND METHODS

### Study area

Between December 2018 and February of 2019, we conducted this study across a social–ecological transect from

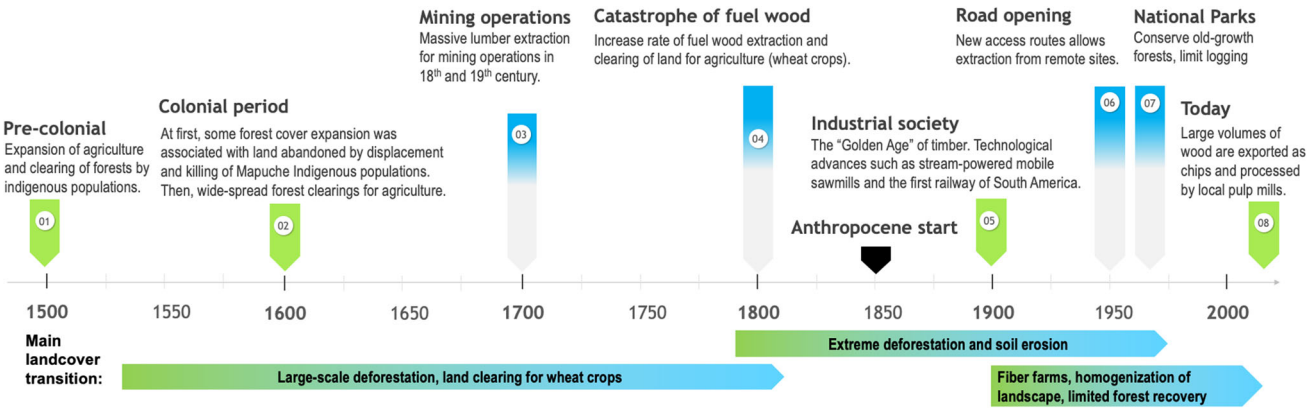


**Fig. 1** Transformation timeline from Holocene to Anthropocene in South American temperate territories. Green flags indicate main historical periods. Blue flags show relevant events for territory transformation. Own elaboration adapted from Armesto et al. (2010)

valleys to Andean mountains in the La Araucanía Region of southern Chile (Fig. 2). The climate is temperate (mean annual precipitation > 2000 mm), with an elevation range from 200 to > 3700 m above sea level (masl (Luebert and Pliscoff 2006)). At lower elevations, the valley near Temuco (capital city in the region) is characterized by a historical massive territory transformation in which intermediate cities and towns (Temuco, Freire, Pitrufquén) are surrounded by large-scale agricultural fields, cattle ranches, non-native tree plantations, variously sized native forest fragments, and shrublands in the hinterland (Salazar et al. 2017). These valley bottoms give way to increasingly forested slopes on hills, mountains, and volcanoes to the east, comprising a mosaic of native forests, lakes, rivers, agricultural fields of different sizes, with the presence of cities (Villarrica, Pucón, Curarrehue) at the foothills of the Rukapillan (2860 masl) or Lanín volcanos (3747 masl (Caviedes and Ibarra 2017). Temperate forests cover about 29% (908,501 ha) of the La Araucanía Region, and most remaining patches are protected in national parks and reserves (304,990 ha, 9.6% of total region) and private protected areas, which are mostly concentrated in Andean slopes to the east of the study area. Deciduous forests, with different levels of disruption and clearance, are dominated by the hualle, pellín, or roble beech (*Nothofagus obliqua*) at lower altitudes and mixed deciduous with conifer forests at higher altitudes. At higher elevations, Andean forests are dominated by the conifer pewen or monkey-puzzle tree (*Araucaria araucana*) and the broad leaf ñirre or Antarctic beech (*Nothofagus antarctica*) and lenga beech (*Nothofagus pumilio*), which extend to the treeline at approximately 1500 masl (Caviedes and Ibarra 2017).

## Study design

Across the transect, we selected 35 "memorial trees" of social–ecological importance from a lingue (*Persea lingue*) in the Ñielol Hill in the city and municipality of Temuco, to a pewen (*Araucaria araucana*) located near the Chile-Argentina border in the Andes of the Municipality of Curarrehue (Fig. 2). Selected trees have a spatial association with anthropogenic habitats, including road or railway networks, trails in protected areas or urban parks, and ceremonial sites. They were evenly present in both public and private lands. We selected each memorial tree according to the following criteria: (i) Location: the tree was located across the valley-mountain transect described above; (ii) Prominence: the tree was relatively larger and visually outstanding in comparison with its neighbors in their locations. These trees also had historical, ecological, and/or spiritual significance as stressed by research participants; and (iii) Narrative: The tree had associated oral histories that set it apart from others in its vicinity. These oral histories were identified through interviews, during participant observation, with local participants and, often, a review of local historical archives, including magazines, guides, newspapers, etc. (Fig. 3).

## Tree and people memories: dendrochronology with dendrography

Dendrochronology studies tree rings to identify the age of trees and their patterns of growth throughout their life. It allows evaluating environmental changes in high temporal resolution for relatively long periods of time (Smith and Lewis 2007). Tree growth rings hold information about the territory in which a tree was formed, revealing historic information about different events related to the environment and the land use where the tree is located (Babst et al. 2018).

We used a 5-millimeter increment borer to collect a total of 40 samples (tree cores) from the 35 memorial trees (Fig. 3). We collected one tree-core from each tree or two when possible. After extracting the tree cores, we stored

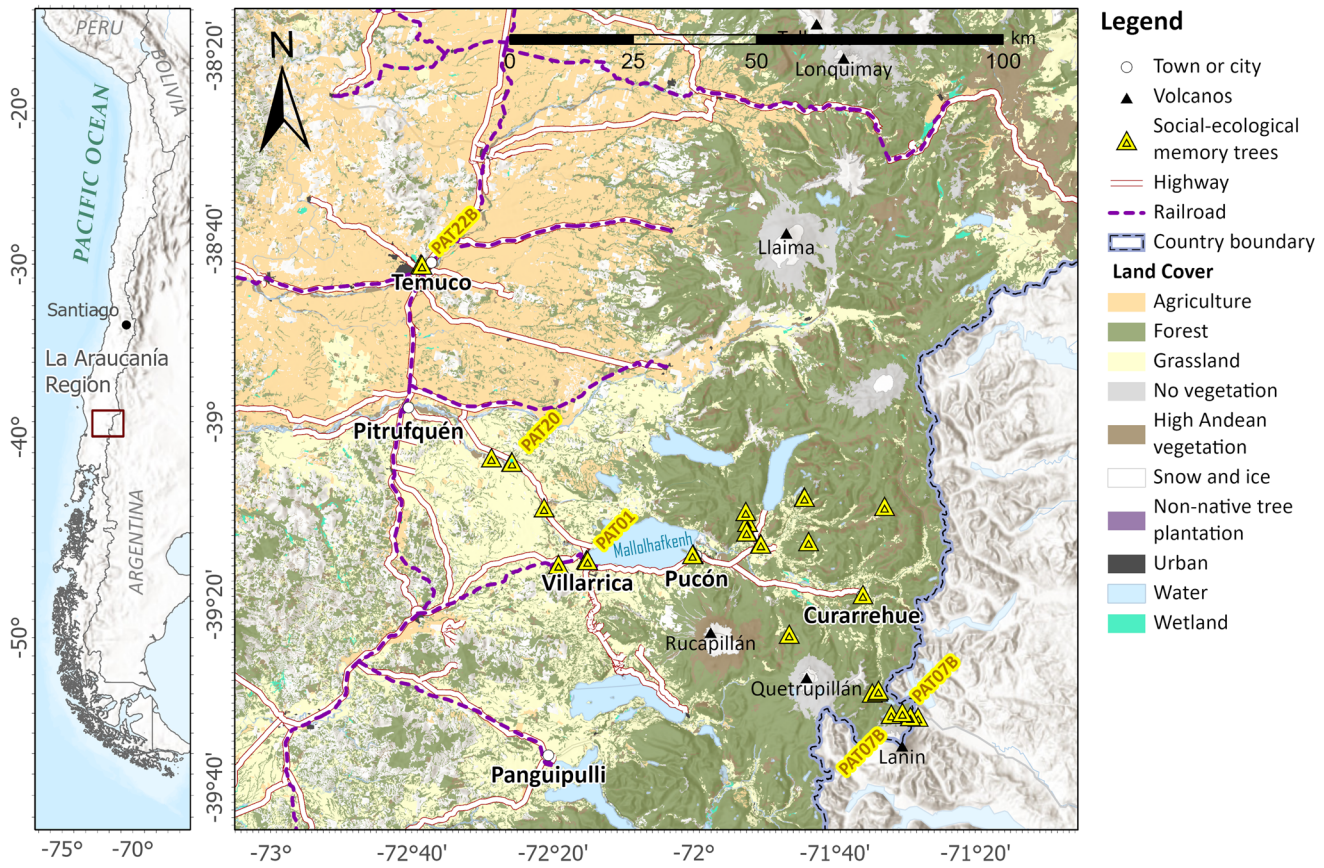


**Fig. 2** Study area. The studied "memorial trees" that include labels (in yellow) are detailed in Fig. 5

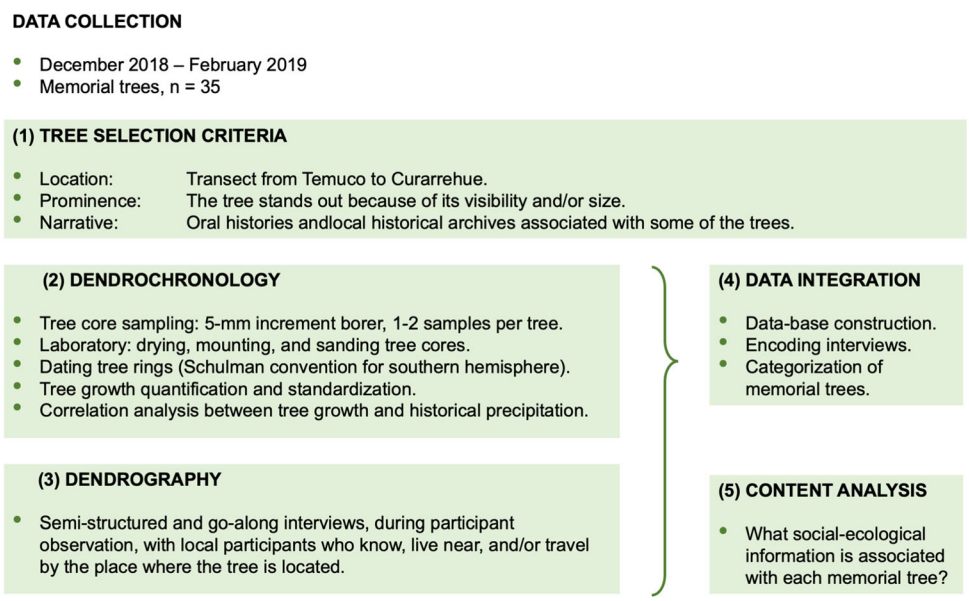


**Fig. 3** Workflow of quantitative and qualitative information analysis

them in an adequately labeled plastic straw. We covered the hole resulting from the drilling with a mix of bee wax and flax seed oil, which is commonly used to avoid the entrance of insects and pathogens into the tree. The laboratory procedure consisted of drying, mounting, and carefully sanding the tree-cores to make visible the cells of the

growth rings. Dating the tree rings was conducted following a standardized convention for the southern hemisphere (Schulman 1956), which establishes that the year of each ring is the year of the date in which the ring started to be formed. In our case, the last complete year considered was 2017 and dating trees until this year was only possible on samples that had bark. In the case of bark being absent, samples could not be dated and only an approximate age could be estimated. Next, the width of each tree ring was measured with a precision of 0.001 mm through a Velmex measuring cart connected to a computer under a stereoscopic magnifying glass. The growth time-series were standardized, and the self-correlation was eliminated using the program ARSTAN (Cook et al. 2017). Finally, once the tree ring measurements were standardized, the relationship between growth and climate was evaluated using nearby rain gauging stations and the growth rates of trees.

To provide in-depth insights into connections between people and trees, we employed dendrography (Achondo 2022). This approach involves interpreting time and territories through an affective ecology lens, exploring disturbance and devastation in the Global South (Tsing et al. 2017; Armiero 2021). Consequently, dendrographies evolve into oral histories, offering a means to write about relationships between people and trees in devastated territories that unfold during the Anthropocene (Rival 2001; Achondo 2023). Dendrographies were built from participant observation (Bernard 2005), involving the active engagement of the researchers in the settings where the trees were situated, allowing for firsthand experiences and a deeper understanding of the systems' social–ecological fabrics (Ibarra et al. 2022). During participant observation, we implemented semi-structured and go-along interviews (Salazar et al. (2017). To capture the richness of participants' experiences, interviews generally took place during their daily routines (e.g., when commuting between their homes and job locations), often passing by, implementing caring practices (details below), or sitting next to the memorial tree.

A total of 14 participants, including six women and eight men with an average age of 50 years, were engaged in the study. The diverse group featured three 'inquilinos' (aged 55–65), who were long-term caretakers of ranches where the trees were located, and four park rangers (aged 55–65) from protected areas. Additionally, interviews were conducted with a 'lonko' (aged 55), an ancestral Mapuche authority, two property owners (aged 30–35), and four neighbors of the trees in urban areas (aged 30–50).

We explored how trees were considered as witnesses and survivors of territorial transformations (Achondo 2022), mainly related to the impact of fire (Otero 2009) and logging activities (Vargas Picón 2020). We gathered oral histories related to trees, with a specific emphasis on the territorial context and participants' estimations of each tree's age. We conducted a content analysis by integrating dendrochronological information, participant observation with interviews, and historical archives, through which the social–ecological memory of trees emerged as part of the living fabric of the territory (Fig. 3; Kohn 2013; Ibarra et al. 2022).

## RESULTS AND DISCUSSION

### Trees as witnesses of territorial transformations

Our study integrating tree growth rings and oral histories bridges temporal gaps, uncovers connections between human experiences and environmental processes and, more broadly, contributes to a more holistic and critical understanding of global narratives of the Anthropocene, but on the trajectories of situated complex social–ecological systems.

The studied memorial trees were not just landmarks in the territory, but also protagonists and witnesses of territorial transformations in the Anthropocene epoch. In these southern latitudes, a significant portion of the surface that was once forests has become fields or human settlements through logging and fires since the Chilean colonization of the territory (Otero 2009). This was silently observed in the late nineteenth century by the Belgian engineer Gustave Verniory, who oversaw the construction of the railway line in the study area and described the territory as follows:

> "The practice of 'slash' involves cutting the undergrowth and thinning out trees during the winter. Once the summer sun has dried everything, the forest is burned to prepare the soil for cultivation. The century-old natural smoke and ashes create excellent conditions for growing wheat for several years with only the need for planting. The large trees that have withstood the fire are dead and partially burnt, but they remain standing. These gigantic skeletons that do not obstruct the air or the sun are not brought down. It is a disastrous devastation that will soon make the Araucanía, once so lush, take on the naked and desolate appearance of Central Chile" (Verniory 1975, 485).

The social–ecological memory of trees carries within its rings the devastating destruction described by Gustave Verniory. These trees bear witness to a time when wheat harvests astound, and sawmills cannot keep up (Durand 1980). The emergence of industrialization in La Araucanía goes hand in hand with processes of occupation and territorial exploitation that leave traces on the trees. Currently, almost every corner of the territory bears marks of these

processes of social and environmental devastation in the La Araucanía Region (Klubock 2014).

## Ages and habitats of trees

Of the 35 individuals sampled, a total of 17 tree species were recorded, of which three were introduced exotic species: *Pinus* spp., *Eucalyptus* spp., and sweet chestnut (*Castanea sativa*; Table 1). Three individuals did not exhibit ring formation, including two of the species huillipatagua, also known as naranjillo, or Chilean citronella tree (*Citronella mucronata*) and one individual of *Eucalyptus* sp. Twenty-four trees had bark, and thus, we were able to precisely age them. The estimated range of ages varied between 43 and 518 years, with an average of 148 years. The largest number of individuals belonged to the species *N. dombeyi* ($n = 7$ individuals), *A. araucana* (7), and *N. obliqua* (4). The oldest individual was an *A. araucana* at the Mirador El Cañi site (518 years), followed by another *A. araucana* at the Huinfuica ceremonial site (504 years), and a tineo or palo santo (*Weinmannia trichosperma*; 342 years) at the Carhuello site (Table 2).

The ages of trees varied substantially in relation to the habitats in which they were located. The trees in ceremonial sites showed the highest average age, while the trees in urban areas had the lowest (Fig. 4). Ceremonial sites are characterized as privately owned sites for common use, providing access to individuals and communities who have cultural ties to the site. Some of the trees in these ceremonial habitats played a central role in them, while others did not play a significant ceremonial role but remained in a sacred site that, according to participants, benefited from human traditional practices (Table 2). Notably, one of the oldest memorial tree, a 504-year-old *A. araucana* tree in the Huinfiuca ceremonial site, which is adjacent to a trail in a State protected area at the mountains, bore traces of recent ceremonial activities in its surroundings. Additionally, there was a 99-year-old *N. obliqua* in the valley, located in the land of a Mapuche community where summer ceremonies took place. This tree bordered the Freire–Villarrica highway, and, according to participants, the tree is drying up. In urban areas, memorial trees were relatively younger, including a *N. dombeyi* in a city park of Curarrehue, a willow-leaf podocarp or mañío de hojas largas (*Podocarpus salignus*) of 79 years in the central park of Villarrica, and a boldo (*Peumus boldus*) of 108 years in an archeological site with strong Mapuche and Hispanic influence within the same city. These trees coexist with urban activities, surrounded by concrete, and were outstanding in their presence and narratives (see below).

In the roadside areas, there were trees of various ages. The age of the trees tended to increase in roadside areas spatially associated with protected areas. Once again, there was an outstanding 233-year-old *A. araucana* located in the middle of a mountain road within a protected area and a 147-year-old *P. lingue* on a trail in the Ñielol Hill in Temuco city. However, the age of the trees in roadside areas decreased near railway lines and roads (Table 2). In rural housing areas, there were remnant solitary trees amidst the fields that were once forests. These trees stand out in the territory and provide shade for people and animals in the grasslands, and they have started to be generally appreciated in southern Chile for their productivity, aesthetics, ecological significance, and tourist importance (Otero and Erlwein 2022). Notable species included an ulmo (*Eucryphia cordifolia*) and a *W. trichosperma*, which were 177 and 342 years old, respectively. Additionally, there was a 43-year-old *C. sativa*, which was the youngest trees recorded and, at the same time, was among the non-native memorial tree species.

Protected areas have been mostly designated over the last 70–80 years, primarily in the mountainous locations in southern Chile, which were previously subject to tree logging (e.g., Villarrica National Park -NP- was founded in 1940). Notable examples of memorial trees here included a 259-year-old *N. obliqua* located beside the old customs office in Puesco (close to the Chile-Argentina border within the Villarrica NP). In its surroundings, participants pointed out important "tree neighbors" of the memorial *N. obliqua*, including a radal (*Lomatia hirsuta*), a *N. dombeyi*, and a raulí beech (*Nothofagus alpina*) of 68, 71, and 47 years, respectively.

**Table 1** Summary of studied "memorial trees" by species in South American temperate territories

| Species | Number of individuals | Average age |
|---|---|---|
| *Araucaria araucana* | 8 | 311 |
| *Castanea sativa* | 1 | 43 |
| *Citronella mucronata* | 2 | ND |
| *Eucalyptus* sp. | 1 | ND |
| *Eucryphia cordifolia* | 1 | 177 |
| *Laureliopsis philippiana* | 1 | 70 |
| *Lomatia hirsuta* | 1 | 68 |
| *Myrceugenia chrysocarpa* | 2 | 81 |
| *Nothofagus alpina* | 1 | 47 |
| *Nothofagus dombeyi* | 7 | 69 |
| *Nothofagus obliqua* | 4 | 145 |
| *Nothofagus pumilio* | 1 | 225 |
| *Persea lingue* | 2 | 109 |
| *Peumus boldus* | 3 | 112 |
| *Pinus* sp. | 1 | 51 |
| *Podocarpus salignus* | 1 | 79 |
| *Sophora cassioides* | 2 | 58 |
| *Weinmannia trichosperma* | 1 | 342 |
| Total | 40 | 148 |

**Table 2** List of studied "memorial trees" in South American temperate territories, Chile

| Code | Species | Age | Site | Habitat | Space | Sociocultural value |
|---|---|---|---|---|---|---|
| PAT01 | *Peumus boldus* | 108 | Villarrica | Urban | Public | Tree located in hispanic fort |
| PAT02 | *Podocarpus salignus* | 79 | Villarrica | Urban | Public | Downtown main square |
| PAT03 | *Eucryphia cordifolia* | 177 | Carhuello | Rural housing | Private | Remnant tree |
| PAT04 | *Araucaria araucana* | 132 | Mamuil Malal | Roadside | Public | Located at the country frontier Paso Mamuil Mala |
| PAT05 | *Nothofagus obliqua* | 63 | Ñancul | Roadside | Public | Tree stands on the railroad tracks |
| PAT06A | *Citronella mucronata* | | Ñielol Hill | Urban | Public | Tree nearby an Indigenous ceremonial site |
| PAT06B | *Citronella mucronata* | | Ñielol Hill | Urban | Public | Tree nearby an Indigenous ceremonial site |
| PAT07B | *Araucaria araucana* | 233 | Mamuil Malal | Roadside | Public | The road was built leaving the tree in the middle |
| PAT08 | *Peumus boldus* | 155 | Coipue | Roadside | Public | Barbecue place |
| PAT09A | *Nothofagus dombeyi* | 46 | Curarrehue | Urban | Private | Periurban forest trail "Bosque Aliwen" |
| PAT09B | *Nothofagus dombeyi* | 59 | Curarrehue | Urban | Private | Periurban forest trail "Bosque Aliwen" |
| PAT10 | *Araucaria araucana* | 298 | Huerquehue | Ceremonial site | Private | Tree nearby an Indigenous ceremonial site |
| PAT11 | *Eucalyptus sp.* | | Pucón | Urban | Public | Downtown main square |
| PAT12 | *Peumus boldus* | 73 | Pucón | Urban | Public | Dense, leafy tree in downtown |
| PAT13 | *Nothofagus pumilio* | 225 | Cañi | Protected Area | Private | Protected area trail |
| PAT15 | *Araucaria araucana* | 279 | Mamuil Malal | Roadside | Public | The road was built leaving the tree in the middle |
| PAT16 | *Araucaria araucana* | 518 | Cañi | Protected Area | Private | Lookout in protected area trail |
| PAT17 | *Araucaria araucana* | 504 | Huinfiuca | Ceremonial site | Private | Tree nearby an Indigenous ceremonial site |
| PAT18 | *Araucaria araucana* | 286 | Mamuil Malal | Roadside | Public | Tree split by a lightining |
| PAT19 | *Nothofagus dombeyi* | 52 | Llancalil | Rural housing | Private | Remnant tree |
| PAT20 | *Nothofagus obliqua* | 99 | Coipue Viejo | Ceremonial site | Private | Tree nearby an Indigenous ceremonial site |
| PAT21 | *Nothofagus dombeyi* | 145 | Cañi | Protected Area | Private | Protected area trail |
| PAT22A | *Persea lingue* | 70 | Ñielol Hill | Protected Area | Private | Remnant tree |
| PAT22B | *Persea lingue* | 147 | Ñielol Hill | Protected Area | Private | Remnant tree |
| PAT23 | *Lomatia hirsuta* | 68 | Puesco | Protected Area | Private | Remnant tree |
| PAT25A | *Sophora cassioides* | 64 | Coipue Viejo | Ceremonial site | Private | Tree nearby an Indigenous ceremonial site |
| PAT25B | *Sophora cassioides* | 52 | Coipue Viejo | Ceremonial site | Private | Tree nearby an Indigenous ceremonial site |
| PAT27 | *Weinmannia trichosperma* | 342 | Carhuello | Rural housing | Private | Remnant tree |
| PAT28 | *Araucaria araucana* | 236 | Huerquehue | Ceremonial site | Private | Tree nearby an Indigenous ceremonial site |
| PAT29 | *Nothofagus dombeyi* | 47 | Namuncay | Rural housing | Private | Remnant tree |
| PAT30 | *Nothofagus dombeyi* | 61 | Liucura | Rural housing | Private | Family significance |
| PAT32 | *Nothofagus obliqua* | 158 | Liucura | Rural housing | Private | Family significance |
| PAT33A | *Myrceugenia chrysocarpa* | 85 | Puesco | Protected Area | Private | Shepherds' refuge |
| PAT33B | *Myrceugenia chrysocarpa* | 77 | Puesco | Protected Area | Private | Shepherds' refuge |
| PAT35 | *Castanea sativa* | 43 | Carhuello | Rural housing | Private | Remnant tree |
| PAT37 | *Pinus sp.* | 51 | San Carlos | Rural housing | Private | Remnant tree |
| PAT39 | *Nothofagus alpina* | 47 | Puesco | Rural housing | Private | "Swing" tree |
| PAT40 | *Nothofagus dombeyi* | 71 | Palguín | Protected Area | Private | Remnant tree |
| PAT41 | *Laureliopsis philippiana* | 70 | Carhuello | Rural housing | Private | Remnant tree |
| PAT42 | *Nothofagus obliqua* | 259 | Puesco | Protected Area | Private | Remnant tree |

The ages of the trees and their habitats illustrate that tree ages are closely related to the types of interventions in the areas where they were found (Fig. 4). Opening roads led to the loss of native trees, and remnant old trees serve as witnesses to these territorial transformations. They were once part of temperate forests but now coexist in social–ecological assemblages associated with open fields, roads, trails, squares, streets, ceremonial sites, and protected areas.

## Situated social–ecological assemblages

Tree growth rings and oral histories narrated the situated relationships between trees and people. We noted that park

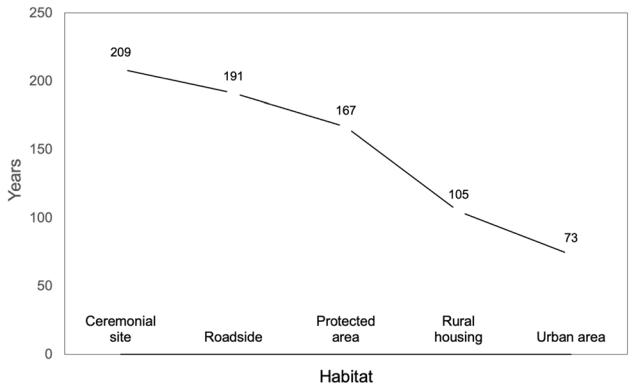


**Fig. 4** Average ages of memorial trees in each habitat where they were studied in South American temperate territories, Chile

rangers in protected areas, "inquilinos" (long-term caretakers of ranches), and the Mapuche lonko had a close and affective relationship with memorial trees. These relationships were characterized by affection because they cohabit daily in the same place, observe their changes throughout the annual cycles, and engage in tree care practices. In their testimonies, it was stressed that the trees were in areas sensitive to climate change, and thus trees required care for their well-being and survival. According to participants, the care involved, first, consider the tree as a family member and, second, maintaining the surroundings with native species, clearing dead branches and parasites, and, most importantly, ensuring that the environment is fenced off to prevent cows from entering.

Social–ecological assemblages (Briassoulis 2017; DeLanda 2021), built from the relationships between people and memorial trees, are often generated in devastated territories. They are assemblages in the sense that forest composition, structure, and functioning are linked to human actors and their practices of care and mutual resilience in the face of devastating contexts (Kohn 2013; Tsing et al. 2017). The memorial trees in our study are the remnants of historical forest exploitation and land-clearing during the nineteenth-twentieth centuries, and their survival makes them protagonists of caring practices in the early twenty-first century, revealing that trees connect sensitivities and concerns about the consequences of living in the Anthropocene across local and global scales (Sassen 2010). In words of Haraway (2016), and using the Chthulucene as a critical alternative framework to the Anthropocene, these practices of care emphasize interconnectedness, multispecies collaborations, and the blurring of boundaries between humans and other-than-humans in local assemblages (Haraway 2016; Ibarra et al. 2022).

To provide further details on these relationships, we selected five trees that exemplify their protagonism in social–ecological assemblages (Fig. 5). The *P. lingue* of the Ñielol Hill (PAT22B) has survived immersed in an urban protected area amidst the accelerated urbanization processes of Temuco. It plays a leading role at the beginning of a trail that leads to a lush valley with regenerating forest. According to participating park rangers, this area of the hill has been prone to recurrent forest fires. Based on its age (147 years old), the tree was a sprout during the foundation of the city of Temuco in 1881. This connects to the accounts of park rangers who narrated that, at the summit of the Ñielol Hill (where the tree is located), Mapuche families sought refuge during the occupation of the region by the Chilean State. Some of the trees at the top of Cerro Ñielol are remarkably large. In the words of a park ranger, this is because it is an important place for Mapuche history and their spiritual relationship with trees, which favors the growth of the trees. He pointed out that "*all trees can transform into* aliwen*, which means that they can become large trees, with wisdom and great strength. If you know how to connect with these trees, they give you a lot of wisdom for life.*" Around these *aliwen*, historical parliaments have been held. Indeed, this *P. lingue* coexists with other memorial trees in the Ñielol Hill, such as a huillipatagua (*Citronella mucronata*; Fig. 6), which served as a site for negotiating agreements between the Mapuche and Chileans (Aylwin 1995). Similar to Mapuche families, memorial trees found refuge in the Ñielol Hill, escaping the threats of logging and fires at the frontiers of colonization.

The *N. obliqua* in the ceremonial site of Coipue Viejo (PAT20) thrives in a Mapuche community's ceremonial site (Fig. 5). It stands as a remnant solitary tree in a grassland, providing shade to domesticated animals. Mapuche ceremonies have taken place in this location for the past 20 years, and the tree holds a central role within them. An anomaly can be observed in the tree's growth during the early 1980s, with a positive increase, coinciding with the removal of part of its associated vegetation. Over the last decades, its growth rings have achieved a certain stability. It is situated alongside the road between Freire and Villarrica, where traffic congestion has increased steadily since 2010 due to tourism toward Villarrica and Pucón. Currently, there are plans to construct a dual highway that, according to participants, would result in the tree's demise. This tree plays a leading role in the care and protection of the Mapuche community's ceremonial site. It is important to consider that, while *N. obliqua* dominates the forested areas of the landscape, social–ecological memories linked to this relatively common species emerge significantly in South American temperate territories. According to Skewes and Guerra (2015), *N. obliqua* trees act as a witness of the logging tradition that mobilized Chilean commercial interests as much as political projects and utopias linked to the formation of a lumberjack proletariat. This tree infiltrates the materiality of everyday life in the form of firewood, building material for housing, or


**Fig. 5** Example of memorial trees representing the studied territory transect and the array of social–ecological importance of these trees in the study area. *Source* The authors


**Fig. 6** Newspaper clipping of the time that indicates: "The parliament of the patagua*. At the foot of this patagua the chiefs of Temuco held a parliament on November 10, 1881 to attack the fort created to protect the nascent city. They were rejected promising to live then in peace and join the citizenry as good Chileans" (Source: 'Austral de Temuco' newspaper, 26 December 1946). *According to a long-term park ranger (interviewee) and our own identification in the field, this tree actually corresponds to a huillipatagua or Chilean citronella tree (*Citronella mucronata*) and not to a patagua or lily of the valley tree (*Crinodendron patagua*)

everyday use objects. On a ritual level, *N. obliqua* stand out for their funeral associations in Mapuche culture in three ritual moments, including in the "*wampos*" or canoes that serve as funeral urns, in the "*chemamull*" or commemorative sculpture, and in the "*descansos*" or resting places for encounters and communication with the deceased (Skewes and Guerra 2015, 2016).

The *P. boldus* at the Fort Villarrica (PAT01) coincides in age with the Chilean refoundation of the city in 1882 (Fig. 5). It is located in a historical site that was once a Mapuche human settlement, upon which the Spanish built a fort that was later abandoned for 300 years after a Mapuche rebellion. Currently, it serves as a visual landmark and as a source of social–ecological memory in a site that has been abandoned by the municipality. Between 2000 and 2010, there were removals on the site due to housing extensions being constructed next to it, which may have caused disturbances in its growth rings. Currently, Mapuche communities claim their ancestral connection to the site and demand its restitution and full control.

The history of the *A. araucana* of Lake Huinfiuca (PAT17) was previously described. It is over 500 years old and is situated in an ancient ceremonial site. However,

significant forest fires occurred in its surroundings, leaving a notable anomaly in its growth rings. Furthermore, in March 2015, the eruption of the Rukapillan (or Villarrica) volcano occurred, which may be another factor contributing to the marked anomaly in the tree's rings. Similar to the *N. obliqua* in the ceremonial site of Coipue Viejo, this *A. Araucana* talks about spiritual connections and the need of rethinking the divide between the human and the other-than-human (Latour et al. 2018). The Mapuche–Pewenche make offerings during these ceremonies, such as the *Nguillatun* and the *Llellipun*, when people offer *muday* (fermented beverage used in ceremonies) to these trees and request permission before beginning to collect the piñones (edible seeds) nearby; the latter helps to assure a bountiful harvest of piñones (Herrmann 2005).

Lastly, another *A. araucana* located on the highway to the Chile–Argentina border (PAT07B) takes center stage in the territory as it stands in the middle of the highway (built during the 1930s). While not entirely clear, the construction of the road may have influenced an anomaly in the growth pattern of rings. According to the participants, its survival was possible by the defense and protection provided by the local Mapuche community during the paving of the highway during the early 2000s. The construction of the road is remembered by a park ranger as "*in the study for paving the road, this tree had to be cut down, but people fought not to do it. Others were cut but this one survived.*" This is attested to in press inserts of the time, which describe the ways in which an environmental council associated with Mapuche communities to protect the trees that will be felled (Fundación Terram 2013). The active defense of this individual tree recalls other political struggles around the *A. araucaria*, north of our study area. In the late 1980s, Mapuche–Pewenche communities teamed up with environmentalist organizations to regain their lands from a timber corporation that was exploiting these sacred trees in their ancient gathering territories (Bengoa 1992). Because of their relationship with the Mapuche–Pewenche, who have traditionally disseminated seeds, planted tree seedlings, or prevented habitat loss, many *A. araucaria* trees are presently in their ancestral forested lands. The social–ecological memory of *A. araucana* people-tree territories is nourished by these interactions of care and protection, which also have an impact on evolutionary and ecological processes (Reis et al. 2014; Speziale et al. 2018; Cockle et al. 2019). Unfortunately, regardless of the local community's struggle to defend this tree (PAT07B), we have confirmed that it is drying up. Although there are several reasons that may be associated with this process, the removal of the associated vegetation community and the physical–chemical changes in the now-paved soil could be linked to its desiccation.

## Moving beyond dominant narratives: nurturing other understandings of social–ecological memory in the Anthropocene

In 1989, the Mapuche poet Leonel Lienlaf reflected, "I became a tree because the tree was my life (Lienlaf 1989)," embracing the notion that people-tree assemblages are dynamic complex systems that must be nurtured and performed daily through social–ecological memory. Social–ecological fabrics are often damaged, but also nourished by possibilities that can be deepened with new interpretations of the Anthropocene. This requires a profound rethinking of our conceptions of 'human nature' as well as our relationships with the different human and other-than-human actors that make up people–tree, social–ecological assemblages.

We have shown that remnant ancient trees, due to their presence and social–ecological roles, provide insights into the Anthropocene in South American temperate territories. Elsewhere, similar insights derive from, for example, Sundarbans mangrove trees (*Avicennia marina*, *Rhizophora mucronata*, *Ceriops decandra*, and other tree species) from India and Bangladesh. These systems have withstood habitat loss and environmental degradation caused by intensive human activities and events characteristic of the Anthropocene, such as sea-level rise (Paul et al. 2017). Ancient mangrove trees, however, keep been serving as a source of livelihood, protection, and spirituality (Saha 2017). In Tropical territories, globally, where colonization has had a significant impact on forest loss, remnant large trees harbor myriad of species assemblages and are tied to a diversity of ongoing and critical local livelihoods, myths, and rituals (Pinho et al. 2020).

In the context of the emergence of social–ecological memory in devastated territories in Anthropocene, our study points out that remnant ancient trees may be intertwined with practices of tree care emphasizing interconnectedness, multispecies collaborations, and the blurring of boundaries between humans and other-than-humans. Haraway's (2016) emphasis on "becoming-with" rather than "dominating-over" aligns with the idea that humans and trees are entangled in a shared coexistence in which the agency of trees and other other-than-human entities is acknowledged, emphasizing the importance of recognizing their subjectivity and contribution to the ongoing narrative of life on Earth. Trees, as integral components of this interconnected social–ecological fabrics, contribute to the ongoing process of becoming-with other species (Kohn 2013; Ibarra 2024). This challenges rigid ontological categories and invites a reconceptualization of humanity's place within broader social–ecological crises. Furthermore, the firsthand life histories of people raised in the midst of forests and logging industries in the global south are

reflected in dendrographies (sensu Achondo 2022). These narratives may help balancing personal well-being with the recovery of a land damaged by destructive models driven by capital, labor forces, and infrastructure (Skewes et al. 2017). They also hold a deep moral significance as they acknowledge a connection between human experiences and those of other beings in nature, leading to a sense of responsibility toward trees and associated assemblages of species that were previously, or continue to be, harmed (O'Connor 2001; Wall 2022).

## CONCLUSION

In our study, we have shown that the relationships between dendrography (oral histories) and dendrochronology (tree rings) offer valuable insights when analyzed through an interdisciplinary and relational approach. Below, we briefly describe some of these insights, which may prove valuable for future research, political agendas, and educational programs in South America and beyond.

Complementarity of data: dendrography and dendrochronology provide complementary types of data that enrich our understanding of social–ecological memory. Oral histories offer subjective, contextualized narratives that capture the socio-cultural dimensions of environmental changes and human responses (Tsing et al. 2017). Tree rings, on the other hand, offer quantitative data on ecological processes and climatic variations (Babst et al. 2018). Tree rings provide long-term ecological records that extend beyond human memory in forested territories, especially when delving into the memory of remnant ancient trees (Babst et al. 2018). By integrating dendrography and dendrochronology, researchers can uncover connections between cultural practices, human experiences, and ecological dynamics across spatial and temporal scales.

Challenges of interpretation and contextualization: interpreting the relationships between oral histories and tree rings requires careful consideration of historical, cultural, and ecological contexts. Oral histories are influenced by subjective experiences, cultural perspectives, and social dynamics (Bernard 2005). Researchers must critically analyze these narratives while considering factors such as memory biases, changing cultural contexts, and the potential influence of power dynamics (Eelderink et al. 2020; Salazar et al. 2020). Indeed, it is politically significant to comprehend the characteristics resulting from people–tree relationships, such as the system's social–ecological memory. Lack of attention to the history of interpersonal relationships and shared experiences, from which the system's social–ecological memory emerges (Toledo and Barrera-Bassols 2008), can exacerbate social injustices that affect Indigenous Peoples' and Local Community livelihoods, lead to conflicts and, more broadly, perpetuate colonialism (Ludwig 2016; Aedo et al. 2017; Ignace et al. 2023). Indeed, we have shown diverse, entangled, and caring relationships between people and trees in an area subject to historical transformation, deforestation, and colonization. Additionally, tree ring analysis needs an understanding of local environmental conditions, disturbance regimes, and ecological processes. Integrating these different sources of knowledge requires inter- and transdisciplinary collaboration and a critical lens to navigate the critical complexities of social–ecological systems (Audouin et al. 2013).

Complex social–ecological interactions: complex systems are characterized by many interactions, feedback loops, openness, and nonlinear dynamics (Parrott and Meyer 2012; Ibarra et al. 2020b). While oral histories provide insights into human experiences and cultural meanings of trees, they may not fully capture the intricate ecological processes and long-term environmental changes recorded in tree rings. The integration of oral histories and tree ring analysis should be approached with caution, recognizing that they offer different but complementary perspectives. Inter- and transdisciplinary collaboration is necessary to navigate these complexities and develop a more comprehensive understanding of social–ecological memory as an emergent property of local assemblages.

In conclusion, dendrographies serve as a repository of intergenerational knowledge and social–ecological memory in forest territories. They provide accounts of past experiences and the historical relationship between people, trees, and their territories. With caution, the integrating dendrographies with dendrochronology enhance our relational understanding of social–ecological memory by connecting historical narratives with ecological data. This integration allows for a more comprehensive exploration of how knowledge and practices have been transmitted across generations and how they contribute to both historical and present-day social–ecological dynamics in the Anthropocene and beyond.

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