

Temporal progression trends of cypress mortality at permanent plots in a National forest reserve of *Austrocedrus chilensis* (Patagonia, Argentina)

V. A. El Mujtar^{1,3*}, E. Andenmatten², M. H. Perdomo², F. Letourneau²,
O. Grau¹ and L. A. Gallo³

¹ Instituto de Biotecnología y Biología Molecular (IBBM). CCT CONICET La Plata-Facultad de Ciencias Exactas. Universidad Nacional de La Plata. Calle 49 y 115, s/n. 1900 La Plata (Buenos Aires). Argentina

² Campo Forestal General San Martín. EEA INTA. Bariloche. CC26-8430 El Bolsón (Río Negro). Argentina

³ Unidad de Genética Ecológica y Mejoramiento Forestal. EEA INTA Bariloche. CC277-8400 San Carlos de Bariloche (Río Negro). Argentina

Abstract

Longevity is a characteristic of forest trees that influences their responses to challenges by biotic and abiotic stresses and the temporal development of symptoms. Monitoring programs have been extensively used to detect the impact of climatic change, air pollution and outbreaks of pathogens on forest health, growth and dynamics. In Argentina, forests of Patagonian cypress are affected since mid twenty century by a mortality process called «mal del ciprés» (cypress mortality), but information about their temporal progression is scarce. In the present work we used a database from a program of dasometric permanent plots to analyse the temporal development of cypress mortality on plot and tree level, and determine qualitatively the spatial distribution of affected trees. Particular pulses of appearance of affected trees shared by all plots, rapid or slow progress of mortality at tree level and a homogeneous distribution of affected trees without a clear pattern of expansion from a central point were determined. The results indicate that the episodic appearance of affected trees can be related with warm and dry climatic periods and suggest that the individuals affected by cypress mortality share some special characteristics such as genetic background, developmental conditions or physiological mechanisms for drought responses.

Key words: symptoms development; monitoring; spatial distribution; drought; mortality pattern.

Resumen

Tendencias en el desarrollo temporal del mal del ciprés en parcelas permanentes de una Reserva Forestal Nacional de *Austrocedrus chilensis* (Patagonia, Argentina)

La longevidad de las especies arbóreas afecta la respuesta a estreses bióticos o abióticos y, en gran medida, determina el desarrollo temporal de los síntomas. Por tal motivo, los programas de monitoreo se han empleado para detectar el impacto del cambio climático, la polución ambiental o estallidos de patógenos en la sanidad y dinámica de los bosques. En Argentina, los bosques de *Austrocedrus chilensis* sufren desde 1945 una mortalidad masiva conocida como «mal del ciprés»; sin embargo, hay escasa información sobre su progresión temporal. En el presente trabajo una base de datos de un programa de parcelas permanentes se empleó para analizar el desarrollo temporal de la mortalidad a nivel de parcela e individuo y la distribución espacial de los árboles afectados. Se determinó que la aparición de síntomas sigue un patrón de pulsos compartido por todas las parcelas, con mortalidad rápida o lenta a nivel de individuo y una distribución homogénea de la mortalidad sin un patrón de expansión desde un punto central. Los resultados indican que los episodios de afectación pueden ser relacionados con períodos climáticos cálidos y secos, sugiriendo que los individuos afectados comparten características tales como *background* genético, condiciones de sitio o respuesta a la sequía.

Palabras clave: desarrollo temporal de síntomas; monitoreo; distribución espacial; sequía; patrón de mortalidad.

* Corresponding author: velmuj@gmail.com

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Introduction

Longevity is a characteristic of forest trees that influences their responses to challenges by biotic and abiotic stressors. The aerial symptoms detected nowadays can be a consequence of a stress experienced several years ago, and recurrent stresses can also increase the level of observed symptoms along time. In the last decades several monitoring programs have been implemented to evaluate the impact of air pollution, climatic change and pathogen outbreaks on forest health and dynamics (McLaughlin, 1998; Alexander and Palmer, 1999; Petriccione and Pompei, 2002; De Vries *et al.*, 2003).

In Argentina, forests of *Austrocedrus chilensis* (D. Don) Pic. Ser. et Bizarri (Patagonian cypress) are affected since mid twenty century by a mortality locally called cypress mortality. The mortality has characteristic but unspecific symptoms of crown (defoliation and yellowing) and its etiology is still unknown (El Mujtar and Andenmatten, 2007a). Although biotic agents and soil properties associated with cypress mortality have been studied by several scientific groups (for a review, El Mujtar and Andenmatten, 2007b), information from temporal progression of mortality is scarce and mainly restricted to dendrochronological analysis on individual trees. Recently, the impact of cypress mortality on dynamics of *A. chilensis* forests was studied using dendrochronological tools to determine temporal development of the radial growth at the tree and stand levels (Amoroso, 2009). This study showed that tree death was preceded by a decline in radial growth that is independent of canopy position and unpredictable in time. Although the occurrence of radial growth decline was analysed among trees differentiated by health or relative position in the canopy a combination of both factors was not considered. On the contrary, years with warm and dry weather conditions were dendrochronologically related with the beginning of decrease in radial growth on symptomatic trees (Calí, 1996) and on trees selected by a matched-pair case-control strategy (Mundo *et al.*, 2010). This decrease on radial growth also precedes the development of the external symptoms in the crown. Satellite images were used to construct a map of the spatial distribution of patches of cypress mortality and to quantify the affected forest surface, nevertheless the methodology was only used on a special area and time (La Manna *et al.*, 2008).

The knowledge of temporal development of symptoms and mortality progression could be useful to under-

stand the etiology of the mortality process and to establish control and management strategies. This sort of studies have been done with others species with interesting results (Milgroom and Peever, 2003; Holdenrieder *et al.*, 2004; Jeger, 2004). In the case of *A. chilensis* a program of dasometric permanent plots (PP) was initiated in 1988 on a National forest reserve (Province of Río Negro, Argentina) by the Instituto Nacional de Tecnología Agropecuaria (INTA) in order to generate a database for silvicultural and ecological studies. Due to the importance of cypress mortality in the region, the tree sanitary condition was incorporated as a parameter in the monitoring of PP. The registered information was used in the present work to analyse the temporal development of cypress mortality on plot and tree level, and to determine qualitatively the spatial distribution of affected trees.

Materials and methods

Study sites

Three PP from the forest reserve located near El Bolsón town, Río Negro province, Patagonia, Argentina (41° 57' 01" S, 71° 31' 54" W) were used. The PP were circular plots of 1,000 m² where each tree with diameter at breast height (DHB) higher than 5 cm was classified, on each inventory, according to species, sanitary conditions based on aerial symptoms (defoliation and yellowing), DHB, canopy position, vigour, growth tendency and utility (wood, cordwood, pole). All tree positions were registered by measurement of the angle and distance from the central point of PP.

The three selected PP had at least three inventories (Table 1). The PP16 was monitored in five opportunities with a total period of eighteen years, the PP12 was monitored in four inventories with a total period of fifteen years and the PP26 was monitored three times along seven years.

Processing of database

Data from the first inventory on each PP were used to characterize number of tree species, contribution of *A. chilensis* to the total number of individuals, and diametric class distribution of trees (Table 1). The distribution of *A. chilensis* trees on three categories of vigour and growth tendency (low, intermediate and high) was

Table 1. Descriptions of permanent plots (PP)

	PP16	PP12	PP26
<i>General Information</i>			
Slope (°)	10	25	14
Aspect	E-SE	W-SW	W-SW
Density (trees/ha)	1,260	1,570	660
Density (<i>A. chilensis</i> trees/ha)	960	1,130	580
<i>Years of monitoring</i>			
1988	✓	✓	×
1996	✓	✓	×
1999	✓	✓	✓
2003	✓	✓	✓
2006	✓	×	✓

✓: year with monitoring data. ×: year without monitoring data.

also determined (Table 2). Vigour, a characteristic of each individual, was used to describe the level of vitality; whereas growth tendency was used to characterize the spatial environment of each individual.

In order to standardize the nomenclature and to adjust the classification of sanitary condition to dendrochronological results (decline of radial growth that precedes the development of the aerial symptoms) the available information was recodified. Healthy trees were codified as asymptomatic trees (A) and diseased trees as symptomatic trees (S) independently of the level of the symptoms. Classification of dead trees (D) was unchanged and harvested, fallen and uprooted trees were codified as other class (O). Trees without information of any inventory were codified as not determined (ND).

Three classes of symptoms evolution were established after codification: DIRECT, INVERSE and ALTERNATED. Each class corresponds to a different pattern of temporal manifestation of the symptoms. DIRECT class represents the evolution expected for cypress mortality with trees that follow the tendency $A \rightarrow S \rightarrow D$. INVERSE class corresponds to contrary evolution with trees that follow the tendency $S \rightarrow A$. ALTERNATED class groups

trees without any clear tendency of evolution such as $S \rightarrow A \rightarrow S$ or $A \rightarrow S \rightarrow A$.

DIRECT class was used to analyse temporal evolution of cypress mortality on plot and tree level. Appearance of affected trees was expressed as percentage relative to the asymptomatic trees and normalized by the corresponding number of years on the period between inventories (PAfT). $PAfT = (Af * 100 / A) / Y$ with Af the number of affected trees (S + D + O) on the corresponding inventory, A the number of asymptomatic trees to the end of the previous inventory, and Y the number of years between inventories. The spatial information of each tree was transformed to (x, y) coordinates and used to construct distribution maps of affected trees (S + D + O) in each inventory.

Results

Austrocedrus chilensis is the principal tree species on the analysed PP. The corresponding percentage based on the number of individual/ha, was of 76, 72 and 88% for the PP16, PP12 and PP26, respectively (Table 1). Similar diameter distributions were detected for PP16 and PP12 whereas PP26 had a lower contribution of diameter class I (Fig. 1).

Vigour and growth tendency showed different distributions for each PP. PP16 had more than 53% of trees in the low vigour category and a relatively uniform distribution at the three growth tendency categories. PP12 had 44% of trees in the high growth tendency category and a relatively uniform distribution at the three vigour categories. PP26 had more than 67% of trees in the intermediate vigour category and 43% in the intermediate growth tendency category (Fig. 2).

For the three selected PP the DIRECT class includes more than the 66% of the trees. Therefore, the DIRECT class could be considered as a good parameter for the temporal development of cypress mortality in each PP.

Table 2. Vigour and growth tendency assignation

Category		Crown	Foliage colour	Distance ^a	Competition
Vigour	High	Big, closed	Green		
	Intermediate	Small, opened or incompletely	Green pale		
	Low	Big or very small	Yellowing		
Growth tendency	High			Long, no crown contact	Low
	Intermediate			Moderate, little crown contact	Moderate or low
	Low			Intense crown contact	High

^a Distance relative to neighbour trees.

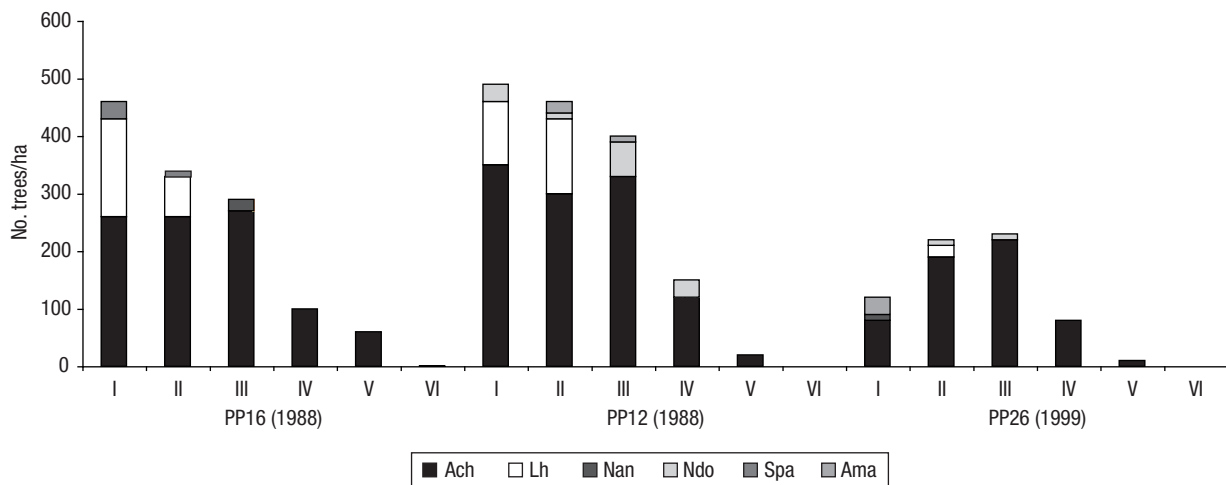


Figure 1. Diameter distribution of the trees (> 5 cm DBH) in 10 cm classes for the first inventory on each PP. Year of the first inventory is indicated between parentheses for each PP. Species code are Ach: *Austrocedrus chilensis*, Lh: *Lomatia hirsuta*, Nan: *Nothofagus antarctica*, Ndo: *Nothofagus dombeyi*, Spa: *Squinus patagonicus*, Ama: *Aristotelia maqui*.

The INVERSE class was only 8% and a great proportion of trees had a corresponding change on growth tendency suggesting that release of competence could modify the classification of sanitary condition. The maximum percentage for the ALTERNATED class was of 31% but more than 55% of these trees corresponded to individuals with important level of competition. These results reinforce previous reported difficulties to differentiate symptomatic trees from individuals affected by competition (El Mujtar and Andenmatten, 2007b) (Table 3).

Temporal development of cypress mortality

In the DIRECT class the number of affected trees increased with time on each PP. The percentage of

affected trees, grouping S (symptomatic), D (dead) and O (logged, fallen and uprooted) trees, increased from 29 to 60% for the PP16 and from 25 to 59% for the PP12. For the PP26, with only seven years of monitoring, the affected trees increased from 5 to 36% (Fig. 3).

This temporal progression analysis indicated an increment of cypress mortality along time, but this was not useful to determine the distribution of appearance of affected trees. However, the analysis of the temporal change of sanitary condition A → S + D + O indicated that the increment of affected trees was episodic (Fig. 4). A similar episodic pattern was observed for the three PP suggesting the influence of general factors such as climatic change or outbreaks of pathogens. The appearance of affected trees was lower along the period 1996-1999 and higher for the periods 1999-2003 and 2003-2006 (Fig. 5).

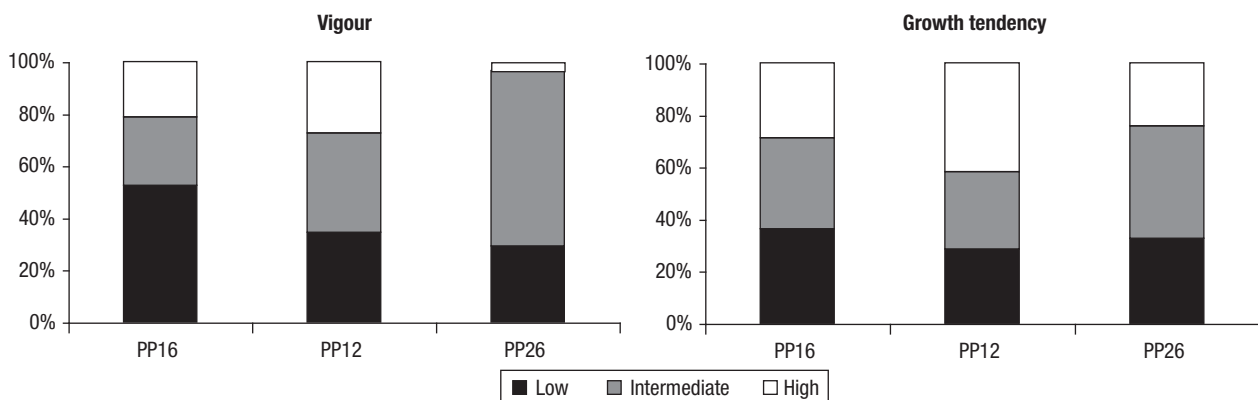


Figure 2. Vigour and growth tendency distribution of *Austrocedrus chilensis* trees in each permanent plot (PP). Y axis corresponds to the percentage of trees in each category of vigour and growth tendency.

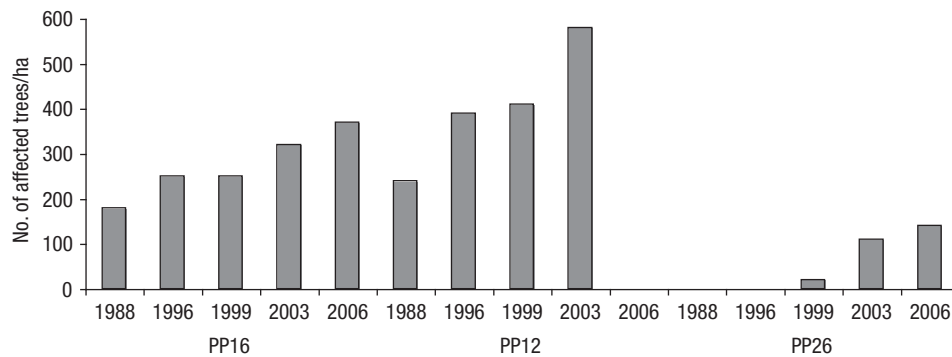


Figure 3. Temporal progression on number of affected *Austrocedrus chilensis* trees by inventories on each permanent plot (PP).

The temporal change of sanitary condition showed that the mortality progression can be different among individual trees. On the time between inventories some asymptomatic trees changed to symptomatic trees but others changed to dead trees. The minimum time for transition $A \rightarrow S$ or $A \rightarrow D$ was of three years. Similarly, the minimum time of transition $S \rightarrow D$ was of three years although some individuals remained long time as symptomatic trees (three to eleven years). Therefore, some asymptomatic individuals die on a minimum time of three years (estimation limited by years among inventories) whereas on others the process takes fifty or more years.

Spatial distribution of affected trees

Maps of the spatial distribution of affected trees ($S + D + O$) were produced to analyse the progression of cypress mortality on each PP (Fig. 6). The maps showed a relatively homogeneous distribution of affected trees without a clear pattern of expansion from a central point. Some affected trees appeared in the

Table 3. Symptoms evolution of each class indicated as percentage of the total number of trees on each PP

	Direct ^a	Inverse ^b	Alternated ^c
PP16	67	8	25
PP12	86	3	11
PP26	66	3	31

^a Represents the evolution expected for cypress mortality with trees that follow the tendency $A \rightarrow S \rightarrow D$. ^b Corresponds to the contrary evolution, with trees that follow the tendency $S \rightarrow A$. ^c Groups trees without any clear tendency of evolution such as $S \rightarrow A \rightarrow S$ or $A \rightarrow S \rightarrow A$. A: asymptomatic tree. S: symptomatic tree. D: dead tree.

neighbourhood of previous symptomatic trees, whereas others appeared next to the asymptomatic trees. Although the results are only qualitative, the maps provide a good visualization of the relationships among symptomatic trees and episodes of high appearance of trees affected by cypress mortality.

Discussion

Monitoring programs have been extensively used to detect the impact of climatic change, air pollution and outbreaks of pathogens on forest health, growth and dynamics (Dobbertin *et al.*, 2001; Solberg, 2004; Badea *et al.*, 2004; Bussotti and Ferretti, 2009; Klos *et al.*, 2009; Brown and Allen-Díaz, 2009). In the present work three PP from an existing dasometric monitoring program were used to analyse the temporal development of cypress mortality on plot and individual level.

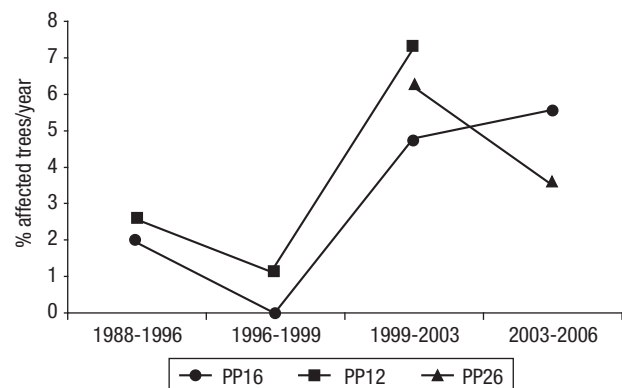


Figure 4. Temporal change of sanitary condition on each permanent plot (PP) of *Austrocedrus chilensis*. Appearance of affected trees expressed as percentage relative to the asymptomatic trees and normalized by the corresponding number of years on the period between inventories (PAfT).

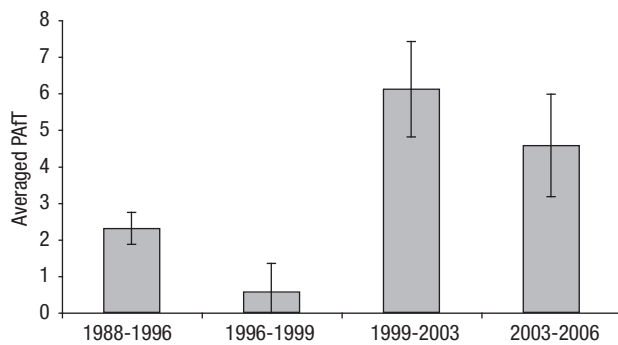


Figure 5. Trends of temporal appearance of affected *Austrocedrus chilensis* trees. Values of averaged PAfT and standard deviations (bars) corresponding to each period between inventories.

There is scarce information about temporal progression on cypress mortality to compare with the accumulative increment of affected trees detected on PP. Havrylenko *et al.* (1989) reported an increase of percentage of affected trees from 24 to 61%; however, this change was observed along six months (spring of 1988 to winter of 1989). In the same way, Rosso *et al.* (1994) established an increase from 52 to 72% along ten months (December 1990 to September 1991). Both studies were developed in other *A. chilensis* forests and the rapid progression of mortality was probably influenced by the soil properties and the abiotic conditions on the sites (La Manna and Rajchenberg, 2004a,b).

The episodic pattern observed for the three PP suggests the influence of general factors such as climatic change or outbreaks of pathogens. The low precipitation level should be considered at least as an important contributing factor on the development of symptoms and on the apparition of affected trees in the period 1988-1996. The 80s have been described as a warm and dry period (Villalba and Veblen, 1997) and similar conditions were registered for the last 90s (Suárez *et al.*, 2004; Le Quesne *et al.*, 2006). On the same way the regional drought of 1998-1999, that was involved on the high mortality of *Nothofagus* forests (Suárez and Kitzberger, 2008), could be related with the affected trees appeared along the period 1999-2003 and 2003-2006. These results agree with dendrochronological studies that refer the influence of warm and dry years on the beginning and progression (intensification) of radial growth decline (Calí, 1996; Villalba and Veblen, 1998; Mundo *et al.*, 2010). Dendrochronological analysis from trees on these PP, comparing the temporal development of radial growth decline and aerial symp-

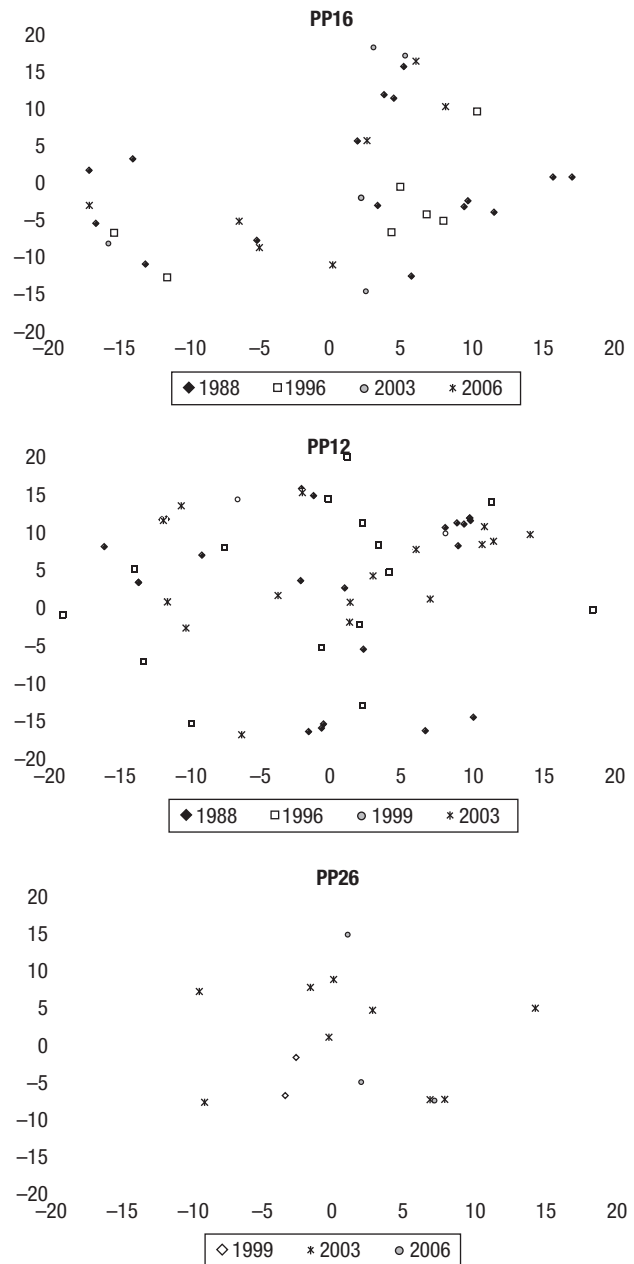


Figure 6. Spatial distribution of *Austrocedrus chilensis* trees affected by cypress mortality on each permanent plot (PP) and inventory. Distances from the central point of the plot are indicated in axes (x, y) at meters.

toms appearance will be needed to verify this hypothesis.

The three PP showed rapid and slow tree mortality, and this pattern agrees with the two previous reported tendencies of mortality for cypress mortality (Havrylenko *et al.*, 1989; Calí, 1996; Filip and Rosso, 1999) suggesting that the differences are probably determined on individual tree level.

Areas affected by cypress mortality are generally classified as disaggregated or aggregated (La Manna and Rajchenberg, 2004a). Disaggregated spatial pattern presents a distribution of affected trees fairly uniform over the area; on the contrary, in aggregated pattern the symptomatic trees form hot spots clearly separated from the asymptomatic neighbourhood. The fairly homogeneous distribution of affected trees detected in the PP seem to correspond to the disaggregated patterns frequently observed from the *A. chilensis* forests on the studied area. Distribution maps of cypress mortality were previously reported by plotting the sanitary condition of trees according to the beginning of decline of radial growth (Calí, 1996). These dendrochronological derived maps showed several points of appearance of affected trees and their relationships with temporary or permanent water streams. Analysis of spatial association between symptomatic and asymptomatic trees suggested that the mortality tends to occur patchily (Rosso *et al.*, 1989), and autocorrelation analysis showed that affected pairs of trees appear aggregated at 3 m distance (Rosso *et al.*, 1994). The last mentioned works have a great proportion of areas with aggregated pattern and high incidence of cypress mortality. Therefore, the impact of different distribution patterns should be considered on the future analysis of spatial association of affected trees.

Although we used only three PP, our results encourage the utilization of all PP included on the monitoring program of *A. chilensis* forests (37 PP) on a future study and provide the opportunity to promote a network of new PP installed on areas with different conditions of spatial distribution of cypress mortality (aggregated or disaggregated) and forest management strategies. The combination of distribution maps based on detection of aerial symptoms and beginning of radial growth decline appears as a powerful strategy to evaluate the impact of abiotic factors as the cause of cypress mortality. Discrimination between affected trees and individuals with high level of competition appears as a difficulty due to the unspecific symptoms of cypress mortality. Only three sanitary conditions based on the aerial symptoms were used in this work (asymptomatic, symptomatic and dead) because the level of affection is determined by visual observation of defoliation and yellowing. An objective and quantifiable index of cypress mortality needs to be incorporated and evaluated on future works to allow a better discrimination of affected trees and comparison among different studies. However, the database of the moni-

toring program provides other parameters that can be used to discriminate cypress mortality and mortality by competition. The distribution of trees in growth tendency, vigour and diameter categories allowed a more complete characterization of each PP. The level of competition and vigour varied among PP, showing the following patterns, $PP26 < PP12 < PP16$ and $PP16 < PP26 \leq PP12$, respectively. At PP16 similar percentage of trees in the low and intermediate growth tendency categories not determine similar percentage of trees for the low and intermediate vigour categories. A higher percentage is observed at the low vigour categories suggesting that competence has a great influence at the vigour trees in this PP. On the contrary, at PP12 and PP26 an increase of the percentage of tree in the high growth tendency was not accompanied by an increase of the percentage in the high vigour group, showing that other factors influence tree vitality. In other terms, the analysis indicates that competence is probably the principal factor that influences the vigour of trees in the lower diameter class; whereas the low vigour of trees that growth without a high level of competition should be a consequence of cypress mortality. This result agrees with the dendrochronological detection of larger tree growth at symptomatic trees than at asymptomatic trees before of beginning of cypress mortality (Mundo *et al.*, 2010).

In summary, this is the first report of temporal development of cypress mortality and patterns of mortality trees based on systematic monitoring of appearance of crown symptoms. The increase of cypress mortality along time was determined by particular episodes of appearance of affected trees on all PP, which can be related with warm and dry climatic periods. Tree mortality progresses rapidly or slowly, regardless of PP, suggesting that differences are probably determined on individual tree level. A relatively homogeneous distribution of affected trees without a clear pattern of expansion from a central point reinforces the hypothesis that the individuals affected by cypress mortality share some special characteristics such as genetic background, developmental conditions or physiological mechanisms for drought response.

The monitoring program of INTA provides an important database to analyse the development of cypress mortality. The study of the impact of mortality and logging of affected trees on forest dynamics, based on these resources, can help to define adapted management strategies of *A. chilensis* forests with cypress mortality.

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References

- ALEXANDER S.A., PALMER C.J., 1999. Forest health monitoring in the United States: first four years. *Environ Monit Assess* 55, 267-277.
- AMOROSO M., 2009. Stand development patterns as a consequence of the decline in *Austrocedrus chilensis* forests. PhD thesis. The University of British Columbia, Vancouver.
- BADEA O., TANASE M., GEORGETA J., ANISOARA L., PEIOV A., UHRILOA H., PAJTIK J., WAWRZONIAK J., SHPARYK Y., 2004. Forest health status in the Carpathian Mountains over the period 1997-2001. *Environ Pollut* 130, 93-98.
- BROWN L.B., ALLEN-DÍAZ B., 2009. Forest stand dynamics and sudden oak death: Mortality in mixed-evergreen forests dominated by coast live oak. *For Ecol Manage* 257, 1271-1280.
- BUSSOTTI F., FERRETTI M., 2009. Visible injury, crown condition and growth responses of selected Italian forests in relation to ozone exposure. *Environ Pollut* 157, 1427-1437.
- CALÍ S.G., 1996. *Austrocedrus chilensis*: estudio de los anillos de crecimiento y su relación con la dinámica del «Mal del ciprés» en el Parque Nacional Nahuel Huapi, Argentina. Degree thesis. Universidad Nacional del Comahue, Bariloche, Argentina.
- DE VRIES M., VEL E., REINDS G.J., DEELSTRA H., Klap J.M., LEETERS E.E.J.M., HENDRIKS C.M.A., KERKVOORDEN M., LANDMANN G., HERKENDELL J., HAUSSMANN T., ERISMAN J.W., 2003. Intensive monitoring of forest ecosystems in Europe. 1. Objectives, set-up and evaluation strategy. *For Ecol Manage* 174, 77-95.
- DOBBERTIN M., BALTENSWEILER A., RIGLING D., 2001. Tree mortality in an unmanaged mountain pine (*Pinus mugo* var. *uncinata*) stand in the Swiss National Park impacted by root rot fungi. *For Ecol Manage* 145, 79-89.
- EL MUJTAR V., ANDENMATTEN E., 2007a. Análisis del «Mal del Ciprés» mediante un «Modelo de Enfermedad»: Vacíos de Información y Perspectivas. *Revista de la Facultad de Agronomía, La Plata*, 106(2), 119-133.
- EL MUJTAR V., ANDENMATTEN E., 2007b. «Mal del ciprés»: búsqueda de la causa más probable de daño mediante un análisis deductivo y comparativo. *Bosque* 28(1), 3-9.
- FILIP G.M., ROSSO P.H., 1999. Cypress mortality (*mal del ciprés*) in the Patagonian Andes: comparisons with similar forest diseases and declines in North America. *Eur J For Path* 29, 89-96.
- HAVRYLENKO M., ROSSO P.H.A., FONTENLA S.B., 1989. *Austrocedrus chilensis*: contribución al estudio de su mortalidad en Argentina. *Bosque* 10(1), 29-36.
- HOLDENRIEDER O., PAUTASSO M., WEISBERG P.J., LONSDALE D., 2004. Tree diseases and landscape processes: the challenge of landscape pathology. *Trends Ecol Evol* 19(8), 446-452.
- JEGER M.J., 2004. Analysis of disease progress as a basis for evaluating disease management practices. *Annu Rev Phytopathol* 42, 61-82.
- KLOS R.J., WANG G.G., BAUERLE W.L., RIECK J.R., 2009. Drought impact on forest growth and mortality in the southeast USA: an analysis using Forest Health and Monitoring data. *Ecol Appl* 19(3), 699-708.
- LA MANNA L., RAJCHENBERG M., 2004a. The decline of *Austrocedrus chilensis* forests in Patagonia, Argentina: soil features as predisposing factors. *For Ecol Manage* 190, 345-357.
- LA MANNA L., AND RAJCHENBERG M., 2004b. Soil properties and *Austrocedrus chilensis* forest decline in Central Patagonia, Argentina. *Plant Soil* 263, 29-41.
- LA MANNA L., CARABELLI F., GÓMEZ M., MATTEUCCI S., 2008. Disposición espacial de parches de *Austrocedrus chilensis* con síntomas de defoliación y mortalidad en el Valle 16 de Octubre (Chubut, Argentina). *Bosque* 29(1), 23-32.
- LE QUESNE C., STAHL D.W., CLEAVELAND M.K., THERRELL M.D., ARAVENA J.C., BARICHIVICH J., 2006. Ancient *Austrocedrus* Tree-Ring Chronologies Used to Reconstruct Central Chile Precipitation Variability from AD 1200 to 2000. *J Clim.* 19, 5731-5744.
- MCLAUGHLIN D., 1998. A decade of forest tree monitoring in Canada: evidence of air pollution effects. *Environmental Reviews* 6(3-4), 151-171.
- MILGROOM M.G., PEEVER T.L., 2003. Population biology of plant pathogens. The synthesis of plant disease epidemiology and population genetics. *Plant Dis* 87(6), 608-617.
- MUNDO I.A., EL MUJTAR V.A., PERDOMO M.H., GALLO L.A., VILLALBA R., BARRERA MD., 2010. *Austrocedrus chilensis* growth decline in relation to drought events in Northern Patagonia, Argentina. *Trees*. doi: 10.1007/s00468-010-0427-8.
- PETRICCIONE B., POMPEI E., 2002. The CONECOFOR Programme: general presentation, aims and co-ordination. *J Limnol* 61(Suppl 1), 3-11.
- ROSSO P.H., BACCALÁN, HAVRYLENKO M., FONTENLA S., 1994. Spatial pattern of *Austrocedrus chilensis* wilting and the scope of autocorrelation analysis in natural forests. *For Ecol Manage* 67, 273-279.
- ROSSO P.H.A., HAVRYLENKO M., FONTENLA S.B., 1989. *Austrocedrus chilensis*: asociación espacial entre individuos sanos y afectados por la mortalidad. *Bosque* 10(2), 85-88.
- SOLBERG S., 2004. Summer drought: a driver for crown condition and mortality of Norway spruce in Norway. *For Path* 34, 93-104.

- SUÁREZ M.L., KITZBERGER T., 2008. Recruitment patterns following a severe drought: long-term compositional shifts in Patagonian forests. *Can J For Res* 38, 3002-3010.
- SUÁREZ M.L., GHERMANDI L., KITZBERGER T., 2004. Factors predisposing episodic drought-induced tree mortality in *Nothofagus* – site, climatic sensitivity and growth trends. *J Ecol* 92, 954-966.
- VILLALBA R., VEBLEN T., 1997. Regional patterns of tree population age structures in Northern Patagonia: climatic and disturbance influences. *J Ecol* 85(2), 113-124.
- VILLALBA R., VEBLEN T.T., 1998. Influences of large-scale climatic variability on episodic tree mortality in Northern Patagonia. *Ecology* 79(8), 2624-2640.