A Dendrogeomorphological Study of the Local Effect of Climate Change

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Abstract

The climatic and environmental conditions of Patagonia changed substantially after 1850 and after the mid-1970s decade. The impact of these changes is being observed in the new configuration of rivers and their riverine vegetation. The objective of this work is to integrate dendrogeomorphological techniques to the mapping and modeling of the recent distribution of vegetation of the riverine landscape, as an indicator of the local effect of climate change.The hydrological regime and the evolution of riparian vegetation at the confluence of the Cuyin Manzano and Traful Rivers were synchronized using the data obtained from 34 samples of plots of 6x6 meters. The plots were adjusted to the pixel resolution of two SPOT 7 satellite images (flood and dryness), concentric to an area of 18x18 meters, in order to validate a supervised classification of vegetation, belonging to different fluvial geoforms. In the plots with woody vegetation two trees corresponding to one or two age classes characteristic of the stands were drilled. The results indicate that, in agreement with global and Patagonia climate change estimates, there is a slight tendency of change in the flood and drought regime, with decreases in mean annual minimum flows and a period of drought in the last six years. The most outstanding result of our study indicates that the change of the hydrological regime implies a slight reduction of the average minimum flows, without this entailing a modification of the regime of flood pulses that in some cases are very extreme. This situation has a marked incidence in the fact that the woody vegetation colonizes new substrates and emerged landforms, while it is affected by frequent and intense flood events, with a change of the compositions and distribution of the vegetation.

Keywords: Climate change, vegetation, Patagonia

Introduction

Since 1850, and particularly since mid-1970s, some of the most important consequences of global climate change have been the increase of average annual temperature or seasonal temperaturas, the increase or decrease in rainfall at regional and widespread sea levels and a substantial rise in the frequency of extreme weather events (Rabassa 2010a). Averaged global data of terrestrial and oceanic temperature shows 0,85° C warming during the 1880-2012 period. A total increase of global temperature between 1850-1900 and 2003-2012 periods is of 0,78°C. The prospect for change in average precipitation based on several models at Patagonia's level, data from 1986-2005 projected to the period 2081-2100, indicates a decrease in the precipitation in the arid steppe and up to 30% in the Andean-Patagonic region (IPCC Report, 2014).

In Patagonia there is abundant dendrochronological, geological and glaciological information on climate changes and their regional effects. Between 1645 and 1715, due to the reduction of sunspots (Maenza et al., 2013), ice expansion in northern Patagonia ocurred, which was recorded by dendrochronological studies in moraines (Rabassa 2010a, b, Delgado et al., 2002). There is more history of studies of these characteristics that have allowed the dating of different climatic episodes at local and global level, in the Andean-Patagonic forests and in particular with conifers. In the 1970s, Lamarche (1979a, b) performed ring-width chronologies on *Araucaria araucana* and *Austrocedrus chilensis*. The forests of *A. chilensis* comprise a regional element of fundamental study of climate change (Souto et al., 2015).

The local effects of climate change in Patagonia have strongly manifested themselves since 1978. This region is characterized by its high vulnerability to the influence of its latitudinal position and the austral oceans, marine currents, its extreme climates partly derived form position and height in relation to the andes and high intrinsico variability. The local effects of climate change are manifestad in full loss of biodiversity and forests particularly in the steppe forest ecotone, increased frequency of extreme hydrological events such as floods and droughts, dessication of peatlands and wetlands, the retreta of glaciers, among others (Garreaud, 2011; Rabassa, 2010a; Villalba, 2002).

The objective of this paper is to integrate dendrogeomorphological techniques to the mapping and modeling of the recent distribution of riverside vegetation as an indicator of the local effect of climate change. The implications of the changes in a system for which a complete record of hydrological data was available were explored from the floodplain of the Traful river and Cuyin Manzano confluence. In this way, an improvement in analysis and a risk estimate is aimed to be achieved, focusing on the identification of extreme floods or droughts based on the tree ring growth analysis located over torrential surfaces of lower reaches or rivers. (Ruiz-Villanueva et al., 2010) and its spatial context.

Materials and Method

Study area

Traful river flows into the homonymous lake along its 21 km to its confluence with Limay river within the Parque Nacional Nahuel Huapi, with an average flow of 50 m3/s. Its main tributaries are the Rivers Minero, Cordoba and Cuyin Manzano. There is no systematic historical hydrologic data, but due to its geographical characteristics it can be said that hydrological regime is controled by a regulation factor established by the drainage of most of the basin of Traful Lake. Along its flow, it receives water from three mountain rivers, with evidential alluvial inputs that are characterized by the alluvial cone which converge in Traful's valley (Figure 1). The riverside wetland is composed of modest areas of exotic willows belonging to the *Salix alba – Salix fragilis* complex and its hybrid *Salix rubens*, along with *Austrocedrus chilensis, Discaria chacaye, Nothofagus dombeyi*, mainly alternated by coironal areas and *Schinus patagonicus* y *Fabiana imbricata* brushwood (Kitzberger et al., 2014). Likewise, Traful's hydrological regime and its riparian wetland comprise a sensor of the changes that occur in the basin as a result of the fluctuations of the rainfall regime and the geomorphological and ecologic process that make up the current riverside landscape. In the absence of full, scientific data, plain trees represent mostly hydrological information and the ecologic processes underway, as a consequence of the local effect of climate change.

Figure 1. Extension of the floodplain's surface and the influence of the main tributaries of the basin.

Methodology

Dendrogeomorphological techniques are a group of techniques based on the information of roots, logs and branch growth rings and bushes located in specific geomorphologic areas (Diez-Herrero et al., 2007). They are a fundamental tool in the analysis of natural risk, the modelling of river's water flood, and the dynamics of dead wood (Ruiz-Villanueva et al., 2017; Ruiz-Villanueva et al., 2010; Stoffel y Bollscheweiler, 2008). Data obtained allowed the completion us to complete, increase and even the re´placement of parts of hydrologic regime's register, reference of a basin's river in ecotonal forest-steppe region of northern Patagonia. In this way, baseline data uncertainty was reduced, giving a space-time validity framework to the ecological analysis possibility, natural risk of alluvial events, flood and drought with their managements and riverside planning in the immediate future.

Hydrological Data Analysis

The most extreme flood and drought regime was established with dates, duration and median for different flow rates with data pertaining to Cuyin Manzano river capacity station (data provided by Secretaria de Recursos Hidricos de la Nacion) closest to the study area throughTraful River
Córdoba stream
Cuyín Manzano River
Minero River
Limay River
Alicurá Lake
Alluvial fan (Córdoba stream)
Alluvial fan (Cuyín Manzano River)
Alluvial fan (Minero River)
Mallín
Cuyín Manzano floodplain
Traful floodplain

Legend
Traful River
Cuyín Manzano
River Limay River
Córdoba stream
Minero River
Alicurá Lake

Traful Lake the PULSO program (Neiff y Neiff, 2003). The series supplied covered daily median flows from 1971 to 2015, with cuts in 2005's series, and in some isolated days, throughout the record.

Dendrogeomorphlogical Data Analysis

A model which sincronizes reference hydrologic regime of Cuyin Manzano was applied and the development of growth ring of riparian arboreal vegetation of flood plains in Cuyin Manzano and Traful rivers confluence. Data was obtained of 34 plot samples of 6 x 6 m. Spots were adjusted to pixel resolution from two SPOT 7 satellite images obtained from flood period (10/15/2015) and another from drought (2/11/2016) concentric to an area 18 x 18 m, from which patch age and information of dominant species belonging to different vegetation stratum (tree, shrubs, herbs, bryophytes, aquatic plants and young trees with DAP <5cm) were obtained. Together, a geomorphological characterization was made and the height was estimated with a clinometer according to the river level in dry season and the rocky cover of the soil was measured as well. In woody vegetation plots, two trees corresponding to one or two age classes characteristics of the stand were drilled, by means of Pressler drill at chest height (DAP). From this measurement, a total of 32 representative samples of typical individuals of each forest age class area were obtained.

Spacial Data Analysis

A main components analysis (PCA) was carried out to recover a stability gradient conformed of pebbles, height and age of every patch area. Plots were classified according to six classes of CP1 values at equal intervals. These units represented training areas for a classification performed using Mahalonobis algorithm. From these images normalized difference water index (NDWI) was obtained, which were divided between flood and drought seasons with the purpose of acquiring more information on flood influence over each area. The digital processing was carried out with SOPI and Qgis 2.18. These allowed to compare valitidy of areas classification and flood effect by means of a categorizing of quotient between spring and summer NDWI by the technique of natural breakdown. At the same time, these were in turn confronted with pioneer tree species of each area that were analized by simple correspondence analysis (ACS) with Infostat software.

Results

Results demonstrate that Cuyin Manzano river has an average annual flow of 9.77 m3/s.

Between summer’s drought (Andean Patagonia’s dry season) and winter floods (wet season) and spring (ice melting of high basins), there is an average amplitude of flood pulses for a cut line equal to the median of maximum flows (19.77 m3 / s) of 92 days approximately. From pulses analysis it become deduced that long and prolonged droughts (1998, 1996, 1988 and 1974), including an extra-dry period from 2009 to 2015 and extreme events of flood exceeding 478.66 m3/s (2010). The recurrence of above-average flood pulses is quite frequent, occurring almost annually. However, recurrence of high-intensity floods, with a duration of more than 50 days, is less frequent, with events of this type occurring in 2008, 2006, 2002, 1994, 1993, 1991, 1984, 1982, 1980, 1979, 1972 and 1971. These data gives a recurrence of 3.7 years of intense pulses (Table 1).

Table 1. Summary of Cuyin Manzano River measurements obtained with PULSO and data provided by SHRN.

Six tree species composed by *Salix fragilis, Austrocedrus chilensis,*

Nothofagus dombeyi,

Nothofagus antarctica, Discaria chacaye and *Schinus patagonicus* were identified.

Dendrochronologic results in willows and cipresses showed significant fluctuations in the flows of intense flood of 2008, 2006, 2002, 1994, 1993, 1991, 1984, 1982, 1980, 1979, 1972 and 1971, and extreme droughts of 1998, 1996, 1988 and 1974, as well as extra-dry period from 2010 to 2015. In particular, all species exhibited the dry periods of 1974, 1988 and 1998, with great precision. (Figure 2).

Figure 2. Bloxplot with representation of all the growth samples from the ring trees of the floodplain of Traful and Cuyin Manzano rivers.

The average size of the ring of all species surveyed had a proper fit to the extreme flood events of 1997, 2002 and 2009. In the latter case, it is emphasized that although the flood pulse lasted 31 days, the average of the maximun reached 97.45 m3/s. In realtion to the

Function Values Units Dates
Average amplitude 91,99 days
Average intensity 23,64 m³/s
Number of pulses 163,00 pulses
Average 9,77 m³/s
Average of maximums 19,21 m³/s
Average of minimums 3,92 m³/s
Tension of maximum 1,046536E+09
Tension of minimum 1E+09
Mode 4,29 m³/s
Maximum 478,66 m³/s 24/5/2009
Minimum 0,00 m³/s 5/6/2011
Rings (mm)
Years median of the minimun flows, there is a better overall adjustment of ring sizes to droughts

(Figure 3).
Figure 3. Relationship of rings means of all species to: a) Average annual flow rates,
maximum flow rates (>19,7 m3/s) and mean minimum flows; b) the amplitude of the annual flood pulse and the dry season.
Salix fragilis and *Austrocedrus chilensis* showed through ring size a better fit to the reference hydrological record of Cuyin Manzano river. We estimate that throughout the rings an adjustment of the hydrological regime of the whole basin can be made, since at the same time willows and especially cypresses were adjusted to data of less extremes of two wet years in 2006 and 2013. *S. fragilis* showed a medium size fit of the rings to the extremely dry period such as 1988, 1996, 1998, 2004 and the period beginning in 2010 to 2015, with less than 8 days duration of the flood pulse. Included a dry year in 1968 for which there is no hydrological record, but the measurement of willows of more than 45 years is available.

Willows generally showed a tendency to increase around the wet years. For years with extreme flood event lasting more than 50 days, *A. chilensis* showed a better fit in relation to
S. fragilis, more accuratelly detecting the floods of 1979, 1984, 1993, 1994, 2002 and 2006.

However, it also showed a great fit to years with extreme flood pulses with maximum means upper to 70 m3/s in 1997, 2001 and 2009 (Figure 4). In all cases, dendrochronological record
0,00
20,00
40,00
60,00
80,00
100,00
120,00
0,00
1,00
2,00
3,00
4,00
5,00
6,00
media max
media min
media
media anillos

Año
Anillos (mm)
Caudales (m3/s)
0
50
100
150
200
250
300
350
400
0,00
1,00
2,00
3,00
4,00
5,00
6,00
días estiaje
días inundados
media anillos

Año
Anillos (mm)
Días
Average max.
Average min.
Average
Average rings
Rings (mm) Rings mm)
Days
Flow m³/s
Years
Years
Drought days
Flooded days
Rings average

A
B

completes absent hydrological information of 2005, evidencing a slightly humid year in relation to previous years.

Figure 4. Relationship of amplitude of flood and droughts pulses with ring growths in: a) willows (*Salix fragilis*) and b) cypress (*Austrocedrus chilensis*).

PCA generated a stability gradient mainly explained by CP1 (49.7 %) and between low and stony areas and high zones (Figure 5). The PCA explained the 84.5 % of the variance of the samples. The CP1 explained the 49. 7 % of the variation on a gradient of greater rocky and lower areas in opposition to the other higher and stable end. This axis resulted in six categories created by six fixed intervals plus one additional category not sampled in the field, corresponding to water bodies obtained from NDWI. Among the six categories of terrestrial coverage it is highlighted that five had some level of presence of the exotic willow *S. fragilis*.

The supervised classification made it possible to obtain a map of vegetation cover associated with the disturbance gradient. This, together with the flood limits reached in October 2015, constituted a good adjustment of new colonization and riverbed dynamics (Figures 6 and 7).

Rings (mm)
Rings (mm)
Days Days
Years
Years
Drought days
Flooded days
Willows average
Drought days
Flooded days
Ciprés average
0
50
100
150
200
250
300
350
400
0,00
1,00

2,00
3,00
4,00
5,00
6,00
días estiaje
días inundados
Media sauces

Año
Anillos (mm)
Días
0
50
100
150
200
250
300
350
400
0
1
2
3
4
5
6
días estiaje
días inundados
Media ciprés

Año
Anillos (Días
Rings (mm)
Days Drought days
Flooded days
Ciprés average
Drought days
Flooded days
Willows average
A

B

Figure 5. Representation of stable gradient between rocky coverings, height and age of patches by means of ACP.

Figure 6. Classification of the coverages on the floodplain of Traful river according to a stability gradient.

Patch age
Height
Rocky
Legend
Rocky Baccharis sp. - Discaria sp.
Water
Shrubs Schinus sp. - Fabiana sp. - Stipa sp.
Low plain Willows – Baccharis sp.
Mixed forest
Riverine forest Willows
Active riverbed Willows – Discaria sp.

Figure 7. Zoom of the confluence of Cuyin Manzano and Traful Rivers and delimitation of October 2015 flood.

From the classification by natural breakdown six classes were obtained, one of them comprises the stability range around 1 (0.94-1.20) (Figure 6). Through ACS, complementary information was acquired which indicated that both classifications showed a good association level on axis 1 of 63% (Figure 8).

Legend

----- Flood limit of Spring (2015)

Figure 8. Correspondence analysis between classifications: stability gradient classes (green) and obtained classes form spring-summer NDWI cocient (red).

In more detail, both classifications show relatively similar adjustment to the pioneer vegetation of each plot. Together these demonstrate that young trees of *Discaria chacaye* colonizes very unstable areas in the range of NDWI ratios <1.98 (Figure 9a) or associated to higher instability categories (C5 and C6) (Figure 9b). On the opposite side, *Schisnus patagonicus* does it around quotient ranges near 1 of greater stability and to higher classes C1 in regard to Floyd level. Willows cover classes in both cases of relative disturbance, which showed to cover instable areas with new plants and covering stable areas but low in relation with the flood level.

Rocky Baccharis sp. - Discaria sp.
Active riverbed Willows – Discaria sp.
Shrubs Schinus sp. - Fabiana sp. - Stipa sp.
Riverine forest Willows

Mixed forest
Low plain Willows – Baccharis sp.

Contribution to Chi square (A)
Eigenvalue Inertia Chi-square (%) accumulated

No tree
Contribution to Chi square
Eigenvalue Inertia Chi-square (%) accumulated

Figure 9. Simple correspondance analisis for two classifications: a) by natural breakdown resulting from spring-summer NDWI ratio and b) obtained from CP 1 of the ACP (r: young trees)

Regardless of the classifications (Figures 9a and 9b) and the techniques used individually, all data shows a colonization in unstable zones associated with rocky streambed and rocky sand, but also at extreme wet or dry periods (Figures 2, 3 and 4). The height imposes a limit to willows development in the humid river ecotone and steppe. The interface shows that between the streambed and the steppe there is a variety of tree species and age structures and an evolution of the system to a greater diversification of the floodplain. This is associated to a reduction of flows means and rings growths, without any implication of events reduction of extreme flood events.

Discussion

Our methodological model, which combined the study of patches and trees' age, the influence of the pulses of flood and drought and the position in space, allowed to approach a spatial dimension of the process. As a consequence, each patch configures a position in relation to a stability gradient reached by more frequent floods. Height data, disturbance indicators such as rockiness or patch's age, all associated with the influence of flood obtained form NDWI quotient, comprise the information of representative variables of the river dynamics.

According to the IPCC report (2014) there is no widespread confidence that global climate change will affect the frequency and magnitude of global river floods (IPCC, 2014). This is because the evidence is limited by the scarcity of long-term records of unmanaged basins.

This is due to the fact that floods can be strongly influenced by various human activities such as deforestation which affects watersheds. In the case of Traful river basin, instead, the basin has a very high level of conservation because it is entirely within the Nahuel Huapi National Park, which administration reduced the frequency of historical fires that until the middle of 20th Century were practiced, associated to cattle raising

(Kitzberger at al., 2014). Thus, not only the basin counts but the native forest has recovered as Kitzberger and Jump (Jump et al., 2017; Kitzberger et al, 2014) and Gowda (Gowda et al., 2012 have evidenced.

Contribution to Chi square (B)

Eigenvalue Inertia Chi-square (%) accumulated

No tree

The results of this study on *Austrocedrus chilensis* individuals and patches show two important aspects: the recent colonization of cypresses on the floodplain and the adjustment of cypress growth data to the hydrological variables. In relation to the exotic species of the *Salix alba – Salix fragilis* complex, in our study state, our results indicate simultaneous invasions in other parts of the Limay river basin (Datri et al., 2016) and in analogous way in another mountain rivers (Datri et al., 2017) of same complex species. In this way, species an their hybrids are sensitive to the stochastic dynamics of flood pulses that, in first instance, produce a large amount of vegetative material that constitutes the means of asexual reproduction.

Then, associated with periods of drought that release disturbance surfaces, the species successfully colonize new river geoforms that open the way to a process of complex sucesion directed by endogenous and exogenous processes related to the disturbance recurrence.

In the floodplain of Traful river, the willows are associated to events of perturbation by extreme floods followed by droughts of interannual amplitude. This is demonstrated by the increase of willow rings associated with wet years, but above all by the increase of individuals belonging to well-defined age classes. In fact it was recorded in the ethnic groups associated with extreme event years of 1971, 1972, 1983, 1984, 2001 and 2002 followed by periods of relative stability and subsequent sequences. This confirms the presumption about the configuration of the willow cycle in the Limay basin, using dendrogeomorphological techniques to explain the effect of regulation by hydroelectric dams (Datri et al., 2016). Both hydrological and dendrochronological records in the case of Traful basin, the idea that a natural cycle induced by changes of elements in the climate control the succession of the floodplain. Proof of this is that, in addition to willows, it favored the forest native species like coihues and cipresses, in Azul river (Datri and others, al 2017), also employing similar techniques.

Species like *Discaria chacaye*, *Nothofagus dombeyi* and *Austrocedrus chilensis* most recently have colonized unstable areas due to the reduction of median flows and the increasing of inferior flows amplitude below the minumun means. This added to the stabilization factor of riverbank which liberate raised and isolated surfaces of the frequent disturbance, that promoted the development of *Schinus patagonicus*. In this sense, dendrogeomorphological techniques describe the succession process that originates in the changes induced by the climate. We only had an incomplete hydrological record and for guidance only. But the age of the trees and the distribution on the fluvial geomorphology allowed to complete information of the processes that occur there.

From the detailed topography of river's sections, localization and height of the elements associated to the current, we got two spatial models which allowed to be close to the flood magnitude and its ecological dynamic (Stoffel y Bollscheweiler, 2008; Diez-Herrero et al., 2007). According to Ruiz and Villanueva (Ruiz-Villanueva et al., 2010), the dendrogeomorphology constitutes a tool for flood analysis and the dating of past events, improving the absence of historical records of floods and flows. Completing with a detailed mapping and associating each plot to a defined spatial process, we can detect three succession periods with specific geomorphological positions along a stability gradient conferred by changes in hydrological dynamics. In the highest part, it has been released from most frequent means and low intensity disturbance on which grasslands developed with *Schinus patagonicus.* A large transition zone affected by a higher recurrence of disturbances in relation to the first two decades of the dating scheme, colonized by mixed forests and riparian forests with *S. alba- S. fragilis* complex species. Finally, a stage on the fluvial bed, probably reached by willows and by *Discaria chacaye*, as a consequence of a reduction of average flow in the last six years.

Our work supports the idea that the climate change to local scale implies modifications on the flood regime (IPCC, 2014) with a certain risk increase associated to human activities on riparian wetlands. In this case, it is synthesized in the increase of the amplitude of the dry season, a reduction of mean flows (Garreaud, 2011; Lara et al, 2008) but with some increase of extreme flood events. As Villalba (2002) indicates, the changes in all climatic variables implied a change in the plants' physiology. In the cypress case, which is favored in the transition steppe-forest by wet and fresh summers in the first years, it was followed by droughts that control the competitive capacity of pastures and comprised the most favorable condition for its establishment and development (Villalba, 2002). In our case, these dynamics are confirmed, since the registered individuals belong to the age classes associated to the water alternation on the floodplain. The willow could be a competitor affected by this dynamic, although our work shows that there is a movement of the species along with *D. chacaye* towards the riverbed (figure 10). Figure 10. Model distribution of species and patch ages on a profile of the Traful River.

If the trend analyzed here is generalized over the next few years in the Traful and Limay basins in particular, this colonization of riverbeds and active floodplains brings a greater risk of removal of senile trees and riverbank instability (Ruiz-Villanueva et al., 2017). This is why the techniques conjugated in this work show not only the evolution of riparian dynamics, but also that dendrogeomorphological support is a useful tool for the analysis of natural risk (Ruiz-Villanueva et al., 2010; Stoffel and Bollscheweiler, 2008; Boninsegna and Delgado, 2002) and spatial expression of changes (Kitzberger et al., 2014).

Conclusion

The colonization of the emergent substrates of the Traful riverbed and the active floodplain (componed by *S. fragilis*, *Austrocedrus chilensis* and *Discaria chacaye* complex species) result from the reduction of the annual volumes of runoff and the process of thawing. These modifications are in line with local change models of global climate change, which imply implicate a decreasing rainfall and rising temperatures, according to global climate change for northern Patagonia. Dendrogeomorphological tecniques (with the complementation of digital processing of satellite images tools) contributed to the understanding of spatial dimension of the change process in the watershed. The stability gradients, constructed with topographic variables and dating, allowed the recognition of vegetation classes associated to a spatial position united with interannual river dynamics.

Acknowledgments

This project has the financing of the University of Flores. A special thanks to Tania Molina for the revision of the english text.

References:

Boninsegna, J. & Deldado de Brun, S. (2002) Variaciones en el caudal del rio Atuel desde 1575 hasta el presente reconstruidas con series de anillos de arboles y sus relaciones con la oscilacion del sur. En: Tromboto D., Villalba R. (Editores) *IANIGLA, 30 anos deinvestigacion anos de investigacion basica y aplicada en ciencias ambientales*. IANIGLIA. PP: 269.

Datri, L., Faggi A. & Gallo L. (2017) *Crack willow changing riverine landscapes in Patagonia*. Ecohydrology (in press)

Datri L., Faggi A., Gallo, L. & Carmona F. (2016) *Half a century of changes in the riverine landscape of Limay River: the origin of a riparian neoecosystem in Patagonia (Argentina).*

Biological Invasions. ISSN 1573-1464. Delgado, S., Masiokas, M., Villalba R., Trombotto D., Ripalta A., Hernandez J. & Cali S. (2002) Evidencias historicas y dendrocronologicas de las variaciones climaticas en la patagonia

durante los ultimos 1000 anos (PATAGON-1000). En: Tromboto, D., Villalba, R.
(Editores) *IANIGLA, 30 anos de investigacion basica y aplicada en ciencias ambientales*. IANIGLIA. PP:269.
Diez-Herrero, A., Ballesteros, J., Bodoque J., Eguibar, M., Fernandez, J., Genova, M., Lain,
L., Llorente, M., Rubiales, J. & Stoffel, M. (2007) *Mejoras en la estimacion de la frecuencia y magnitud de avenidas torrenciales mediante tecnicas dendrogeomorfologicas*. Boletin Geologico y Minero, 118 (4): 789-802
Garreaud, R. (2011) *Cambio Climatico: Bases Fisicas e Impactos en Chile*. Revista Tierra Adentro – INIA No. 93.
Gowda, J.H., Kitzberger, T. & Premoli A.C. (2012) *Landscape responses to a century of land use along the northern Patagonian forest-steppe transition*. Plant Ecology 213: 259-272
Jump, A., Ruiz-Benito, P., Greenwood S, Allen C., Kitzberger T., Fensham, F., Martinez-
Vilalta, J. & Lloret, F. (in press) *Structural overshoot of tree growth with climate variability and the global spectrum of drought-induced forest dieback*. Global Change Biology
Kitzberger, T., Blackhall M., Cavallero L., Ghermandi L., Gowda J., Heinemann K., Raffaele
E., Sanguinetti J., Suarez M.L. & Tercero Bucardo N. (2014) Comunidades dinamicas. Pp. 37-78 en: E. Raffaele, M. de Torrres Curth, C.L. Morales & T. Kitzberger (Eds.). *Ecologia e Historia Natural de la Patagonia Andina. Un cuarto de siglo de investigacion en biogeografia, ecologia y conservacion*. Editorial. Felix de Azara. Buenos Aires
Lamarche, V., Holmes, R., Dunwiddie, P. & Drew, L. (1979a). *Tree-ring Chronologies of the Southern Hemisphere*. Vol 1: Argentina. Chronology Series V, University of Arizona, Tucson, Arizona.
Lamarche, V., Holmes, R., Dunwiddie, P. & Drew, L. (1979b). *Tree-ring Chronologies of the Southern Hemisphere.* Vol 2: Chile Chronology Series V, University of Arizona, Tucson, Arizona.
Lara, A., Villalba, R. & Urrutia, R. (2008) *A 400-year tree-ring record of the Puelo River summer–fall streamflow in the Valdivian Rainforest eco-region, Chile*. Climatic Change.
Volume 86, Issue 3, pp 331–356. Maenza, R., Compagnucci, R. & Ariztegui, R. (2013) *Salidas del ECHO-G de campos de temperatura y viento zonal en 1000hPa sobre el sur de Sudamerica para el ultimo milenio.* GEOACTA 38(1): 61-80.
Rabassa, J. (2007) *El impacto del cambio climatico en los glaciares patagonicos y fueguinos.* Ciencia Hoy 17(97): 50-57, Buenos Aires.

Rabassa, J. (2010a) *El cambio climatico global en la Patagonia desde el viaje de Charles Darwin hasta nuestros dias*. Revista de la Asociacion Geologica Argentina 67 (1): 139 – 156.

Rabassa, J. (2010b) Impact of global climate change on glaciers and permafrost of South America, with emphasis on Patagonia, Tierra del Fuego and the Antarctic Peninsula. En: Latrubesse, E. (ed.) *Natural Hazards and human-exacerbated disasters in Latin America, Special volumes of Geomorphology*. Developments in Earth Surface Processes 13: 415438, Amsterdam.

Ruiz-Villanueva, V., Diez-Herrero, A., Stoffel, M., Bollscheweiler, M., Bodoque J. & Ballesteros J. (2010) *Dendrogeomorphic analysis of flash floods in a small ungauged mountain catchment (Central Spain)*. Geomorphology. Volume 118, Issues 3–4, 1. Pages 383–392.

Ruiz-Villanueva, V., Wyżga, B., Mikuś, P., Hajdukiewicz, M. & Stoffel M. (2017) *Large wood clogging during floods in a gravel-bed river: the Długopole bridge in the Czarny Dunajec River, Poland.* Earth Surface Processes and Landforms. PP: 16.

Souto, C.P., Kitzberger, T., Arbetman M.P. & Premoli M.P. (2015) *How cold-sensitive species endure ice ages? Phylogeographic and paleodistribution models of postglacial range expansion of the mesothermic drought tolerant conifer Austrocedrus chilensis.* New Phytologist. 208: 960-972.

Stoffel, M. & Bollscheweiler, M. (2008) *Tree-ring analysis in natural hazards research – an overview.* Natural Hazard and Earth Systems Science. 8 187-202.

Villalba, R. (2002) Influencias climaticas en la dinamica forestal del ecotono bosque-estepa en el norte de patagonia. En: Tromboto D., Villalba R. (Editores) *IANIGLA, 30 anos de investigacion basica y aplicada en ciencias ambientales*. IANIGLIA. PP:269.