v. 3, n. 20, 2023

Journal of
Engineering
Research

POST-FIRE RESPONSE ANALYSIS BASED ON LANDSAT TIME SERIES IN ARAUCARIA-LENGAFORESTS IN SOUTH-CENTRAL CHILE

Valentina Gonzalez-Castro
Geomatics and landscape ecology laboratory (GEP), Forestry and Nature Conservation Faculty, Universidad de Chile

Franco Magni-Pérez
Geomatics and landscape ecology laboratory (GEP), Forestry and Nature Conservation Faculty, Universidad de Chile

Liliana Guzman-Aguayo
Geomatics and landscape ecology laboratory (GEP), Forestry and Nature Conservation Faculty, Universidad de Chile

Lissette Cortés
Geomatics and landscape ecology laboratory (GEP), Forestry and Nature Conservation Faculty, Universidad de Chile

H. Jaime Hernández
Geomatics and landscape ecology laboratory (GEP), Forestry and Nature Conservation Faculty, Universidad de Chile

Abstract: Phenological processes such as the appearance or abscission of leaves depend on the environmental conditions in which a plant or plant community develops. Anthropic disturbances such as forest fires can modify these conditions, affecting phenology. Free access satellite information allows the monitoring of vegetation over time. In this work, the phenology of Andean forests of *Araucaria araucana* (araucaria) associated with *Nothofagus pumilio* (lenga) from south central Chile was analyzed using NDVI time series with the objective of identifying seasonal changes, trends or abrupt changes related to forest fires that occurred between 1998 and 2021. The results show that the start (SOS) and end of the growing season (EOS) could be related to the fire events. In addition, abrupt changes in the trend component coincident with the fire events were detected. These preliminary results lay a foundation to continue studying the phenological behavior of these forests under different environmental conditions.
Keywords: Time series, NDVI, Pheology, Wildfires, *Araucaria araucana*.

INTRODUCTION

Vegetation phenology consists of the series of seasonal biological processes controlled by the environmental conditions in which they develop. Through the study of anomalies in phenology, it can be analyzed how environmental alterations impact a plant community[1]. Index time series are a key tool for studying vegetation dynamics[2]. The Normalized Difference Vegetation Index (NDVI) is a greenness measure related to plants structural and productive properties[3]. The NDVI time series are used to interpret environmental phenomena impacts (i.e., wildfires) since it allows the construction of temporal and seasonal profiles of plant activity.[3,4,5]. Today there is a wide availability of NDVI data from different remote sensors[2,5]. However, only two missions allow the construction of time series of more than 30 years, one of them is LANDSAT.

Araucaria araucana (Mol.) K. Koch (monkey puzzle tree) is a native conifer world-renowned for its high cultural, ecological and economic value. In Chile, it grows from Biobío to Los Lagos both in the Coastal and Andes Mountains. is part of the "High Andean Deciduous Forest" where it is associated with various species of the *Nothofagus* genus, with *Nothofagus pumilio* (lenga) being one of its main companions in the Andes[6,7].

Is a natural monument[8] and the commercialization of its wood and fruits is internationally prohibited[9]. Currently, it is a vulnerable species in the populations of the Andes[10] and the forests where it grows are considered preservation forests[11]. However, this species continues to decline[10] with forest fires currently being its greatest threat[7].

Fire plays a fundamental role in *Araucaria-Nothofagus* forests, and the species have adaptations that allow them to resist[12]. But the occurrence of forest fires has significantly increased due to the increase in anthropic presence in the south-central zone of the country[7]. This is aggravated by climate change, which has caused a decrease in rainfall and an increase in electrical storms in the Andean area[13,14]. this work seeks to evaluate the temporal response of the photosynthetic and phenological activity of araucaria- lenga stands in south-central Chile to forest fire events.

MATERIAL AND METHOD

Study area. Three stands located northeast of the Araucanía region in central-southern Chile affected by forest fires in the last 30 years and made up mainly of *Araucaria araucana* and *Nothofagus pumilio* were included, according to information from the Native

Forest Registry (CBN)[15] and information compiled in the FIBN 016/2019 CONAF project.

The first stand located inside *China Muerta* National Reserve affected by a fire in 2015 that burned about 50% of the reserve[16]. 16. The second corresponds to an area inside the fund *La Fusta* located about 15 km south of Lonquimay that was affected by a forest fire in 2002[17]. The third correspond to an area inside the *Conguillío* National Park, in sector "La Marsella" (western limit of the park) affected by wildfire in 2015 that consume 62 ha. The stand show differences in the composition of species, vegetation cover and topography (Table 1).

Code.	Name	Date of fire	Area (ha)	Altitude (m.a.s.l.)	Slope°	*Coverage Sp1 Sp2 Sp3*
FCHM	China Muerta	2015	45	1538	13	*Dense N. pumilio A. araucana C.coleou*
FLF	La Fusta	2002	80	1396	15	*Open A.araucana N. pumilio C.coleou*
FLM	La Marsella	2015	12	1394	7	*Dense N. Dombeyi A. araucana N. pumilo*

Table 1: Characteristics of studied **stands.**

Time series. For the construction of time series, we worked on the *Google Earth Engine* platform. Images from the Landsat TM (L5), ETM+ (L7) and OLI/TIRS (L8) sensors were used, specifically the products of Collection 2 Level-2 Surface reflectance, which are generated from Level-1 inputs. that meet the constraint of solar zenith angle < 76° and include the necessary ancillary data inputs to generate a scientifically feasible product[18,19]. These images come with built-in radiometric and geometric corrections. The ETM+ sensor of the Landsat 7 satellite from June 2003 presents a problem with its line scan corrector which is turned off (SLC- OFF). Due to this, the images of this sensor present bands of invalid data or Gaps[20]. For this reason, Landsat 7 images were mainly used to fill in the discontinuities presented by L5 and L8.

Lastly, even though preprocessing increases the compatibility of information between sensors, there are still small but potentially significant differences in the quality of the information detected[20,21]. These differences are created mainly in the bands that correspond to the segments of the infrared light spectrum and cause that in the calculation of certain indices (i.e., NDVI) an increase in this can be observed in the last portion of the series[20]. To minimizes this effect, the equations of Roy et al., (2016) were applied to harmonize the OLI signal with ETM+ and TM. Scenes with cloud percentage greater than 50% were filtered, then a cloud mask was applied using the quality band of each image. Once these steps were executed, all the images were joined to calculate the NDVI index on this collection according to the next formula: **NDVI = (NIR - RED)(NIR + RED)[22].**

Then, the maximum value of monthly NDVI per pixel was calculated with all the images available in each period, obtaining a time series of NDVI of 288 months in total (or 24 years). Finally, the maximum time series of the area was extracted for each stand.

Phenological analysis. For the phenological analysis, we worked in the R-studio environment. The Greenbrown package was used[23] which allows the extraction of a series of metrics (phenophases) that characterize the phenological cycle in each pixel. For this, a series of methodological steps must be followed: (i) filling of permanent gaps with the minimum of each year; (ii) smoothing and interpolation to daily values applying a spline function and (iii) detection of phenological events using the threshold methods[1]. he result of this process was a table with the phenological metrics of each stand expressed in DOY (day of the year).

Phenophases	Description
SOS	Start of season
EOS	Endof season
LOS	Length ofseason
POT	Position of trough value NDVI
POP	Position of peak value NDVI

Table 2: phenological metrics.

Trend and trend change (breakpoints). The methodology proposed by Verbesselt et al., 2010 [24] was applied to the time series resulting from the preprocessing in greenbrown to detect abrupt changes in the series produced by variations in the environment. Using the BFAST algorithm, the time series was decomposed into (i) seasonality, (ii) long-term trend, and (iii) residual variations based on a fitted additive model. By default, the package considers a linear trend function in addition to a harmonic component which is common for phenological analysis[24]. In this case, it was of interest to evaluate the highest magnitude breakpoints in the trend and seasonality component in each stand.

RESULTS

Time series. The methods used to reduce outliers and gaps in the time series show a good fit. In the three stands, marked seasonal behavior and a clear decrease in post-fire photosynthetic activity, with the "La Fusta" stand showing the smallest variation (fig 1.)

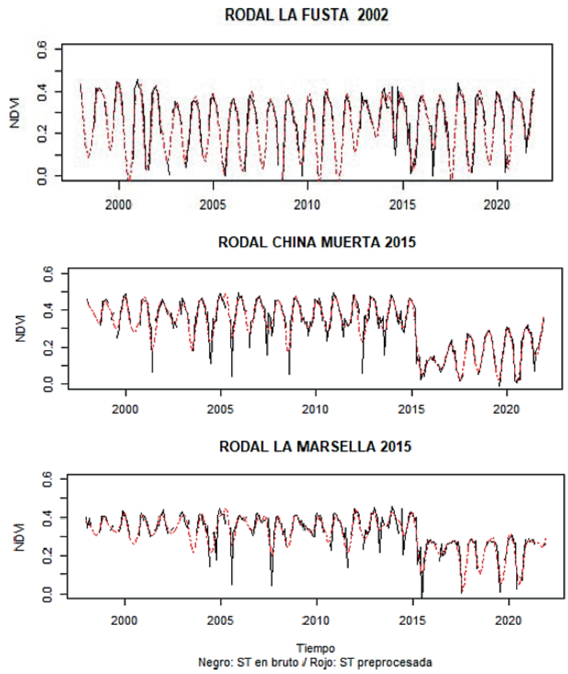

Fig 1: Stand time series (1998-2021), in black raw data and in red smooth data.

Detecting trend changes. Abrupt changes were detected in the trend component of the three time series considering that the change should have a duration of at least 5% of the total length of the data base. No significant changes were detected in the seasonality component.

	CHM	LF	LM
Trend **Seasonality**	Yes None	Yes None	Yes None
Year (month) BP	2015(3)	2000(2)	2015(3)
Data BP	207	26	207

Table 3. Output **BFAST.**

These changes coincide with the fire date in "China Muerta" and "La Marsella", in the case of "La Fusta" the algorithm detected the anticipated change (Fig 2, Table 3).

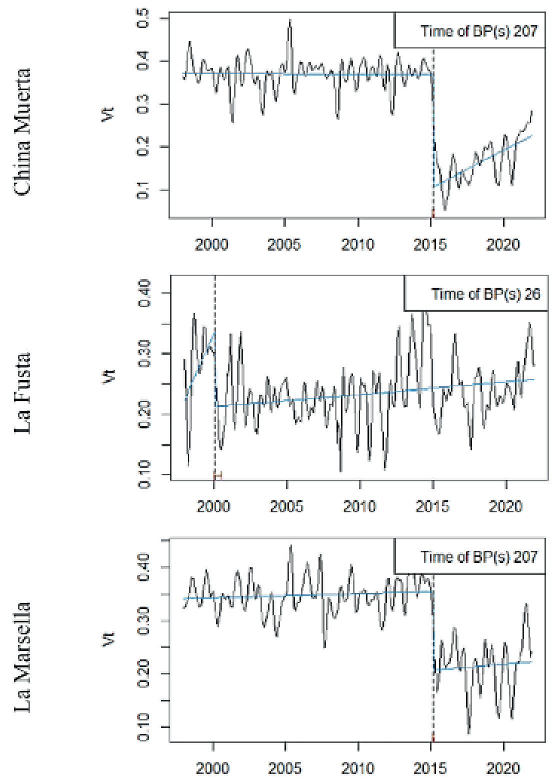

Fig 2: Breakpoint detection on the trend component.

Phenological Characterization. The phenological cycle of the analyzed araucaria-lenga stands begins between September and October, ends between April and May and the maximum photosynthetic expression occurs at the end of December and the beginning of January (table 4). Although the sites present differences in terms of their spatial location and topography, the occurrence of the phenophases was similar in all cases (fig 3), only La Marsella showed early values for average SOS, however, the difference is smaller.

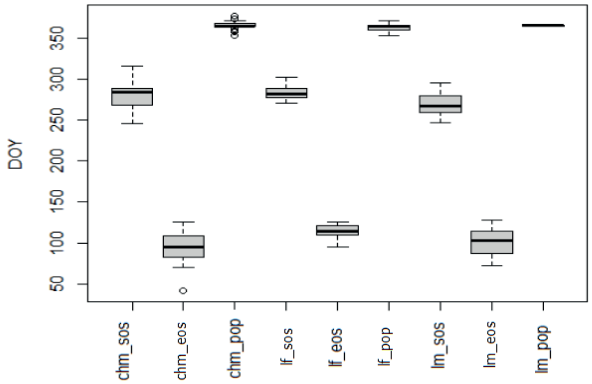

Fig 3. Phenophases.

	CHM	LF	LM	
SOS	281±17	282±8	269±14	sep-oct
EOS	93±20	114±9	186±17	apr-jul
POP	366±5	363±4	366±1	Dic-Jan

Table 4: Mean phenological metrics and standard deviation.

Phenological metrics show great variation year to year. No significant negative or positive trends were found in any of the metrics evaluated for any stand. The little variability in the PEAK in La Marseille is striking. Regarding the effect of fire on the metrics, apparently the beginning of the growing season is the value that could be affected since it shows advances or missing data in the occurrence in years after the fire.

Journal of Engineering Research ISSN 2764-1317 DOI 10.22533/at.ed.3173202307064

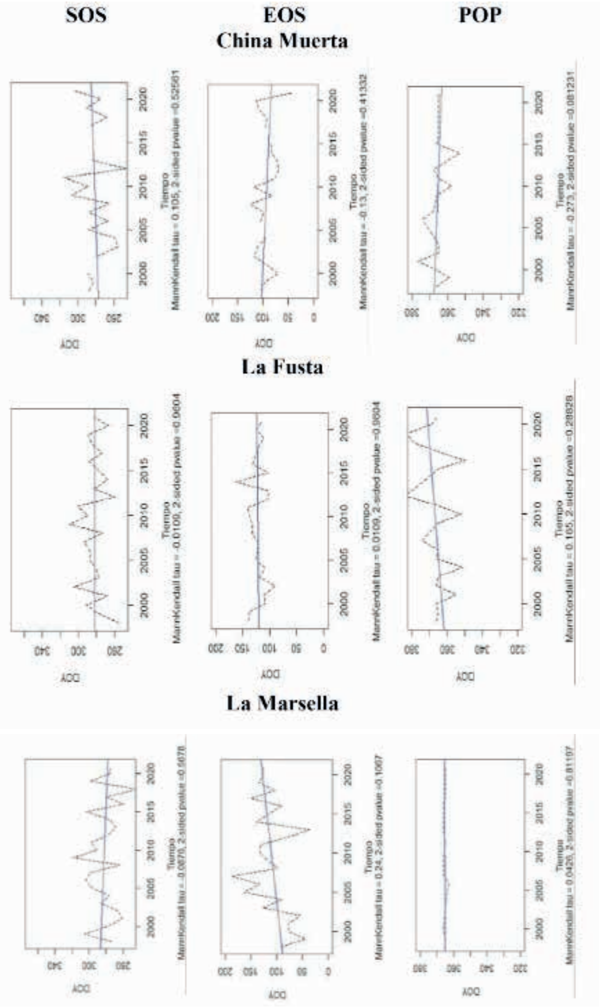

Fig 4. Temporal variation of the phenophases.

Finally, the average metrics of the five years before and after the fire event are compared, to which only EOS shows a slight delay in the average occurrence (table 5).

	CHM	LF	LM	
SOS_pre	287±24	282±8	271±13	sep-oct
SOS_post	284±14	282±7	272±19	sep-oct
EOS_pre	84±18	110±13	97±16	apr-may
EOS_post	90±29	115±9	109±18	apr-may*
POP_pre	362±6	361±6	366±1	dic-jan
POP_post	365±1	366±4	365±1	dic-jan*

Table 5. Pre and post fire metrics.

DISCUSSION

The phenology and photosynthetic activity of plants is strongly controlled by climatic variations in factors such as temperature, precipitation, etc. Both, annual and decadal variations generate variations in the spectral vegetation response[23,25] In this area, because of the megadrought in south-central Chile the vegetation tends to present negative trends[26,27,22]. But, alteration factors such as forest fires modify these trends, generating breakpoints easily detected by specialized algorithms and increasing post-fire NDVI trends related to subsequent recovery, which coincides with what was observed in this case.

According to some authors, the post-fire recovery is not of the original species, the fire causes a change in the composition of species that is greater or lesser according to factors such as the intensity of the fire and climate change[29,30]. For example, after the China Muerta fire in 2015, the species that sprouted the fastest belonged to the genus *Chusquea*, *Alstroemeria* and *Gaultheria*[31]. While, in the results of the FIBN 016/2019 project in "La Fusta", the intensity of the fire varied throughout the affected area, being those most damaged sectors where extensive and dense patches of *Chusquea coleou*[28].

The results in the phenological analysis that in general agree with those reported by similar studies in the area[28,32], and also with particular studies of the phenological cycle of the araucaria and lenga species that occupy the upper stratum in these stands[7,33]. The differences detected in the pre and post fire values at the end of the season (EOS) as well as the advances in the start of the season (SOS) in the temporal variation graphs could be explained by this initial occupation of the shrubby/herbaceous stratum immediately after the fire which decreases as the araucaria and lenga individuals, thanks to their adaptations, return to occupy their place in the forest[6,7] .

CONCLUSIONS

The results obtained in this study indicate that forest fires in araucaria-lenga forests in south-central Chile cause changes in the vegetation temporal dynamics behavior, and, more subtly, in the phenology mainly at the start (SOS) and at the end of the growing season (EOS). However, it is necessary to consider that this response is not unique and is affected by other variables such as the intensity of the fire, drought and other disturbance events (livestock, seed collection, logging, etc). Therefore, more studies should be carried out to characterize the behavior of these plant communities under different topographic conditions and their correlation with environmental variables, with and without anthropic alteration, defining a normal range for the entire population that allows better detection of anomalies when they occur.

REFERENCES

[1] White, M.; Thornron, P. y Running, S. 1997. A continental phenology model for monitoring vegetation responses to interannual climatic variability. Global Biogeochemical Cycles. 11(2), 217-234.

[2] Kuenzer, C., Dech, S. y, Wagner, W. (2015). Remote Sensing Time Series Revealing Land Surface Dynamics: Status Quo and the Pathway Ahead. En: C. Kuenzer, S. Dech, y, W. Wagner, Remote Sensing Time Series: Revealing Land Surface Dynamics. Springer. Suiza. 22: 1-24.

[3] Forkel, M.; Carvalhais, N.; Verbesselt, J.; Mahecha, M.; Neigh, C. y Reichstein, M. 2013. Trend Change Detection in NDVI Time Series: Effects of Inter-Annual Variability and Methodology. Remote Sensing, 5: 2113-2144.

[4] Ballejo da Costa, L., y Guasselli, L. 2017. Seasonal Dynamics of the Remaining Atlantic Forest, from a Time Series NDVI/ MODIS. GeoUERJ. 1981-2021.

[5] Deka, J., Kalita, S. y, Khan, M. 2019. Vegetation Phenological Characterization of Alluvial Plain Shorea robusta-dominated Tropical Moist Deciduous Forest of Northeast India Using MODIS NDVI Time Series Data. Journal of the Indian Society of Remote Sensing. 47(8): 1287-1293.

[6] Donoso C. 1993. Estructura y Dinámica de los Bosques Dominados por Especies de Coníferas. En: Bosques templados de Chile y Argentina: Variación, Estructura y Dinámica. 4ta ed. Chile. Editorial Universitaria. pp. 385 - 390.

[7] González, M. E., Cortes, M., Gallo, L., Bekessy, S., Echeverría, C., Izquierdo, F. y, Montaldo P. 2013. Araucaria araucana (Molina) K. Koch. Araucaria (o), Pehuén, Piñonero, Pino Araucaria, Pino chileno, Pino del Neuquén, Monkey puzzle tree. EN: Donoso C. (ed). Las especies arbóreas de los bosques templados de Chile y Argentina. Autoecología. Marisa Cuneo Ediciones, Valdivia, Chile. 33-55p.

[8] CHILE. Ministerio de Agricultura (MINAGRI). 1990. Decreto 43: Declara Monumento Natural a la Araucaria Araucana. 3 de abril, 1990. 2p.

[9] Ministerio de Relaciones Exteriores. 1975. Decreto 873: Aprueba Convención Sobre el Comercio de Especies Amenazadas de Flora y Fauna Silvestre. (CITES). 28 de Enero, 1975. 1p.

[10] Premoli, Z., Quiroga, P. y, Gardner, M. 2013. Araucaria araucana. The IUCN Red List of Threatened Species 2013: e.T31355A2805113. [En línea] http://dx.doi.org/10.2305/IUCN.UK.20131.RLTS.T31355A2805113.en> Consultado el 11 junio de 2020.

[11] CHILE. Ministerio de Agricultura (MINAGRI). 2008. Ley 20.283: Ley Sobre Recuperación de Bosque Nativo y Fomento Forestal. 11 de Julio de 2008.

[12] Úbeda, X. y Sarricolea, P. 2016. Wildfires in Chile: A review. Global and Planetary Change. 146: 152- 161.

[13] González, M. y Veblen, T. 2007. Incendios en bosques de Araucaria araucana y consideraciones ecológicas al madereo de aprovechamiento en áreas recientemente quemadas. Revista Chilena de Historia Natural. 80: 2143-253.

[14] González, M.E., Lara, A., Urrutia, R., & Bosnich, J. (2011). Climatic change and its potential impact on forest fire occurrence in south-central Chile (33º - 42º S). Bosque 32(2), 215-219.

[15] Corporación Nacional Forestal (CONAF). 2014. Catastro de Bosque Nativo Región de la Araucanía Actualización 2014 [en línea] < http://sit.conaf.cl/exp/ficha.php> [Consultado el 13 de agosto de 2020].

[16] Corporación Nacional Forestal (CONAF). 2015. CONAF entregó Plan de Restauración de Incendio China Muerta. [En línea] <https://www.conaf.cl/conaf-entrego-plan-derestauracion-de- incendio-china-muerta/> [Consultado el 06 de abril 2021]

[17] Sanhueza, G., 2011. Impacto del incendio forestal del año 2002 en el predio La Fusta, Lonquimay. Evaluación multitemporal de la diversidad, utilizando imágenes satelitales, ETM+, Aster y Ali. Tesis ingeniería Forestal. Temuco. Universidad de la Frontera. 92p.

[18] Sayler, K., 2021. Landsat 4-7. Collection 2 (C2) Level 2 Science Product (L2SP) Guide. Versión 4.0. Department of the Interior U.S. Geological Survey.

[19] Sayler, K., 2022. Landsat 8-9. Collection 2 (C2) Level 2 Science Product (L2SP) Guide. Versión 4.0. Department of the Interior U.S. Geological Survey.

[20] Brown, E., (2006). Preliminary Assessment of the Value of Landsat 7 ETM+ Data following the Scan Line Corrector (SLC) Malfunction. Including input from Scientists from the USGS, NASA, and the Landsat 7 Science Team Compiled and summarized by the staff of the U.S. Geological Survey, EROS Data Center, Sioux Falls, SD 57198 16 July 2003

[21] Roy, D. P., Kovalskyy, V., Zhang, H. K., Vermote, E. F., Yan, L., Kumar, S. S., & Egorov, A. (2016). Characterization of Landsat-7 to Landsat-8 reflective wavelength and normalized difference vegetation index continuity. Remote sensing of Environment, 185, 57-70.

[22] Che, X., Zhang, H. K., & Liu, J. (2021). Making Landsat 5, 7 and 8 reflectance consistent using MODIS nadir-BRDF adjusted reflectance as reference. Remote Sensing of Environment, 262, 112517. Doi: 10.1016/j.rse.2021.112517 de Rouse et al., 1973:

[23] Forkel, M., Migliavacca, M., Thonicke, K., Reichstein, M., Schaphoff, S., Weber, U. y, Carvalhais, N. 2015. Codominant water control on global interannual variability and trends in land surface phenology and greenness. Global Change Biology. 21: 3414-3435.

[24] Verbesselt, J.; Hyndman, R.; Zeileis, A. y Culvenor, D. 2010b. Phenological change detection while accounting for abrupt and gradual trends in satellite image time series. Remote Sensing of Environment. 114(12): 2970-2980.

[25] Liu, Y., Li, Y., Li, S. y, Motesharrei, S., 2015. Spatial and Temporal Patterns of Global NDVI Trends: Correlations with Climate and Human Factors. Remote sensing. 7(10): 13233-13250.

[26] Santibáñez, F. y, Santibáñez, P. 2018. Evaluación de las forzantes bioclimáticas en la sustentabilidad de las comunidades de Araucarias en Chile. Santiago. INFODEP. 39p.

[27] Gipoulou, T. 2017. Pérdida de vigorosidad de individuos de Araucaria araucana (Molina) K. Koch por la megasequía del periodo 2010-2015. Tesis Ingeniera en Recursos Naturales. Valdivia. Universidad Austral de Chile. 23p

[28] Hernández J., González-Castro V., Promis A., Corvalán P., Kutchartt E., Pirotti F. y Carrer M. 2022. Los bosques de araucaria- lenga. Curacautín, Lonquimay y Melipeuco. Alteraciones de hábitat. Universidad de Chile. Andros Ltda., Santiago, Chile. 161 pp.

[29] Leeeuwen, W. 2008. Monitoring the Effects of Forest Restoration Treatments on Post-FireVegetation Recovery with MODIS Multitemporal Data. Sensors. 8(3): 2017-2042.

[30] Walker, J. y, Soulard, C. 2019. Phenology Patterns Indicate Recovery Trajectories of Ponderosa Pine Forests After High-Severity Fires. Remote sensing. 11(23): 2782.

[31] Urrutia-Estrada, J., Fuentes-Ramirez A., Hauenstein, E. 2019. Diferencias en la composición florística en bosques de Araucaria Nothofagus afectados por distintas severidades de fuego. Gayana Botanica. 75(2):625-638.

[32] Kozczor, E. (2021). Assessing environmental Controls on phenology with Dense landsat and sentinel-2 Time series in andean araucaria Forests of Chile. Master's thesis (MSc). Technische Universität Dresden. Germany. 84 p.

[33] González, M.E., Donoso, C., Ovalle, P. y, Martínez-Pastur, G. 2006. Nothofagus pumilio (Poep. et Endl) Krasser. Lenga, roble blanco, leñar, roble de Tierra del Fuego. EN: Donoso C. (ed). Las especies arbóreas de los bosques templados de Chile y Argentina. Autoecología. Marisa Cuneo Ediciones, Valdivia, Chile. 486-500p