Linking scientific-based information and farmers' perception of drought in North-West Patagonia, Argentina

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Abstract

Drought is a constant part of rangeland dynamics in semi-arid environments which are at the same time highly variable. Drought events have enormous impacts on vegetation and on extensive livestock production by reducing outputs and quality as well as by generating farm decapitalization when livestock die. Droughts cannot be stopped, however their impacts can be mitigated through drought management strategies. This study aimed to explore the relation between the Normalized Difference Vegetation Index (NDVI) dynamics and farmers' perception of drought in North-West Patagonia, Argentina, to improve drought monitoring tools. The specific objectives were to: (1) Examine the evidence and characteristics of droughts for the period 2000-2018 by identifying inter-annual changes in the NDVI and by describing drought effects on farming systems and adaptive strategies, (2) Identify farmers' perceptions of drought, drought occurrences and duration, and adaptive strategies for the period 2000-2016, and (3) Compare the NDVI-derived vegetation dynamics with farmer perceptions. A time series analysis of vegetation dynamics was applied to identify inter annual vegetation dynamics and semi-structured interviews were used to identify farmers' perception of drought in two study areas, Laguna Blanca and Paso Aguerre located in North-West Patagonia, Argentina. Time series analysis of NDVI dynamics using the Basis Pursuit algorithm were sensitive enough to capture several periods when natural vegetation of steppe rangelands suffered a drastic decrease of photosynthetic activity. These perturbations were linked to a decrease of precipitation of the previous year and finally related to drought events. By this means, several droughts events with their onset, peak and cessation and the recovery periods were identified. Drought frequency increased after 2009 while recovery periods became shorter in both study areas. Farmer's perceptions of drought enriched the interpretation of droughts in North West Patagonia, however they were partially linked to scientific based information. Further research is needed to develop and validate NDVI dynamics for drought detection and link precipitation to water resources availability. Drought managerial strategies of farmers to cope with and adapt to drought were already existing. In the period 2000-2016 some farmers changed their managerial practices to reduce negative effects of drought and to deal with predation and problems derived from ash deposits from the volcanic eruption of Puyehue. Further research is needed to understand how particular strategies benefit farming systems in reducing their vulnerability to drought to better target policy developments in semi-arid rangelands with similar farming characteristics.

Keywords

Environmental hazard, Inter annual variability, Perceptions, Strategies

1. Introduction

Droughts are natural hazards with drastic implications on human lives, food insecurity and natural resources. Rising temperatures and more extreme precipitation regimes expected in the context of climate change might increase drought frequency and severity and aggravate its negative effects (FAO, 2018). In the context of a growing global population, water shortages and reduction of agricultural production are of main concern. Even though drought is of major importance, it is still not universally defined leading sometimes to misunderstandings. Mishra and Singh (2010) reviewed drought concepts and classified these as (i) meteorological drought defined as lack of precipitation over a region and for a certain period, (ii) hydrological drought related to a period with inadequate streamflow for a given water management system, (iii) agricultural drought defined as a period with declining soil moisture and consequent crop failure without any reference to surface water resources, (iv) socio-economic drought associated with failure of water resources systems to meet water demands, and (v) groundwater drought when groundwater recharge and later groundwater levels and groundwater discharge decrease. The present study stretches the definition of agricultural drought including the drastic decrease of photosynthetic activity of natural pasture with severe consequences on extensive grazing systems. Other particularities of droughts are the difficulty to determine the onset and cessation of drought periods and its negative effects remain after its termination. Moreover, human activities as (over)grazing, deforestation, over exploitation of water resources, among others, can aggravate drought related negative effects.

The arid and semi-arid regions are home for 1.10 billion people in the world and to about 17% of the total population in the Americas (Sivakumar et al., 2005). For these regions drought is a constant part of rangeland dynamics and is perceived by farmers as a major productivity-reducing factor (Slegers, 2008). Grasslands are very frequently found in arid and semi-arid environments and are used as grazing lands for livestock herds. In extreme and variable environments, an efficient and reliable way to turn sunlight into human food is through grazing (Galvin et al., 2008). The negative impact of drought periods on biomass production can have huge consequences for livestock production relying on forage productivity, mostly when animals die, generating quick farm decapitalisation (Easdale and Rosso, 2010).

Vegetation dynamics of arid and semi-arid regions of the world are influenced by climatic factors and droughts are part of them. These ecosystems are considered vulnerable to suffer undergoing processes of land degradation also known as desertification (Hogrefe et al., 2015) South America and particularly the Patagonian region have a vast surface area under arid and semi-arid climatic conditions were many smallholders' production systems rely on extensive livestock production (Villagra et al., 2015; Easdale and Rosso, 2010).

Satellite remote sensing monitoring tools are in demand to support decision making to prevent or cope with the impacts of drought (Easdale et al., 2012; Keshavarz et al., 2012). In the last 40 years, several indices had been developed to monitor drought. These indices are mostly derived from long-term records of precipitation and temperature (Mishra and Singh, 2010), and their performance is region specific. Using remote sensing data for drought assessment offers many advantages such as low costs, continuous updating of information and a direct relation of measured indicators to pasture production. Normalized Difference Vegetation Index (NDVI) derived from Red and NIR spectral bands, was found as the best predictor of ecosystem attributes as vegetation cover and species richness in Patagonian steppes (Gaitán et al., 2013). NDVI can be used as a proxy variable of Aboveground Net Primary Production (ANPP) (Blanco et al., 2016; Fabricante et al., 2009; Paruelo et al., 2004; Jobbágy et al., 2002) which at the same time is strongly linked to forage availability for livestock production in extensive grazing systems. The NDVI index provides reliable information to investigate the effects of meteorological, hydrological and agricultural droughts on the vegetation cover (Yengoh et al., 2015).

Easdale et al. (2012) explored the first steps for drought monitoring using monthly mean NDVI values in arid and semi-arid regions of North Patagonia. Recently, studies about vegetation dynamics in arid rangelands propose to move forward from old methods focusing on simple measures of variability (i.e. tendencies) to time series analysis methods for further understanding of the complex dynamics of rangelands. In this context, wavelet autoregressive methods to study vegetation cyclic behaviour showed promising results in five contrasting biomes, including arid and semi-arid rangelands (Easdale et al., 2017) and for the detection of spatial distribution of volcanic ash fallout as measured by a perturbation in NDVI temporal dynamics (Easdale and Bruzzone, 2018) both based on the study of NDVI trends. However, generating valuable information through monitoring tools is complex and must integrate different disciplines to improve drought monitoring and interpretation.

Droughts cannot be stopped. However, their impacts can be mitigated through drought management strategies. Traditional ecological knowledge is based on an accumulation of observations and reveal local or traditional practices for ecosystem management (Berkes et al., 2000). Therefore, local knowledge might be of help to monitor and interpret drought occurrences in specific environments. At the same time, exploring about the social and ecological practices which farmers use to respond to and manage droughts, are essential for increasing resilience of livelihoods (Keshavarz and Karami, 2014). An example of mitigation practices in dryland pastoral systems, also found in North West Patagonia, are seasonal movements of herds or transhumance as social adaptations responding to seasonal forage variability (Easdale et al. 2015; Neely et al., 2009).

Risk perception of drought and reaction to drought are strongly linked to past experiences and memories of drought (Taylor et al., 1988). Recent studies about farmers' perception of drought and climate variability illustrate the bond between perceptions and adoption of managerial strategies and evidenced the discrepancies between those with scientific based information (Muita et al., 2016; Simelton et al., 2013; Slegers, 2008). Matching scientific and farmers' perception of drought will improve the understanding about the problems in which man and ecosystems interact in the attempt to offer solutions to deal with ecological insecurity (Chaudhury et al., 2013; Herrero et al., 2014; Slegers, 2008; Whitfield and Reed, 2012).

This study aimed to explore the relation between the Normalized Difference Vegetation Index (NDVI) dynamics and farmers' perception of drought in North-West Patagonia, Argentina, to improve drought monitoring tools. The specific objectives were to: (1) Examine the evidence and characteristics of droughts for the period 2000-2018 by identifying inter-annual changes in the NDVI and by describing drought effects on farming systems and adaptive strategies, (2) Identify farmers' perceptions of drought, drought occurrences and duration, and adaptive strategies for the period 2000-2016, and (3) Compare the NDVI-derived vegetation dynamics with farmer perceptions.

2. Material and methods

Study area

This research was carried out in North-West Patagonia in Neuquen province, Argentina (Fig. 1). From West to East, there is a biophysical gradient in altitude (from 2.000 to 400 m.a.s.l.) and rainfall (from 1.000 to 200 mm). Two sites were selected in the cold semi-arid rangelands of Northern Patagonia (Fernández & Busso,1999). There, extensive livestock production of small ruminants is an important livelihood for small farming systems which also suffered farm decapitalisation due to the impacts of drought events that occurred between 2000 and 2018 (Easdale & Rosso, 2010). Laguna Blanca (LB) (39°2'S; 70°21'W) is located in the east of the Chachil mountains and characterized by its very undulating topography and scattered lagoons and volcanic rock. A total surface of 365.186 ha were analysed where vegetation is dominated by grass-shrub steppes of less than 1 m high (Bran & Ayesa, 2002). Moreover, some wetlands or meadows with high productivity rates locally known as "mallines" are present. Paso Aguerre (PA) (39°20'S; 69°50'W) is located in the lower lands on the riverside of the river Picun Leufú. A total surface of 114.734 ha was analysed including a small portion of irrigated land. Natural vegetation is of steppe rangeland with vegetation dominated by shrubs of 1.5-2 m also including grasses, herbs and geophytes (Bran and Ayesa, 2002).

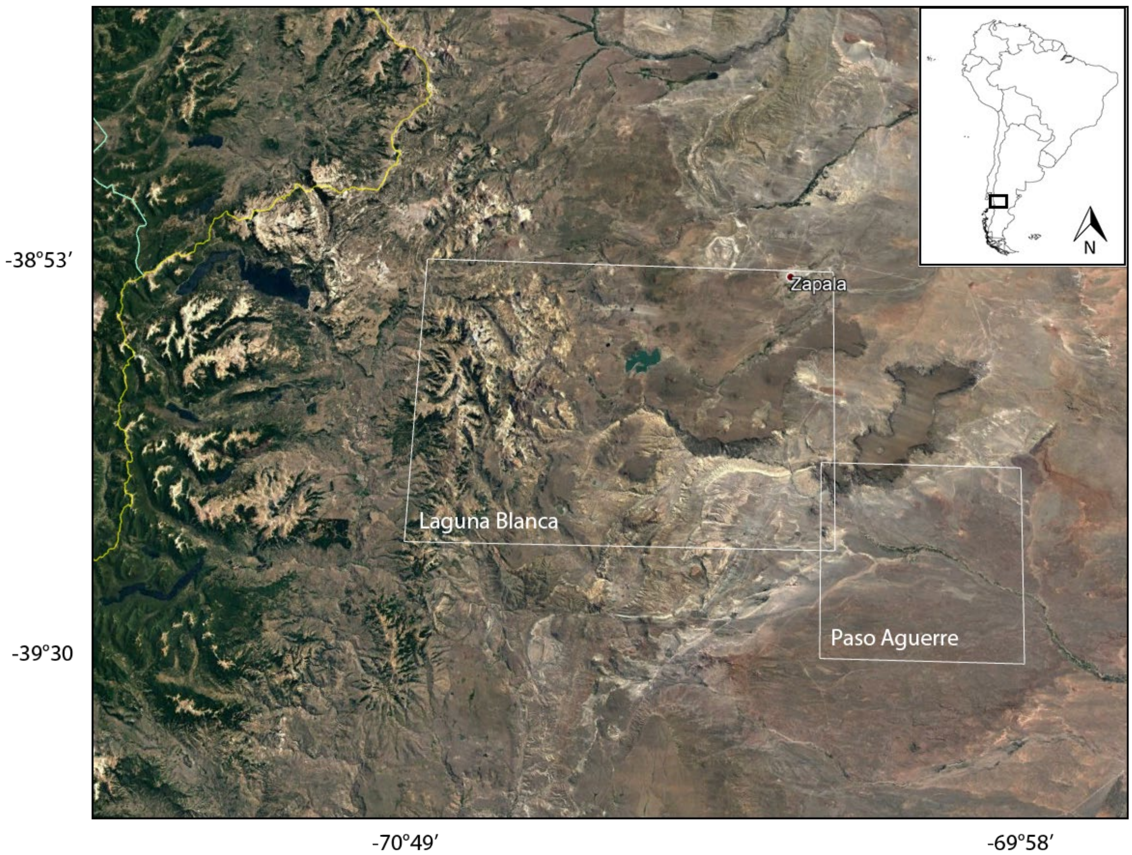

Fig. 1. Case study areas Laguna Blanca and Paso Aguerre location in South America and North West Patagonia (Google Earth, 2018).

Table 1. Main biophysical features of the study sites (Gardi et al., 2015; Gaitán et al., 2013; Pereyra and Irisarri, 2011; Bran and Ayesa, 2002; Paruelo et al., 1998).

Variable	**Study site**	
	Laguna Blanca (LB)	**Paso Aguerre (PA)**
Altitude (m.a.s.l.)	1.300	630
Annual mean temperature (°C)	10-12	14
Annual rainfall (mm)	300-700	<200
Topography	Very undulating (slopes up to 45%)	Moderately undulating (slopes up to 10%)
Phytogeographic province	Patagonia and Monte	Monte
Soil type	Regosol and Luvisol	Regosol
Landscape typologies		
Irrigated land	Not present	Crop production and crop-livestock production systems
Steppe rangeland	Vegetation dominated by shrubs and grasses. Principal species are *Adesmia campestris, Mulinum spinosum, Senecio filaginoides, Berberis heterophylla, Stipa humilis, Festuca argentina* and *Poa ligularis*	Vegetation dominated by shrubs also including grasses, herbs and geophytes. Principal species are *Larrea divaricata, Larrea cuneifolia, Atriplex lampa, Proposis alpataco, Schinus polygamus, Bougainvillea spinosa, Acantholippa seriphioides, Hyalis argentea,* and *Stipa tenuis*
Wetland rangeland	Highly productive meadows located in drainage lines.	Not present

Meteorological data

Precipitation data was obtained from the Weather Station of Zapala Airport (38º58'S; 70º6'W) for the period from 1999 until 2016. From 1999 until 2010 rainfall data was obtained as total annual rainfall, and for the period 2011 until 2016, monthly rainfall data was obtained. Precipitation deficit or surplus was calculated as the difference between total annual rainfall and the average annual rainfall calculated from 1999 until 2016.

Remote sensing data source

The present study analyses vegetation dynamics and inter-annual cycles based on the Normalized Difference Vegetation Index (NDVI) as an indicator of photosynthetic activity of vegetation in NDVI units. The NDVI index was calculated using the reflectance of the Red (R) at 645 nm and the Near Infrared (NIR) at 858 nm portions of the electromagnetic spectrum as follows:

$$NDVI = (NIR-R)/(NIR+R) \quad (Eq.1)$$

A series of 16-day composite MODIS images (MODIS13Q1 product) for the period February 2000–February 2018 was obtained from the USGS Earth Resources Observation and Science (EROS) Center. This sequence was used to build up a three-dimensional matrix of the selected study site consisting of longitude, latitude and time. Each pixel unit represents a surface of 6.25 ha (i.e.: 250m x 250m of spatial resolution).

Remote Sensing Data Processing

Data processing and trend estimations of Remote Sensing data followed the method described in Easdale et al. (2018) as explained below.

NDVI is a continuous finite variable therefore the NDVI error was assumed to follow a logit-normal distribution which logit transform follows a normal distribution (Ashton, 1972). In order to use a normal likelihood function, temporal data were logit-transformed before fitting the NDVI time series. NDVI values ranged from -1 and 1 and were treated as a proportion between 0 and 1. Zero and negative values were related to snow cover, clouds, water, rocks or bare soil and therefore not related to photosynthetic activity of vegetation.

After the transformation of NDVI data, the series were centred by removing the mean. Values lower than zero or bigger than one were treated as missing values. Other discarded data from the analysis were pixels which presented more than 20 negative values within the data stack. Those pixels mainly corresponded to borders of water bodies and mountain tops.

Time Series Analysis

Signal processing methods were used to filter out the noise before analysing the NDVI time series variability. For this, a sparse wavelet transform using the matching pursuit algorithm (Mallat & Zhang, 1993) was applied to the time series by using the gpu_pursuit package (Bruzzone, 2018) for the python programming language.

After the series was wavelet-transformed, a low-pass filter was applied to remove any frequency component with a wavelength shorter than two years. The resulting time series was centered (i.e. had zero mean, and no trend), denoised, and contained only inter annual variability, so the drought estimation was without seasonal effects.

Drought events were defined as the periods in which the filtered NDVI pixel values were found to be negative, which is the same as being below the mean NDVI value of the pixel (Mishra and Singh, 2010). The drought event was considered to be finished when NDVI value became positive. From this, drought event features were described by duration, severity and occurrence.

Beginning and cessation years of drought events, measured in years, were detected by the change in sign of NDVI values. Total number of drought events was the sum of drought events identified. From the relative frequencies of starting and ending years of drought events identified in the study sites (Fig. 5; Fig. 10), the beginning of a drought event was considered when the highest frequency peak occurred if the curve exceeded the cessation of drought events, the event included more than 70% of the pixels and showed a peak for around 10% of the pixels and vice versa for considering the cessation year of droughts.

The most severe drought was defined as the lowest NDVI value found in each pixel. Therefore, the year in which the lowest value occurred was named as the moment of the most severe drought. The duration of the event with the lowest detected NDVI value was calculated. Peak recovery was defined as the highest NDVI value and its duration was calculated for the period in which NDVI remained above the mean value.

For the final presentation of the maps, editing was done using Adobe Photoshop CC 2017.

Farmer Data Gathering and Analysis

The field study was conducted between September 2016 and December 2016. A baseline questionnaire was applied to 23 smallholder farm-households (n=12 in LB and n=11 in PA) with open-ended questions to obtain general information about the area, its population and production systems. Also, farmers were asked about their land, livelihoods, assets, farming practices, main problems perceived, drought perceptions and strategies adopted. Only farmers' answers (head of household or main responsible of the farm work) were included in the analysis. All participants in the study were recruited using snowball sampling (non-probability sampling method).

Livelihood types were identified based on interviews with local technicians, researchers and farmer's answers about the contribution of different activities to household income. Four livelihood types were identified based on income diversification and farming system (Table 2) and will be used throughout this study. All participants are smallholders with family-based labour. Few producers also employ other labour for certain tasks or moments in the year (e.g. wool shearing, herding, etc.).

Table 2. Description of livelihood types identified based on interviews with farmers (n=23).

Livelihood type	**Description**
Livestock-based	Livestock production is the only livelihood activity to household food self-sufficiency.
Livestock & non-farm based	Household livelihood is based on livestock production (from 50 to 79% total income) and non-farm income, which includes outside farm activities, pensions and/or subsidies.
Crop & non-farm based	Household livelihood is based on crop farming (from 50 to 79% total income) and non-farm income, which includes outside farm activities, pensions and/or subsidies. This category type was only found in PA.
Non-farm based	Most of the household income (from 80 to 100% total income) it is provided by outside farm activities, pensions and/or subsidies.

The information gathered from the interviews was summarised and expressed as the total number of farmers e.g. drought perceptions or fresh water resources and average values for different indicators such as family size or herd size.

3. Results

3.1. Drought identification and characteristics

3.1.1. Meteorological drought

Meteorological drought is defined according to Mishra and Singh (2010) as lack of precipitation over a region for a period of time. The annual rainfall registered for the period 1999-2016 in Zapala Airport meteorological station shows a highly variable precipitation ranging from 58.8 to 368.6 mm of rainfall per year (Fig. 2). The function resulting from annual rainfall data, presents a negative slope. Average annual rainfall for the period 1999-2016 was 217.2 mm (Table A.1). Precipitation deficit occurred for the periods 2002-2003, 2007-2012 and 2015 (Fig. 3). Precipitation surplus was found for the periods 1999-2001, 2004-2006, 2013-2014 and 2016.

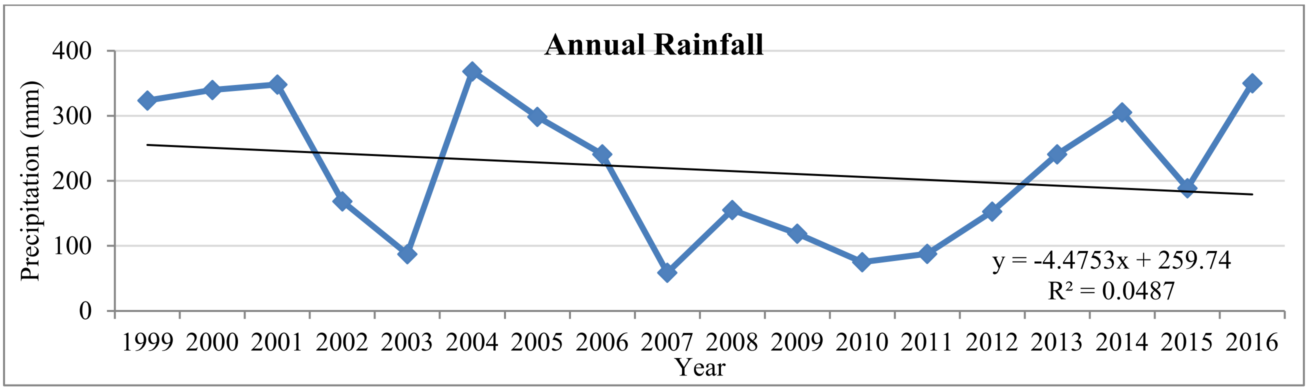

Fig. 2. Annual rainfall measured for the period 1999-2016 at the weather station of Zapala Airport (Zapala, Neuquén) (AER Zapala).

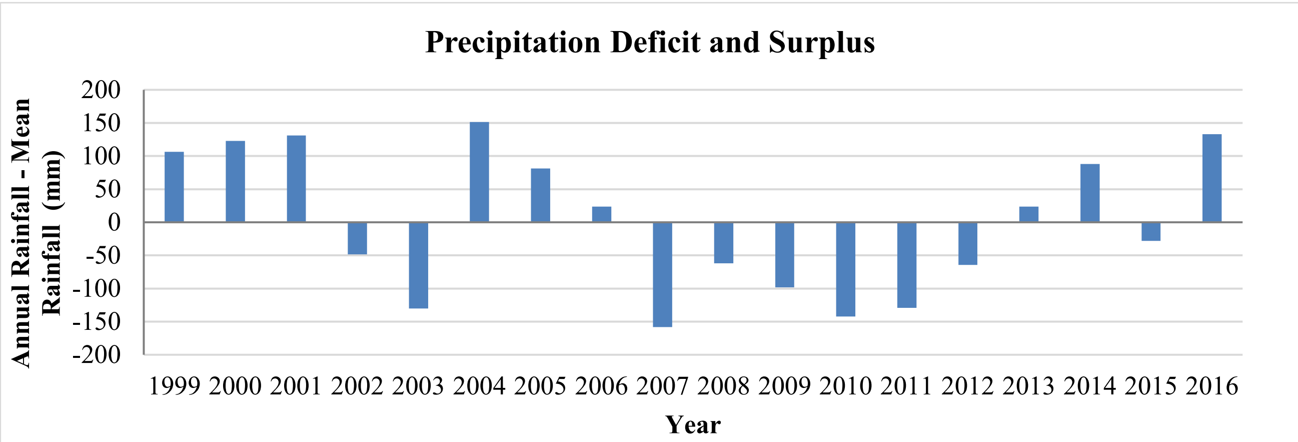

Fig. 3. Precipitation deficit and surplus in comparison to mean value at the weather station of Zapala Airport (Zapala, Neuquén) (AER Zapala).

3.1.2. Drought Identification and Characteristics Using Remote Sensing Data

LAGUNA BLANCA

The time series analysis for the period 2000-2018 showed an NDVI mean value gradient from west to east in Laguna Blanca. It showed altitudinal variability ranging from 0.00 to 0.54 NDVI values (Fig. 4). Mean NDVI data frequencies show a right-skewed histogram and a peak mean NDVI value of 0.14 (7.60% of the total surface) (Fig. A. 3.). The Chachil mountains and valleys, where water content is higher, presented the highest NDVI values. Zero values were found for water bodies, snow cover, rocks and bare soil.

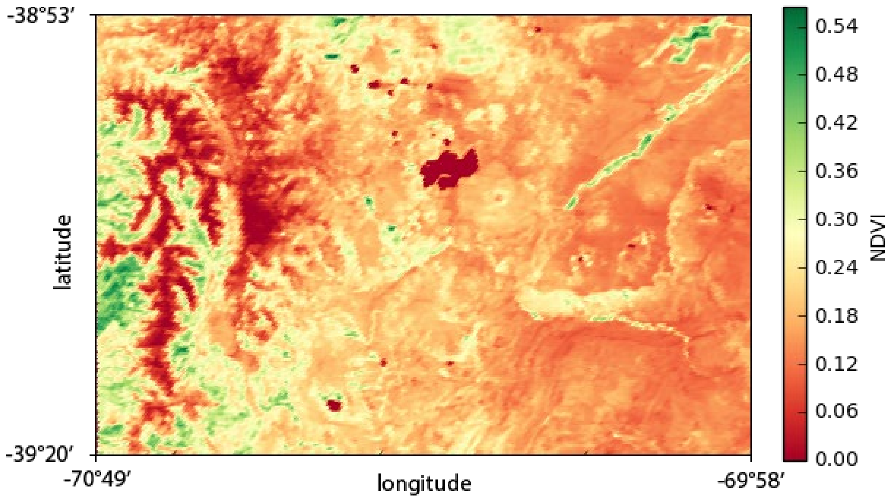

Fig. 4. Mean NDVI values in Laguna Blanca for the period 2000-2018.

Multiple drought events occurred in LB area and the starting and ending years were identified using time series analysis of NDVI dynamics (Fig. 5). Onset and cessation of drought events showed a gradual increase of proportion of pixels as an indicator of the affected surface. Frequency peaks for starting years (around 8 % of the surface) were found in 2003, 2007, 2015 and 2018. End of drought events (around 10% of pixels) were found in 2005, 2009, 2014 and 2017. Also, from 2002 until 2009 data showed a periodicity of two years of drought and a recovery period of two years. However, from 2014 until 2018, recovery periods were found to last one year while drought events lasted for two years. Apparent starting and ending drought events were occurring simultaneously between 2011 and 2014 showing unclear results.

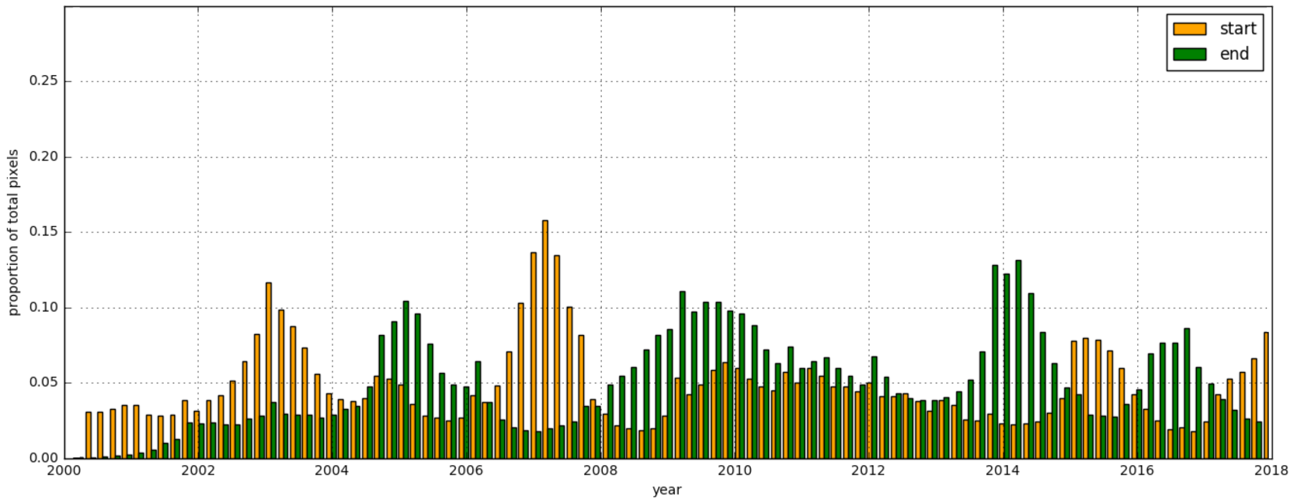

Fig. 5. Proportion of pixels indicating starting and ending years of drought events identified in Laguna Blanca for the period 2000-2018.

Total number of drought events identified in LB varied spatially from West to East (Fig. 6). At the West of LB, one drought event was most commonly identified while in the East the number of drought events ranged from three to five. Relative frequencies showed two peaks at one drought event (19% of the pixels) and at five drought events (17% of the pixels) (Fig. A. 6).

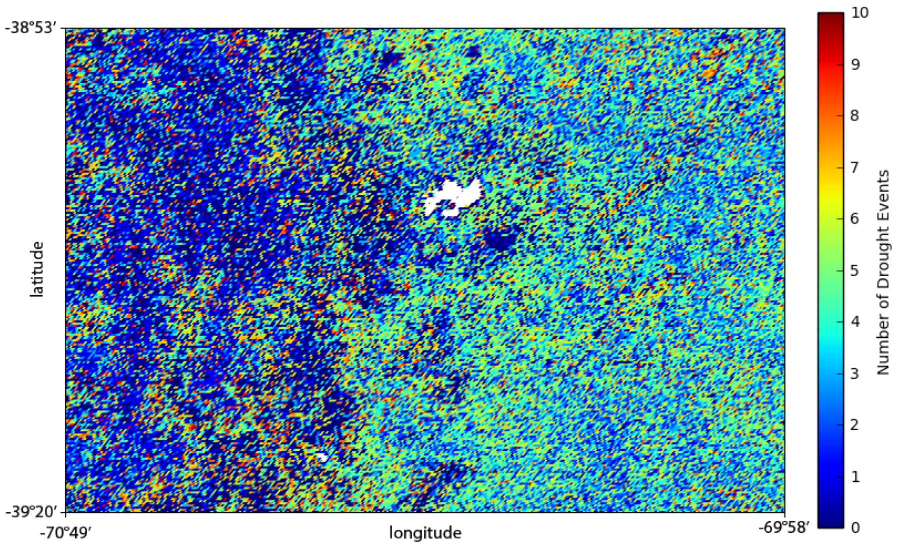

Fig. 6. Total number of drought events identified in Laguna Blanca for the period 2000-2018.

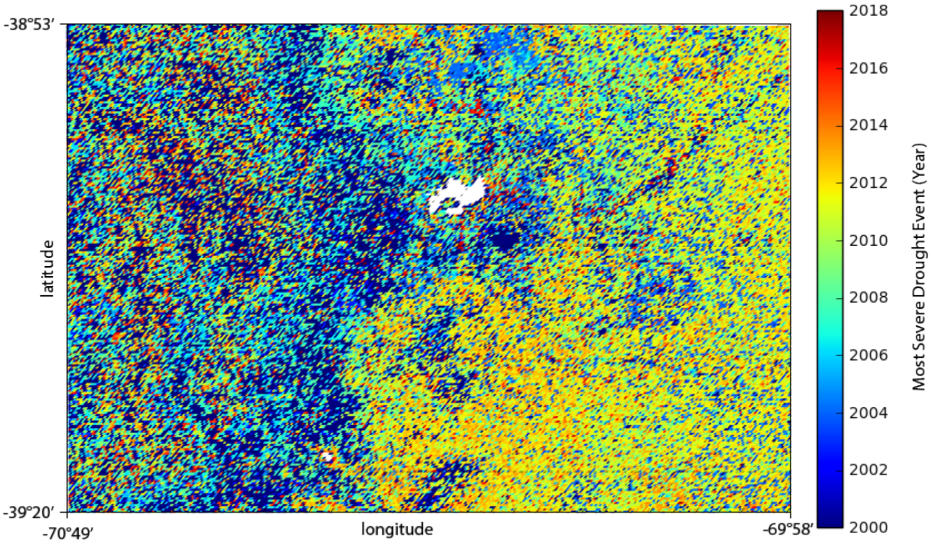

Fig. 7. Most severe drought event identified (Year) in Laguna Blanca for the period 2000-2018.

The most severe drought in the West and North of LB occurred in 2004 (9.3% of the pixels) and 2008 (9.9 of the pixels) (Fig. 7 and Fig. A. 8). In the East of LB, the most severe drought occurred in 2011 (14.4% of the pixels) followed by two more years of severe drought events (2012, 12.2% of the pixels; 2013, 10.8% of the pixels). Duration of most severe drought events were found to last 2 years in 27.4% of the pixels (Fig. A. 9 and Fig. A. 10).

Peak recovery periods also showed some spatial differences in LB (Fig. 8). In the West, the highest NDVI values occurred around 2002 (8% of the pixels) and 2006 (11% of the pixels) (Fig. A. 12). However, 38.8% of the pixels showed a peak recovery period between 2015 and 2017. Peak recovery periods lasted for 2 years for 30.3% of the surface (Fig. A. 13; Fig. A. 14).

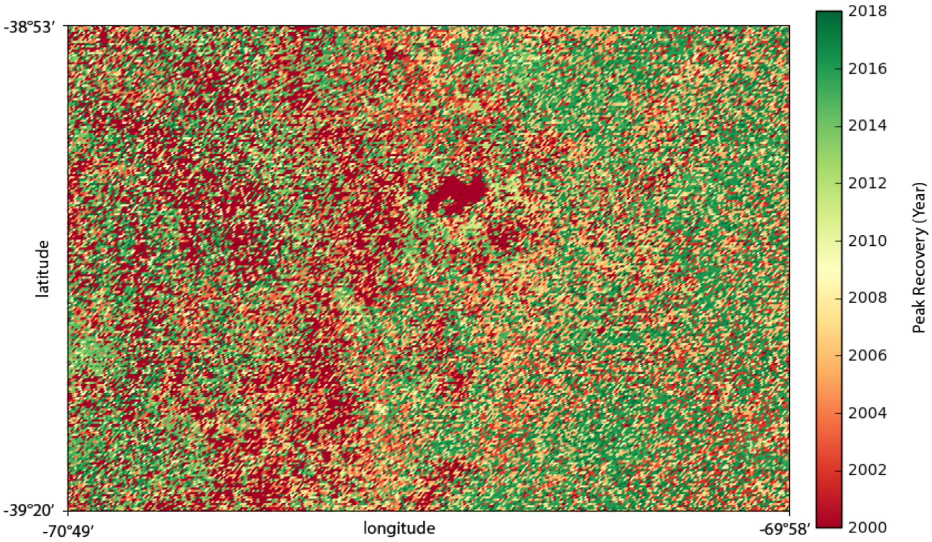

Fig. 8. Peak recovery (Year) identified in Laguna Blanca for the period 2000-2018.

PASO AGUERRE

For the study area of PA, satellite images showed a data set of NDVI mean values ranging from 0.1 and 0.5 (Fig. 9). However, most of the values were found between 0.1 and 0.2 (96.4% of pixels) and the peak was found at about 0.15 (Fig. A. 16). A large proportion of the studied area was of steppe rangeland and only a few hectares were irrigated land where mean NDVI values found were higher than 0.30. Zero values were found for water bodies, snow cover, rocks and bare soil.

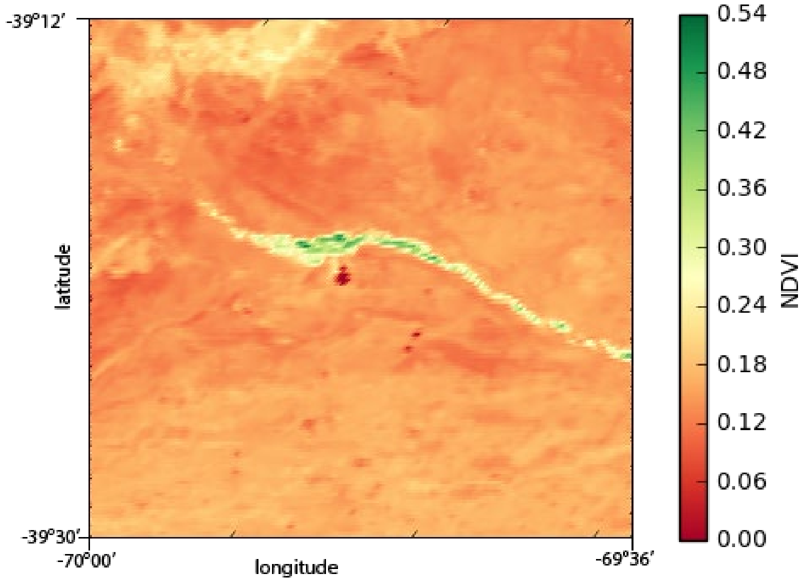

Fig. 9. Mean NDVI values in Paso Aguerre for the period 2000-2018.

Time series analysis of NDVI dynamics determined several start and end drought events in PA (Fig. 10). Starting years showed peak frequencies in more than 10% of the surface in 2003, 2007, 2011, 2015 and 2018. Ending of drought events occurred in 2005, 2006, 2009, 2012, 2014, 2016. Periodicity of drought events from 2003 until 2009 showed every four years a starting drought event, however after 2009 until the end of the study in 2018 the cycle changed to two years. Total amount of drought events within 18 years were five for 21% of the studied surface (Fig. 11; Fig. A. 19).

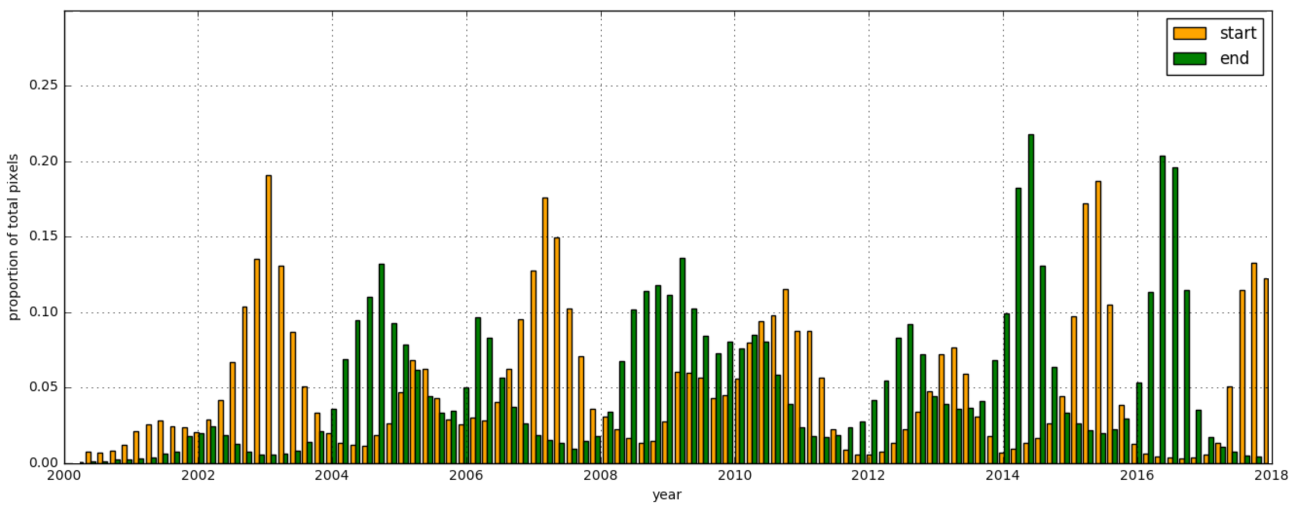

Fig. 10. Proportion of pixels indicating starting and ending years of drought events identified in Paso Aguerre for the period 2000-2018.

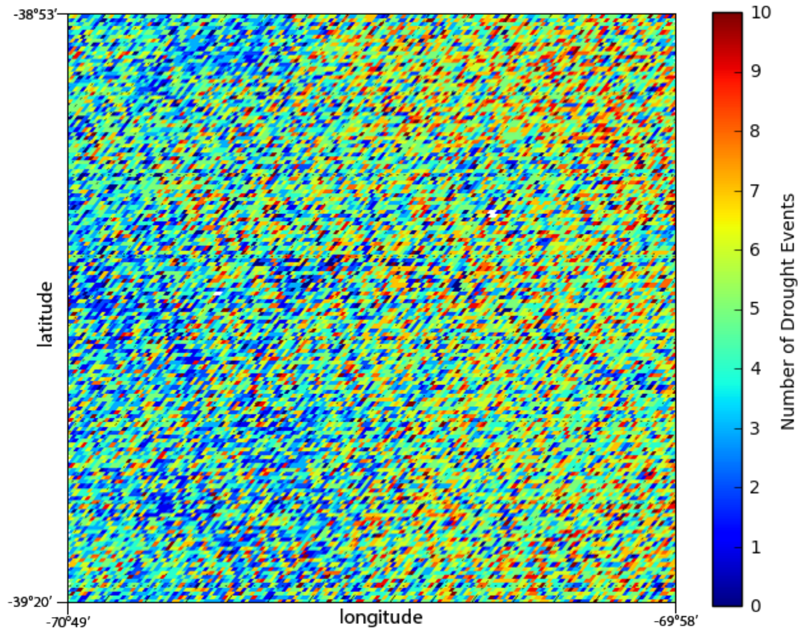

Fig. 11. Total number of drought events identified for each pixel in Paso Aguerre for the period 2000-2018.

The most severe drought event in PA occurred in 2012 (29% of the pixels) (Fig. 12; Fig. A. 21) and in 2004 (10% of pixels). Length of drought events most frequently found was 2 years (19.2% of pixels) and 4 years (17.5% of pixels).

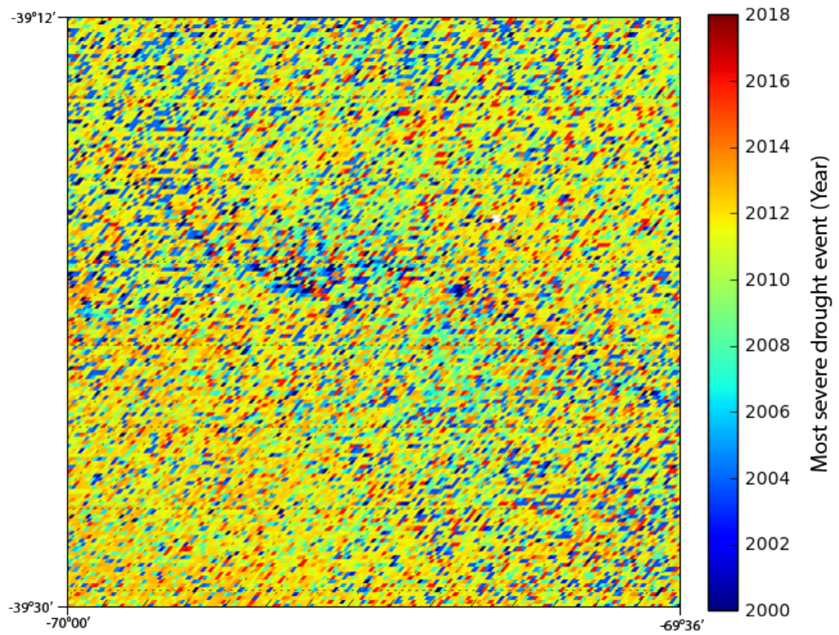

Fig. 12. Most severe drought events identified (Year) in Paso Aguerre for the period 2000-2018.

Peak recovery periods occurred in 2017 (31% of pixels) (Fig. 13; Fig. A. 25). Moreover, two other peaks where identified in 2002 (13% of pixels) and 2006 (9% of pixels). Duration of recovery periods lasted for 2 years (36.9% of the pixels) (Fig. A. 26; Fig. A. 27).

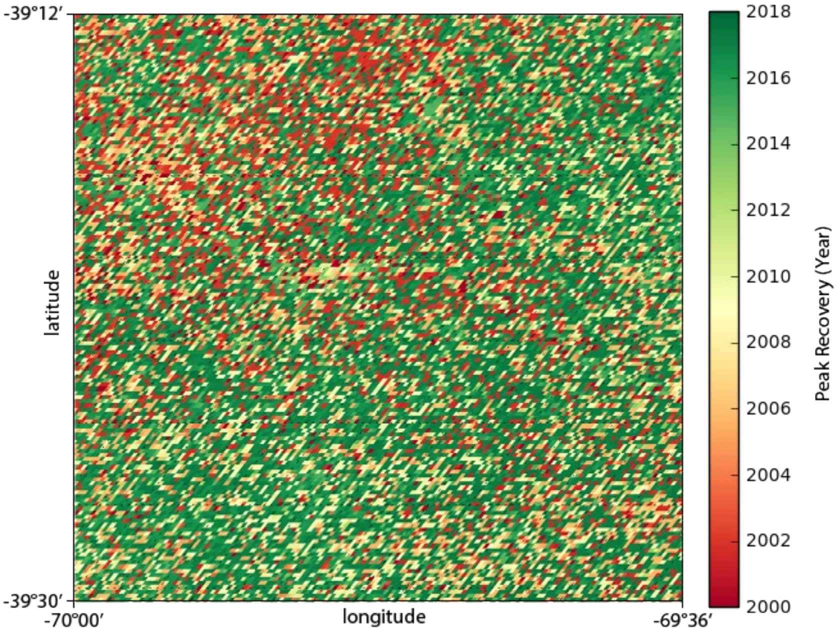

Fig. 13. Peak recovery (Year) identified in Paso Aguerre for the period 2000-2018.

3.1.3.Farmers Experiences of Drought

Definitions of drought

Farmers in both study areas used several descriptions of unfavourable weather conditions and non-weather indicators to define drought (Fig. **14**). Generally, farmers defined drought mainly as lack of grass and lack of rain. In PA farmers also referred to drought as lack of water for irrigation and low mood periods in which they feel depressed. In LB many farmers said to be affected by cold drought events, which are strong and long duration wind events, low snowfall during winter and cold temperatures or frost.

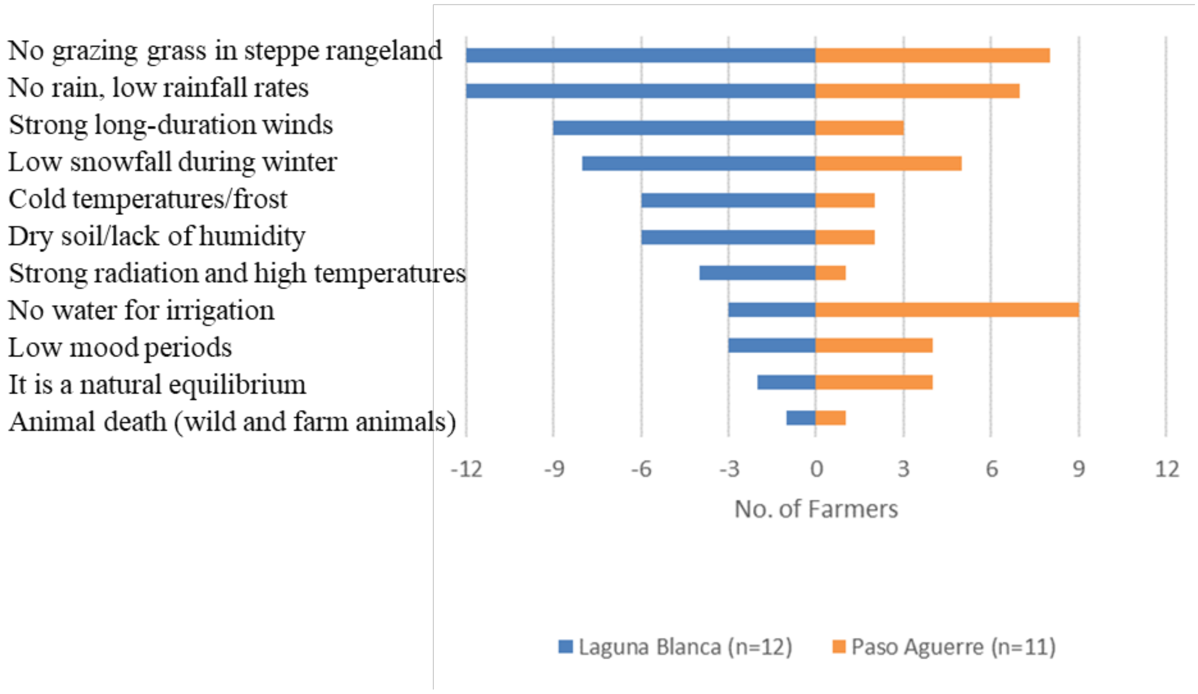

Fig. 14. Farmer answers to the question "What is drought?" in Laguna Blanca (n=12) and Paso Aguerre (n=11).

Memories of drought

All interviewed farmers in LB and PA identified drought as one of the main problems for production if not the most constraining. All farmers expressed to have memories of drought periods lasting for several years as well as recovery periods (Fig. 15 and Fig. 16). Producers could remember specific years or periods of severe droughts, however, before 2011 farmers memories about drought events were hardly remembered.

Farmers in LB perceived long periods of drought lasting for 1 to 15 years (Fig. 15). They remembered a number of droughts with starting years in 2000, between 2003-2004, between 2007-2008, 2011 until 2013 and 2015. Most severe drought events were remembered in 2008, 2011, and from 2011 until 2015. Specially 2011 was remembered as a severe drought event together with a volcanic eruption (Volcano Puyehue-Cordón Caulle) which covered the area with volcanic ash deposits. Interviewed farmers identified only one recovery period in 2016 or for the period 2015 until 2016. Vegetation recovery events were perceived to last for one or two years. Five farmers in LB differentiated drought events from cold drought periods when snowstorms or frost events occurred. "When cold droughts occur, it is not possible to graze the natural vegetation because it is covered by snow or died due to frost. Also, our animals are exposed to prolonged cold temperatures and sometimes die" one farmer in LB explained. Cold droughts were remembered to last for one to three years since the year 2000, for the period between 2002-2004 and 2011-2012, 2014 and 2015.

Interviewed farmers in PA had different memories of drought for the steppe rangeland and arable irrigated land (Fig. 16). In the first case, starting years of drought were found in 2001, 2006, 2011 and 2013. In total, each farmer remembered one or two drought events with a short recovery period in between. Most severe droughts were remembered to occur in 2011 and for the period from 2011 until 2013. Also, in two cases farmers perceived 2001 and 2015 as years with severe droughts. Drought events duration were perceived to last for couple of years, ranging from 3 to 14 years. However, most severe drought periods were remembered to last for one to three years. Recovery periods were mostly remembered in 2016 and in some cases in 2014 and 2015. Duration of recovery periods was perceived to last from one to three years. In the irrigated arable land, all interviewed farmers remembered different starting years of drought, those were 2000, 2005, 2008, 2009 and 2012. Most severe drought events where perceived from 2011 until 2014, lasting for one to two years. Recovery periods were remembered from 2003 until 2005, and most frequently for the period from 2015 until 2016.

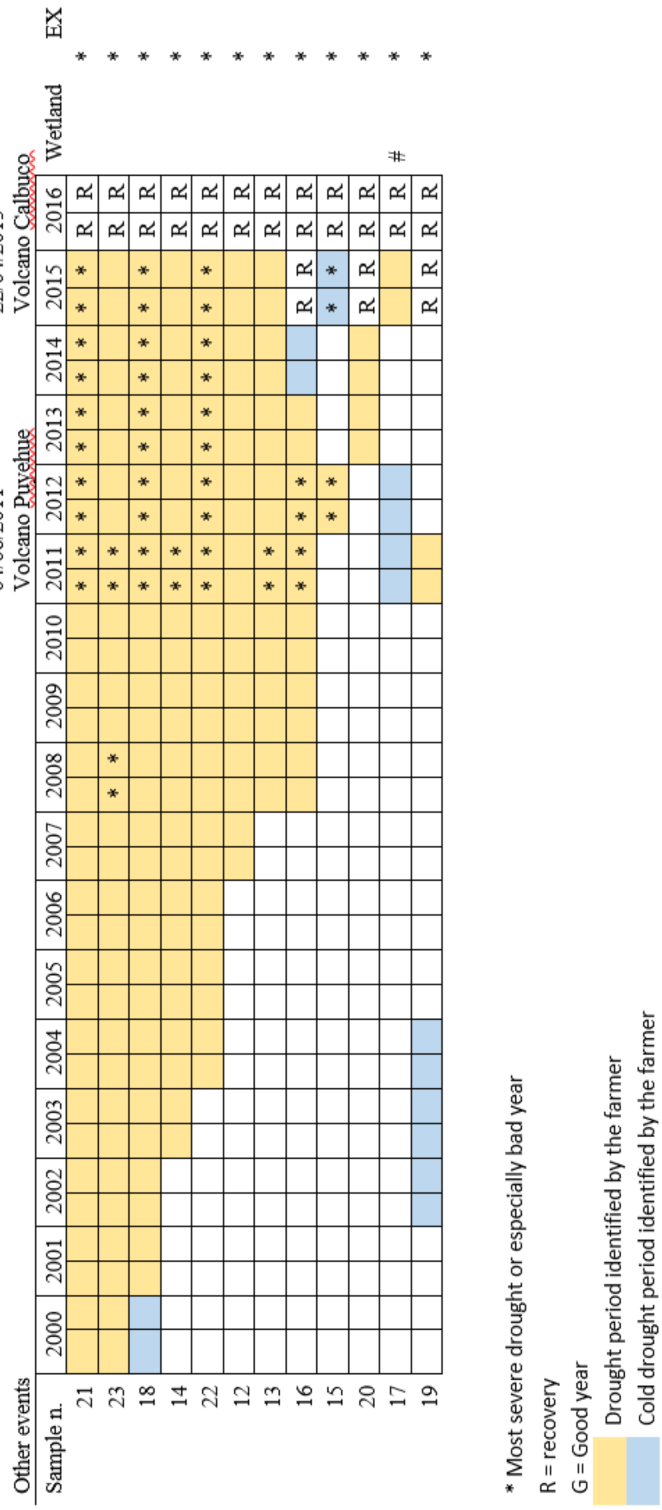

Fig. 15. Farmers' experiences of drought in Laguna Blanca.

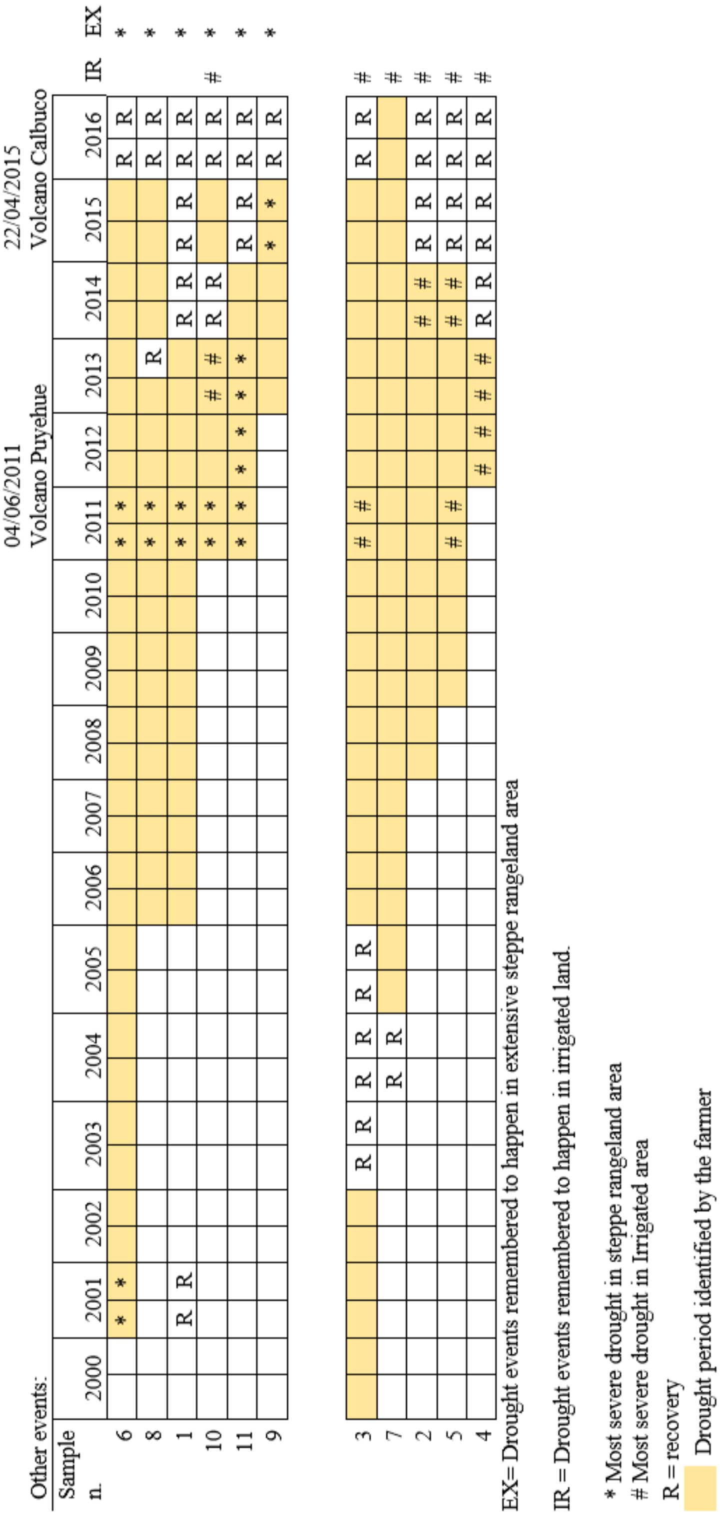

Fig. 16. Farmers' experiences of Drought in Paso Aguerre.

Production systems' most vulnerable moment

Production systems are dynamic and therefore present different stages and degrees of sensitivity around the year. Therefore, farmers were asked to explain about the most vulnerable moment for their systems when drought events occurred. In both study sites, farmers perceived summer and winter seasons as the most vulnerable moments for their farming systems when drought occurs and were related to their strategic management.

Farmers with only extensive grazing systems in LB perceived the most vulnerable moment during the summer due to drinking water scarcity for animals (Fig. A. 30). During the summer seasonal movement of livestock or transhumant pastoralism takes place, in LB many farmers were found to have this strategic management. Farmers move their herds to wetlands or mountain grasslands were biomass production is high and available for grazing. In these cases, farmers perceived the summer season to be the most difficult if there was water scarcity and the winter season was difficult when cold drought occurred. They explained that long cold weather events hamper forage production and offspring survival during lambing time.

In PA, farmers with irrigated systems said to have the largest production losses during the summer when there is water shortage for irrigation (Fig. A. 31). Others with diversified production strategies identified winter as the most critical moment for their production, referring to the extensive grazing systems. Farmers explained that during early winter until late spring lambing takes place, which is the most vulnerable moment for the offspring, goat and sheep mothers to survive if forage and water shortage happens. Differently, one farmer perceived the whole year as critical for his production strategy explaining that "Sometimes you expect the pasture to be ready for grazing, but it happens that rain falls too late and then it is also late for the vegetation to recover".

3.1.4. Comparison

Variation of NDVI explained by previous year precipitation

A pixel in the surrounding area of the weather station Zapala Airport was analysed to characterize the relationship between annual rainfall and annual mean NDVI values. The mean annual NDVI values were more correlated with annual rainfall data of the previous year than of the current year (Fig. 17).

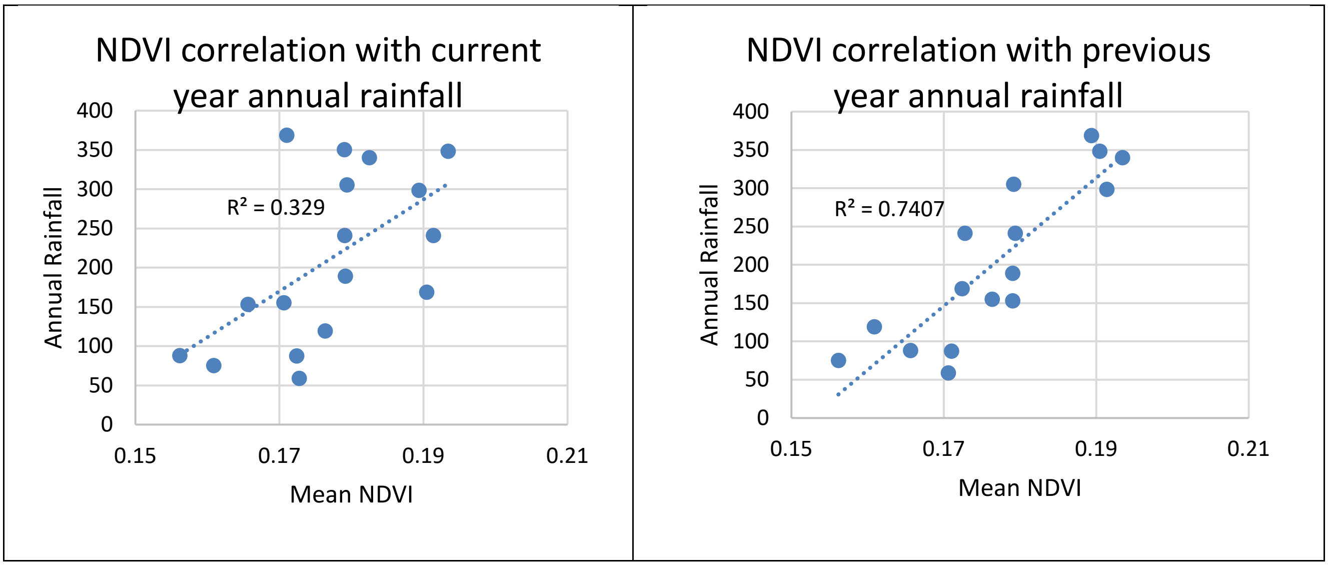

Fig. 17. Correlation between annual mean NDVI values of one pixel and annual rainfall data from Weather station Zapala Airport.

Linkage between Time Series Analysis and Farmers' memories of drought events

Time Series Analysis showed similar drought patterns in steppe rangeland in both study areas LB and PA (i.e. starting and ending drought events, five drought events, etc.), but differences were found for the most severe drought of which the frequency peak occurred a year later and lasted for a longer period in PA than in LB (i.e. peak frequency found in 2012 for 4 years duration in PA). Some different features where also observed in the West of LB were one drought event was mostly found and the most severe drought occurred in 2004. Top of the Chachil Mountains also presented several differences compared to the rest of the study site which might require further corrections for snow cover and rocky surfaces. High productivity areas as Wetlands in LB and Irrigated land in PA are hardly distinguished from the time series analysis.

Generally, farmer definitions of drought included lack of pasture as a consequence of low precipitation and other weather hazards (i.e. strong long-duration winds, frost, etc.). They also used other indicators not related to photosynthetic activity as measured using NDVI dynamics. Farmers' memories of drought events starting and ending years varied greatly, however some features as most severe droughts and recovery periods showed some similarities.

In LB, farmer memories of drought events had similarities with time series analysis findings. They identified as starting droughts the most severe droughts found with time series analysis as well as the peak in 2011. The end of drought events was generally not expressed by farmers, who remembered drought events lasting for longer than those identified with NDVI dynamics.

Perceptions of drought recorded in PA were differentiated for steppe rangeland and irrigated land. In the first case, farmer memories before 2011 did not coincide with time series analysis results in identifying the starting year for drought events. The most severe drought was remembered in 2011 together with the volcanic eruption, however NDVI showed the lowest values in 2012. From 2013 onwards, farmers perceived the starting of the recovery period mostly in 2016 when the interview took place. Time series analysis of NDVI showed the highest peak one year later in 2017.

3.2. Household characteristics and assets

The population in LB lives scattered in the territory inside and outside the Laguna Blanca National Park and some are also part of the Macho negro community. Non-farm-based households had the largest family size in LB with an average of four family members (n=3) and the youngest with an average age of 33.2 years old (Table B. 1). Only one livestock-based farmer was interviewed who was also single-household based of 45 years old. Livestock & non-farm-based households had an average size of 3.1 family members and average age of 52.6 years old. From the interviews, seven respondents were male farmers and five were female farmers. Most of the heads of the households finished primary education, four also finished secondary education, one higher education studies and three were illiterate. All farmers interviewed come from a long tradition of family farming.

In PA, the population mostly lives in a village and its close surroundings. Non-farm-based livelihood type had the largest family size (average 4.3 members, n=3) (Table B. 1) and the youngest (average 35.8 years, n=3). This group was followed by livestock & non-farm based in family size average of 2.8 members and average age of nearly 45 years old (n=5). Livestock-based household results are only provided by one household consisting in 3 members and average age of 52.3 years old. Crop & non-farm-based farmers both were single-household member with an average age of 67 years old. From the respondents, 9 were male farmers and 2 were female farmers. Most of the heads of the household finished primary education, 2 also secondary education and 2 were illiterate. Most farmers are farmers descendants and involved in farming activities for several generations, however three farmers started farming within the previous 10 years to the study.

3.2.1. Grazing land, cropping land and water resources

In LB farm production systems found were wetlands and steppe rangelands. Some wetlands were fenced. LB is located on a transhumant route that brings the herds from the east planes to the west mountain grasslands of the Andes. This involves a rapid increase of livestock density and grazing rates during the summer.

Water sources in LB were also diverse. The drinking water sources of households were mostly springs and small rivers (Fig. B. 1). When those are not close to the house, some have their own water wells or buy the water brought from the nearest city with water tankers. Animals reared in the open steppe rangelands drink water from the river, springs, rainwater harvesting systems, lagoons and water wells (Fig. B. 2).

Irrigated cropping systems were only found in PA. Interviewed farmers had on average 11.1 ha of irrigated arable land. Irrigated land was fenced and either it was owned by the farmer or he/she owned the rights for its use. The rest of the territory is shrub steppe rangeland where extensive grazing production systems and honey production takes places. Livestock farmers had rights on vegetation grazing resources and water resources of a certain area. However, those areas were not marked or fenced and thus, farmers did not know about the exact boundaries or extension their livestock were grazing.

Water sources in PA varied with landscape typology. Most households' homes were connected to the public water supply (Fig. B. 1). However, some of the interviewed farmers lived too far to reach the water supply network and therefore, they consumed water from wells and river water. River water was used for the irrigation of the fields during spring and summer. Its water flow greatly varied between years. Water resources in steppe rangeland are scarce. Farmers combined different sources as water wells and rainwater harvesting systems to provide drinking water for livestock (Fig. B. 2). If not too far, they also bring the animals to drink river water.

3.2.2. Number and type of animals

Interviewed livestock farmers produced cattle, sheep and goat (Fig. B. 4). Some farmers also had honey bees, laying hens and turkeys for self-consumption or extra income. In LB all interviewed farmers were livestock farmers and many of them specialized goat producers (Table B. 2). Herd size of goats is of the order of 155 mother goats (n=11). Farmers with diversified animal production have mixed grassland-steppe rangeland systems where they rear sheep and cattle, with an average herd size of 71.2 (n=5) and 15.8 (n=4) respectively.

In PA, specialized crop farmers did not have animals (Table B. 3). Number of Animal Units (AU) per household in PA showed an average of 47.0 AU (n=9) while in LB, it was 35.0 AU (n=12). Extensive animal husbandry held the largest number of animals, also, farmers with diversified production systems scored the highest AU. Most livestock producers in PA had goats and diversified their animal production with sheep and/or cattle. Farmers with cattle hold the largest AU. Average mothers herd size of sheep and cattle in irrigated area was 33.0 (n=4) and 62.5 (n=6) respectively while in steppe rangeland sheep mothers and goat mothers were 265.0 heads (n=2) and 181.7 heads (n=6) respectively.

3.2.3. Ownership of farming assets and finances

In LB only infrastructure related to animal husbandry was found (Table B. 4). All farmers had a livestock pen, most also had a small hay barn and animal sheds. Animal sheds were built only within the previous 10 years. Equipment to shear the wool of sheep and cut angora goat fibre, which was mostly done manually by farmers.

In PA crop production systems were found the most technified. Most farmers did not own a tractor or implements to cultivate the land but rely on cooperative services. However, three of the interviewed farmers owned a tractor and some attachments. Infrastructure used for livestock production in both irrigated and extensive grazing systems were in most cases livestock pens and small hay barns. Livestock pens are used to gather the animals for shearing or medical care, e.g., vaccination. Only two livestock farmers out of nine had animal sheds. Only few farmers had vehicles as motorcycles or small trucks that they use for their farming activities. Goats are sheared once or twice per year and sheep once. Four farmers use scissors to shear the wool, two use a wool shearing machine, one farmer rents the scissors and two farmers employ someone else to shear the animals.

Farmers in both study sites have access to financial services provided by banks or cooperatives, however not all farmers expressed to know about this possibility or did not want to take the risk of getting loans. Many farmers got small loans during drought periods to buy forage or water.

3.3. Major activities contributing to farmers' livelihood

Major activities contributing to farmer's livelihood are listed below based from farmers interviews (Table 3).

Table 3. Description of livelihood activities of livestock farmers.

Activity	**Description**
Crop farming	Crop involves irrigated crops as alfalfa, oat, maize, melilotus and aspen trees for wood production using flooding irrigation systems. The end product is aimed to be sold directly to neighbouring farmers or to middle man.
Crop and livestock production in mixed system	Mixed production system with irrigated pasture and livestock. Mainly irrigated by flooding system and in some cases also combined with sprinkle irrigation. Crops or pastures are aimed as fodder to feed livestock and in good years sell it to neighbouring farmers. Livestock reared are cattle and certain sheep breeds adapted to rich grassland feeding.
Extensive animal husbandry	Pastoral farming systems of semi-wild herds grazing extensively. Small ruminants produced for meat, wool and angora fibre and livestock are goats ("criollas" and angora breeds) and sheep (merino breed) well adapted to shrub steppe grazing and with low or non-external input. Cattle and horses are also reared extensively most of the time with extra external input. Cattle are aimed for meat, production of calves as well as for wealth storage. Horses are used for transportation and foal production.
Wetland/mountain grassland (sheep and/or cattle)	Wetlands are intended for sheep, cows and horses grazing during the summer. The rest of the year they graze extensively in the surrounding steppe rangelands. Goats are only reared extensively in the steppe rangelands as they are perceived to damage the irrigated grasslands and profit more from bush grazing.
Other farm activities	Honey production. Small vegetable gardens for self-consumption. Handicraft.

3.4. Impact of drought

Interviewed farmers in both study sites identified drought as one of the main causes for production losses (Table 4). Other hazards identified were adverse weather conditions, predation and volcanic ash deposits (Table B. 5; Table B. 6).

Table 4. Drought effects on extensive animal husbandry LB vs PA.

	Study area	
	LB	**PA**
Extensive animal husbandry	-Abortion (20%) of goat kids -Kids and lambing death (10% lambing rate) -Animals death (25-50% herd reduction) goats, sheep and cows. -Animals abandoning their offspring (sheep and goats) -Animals become skinny (goats) and many times die (sheep and goats). - When cows get very slim increase birth delivery problems and difficult recovery after birth. -Wool and animal fibre production declines in quantity and quality	-No kids or lambing. Very low offspring rates. -Goat kids and lambing death (10% marking rate) -Animals become skinny -Animals death (50-88% herd reduction) goats and sheep. -Animals walk far from the farm and get lost abandoning their offspring -Little milk production for the offspring in goats -In the long-term herd reduces and ages due to low replacement rate -Wool and animal fibre production declines in quantity and quality

3.5. Adaptation strategies

Some interviewed farmers had already implemented diversification of production and household income, and some also decided to change their management practices aiming to reduce drought negative effects on their farming systems. Survey questions were addressed to understand adaptation strategies adopted by farmers for the period 2000-2016 and farmers' perception about the most difficult barriers they face to recover from drought (Tables 5 and 6). Farmers used a few short-term strategies or adjustments in response to drought (such as purchasing supplementary feed or reduce herd size and slaughter unproductive animals to reduce animal density), but most strategies were long-term managerial or community-based adaptation measures to cope with drought. In particular for farmers using the steppe rangeland for extensive animal grazing there were additional constraints besides the drought problems that complicated the recovery after a drought period, such as slow regrowth of vegetation, land degradation due to heavy rains and negative effects of low temperatures on grassland and animals.

Table 5. Adaptive strategies employed by farmers in Laguna Blanca (n=12). In brackets (n=) total number of respondents.

	Production system	
Drought	**Mixed Rangeland grassland (summer pasture) and steppe (Wetland) (sheep and cattle) n=6**	**Rangeland steppe extensive animal husbandry (Goats and horses) n =11**
Short term managerial strategies		-Occasionally buying forage and feed supplements (grain based) for goats (n=2) -Reduce herd size and slaughter kids of oldest goats for faster recover (n=1) -Occasional transhumance (goats) (n=1)
Long term managerial strategies	-Feed supplements to complement natural pasture as part of their management (grain based) for sheep and cattle (n=6) -Building up infrastructure: animal shed (n=6); barn for forage storage (n=5) -Animal genetics improvement (n=4) -Adjust herd size according to grassland production (n=1) -Pasture management and grazing rest periods (n=1)	-Feed supplements to complement natural pasture as part of their management (grain based) for goats (n=5) -Building up infrastructure: animal shed (n=9); barn for forage storage (n=2) -Transhumance or seasonal pastures (concern about pasture resting periods) (n=7) -Reduce herd size (n=3) -Animal specialisation keeping only goats (n=4) -Animal diversification buying sheep (n=1)
Community-based strategies	-Infrastructure for public water supply to the households in construction (n=1) Group commercialisation of wool and angora fibre through the cooperative (n=1)	
Other strategies	-Non-farm jobs (n=1) -Obtaining subsidies and pensions (n=3) -Selling eggs and vegetables (n=2) -Selling handicraft (n=2) -Keeping animals healthy (vaccination) (n=2)	
Barriers to recovery from drought		-Low temperatures (n=3) -Trade-offs associated with wrong implementation of strategies (livestock behaviour as semi-wild animals difficult to tame, diet changes and diarrhoea) (n=2) -Slow steppe vegetation recovery (very resistant but slow recovery once it dies) (n=1) -Short growing season (n=1) -Fire destroying vegetation (n=1) -Overgrazing of land leading to degradation of the natural pasture (n=1)

Table 6. Adaptive strategies employed by farmers in Paso Aguerre (n=11). In brackets (n=) total number of respondents.

	Production system			
Drought	**Crop farming (Alfalfa, grasses, etc.)** **n=3**	**Crop-livestock system (Grassland & sheep and/or cattle)** **n=8**	**Rangeland steppe extensive animal husbandry (Goats, Sheep, horses)** **n=5**	**Others (Honeybees and vegetable garden)** **n=2**
Short term managerial strategies		-Buying forage and feed supplements (grain based) for sheep and cattle (n=7) -Pasture grazing rest periods (n=3) -Reduce herd size (n=1)	-Reduce herd size and slaughter unproductive animals (n=4) -Buying feed supplements (grain based) for sheep and goats (n=3) -Occasional transhumance (goats) (n=1)	-Sugar supplement and water for honey bees (n=1)
Long term managerial strategies		-Find new water sources (water well) (n=5) -Crop switch and/or diversification (e.g. from poplar trees and alfalfa to fescue pasture or maize) (n=3) -Improve water use efficiency installing pump and sprinkler irrigation system (n=2) -Switch from crop farming to crop-livestock system with pasture and sheep (n=2) -Animal switch: from pork to sheep (n=1); from extensive grazing sheep to crop-livestock system with cattle (n=1)	-Building up infrastructure: animal shed (n=2); barn for forage storage (n=2) -Improve rain water harvest system (n=1)	
Community-based strategies	-Shared machinery to ensure timely cropping and reduce costs (n=7) -Group buying of seeds (n=7)	-Animal genetics improvement (n=6)	-Shear wool and cut angora fibre within cooperative work (n=5) -Group commercialisation of wool and angora fibre through the cooperative (n=3)	-Honeybee keepers cooperative for tools, group buying of materials and selling (n=1)
Barriers to recovery from drought		-Limited/slow water table recovery in water wells (n=2) -Limited amount of forage available for buying (n=1) -Short growing season for crops (n=1)	-Iodine deficiency in goats (n=3) -Slow grass-shrub steppe pasture biomass production recovery (n=2) -Heavy rains after drought periods destroyed rainwater harvest dam system (n=2) and increased soil erosion (n=1) -Long rain periods are too cold for animals without shelter (n=1).	-Long windy periods when bees can't fly(n=1).

4. Discussion

Evidence of drought in North West Patagonia

Satellite images provided consistently measured periodical information for the study of vast and remote areas where meteorological data was difficult to obtain. Time series analysis of remote sensing data identified that multiple droughts and recovery periods have occurred during the period 2000-2018 in North-West Patagonia. Onset and cessation of drought events showed a gradual increase of proportion of pixels as an indicator of the affected surface (Fig. 5 and Fig. 10). These results illustrated drought as a process which took several seasons to be detected on most of the area. Only one drought was found in the West LB and five droughts were most frequently found in East LB and PA. The most severe drought was observed in 2011 in LB and in 2012 in PA. Most severe drought duration was around 2 years in LB and for the PA study site, results showed similar frequencies for the duration of two and four years. This difference between study sites might be explained by the differences in climate, as for instance PA is much drier than LB (Bran & Ayesa, 2002). Another possibility could be that low NDVI values were detected for a period of 4 years including a small recovery period in the middle, while only for some pixels the NDVI values were higher than the mean resulting in two consecutive drought periods of 2 years each. Peak recovery periods were found in 2016 in LB and in 2017 in PA. The frequency of drought events increased after 2009 and there was a reduction in the duration of recovery periods.

The LB study site showed a gradient of NDVI mean values from West to East as an altitudinal gradient which might be also associated to a transition of the phytogeographic provinces from Patagonia to Monte (Fig. 4) also associated to climatic differences as for instance rainfall patterns and temperature (Gaitán et al., 2013; Paruelo et al., 1998). Other differences found were total number of drought events identified, five droughts in the East while it was only one drought event most commonly found in the West. In PA, the dominant phytogeographical province is only Monte and represented less variation of mean NDVI values for the steppe rangeland than LB (Fig. 9), suggesting more homogeneity of vegetation. This could provide an explanation for the higher amount of proportion of pixels found when analysing some drought characteristics as for instance starting and ending years of drought and most severe drought, compared to LB. Another explanation could be derived from the limitations of the method (such as limitation from the use of vegetation indices for mountain areas were vegetation is largely dormant during long cold seasons (Mishra and Singh, 2010)). Therefore, for the case of LB were several differences were found in the West and the East, it could be useful to analyse NDVI dynamics of those two areas separately and investigate differences if there are of drought features. Moreover, in both study areas highly productive areas were found (NDVI higher than 0.30) covering small areas (sometimes smaller than the pixel size of 6.25 ha). These areas play a very important role for farming systems and it could be expected that vegetation dynamics in these areas greatly differ from steppe rangeland vegetation dynamics. Further and more specific studies are needed for a better understanding of mountain grasslands, wetlands and irrigated areas dynamics where other factors as for instance the flow characteristics of ground water and surface water have a strong influence on the vulnerability to droughts (Winter, 2000).

Inter-annual NDVI variability greatly correlated with annual rainfall data with a one-year lag. Similarly, Fabricante et al. (2009) found that inter-annual variation of NDVI in Northern Patagonia was highly correlated with precipitation accumulated during few months of the previous growing season. Lags in vegetation response after precipitation together with the analysis of inter-annual NDVI dynamics provide an opportunity for forecasting drought events and vegetation production. However, more research is needed to understand the influence of other factors as temperature, strong winds events, plant species composition and plant coverage on NDVI variations to enhance drought forecasting.

The farm production system most frequently found was extensive animal husbandry with goats (Table B. 2. and Table B. 3.). Extensive animal husbandry is one of the main agricultural activities in semi-arid rangelands worldwide (Easdale and Rosso, 2010) and goats were perceived by farmers as the livestock best adapted to drought and steppe rangeland conditions and also, less susceptible to predation (Results not showed). Interviewed farmers with diversified production systems presented the largest herds (highest AU) and they were the ones to have access to high productive forage areas (i.e. mountain grassland areas and wetlands associated with transhumant practices or seasonal movements in LB and irrigated crop area in PA). Therefore, diversification of production in both study areas was strongly linked to forage availability and the possibility to access high productive areas. Farmers expressed different drought impacts on farming systems according to the production system. Extensive animal husbandry was perceived by farmers as the most exposed to droughts in both study areas. Production losses for extensive animal husbandry during drought were related to a dramatic increase in animal mortality, abortions, lamb and goat kid mortality and lower quality of meat, wool and fibre. Animals dying lead to a rapid decapitalization of the production systems and hinders the continuity of their enterprise (Easdale and Rosso, 2010). Other losses for crop, crop-livestock and wetland/mountain grassland production systems were caused by crop failure and reduction of forage production.

Most farmers combined different adaptive strategies which were managerial, community and non-farm-based strategies to deal with drought and other hazards such as predation, weather hazards, diseases and genetic disorders and volcanic ash deposits. Easdale and Rosso (2010) assessed the effects on household income of different smallholder survival strategies in Northern Patagonia after the drought in 2007. The study showed better household economic performance for those who joined associated sales and had off-farm incomes, compared to those who chose farm production diversification. Therefore, non-farm and community-based strategies might be effective strategies to decrease systems sensitivity and recovery capacity during and after severe droughts, when costs and losses increase.

Farmers' perception and memories of drought

Farmers' definitions of drought could be related to agricultural, meteorological and socio-economic drought as they referred to forage production failure, lack of precipitation (i.e. rain and snow) and failure of water resource systems to meet water demands as defined by Mishra and Singh (2010).

Watershed management integrated different water resources and practices due to the existing scarcity of water in the area. During severe droughts, many of those sources were depleted and some of the farmer's households did not have enough drinking water for human or animal consumption. Water management strategies are key for the persistence of the inhabitants in semi-arid environments and therefore, precipitation data could be used as a good predictor of water scarcity. Further studies are needed to understand how the fluctuation of water resources are influenced by droughts and what are the strategies that lead to more water collection and higher water-use efficiency.

All interviewed farmers perceived drought as one of the most reducing productivity factors however, not all farmers changed their managerial practices in the period 2000-2016. Further, droughts are not the only large problem producers have to deal with. And for instance, predation of fox and puma and ash deposits from the volcanic eruption of Puyehue were perceived to provoke important added problems to that of impact of drought. The volcanic ash affected livestock's health with sight problems, changes in nutritional behaviour and tooth wear. Moreover, the ash covered pasture resources and as a consequence offspring declined due to abortions or abandonment and the quality of wool and angora fibre decreased.

Farmers clearly identified the production systems' most vulnerable moment and differed within production strategies. As an example, in LB study site, on one hand the extensive animal husbandry production system most critical moment was perceived to occur during the summer months due to water scarcity. On the other hand, the rest of interviewed farmers perceived winter as the most difficult due to cold droughts and long cold weather events hampering forage production and offspring survival during lambing time. Similar results were found in PA. These results illustrate different perceptions for the same hazard. Expectations of drought are shaped by memories and experiences of drought, at the same time this will influence drought risk perception and future drought expectations (Slegers, 2008). Therefore, the adoption of certain strategies might also have a link with farmers' perceptions. For this, monitoring tools with the use of remote sensing data as Satellite MODIS imagery, updated every 16 days, with further attention on seasonal evaluations of vegetation dynamics, could provide valuable information for farmers to anticipate and manage drought according to their production systems' needs. Furthermore, seasonal information of drought could provide the basis to evaluate adaptation strategies.

Matching scientific based information and farmers' perception of drought

In LB, both the time series analysis of satellite images and farmers identified 2011 as the worst year of drought. Differently in PA, the time series analysis of satellite images identified 2012 as the worst year of drought while most farmers indicated 2011 to be the worst year. Farmers in both study sites remembered that year together with the Puyeue volcano eruption in which they experienced livestock losses due to ash deposits. Results obtained from the NDVI dynamics showed the previous drought onset in 2007 with its peak in 2008 and had an almost inexistent recovery period before 2011. Mismatch between vegetation dynamics and farmers' perceptions of drought might be due to different reasons as farmer's experiences of drought, not only related to forage availability but to water scarcity, a dry year with low precipitation (88.0 mm rainfall registered in 2011), and the most vulnerable moment for their production systems, shape their memories and perceptions (Taylor et al., 1988). Farmers might experience higher losses before drought events reach their severity peak. Another explanation could be related to higher losses when repetitive droughts with short recovery periods occur, hampering the possibility of the systems to recover. A decapitalized farming system due to animal death takes a long time to recover the initial size of the flock before the disturbance. Further studies to better understand this relationship would be useful to anticipate drought negative effects on farming systems and allow the adaptation of management strategies.

5. Conclusion

Time series analysis of NDVI dynamics using the Basis Pursuit algorithm were sensitive enough to capture several periods when natural vegetation of steppe rangelands suffered a drastic decrease of photosynthetic activity. These perturbations were linked to a decrease of precipitation of the previous year and finally related to drought events. By this means, several droughts events with their onset, peak and cessation and the recovery periods were identified. For the period 2000-2018 a total of five drought events lasting for two to four years were most frequently found. Drought frequency increased after 2009 while recovery periods became shorter. The applied methodology provided a valuable overview of the spatial and temporal characteristics of droughts. However, results were not always clear, for instance in determining the onset and cessation of drought events for all the study site. Further research is required about the patterns of primary production in the Patagonian steppe when drought events occur to overcome the limitation in the use of NDVI dynamics for drought monitoring. More, a validation of the method for drought monitoring should be done using other indices.

Scientific based information using remote sensing data and annual rainfall data could be partially matched with farmers' perception of drought. These results evidence a certain mismatch between the used methods and farmers perceptions which are influenced by more factors than lack of pasture. For instance, water scarcity was not pictured by the analysis of vegetation dynamics and it was perceived by farmers as one of the most negative effects of drought on their production systems and households. Farmers' perceptions, memories and explanations about their systems and drought strategies enriched the interpretation of droughts in North West Patagonia and the affected resources important for farming systems which are mainly forage and water availability. All interviewed farmers perceived drought as one of the most reducing productivity factors. Drought is a constant part of semi-arid regions and managerial strategies of farmers to cope with and adapt to drought were already existing. Moreover, some farmers changed their managerial practices in the period 2000-2016 not only to reduce negative effects of drought but also to deal with predation and problems derived from ash deposits from the volcanic eruption of Puyehue. Further research is needed to understand how particular strategies benefit farming systems in reducing their vulnerability to drought to better target policy developments in semi-arid rangelands with similar farming characteristics.

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6. References

Akaike, H. (1974). A new look at the statistical model identification. IEEE transactions on automatic control, 19(6), 716-723.

Allen, V. G., Batello, C., Berretta, E. J., Hodgson, J., Kothmann, M., Li, X., ... & Sanderson, M. (2011). An international terminology for grazing lands and grazing animals. Grass and forage science, 66(1), 2-28.

Ashton, W. D. (1972). logit transformation with special reference to its uses in bioassay.

Blanco, L. J., Paruelo, J. M., Oesterheld, M., & Biurrun, F. N. (2016). Spatial and temporal patterns of herbaceous primary production in semi‐arid shrublands: a remote sensing approach. Journal of vegetation science, 27(4), 716-727.

Bran, D., & Ayesa, J y Lopez, C. (2002). Areas ecologicas de neuquen, 1-8.

Bruzzone, Octavio. (2018). okktawio/gpu_pursuit v0.0-alpha (Version v0.0-alpha). Zenodo. http://doi.org/10.5281/zenodo.1173183

Chaudhury, M., Vervoort, J., Kristjanson, P., Ericksen, P., & Ainslie, A. (2013). Participatory scenarios as a tool to link science and policy on food security under climate change in East Africa. Regional Environmental Change, 13(2), 389-398.

Domptail, S., & Easdale, M. H. (2013). Managing Socio‐Ecological Systems to Achieve Sustainability: A Study of Resilience and Robustness.Environmental policy and governance, 23(1), 30-45.

Easdale, M. H., & Rosso, H. (2010). Dealing with drought: social implications of different smallholder survival strategies in semi-arid rangelands of Northern Patagonia, Argentina. The Rangeland Journal, 32(2), 247-255.

Easdale, M. H., Bruzzone, O., Mapfumo, P., & Tittonell, P. (2018). Phases or regimes? Revisiting NDVI trends as proxies for land degradation. Land Degradation & Development, 29(3), 433-445.

Easdale, M. H., López, D. R., Bianchi, E., Bruzone, O., Siffredi, G. L., Gaitán, J. J., ... & Oricchio, P. (2012). Una herramienta para monitorear sequías en regiones áridas y semiáridas de Patagonia Norte. RIA. Revista de investigaciones agropecuarias, 38(2), 158-164.

Easdale, M. H., López, D. R., Bianchi, E., Bruzone, O., Siffredi, G. L., Gaitán, J. J., ... & Oricchio, P. (2012). Una herramienta para monitorear sequías en regiones áridas y semiáridas de Patagonia Norte. RIA. Revista de investigaciones agropecuarias, 38(2), 158-164.

FAO (2018) Land & Water. Drought and Agriculture. Retrieved from: http://www.fao.org/land-water/water/drought/en/

Gaitán, J. J., Bran, D., Oliva, G., Ciari, G., Nakamatsu, V., Salomone, J., ... & Celdrán, D. (2013). Evaluating the performance of multiple remote sensing indices to predict the spatial variability of ecosystem structure and functioning in Patagonian steppes. Ecological indicators, 34, 181-191.

Galvin, K. A., Reid, R. S., Behnke, R. H., & Hobbs, N. T. (2008). Fragmentation in semi-arid and arid landscapes. Consequences for Human and Natural Systems. Dordrecht, The Neth.: Springer.

Gardi, C., Angelini, M., Barceló, S., Comerma, J., Cruz Gaistardo, C., Encina Rojas, A., Jones, A., Krasilnikov, P., Mendonça Santos Brefin, M.L., Montanarella, L., Muñiz Ugarte, O., Schad, P., Vara Rodríguez, M.I., Vargas, R., Ravina da Silva, M. (eds), 2015. Soil Atlas of Latin America and the Caribbean, European Commission - Publications Office of the European Union, L-2995 Luxembourg, 176 pp.

Herrero, M., Thornton, P. K., Bernués, A., Baltenweck, I., Vervoort, J., van de Steeg, J. & Staal, S. J. (2014). Exploring future changes in smallholder farming systems by linking socio-economic scenarios with regional and household models. Global Environmental Change, 24, 165-182.

Jobbágy, E. G., Sala, O. E., & Paruelo, J. M. (2002). Patterns and controls of primary production in the Patagonian steppe: a remote sensing approach. Ecology, 83(2), 307-319.

Keshavarz, M., Karami, E., & Vanclay, F. (2013). The social experience of drought in rural Iran. Land Use Policy, 30(1), 120-129.

Mallat, S. G., & Zhang, Z. (1993). Matching pursuits with time-frequency dictionaries. IEEE Transactions on signal processing, 41(12), 3397-3415. Mishra, A. K., & Singh, V. P. (2010). A review of drought concepts. Journal of hydrology, 391(1-2), 202-216.

Neely, C., Bunning, S., & Wilkes, A. (2009). Review of evidence on drylands pastoral systems and climate change. Rome: FAO.

Paruelo, J. M., Golluscio, R. A., Guerschman, J. P., Cesa, A., Jouve, V. V., & Garbulsky, M. F. (2004). Regional scale relationships between ecosystem structure and functioning: the case of the Patagonian steppes. Global Ecology and Biogeography, 13(5), 385-395.

Pereyra, F.X., & Irasarri, J.A. (2011). Suelos: Factores de formación, procesos pedogenéticos y distribución, (2006), 871-880.

Peters, A. J., Walter-Shea, E. A., Ji, L., Vina, A., Hayes, M., & Svoboda, M. D. (2002). Drought monitoring with NDVI-based standardized vegetation index. Photogrammetric engineering and remote sensing, 68(1), 71-75.

Rutherford, M. C. (1980). Annual plant production-precipitation relations in arid and semi-arid regions. South African Journal of Science, 76(2), 53-57.

Sivakumar, M. V. K., Das, H. P., & Brunini, O. (2005). Impacts of present and future climate variability and change on agriculture and forestry in the arid and semi-arid tropics. In Increasing Climate Variability and Change (pp. 31-72). Springer, Dordrecht.

Slegers, M. F. (2008). “If only it would rain”: Farmers’ perceptions of rainfall and drought in semi-arid central Tanzania. Journal of Arid Environments,72(11), 2106-2123.

Slegers, M. F., & Stroosnijder, L. (2008). Beyond the desertification narrative: a framework for agricultural drought in semi-arid east Africa.AMBIO: A Journal of the Human Environment, 37(5), 372-380.

Taylor, J. G., Stewart, T. R., & Downton, M. (1988). Perceptions of drought in the Ogallala Aquifer region. Environment and Behavior, 20(2), 150-175.

Whitfield, S., & Reed, M. S. (2012). Participatory environmental assessment in drylands: introducing a new approach. Journal of Arid Environments, 77, 1-10.

Winter, T. C. (2000). The vulnerability of wetlands to climate change: a hydrologic landscape perspective. JAWRA Journal of the American Water Resources Association, 36(2), 305-311.

Yengoh, G. T., Dent, D., Olsson, L., Tengberg, A. E., & Tucker III, C. J. (2015). Use of the Normalized Difference Vegetation Index (NDVI) to Assess Land Degradation at Multiple Scales: Current Status, Future Trends, and Practical Considerations. Springer.

7. Appendices

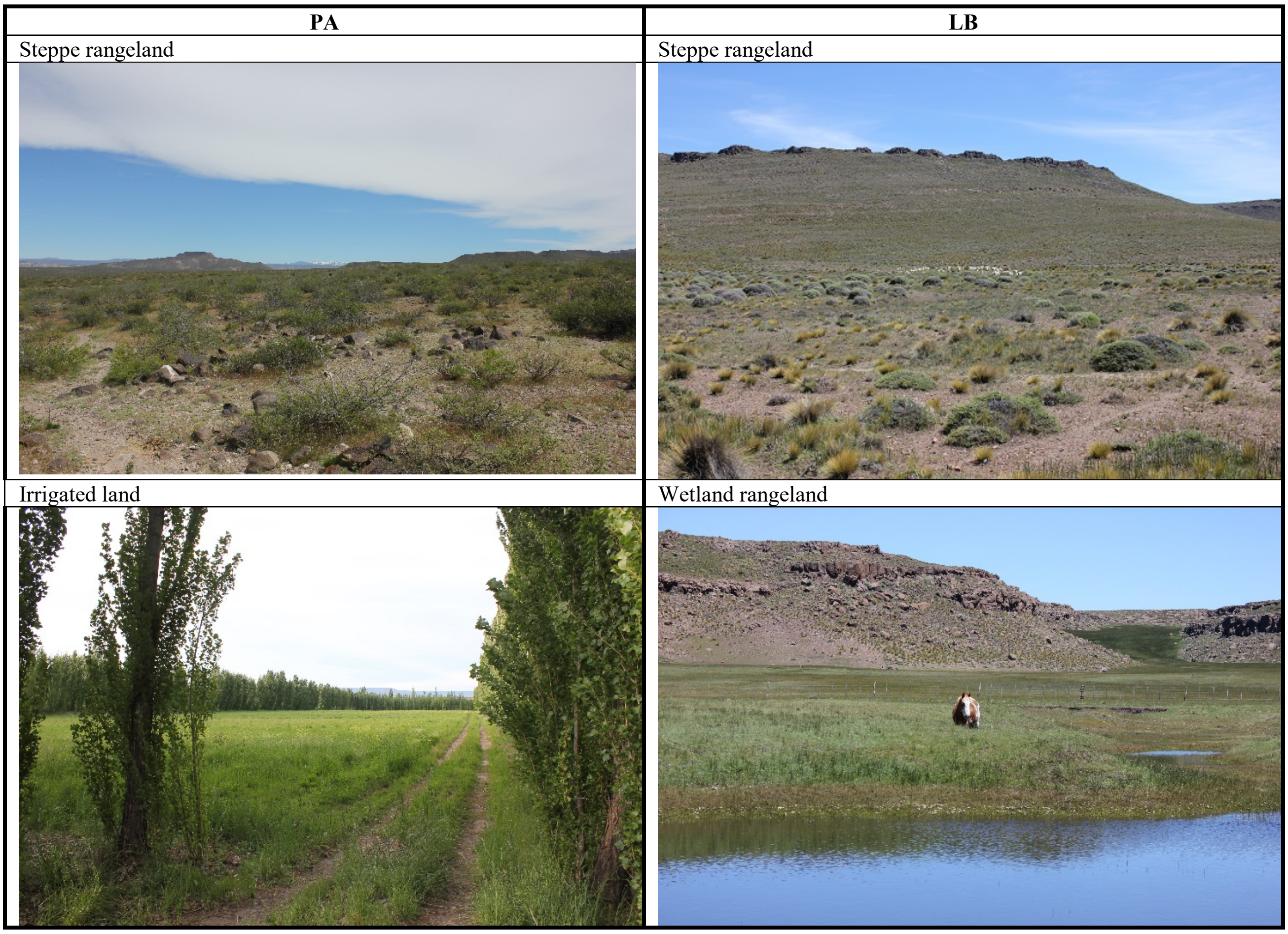


Fig. A. 1. Landscape typology.

Table A. 1. Meteorological data from Zapala Airport Weather station.

Year	Annual rainfall	Annual rainfall – Mean Annual rainfall
1999	323.5	106.3
2000	340.0	122.8
2001	348.3	131.1
2002	168.8	-48.4
2003	87.2	-130.0
2004	368.6	151.4
2005	298.3	81.1
2006	241.0	23.8
2007	58.8	-158.4
2008	155.1	-62.1
2009	119.1	-98.1
2010	75.0	-142.2
2011	88.0	-129.2
2012	153.0	-64.2
2013	241.0	23.8
2014	305.2	88.0
2015	188.9	-28.3
2016	350.2	133.0

Mean	217.2	
Maximum	368.6	151.4
Minimum	58.8	-158.4

7.1. Appendix A. Results Maps and Histograms

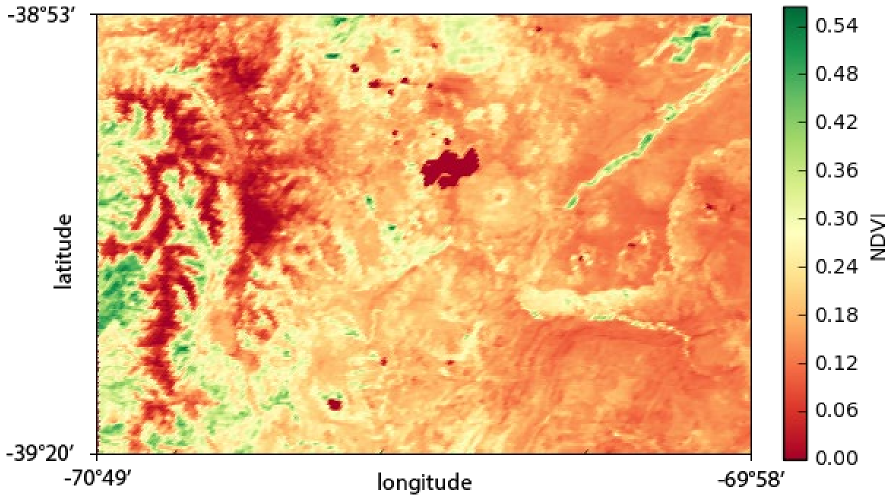


Fig. A. 2. Mean NDVI values in Laguna Blanca for the period 2000-2018.

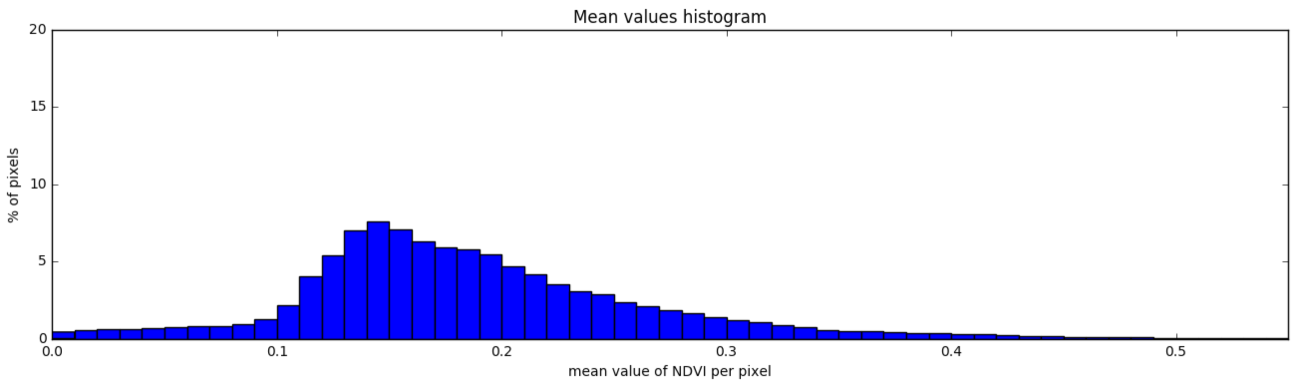


Fig. A. 3. Relative frequencies of mean NDVI values found in Laguna Blanca for the period 2000-2018 expressed as % of pixels.

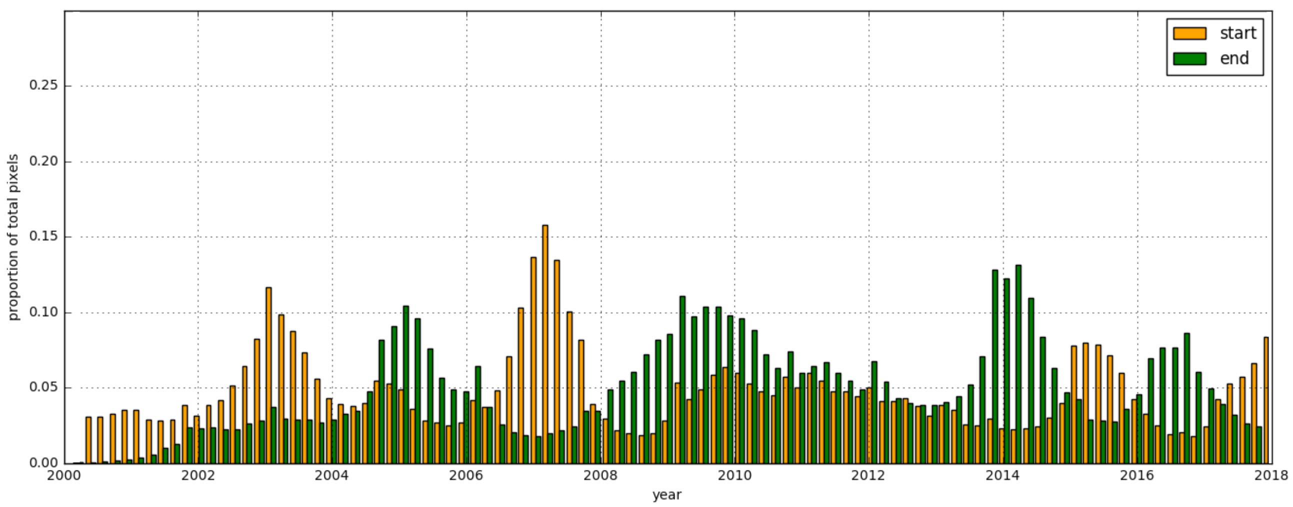


Fig. A. 4. Proportion of pixels indicating starting and ending years of drought events identified in Laguna Blanca for the period 2000-2018.

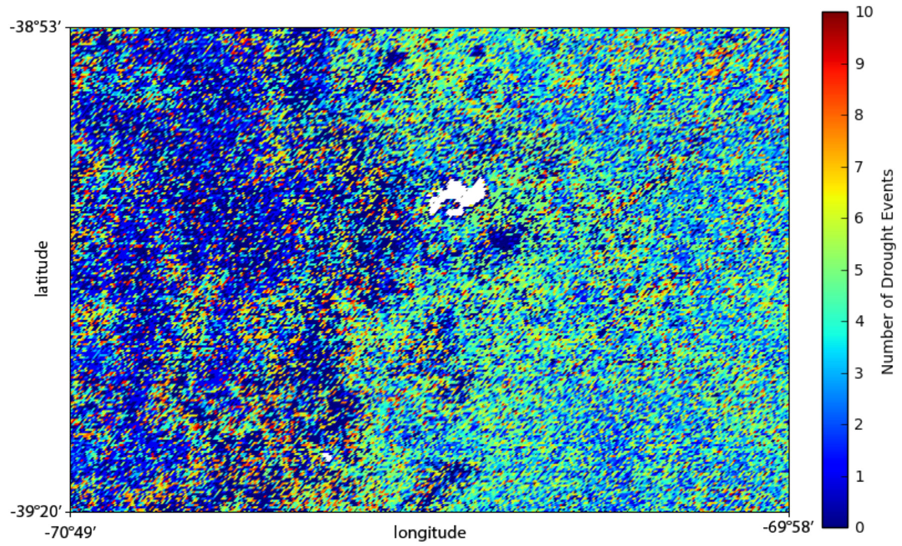


Fig. A. 5. Total number of drought events identified for each pixel in Laguna Blanca for the period 2000-2018.

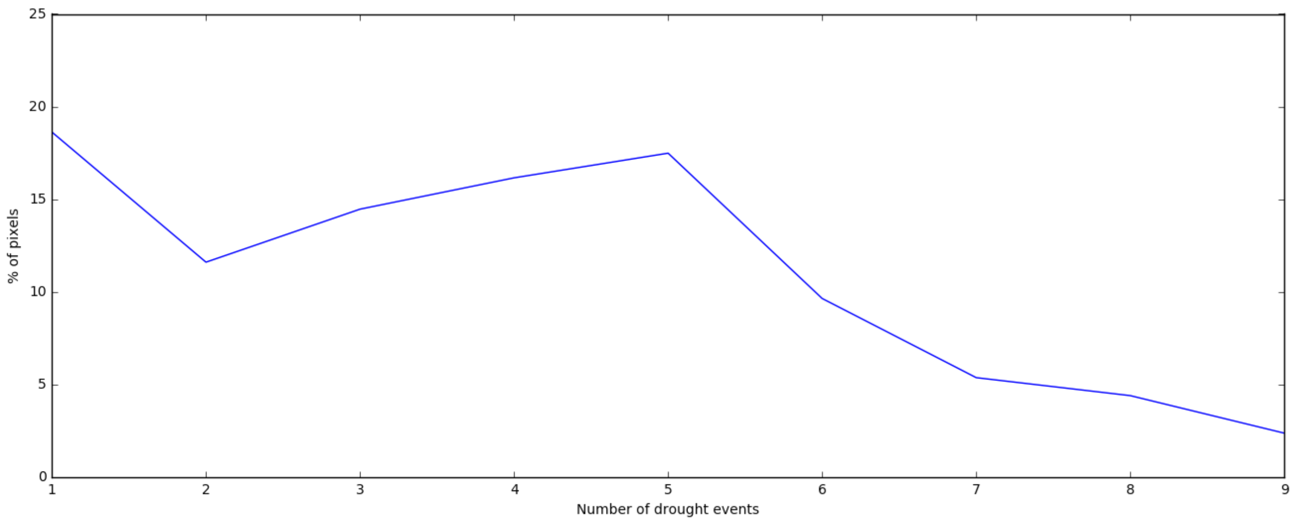


Fig. A. 6. Relative frequencies of number of drought events identified in Laguna Blanca for the period 2000-2018 expressed as % of pixels.

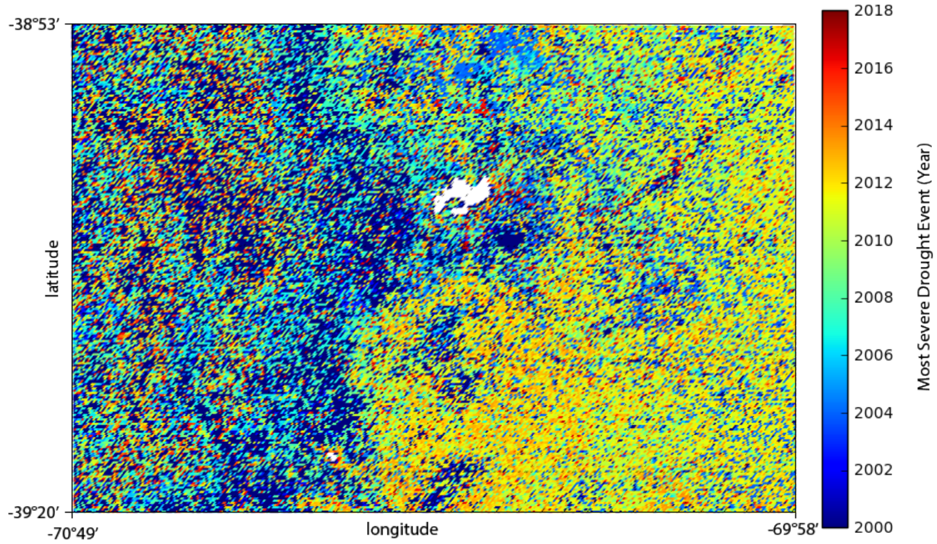


Fig. A. 7. Moment of the most severe drought event identified (Year) in Laguna Blanca for the period 2000-2018.

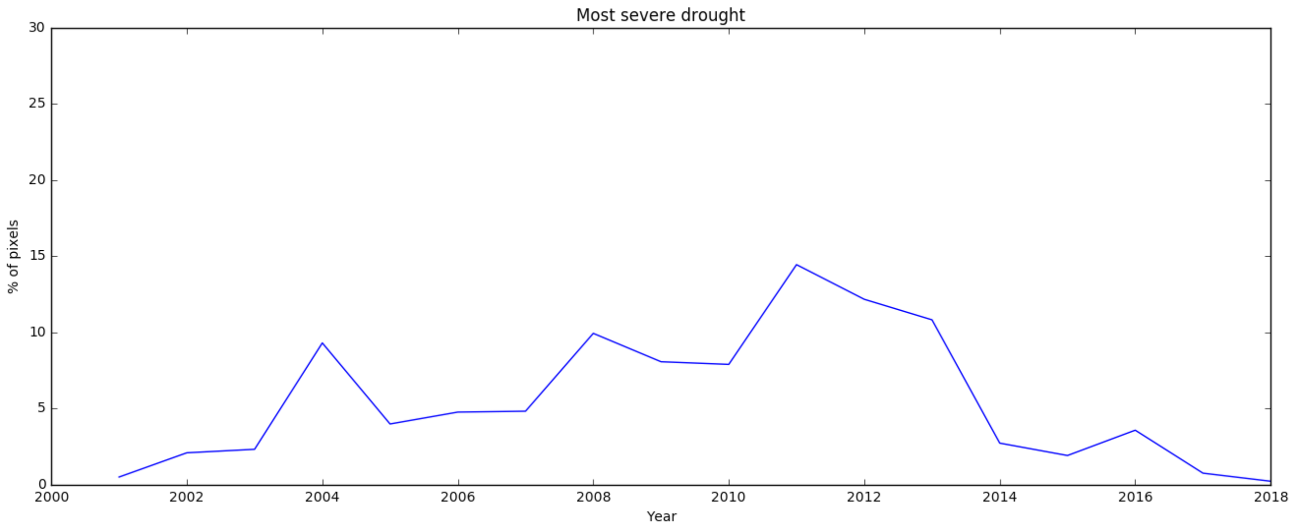


Fig. A. 8. Relative frequencies of the most severe drought event identified (Year) in Laguna Blanca expressed as % of pixels.

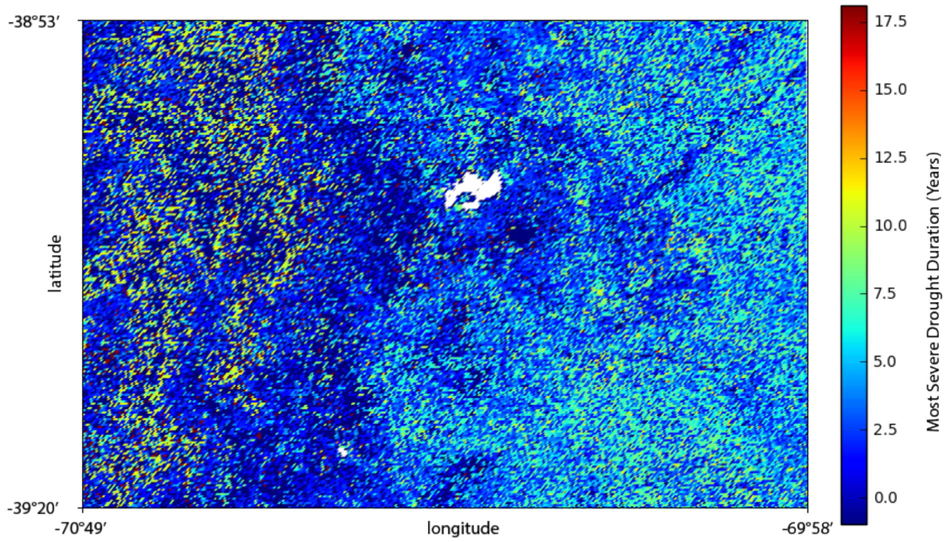


Fig. A. 9. Most severe drought duration (Years) identified in Laguna Blanca for the period 2000-2018.

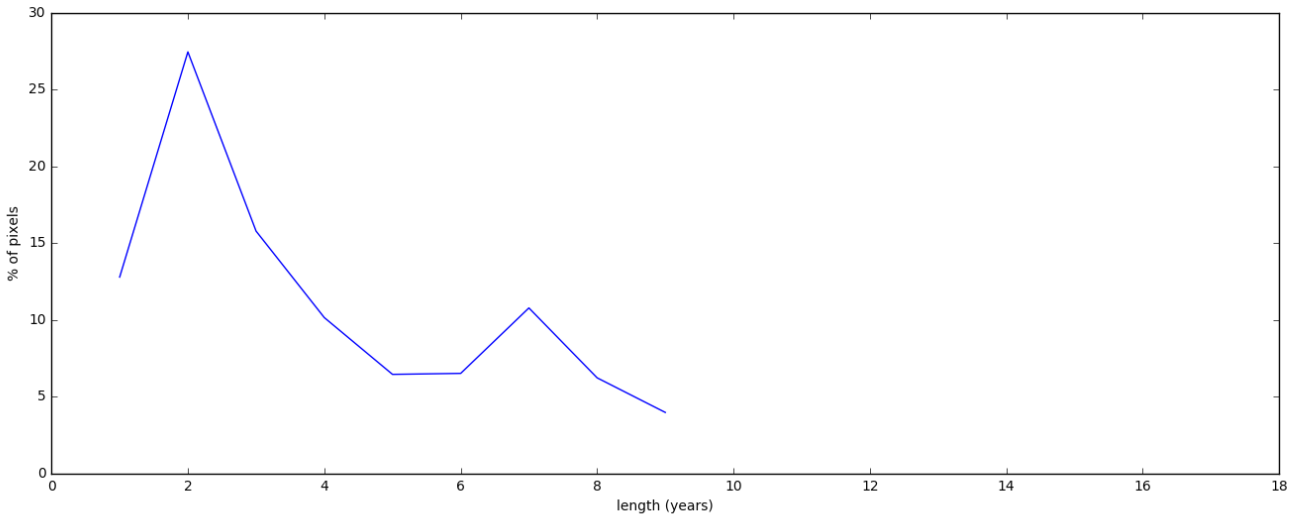


Fig. A. 10. Relative frequencies of the most severe drought duration identified in Laguna Blanca for the period 2000-2018 expressed as % of pixels.

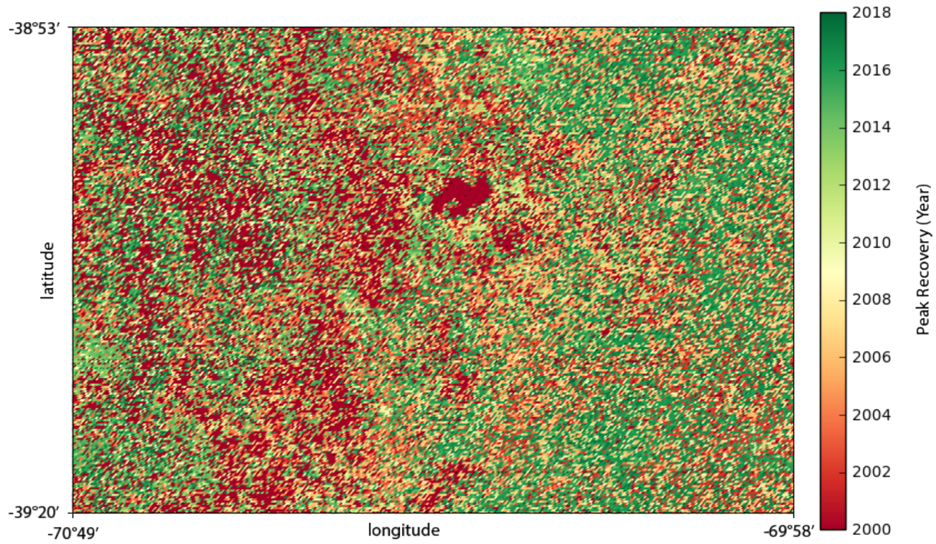


Fig. A. 11. Peak recovery (Year) identified in Laguna Blanca for the period 2000-2018.

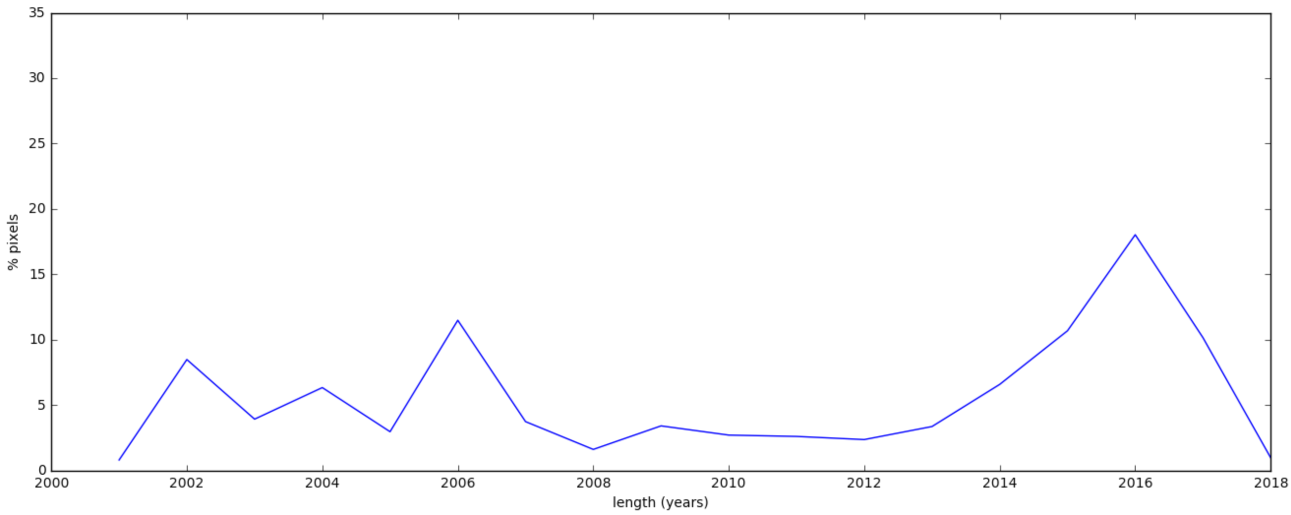


Fig. A. 12. Relative frequencies of peak recoveries identified in Laguna Blanca for the period 2000-2018.

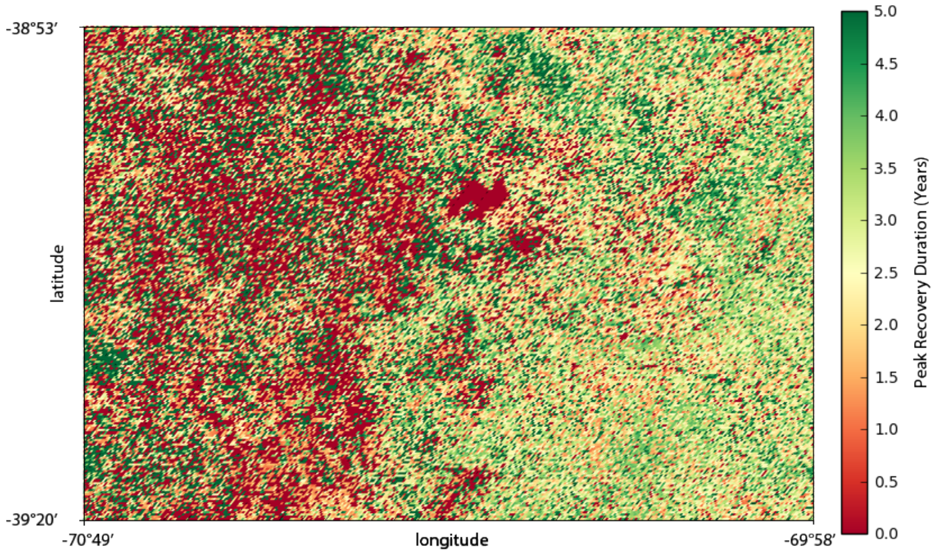


Fig. A. 13. Peak recovery duration (Years) in Laguna Blanca for the period 2000-2018.

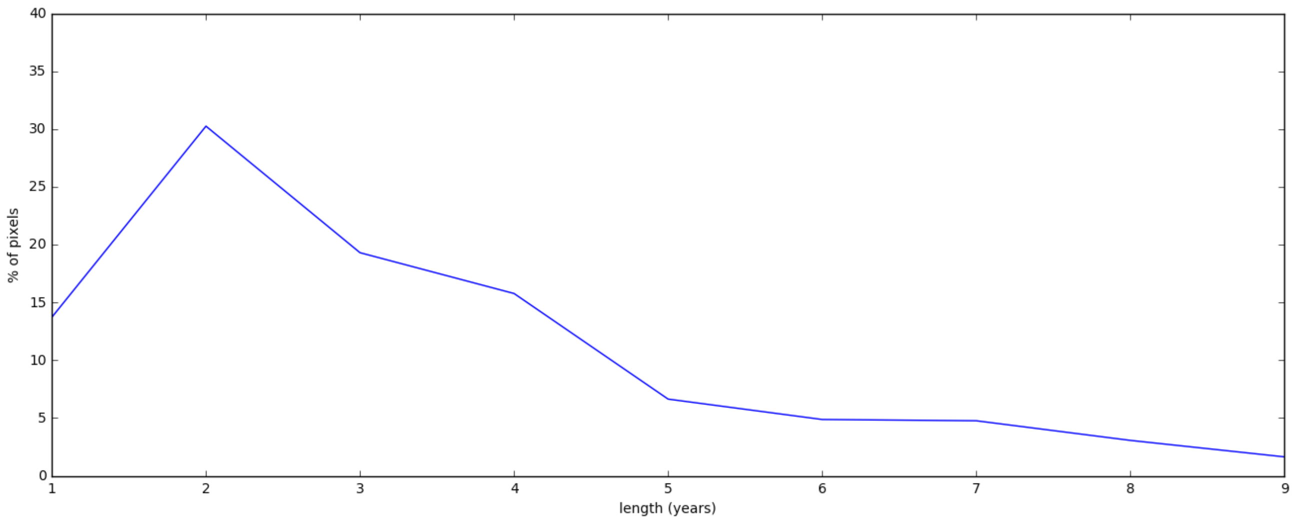


Fig. A. 14. Relative frequencies of peak recovery duration (Years) identified in Laguna Blanca for the period 2000-2018.

Paso Aguerre Results Maps and Histogram

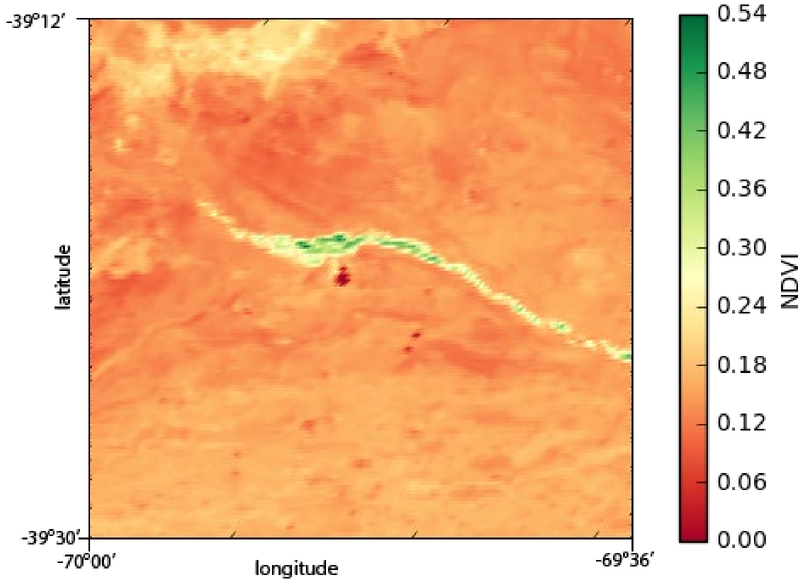


Fig. A. 15. Mean NDVI values in Paso Aguerre for the period 2000-2018.

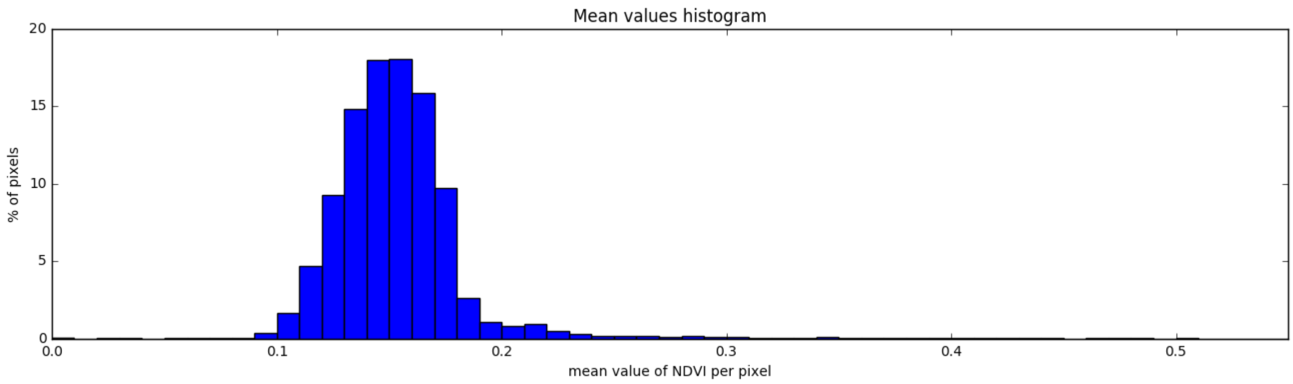


Fig. A. 16. Relative frequencies of mean NDVI values found in Paso Aguerre for the period 2000-2018 expressed as % of pixels.

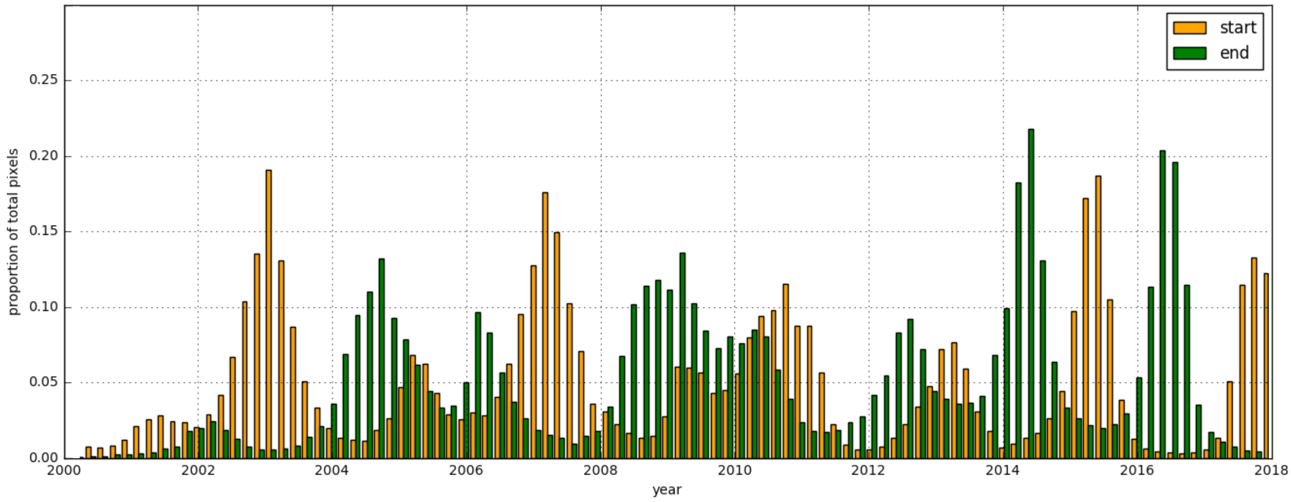


Fig. A. 17. Proportion of pixels indicating starting and ending years of drought events identified in Paso Aguerre for the period 2000-2018.

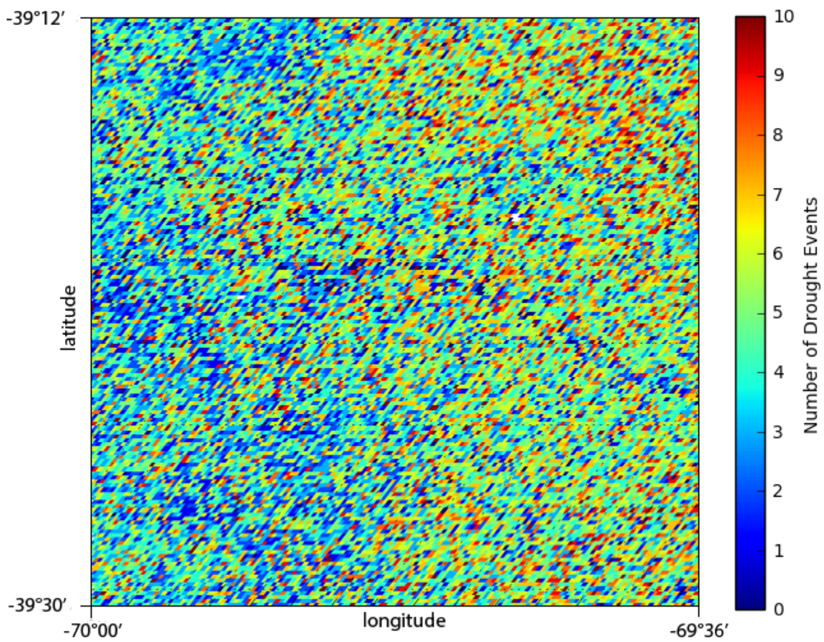


Fig. A. 18. Total number of drought events identified for each pixel in Paso Aguerre for the period 2000-2018.

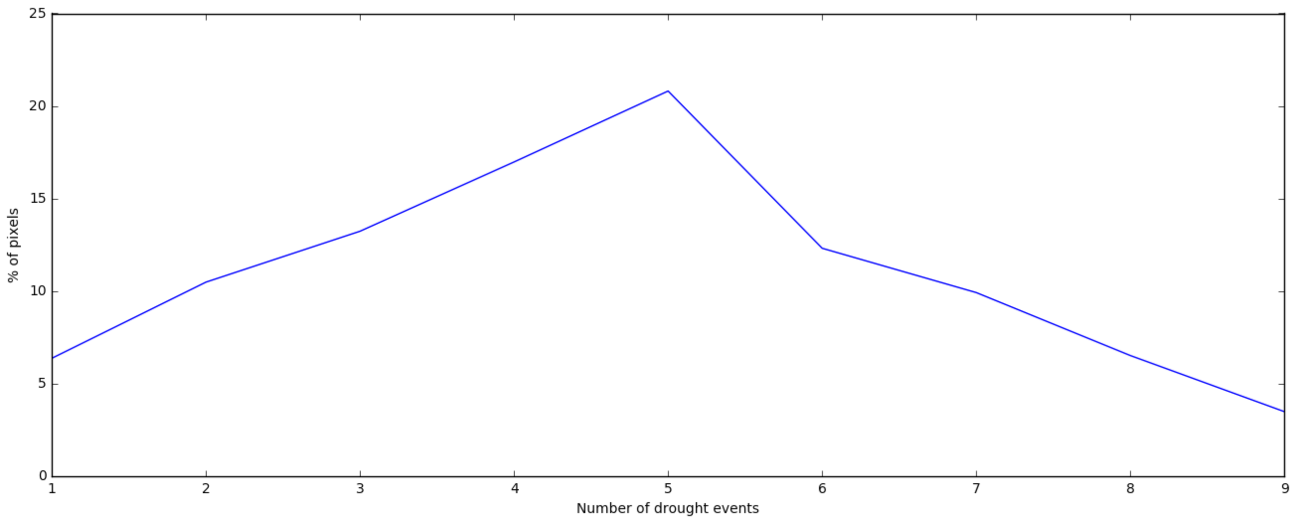


Fig. A. 19. Relative frequencies of number of drought events identified in Paso Aguerre for the period 2000-2018 expressed as % of pixels.

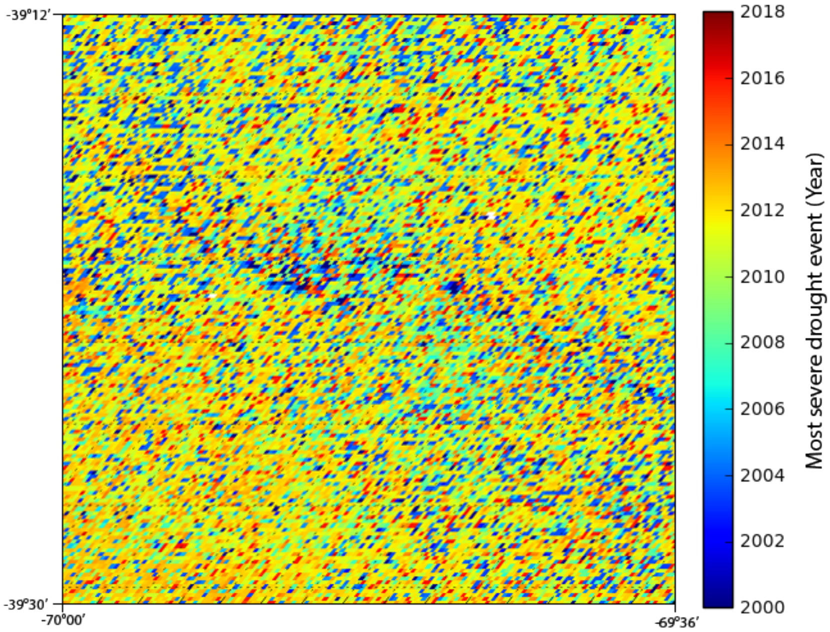


Fig. A. 20. Most severe drought event identified (Year) in Paso Aguerre for the period 2000-2018.

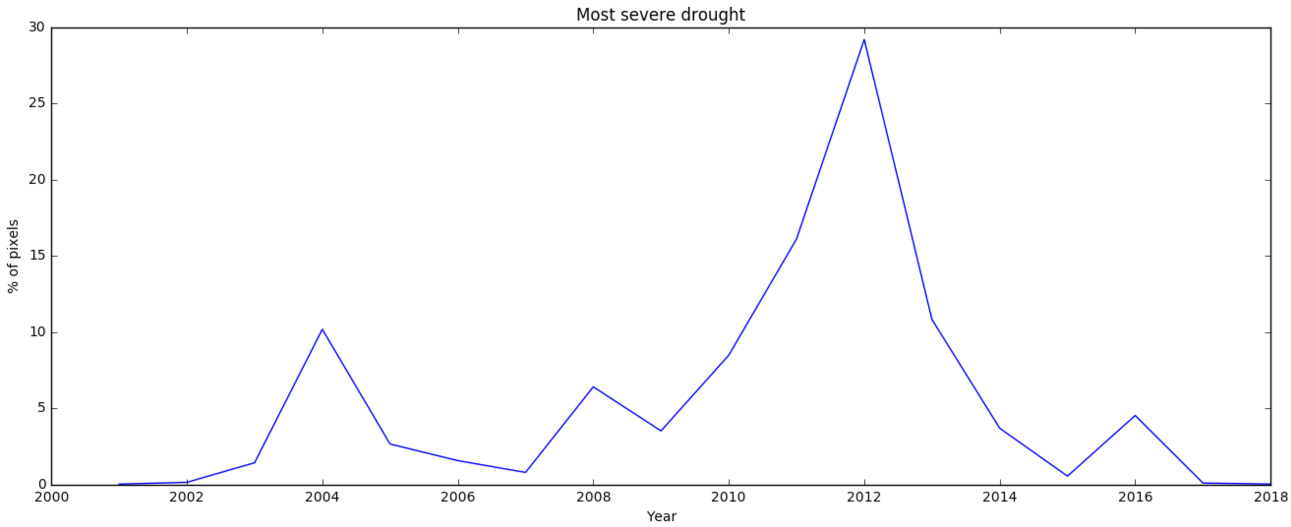


Fig. A. 21. Relative frequencies of the most severe drought event identified (Year) in Paso Aguerre expressed as % of pixels.

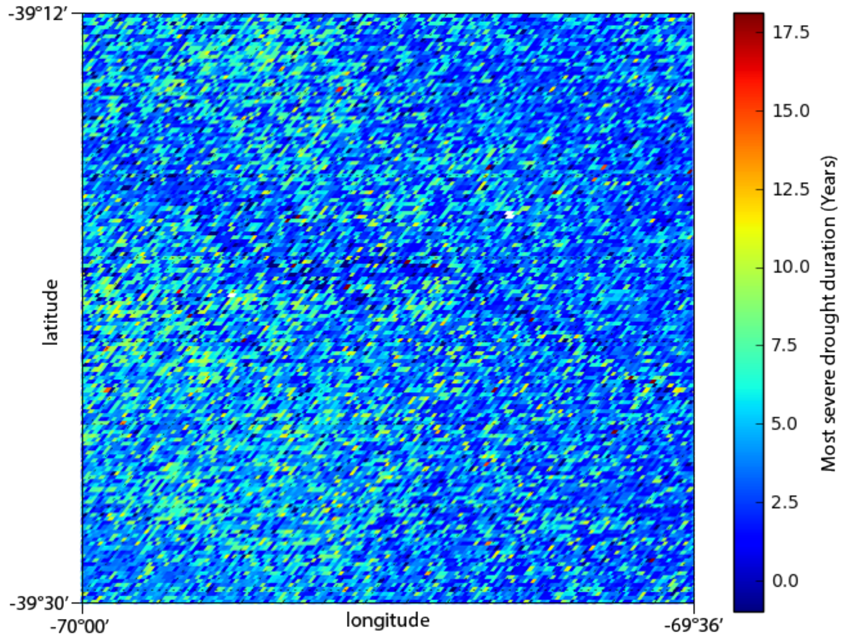


Fig. A. 22. Most severe drought duration (Years) identified in Paso Aguerre for the period 2000-2018.

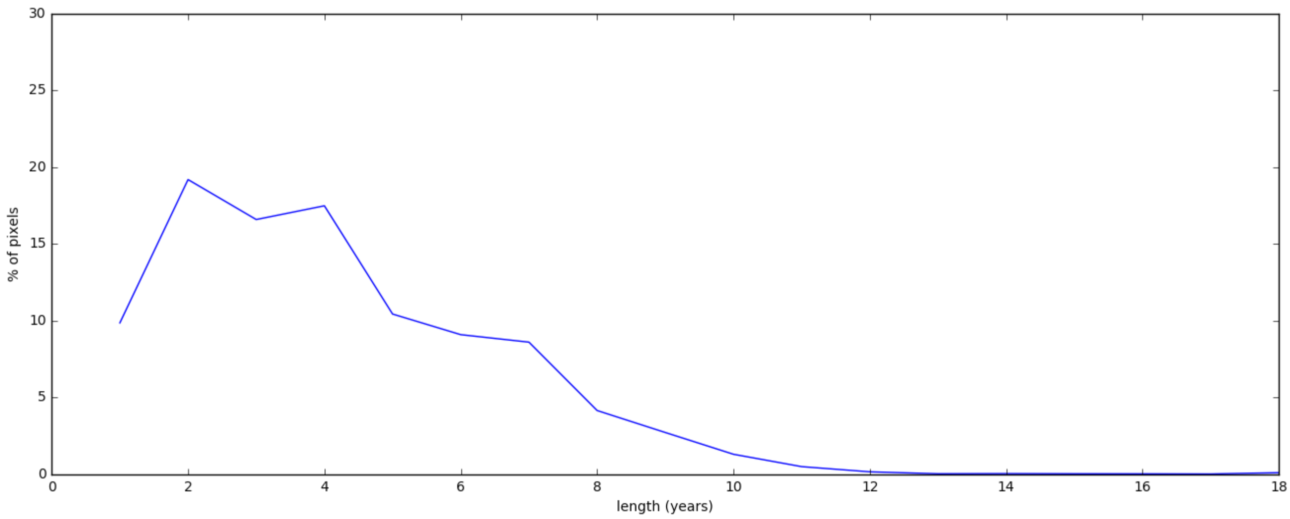


Fig. A. 23. Relative frequencies of the most severe drought duration identified in Paso Aguerre for the period 2000-2018 expressed as % of pixels.

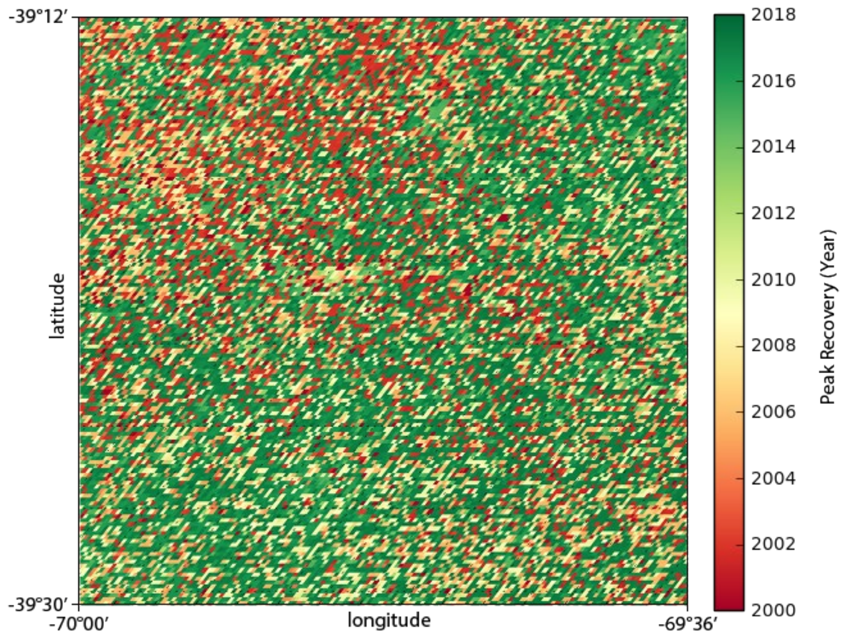


Fig. A. 24. Peak recovery (Year) identified in Paso Aguerre for the period 2000-2018.

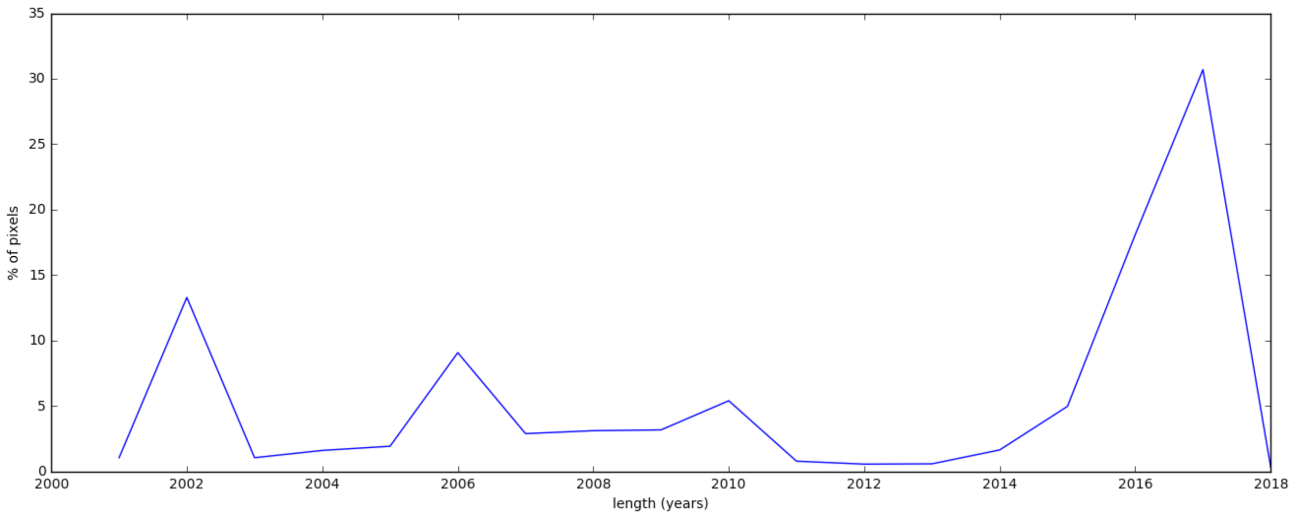


Fig. A. 25. Relative frequencies of peak recoveries identified in Paso Aguerre for the period 2000-2018.

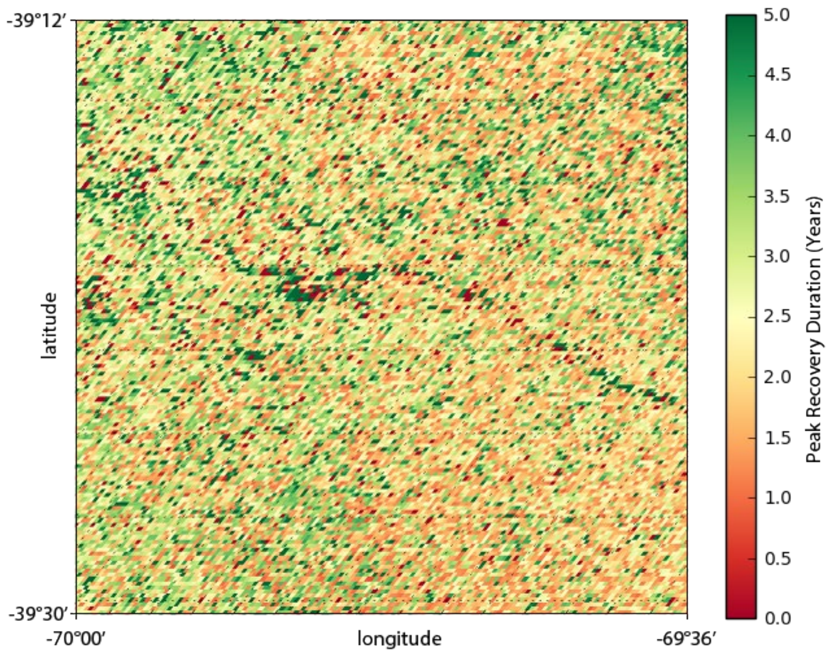


Fig. A. 26. Peak recovery duration (Years) in Paso Aguerre for the period 2000-2018.

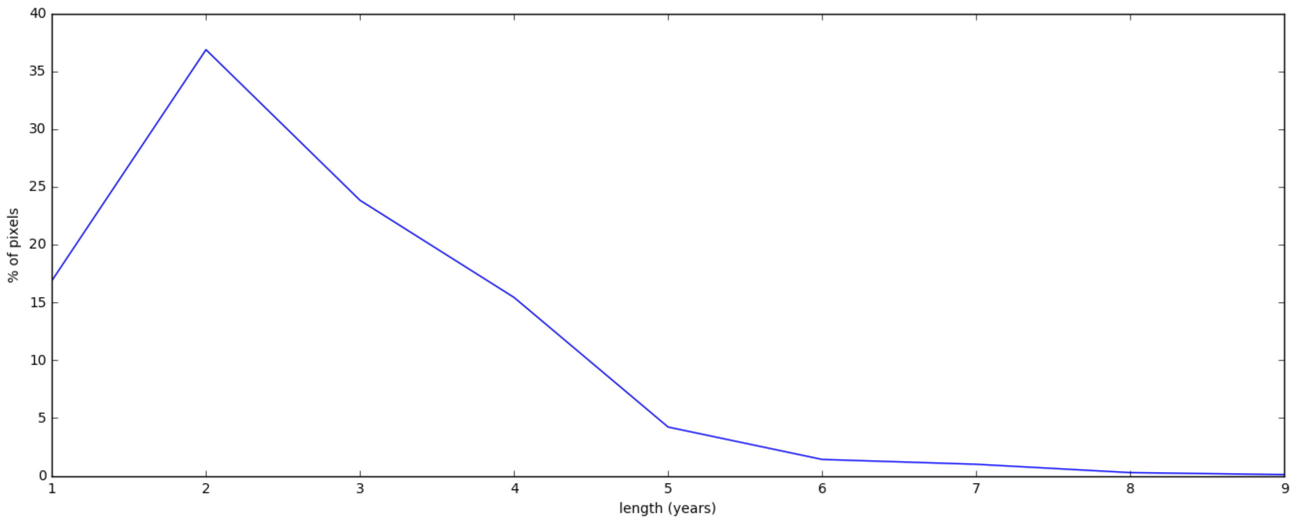


Fig. A. 27. Relative frequencies of peak recovery duration (Years) identified in Paso Aguerre for the period 2000-2018.

Other events																							04/06/2011 Volcano Puyehue								22/04/2015 Volcano Calbuco					
Sample n.	2000		2001		2002		2003		2004		2005		2006		2007		2008		2009		2010		2011		2012		2013		2014		2015		2016		Wetland	EX
21																							*	*	*	*	*	*	*	*	*	*	R	R		*
23																	*	*					*	*									R	R		*
18																							*	*	*	*	*	*	*	*	*	*	R	R		*
14																							*	*									R	R		*
22																							*	*	*	*	*	*	*	*	*	*	R	R		*
12																																	R	R		*
13																							*	*									R	R		*
16																							*	*	*	*					R	R	R	R		*
15																									*	*					*	*	R	R		*
20																															R	R	R	R		*
17																																	R	R	#	*
19																															R	R	R	R		*

* Most severe drought or especially bad year

R = recovery

G = Good year

Drought period identified by the farmer

Cold drought period identified by the farmer

Fig. A. 28. Experiences of Drought in Laguna Blanca.

Other events: 04/06/2011 Volcano Puyehue (2011); 22/04/2015 Volcano Calbuco (2015)

Sample n.	2000		2001		2002		2003		2004		2005		2006		2007		2008		2009		2010		2011		2012		2013		2014		2015		2016		IR	EX
6			*	*																			*	*									R	R		*
8																							*	*				R					R	R		*
1			R	R																			*	*					R	R	R	R	R	R		*
10																							*	*			#	#	R	R			R	R	#	*
11																							*	*	*	*	*	*			R	R	R	R		*
9																															*	*	R	R		*
3							R	R	R	R	R	R											#	#									R	R	#	
7									R	R																									#	
2																													#	#	R	R	R	R	#	
5																							#	#					#	#	R	R	R	R	#	
4																									#	#	#	#	R	R	R	R	R	R	#	

EX= Drought events remembered to happen in extensive steppe rangeland area

IR = Drought events remembered to happen in irrigated land.

* Most severe drought in steppe rangeland area
# Most severe drought in Irrigated area
R = recovery
Drought period identified by the farmer

Fig. A. 29. Experiences of Drought in Paso Aguerre.

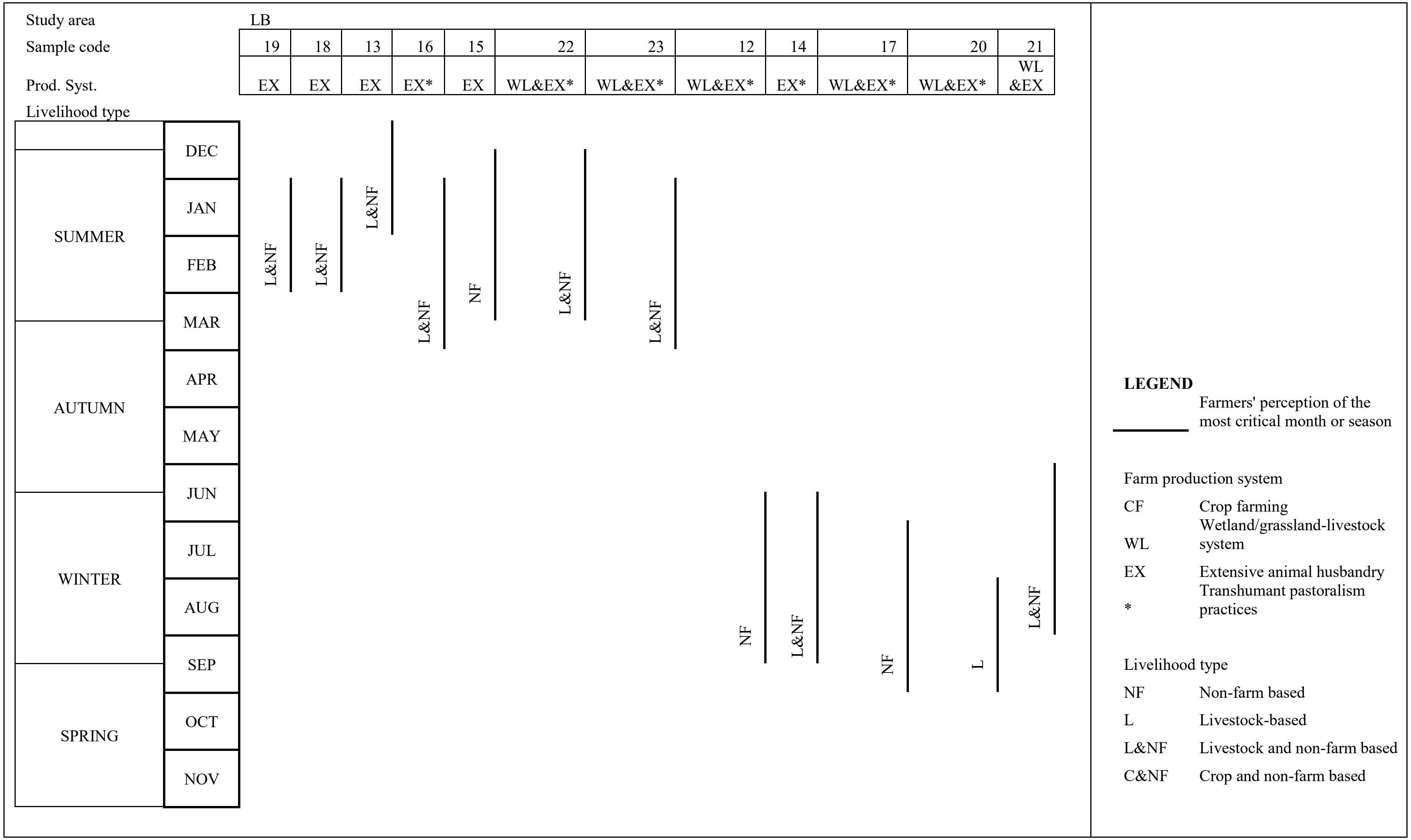


Fig. A. 30. Farmers' answers in LB for the question: if drought happens, when is the most critical month for your production system?

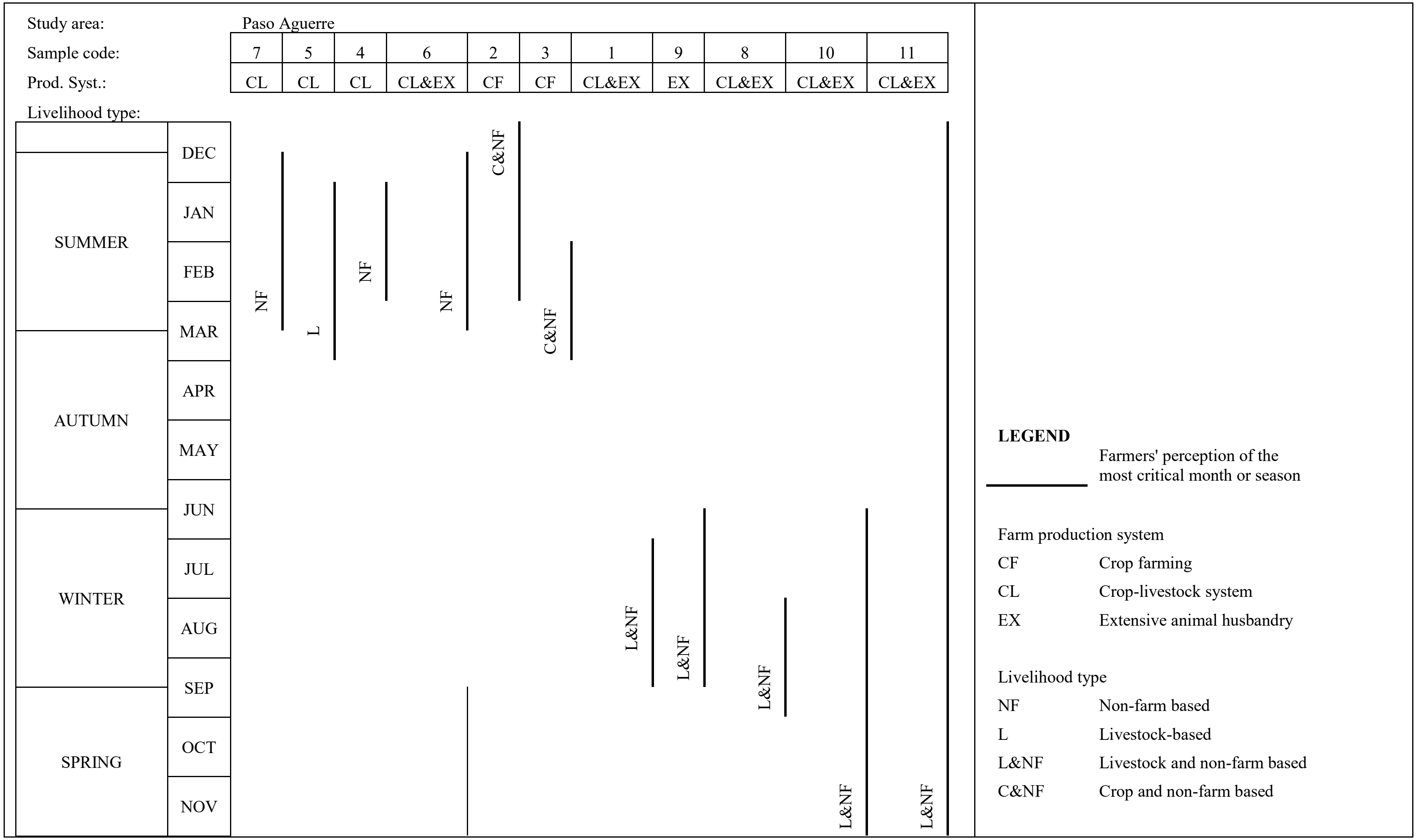


Fig. A. 31. Farmers' answers in PA for the question: if drought happens, when is the most critical month for your production system?

7.2. Appendix B. Results Interviews to Farmers.

Table B. 1. Family size and age distribution of household heads of the different type of livelihoods in Laguna Blanca and Paso Aguerre.

	Livelihood type	Average family size (n=)	Average age (years)	Up to 19 years (n=)	20-40 years (n=)	41-60 years (n=)	Above 60 years (n=)
Laguna Blanca	Livestock-based n=1	1	45	0	0	1	0
	Livestock & non-farm based n=8	3.1	52.6	7	3	6	9
	Non-farm based n=3	4.0	33.2	5	4	1	2
Paso Aguerre	Livestock-based n=1	3	52.3	0	0	2	1
	Livestock & non-farm based n=5	2.8	44.9	4	3	5	2
	Crop & non-farm based n= 2	1	67.0	0	0	1	1
	Non-farm based n=3	4.3	35.8	4	3	6	0

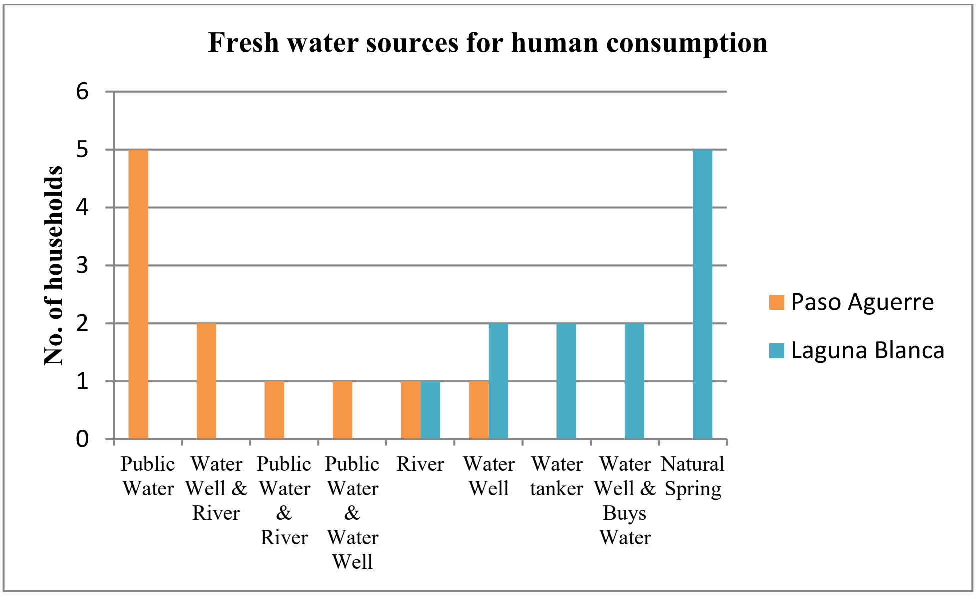


Fig. B. 1. Summary of fresh water sources for human consumption in Paso Aguerre (n=11) and Laguna Blanca (n=12).

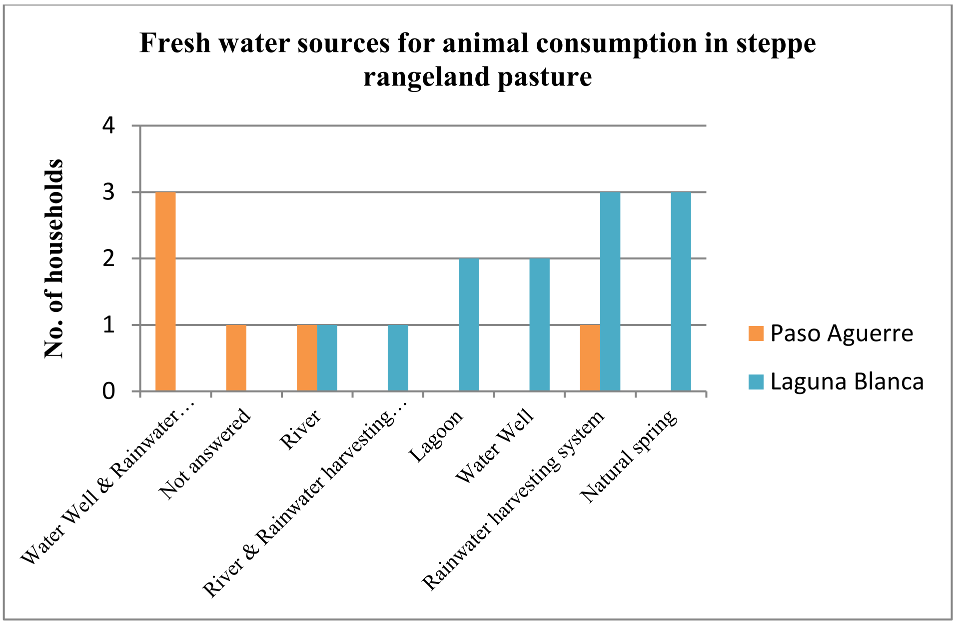


Fig. B. 2. Summary of fresh water sources for animal consumption in steppe rangeland pasture in Paso Aguerre (n=11) and Laguna Blanca (n=12).

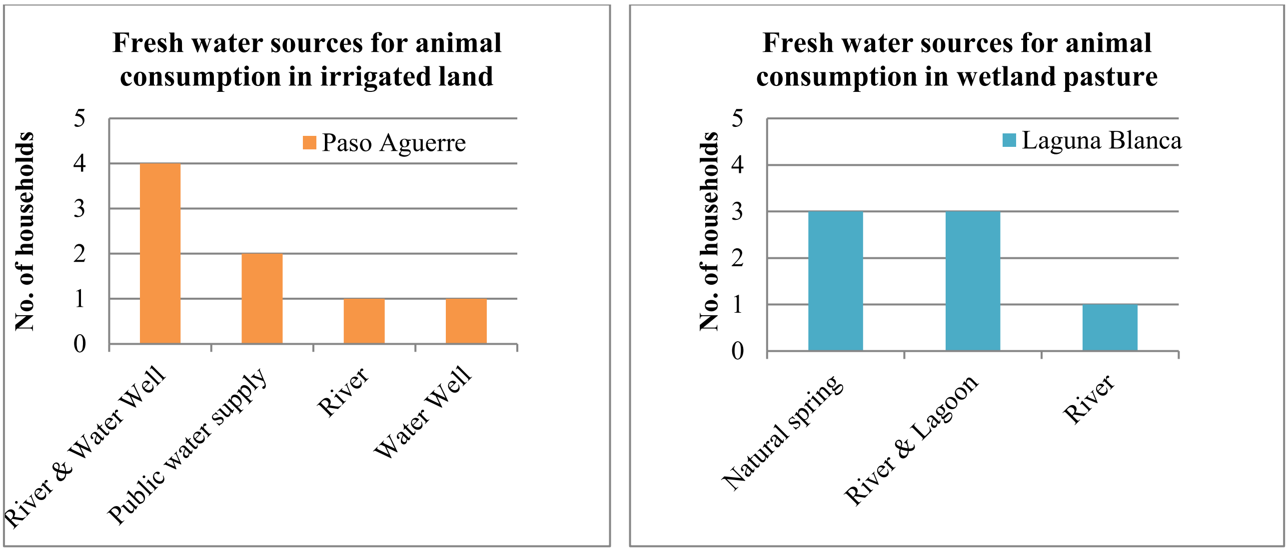
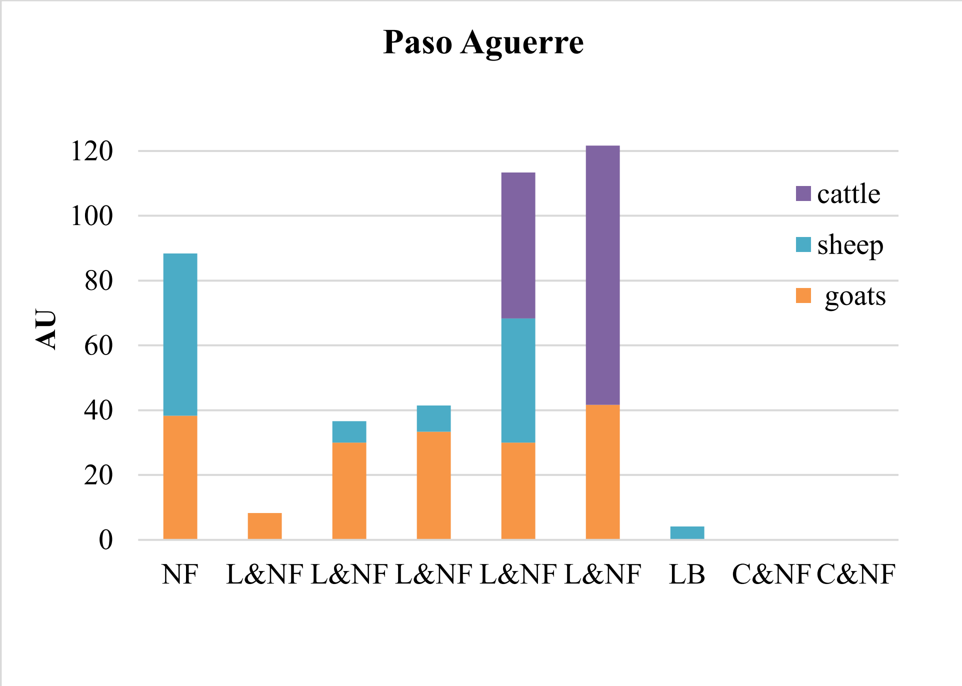
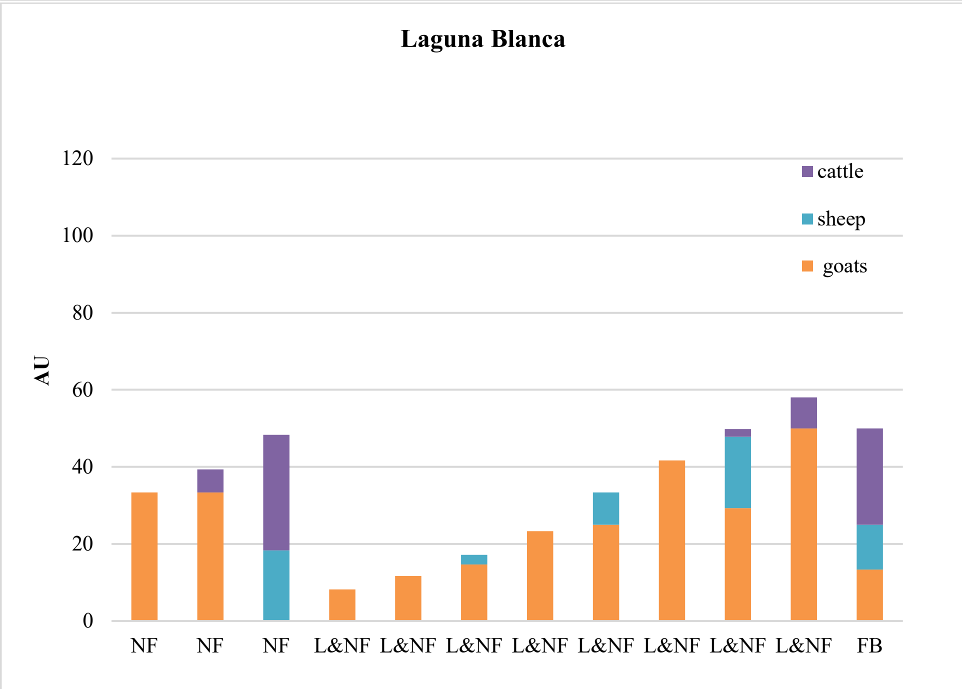


Fig. B. 3. Summary of fresh water sources for animal consumption in irrigated land in Paso Aguerre (n=11) and wetland rangeland in Laguna Blanca (n=12).





NF= Non-farm based
LB = Livestock-based
L&NF = Livestock and non-farm based
C&NF = Crop and non-farm based

Fig. B. 4. Amount and type of animals of interviewed farmers in Paso Aguerre and Laguna Blanca. Livestock numbers are transformed to Animal Units (AU) (1 AU = 1 cow = 6 sheep (ewe) = 6 goats) (Allen et al., 2011).

Table B. 2. Farmers production systems, type and amount of animals and livestock numbers transformed to Animal Units (AU) (1 AU = 1 cow = 6 sheep (ewe) = 6 goats) (Allen et al., 2011) in Laguna Blanca.

Sample num.	**Livelihood type**	**AU total**	**Mixed Rangeland grassland (summer pasture) and steppe (Wetland)**		**Extensive animal husbandry**
			sheep	**cows**	**goats**
19	Livestock & non-farm based	8.2			49
18	Livestock & non-farm based	11.7			70
13	Livestock & non-farm based	17.2	15		88
16	Livestock & non-farm based	23.3			140
21	Livestock & non-farm based	33.3	50		150
15	Non-farm based	33.3			200
12	Non-farm based	39.3		6	200
14	Livestock & non-farm based	41.7			250
17	Non-farm based	48.3	110	30	
22	Livestock & non-farm based	49.8	111	2	176
20	Livestock-based	50.0	70	25	80
23	Livestock & non-farm based	58.0		8	300

Table B. 3. Farmers production systems, type and amount of animals and livestock numbers transformed to Animal Units (AU) (1 AU = 1 cow = 6 sheep (ewe) = 6 goats) (Allen et al., 2011) in Paso Aguerre.

Sample num.	**Livelihood type**	**AU total**	**Crop-livestock system**		**Extensive animal husbandry**	
			sheep	**cow**	**goat**	**sheep**
3	Crop & non-farm based	0.0				
2	Crop & non-farm based	0.0				
7	Non-farm based	3.0	18			
5	Livestock-based	4.2	25			
4	Non-farm based	5.8	35			
9	Livestock & non-farm based	8.3			50	
8	Livestock & non-farm based	36.7	40		180	
1	Livestock & non-farm based	41.5	49		200	
6	Non-farm based	88.3			230	300
11	Livestock & non-farm based	113.3		45	180	230
10	Livestock & non-farm based	121.7		80	250	

Table B. 4. Summary of infrastructure, machinery and equipment of interviewed farmers in Laguna Blanca and Paso Aguerre expressed as number of farmers.

	Laguna Blanca (n=12)	**Paso Aguerre (n=11)**
INFRASTRUCTURE	No. of farmers	
Animal shed	11	2
Livestock pen	12	9
Small hay barn	11	9
MACHINERY		
Tractor	0	3
Tractor implements (e.g. plough, cultivator)	0	3
EQUIPMENT		
Wool shear scissors	11	4
Wool shear machine	1	2

Table B. 5. Hazards VS production system in LB.

	Production system		
Hazard	**Wetland/mountain grassland**	**Extensive animal husbandry (Goats, Sheep, horses)**	**Others (vegetable garden)**
Agricultural drought	Short period grass growth Wetland degradation	(Table 4)	No water for garden irrigation
Predation		Fox Wild cat Puma Fox killed goats and kid goats Puma kills goats, sheep and foals.	
Weather hazards (Cold temperatures, snow and wind)	Reduced biomass production	-Animal death (goats, sheep and cows). -Animal fibre losses -Animals with a lot of wool if they get wet and cold stop eating. -Wind and cold dry the natural pasture	
Diseases and genetic disorders		-Harelip on kid goats (genetic disorders) -Parasites (sauaipe) in sheep, goats and cows	
Volcanic ash deposits		-Animals death and abortions (goats) Goats lost their teeth. -Deterioration of animal's health. -Decreased wool and fibre quality from dirt. -Intensified drought effects.	

Table B. 6. Hazards and damages affecting farmers in Paso Aguerre.

	Production system			
Hazards	**Crop farming (Alfalfa, grasses, etc.)**	**Crop-livestock system (Grassland & sheep or cattle)**	**Extensive animal husbandry (Goats, Sheep, horses)**	**Others (Honeybees and vegetable garden)**
Drought	No water for irrigation 25-75-100% crop production losses	No water for irrigation 25-100% forage grassland losses	(Table 4)	(100-60%) Decrease in honey production. Bees death. No irrigation for garden
Predation			Dogs Fox Wild cat Lambs, sheep and chicken's death	
Weather hazards (Cold temperatures, snow and wind)	Crop death		-Animal death (lambs, goats after shearing the fibre, skinny animals) -Wind and cold dry the natural pasture	Wind for many days decreases honey production
Diseases			Iodine deficiency in goats	
Volcanic ash deposits			-Deterioration of animals' health. -No grass. -Goats and sheep lost their teeth. -Goats abortion -Intensified drought effects.	Bees death