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ABSTRACT

Drought is a complex natural hazard with social and environmental implications. Satellite information is increasingly used to support decision-makers in preventing or coping with the negative impacts of drought. The integration of local and scientific knowledge to support drought monitoring is still far from being the main procedure in the development of drought monitoring and early warning systems. This study aimed at assessing the degree of convergence between satellite information on the effect of droughts on rangeland vegetation, from time series analysis, and farmers' perception of drought in North-West Patagonia, Argentina. We characterised the scientific evidence of drought in terms of duration, spatial distribution, most severe years and recovery for the period 2000–2018 by identifying inter-annual NDVI changes. Farmers' perceptions and experiences of drought were studied with open-ending interviews, with respect to occurrence, duration and recovery for that period. Satellite information matched farmers' perception of drought at a regional scale, emphasising the value of remote sensing tools in supporting regional policy decision-making. However, farmers' perceptions and recall of past drought impacts were more diverse than satellite information at a local level, highlighting the need for knowledge integration at finer scales.

1. Introduction

Drought is a complex natural hazard with drastic environmental and social consequences (Wilhite et al., 2007). Drought is a complex process since its appearance is slow, occurrence is often not recognized until human activity and the environment have already been significantly affected, and often the effects of drought persist for a long time (Ruiz-Sinoga and León-Gross, 2013). In the context of rural communities from arid and semi-arid environments, 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 to meet water demands, and (v) groundwater drought, when groundwater recharge and later groundwater levels and groundwater discharge decrease. Other complex features of drought definition are the difficulty to determine the most severe periods, the peaks with most negative effects and afterward recovery. Our study broadens the definition of agricultural drought including a significant decrease of primary productivity of rangelands with severe consequences on extensive grazing systems.

Satellite remote sensing tools are in demand to support decision making to prevent or cope with the impacts of drought (Keshavarz et al., 2013). In the last 30 years, several indices have been developed to monitoring drought (e.g. Liu and Kogan, 1996; Peters et al., 2002; Wang and Qu, 2007; Brown et al., 2008; Gouveia et al., 2009; Easdale et al., 2012). Using remote sensing data for drought assessment offers

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many advantages in arid and semi-arid regions where meteorological data are scarce due to low costs, continuous updating of information and direct indication of vegetation productivity. The Normalized Difference Vegetation Index (NDVI) derived from Red and Near-Infrared spectral bands, is frequently used as a proxy for Aboveground Net Primary Production (ANPP) (Blanco et al., 2016; Fabricante et al., 2009; Paruelo et al., 2004; Jobbágy et al., 2002). NDVI was found to be strongly linked to forage productivity of rangelands (Golluscio et al., 1998; Easdale and Aguiar, 2012) and it is the best spectral predictor of ecosystem attributes such as vegetation cover and species richness in Patagonian steppes (Gaitán et al., 2013). NDVI provides reliable information to assess the effects of meteorological, hydrological and agricultural droughts on vegetation cover (Yengoh et al., 2015). However, generating information that can be directly used by decision makers through monitoring tools is complex and must integrate different disciplines and knowledge.

The integration of local and scientific knowledge to support drought monitoring is still far from being the main procedure in the development of drought monitoring and early warning systems (Giordano et al., 2013; Leclerc et al., 2013). Risk perception and reaction to drought are strongly linked to past experiences and memories of drought events (Taylor et al., 1988). Recent studies about farmers' perception of degradation, drought and climate variability illustrate the link between perceptions and adoption of managerial strategies, and evidenced discrepancies between those with scientific based information (Slegers and Stroosnijder, 2008; Simelton et al., 2013; Muita et al., 2016; Ngwenya et al., 2017; Easdale and Aguiar, 2018). Matching scientific and farmers' perception of drought will improve the understanding on the problems around which local communities interact in their attempt to dealing with ecological hazards (Slegers, 2008; Whitfield and Reed, 2012; Chaudhury et al., 2013; Herrero et al., 2014).

This study aimed at assessing the linkage between remotely-sensed information, as measured by changes in NDVI dynamics, and local farmers' perception of drought in the rangelands of North-West Patagonia, Argentina. The research was oriented towards the improvement of drought-monitoring tools by complementing scientific and local knowledge. The specific objectives were to: (1) characterize the scientific evidence of drought in terms of duration, spatial distribution, most severe years and recovery for the period 2000–2018, by identifying inter-annual NDVI changes; (2) identify farmers' perceptions and experiences of drought, with respect to occurrence, duration and recovery for the period 2000–2016; and (3) compare the remote-sensed information with farmer's perceptions.

2. Material and methods

2.1. Study area

This research was carried out in Neuquén province, North-West Patagonia, Argentina (Fig. 1). From West to East, there is a biophysical gradient in altitude (from 2000 to 400 m.a.s.l.) and rainfall (from 1000 to 200 mm year^{-1}). Two zones were selected in the cold semi-arid rangelands of North-West Patagonia (Bran et al., 2002), where extensive livestock production of small ruminants is a relevant livelihood for smallholders. On the one hand, Laguna Blanca (LB) (39°2′S; 70°21′W) included a West-East biophysical gradient, where a total surface of 365,186 ha were analysed. At the West, the Chachil Mountains are highlands used by transhumant pastoralists as summer pasturelands, where meadows and grass steppes with high productivity are located (Fig.1a). Altitude decreases towards the East, where winterlands are located, mostly dominated by grass-shrub steppes of less than 1 m high (Bran et al., 2002). On the other hand, Paso Aguerre (PA) (39°20′S; 69°50′W) is located in the lower lands on the riverside of the Picún Leufú river. This area has a seasonal water supply during spring and early summer based on snowmelt and rainfall that occurs in the high basin of Chachil Mountains, and very low supply during late summer and autumn. A total surface of 114,734 ha was analysed including a small portion of irrigated land (Fig. 1b). Natural vegetation is dominated by shrub steppes of 1.5 − 2 m high, which also includes grasses, herbs and geophytes (Bran et al., 2002) (Table 1).

2.2. Meteorological data

Precipitation data was obtained from the Weather Station of Zapala Airport (38°58′S; 70°6′W) for the period from 1999 until 2016. Precipitation deficit or surplus was calculated as the difference between total annual rainfall and the average annual rainfall from 1999 until 2016.

2.2.1. Remote sensing data source and processing

Since meteorological data was scarce in the study area, remote sensing information was highly useful to perform spatially explicit analyses. 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:

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

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.: 250 m × 250 m of spatial resolution). The studied period was slightly larger than the referenced period used for the study of farmers' perceptions (interviews were done in 2016) to have a wider picture of the overall regional situation. However, the main comparative analysis was performed for the series 2000–2016.

Data processing of remote sensed data followed the method proposed by Easdale et al. (2018). NDVI is a continuous finite variable, therefore the NDVI error was assumed to follow a logit-normal distribution, since 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. After the transformation of NDVI data, the series were centred by removing the mean. 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 deleted since they were not related to photosynthetic activity of vegetation. 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 mountaintops.

2.2.2. NDVI 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 and Zhang, 1993) was applied to the time series by using the gpu_pursuit software (Bruzzone and Easdale, 2018).

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 centred (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 by the anomaly, 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 data series (Peters et al., 2002; Easdale et al., 2012), used as a threshold (Mishra and Singh, 2010). The

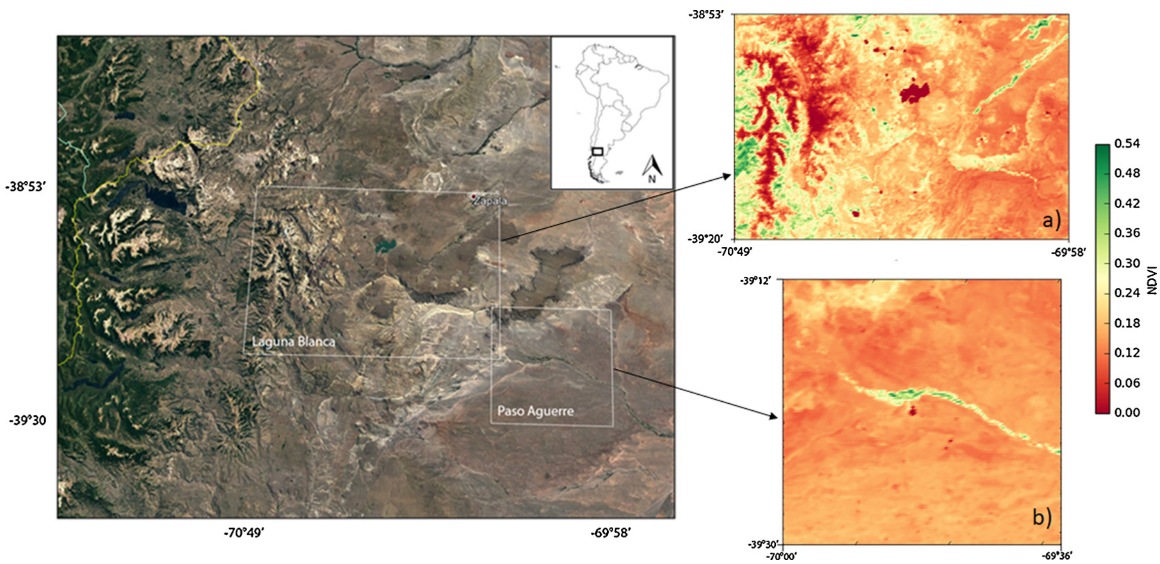

Fig. 1. Location of case study areas of Laguna Blanca and Paso Aguerre, North West Patagonia, Argentina, a) Mean NDVI values in Laguna Blanca for the period 2000-2018, b) Mean NDVI values in Paso Aguerre for the period 2000-2018.

Table 1
Main biophysical features of the study sites. References: (Gaitán et al., 2013; Bran et al., 2002; Paruelo et al., 1998).

Variable	Study site	
	Laguna Blanca (LB)	Paso Aguerre (PA)
Altitude (m.a.s.l.)	1300	630
Annual mean temperature (°C)	10 − 12	14
Annual rainfall (mm)	700 (West) – 200 (East)	< 200
Topography	Very undulating in the mountains (slopes up to 45%)	Moderately undulating (slopes up to 10%)
Phytogeographic province	Patagonian District and Monte Austral	Monte Austral
Soil type	Regosol and Luvisol	Regosol
Landscape types		
Irrigated land	Not present	Crop production (mainly fodder crops) and crop-livestock production systems
Steppe rangeland	Vegetation dominated by shrubs and grasses. Main species are *Adesmia campestris, Azorella prolifera, Senecio filaginoides, Berberis heterophylla, Pappostipa 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 *Pappostipa tenuis*
Meadows	Highly productive meadows located in the Chachil Mountains and drainage lines in hills and plateaus.	Not present

drought event was considered to be finished when NDVI value became positive. From this, drought event features were described by duration and occurrence. The year of the most severe drought was defined as the lowest NDVI value found in each pixel. 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.

2.3. 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, livelihoods and production systems. All farmers interviewed were smallholders relying on family labour, with the following gender participation during interviews: only male (43%), only female (35%) and both male and female (22%), Their main livelihoods were based on the combination of income diversification strategies and types of farming system. Few farmers also employed hired labour for certain tasks or moments in the year (e.g. wool shearing, herding). Information about their livelihoods, the impacts and adaptive responses to drought can be found in Tittonell et al. (2020).

Farmers were asked about drought definition, perceptions and memories of drought in terms of dates, duration and severity. All participants in the study were recruited using snowball sampling (non-probability sampling method). Gathered information from interviews were analysed for each farmer, and summarised in the following indicators: i) farmers' definitions of drought, grouped in statements that represent similar responses, ii) main drought period identified by each farmer, ii) the recovery period, and iii) the most severe drought years identified both in steppe rangelands and in the wetland area. These indicators were used for the comparison with satellite information.

3. Results

3.1. Drought identification and characteristics

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 per year (Fig. 2). Average annual

Fig. 2. Precipitation deficit and surplus in comparison to average value at the weather station of Zapala Airport (Zapala, Neuquén).

rainfall for the period 1999–2016 was 217.2 mm and standard deviation was 108.3 mm. The largest precipitation deficit occurred during the period 2007–2012 (Fig. 2).

The time series analysis for the period 2000–2018 showed an NDVI mean value gradient from West to East in Laguna Blanca (LB). The Chachil Mountains and valleys, where water content was higher, presented the highest NDVI values (Fig. 1a).

The most severe droughts in the West and North of LB occurred in 2004 (9.3% of the pixels) and 2008 (9.9 of the pixels, Fig. 3a). In the East of LB, the most severe drought occurred in 2011 (14.4% of the pixels, Fig. 3b) followed by two more years of severe drought events (2012, 12.2% of the pixels; 2013, 10.8% of the pixels), (Fig. 3a). Peak recovery periods also showed some spatial differences in LB (Fig. 4b). In the West, the highest NDVI values occurred in the year 2002 (8% of the pixels) and 2006 (11% of the pixels) (Fig. 4a). However, 38.8% of the pixels showed a peak recovery period between 2015 and 2017 (Fig. 4a).

For the study area of Paso Aguerre (PA), satellite images showed a data set of NDVI mean values ranging from 0.1 to 0.5 (Fig. 1.b). A large proportion of the studied area consisted of steppe rangelands and only a few hectares were irrigated land, where mean NDVI values reached the highest levels.

The most severe drought events in PA occurred in 2012 (29% of the pixels), 2011 (16%) associated to rangelands (Fig. 5a), and in 2004 (10% of pixels) associated to irrigated lands (Fig. 5b).

Peak recovery periods occurred in 2017 (31% of pixels) (Fig. 6.a). Moreover, two other peaks where identified in 2002 (13% of pixels) and 2006 (9% of pixels), mostly located at the North-West of the study area (Fig. 6b).

3.2. Farmers experiences of drought

Farmers in both study areas used several descriptions of unfavourable weather conditions and non-weather indicators to define drought (Fig.7). In general, farmers defined drought mainly as lack of grass and lack of rain, with the highest frequencies for these answers in Laguna Blanca, where farmers manage extensive pastoral systems. In this study area, many farmers also said to be affected by strong and long-lasting wind events, low snowfall during winter and cold temperatures or frost. On the other hand, farmers from Paso Aguerre mostly associated drought with lack of water for irrigation and with low snowfall during winter.

All farmers interviewed were able to recall drought periods lasting for several years as well as post-drought recovery periods. Although farmers remembered specific years or periods of severe droughts, before 2011 farmers' references about drought events were, however, hardly remembered.

Farmers in Laguna Blanca perceived a diversity of periods of drought, lasting from one to 15 years (Table 2). Most severe drought events were most frequently remembered for the period between 2011 and 2015. In particular, the year 2011 was remembered as a severe one, with a drought event coinciding with a volcanic eruption (Puyehue-Cordón Caulle Volcanic Complex) which covered the area in volcanic ash deposits. All interviewed farmers identified only one recovery period in 2016 and a few for the period 2015-2016.

Vegetation recovery events were perceived to last for one or two years. Five farmers in Laguna Blanca distinguished drought events from cold dry 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" (a Laguna Blanca farmer). Cold droughts were remembered to last for one to three consecutive winters since the year 2000, for the periods between 2002 and 2004, 2011 and 2012, 2014 and 2015.

Interviewed farmers in Paso Aguerre had different memories of drought, but made a distinction between events that affected the steppe rangeland or the irrigated land, since irrigation rely on the snowfall in the mountains, which supply water for the Picún Leufú river (Table 3). Duration of drought events were perceived to last from three to 14 years. Most severe drought in steppe rangelands were most frequently remembered for the year 2011, but farmers remembered shorter periods of drought than in Laguna Blanca, lasting from one to three years. Recovery periods were mostly remembered in 2016 and in some cases in 2014 and 2015 too. With respect to irrigated land, all interviewed farmers remembered that most severe drought events occurred from 2011 until 2014, lasting for one to two years. Recovery periods were most frequently remembered for the period between 2015 and 2016.

3.3. Comparison between remotely-sensed time series and farmers' recall of past drought events

At both sites, NDVI time series indicated similar periods for the most severe drought that affected steppe rangeland of both study areas, but differences were found in the year of peak and in the inter-annual length of the drought process (Figs. 3a and 4 a). Laguna Blanca was spatially fragmented in terms of the moment of severe droughts, with a clear distinction between the Chachil Mountains (West, Fig. 3b) and the shrub rangelands (East, Fig. 3b), whereas Paso Aguerre had a more uniform spatial pattern, with irrigated lands being hardly differentiated from the rest.

Generally, farmer definitions of drought included lack of pasture as a consequence of low precipitation and other weather hazards (e.g. strong long-duration winds, frost) (Fig. 7). Low snowfall related to less forage productivity and water availability in the highlands affected mostly transhumant pastoralists. Valley bottom farmers managing irrigated land indicated that low snowfall in the highlands led to a reduction of water supply by the river used for irrigation during spring and summer. This evidenced that farmers used many more indicators to assess drought than solely those related with rangeland productivity, as measured by NDVI dynamics. Although farmers' ability to recall drought periods varied greatly between sites and among farmers, the identification of the drought period, the most severe droughts and the recovery periods showed similarities with remotely sensed NDVI information.

In Laguna Blanca, farmer memories of drought events had

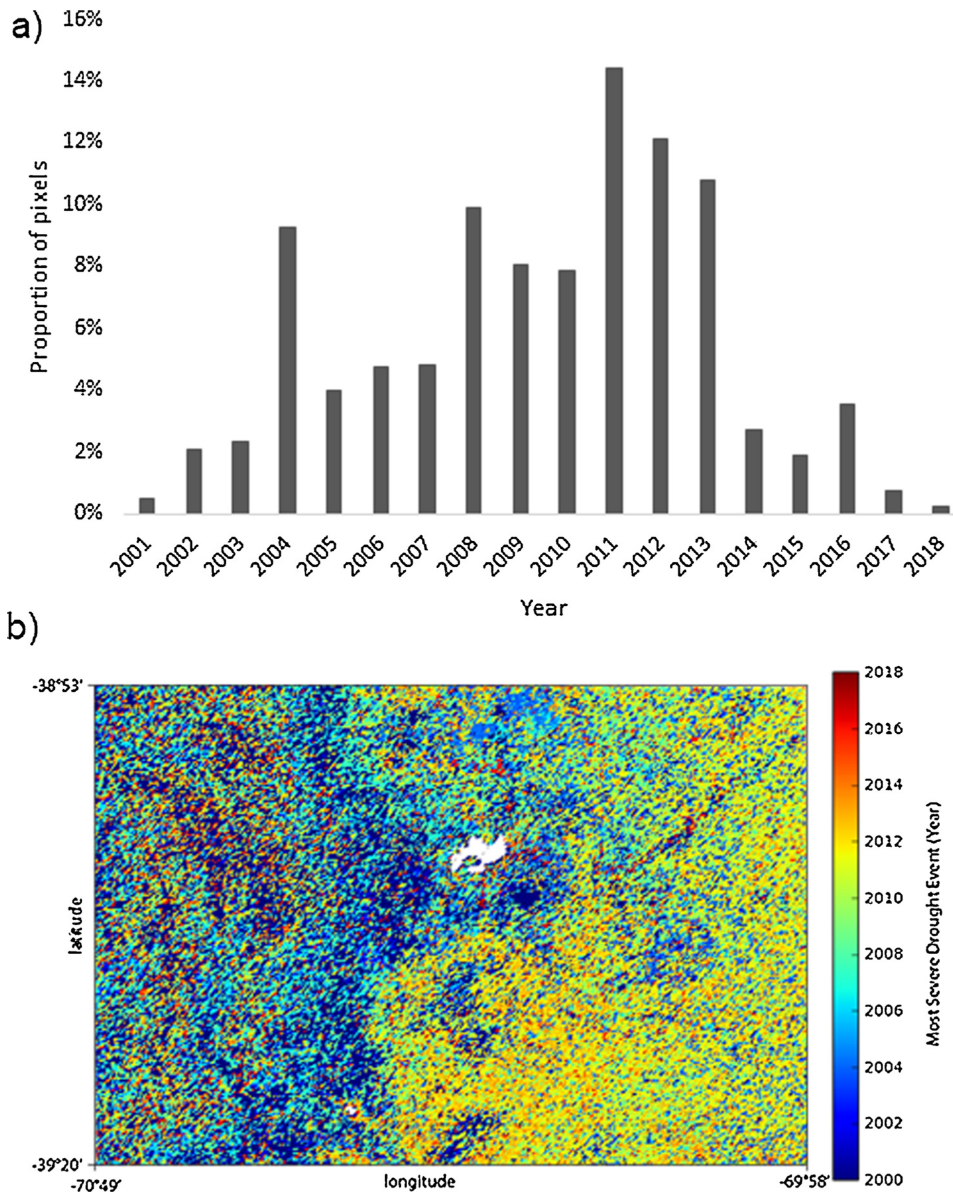

Fig. 3. Most severe drought event identified in Laguna Blanca for the period 2000-2018, a) proportion of pixels by year, b) spatial distribution by year of the most severe event.

similarities with satellite information, as the most severe drought was recorded for 2011. Farmers did generally not refer to the end of drought events, but the 2016-peak of recovery identified by satellite information concurred with farmers' perception of post-drought recovery. Perceptions of drought recorded in Paso Aguerre were different for steppe rangelands and irrigated lands. In the first case, farmer memories before 2011 did not coincide with scientific results at identifying the most severe drought event, in 2004 (Fig. 4b). On the other hand, the most severe drought was remembered to have occurred in 2011 (together with the volcanic ash deposits). Whereas satellite information showed an increase in the proportion of pixels with negative values, the lowest value was mostly recorded in the year 2012 (Fig. 5a). From 2014 onwards, farmers perceived the starting of the recovery period, with the highest agreement in the year 2016, concurring with scientific-based information.

4. Discussion

We studied the degree of convergence between satellite-based information on droughts, as measured by changes in NDVI dynamics, and farmers' perception of drought in North-West Patagonia, Argentina. Time series analysis of remote sensing data identified a drought period that spatially ranged from three to six years between 2008 and 2013, which was mostly similar to the main unfavourable period perceived by farmers in both study areas. Whereas the most severe drought year was identified through both sources of information in Laguna Blanca (associated with lowlands), a slight difference of one year between scientific-based information and farmers' perception was recorded in Paso Aguerre. The peak and the recovery period were also detected similarly by both sources of information in Laguna Blanca (Table 2 and Fig. 4a). On the other hand, whereas the identification of the recovery peak coincided between both methods in Paso Aguerre, more than half of the farmers perceived the start of a recovery period one or two years earlier (Table 3) than that detected through NDVI time series (Fig. 6).

Drought risk perceptions are complex and often conflicting. Sometimes, people oppose resource management options because they consider that it threatens their worldviews or stated ideal ways of life (Lazrus, 2016). Remote sensing techniques can greatly enhance

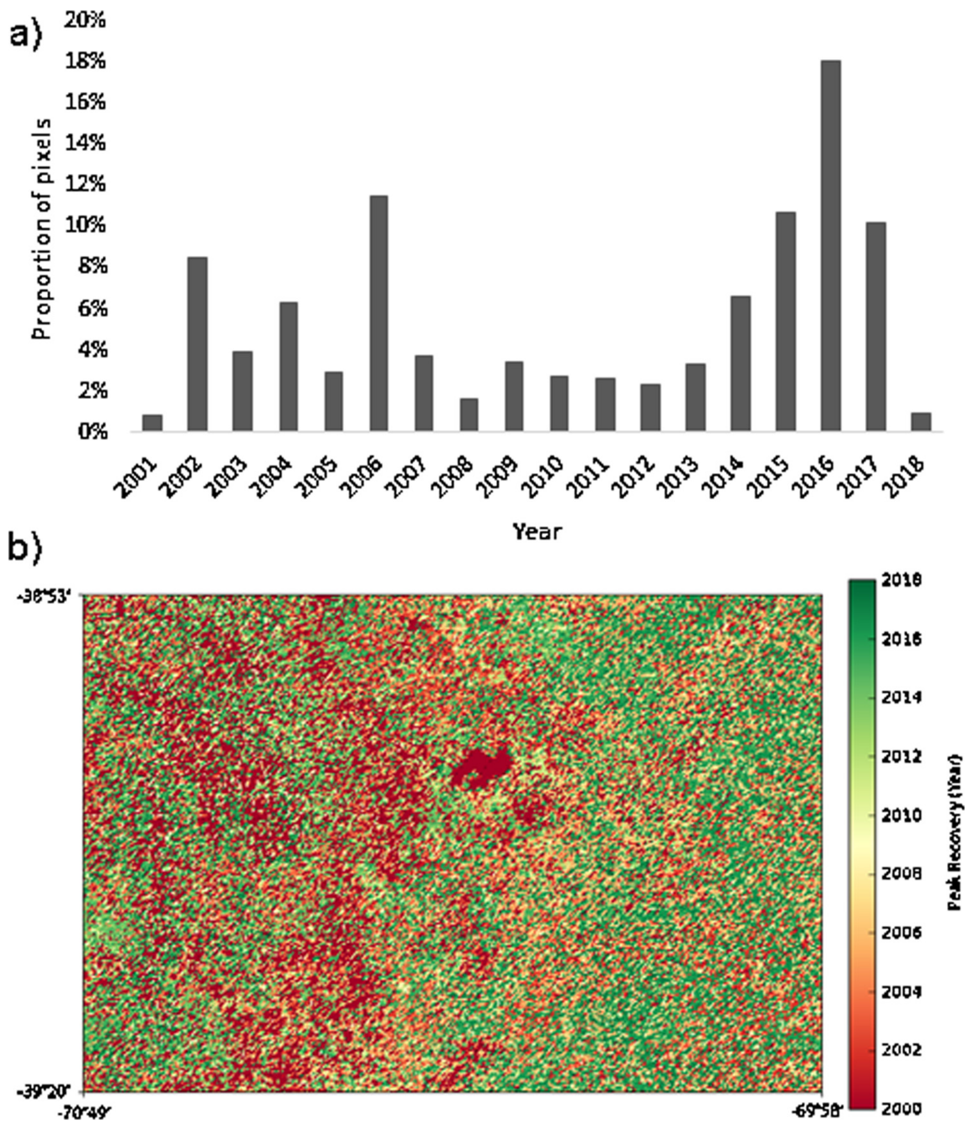

Fig. 4. Drought recovery peak identified in Laguna Blanca for the period 2000-2018, a) Proportion of pixels by year, b) spatial distribution by year of recovery peak.

ethnographic research in the study of cultural landscapes by providing historical record that can rebuild the past (Jiang, 2003). Yet, empirical evidence show more successful results when the use of scientific-based climate knowledge involved some kind of iteration with the knowledge of famers and users (Dilling and Lemos, 2011). Social characterizations of climate risks at the scale of community are associated to productive practices, household composition and symbolic representations of local climates in the Andes (Boelens, 2014; Romero and Opazo, 2015). In the context of our study, whereas satellite information was consistent and sensitive at regional scale, the differences between study areas suggest the need for a local adaptation of a satellite drought-monitoring through its integration with local knowledge (Tadaki et al., 2012; Romero et al., 2013). For instance, differences between sources of data were recorded for the cases of farmers with both steppe rangelands and irrigated lands. More specific studies are needed for a better understanding of the flow characteristics of ground and surface water streams, which may have a strong and delayed influence on the agronomic evidence of droughts in irrigated lands (Winter, 2000; Bruelle et al., 2017), as well as in mountain grasslands and wetlands.

Mismatches between vegetation dynamics and farmers' perceptions of drought highlight the need to analyse longer periods of data series for a more fully understanding of drought and recovery periods, but also of social memory and experience (Taylor et al., 1988; Slegers, 2008). Besides, men and women, and people of different ages have differentiated memories of historical events (Ngwenya et al., 2017). For instance, farmer's experiences of drought can be also shaped by water scarcity or the most sensitive moment for their production systems in the past, where productive losses occur. That key moment may not necessarily coincide solely with forage scarcity. Farmers' perceptions of drought are not driven by the magnitude and frequency of dry months alone but rather by the difference between growing seasons (Gamble et al., 2010). In addition, farmers might experience higher productive losses before drought events reach their severity peak. Moreover, the fuzzy logic nature of local climatic knowledge appears in association with heavy drought events, contrasting with a fuzzy picture in the intermediate climatic situations (Leclerc et al., 2013). As well, rangeland productivity losses can be more severe when repetitive droughts with short recovery periods occur, hampering the possibility of the system to recover (Oba, 2001). A decapitalized farming system due to animal death may result from the synergistic impact of droughts and other factors such as volcanic ash deposits (Easdale et al., 2014), from which systems typically take a long time to recover their livestock and rangeland productivity (McCabe, 1987).

Non-drought factors such as poverty, inadequate resources, low livelihood diversification, insufficient infrastructure and communication means, and lack of information and preparedness expose farmers to

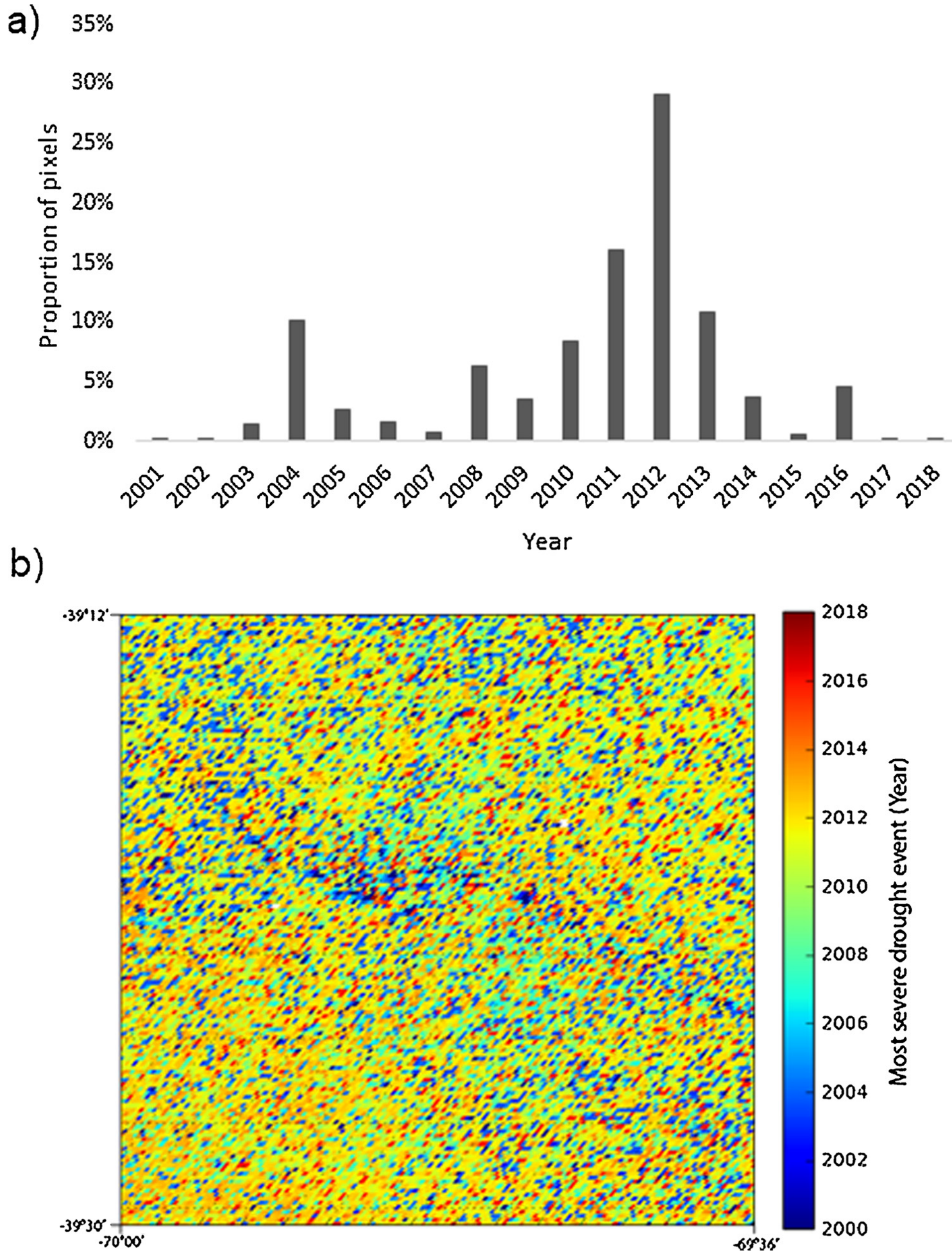

Fig. 5. Most severe drought event identified in Paso Aguerre for the period 2000-2018, a) proportion of pixels by year, b) spatial distribution by year of the most severe event.

drought impacts and limit their adaptive capacity (Speranza et al., 2010; Easdale and Rosso, 2010; Valbuena et al., 2015). On the other hand, environmental change reports are also strongly influenced by awareness of climate science (Rudiak-Gould, 2014), but there is still a gap between this scientific-based information and decision-making at farm level (Giordano et al., 2013; Easdale and Aguiar, 2018). Farmers' long-term adaptation strategies and innovations need to be strengthen at a local scale, which can be favourably guided by policy priorities and driven by local perceptions of tangible benefits (Postigo, 2014; Pradhan et al., 2017; Bruelle et al., 2017; Michalscheck et al., 2018; Alomia-Hinojosa et al., 2018). Future studies need to focus on understanding the factors underlying limitations for closer knowledge dialogues, oriented at building adaptation strategies and promoting the implementation of forecast systems for more effective decisions to anticipate drought negative effects on farming productivity and livelihoods.

5. Conclusions

We studied the degree of convergence between satellite-based information on droughts and farmers' perception of drought in North-West Patagonia, Argentina. Time series analysis of remote sensing data matched farmers' perception of drought at a regional scale. However, farmers' references of drought did not fully concur with satellite information with respect to the identification of the most severe year of drought and the start of a recovery period. Farmers' perceptions, memories and explanations about their systems and the impact of droughts enriched the interpretation of droughts at a local level, highlighting the need for knowledge integration at finer scales. Results suggest that drought-monitoring tools, which are based on satellite data, provide sound and trustworthy information at regional scales, emphasising the value of remote sensing tools in supporting regional policy decision-making. However, there is a need for future developments aimed at complementing remote sensing information with

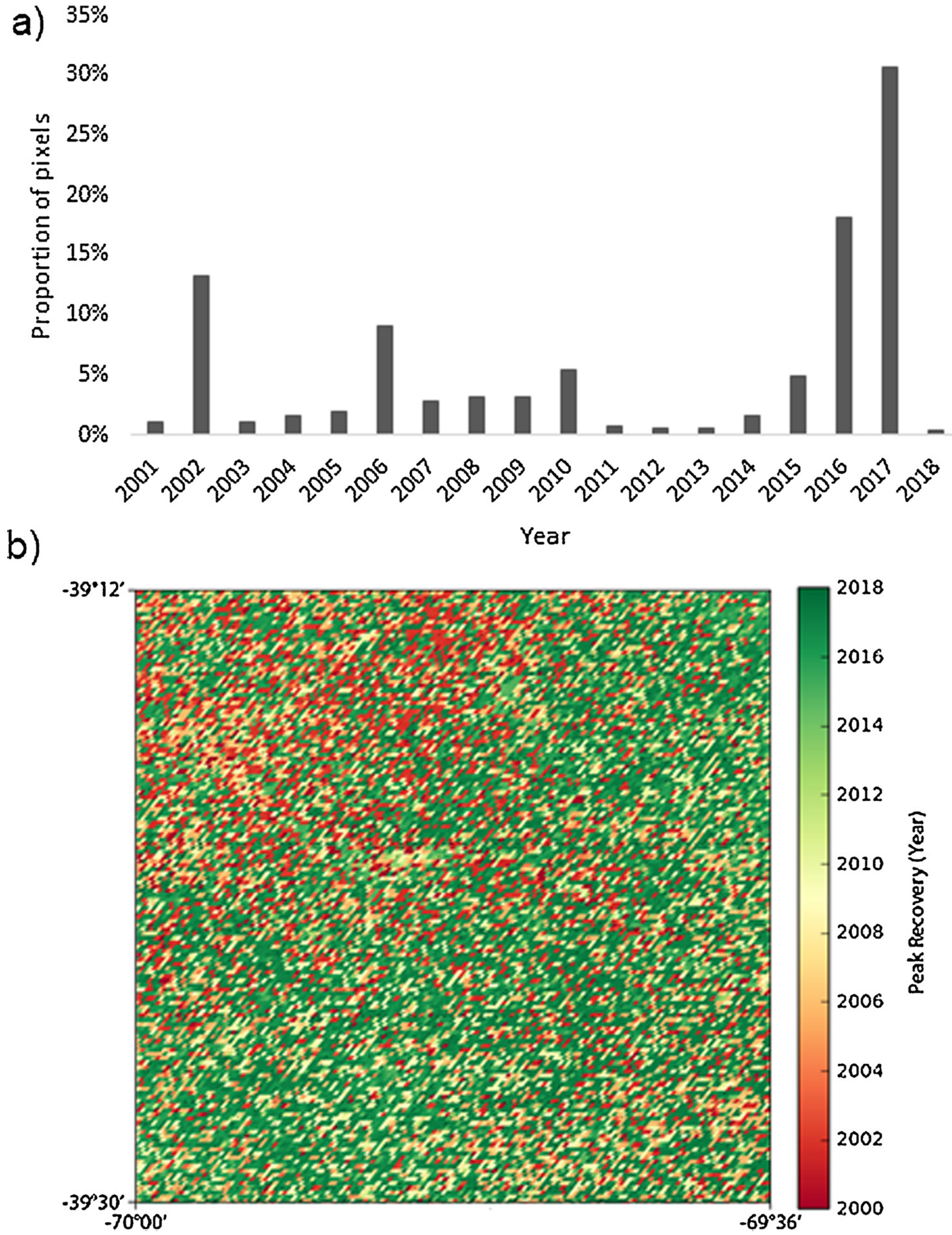

Fig. 6. Drought recovery peak identified in Paso Aguerre for the period 2000-2018, a) Proportion of pixels by year, b) spatial distribution by year of recovery peak.

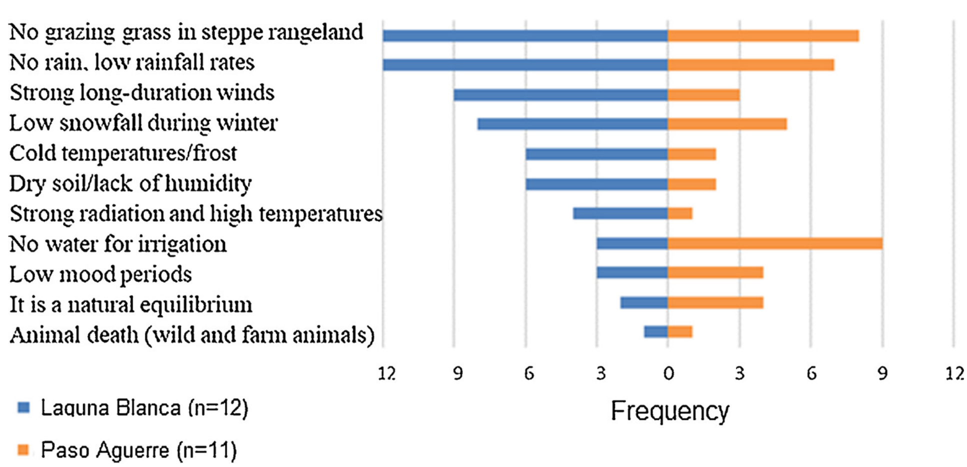

Fig. 7. Frequency of farmers' definitions of drought, grouped in statements that represent similar responses, discriminated by study area: Laguna Blanca (n = 12, pastoral zone) and Paso Aguerre (n = 11, pastoral and irrigated zone).

Table 2
Experiences of drought in Laguna Blanca, Patagonia, Argentina. Drought period (orange) and cold drought period (light blue) identified by the farmer and Recovery period (R). Drought events remembered to happen in extensive steppe rangeland area (EX) and in the wetland (W), and most severe drought year identified in steppe rangeland area (*) and in wetland area (+).

Farmer	2000		2001		2002		2003		2004		2005		2006		2007		2008		2009		2010		2011		2012		2013		2014		2015		2016		W	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		*

Table 3
Experiences of drought in Paso Aguerre, Patagonia, Argentina. Drought period identified by the farmers (orange) and Recovery period (R). Drought events remembered to happen in extensive steppe rangeland area (EX) and in irrigated land (IR), and most severe drought year identified in steppe rangeland area (*) and in irrigated area (#).

Farmer	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	#	

farmers' knowledge and indicators at local scales. This should be a future step in the improvement of drought-monitoring tools, aimed at providing information and early warnings across spatial and temporal scales in arid and semi-arid regions.

Author statement

Research data cannot be shared because research project is still active and data will be available once the project is finished. Required by the funder.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.landusepol.2020.104726.

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