## <sup>8</sup>Thirty Years of Multilevel Processes for Adaptation of Livestock Production to Droughts in Uruguay

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#### ABSTRACT

Most countries lack effective policies to manage climate risks, despite growing concerns with climate change. The authors analyzed the policy evolution from a disaster management to a risk management approach, using as a case study four agricultural droughts that impacted Uruguay's livestock sector in the last three decades. A transdisciplinary team of researchers, extension workers, and policy makers agreed on a common conceptual framework for the interpretation of past droughts and policies. The evidence presented shows that the set of actions implemented at different levels when facing droughts were mainly reactive in the past but later evolved to a more integral risk management approach. A greater interinstitutional integration and a decreasing gap between science and policy were identified during the period of study. Social and political learning enabled a vision of proactive management and promoted effective adaptive measures. While the government of Uruguay explicitly incorporated the issue of adaptation to climate change into its agenda, research institutions also fostered the creation of interdisciplinary study groups on this topic, resulting in new stages of learning. The recent changes in public policies, institutional governance, and academic research have contributed to enhance the adaptive capacity of the agricultural sector to climate variability, and in particular to drought. This study confirms the relevance of and need to work within a transdisciplinary framework to effectively address the different social learning dimensions, particularly those concerning the adaptation to global change.

### 1. Introduction

Understanding and responding to drought is one of the most critical challenges of decision-makers worldwide. Most countries have growing concerns about impacts of climate change, including the expected increases in drought frequency, intensity, and duration. However, almost every country in the world still lacks the planning and effective management policies to effectively deal with droughts (Sivakumar et al. 2014). Governments' actions often take place after a drought event, with interventions focused on providing support for emergencies. This reactive or disaster response approach may involve lending money (credit) or waiving or rescheduling tax payments, which can increase the vulnerability to future droughts by reducing autonomy

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and increasing the farmers' dependence on government organizations and donors (Wilhite et al. 2014). An alternative approach is the proactive development of risk management government programs that ultimately aim at reducing vulnerability to droughts (Wilhite 1993) and induce changes in resource management practices to reduce systems' fragility (Taleb 2012). The proactive approach includes monitoring and early warning systems capable of delivering useful and timely information for decision-making (Wilhite 2000; Pulwarty and Sivakumar 2014), effective procedures for assessing impacts, proactive measures for risk management, suitable planning in advance of droughts, and emergency response programs (Sivakumar et al. 2011). This paper aims to contribute to the understanding of the process of changing from a reactive to a proactive policy approach, based on a successful case study.

Although droughts affect more people than any other natural hazard, they remain one of the most difficult phenomena to quantify objectively (Vicente-Serrano et al. 2012). Droughts can become a disaster depending on their impact on the local population, the economy, and the environment. The effects of droughts are especially important in regions that economically rely on agriculture (Vicente-Serrano et al. 2015). In Uruguay, for instance, agricultural droughts greatly impact livestock production, which generates the largest proportion of exports and employs the majority of smalland medium-scale farmers (Bidegain et al. 2013) and therefore call for policy and economic interventions. Furthermore, drought-management increase requirements on information fosters the link between academia and public policy, and to develop collective learning to deal with the next event more efficiently. Although no trends have been found in the frequency of droughts in Uruguay (Cruz et al. 2014; Bidegain et al. 2013), the perception of agronomists and livestock farmers is that droughts have increased in intensity and/or frequency recently (Lindemann et al. 2013). We could explain this perception by multiple interacting factors: the rise in potential evapotranspiration due to increased temperature (Bettolli et al. 2010; Giménez 2006), variations in the composition of livestock stock, changes in land use increasing stocking rates, and increase in land values and livestock prices, which affect farmers' expectations and production decisions. The system in which a drought occurs is the result of multiple processes operating at different scales and affecting various elements (e.g., water, pasture, livestock, people, and social and economic changes) simultaneously. We, therefore, analyze a number of factors, such as biophysical, productive, socioeconomic, organizational, and political, that by themselves or through interaction have generated reactions and knowledge about the agricultural droughts in Uruguay.

The growing understanding of the complexity of environmental problems and humans' role in shaping the global environment (Clark et al. 2005) has increased the awareness that scientific, social, economic, and political systems are linked. Recognizing all challenges to adapt to new "knowledge-based realities" requires paying attention to institutional learning, networking, and adaptation (De la Mothe 2003). The application of the social learning approach applied to natural resource management attempts to capture its essentials, which occur at various levels (Pahl-Wostl et al. 2007); such is the overarching framework in this article. Promoting social learning requires an emphasis on the process of developing options and different interest groups and relates to the actors' abilities to manage natural resources effectively (Tippett et al. 2005). From an adaptive risk management perspective, policies can be viewed as experiments whose results provide new opportunities to learn from and thus improve subsequent decisions (Lee 1999). Adaptive management is an iterative step-by-step process in which policies are not permanent but represent opportunities to learn and adjust. The ability to maintain information and participation flows between science and decision-makers in the public and private sectors (i.e., "iterativity") is central to successful science-policy coproduction models (Lemos and Morehouse 2005). Consequently, we focus on the iterative changes in the science-policy interface when analyzing the temporal evolution of four agricultural droughts that impacted Uruguay's livestock sector in the last three decades.

In summary, the goal of this paper is to explore if and how there was a shift in the policy approach to deal with droughts from disaster response to risk management. We do so, based on the case study of the livestock sector in Uruguay, where actions, research, and policies evolved over three decades. Our aim is to provide insight into the multilevel system processes, highlighting the importance of the science–policy interaction.

#### 2. Approach

The problem of agricultural drought is complex (temporally and spatially multiscale and cross sectorial) and requires a transdisciplinary approach to set a common framework and to define the research problem, increasing the amount of useful and relevant results (Young et al. 2014). The transdisciplinary approach that includes collaborations between academic and non-academic actors demands a change in the way scientists and decision-makers carry out their work, allowing us to

reach possible solutions for real problems and to make commitments.

By transdisciplinary approach we mean to work beyond the domain of disciplinarity, creating new pathways to the production of scientific knowledge that transcends the formalism of a discipline and/or by promoting and managing integrative collaborations between academia and other stakeholders (e.g., local communities and/or policy makers) as part of the scientific work (Young et al. 2014). In this study, the overall approach to the problem of agricultural drought was built collectively, incorporating diverse views of the problem, and to formulate the research questions by trying to build a process of interpretation through which "people construct and express what gives meaning to the world around them" (Gray 2003).

This study is part of the transdisciplinary project titled Transferring Climate Knowledge in the Science-Policy Interface for Adaptation to Drought in Uruguay (Brasesco et al. 2014), which includes members of the Uruguayan and inter-American academia and representatives of Uruguayan government entities. The members of the working group are from Uruguay, the United States, Brazil, and Argentina. It includes the participation of various universities: Rio Cuarto University, Buenos Aires University, Federal University of São Paulo, University of Miami, Columbia University, University of Wisconsin, University of the Republic of Uruguay (UdelaR), and the Uruguayan National Agricultural Research Institute. Outside-academia entities from Uruguay, such as the Ministry of Livestock, Agriculture and Fisheries (MGAP), the Meteorology National Institute (INUMET), and the National Climate Change Response System (SNRCC) participate as policy informants, while the Uruguayan Extension Institute (IPA) is involved as farmers' reference. All the participants have extensive experience in their field, either as government officials, agriculture extension advisors, or researchers. The team consists of 12 agronomists, 4 anthropologists, 2 biologists, 1 meteorologist, 1 engineer, 1 political scientist, and 1 architect.

The work of the transdisciplinary team was intentionally designed as a coproduction of knowledge. According to the systematization presented in Meadow et al. (2015), the working method was the consultation mode. This means that there were interactions between the scientists and stakeholders at certain stages of the investigation, although these interactions were not necessarily permanent throughout the process. We obtained farmers' perceptions through the perspectives of the extension agents involved in the project (two agronomists from IPA), some farmers' interviews, and the participation of some farmers in workshops of the project. The coproduction method matches what Meadow et al. (2015) call a "rapid assessment process," which uses research to solve real-world problems. In this method of coproduction, stakeholders' input can be facilitated or filtered through a social scientist or other members of the research team that can act as "translators of science." The rapid assessment process of coproduction requires covering two fundamental principles: data triangulation and iterative analysis. In this regard, multiperson data collection, such as documents and field data from interviews with livestock farmers (the latter collected mostly by graduate students), allowed us to homogenize the knowledge of all the participants and to have a more holistic comprehension of the problem. We conducted four project workshops over two years, each lasting three days. Workshops provided opportunities for all project members to meet face to face to reinforce the interrelationships, while new participants joined to fill knowledge gaps and fulfill additional tasks. The workshops were attended by participants coming from different entities and disciplines who made presentations about historical and conceptual issues or provided updates on technologies (i.e., soil water monitoring) and the dissemination of this information. Through discussion sessions, we debated and generated methods to achieve our objectives. Many other meetings and seminars also took place using different forms of communication (face to face, virtual) and were carried out with the participation of some of the team members' depending on the addressed task.

Owing to the negative impacts of droughts, the demand for information and research increased in the last decades. This stimulated the link between academia and the political sector, and to a lesser extent with the farmers, developing collective learning to deal better with the next event. We can find this kind of process within the social learning framework, which it develops in cycles of loop learning (Fig. 1). Single-loop learning refers to an increased improvement of action strategies without questioning the underlying assumptions. Doubleloop learning refers to revising those assumptions (e.g., about cause-effect relationships) within a valuenormative framework. In triple-loop learning we reconsider underlying values and beliefs, different ways to see the world, and if assumptions within one type of view would not hold anymore (Pahl-Wostl 2009) (Fig. 1).

Different rules mediate social changes or group reactions to ecological or socioeconomic problems. An enforced system of norms that set up routines and incentives that shape and limit peoples' preferences and behavior structures the behaviors of political systems and groups, just like any other human culture. These



FIG. 1. Sequences of social learning cycles and applications to drought management. Adapted from Pahl Wostl (2009) and Lavell et al. (2012).

norms are a form of collective memory, that is, a method to integrate experimental knowledge over a time span that is longer than a person's lifetime (Beratan 2007). Consequently, the involvement of the different entities related to the problem of droughts is very important to our study case. The people who represent these entities in this study are "impregnated" with the collective knowledge of their own organization. In our team, each person "negotiated" with other people with different knowledge and institutional culture to reach a collective agreement on the vision of the problem. "People" and "organizations" are not static, as they interact over time, creating a dynamic process in relation to this exchange of knowledge (Meagher et al. 2008). Considering all of the above we ensured that our planning included working with various entities and organizations from the beginning.

The progression and magnitude of the changes that occurred in the last three decades deserve a discussion in terms of collective learning and the ways in which these have been achieved. Uruguayan public entities did not have opportunities to tackle the problem of rural development in a systematic way. The new policies included more social participation, as well as the political and academic commitment to adapt to climate change and its variability, which generated new forms of dialogue. The social learning approach applied to natural resources management attempts to capture the essentials of social learning processes (Pahl-Wostl et al. 2007) (Fig. 1). In this sense, the creation of interinstitutional working groups through the initiative of the Ministry of Agriculture was a strategy that encouraged interactions among several social actors and policy makers. Specifically, we chose to work in "early warnings for livestock production systems," which was one of the most actively

involved topics, with agricultural droughts being the predominant theme in the exchanges. Several networks have emerged from the meetings on early warnings for livestock production systems, updating on policy actions, research results, and concerns about unresolved issues. Pahl-Wostl (2009) describes change as a social phenomenon, where collective learning evolves in a gradual way and informal networks play a crucial role in it. Our team is one of these networks, described as an informal or adaptive network. Adaptive networks are groups of people coming from different backgrounds, who interact and develop ideas that influence other sectors, for the benefit of everyone (Nooteboom 2006). The ideas that emerged in those different backgrounds can evolve separately, but if there are connections, they can influence each other. Adaptive networks consciously try to align the sectors and, in particular, those linked to government, which are characterized by fostering the process of innovation and social learning (Pahl-Wostl 2009).

Within this framework, our approach followed these steps:

- 1) Identification of the problem of study—response to droughts of public policies, academia and farmers
- Conformation of a transdisciplinary team, integrating relevant disciplines and social actors based on the existing adaptive networks
- Conceptual discussion and agreement of the definition of drought, based on a model of social learning suitable for our case
- Description of four cases of historic droughts in Uruguay, through a transdisciplinary discussion, which provided empirical information for a collective reflection

5) Discussion of the pattern of response and collective learning about adaptation to agricultural drought

# 3. Analysis of four recent agricultural droughts in Uruguay

Because of the magnitude of their impacts, we chose four major drought events for this analysis: 1988/89, 1999/2000, 2008/09, and 2015. The events selected had great socioeconomic nationwide impacts and span over a period in which major changes occurred in the agricultural, political, and academic sectors. We did not include other events of minor water deficiencies within the study period because they did not have impacts as great as those selected.

We focus our analyses on the livestock sector, since it is the most important economic agricultural sector in Uruguay (Piedrabuena Perdomo et al. 2011). More than 90% of livestock production in Uruguay is based on grazing native grasslands that occupy more than 65% of its land. Livestock systems have intensified during the last 30 years. Beef cattle graze year-round on native grasslands, improved pastures with legumes, and seeded mixed pastures of grasses and legumes (leys). Cow-calf systems breed heifers at around 2.5 years of age, and calves are weaned at 6 months of age and 130 to 150 kg, with a national weaning rate between 63% and 70% (Piedrabuena Perdomo et al. 2011). Backgrounding and finishing of steers (up to 550 kg) is usually done on native grasslands and seeded pastures, and recently 10% of the steers were finished in feedlots (Picasso et al. 2014). Sheep stocks reached 25 million in 1990 and declined to 6.6 million in 2015 mainly owing to the decline in international wool prices. Beef cattle population was 8.6 million in 1990, and it increased to 12 million in the same period (INAC 2016).

This section describes and analyzes the characteristics of each of the mentioned droughts, including impacts (economic, financial, and ecological) and social responses (government, academia, and farmers) and considering the specific context in which each event occurred. We adopted a chronological approach to the analysis to explicitly show the accumulation of policy interventions and the evolving learning process. Table 1 summarizes all the information described in this section.

#### a. The 1988/89 drought

The drought of 1988/89 was very long (16 months) and intense during winter, spring, and summer. It affected the whole country (Caffera et al. 1989) (Fig. 2), and, in addition to the agricultural sector, it severely affected other sectors of the economy (e.g., generating problems in the generation of hydroelectric power). This event raised awareness of droughts even among the urban population, especially due to scheduled electricity outages (needed to ration hydroelectric power). Changes in the beef cattle and sheep stocking rates are reflected in the reduction of the sheep/cattle ratio presented in Table 1. In 1988 the stocking rate, which refers to the number of animals in livestock units per hectare (LU ha<sup>-1</sup>), was the highest for the entire period considered in this paper (>0.75 LU ha<sup>-1</sup>; Table 1). Using livestock units allows us to compare different animal species and categories considering the differences in forage or food consumption (Saravia et al. 2011). Sheep/ cattle ratio has been associated with lower robustness of livestock farmers to drought (Picasso et al. 2011).

At the time of this drought, there was no strategy for management of climate risk in Uruguay. The governmental response to the 1988/89 drought was reactive, allowing exports of live animals and extending credit lines to producers. Upon the occurrence of the drought, the weather information available to support decisions in the agricultural sector was basically rainfall data collected at meteorological stations operated by INUMET (formerly National Directorate of Meteorology; Table 1), which at that time was housed in the Ministry of National Defense. Considering the statistical analysis of rainfall since 1950, this drought was the most severe in the last decades (Caffera et al. 1989). These authors pointed out the need for interdisciplinary work aimed at the evaluation of the socioeconomic and ecological impacts of droughts and suggested recommendations for improving the monitoring of the climate system, developing climate forecasts, and strengthening university education in meteorology (Caffera et al. 1989). This is referred to as the UdelaR Report in Table 1. Indeed, the development of a university group specialized in atmospheric science can be traced directly to the impact of the 1988/89 drought. The prospect of seasonal climate prediction, particularly associated with the ENSO phenomenon, first became known with the initial publications of the global impact of ENSO (Ropelewski and Halpert 1987, 1989).

Severe production losses and high mortality of animals occurred because of the 1988/89 drought. Moreover, this event contributed to the degradation of native grasslands due to the high sheep stocking rate (sheep can eat shorter grasses) and overgrazing.

Initially, this drought affected mainly northern Uruguay. Accordingly, some farmers from the southern part of the country (who still had fodder available) took the opportunity to buy cheap cattle and sometimes even in exchange of hay bales for animals with ranchers from the north. The majority of the area with shallow soils is located in the north of the country, and thus it is one of

TAI	3LE 1. Biophysical, soci-	oeconomic, and organizational chara	cterization of the main four agricultural	drought events in Uruguay in the la	st three decades (1988–2015).
	Factors	Drought of 1988/89	Drought of 1999/2000	Drought of 2008/09	Drought of 2015
Event	Magnitude of water deficit (duration and intensity)	Very long (16 months) and intense during winter-spring-summer. It affected the whole country. Associated with a strong La Niña.	Short (4 months) but intense during spring-summer. It mainly affected the north and center of the country. Associated with a strong La Niña.	Long (9 months), very intense spring-summer. It affected mostly the north and southeast of the country. Associated with a moderate La Niña.	Long (7 months) and intense during autumn-winter. It mainly affected the east and south of the country. Not associated with ENSO.
Context	Export prices Political party (government)	Increasing as a trend. Colorado (center-right wing, first government after the dictatorship)	Decreasing as a trend. Colorado (center-right wing)	Increasing as a trend. Frente Amplio (left wing)	Stable as a trend. Frente Amplio (left wing)
	Livestock production (stocking rate, for-	Average stocking $> 0.75 \text{ LU ha}^{-1}$ Sheep/cattle ratio: 2.9	Average stocking: 0.72 LU ha <sup>-1</sup> Sheep/cattle ratio: 1.3	Average stocking: 0.74 LU ha <sup>-1</sup> Sheep/cattle ratio: 0.74	Average stocking: 0.75 LU ha <sup>-1</sup> Sheep/cattle ratio: 0.56
	age base, etc.)	Forage base: natural grasslands, little forage improvement.	Increase of area with fertilized soils and broadcast seeding.	Supplemental feeding is generalized during drought (imported) in affected family farms, according to geographical demarcation in the ministerial declaration of drough.	Similar measures and mechanisms taken to supplement animal feeding than the ones taken in the previous droughts.
	Social (perception)	Droughts are a low-frequency event.	No information available about perceptions of droughts.	Droughts are considered imponderable. The climate in the north is different from the one in the south of the country.	Droughts are the first factor of change for family farmers in the northwest of the country. The frequency and intensity of droughts has increased over the past 15 years.
Impacts	Economic	Growth of farmers' debt and disin- vestment. This situation lasted more than 10 years.	Losses in the agricultural sector equivalent to 1% of GDP.	Losses in the agricultural sector equivalent to 3% of GDP.	Direct impacts on livestock, soy, and dairy of \$550 million. Particularly in livestock (\$340 million). Losses in the agricultural sector equivalent to 0.3% of GDP.
	Production	Severe production losses with high mortality of animals.	The damage depended on the stocking in establishments and specific zones (high variance).	Marked reduction of meat production, calving rates, and economic performance of farms.	Marked reduction of meat production, calving rates, and economic performance of the farms. Increased calf mortality (15%). Investment losses in grassland and annual forage crons.
	Ecological	Overgrazing and erosion of natural grasslands.	Overgrazing and erosion of natural grasslands.	Overgrazing and erosion of natural grasslands. Drying of wells. Locust invasion.	Overgrazing and erosion of natural grasslands.

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	Factors	Drought of 1988/89	Drought of 1999/2000	Drought of 2008/09	Drought of 2015
Responses	From the	Exportation 'on foot'' (live animals).	The most affected areas were prioritized hased on information from INI A.GRAS	Government declaration of drought have don objective himburght	Government declaration of drought has a homory based on objective himmory
	reactive	Extending credit lines.	Hotels for calves were implemented.	information provided by the	unservice on objective or physical information (INUMET,
		ı	Authorization for grazing on	Meteorological Service and INIA-	INIA-GRAS). Distribution of
			roadsides.	<b>GRAS.</b> Creation of Agricultural	food rations accounted by the
				Emergency Fund. Distribution of	Agricultural Emergency Fund.
				rations. Credits, tax exemptions.	
	From the government	Atmosphere for debate without	A ''commission of drought'' was created.	The issue was added to the	National assessment of the status of
	proactive	a specific institutional framework;	Development and infrastructure for	government's agenda. Creation of	disaster risk reduction (UN-ISDR
		authorization for direct import of	irrigation and water supply plans.	SNRCC. Decentralization through	2011). Creation of INUMET (2015),
		grains and food rations from		the Boards for Rural Development	which replaces the National Mete-
		neighboring countries.		(MGAP; Registry of Family	orology Service and generates new
				Farmers). Plans for shade and water $\frac{1}{2}$	climate services for monitoring the
				supply. Frograms for better use of	nyurological situation. Creation of the Mational System of Agriculture
			Use of the information system of INIA at	Studies for the development of	Information. Pilot test of insurance
			the request of the commission of	agricultural insurance by MGAP.	based on drought index for livestock
			drought.	2	breeding (MGAP, with support
			Creation of SINAE.		from the INIA-GRAS).
	Scientific-	Rainfall deficit information (National	INIA first collaborates with IRI-Columbia	INIA-GRAS already created. Satellite	Research applied to drought and
	technological	Meteorological Service).	on climate services.	data, vegetation indices, and soil	agricultural problems linked to
	(information,	Postdrought report (University	UdelaR and INIA demonstrate that	water balance in Uruguay	climate change (CIRCVC and
	technologies)	UdelaR).	practice of early calf weaning im-	(INIA-GRAS, INUMET).	Fagro-UdelaR). IRI advice to
			proved the weaning rates.	Specific and more local monitoring	MGAP. Support of research from
		First steps in the formation of an		base on internal political divisions	INIA, UdelaR, and INUMET to
		academic team in atmospheric		and estimation of the absorbed	MGAP (OPYPA) for drought
		sciences in UdelaR.		photosynthetically active radiation	insurance design based on climatic
				(APAR) (INIA-GRAS). Creation	and agroclimatic indices.
				of an Interdisciplinary Center in	
				Response to Climate Variability	
				and Change (UdelaR). New	
				bachelor's degree in atmospheric	
	Facar formers?	Commission of Acalometicae from	المتعادية والمتعادية والمتعادية والمتعادين والمتعاد والمتعادين والمت	Sciences at UdelaR.	Í dame daranakt 2008/00
	organizations and	Comprames and ucciar advins more farmer unions.	calves, providing physical space and	contributing to the distribution of	Inclu al ought 2000/07.
	rural unions		qualified personnel.	food rations from MGAP. Articulation	
		171		with outreach institutions.	[
	From livestock	Very little experience with sumilamental feeding: direct	Sending animals notels for calves.	Reduction of stocking (medium- and large scale farmars) Small scale	Supplemental recting incorporated in the monocement during winter
	ratures	import of food ration from Brazil		farmers: retention of cattle	and drought conditions according
		Exchange of underweight cattle from	Protein supplemental feeding is begin-	stimulated by public policy of food	to zones. Better handling of
		the north of the country with bales	ning to spread in grazing areas.	ration supply. Early weaning and	stocking in relation to the forage
		of hay from the south; sale of un-	) ,	supplemental feeding in winter	supply by areas.
		derweight cattle.		and drought conditions according	
				to zones.	

TABLE 1. (Continued)

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FIG. 2. Main impact areas for the four droughts discussed in Uruguay: (a) 1999/2000, (b) 1988/89 and 2008/09, and (c) 2015.

the most sensitive areas to drought, although there are rocky outcrops in the southeast and a "mosaic" of soils from different depths throughout the country. Droughts were considered as a low-frequency climatic phenomenon at this time (Baethgen and Giménez 2002), but even now people remember it as the most important climatic event of the second half of the twentieth century.

### b. The 1999/2000 drought

A spring–summer agricultural drought occurred in 1999/2000. This event affected mostly the north and center of the country (Table 1 and Fig. 2). The economic consequences of the previous drought (1988/89) in terms of farmers' debt and decapitalization were still evident. While the 1999/2000 drought was relatively short-lived, estimated losses reached about 1% of the national GDP.

By 1997, the first Regional Climate Forum for Southeast South America (RCOF-SESA) was held in Uruguay, fostering collaborative academic exchanges. The National Institute of Agricultural Research (INIA) launched an international research project to evaluate the impacts of El Niño–Southern Oscillation (ENSO) on agriculture (Baethgen et al. 2016) and to develop relationships with the International Research Institute for Climate and Society (IRI) of Columbia University. In 1998, a new technical group from INIA started developing the capacity to use new tools (remote sensing, GIS, and GPS) and subsequently created the Unit of Agroclimate and Information Systems (GRAS) in 2003 (INIA 2016). MGAP created the Drought Commission before this particular drought. During this event, seasonal climate forecasts were, for the first time, regularly analyzed by the agricultural sector, although they were not considered to make decisions. The Drought Commission was later replaced by the National Emergency System (Baethgen and Giménez 2002; Table 1). The first government regulation on climate risks issued in 1995 was the creation of the National Emergency System in the Office of the President, in order to "address situations of emergencies, crises and disasters of exceptional character, which affect or may affect the country severely" (UN-ISDR 2011, p. 10). This constitutes a key step in the institutionalization of the risk management approach in the Uruguayan government.

During the 1999/2000 drought, the Ministry of Agriculture and the National Emergency System prioritized their aid based on satellite information [normalized difference vegetation index (NDVI)] provided by an INIA GRAS-International Soil Fertility and Agricultural Development Center (IFDC) project (INIA GRAS has a letter from a former Minister of Agriculture explaining how they used their data to objectively prioritize aid). This is an important landmark since it was the first time that an objective approach and this type of tool were used in Uruguay for prioritizing responses to an emergency.

The impacts of the 1999/2000 drought on production were quite variable at the farm level: farms that worked with well-adjusted stocking rates, and therefore had more available forage, suffered less damage. On average, the stocking rates and sheep/cattle ratio decreased in the period between the two droughts, mainly due to the reduction in the sheep stock (Table 1). Although during this period there was an increase in the area covered by improved grasslands (fertilized and/or overseeded with legumes) and sown mixed pastures, this development was not enough to meet animal feed requirements during the drought. Until then, and especially among small-scale farmers, sale of animals was the only alternative to overcome a drought, with the consequent loss of capital for the farmer. This situation was common during the 1999/2000 drought, although public policies to supply feed attempted to prevent unprofitable livestock sale (Table 1). Another farm-level management practice to alleviate the effects of the drought was the implementation of "calf hotels" (e.g., in the center of the country, led by a group of rural women and youth; De Grossi 2000). These calf hotels were places (either private or community property) where calves were taken and fed after weaning. This allowed cows to stop lactation, thus reducing forage requirements and allowing animals to reach a more adequate body condition for the next gestation (the economic production objective is to obtain one calf per cow per year, as gestation lasts 9 months). In extreme situations, calf hotels at least allowed cows to remain alive. This early weaning technique allowed the little forage available to be distributed in a better way among the animals that remained on the farm. Subsequently, grown calves were taken back to the farm to continue their backgrounding and finishing processes and to be sold when they had achieved the target weight for meat processing plants (male calves) or for replacement of cows (female calves). Initiatives to establish calf hotels after the 1999/ 2000 drought included technical assistance from the Livestock Extension Service [Instituto Plan Agropecuario (IPA)], INIA, MGAP, and the local-level drought commissions. This was one of the first experiences in which a public/private articulation was put into practice. At the time of this drought, research in Uruguay (from UdelaR and INIA), had already demonstrated that early calf weaning improved the weaning rates of cattle farms (Soca and Orcasberro 1992; Soca et al. 1992; Lacuesta et al. 2000). This practice, together with other low-cost practices could improve the cattle reproduction index, a major cause of low production efficiency in the cow-calf system in Uruguay (Pereira 2003).

#### c. The 2008/09 drought

A severe agricultural drought affecting all of Uruguay (Fig. 2), occurred during the spring of 2008 and summer of 2009. This event, however, took place in a very different context from the drought of 1999/2000. International prices of beef had increased, which was very favorable to Uruguay, a meat-exportation country. There was also a new political context: for the first time

the Uruguayan government was in the hands of a leftwing party, different from the two traditional parties that historically had governed the country (Table 1). The economic impacts of this drought were well studied and direct agricultural losses reached about 3% of GDP, although the estimated total losses (direct and indirect) for the Uruguayan economy tripled that value (342 million U.S. dollars in the agricultural sector and 1026 million U.S. dollars for the entire economy; Paolino et al. 2010). Moreover, employment was also reduced (Paolino et al. 2010). The causes of these "spillover effects" over the entire economy are explained by the lower supply of steers for fattening and heifers for sale in the two years following the event, given the decrease in calves' weaning rates due to the drought (Paolino et al. 2010). This affected the entire beef production chain and associated services. Locust invasions arose in association with this drought (Table 1), a combination that had been reported during droughts occurring at the beginning of the twentieth century (Bertino and Tajam 2000).

To respond to the emergency, the government created an Agricultural Emergency Fund (AEF) (Poder Ejecutivo Uruguay 2008), which empowered the MGAP to support the most affected farmers. To access the AEF, the MGAP must declare an agricultural emergency. An agricultural emergency is an emergency resulting from any extreme climatic, animal health, or phytosanitary event that causes economic losses not recoverable in the agricultural year and that decisively affects the viability of the farmers of a region or sector (Poder Ejecutivo Uruguay 2008). The MGAP defined the characteristics of the beneficiaries, the form of reimbursement (e.g., feed supplements are partly reimbursable), the geographical areas covered, and the period for which the agricultural emergency is in effect. Another public policy implemented was the creation of the Family Farmers' Registry (name given to the most vulnerable farmers according to farm size and income criteria defined by the Ministry), allowing them to qualify for specific prioritized public policies. Furthermore, Rural Development Boards were created as an instrument of public policy, consisting of decentralized structures of public and private participation at the local level (UDC 2007). Since 2002, the MGAP began to promote the development of agricultural insurance to help manage climate risks (Vila 2002). Additionally, almost immediately after the drought was receding, though its impact was still evident, the president created the National Climate Change Response System (SNRCC), a new entity to address the impact of climate variability and change in Uruguay (SNRCC 2009) that constituted another major step in the institutionalization of climate risk management in the country. The SNRCC soon prepared

the National Plan to Respond to Climate Change, which included recommendations for the agriculture sector.

In the scientific/technological dimension, methodologies and technologies of automatic and satellite environmental monitoring were applied in the agricultural research community to inform public policy decisions. GRAS-INIA processed information on agrometeorological variables, including monitoring of water balance and vegetation status coming from satellite images (using the NDVI). INUMET provided rainfall information in real time, and working with UdelaR, they produced quarterly climate forecasts, incorporating the influence of ENSO in the region. The Ministry of Agriculture used all this information to decide when to declare agricultural emergency and the geographical areas that were included. Regarding universities, in UdelaR's School of Agriculture (Facultad de Agronomía), a small group of researchers started research funded by international grants [Inter-American Institute for Global Change (IAI)] focused on the climatic vulnerability of livestock in native grasslands (Cruz et al. 2007; De Torres et al. 2007; Bettolli et al. 2010). This work fostered interactions with the IPA, INIA, and MGAP, facilitating the exchange of ideas and stronger coordination of activities. At the end of 2009, the Interdisciplinary Center in Response to Climate Change and Variability was created within UdelaR with the objective of providing academic foundations to the development of a national strategy to respond to climate variability and change in natural, social, and production systems, as well as creating relevant interdisciplinary knowledge (Astigarraga et al. 2009; Picasso et al. 2013). Initially, the center involved agricultural researchers, but it was later expanded to include researchers from other disciplines such as anthropology, ecology, engineering, law, international relations, and economics (Cruz et al. 2013). UdelaR opened a Bachelor's Degree in Atmospheric Sciences, the first in the country, which was led by the research group created in the aftermath of the 1988/89 drought.

In the private sector, farmer associations collaborated with the internal distribution of animal feed during the emergency, while IPA and INIA held meetings to train farmers in the use of feed (e.g., how to train grazing animals to consume grain feed). The provision of animal feed already had been implemented during a shorter drought in 2004/05 in the northwest region of Uruguay. The practice of establishing calf hotels, initiated in the 1999/2000 drought, had partially contributed to adoption of early weaning. However, these low-cost management practices still were not well known by most farmers, which could explain the low adoption levels. It could be argued that most farmers did not perceive a problem of reproductive efficiency in their farms at the time. The powerful influence of climate on pregnancy strengthened the perception that in a good year there would be a higher production of calves and that the opposite would happen under adverse conditions (Pereira 2003). Soca et al. (2007) stated that the availability of these low-cost management practices was relatively recent and that the proper promotion of the available tools had not yet been solved (Saravia and Gómez 2013).

#### d. The 2015 drought

The drought of 2015 was longer and more intense than other events, presenting some unique characteristics. It occurred during fall and winter (a normally wetter period) and, unlike previous droughts, it did not include the spring. The most affected regions were the east and south of the country, with no significant effects in the northern region (Fig. 2). In addition, this drought was not associated with an ENSO event and thus showed little predictability. Most of the decision process was driven by monitoring and weather forecasts but not by climate forecasts. The political context was similar to the previous period, and the international export prices of beef remained high (Montes 2009; Table 1).

Since 2010, the Ministry of Agriculture had been evaluating the feasibility of designing index insurance to cover impacts of droughts on natural pastures in the spring-summer period, in order to mitigate the effects of extreme droughts on breeding stock. This study was supported by the World Bank during 2011–13. Also, insurance policies based on the NDVI were designed building on experiences from other countries (Spain, United States, Mexico) and on the availability of satellite data for Uruguay. Currently, this insurance program is in a pilot phase for regions with a high proportion of livestock farmers that are vulnerable to droughts (Methol and Mila 2015). During the 2015 drought, the policy response to the emergency operated in an articulated and progressive manner, thanks to the real-time availability of agrometeorological information and to the fact that the AEF was in place. There was also an updated Registry of Family Farmers, the actual beneficiaries of this policy. The agricultural emergency status was declared at three different times, each time including a new region. Emergency declarations were based on agrometeorological data, weather forecasts, and reports of forage availability by farmer organizations. The National Emergency System (SINAE) also participated, convening an interinstitutional commission composed by public representatives from all economic sectors and activities affected by droughts.

Between the 2008/09 and 2015 droughts, public policies and regulations were implemented to improve the adaptation of livestock farmers to climate change and variability, in addition to reactive measures to the event as mentioned above. The development and implementation of these actions came from the science-policy nexus (V. Picasso et al. 2013, meeting presentation). For example, MGAP started to fund projects for family livestock farmers that also promoted an adequate use of forage, shade for animals, and associative use of water resources between farms (MGAP 2015a). The projects also aimed at strengthening the production, economic, and sociocultural dimensions of family farmers' organizations (MGAP 2015b). To inform these policies, MGAP (with FAO funding) asked the Interdisciplinary Center in Response to Climate Change and Variability of UdelaR to conduct an analysis and synthesis of relevant climatic, agricultural, and social information for assessing the vulnerability and adaptive capacity of livestock farmers to drought (Astigarraga and Picasso 2015; Bartaburu et al. 2013). These policies, designed to foster the adaptation of livestock farmers to climate variability, were funded by two initiatives: the "Livestock Family Farmers and Climate Change" project (sponsored by the Adaptation Fund of the Kyoto Protocol) and the "Development and Adaptation to Climate Change" project (DACC; funded by a loan from the World Bank). Within the framework of the DACC, the development of a National Agricultural Information System (SNIA) is also being implemented (Table 1). The objective of the SNIA is to support farmers in the sustainable use of natural resources by generating improved adaptation to climate change and variability and promoting a modernization of the Ministry of Agriculture's capacities in the area of information and services related to climate and natural resources. The SNIA promotes a climate risk management approach (MGAP 2013), proposed by IRI-Columbia University (Baethgen 2010).

A climate risk diagnostic report prepared by a United Nations mission to Uruguay (UN-ISDR 2011) remarked the improved capabilities in the Ministry of Agriculture, in relation to other government organizations. The report also highlighted the creation of SINAE (Table 1) as a positive development (UN-ISDR 2011). However, the report pointed out that key aspects remained to be addressed. Although the SINAE establishes the basis for a comprehensive disaster risk management in Uruguay, transcending the historical approach of emergency management, requires expansion of programs and information to every sector throughout the country. The SINAE also lacks the identification of risks in all its phases and the consolidation of an information system to manage risk comprehensively (UN-ISDR 2011). In this context, and in response to one of the first recommendations of the aforementioned report, INUMET (Table 1) was created in 2013 as a decentralized service under the Ministry of Housing, Land Planning, and Environment. INUMET (2015) replaced the Directorate of National Meteorology that had been housed in the Ministry of National Defense. It should be noted that the resources and installed capacity of the meteorological service had deteriorated in previous decades, going from 42 stations and almost 300 technicians in its staff during the 1980s to 25 stations and 180 technicians in 2010 (UN-ISDR 2011).

At the time of the drought in 2015, the technique of early weaning was known by most cattle farmers. Although its application was not generalized, there was sufficient knowledge of this technique to allow its use in forage crisis conditions, such as during a drought. The calf hotels closed. The advisory organizations considered that knowledge of early weaning at the individual farmer level was sufficient to adapt the feeding of animals within each farm, and, therefore, it was no longer necessary to resort to collective undertakings.

### 4. Discussion

The vulnerability to drought hazards is modulated by interdependencies and feedbacks within components of the affected sector(s) that increase or mitigate climate risks in complex ways. Our central argument is that we should be able to identify viable options to mitigate risks and we should be able to understand the interactions, feedbacks, and unintended consequences between the natural and human components of the drought-sensitive sector to effectively manage risks due to extreme climate events such as droughts.

In Fig. 3 we conceptualize the Uruguayan cattle sector and its linkages to droughts, as well as the chain of impacts associated with drought events. The physical dimension includes interannual and longer-term rainfall variability that modulates the timing, duration, and extent of drought. According to projected climate change trends for the region, this dimension also involves a probable increase in evapotranspiration linked to projected increased temperature (Giménez 2006). Enhanced rainfall variability and higher water atmospheric demand imply a likely increase in water deficits with variable effects depending on the time of year. The production dimension refers to the aspects of agronomic management that modify the impact of water deficiencies, such as livestock stocking rates, sheep/cattle ratio, and the land forage base (natural grasslands and improved or seeded pastures). The economic-political dimension includes the effect of global beef/grain prices that have clear impacts on domestic markets (strongly



FIG. 3. Drivers of agricultural droughts and chain of impacts.

influencing production decisions). This dimension also includes the public policy context that defines the guidelines and instruments of governance for the sector. The interactions between all three dimensions vary over time and give place to changing drought situations with different effects on society as a whole.

Currently, most countries, regions, and communities manage drought risk through reactive, crisis-driven approaches. Alternatively, in a proactive approach, drought information and early warning systems are central to integrated risk assessment, communication, and decision support. Effective drought preparedness depends on a multisectoral and interdisciplinary collaboration among all concerned actors at each stage in the warning process, from monitoring to response and evaluation (Pulwarty and Sivakumar 2014). After reviewing four of the most recent drought events in Uruguay, we attempt to compare their characteristics and the contexts in which they took place, as well as to assess whether there has been progress toward a more effective and proactive approach to prepare for and to manage drought impacts.

# a. Was there a shift in the approach from disaster response to risk management?

The four drought events analyzed presented different characteristics and had distinct impacts, as reviewed in the previous section. Moreover, as these events occurred in a span of 27 years, each event took place in a different political and economic context. All four droughts discussed show that the context in which each one took place was greatly shaped by the cumulative measures adopted in response to earlier droughts. Overall, we propose that there has been an evolution toward a closer integration of entities and organizations and stronger science–policy interactions over time and an increasing understanding of the drought problem.

The issue of climate change and variability has been incorporated into the Uruguayan governmental agenda. Several public policies have been implemented: (i) decentralized participation structures, such as the Rural Development Boards; (ii) instruments of differentiated policy through the registry of family farmers; (iii) plans to foster planting of trees for shade and establishing of water storage reservoirs at the farms; (iv) the declaration of agricultural emergency institutionalized according to zones, facilitating the distribution of animal feed; and (v) developing of the National Agricultural Information System. A similar process took place within the wider multisectorial context of public policies and government organization, mainly resulting in the creation of SINAE and SNRCC, both independent entities that work together with all the ministries in the country.

In the scientific/technological dimension, the following was implemented: (i) seasonal climate forecasts mainly based on the ENSO signal; (ii) routine monitoring of satellite-derived vegetation indices; (iii) realtime, countrywide updates of the soil water balance; (iv) truly interdisciplinary research on droughts and their impacts; and (v) conformation of an academic group on atmospheric sciences at UdelaR, which now offers a bachelor's degree in this field.

At the farm level, good management practices were adopted to increase the sustainability of livestock grazing systems: stocking management, early calf weaning, and supplementation with concentrated feed during a period of forage shortage. These "no regret" practices contributed to managing the impacts of droughts.

Moreover, many of these developments, at political, academic and production levels, can be directly traced back to extreme climatic events, mostly droughts, whose occurrence shaped the environment that made them possible (learning processes as showed in Fig. 1).

The impacts and responses discussed for the four droughts analyzed here were the product of the interaction between biophysical and social processes. Changes at various levels in Uruguay have generated reactions and learning opportunities about agricultural droughts (Fig. 1). We can interpret these reactions as a shift in the approach, where the learnt social lessons and the public policies have allowed us to see beyond the vision of disaster management, in which measures were only imposed after the event occurred. Furthermore, this shift in the approach to droughts is now focusing in risk management, with policies in place before the crisis arrives. In this regard, the answer to our original research question is affirmative. However, the question of whether these changes are the result of a better adaptation to agricultural droughts with the consequent reduction of vulnerability remains open. Adaptation is the objective for vulnerability reduction. It is also important to identify those actors and their organizations that are most active in articulating social learning, promoting mechanisms so that actions could take place in all levels. These aspects are discussed next.

# b. Was there a successful process of adaptation to agricultural droughts?

Adaptation is an adjustment of natural or human systems to actual or expected climatic stimuli or their effects, aimed at moderating damages or taking advantage of potential benefits (McCarthy et al. 2001). The adaptation process describes adjustments made in changing environmental circumstances, which occur naturally in biological systems and, to some extent, in social systems (Nelson et al. 2007; Adger et al. 2009). Moreover, the adjustments made for adaptation to agricultural droughts in Uruguay are in line with the previous definitions and were strongly related to the new policies of greater social participation (Villalba 2015; Thompson 2013) and to the academic impulse to interdisciplinary research. The response of livestock farmers to the increased prices of beef was a slight increase in the stocking rates (Table 1). However, on the one hand, good management of natural grasslands has been reported as an important mechanism of adjustment at the farm level, especially through the management of the stocking rate (Bartaburu et al. 2009) and to a lesser extent by the adoption of early calf weaning. On the other hand, although adaptation may occur in response to some limiting factor (Niles et al. 2015), it is performed in an environment in which other factors also vary. Therefore, it is a dynamic phenomenon of adjustment to the environment over time. In the case of Uruguay, there were important improvements in agrometeorological monitoring and forecasting and in the adjustments for emergency declaration due to droughts. However, climate is only one of many uncertain processes that influence society and its activities; hence, climate monitoring and prediction should not be the central tool to guide adaptation to climate change and variability (Adger et al. 2009). Hence, in Uruguay important changes also occurred in other areas such as governmental organizations and interdisciplinary research, which strengthen the process of adaptation.

Successful adaptation must result in a situation equal to or better than the initial condition; unsuccessful adaptation or maladaptation occurs when the resulting situation is worse than the previous one (Lemos 2007). For the purpose of this assessment, it is pertinent to consider the changes that have taken place within the framework of social factors (economic and political dimension in Fig. 3) that have historically made the livestock farmers of Uruguay more vulnerable to droughts, as well as other climatic or nonclimatic factors. According to Lemos (2007), vulnerability is the range of inequalities that is the root of several weaknesses. From this angle, access to land (De Torres et al. 2014) and inequality in the size of farms are historical explanatory factors. In Uruguay, 61% of the land belongs to 9% of farmers (in farms larger than 1000 ha), and only 39% is owned by smaller farmers, which are 91% of the total number of farmers (Piedrabuena Perdomo et al. 2011). These sources of vulnerability have not been overcome by the measures implemented in the last three decades. However, recent new differentiated policies to support small family farmers can act positively by generating more changes (Lemos 2007) that in the future might help to alleviate inequalities. Another aspect to consider is the need to establish the way in which decentralization efforts are carried out in all sectors and different parts of the country (UN-ISDR 2011). In this regard, some contradictions have been reported in the implementation of decentralization policies in Uruguayan provinces (departamentos in Spanish). For example, the Ministry of Housing, Land Planning, and Environment (MVOTMA) defined geographical units in the Land Planning Program that do not consider rural issues. On the other hand, the geographical units defined by MGAP do not contemplate urban issues (Thompson 2013). These contradictions limit territorial development and possible local strategies to reduce vulnerabilities, aspects that are precisely intended to be promoted with decentralization policies.

#### c. The coproduction and transdisciplinary work

The formulation and implementation of public policies is an activity that usually causes controversy and develops in a nonlinear way, where norms, subjectivity, values, interests, power relationships, and knowledge play a significant role. Science is only one element in this broad framework (Cáceres et al. 2016). As it was clarified in section 2, we developed this work with the participation of actors from different entities and organizations to answer a research question based on an agreed interpretation of the past. This required that we had to elaborate the baseline information and several exercises of interpretation and reinterpretation in an iterative way. On the process of adaptation to agricultural droughts in Uruguay, the work shows a team effort involving research, compilation, systematization, and interpretation of information that was isolated. Moreover, reaching an agreement of certain definitions has also been part of this work, such as the conceptualization of the "agricultural drought" phenomenon

within the framework of complexity that transcends the biophysical dimension, as well as the conceptual framework on adaptation to interpret and evaluate the changes that occurred in the period studied.

Our work reflects one of the first steps to promote a more active science–policy interface in Uruguay, establishing discussions between the parties involved or, as Young et al. (2014) described it, engaging in a conversation instead of just talking to one another. To continue this transdisciplinary dialogue and to promote multilevel social learnings, it will be necessary to include other actors within our society (such as rural organizations) and come to an agreement on long-term strategic visions. Clearly, all previous statements depend on significant changes in the education of the new generations and on the support and encouragement of scientists and policy makers motivated to cross borders and carry out activities in the science–policy–society interface.

#### 5. Conclusions

We found an increasing interinstitutional integration and a closer science-policy relationship in our study period. The Uruguayan government's agenda explicitly incorporated the issue of adaptation to climate variability and change and assembled specific interdisciplinary research groups. Moreover, during the period spanned by the four droughts discussed, more social knowledge has been gained by learning from all different levels. These social lessons learned, together with policy lessons, have transcended the vision of disaster management (ex post management), and they have promoted proactive and effective adaptation measures to agricultural droughts in Uruguay. Although the historical sources of vulnerability have not been yet overcome, recent changes have the potential to trigger other actions, generating additional positive changes in the near future. The transdisciplinary approach allowed us to establish a common conceptual framework characterizing agricultural droughts as a complex problem and as the product of interactions between biophysical and social processes. The study of adaptive or informal networks, a privileged place for the development of innovations, will allow us to strengthen and continue this process for better adaptation to agricultural droughts. Our study confirms how relevant and necessary it is to work within a transdisciplinary framework to address, in depth, the dimensions of social learning, particularly those concerning the adaptation to global change.

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#### REFERENCES

- Adger, W. N., and Coauthors, 2009: Are there social limits to adaptation to climate change? *Climatic Change*, **93**, 335–354, https://doi.org/10.1007/s10584-008-9520-z.
- Astigarraga, L., and V. Picasso, 2015: La investigación para aportar a la elaboración de políticas: Un estudio de caso (Research informing public policy: A case study). Centro Interdisciplinario Respuesta al Cambio y Variabilidad Climática: Vínculos Ciencia-Política y Ciencia-Sociedad, L. Astigarraga et al., Eds., Espacio Interdisciplinario, Universidad de la República, 37–50.
- —, and Coauthors, 2009: Objetivos del Centro Interdisciplinaro de Respuesta al Cambio y la Variabilidad Climática. Espacio Interdisciplinario, UdelaR, accessed 9 August 2016, http:// www.circvc.ei.udelar.edu.uy/institucional/objetivos/.
- Baethgen, W., 2010: Climate risk management for adaptation to climate variability and change. *Crop Sci.*, **50**, 70–76, https:// doi.org/10.2135/cropsci2009.09.0526.
- —, and A. Giménez, 2002: Aplicación de pronósticos climáticos estacionales e información satelital para mejorar la toma de decisiones en el sector agropecuario: Ejemplos de la sequía 1999-2000 en Uruguay y otros. INIA Uruguay, accessed 2 August 2016, http://www.inia.uy/Publicaciones/Paginas/ publicacion-686.aspx.
- —, M. Berterreche, and A. Giménez, 2016: Informing decisions on policy: The National Agricultural Information System of Uruguay. *Agrometeoros*, 24, 97–112.
- Bartaburu, D., E. Duarte, E. Montes, H. Morales, and M. Pereira, 2009: Las sequías: Un evento que afecta la trayectoria de las empresas y su gente. *Familias y Campo: Rescatando Estrategias de Adaptación*, H. Morales Grosskopf and F. Dieguez Cameroni, Eds., Instituto Plan Agropecuario, 155–168.
- —, and Coauthors, 2013: Sensibilidad y capacidad adaptativa de la ganadería frente a los efectos del cambio climático. Clima de cambios: Nuevos desafíos de adaptación para Uruguay, MGAP FAO Rep., Vol. 3, 58 pp., http://www.fao.org/climatechange/ 39805-04fd4a450820d64c555478e4a0939a555.pdf.
- Beratan, K., 2007: Complexity and the science-policy interface. Handbook of Globalization and the Environment, K. Thai, D. Rahm, and J. Coggburn, Eds., CRC Press, 527–548.
- Bertino, M., and H. Tajam, 2000: La ganadería en el Uruguay 1911-1943. Accessed 20 October 2016, www.colibri.udelar.edu.uy/ bitstream/123456789/4217/5/dt-03-00.pdf.
- Bettolli, M. L., M. Altamirano, G. Cruz, F. Rudorff, A. Martínez Ortiz, J. Arroyo, and J. Armoa, 2010: Pastura natural de Salto (Uruguay): Relación con la variabilidad climática y análisis de contextos futuros de cambio climático. *Rev. Bras. Meteor.*, 25, 248–259, https://doi.org/10.1590/S0102-77862010000200009.
- Brasesco, G. C., and Coauthors, 2014: Transferring climate knowledge in the science-policy interface for adaptation to drought in Uruguay. Agrodrought, accessed 8 September 2016, http://www.agrodrought.ei.udelar.edu.uy/?page\_id=40.

- Bidegain, M., and Coauthors, 2013: Variabilidad climática de importancia para el sector productivo. Clima de cambios: Nuevos desafíos de adaptación para Uruguay, MGAP FAO Rep., Vol 1, 128 pp., http://www.fao.org/docrep/field/009/as253s/as253s.pdf.
- Cáceres, D., F. Silvetti, and S. Díaz, 2016: The rocky path from policy-relevant science to policy implementation—a case study from the South American Chaco. *Curr. Opin. Environ. Sustain.*, 19, 57–66, https://doi.org/10.1016/j.cosust.2015.12.003.
- Caffera, R. M., M. Bidegain, and J. Pedrosa, 1989: Recurrencia de las anomalías negativas de la precipitación sobre Uruguay: Informe técnico sobre la sequía 1988-1989. Departamento de Publicaciones de la Facultad de Humanidades y Ciencias Rep., 9 pp.
- Clark, W. C., P. J. Crutzen, and H. J. Schellnhuber, 2005: Science for global sustainability: Toward a new paradigm. Center for International Development Working Paper 120, 33 pp.
- Cruz, G., and Coauthors, 2007: Evaluación de la vulnerabilidad actual y futura de los sistemas pastoriles frente a la variabilidad y al cambio climático: Caso Uruguay. Semana de Reflexión sobre Cambio y Variabilidad Climática, V. Picasso et al., Eds., Facultad de Agronomía, 146–176.
- —, R. Terra, V. Picasso, and L. Astigarraga, 2013: Desafíos del cambio y variabilidad climática. *Cambio y Variabilidad Climática: Re*spuestas Interdisciplinarias, V. Picasso et al., Eds., UdelaR, 23–30.
- —, W. Baethgen, V. Picasso, and R. Terra, 2014: Análisis de sequías agronómicas en dos regiones ganaderas de Uruguay. *Agrociencia*, 18, 126–132.
- De Grossi, A., 2000: Un hotel de varias estrellas para los terneros. *Rev. Inst. Plan Agropecu.*, **90**, 53–55
- De la Mothe, J., 2003: Re-thinking policy in the new republic of knowledge. *Minerva*, **41**, 195–205, https://doi.org/10.1023/A: 1025561613229.
- De Torres, M. F., G. Cruz, and J. Taks, 2007: Una aproximación a la comunicación social del clima en el caso del sistema pastoril del norte de Uruguay, caso Salto. Semana de Reflexión sobre Cambio y Variabilidad Climática, V. Picasso et al., Eds., Facultad de Agronomía, 176–186.
- —, P. Arbeletche, E. Sabourin, J. Cardelliac, and G. Massardier, 2014: La agricultura familiar entre proyectos nacionales de desarrollo. *EUTOPIA*, 6, 25–40.
- Giménez, A., 2006: Climate change and variability in the mixed crop/ livestock production systems of the Argentinean, Brazilian and Uruguayan Pampas. AIACC Final Rep., Project LA 27, 54 pp.
- Gray, B., 2003: Framing of environmental disputes. *Making Sense* of Intractable Environmental Conflicts, R. J. Lewicki, B. Gray, and M. Elliott, Eds., Island Press, 11–34.
- INAC, 2016: Series de stock ganadero. Instituto Nacional de Carnes de Uruguay, accessed 20 October 2016, http://www.inac.gub.uy/ innovaportal/v/5542/10/innova.front/series-de-stock.
- INIA, 2016: Unidad de Agroclima y Sistemas de Información. Accessed 2 August 2016, http://www.inia.uy/gras/Unidad-de-Agroclima-y-sistemas-de-información-del-INIA.
- INUMET, 2015: Ley de creación de INUMET. Accessed 10 August 2015, http://www.meteorologia.com.uy/institucional/documentos.
- IPCC, 2001: Climate Change 2001: Impacts, Adaptation and Vulnerability. Cambridge University Press, 1042 pp.
- Lacuesta, P., A. Vázquez, and G. Quintans, 2000: Control de amamantamiento. I. Destete precoz en vacas de primera cría con diferente condición corporal al parto. Jornada anual de producción animal: Resultados experimentales, INIA Rep., 52–57, http://www.inia.uy/Publicaciones/Documentos%20compartidos/ 14445110313090600.pdf/
- Lavell, A., M. Oppenheimer, C. Diop, J. Hess, R. Lempert, J. Li, R. Muir-Wood, and S. Myeong, 2012: Climate change: New

dimensions in disaster risk, exposure, vulnerability, and resilience. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*, C. B. Field et al., Eds., Cambridge University Press, 25–64.

- Lee, O. N., 1999: Appraising adaptive management. Conserv. Ecol., 3, 3, https://www.ecologyandsociety.org/vol3/iss2/art3/.
- Lemos, M., 2007: Drought, governance and adaptive capacity in north east Brasil: A case study of Ceará. UNDP Human Development Rep., 16 pp., http://hdr.undp.org/en/content/ drought-governance-and-adaptive-capacity-north-east-brazil.
- —, and B. J. Morehouse, 2005: The co-production of science and policy in integrated climate assessments. *Global Environ. Change*, **15**, 57–68, https://doi.org/10.1016/ j.gloenycha.2004.09.004.
- Lindemann, T., V. Plata, W. Oyhantçabal, and D. Sancho, 2013: La percepción de productores y técnicos agropecuarios. Clima de cambios: Nuevos desafíos de adaptación para Uruguay, MGAP FAO Rep., Vol. 2, 95 pp., http://www.fao.org/docrep/ field/009/as254s/as254s.pdf.
- Meadow, A., D. Ferguson, Z. Guido, A. Horangic, and G. Owen, 2015: Moving toward the deliberate coproduction of climate science knowledge. *Wea. Climate Soc.*, 7, 179–191, https:// doi.org/10.1175/WCAS-D-14-00050.1.
- Meagher, L., C. Lyall, and S. Nutley, 2008: Flows of knowledge, expertise and influence: A method for assessing policy and practice impacts from social science research. *Res. Eval.*, **17**, 163–173, https://doi.org/10.3152/095820208X331720.
- Methol, M., and F. Mila, 2015: Implementación de una prueba piloto del seguro de sequía para ganadería de cría basado en el índice NDVI. Anuario OPYPA 2015, MGAP OPYPA Rep., 377–384
- MGAP, 2013: Proyecto desarrollo y adaptación al cambio climático (DACC). Accessed 9 August 2016, http://www.mgap.gub. uy/institucional/dacc.
- —, 2015a: Proyecto ganaderos familiares y cambio climático. Accessed 9 August 2016, http://www.mgap.gub.uy/unidadejecutora/direccion-general-de-desarrollo-rural/institucional/ llamados/cerrados/ganaderos-familiares-y-cambio-climatico.
- —, 2015b: Proyecto más tecnologías. Accessed 9 August 2016, http://www.mgap.gub.uy/unidad-ejecutora/direccion-general-dedesarrollo-rural/galeria/12-12-2016/proyecto-mas-tecnologias.
- Montes, E., 2009: La ganadería bovina del Uruguay del siglo XXI. *Rev. Inst. Plan Agropecu.*, 131, 58–62.
- Nelson, D., N. Adger, and K. Brown, 2007: Adaptation to environmental change: Contributions of a resilience framework. *Annu. Rev. Environ. Resour.*, **32**, 395–419, https://doi.org/ 10.1146/annurev.energy.32.051807.090348.
- Niles, M., M. Lubell, and M. Brown, 2015: How limiting factors drive agricultural adaptation to climate change. *Agric. Ecosyst. Environ.*, 200, 178–185, https://doi.org/10.1016/ j.agee.2014.11.010.
- Nooteboom, S., 2006: Adaptive Networks: The Governance for Sustainable Development. Eburon Academic, 240 pp.
- Pahl-Wostl, C., 2009: A conceptual framework for analysing adaptive capacity and multi-level learning processes in resources governance regimes. *Global Environ. Change*, **19**, 354–365, https://doi.org/10.1016/j.gloenvcha.2009.06.001.
- —, J. Sendzimir, P. Jeffrey, J. Aerts, G. Berkamp, and K. Cross, 2007: Managing change toward adaptive water management through social learning. *Ecol. Soc.*, **12**, 30, https://doi.org/ 10.5751/ES-02147-120230.
- Paolino, C., M. Methol, and D. Quitans, 2010: Estimación del impacto de una eventual sequía en la ganadería nacional y bases

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para el diseño de políticas de seguros. Anuario OPYPA 2010, MGAP FAO Rep., 277–287.

Pereira, G., 2003: La Ganadería en Uruguay. MGAP DIEA, 87 pp.

- Picasso, V., L. Astigarraga, I. Buffa, D. Sotelo, G. Américo, R. Terra, P. van Oort, and H. Meinke, 2011: Robustness of livestock farmers to climate variability: A case study in Uruguay. *Fifth World Congress of Conservation Agriculture Incorporating 3rd Farming Systems Design Conf.*, Brisbane, Australia, CGIAR/CCAFS, 1–3.
- —, G. Cruz, L. Astigarraga, and R. Terra, 2013: Cambio y Variabilidad Climática: Respuestas Interdisciplinarias. Espacio Interdisciplinario, Universidad de la República, 132 pp.
- —, P. Modernel, G. Becoña, L. Salvo, L. Gutiérrez, and L. Astigarraga, 2014: Sustainability of meat production beyond carbon footprint: A synthesis of case studies from grazing systems in Uruguay. *Meat Sci.*, 98, 346–354, https://doi.org/ 10.1016/j.meatsci.2014.07.005.
- Piedrabuena Perdomo, L., and Coauthors, 2011: Censo general agropecuario 2011: Resultados definitivos. Accessed 21 September 2016, http://www2.mgap.gub.uy/portal/page.aspx?2, diea,diea-censo-2011-resultados-definitivos,O,es,0,.
- Poder Ejecutivo Uruguay, 2008: Normativa y avisos legales del Uruguay: Decreto 829/008. Creación del Fondo Agropecuario de Emergencia, accessed 19 July 2016, https://www.impo.com. uy/bases/decretos-originales/829-2008.
- Pulwarty, R., and M. Sivakumar, 2014: Information systems in a changing climate: Early warnings and drought risk management. Wea. Climate Extremes, 3, 14–21, https://doi.org/ 10.1016/j.wace.2014.03.005.
- Ropelewski, C. F., and M. S. Halpert, 1987: Global and regional scale precipitation patterns associated with the El Niño/ Southern Oscillation. *Mon. Wea. Rev.*, **115**, 1606–1626, https:// doi.org/10.1175/1520-0493(1987)115<1606:GARSPP>2.0.CO;2.
- , and —, 1989: Precipitation patterns associated with the high index phase of the Southern Oscillation. J. Climate, 2, 268–284, https://doi.org/10.1175/1520-0442(1989)002<0268: PPAWTH>2.0.CO;2.
- Saravia, A., D. César, E. Montes, V. Taranto, and M. Pereira, 2011: Manejo del rodeo de cría sobre campo natural. Instituto Plan Agropecuario Rep., 80 pp., https://www.planagropecuario. org.uy/uploads/libros/21\_manual.pdf.
- Saravia, H., and R. Gómez, R., 2013: Cambio técnico en sistemas ganaderos criadores de Sierras del Este. Ed INIA. INIA Serie Técnica 207, 130 pp.
- Sivakumar, M. V., R. Motha, D. Wilhite, and J. Qu, 2011: Towards a compendium on national drought policy. *Proc. Expert Meeting, July 14–15, 2011*, Washington, DC, WMO, AGM-12/WAOB-2011.
- —, R. Stefanskib, M. Bazzac, S. Zelayad, D. Wilhitee, and A. Rocha Magalhaesf, 2014: High level meeting on national drought policy: Summary and major outcomes. *Wea. Climate Extremes*, **3**, 126–132, https://doi.org/ 10.1016/j.wace.2014.03.007.
- SNRCC, 2009: Decreto de creación del Sistema Nacional de Respuesta al Cambio Climático. MVOTMA Rep., 6 pp., http:// www.cambioclimatico.gub.uy/images/stories/documentos/marco\_ legal/dec\_238\_09.pdf.
- Soca, P., and R. Orcasberro, 1992: Propuesta de Manejo del Rodeo de Cría en base a estado corporal, altura del pasto y aplicación del destete temporario. Evaluación física y económica de alternativas tecnológicas en predios ganaderos, INIA Rep., 54–56.

- —, —, G. Córdoba, D. Laborde, V. Beretta, and J. Franco, 1992: Efecto del destete temporario sobre la performance de rodeos de cría. Primera jornada de producción animal: Evaluación física y económica de alternativas tecnológicas en predios ganaderos, INIA Rep., 45–53.
- —, M. Claramunt, and M. Do Carmo, 2007: Sistemas de cría vacuna en ganadería pastoril sobre campo nativo sin subsidios: Propuesta tecnológica para estabilizar la producción de terneros con intervenciones de bajo costo y de fácil implementación. *Rev. Cienc. Anim.*, **3**, 3–22.
- Taleb, N. N., 2012: Antifragile: Things That Gain from Disorder. Random House, 544 pp.
- Thompson, D. 2013: Governance under sociopolitical decentralization efforts and local adaptive actions to disturbances and increasing environmental stresses among rural communities; four case studies from Southwestern Uruguay. *Agrar. Front.*, 1, 55–74.
- Tippett, J., B. Searle, C. Pahl-Wostl, and Y. Rees, 2005: Social learning in public participation in river basin management early findings from HarmoniCOP European case studies. *Environ. Sci. Policy*, 8, 287–299, https://doi.org/10.1016/ j.envsci.2005.03.003.
- UDC, 2007: Ley de creación de la Unidad de Descentralización y Coordinación de Políticas con Base Departamental del Ministerio de Ganadería, Agricultura y Pesca. Law 18.126, http://www.mgap.gub.uy/sites/default/files/multimedia/1269\_ Descentralizacic3b3n\_LEY\_aprobada.pdf.
- UN-ISDR, 2011: Informe Uruguay: Diagnóstico del estado de la reducción del riesgo de desastres. UN Rep., 66 pp.
- Vicente-Serrano, S. M., S. Beguería, L. Gimeno, L. Eklundh, G. Giuliani, D. Weston, A. El Kenawyg, and J. López-Moreno, 2012: Challenges for drought mitigation in Africa: The potential use of geospatial data and drought information systems. *Appl. Geogr.*, 34, 471–486, https://doi.org/10.1016/ j.apgeog.2012.02.001.
- —, G. Van der Schrier, S. Beguería, C. Azorin-Molina, and J. Lopez-Moreno, 2015: Contribution of precipitation and reference evapotranspiration to drought indices under different climates. J. Hydrol., 526, 42–54, https://doi.org/10.1016/ j.jhydrol.2014.11.025.
- Vila, F., 2002: Acciones emprendidas por el MGAP y OPYPA en el tema de los seguros agropecuarios en el ejercicio 2002. Anuario OPYPA 2002, accessed 20 July 2016, http://www. mgap.gub.uy/unidad-ejecutora/oficina-de-programacion-ypoliticas-agropecuarias/publicaciones/anuarios-opypa/2002.
- Villalba, C., 2015: Estudio de las mesas de desarrollo rural en Uruguay como innovación institucional para la participación y la inclusión. MGAP DGDR Rep., 62 pp., http://repositorio. iica.int/bitstream/11324/2676/1/BVE17038756e.pdf.
- Wilhite, D. A., 1993: Drought Assessment, Management, and Planning: Theory and Case Studies. Springer, 293 pp.
- —, 2000: Drought as a natural hazard: Concepts and definitions. Drought: A Global Assessment, D. A. Wilhite, Ed., Routledge, 1–18.
- —, M. V. Sivakumar, and R. Pulwarty, 2014: Managing drought risk in a changing climate: The role of national drought policy. *Wea. Climate Extremes*, **3**, 4–13, https://doi.org/10.1016/ j.wace.2014.01.002.
- Young, J. C., and Coauthors, 2014: Improving the science-policy dialogue to meet the challenges of biodiversity conservation: Having conversations rather than talking at one-another. *Biodivers. Conserv.*, 23, 387–404, https://doi.org/10.1007/ s10531-013-0607-0.