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To my friends and family.

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LIST OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Human-induced global changes, in particular, population growth, changes in consumption patterns and the globalization of markets have increased global demand for water and food. While more frequent and intense droughts further threaten water supply in semi-arid regions worldwide, irrigated agriculture is simultaneously seen as a chance and a challenge to water availability.

As reduced water availability has major impacts on both, the society and ecosystems, a social-ecological system's approach to the topic of drought vulnerability facilitates deeper understanding of the complex dynamisms in the Recoleta System in northern Chile's Limarí River Basin, which focuses on irrigated agriculture supplied by a highly technified reservoir and channel system.

Forming part of the Paloma's super system, the Recoleta System consists of an ecological and socio-economic subsystem and system components, the Recoleta farmers. As Recoleta drought is related to the reduction of the reservoirs' storage volumes and the decisions made by the system's institutions in charge of water allocation, the system currently experiences a drought event due to a multi-year dry spell, which dried out the reservoirs.

Recoleta System's drought vulnerability is assessed by making use of a mix of quantitative and qualitative data in form of semi-structured interviews conducted during field research. Differential drought vulnerability within several organizational and spatial scales and among the system's elements is highlighted. The system's water governance institution provides homogenous conditions of water supply through the so-called solidarity concept, which implies equal distribution of water losses throughout all system elements. Flexibility of farmers in terms of an expanded range of decisions reduces their specific drought vulnerability, hence, leading to differences among farmers. Present and future adaptation strategies differ within the organizational scales and whether they focus immediate, short-term adaption or long-term adaptation.

Key words: Differential drought vulnerability; Social-ecological systems; Water governance; Irrigated agriculture; Global change

RESUMEN

Cambios globales inducidos por el hombre, en particular, el crecimiento demográfico global, cambios en los patrones de consumo y la globalización de los mercados han aumentado la demanda global de agua y de alimentos. Mientras que el aumento en la frecuencia e intensidad de las sequías amenazan el abastecimiento de agua en todas las regiones semiáridas del mundo, la agricultura bajo riego es vista tanto como oportunidad y como reto para la disponibilidad de agua.

Dado que la reducción en la disponibilidad de agua tiene un impacto sobre ambos, la sociedad y los ecosistemas, abordar desde un sistema socio-ecológico el tema de vulnerabilidad a las sequías, facilita una comprensión más profunda de los dinamismos complejos en el Sistema Recoleta, ubicado en la cuenca del río Limarí en el norte de Chile, centrado en agricultura bajo riego suministrada por un sistema altamente tecnificado de embalses y canales.

Formando parte del super-sistema Paloma, el Sistema Recoleta consta tanto de un subsistema ecológico y socio-económico, como de los componentes de un sistema, los agricultores de Recoleta. Así como la sequía en el Sistema Recoleta está relacionada con la reducción de los volúmenes de almacenamiento de los embalses y con las decisiones tomadas por las instituciones a cargo de la distribución del agua, actualmente el sistema experimenta un episodio de sequía debido a un período de sequía de varios años que ha vaciado los embalses.

La vulnerabilidad a sequías del Sistema Recoleta se analizó mediante el uso de datos cuantitativos y cualitativos, haciendo uso de entrevistas semi-estructuradas realizadas durante el periodo de investigación en campo. La vulnerabilidad a sequías diferencial dentro de varias escalas organizativas y espaciales, y entre los elementos del sistema se pone de relieve. El sistema de la institución de gobernabilidad del agua asegura condiciones homogéneas de suministro de agua a través del denominado concepto de la solidaridad, que implica la distribución equitativa de las pérdidas de agua a todos los elementos del sistema. La flexibilidad de los agricultores refiriéndose al hecho de tener una gama más amplia de decisiones, reduce su vulnerabilidad específica a sequías y por lo tanto, es lo que lleva a diferencias en vulnerabilidad entre los agricultores. Estrategias de adaptación actuales y futuras difieren según la escala organizacional y el enfoque temporal que se asume, si es adaptación inmediata, a corto plazo o adaptación a largo plazo.

Palabras clave: Diferencias en vulnerabilidad a sequías; Sistemas socio-ecológicos; Water governance; Agricultura bajo riego; Cambio global

DISSERTATION FORMAT

The document is structured into the introductory Chapter 1, which leads to the topic of drought vulnerability. First, putting vulnerability into the broader context of global changes, then directly focusing the specific drought hazard and finally, the conceptual framework of vulnerability and complex systems. From here on, the research questions and hypotheses are stated and the research objectives introduced.

In Chapter 2, the case study region of the Recoleta System located in the Limarí River Basin in Chile is presented and an in-detail description of the problem is given. Chapter 3 addresses the methodology used to achieve the research objectives.

The presentation of the thesis results starts with Chapter 4 by defining the Recoleta System as the unit of analysis. The system’s stakeholder network is presented, their views on drought vulnerability are portrayed and the peculiar type of drought for the Recoleta System is defined.

Chapter 5 presents differential drought vulnerability in the case of the Recoleta System where flexibility is a decisive factor. Adaptation strategies of the Recoleta’s stakeholders are portrayed.

The discussion on research findings is conducted in Chapter 6 and the final Chapter 7 sums up the research findings, highlights shortcomings and gives recommendations and an outlook for further studies.

1 INTRODUCTION

Severe stress is exercised upon water supply, as a result of increasing global demands for the vital liquid resource (Vörösmarty, 2000). Global population growth, globalized markets and the associated changes in global consumption patterns threaten the regeneration of this so-called renewable resource (Ingram et al., 2010).

Focusing on coupled human-environmental or social-ecological systems, human activities in ecosystems induce global changes as human-environmental interactions cause modifications in the ecosystem functioning and processes and thus, have adverse effects not only on the ecosystems themselves as these systems are interrelated with society (Chapin et al., 2011). Anthropogenic repercussions on ecosystems are the reason scientists denominate the current geological epoch *Anthropocene* (Steffen et al., 2007).

Besides the global population's demand for freshwater, the agricultural sector is a major consumer of water and competes with the other sectors for the resource. As irrigation has enabled an increase in agricultural yields, it is therefore often considered an essential instrument to face the challenge of achieving global food security by feeding the more than nine billion inhabitants that are expected to be living on planet Earth by 2050 (Rosegrant et al., 2009).

In addition to the human demand, increases in extreme weather events such as droughts exacerbate the already critical situation of water scarcity. Thus, water governance and water management have become important issues in water-scarce regions (Wilhite, 2005).

1.1 Background

Over the past two decades, droughts and the pressure on water availability have become one of the most daunting problems in almost all regions of the world (Falkenmark & Rockström, 2004) having pushed our planet in a global water crisis (Gleick, 2014). Water stress has increased due to the scarcity of this vital resource in addition to the increasing global demand for water caused by population growth and changes in water consumption patterns (Scott et al., 2013; Vörösmarty, 2000). Additionally, future climate scenarios estimate more frequent drought events, which combined with desertification processes will ultimately lead to challenges and conflicts in terms of water allocation and distribution (IPCC, 2012). Especially in the semi-arid areas where the primary economies are agricultural and livestock farming, people depend heavily on the outcomes they achieve from cultivating land under the artificial application of water, i.e. areas under irrigation. Droughts, in its most general terms are temporary climatic events with lower than average water availability – therefore posing a threat to livelihoods (Reynolds, 2007).

Droughts are one of the most challenging phenomena to understand and manage, as they present a spatio-temporal hazard difficult to perceive, measure and determine. Due to the complexity of the problem, the scientific community has not managed to come up with a universally accepted definition of drought. Yet, as a consensus, a drought could be defined as an event with less than normal precipitation for a prolonged period that can occur in almost any climatic region, resulting in crisis and conflicts related to water availability, distribution and access. Droughts imply losses on all components of a system and affect more people than any other natural hazard; the magnitude of these losses depends on the intensity, duration and spatial extent, which are features used to characterize drought events (Mishra & Singh, 2010).

There is agreement on four general categories of drought: meteorological, agricultural, hydrological and socio-economic drought. Precipitation shortfall is the principal variable of concern when defining a meteorological drought, whereas an agricultural drought is primarily defined by reduced soil moisture for crop production. Shortages of streamflow of surface and ground water determine the degree of hydrological drought. A socio-economic drought happens when the demand for a good surpasses the supply as a result of any of the previously mentioned drought categories (Mishra & Singh, 2010).

While drought *per se* is not considered a disaster but rather a natural phenomenon or hazard, it may, however, turn into a disaster when it strikes a site and entails negative impacts on drought-vulnerable ecosystems and society (Wilhite, 2005). In other words, if the hazard does not hit a coupled human-environmental system, which is vulnerable to this hazard, there is no disaster and, vice versa, the system is not vulnerable if there is no hazard to be vulnerable to (Eakin & Luers, 2006).

Considering vulnerability as a weakness of a system (Smit & Pilifosova, 2003), the vulnerability to a drought event of a specific system depends on the exposure to the hazard, the susceptibility of the system and the system's capacities to cope with, respond to, recover from and adapt to the stress (Adger, 2006), the resilience of the system (Folke et al., 2004). The challenge in assessing vulnerability of a coupled human-environmental or social-ecological system to drought lies in the nature of the system's vulnerability, which is not measurable *per se* as it is an emerging property of a system (Walker & Salt, 2006), but has to be identified by using approximations that represent the system's vulnerability.

This work focuses on evaluating drought vulnerability in a specific case study located in the semi-arid northern-central Chile (Figure 1). Although droughts in semi-arid regions are common phenomena, their impacts are expanding as agricultural and industrial activities have increased water demands there (Mishra & Singh, 2010). In arid and semi-arid Americas, agriculture is a profitable enterprise as there is plenty, comparably low-priced land available. In addition, the climatic conditions in these areas with year-round high solar irradiance as well as relatively warm winters favor agricultural production, especially for cash crops with high market value (Safriel & Adeel, 2005).

Being a region that has been frequently affected by severe water scarcity, the current case study is located in Chile's semi-arid province of Limarí, where the booming agricultural sector has considerably increased the region's water demand. As a buffer to mitigate inter and intra-annual variations in water availability and dryspells, a reservoir and channel network has been established during the 20th century as an adaptation to drought events, thus lowering the system's vulnerability to droughts (León, 2008). The Paloma System, an irrigation infrastructure for storage and distribution consisting of a system of three reservoirs and a broad channel network characterize this study case. Due to the large storing capacity of the dams, a single drought year does not have strong impacts on the irrigation security of the area, while several continuous drought years do lead to hydrologic deficits, which affect the agricultural productivity as the stored volumes of the reservoirs decline.

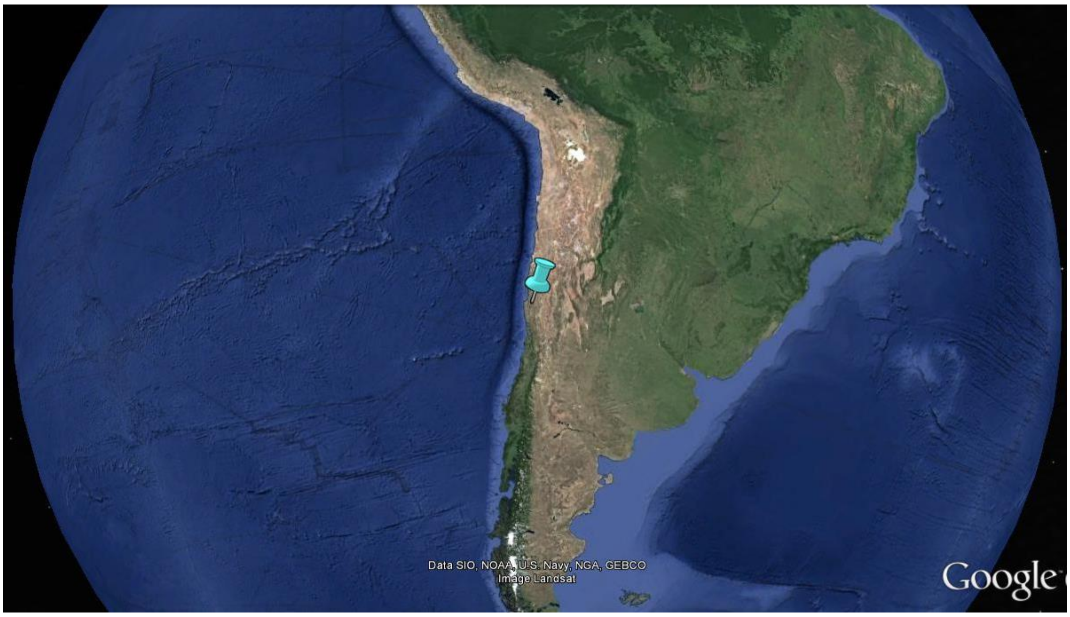

Figure 1: Location of Recoleta System in South America
(Icon indicates location of Recoleta System; Elaborated with Google Earth)

The thesis focuses on a subsystem of the Paloma System: an area denominated Recoleta System, which receives water assigned by the *Asociación de Canalistas Embalse Recoleta* (ACER), the Recoleta Channel Association. Thus, the focal system (Resilience Alliance, 2010) is an entity centered in agricultural activities dependent on irrigation.

As droughts are supposed to "have greater impacts on sectors with closer links to climate, such as water, agriculture and food security […]" (IPCC, 2012: 16), research on drought vulnerability in the highly water dependent Recoleta System will emphasize the critical situation of water scarcity and foster the discussion on more sustainable ways of agriculture and water use.

1.2 Research questions and hypothesis

Being drought and vulnerability both technical terms with no universally accepted definition but merely hundreds of different ones, the very same applies to the definition of drought vulnerability. Additionally, there is no systematic approach to assess drought vulnerability yet. Instead, assessments are either highly case specific or rather generic. Consequently, assessing drought vulnerability is a challenging task.

The Limarí River Basin (LRB) is widely studied. Especially the functioning of the Chilean water market and rights is of interest (Bauer, 1997; Bauer, 2005; León, 2008). Besides, the impact of desertification processes, investigations on droughts, on climate variability and the El Niño and Southern Oscillation (ENSO) phenomenon are conducted (Verbist et al., 2010; Vicuña et al., 2010; Vicuña et al., 2012).

Currently, the WEIN[1] project (*Development of an information and monitoring system to improve water use efficiency in Northern Central Chile*) funded by the German Federal Ministry of Education and Research (BMBF) with a German-Chilean consortium of universities, research institutions and private sector companies aims at improving water use efficiency of the agricultural sector by implementing a monitoring and information system of water use. The project focus is set on the analysis of drought hazards. In turn, this thesis aims at evaluating the other often less frequently considered side of drought risk, the system's vulnerability. Previous studies undertaken in the LRB focused on drought vulnerability at the household (León, 2007) and community levels (Meza-Morales, 2010), while this work investigates drought vulnerability of a highly specialized agricultural, coupled human-environmental system, the Recoleta System. Ultimately, in combination with the information generated on the drought hazard, a proper risk analysis can provide relevant information for decision makers and local communities on potential adaptation strategies to reduce the negative impacts of drought.

Under the assumption that the Recoleta System is currently vulnerable to drought and that there are differences in drought vulnerability, when considering the system's elements, induced – among others – by location and access issues, the study addresses the following research questions:

1. How does vulnerability to drought differ within the Recoleta Social-Ecological System and related systems and among the system's elements?

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[1] WEIN comes from the German project title *Entwicklung eines Informations- und Monitoringsystems zur Förderung der "W"assernutzungseffizienz am Beispiel eines semi-ariden "EIN"zugsgebiets in Zentralchile*.

2. Which variables describe best the variability in drought vulnerability of the Recoleta System and its subsystems?
3. In which way does the Recoleta System adapt to the current drought event?

There are two variables that may induce differences in drought vulnerability within the Recoleta System to be tested in field.

One of the variables is the geographic location in the context of water sources, as it is directly related to one of the vulnerability components: exposure. In case of the Recoleta System, the geographic location within the region refers to the distance between a particular location and the nearest water source, which is the reservoir. This distance induces differences in drought vulnerability: while farmers close by neighborhoods of the Recoleta dam receive the assigned waters immediately, those located in more remote areas from the reservoir probably suffer from water shortages and losses. Thus, hypothesis 1 addresses the variable of location inside the Recoleta System in terms of proximity to the reservoir.

H1: Producers located closer to the Recoleta reservoir are less impacted from drought events and water shortages than those located further away from the reservoir.

The second hypothesis addresses farmer types and their infrastructure and resources to maintain agricultural production during drought events. Literature indicates that smallholders in a technological system such as the Recoleta System are less capable to cope with drought events than middle scale farmers or agribusinesses (cf. sub chapter 2.2). This is related to the system’s dependence on water for irrigation. Smallholders lack infrastructure to store water or resources to buy additional water during a drought event. It is assumed that they are less capable to cope with the impacts of drought events.

H2: Recoleta System smallholders are more vulnerable to droughts than agribusinesses.

1.3 Objectives

The general objective was to analyze the Recoleta System's current drought vulnerability with the aim of providing essential information for decision makers and local communities on the most vulnerable elements, the differences in vulnerability and the interactions between the system's elements.

The specific objectives are:

1. Determine the Recoleta System with its biophysical, socio-economic and institutional preconditions;
2. Identify and describe particular types of drought and drought vulnerability in the Recoleta System;
3. Identify key stakeholders, their linkages and relations in the Recoleta System;
4. Identify the factors and processes that may contribute to the Recoleta System's vulnerability to drought;
5. Analyze current or potential adaptation strategies in the Recoleta System to drought.

2 CONCEPTUAL FRAMEWORK

In this section, vulnerability is presented in the context of Disaster Risk Management, introducing the concept of vulnerability and its components. Further, a literature review is presented on the state of the art knowledge of drought vulnerability highlighting variables, which lead to differences in drought vulnerability. The findings of the review were useful in the selection process of refining the case study area. This chapter concludes with the topic of complex systems.

2.1 Vulnerability and Disaster Risk Management

Vulnerability and vulnerability assessments form part of Disaster Risk Management (DRM), an approach supported by the United Nations International Strategy for Disaster Reduction (UNISDR). Disaster Risk Management evolved to improve disaster management where a disaster is an event caused by a natural or anthropogenic hazard, which negatively affects socio-economic systems or produces alterations in ecosystem functioning, or both, and requires immediate emergency action as well as actions to prepare for, prevent and mitigate future events (UNISDR, 2009).

In accordance with the terminology of the UNISDR (2009), DRM is "[t]he systematic process of using administrative directives, organizations, and operational skills and capacities to implement strategies, policies and improved coping capacities in order to lessen the adverse impacts of hazards and the possibility of disaster" (UNISDR, 2009: 10). The overall aims of

DRM are increased human well-being and sustainable development by reducing disaster risk (IPCC, 2012).

Since the earlier post-disaster recovery management plan, there has been a shift of the focus from treating disaster impacts towards increasing the preparedness of a system and there dealing with disaster risk (UNISDR, 2013). According to the IPCC's SREX report (2012), the key elements of disaster risk are the hazard, for instance in form of an extreme climatic event such as a drought, the exposure to this hazard and the vulnerability of the system in question to the hazard (Figure 2).

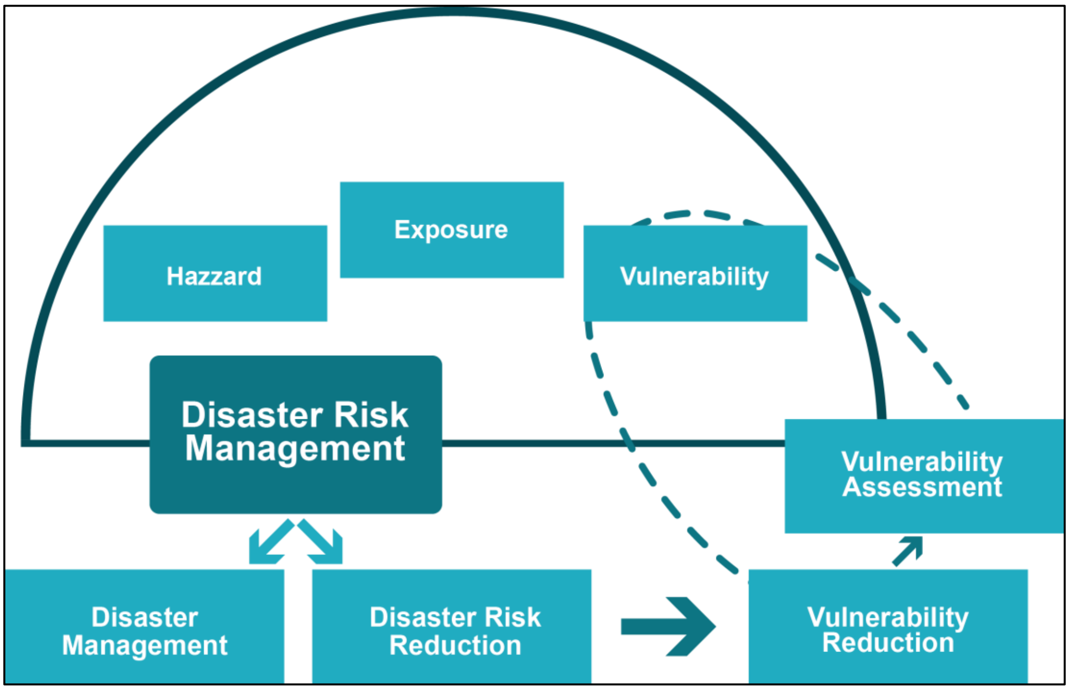

Figure 2: Vulnerability Assessment in the context of Disaster Risk Management
(Elaborated by the author based on IPCC, 2012)

The main actions in DRM are Disaster Risk Reduction (DRR) as the more pro-active approach and Disaster Management (DM), being a more reactive, post-disaster strategy as it is the response to disaster events. Since it is almost impossible to reduce the hazard itself, DRR targets towards reducing vulnerability and exposure to hazards. Vulnerability reduction is a key strategy to manage and reduce disaster risk. Vulnerability reduction previously requires a vulnerability assessment of the target system in question (IPCC, 2012).

Vulnerability is an inherent characteristic of a system (Smit & Pilifosova, 2003). There is general agreement on its "negative" nature as it is not a desirable property of a system

(Engle, 2011), occasionally speaking of vulnerability as the “relative lack of capacity” (IPCC, 2012: 33).[2]

Several components determine the degree of vulnerability of a particular system towards climate change or extreme climatic events such as droughts. Although there is no consensus on its particular components, vulnerability of a system can be described as a function of exposure to a hazard, the susceptibility or sensitivity of a system and its inability to cope with, respond and adapt to the hazard’s impacts (Figure 3) (Adger, 2006).

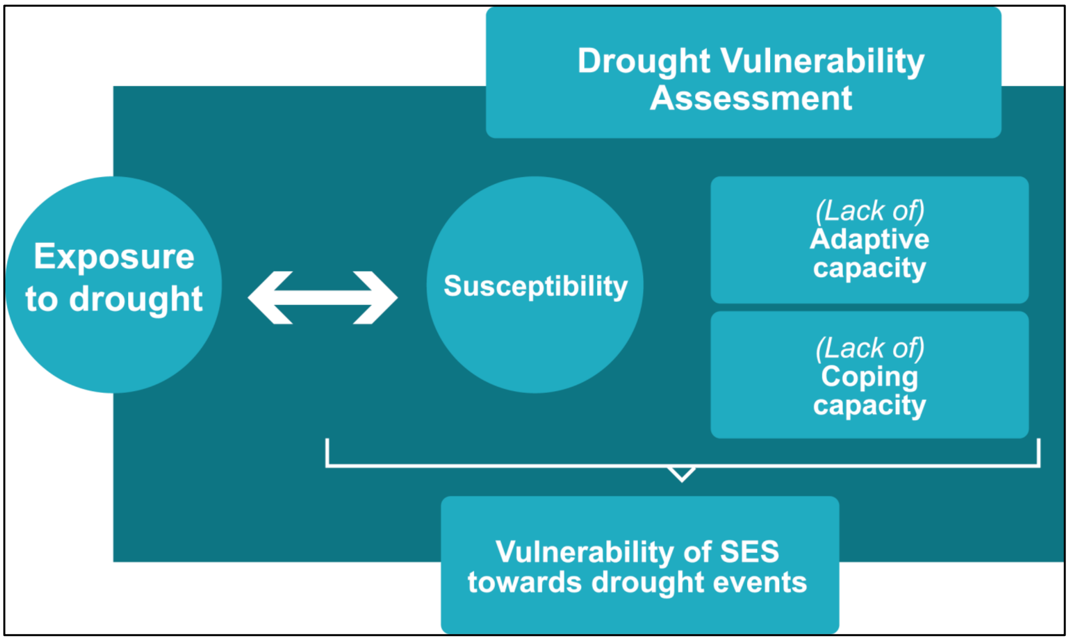

Figure 3: Vulnerability and its assessment
(SES = Social-ecological System; Elaborated by the author based on Adger, 2006; Eakin & Luers, 2006; Gallopín, 2006; IPCC, 2012; Smit & Wandel, 2006; Turner et al., 2003a; UNU, 2012)

2.1.1 Exposure and sensitivity

Exposure is the situation of exposition of the unit of analysis in a place that is at risk of being struck and harmed by a stress or stressor. The IPCC defines exposure as the “presence of people; livelihoods; environmental services and resources; infrastructure; or economic, social, or cultural assets in places that could be adversely affected” (IPCC, 2012: 5).

While some authors include exposure into the concept of vulnerability (Adger & Vincent, 2004; Adger et al., 2007; MA, 2005; Smit & Pilifosova, 2003; Smit & Wandel, 2006), others, like Gallopín (2006) exclude this component or do not address it explicitly as a component of vulnerability (Berman et al., 2012; UNU, 2012).

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[2] For a deeper look at vulnerability, Eakin and Luers (2006) provide a review on vulnerability of socio-ecological systems.

Susceptibility or sensitivity is another constituent of vulnerability and equally generates disputes between scientists (Gallopín, 2006). Here, it is the degree a social-ecological system is affected by a climatic perturbation, stress or stressor (IPCC, 2012). Susceptibility is determined by the human and environmental conditions which shape the system, i.e. the existing social and organizational infrastructure, the natural resources and economic resources available (Turner et al., 2003a).

2.1.2 Adaptation and capacities

With the UNISDR (2009), capacity also named capability is the “combination of all the strengths, attributes and resources available within a community, society or organization that can be used to achieve agreed goals.” (UNISDR, 2009: 5).

Originating from Biology, adaptation refers to actions or processes of adjustment to changing conditions, e.g. to climate change or extreme climatic events like a drought, with the goal of reducing negative impacts and achieving beneficial situations (Smit & Wandel, 2006). Alongside mitigation, adaptation is one of the policy responses to climate change promoted by the United Nations Framework Convention on Climate Change (UNFCCC) (Smit & Pilifosova, 2003).

Adaptions can be anticipatory or reactive, autonomous or planned, private or public (Engle, 2011; MA, 2005; Smit & Pilifosova, 2003; Smit & Wandel, 2006). Usually they happen autonomously after a disaster event, i.e. a more re- than proactive approach, which in the end, can turn out to be quite costly (Smit & Pilifosova, 2003). With Smit & Wandel (2006), adaptations are “manifestations of adaptive capacity, and they represent ways of reducing vulnerability” (Smit & Wandel, 2006: 286).

Coping capacity and adaptive capacity are frequently treated as synonyms whereas there are a set of properties that distinguish one from another. Gallopín (2006) argues that the vagueness of the definitions implies the threat of mixing up the two concepts.

There are varieties of attributes, which separate coping from adapting: coping capacity builds on existing assets, infrastructure, resources and knowledge; its strategies and activities have a short-term focus. Coping actions are taken immediately after a disaster in order to diminish the effects and are therefore, normally not planned but happen autonomously. Coping capacity can be analyzed by assessing the existing assets of a community (Berman et al., 2012).

Adaptive capacity is a “positive” or beneficial property or characteristic of a system, while lacking it enhances vulnerability (Engle, 2011). In generic terms, it is the capacity of a system to adapt to stresses (Smit & Pilifosova, 2003), while in a more specific sense, adaptive capacity includes “the ability to prepare in advance for stresses and changes and to adjust, respond and adapt to the effects caused by the stress” (Berman et al., 2012: 91). Adaptive capacity varies spatially, temporally and among social groups (Young et al., 2010). Contrary to coping capacity, activities of adaptive capacity focus on long-term goals with profound changes in organizational structures or systems. Adaptive capacity treats the causes of disaster risk. Enhanced adaptive capacity reduces vulnerability as it modulates the other components of vulnerability (Adger et al., 2007). Often, the enhancement of adaptive capacity requires institutional changes and an in-depth look at local vulnerabilities as well as the involvement of relevant stakeholders is needed (Smit & Pilifosova, 2003).

As the transformation of coping capacity into adaptive capacity can reduce vulnerability on the long term, the focus of DRM actions should be on enhancing adaptive capacity in order to develop disaster resilient communities and nations (Berman et al., 2012).

2.2 Review: Differential drought vulnerability

Twenty study cases were reviewed to identify the main variables and factors related to drought vulnerability (Biazin & Sterk, 2013; Brant, 2007; Costa et al., 2011; León, 2007; Liverman, 1999; Luers et al., 2003; Luers, 2005; Meza-Morales, 2010; Meze-Hausken, 2000; Arredondo & Huber-Sannwald, 2011; Naumann et al., 2013; Nelson et al., 2010; Salas et al., 2012; Simelton et al., 2009; Singh et al., 2014; Turner et al., 2003b; Vicente-Serrano, 2006; Wilhemi & Wilhite, 2002; Wittrock et al., 2011; Young et al., 2010). The selection criteria were their commonalities with the Chilean study case, i.e. places in dryland ecosystems focused on agricultural activities. The review's aim was to highlight variables that lead to differences in drought vulnerability between a system's elements. Here, the terms variability and differences in drought vulnerability are used as synonyms. Thus, differential drought vulnerability refers to the state of differences in drought vulnerability within a system and among system elements.

The variables identified to induce variability in drought vulnerability in the study cases are summarized into three major groups: biophysical, socio-economic and institutional factors.

There is common agreement that climatic conditions such as temperature, precipitation and evapotranspiration influence the exposure of a system to the drought hazard (Luers et al., 2003; Meza-Morales, 2010; Meze-Hausken, 2000; Arredondo & Huber-Sannwald, 2011; Wilhelmi & Wilhite, 2002; Wittrock et al, 2010). Besides these meteorological characteristics, soil characteristics (i.e. soil type and soil moisture) are decisive preconditions for enhancing or reducing vulnerability to droughts (Luers et al., 2003; Wilhelmi & Wilhite, 2002). Depletion of resources and ecosystem degradation (e.g. in form of desertification) are further mentioned as biophysical preconditions that may enhance drought vulnerability (Meza-Morales, 2010; Arredondo & Huber-Sannwald, 2011). The availability of natural capital in form of water resources additionally reduces drought vulnerability (Meze-Hausken, 2000; Naumann et al., 2013).

Economic income, technological and social infrastructure, land use and management, as well as market fluctuations and socio-economic stability are the main socio-economic causes for drought vulnerability mentioned as will be explained more in detail in this section.

Income from agricultural as well as non-agricultural activities provides a buffer and increases adaptive capacity before, during and after drought events (Biazin & Sterk, 2013; Meza-Morales, 2010; Meze-Hausken, 2000; Naumann et al., 2013; Simelton et al., 2009; Wittrock et al., 2010). Socio-economic stability of a system reduces vulnerability while market fluctuations due to speculations may lead to increased vulnerability (Meza-Morales, 2010; Arredondo & Huber-Sannwald, 2011; Salas et al., 2012). The globalization trend of markets can either enhance or reduce vulnerability to drought resulting in differential drought vulnerability since not all can afford the access and trade in global markets (Arredondo & Huber-Sannwald, 2011; Salas et al., 2012).

The social infrastructure in form of social networks, trust, kinship and neighborhood help increase social capital and enhance the capacity to cope with drought events. Social cohesion enhances preparedness for droughts (Biazin & Sterk, 2013; Meza-Morales, 2010; Meze-Hausken, 2000; Naumann et al., 2013). Demographic changes such as population growth, outmigration and ageing of the population enhance drought vulnerability (Meza-Morales, 2010; Simelton et al., 2009; Wittrock et al., 2010), whereas access to assets and entitlements increases the system’s adaptive capacity (Biazin & Sterk, 2013; Meze-Hausken, 2000). Finally, social conflicts such as war further destabilize a system (Meze-Hausken, 2000).

Access to technological infrastructure such as irrigation systems with storage and distribution facilities partly decouples farmers from dependency on rainfall and thus, can increase adaptive capacity to droughts (Meza-Morales, 2010; Naumann et al., 2013; Simelton et al., 2009; Wilhelmi & Wilhite, 2002; Wittrock et al., 2010). Management, e.g. in the form of land management techniques and land use planning is another decisive trigger of drought vulnerability as smart land management can reduce vulnerability to droughts (Biazin & Sterk, 2013; Luers et al., 2003; Arredondo & Huber-Sannwald, 2011; Salas et al., 2012; Simelton et al., 2009; Wilhelmi & Wilhite, 2002). Land tenure and access to land determine the exposure of a system component to drought, as some areas are more vulnerable than others (Biazin & Sterk, 2013; Arredondo & Huber-Sannwald, 2011).

There is common belief that institutions and governance play a major role in enhancing adaptive capacity and thereby reducing vulnerability of systems towards a hazard (Berman et al., 2012; Engle, 2011; Hurlbert & Diaz, 2013). Institutional response capacity in the form of aid programs for drought impact mitigation and subsidies are of importance in various cases (Costa et al., 2011; Luers et al., 2003; Arredondo & Huber-Sannwald, 2011; Salas et al., 2012). In advance, credits and crop insurances can reduce drought vulnerability.

Nonetheless, in the majority of the cases reviewed, institutional and legislative activities may further enhance drought vulnerability due to the inefficient use of resources and failures in communication, top-down governance, as well as widening the social gap due to unequal distribution of subsidies (Costa et al., 2011; Luers et al., 2003; Meza-Morales, 2010; Salas et al., 2012).

Location and climatic conditions are the most frequently mentioned variables referred to the exposure component of vulnerability. Still, it is not only the biophysical conditions that lead to differences in drought vulnerability, but it is mostly socio-economic and political-institutional drivers which finally lead to differences in drought vulnerability between the system's elements. Access to irrigation infrastructure, technology, knowledge and education as well as management practices and organizational structure and government support may equally contribute to variability in drought vulnerability.

Although the selection criterion of the reviewed case studies has been their similarity to the Chilean Recoleta System, they are not directly comparable concerning vulnerabilities to drought as the systems considered and the units of analysis vary.

The examples of the case studies support the notion that drought vulnerability needs to be addressed both within a system and by comparing across similar systems. In almost all case studies examined, vulnerability to drought differed among farmer groups, where smallholders were the most susceptible group due to the lack of resources and missing access to irrigation infrastructure and land. Ethnicity and social class are decisive when looking at the income gap and the differences in vulnerability between socio-economic groups (Biazin & Sterk, 2013; Luers et al., 2003; Meza-Morales, 2010; Salas et al., 2012; Wilhemi & Wilhite, 2002; Wittrock et al., 2012).

A notable issue of concern is the great diversity of methodologies used to assess drought vulnerability, varying from quantitative indicator approaches to qualitative assessments with questionnaires, focus groups and semi-structured interviews. Emphasis is placed on the fact that the indicator approach is only a proxy for drought vulnerability. There is demand for filling research gaps in the field of methodologies for drought vulnerability assessment and the topic of differential drought vulnerability.

Finally, the majority of authors adopt the holistic view of interrelated ecological and anthropogenic systems, i.e. drought vulnerability assessment cannot be limited to one single point of view but should take into account the complexity and dynamism of these complex systems presented hereafter.

2.3 Introducing complex systems

As a result of the review on differential drought vulnerability, it is evident that drought events are not only induced by climatic features nor do they affect exclusively one specific group but have repercussions on various spatial, functional and temporal scales and on the whole system. Thus, an insight into complex systems theory is given.

According to the theories of coupled human-environment system or also named social-ecological system promoted by Ecology and Sustainability Sciences, the focal system consists of ecological and socio-economic subsystems which contain system elements, it forms part of a broader super system, and can be in contact with other social-ecological systems (Figure 4). Complex system theory includes several spatial, temporal and functional scales; systems are dynamic as well as multidimensional at an organizational level, i.e. the simultaneous consideration of socio-economic, political and biophysical aspects is necessary (Adger, 2006; Tuner et al, 2003a).

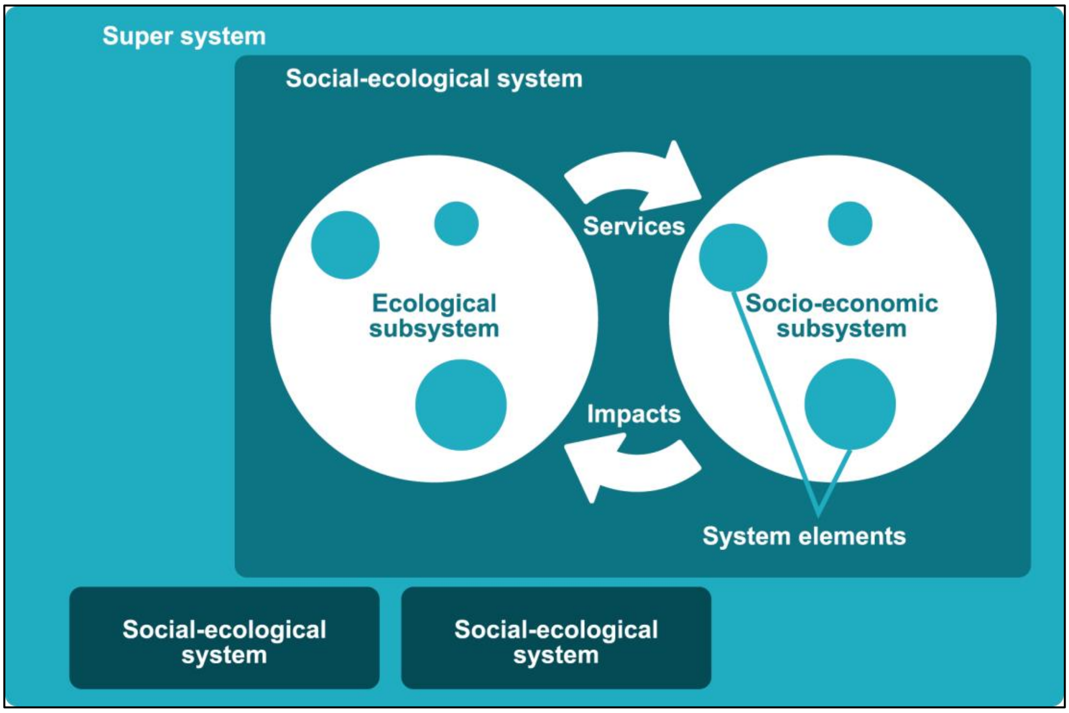

Figure 4: Social-ecological system
(Elaborated by the author based on Chapin et al., 2011)

Precisely because a drought only turns into a disaster when high losses occur, it is indispensable to take into consideration, the socio-economic subsystem and its processes as well as the ecosystem and its processes. For instance, there are cross-system dynamics and feedbacks when agricultural harvests fail due to water scarcity and this lack of production induces alterations in the local or even national markets and on people’s livelihoods (Chapin et al., 2011).

Humans form part of and take part in natural ecosystems (Resilience Alliance, 2010). The ecosystem provides resources and a variety of different ecosystem services to the socio-economic subsystem, whereas the latter alters the functioning of the ecosystem by e.g. changes in land use or the alteration of water courses due to the construction of reservoirs and channel systems. Figure 5 presents the interactions and controls of a social-ecological system where the social subsystem and the ecosystem interact via ecosystem services and impacts. The controls outside the bigger circle are the independent state factors, which determine the bio-physical and organizational preconditions of the subsystems, while the controls inside the circles are dependent controls or also called interactive controls as they influence and are influenced by the subsystems' characteristics (Chapin et al., 2011).

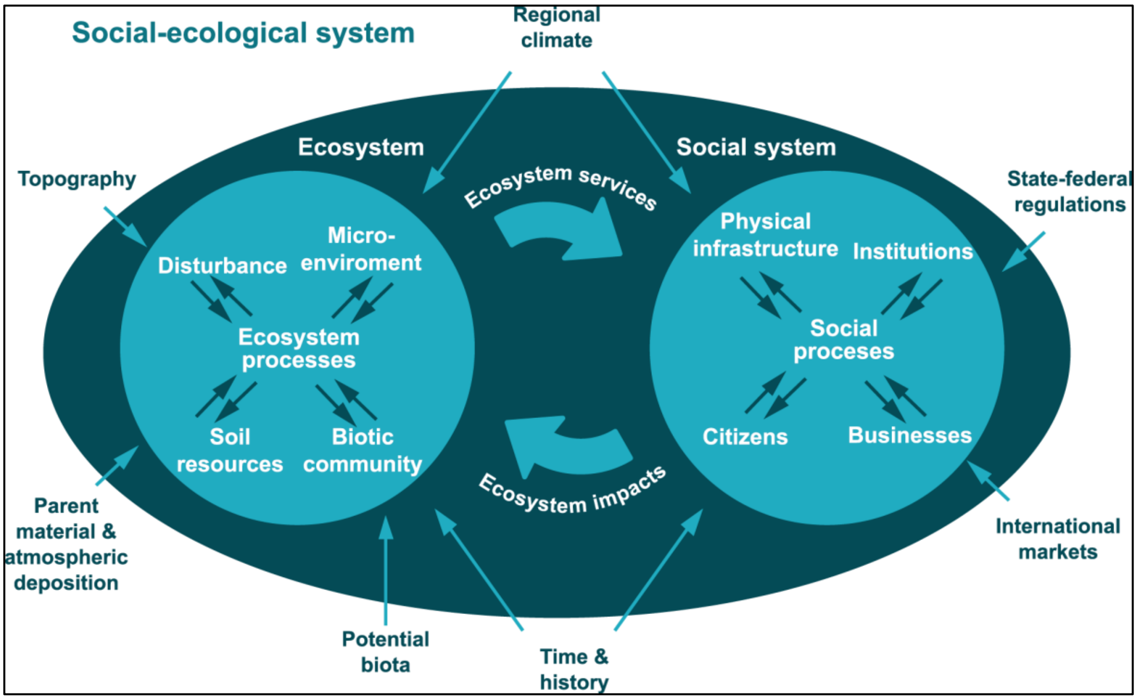

Figure 5: The functioning of social-ecological systems
(Elaborated by the author taken from Chapin et al., 2011: 426)

To increase complexity, any social-ecological system, here often referred to as a focal system as it presents the focus of the research, is influenced by larger scale systems and integrates subsystems and system elements. Cross-scalar effects between these spatial scales modify the focal system and are therefore important to consider (Resilience Alliance, 2010).

3 CASE STUDY

3.1 Description of the study site

The Recoleta System is located in the north-eastern part of Ovalle, one of the five communes of the province of Limarí, which practically coincides with the Limarí River Basin (LRB) in Chile's fourth region or region of Coquimbo (Figure 6; DGA, 2004). The snowmelt-driven LRB is located in the center of the so-called *Norte Chico* in north-central Chile: it constitutes the transitional zone between the northern Chilean arid deserts and the more fertile central Chilean zone located between 29° and 33° latitude south and characterized by a semi-arid climate (Schneider, 1982). The LRB limits in the north with the Elqui valley, in the south with the Choapa valley, in the east with the Andes mountain ranges and in the west with the Pacific Ocean (DGA, 2004).

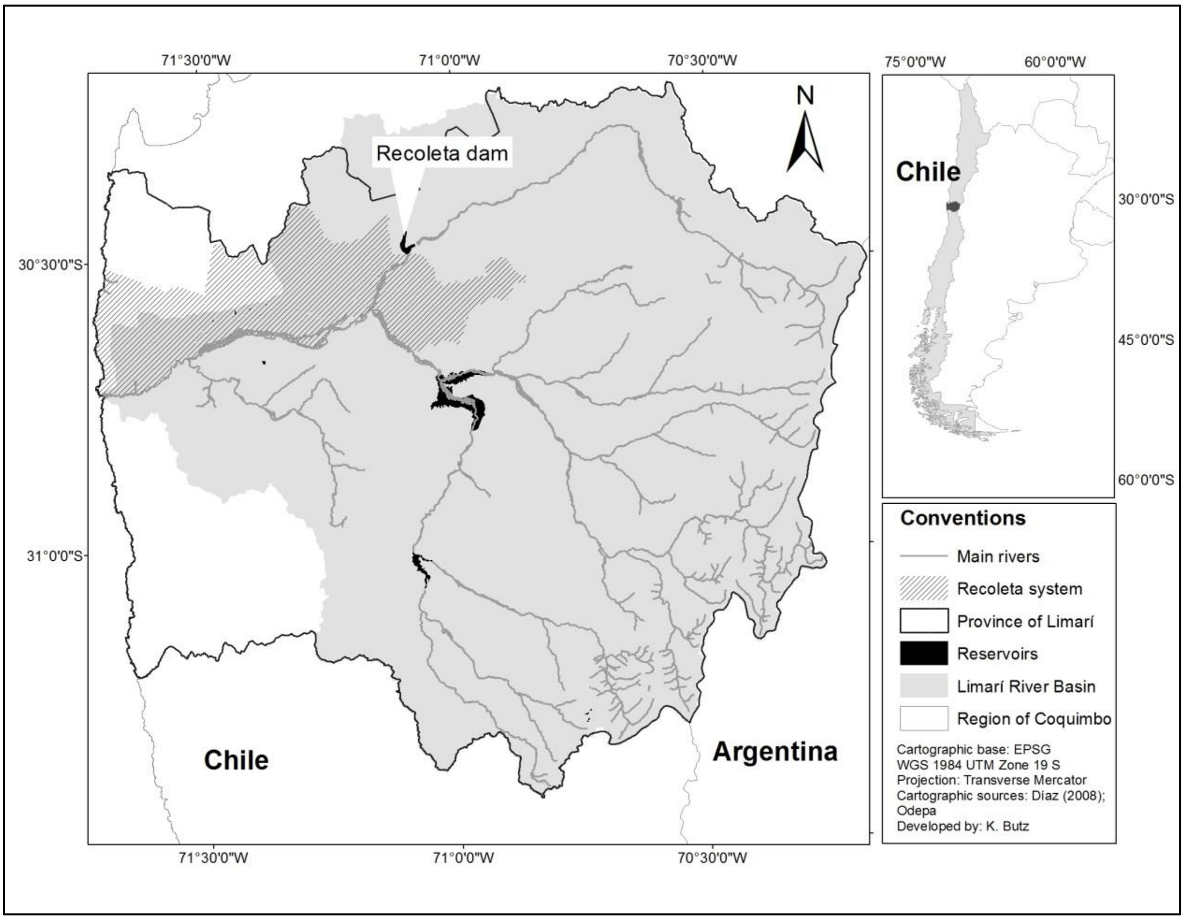

Figure 6: Hydrology of the Recoleta System in the Limarí River Basin, Chile
(Representation of the Recoleta System in the LRB with the basin's main river courses and the three reservoirs of the Paloma System where the Recoleta dam is marked explicitly; Elaborated by the author)

The relief structure of the Limarí valley is characteristic for the Norte Chico with its *valles transversales*, transverse valleys, where the rivers originate in the higher mountain ranges with slopes from east to west (DGA, 2004).

The province's climate is semi-arid. There is strong inter- and intra-annual spatial and temporal variability in precipitation and temperature at the basin scale further influenced by the ENSO phenomena. These phenomena bring long and persistent dry periods during *La Niña* and short, intense rainfalls during the period of *El Niño*. Despite this climatic variability at the basin-scale, the Recoleta System comprises relatively homogenous climatic conditions. The main pluvial precipitation falls in winter, between May and August while summers are usually dry. For the province's capital Ovalle, the average annual temperature is 16.6°C (DGA, 2004). Average annual precipitation for Ovalle is 107 mm (cf. RBIS). According to Ferrando (2002), precipitation in the LRB has dropped by 30% in the last century.

The LRB comprises an area of approximately 12.000 km^2. The Limarí River has numerous tributaries originating in the Andes with the Hurtado, the Grande and the Guatulame Rivers as main contributors. Outstanding in the LRB's infrastructure are the regulating reservoirs of the Paloma System – Recoleta, La Paloma and Cogotí – with a total combined storage capacity of 1,000 hm^3 (with 100 hm^3 in Recoleta, 750 hm^3 in Paloma and 150 hm^3 in Cogotí) and a broad channel network used for the irrigation of crops grown in the valley (DGA, 2004).

Here, focus is placed on the Recoleta System, which consists of the irrigation infrastructure of the Recoleta reservoir fed by the Hurtado River and various channels to distribute the accumulated water to its respective consumers, plus the districts that host the irrigated surface associated to waters from the Recoleta dam. Additionally to the waters from the Recoleta dam, the Paloma reservoir is another important source of water supply for the Recoleta System's area as almost two thirds of the total water rights of Recoleta's Channel Association ACER are served with Paloma waters (Modelo Operacional Embalse Paloma, n.d.).

With its constructions starting in 1929 and the inauguration in August 1934, the Recoleta dam is the oldest reservoir of the Paloma System (cf. Embalse Recoleta). It is located 18 km northeast from the commune's capital Ovalle where the Hurtado River drains into the reservoir. Recoleta's storage capacity is 100 hm^3 (DGA, 2004). With the construction of the Paloma dam in the 1970s with a storage capacity of 750 hm^3, the *Modelo Operacional Embalse Paloma*, a water distribution model for the whole river basin was put into practice. From then on, the connected reservoirs have been working as a joint system and not as single dams.

In the whole basin, agricultural activities have led to a decline of the native vegetation types. The construction of the reservoir system induced changes in agricultural practices from rain-fed to irrigated farming. Thus, changes in land cover have also altered the natural appearance of the valley and native plant communities present a tapestry of poor, uneven and sparse coverage (INE, 2008).

Reservoir waters are exclusively used for agricultural purposes. Agriculture is the main economic activity in the LRB and while the commune of Ovalle with the province's capital of the same name also holds a large share in other economic activities, the focal Recoleta System is exclusively dedicated to irrigated agriculture (SiTRural, 2012 a/b). The total area that can be irrigated with Recoleta waters is approximately 15.000 hectares (ACER. Vice-president). Fruits, vineyard and vegetables are the predominant crops (cf. Agricultural Census 2007).

Since the end of the 1990s, there has been a series of changes in agricultural production of the Recoleta System: while the total number of agricultural operations as well as the total agricultural surface decreased notably, the total explored surface as well as the total irrigated surface increased (Figure 7) (cf. Agricultural Census 1997; Agricultural Census 2007).

Since the end of the 1990s up to 2007, there has been a clear trend towards cultivating permanent crops (i.e. plants, which last for more than one season) and a shift away from horticulture. In addition, there has been a rise in the overall agricultural production in the Recoleta System with remarkable increases in the area planted with fruits, vineyard, vegetables and cereals, while the surface cultivated with pastures and flowers remained the same. Predominant permanent crops for the commune of Ovalle are avocado, olives, table grapes, almonds and citrus fruits: an important share of the harvest is dedicated to exportation (Larrañaga & Osores, 2011). All these crops require high amounts of water to guarantee production.

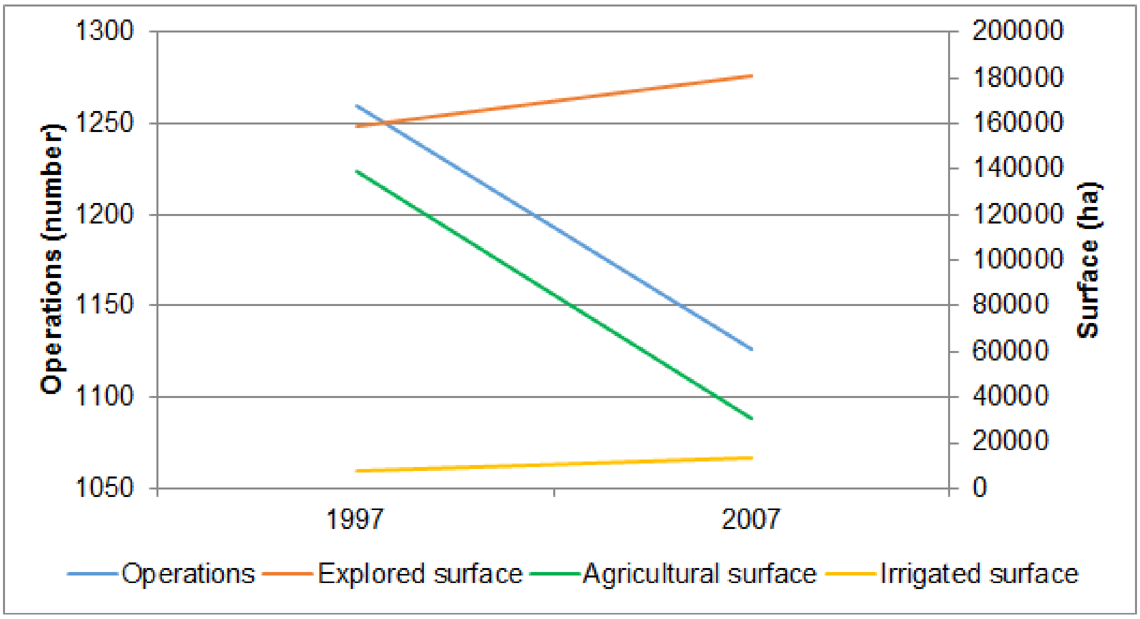

Figure 7: Changes in agriculture in Recoleta System
(Changes in number of operations as well as explored, agricultural and irrigated surface from 1997 to 2007; Elaborated by the author based on Agricultural Censuses 1997 and 2007)

The currently valid Chilean Water Code (*Código de Aguas*) dates back to 1981 and was enacted by Pinochet's military regime. It promotes a neoliberal market-oriented in agricultural production. It is a reform of the previous water law, which declares the resource water as national property for public use and guarantee free markets for trading water rights as good separated from land in accordance with the rules stated in the Water Code (Bauer, 2005).

At the national level, the General Water Directorate, *Dirección General de Aguas* (DGA) is the government agency responsible for managing water resources and granting water rights. The Water Code from 1981 promotes the creation of *Juntas de Vigilancia* and *Asociaciones de Canalistas*, which is in charge of water governance at smaller spatial scales, managing natural watercourses or artificial water channels (Código de Aguas, 1981).

For the Recoleta System, the *Asociación de Canalistas del Embalse Recoleta* (ACER) manages the water of the Recoleta reservoir and the share on water from the Paloma reservoirs equally belonging to ACER. Upstream the Recoleta reservoir, the *Junta de Vigilancia Río Hurtado* (JVRH) is responsible for water governance of the Hurtado River. For the Paloma System, the *Comunidad de Aguas del Sistema Embalse Paloma* (CASEP) is the super-organization that unites the LRB's water user organizations which form part of the Paloma System.

3.2 Problem description

The main limiting resource of the study region is water, which, in the past century, has led to the construction of the three dams of the Paloma System (León, 2008). The implementation of the reservoir system with its distribution model has reduced the variability in water supply and has thereby improved the irrigation security of the whole province. Additionally, the reservoirs serve as buffers during dryspells and attenuate the impact of drought events (DGA, 2004).

According to the IPCC's SREX report (2012), droughts associated with desertification processes will increase in frequency, intensity and magnitude in the future. Meanwhile, in the Recoleta System agriculture remains as the primary economic activity, which in turn requires increased amounts of water for irrigation. The move from primarily pastures and horticulture to intensively water-consuming crops such as citrus fruit, table grapes and avocado, further increased the demand for water. Also, the expansion in cultivated land requiring irrigation in the Recoleta System equally increases water demands. In short, all Recoleta farmers – no matter whether smallholders, middle scale farmers or big agribusinesses – depend on water from the reservoirs to continue their agricultural activities and sustain their livelihoods or enterprises.

The LRB's crisis is related to several drought events in the last seven years caused by less than normal rainfall and less than normal water discharge from snowmelt resulting in less than normal water inflow into the reservoirs. Additionally, national and global food demand and the neoliberal market-orientation of the Chilean government have further enhanced water consumption. In particular, change in and focus on cash crops (requiring irrigation) have exacerbated the demand for water for irrigation. The distribution of ACER's reservoir water to its respective water right holders has greatly reduced the volume of stored water in the last agricultural year (i.e. the period from May to April).

For the closing agricultural year, the DGA expected water supply will not meet current demand of the respective basins as the reservoirs stored less water than in previous years (DGA, 2013). During the field research period, the Paloma System entered in failure, i.e. the original distribution rules of the model were not applicable anymore due to the reservoirs drying out. In short, water demand exceeded water supply for irrigation in the Recoleta System. Hence, water management by ACER to guarantee equitable water distribution and assignment to the water right holders has become increasingly challenging.

Without doubt, the biophysical preconditions including climatic features are not the only triggers of Recoleta's current drought vulnerability. Indeed, socio-economic activities and institutional decisions are expected to play an even more important role.

4 METHODS

To achieve the specific objectives and by that answer the research questions, the methodology comprises three phases:

First, during the preparatory phase extensive literature research on drought vulnerability and the study region was conducted. Information on key variables related to differential drought vulnerability was extracted from literature (cf. sub-chapter 2.2) and thereby the focal system was identified. Once the focal system was chosen, information on the system was collected to refine its boundaries. Also, statistical meteorological, hydrological and data on the reservoirs' regulated system were analyzed to understand the specific nature of a Recoleta drought.

Secondly, key stakeholders related to the Recoleta System were identified. Then semi-structured interviews were prepared for specific stakeholder groups: interviews were conducted *in-situ*, then transcribed and analyzed. Information extracted from interviews allowed complementing information extracted from literature review.

The final phase comprised the analysis and arrangement of all relevant information. This phase concluded with the writing of the master thesis, the presentation of research results and the visualization of the findings in form of graphics or maps.

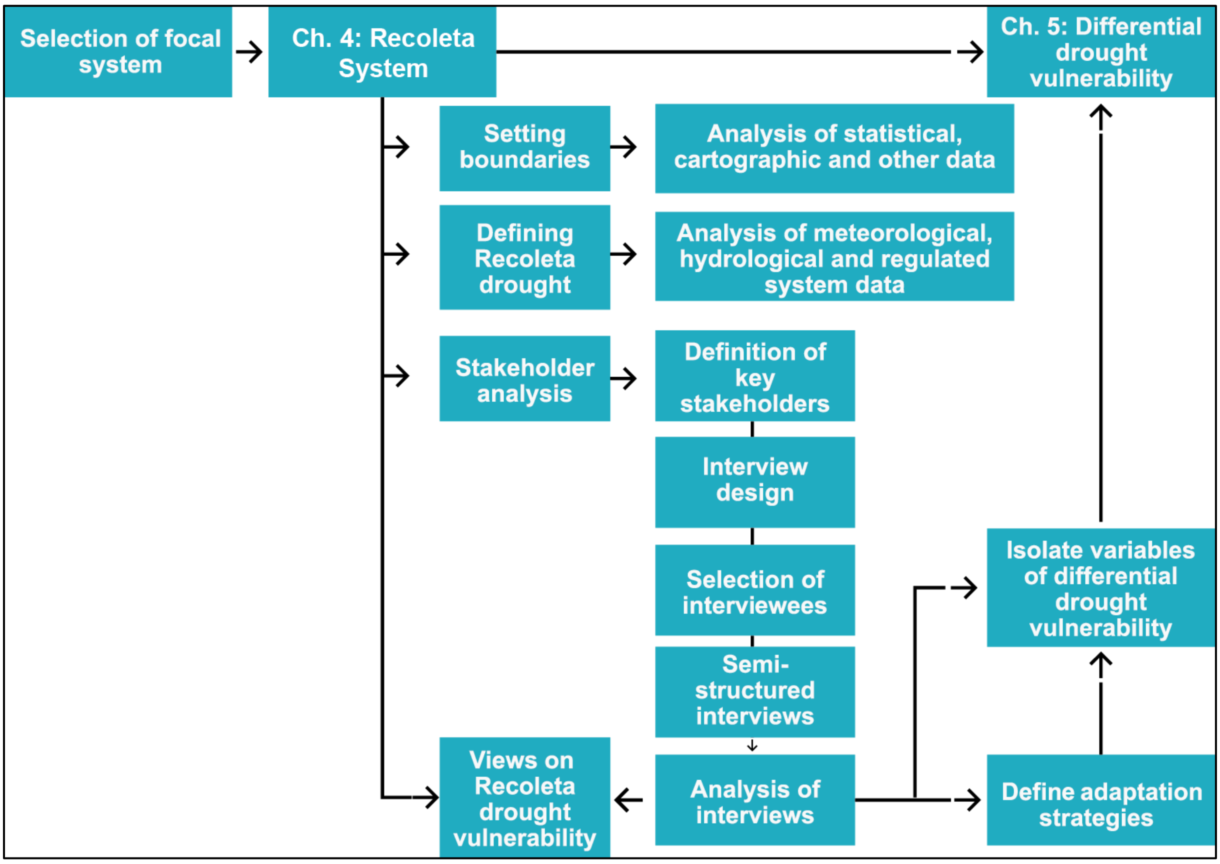

Figure 8: Methodological process
(Elaborated by the author based on the structure of the applied methodology)

4.1 Preparatory phase

4.1.1 System selection

Prior to the selection of the focal system, general literature, statistical data and cartographic information of the Limarí River Basin was analyzed to become familiar with the specific case study and to identify knowledge gaps. In order to respond the question on variables and factors that may lead to differential drought vulnerability, a literature review was conducted on twenty case studies sharing similar conditions as the Chilean Limarí River Basin (cf. sub-chapter 2.2).

The variables that induce differences in drought vulnerability were discussed on the whole LRB scale in order to select a sub-system, which is homogenous concerning the broad majority of these variables (Table 1). Climatic conditions, for instance, divide the basin into three parts (DGA, 2004), while access to irrigation infrastructure further divides the LRB into areas upstream and downstream the reservoirs (i.e. without and with access to the irrigation infrastructure, respectively).

Table 1: Variables of differential drought vulnerability

(The number represents the frequency with which certain variables are mentioned in the twenty selected cases; Elaborated by the author)

Variable	Frequency
Location	9
Climatic conditions	8
Access to irrigation infrastructure and technology	8
Soil management	7
Organizational structure	7
Access to education, information and knowledge	7
Governmental support and relief programs	6
Diversification of incomes	6
Access to water	5
Soil characteristics	4
Farmer type	4
Access to, dependence on and conduction of markets	4
International market and globalization	4
Economic income	4
Land tenure	3
Water quality	3
Occupation/ job	3
Neoliberalism	3
Access to credits	2
Political reforms	2
Social cohesion	2

Based on the homogeneity criterion, the Recoleta System was selected as unit of analysis in the sense that the majority of the variables mentioned in the literature review as well as others that turned out to be important for the Recoleta System were taken as constant conditions.

Variables that were not considered in other studies but are decisive according to expert consultation for the selection of the Recoleta System are water sharing, water organization and governance, water accessibility and irrigated agriculture.

4.1.2 System delimitation and description

As a next step, a proper description of the selected area with data on the biophysical, socio-economic and institutional preconditions was done.

The Recoleta System was defined using cartographic information from ODEPA (*Oficina de Estudios y Poltícas Agrarias*), census data from the Chilean Agricultural Census, meteorological and hydrological data from Limarí RBIS (River Basin Information System) and data on the regulated reservoir Paloma System from WEAP (Water Evaluation And Planning System) Limarí.

The Chilean Agricultural Census data was refined to its smallest spatial level, which is the census district. Information on the seventeen census districts of the Recoleta System was analyzed to achieve information on the production patterns of the system, keeping in mind that this information is valid for the whole polygon of one district.

Cartographic data was analyzed with ArcGIS 10.2 to create maps of the study area, while Microsoft Excel was used to identify trends in agricultural production.

The Resilience Assessment Framework for social-ecological systems presented in the *Workbook for Practitioners* was consulted as a supportive guideline of steps to assess and describe the focal system and to better understand the system dynamics (Resilience Alliance, 2010).

4.1.3 Recoleta drought detection

The analysis of the particular type of drought in the Recoleta System required meteorological and hydrological data from Limarí RBIS and data on the regulated reservoir system such as reservoir inflows, stored reservoir volume and assigned water volumes per reservoir from WEAP Limarí.

With the use of Microsoft Excel, graphical analyses of anomalies of precipitation data from meteorological stations within or adjacent to the Recoleta System were conducted. These anomalies were calculated from a mean value, i.e. in the case of precipitation, the mean annual precipitation, obtained from a fixed base period of normal precipitation used as a basis for several studies on the ENSO phenomenon (1971-2000) (Table 2). The very same applied to the analysis of anomalies in river discharge from the mean monthly average discharge (standard base period 1971-2000), while the mean annual reservoir inflow was obtained from a thirty-year base period from 1981-2010.

Table 2: Data used to determine Recoleta drought

(Elaborated by the author)

Type of data	Station name	Elevation	Mean	Considered time frame	Base period
Annual precipitation	Ovalle DGA	220 m	108.3 mm	1990-2012	1971-2000
	Recoleta	400 m	100.62 mm	1990-2012	1971-2000
	Paloma	430 m	132.67mm	1990-2012	1971-2000
Monthly river discharge	Río Hurtado en Angostura de Pangue	500 m	3.15 cbm/s	1990-2009	1971-2000
	Las Ramadas	1380 m	4.63 cbm/ s	1990-2012	1971-2000
Annual reservoir inflow	Recoleta	400 m	57.56 mill m^3	1990-2013	1981-2010
	Paloma	430 m	347.32 mill m^3	1990-2013	1981-2010
Annual stored reservoir volume	Recoleta	400 m	75.05 mill m^3	1992-2012	1992-2012
	Paloma	430 m	494.69 mill m^3	1992-2011	1992-2011
	Cogotí	n/a	77.6 mill m^3	1990-2011	1991-2011

Type of data	Station name	Elevation	Maximum storage	Considered time frame
Observed annual reservoir volume	Recoleta	400 m	100 mill m^3	1992-2013
	Paloma	430 m	750 mill m^3	1991-2011
	Cogotí	n/a	150 mill m^3	1990-2011
Annual volume assigned to each reservoir	Recoleta, Paloma and Cogotí	-	-	1989-2013

When analyzing the anomalies, those years that depart positively from the average, i.e. values above the zero-axis, are years with precipitation, discharge, reservoir inflow or reservoir volume higher than the average while those with less than average precipitation, discharge, inflow or stored volume show values lower than the zero-axis.

The following figures present the meteorological, hydrological and regulated system data analysis. Figure 9 depicts the anomalies in the precipitation pattern for the period from 1990 to 2012 for the Recoleta reservoir. Figure 10 shows the course of anomalies in river discharge for the hydrological station of Las Ramadas in the Grande River at an altitude of

1380 m.a.s.l. Figure 11 depicts the simulated reservoir inflow conducted by WEAP Limarí for the Recoleta reservoir from 1990 to 2013.

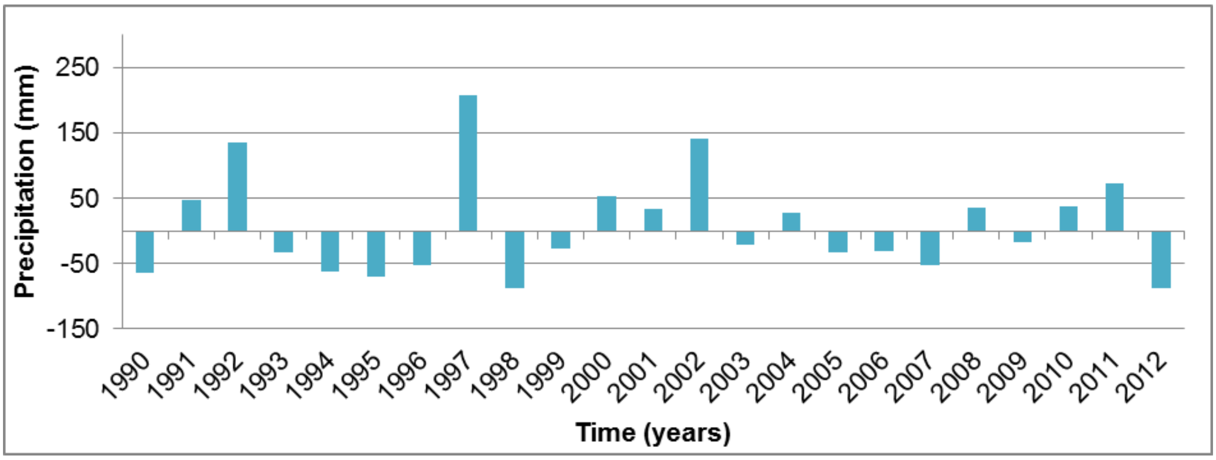

Figure 9: Precipitation anomalies for Recoleta reservoir
(Anomalies in precipitation from the mean annual precipitation of 100.62 mm (1971-2000 standard base period) at Recoleta (400 m.a.s.l).; Elaborated by the author based on data from Limarí RBIS)

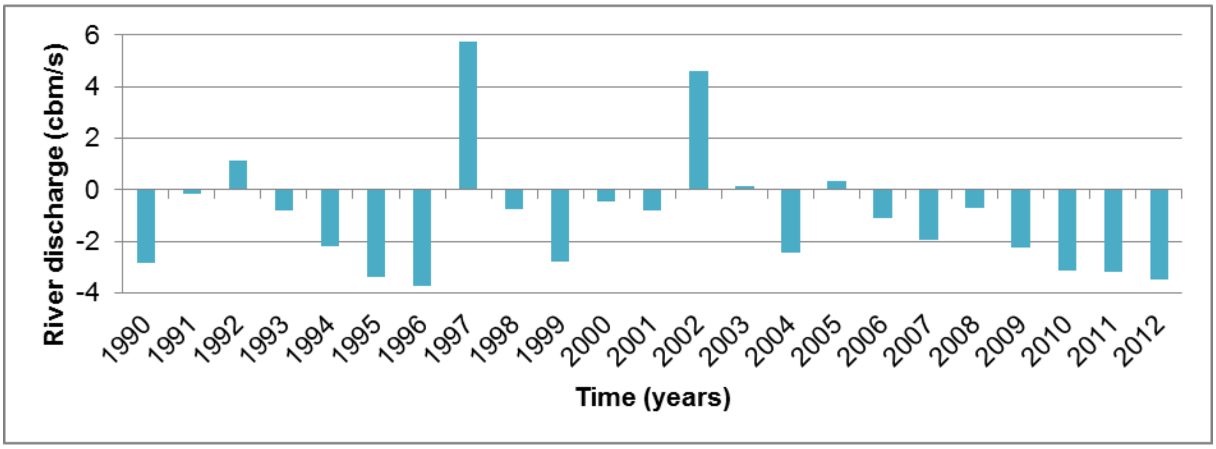

Figure 10: River discharge anomalies for Las Ramadas
(Anomalies in monthly river discharge from the mean of 4.63 cbm/s (1971-2000 standard base period) measured at Las Ramadas (1380 m.a.s.l.); Elaborated by the author based on data from Limarí RBIS)

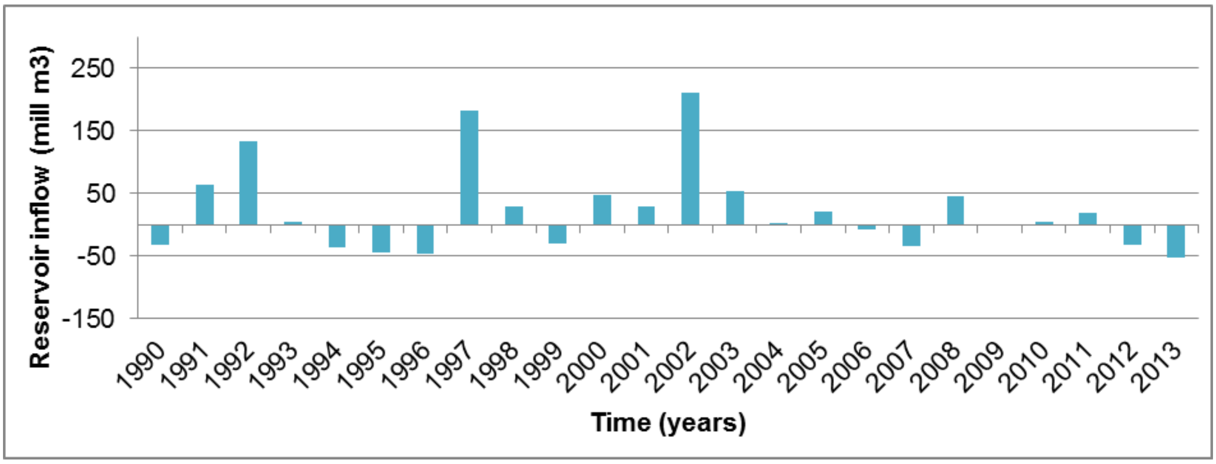

Figure 11: Reservoir inflow anomalies for Recoleta reservoir
(Anomalies in annual reservoir inflow from the mean of 57.56 million m^3 (1981-2010 base period) simulated by WEAP for the reservoir entrance; Elaborated by the author based on data from WEAP Limarí)

4.2 Primary data collection: The interviews

After setting soft system boundaries, seven semi-structured interviews (SSI) were conducted between April and May 2014 to collect missing data for a stakeholder analysis, to define perceptions and views on drought vulnerability in the Recoleta System as well as to identify adaptation strategies to droughts, factors, and variables that lead to differential drought vulnerability.

Semi-structured interviews are a mixture of questions and discussion between the interviewer and the interviewee(s) where the interviewer arranges a set of questions or topics in a loose structure, which still gives enough space and flexibility to include unforeseen topics, which might be of further interest to the researcher (Mikkelsen, 2005). Proper preparation of the interview is crucial and a plan of how to address the “big” research question via different minor questions and topics is set (Cloke et al., 2004). An introductive part with presentation of the researcher and the study is obligatory.

The decision to use semi-structured interviews for primary data collection is due to their open structure, which offers flexibility when addressing the topic of drought vulnerability. Besides, SSIs offer the possibility to include further issues brought up by the interviewees (Mikkelsen, 2005).

4.2.1 Selection of interview partners

Expert or farmer knowledge and opinions are primary sources accessed through consultations and semi-structured interviews with individual persons, e.g. consulting experts from the Universidad La Serena or from water user organizations deliver relevant information for identifying key stakeholders (Schmeer, 1999).

The academic staff of the Universidad La Serena was consulted as “outsiders with inside knowldege” (Mikkelsen, 2005: 171) to get a first impression on key stakeholders of the Recoleta System, their organizational structure and relationships. This implied the decision on approaching the stakeholders from the broadest to the smallest organizational scale, i.e. from the super system scale organization CASEP to the focal system scale organization ACER and finally to the system’s elements, the Recoleta farmers (Figure 12).

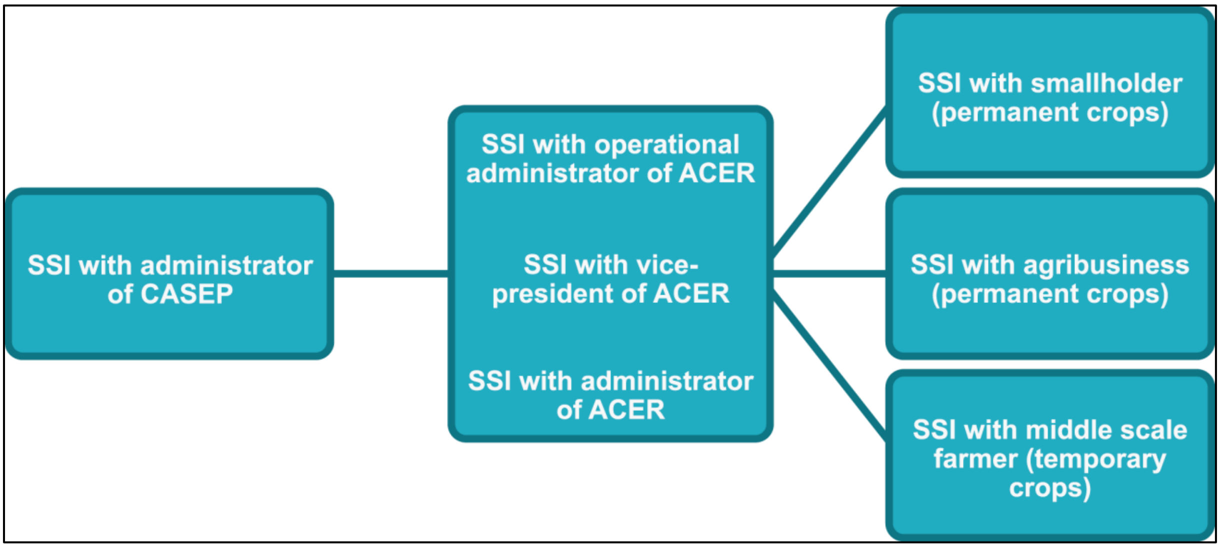

Figure 12: Procedure of semi-structured interviews

(Chronological sequence (left to right) with first interviewing the administrator of the super system organization CASEP, than the operational administrator, the vice-president and the administrator of Recoleta's channel association ACER and finally interviews with farmers which are taken as representative for the diversity of producer types to be found in the Recoleta System; Elaborated by the author)

The first interview was conducted with the administrator of the CASEP. As a next step, the focal system association ACER was focused on, where the operational administrator, vice-president and head administrator were interviewed. Finally, three farmers of the Recoleta System were consulted. They were selected based on the criterion of diversity as their responses were considered to depict different farmer types of the Recoleta System with one smallholder who cultivates permanent crops, a representative of an agribusiness with permanent crops and a middle scale farmer who cultivates temporary crops. The sample of one farmer for each farmer type is not representative to draw conclusions on the specific group but gives an insight on differences in drought vulnerability.

4.2.2 Preparation of interviews

Besides the introductory part, there were four standard topics, which were addressed in practically all interviews in a flexible manner (Figure 13). As the introductory part included a few sentences on the thesis topic, the move on to the standard topic drought vulnerability was easily managed. All interviewees were asked whether they understood the term drought vulnerability and if they had an own definition for it. Further, they were asked for a variable to measure drought vulnerability.

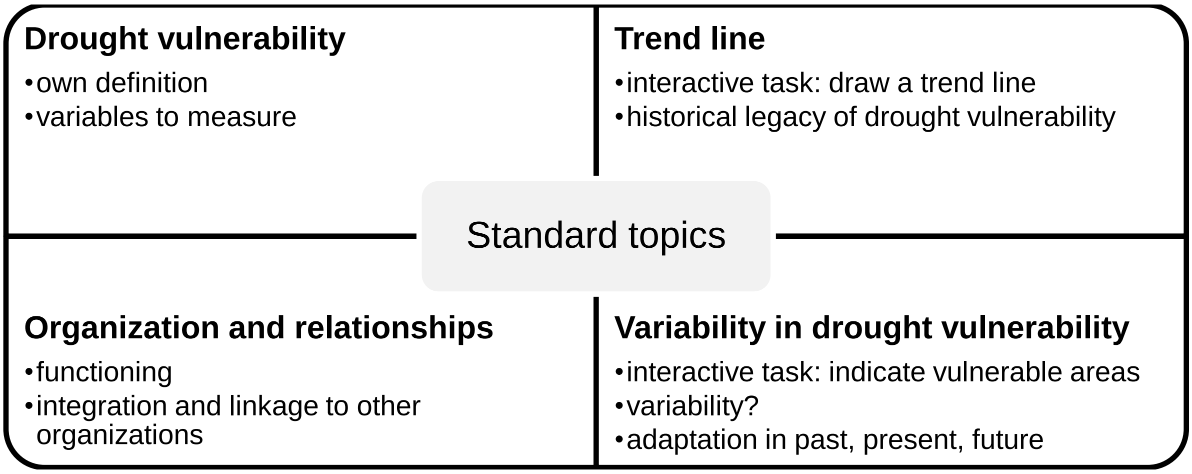

Figure 13: Standard topics addressed in SSIs
(Elaborated by the author)

The task of drawing a trend line on a sheet of paper concerning the topic of drought vulnerability was supposed to support and reaffirm the results on drought years identified during the statistical data analysis. The trend line should have presented important milestones from the actors' point of view. The task was to draw a trend line with a graph that depicts time in years from 1990 to 2014 on the horizontal axis while deviations upwards or downwards the vertical axis mean an increase or decrease in drought impacts. Further, explanations to the interviewer should have increased information on recent historical changes (Geilfus, 2008). Exclusively water user organizations were asked to draw the trend line.

Questions on the organizational structure, the organizations functioning and/ or the linkage of the interviewee or the interviewee's organization into the broader context helped to provide information on the organization itself and the interactions and relationships to other stakeholders as a basis for the stakeholder portrays.

Finally, the topic of variability in drought vulnerability tackled the objective of highlighting factors and processes that lead to differential drought vulnerability. ACER members were asked to indicate more and less vulnerable areas on a map of the Recoleta System. Information on adaptive strategies for the future as well as adaptations in the past and during the current drought was collected.

All interviews were conducted by the author (i.e. an outsider of the system), while the ones with the three agricultural producers were conducted accompanied by a research assistant from the Universidad La Serena, an expert of the system familiar with the study region and the interviewees.

The transcription of the recorded interviews with the free test-version of InqScribe[3] into text format enables coding of these qualitative data into conceptual categories, which were then analyzed. The visualization of qualitative interview data in matrix form, organization charts or networks facilitated analysis and represent linkages and relationships (Mikkelsen, 2005).

4.2.3 Shortcomings of SSIs

While it turned out to be difficult to get into contact with the authorities of ACER because of the current critical drought situation and a quite hierarchical and bureaucratic structure, contacting the producers was even more difficult as many of them either were hard to locate or they did not want to participate in interviews because of different reasons.

Concerning the task to draw a drought trend line, it is important to mention that none of the interviewees was willing to realize this task. Nonetheless, the interviewees provided the author with statistical information to answer the task of trend line drawing. This is probably due to the fear of releasing non-representative, subjective information they could be made responsible for.

ACER members were asked to indicate and color the most and the least vulnerable areas to drought of the Recoleta System. Equally to the trend line task, interviewees responded that there is no difference in drought vulnerability, consequently, they did not indicate any area.

4.3 Data processing and presentation of interviews

It has to be emphasized that the transcription of the interviews and the subsequent analysis and construction of results is a highly subjective task, just as is the case for qualitative data analysis (Cloke et al., 2004).

The transcribed primary data from SSIs was analyzed making use of a qualitative analytic approach of conventional and directed content analysis where repeated reading of the interview results led to the selection of keywords and categories (Hsieh & Shannon, 2005).

Some of the categories – drought vulnerability, differences in drought vulnerability, adaptation strategies and organizational functioning and linkages – were predetermined by the standard topics of the SSI (Figure 13), while others were detected during the in-detail reading process (e.g. *turnos de agua* as a subcategory of adaptation strategy or the solidarity concept as a subcategory of differential drought vulnerability).

The key concepts derived from the SSIs, the results from literature research on drought vulnerability and the outcomes of the statistical data analyses were presented in graphical and text from in the result chapters 5 and 6.

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[3] For the free or premium software visit: www.inqscribe.com (last visited: 14.06.2014).

The methodological procedure divided into data needs, data sources and data analysis and finally, the products are presented in relationship with the research objectives (Table 3).

Table 3: Research objectives related to methods

(Elaborated by the author)

Objectives	Data needs	Data source	Data analysis	Product
Delimitation of Recoleta System	Data on biophysical, socio-economic and institutional preconditions Cartographic information	RBIS WEAP Agricultural Census 1997 and 2007 Cartographic data from ODEPA	ArcGIS 10.2 Microsoft Excel Approach from Resilience Alliance	Chapter 4: The Recoleta System Map of Recoleta System
Description of Recoleta drought and drought vulnerability	Meteorological, hydrological and regulated system data	RBIS WEAP Interviews	Microsoft Excel Interview transcription with InqScribe Content analysis	Definition of Recoleta drought Graphics with anomalies Views on drought vulnerability
Stakeholder analysis	Information on system components, organizational structure, linkages and power relations	Expert knowledge Interviews	Interview transcription with InqScribe Content analysis Listing, networks	Functional organization chart Description of stakeholders
Identification of factors and variables that induce differential drought vulnerability	Data on variables that induce differential drought vulnerability, Data on production, crops and land use change Information on historical droughts and management practices Information on drought vulnerability perception	Literature review on differential drought vulnerability Interviews Agricultural census and CASEN data	Microsoft Excel Interview transcription with InqScribe Content analysis	Chapter 5: Differential drought vulnerability Graphical representation of changes in agricultural production
Analysis of adaptation strategies	Data on methods, instruments or strategies to adapt to drought Data about land cover and land use changes Information on agricultural techniques and water use Information on policies and institutions	Literature review Interviews Field observation Agricultural census data	Interview transcription with InqScribe Content analysis Excel	Chapter 5: Differential drought vulnerability Recoleta farmer’s specific drought vulnerability

5 THE RECOLETA SYSTEM

This chapter describes the focal system denominated Recoleta System by setting loose boundaries where the variable of homogeneity is decisive for determining the system's extent. Setting loose or soft boundaries refers to a process of system limitation, which is not totally fixed but flexible and can change over time (Resilience Alliance, 2010). The system's key actors are introduced and their linkages and relationships presented. The second part of the chapter addresses the particular type of drought for the Recoleta System and induces a series of definitions of drought vulnerability from the focal system stakeholders' perspectives.

5.1 Setting system boundaries

Setting boundaries is a procedural and iterative task to simplify the complex structure of the focal system by reducing it to its most important variables (Resilience Alliance, 2010).

The Recoleta System is an artificial construct, which represents a social-ecological system highly specialized on agricultural activities. The Recoleta social-ecological system consists in the ecosystem and the socio-economic system and is integrated into the larger scale Paloma System. Smaller subsystems and system elements define the specific nature of the Recoleta System. For its delimitation and definition not only spatial aspects but also the consideration of historical legacies are of interest.

Indeed, the key issue of being one homogenous functional unit dedicated to irrigated agriculture and belonging to the same channel organization, ACER, is the decisive factor, which ultimately determines the spatial extent of the Recoleta System.

As the economic interest is set on irrigated agriculture, the Recoleta System's main concern is water availability for agricultural purposes during the agricultural cycle (i.e. during the hydrological year from May to April). The system strongly depends on water from the reservoirs for its economic development.

The volume of water assigned from the Paloma System to ACER and then assigned by ACER to Recoleta farmers is distributed throughout the Recoleta System via the broad channel network of the association. Therefore, the area under irrigation depends on the presence and the proper functioning of this channel network.

5.1.1 Spatial delimitation

The outer limits of the Recoleta System (Figure 14) are defined by the seventeen census districts considered part of the Recoleta System based on the opinion of experts from the Universidad La Serena. They include the area irrigated with ACER waters. Although the irrigated area of the Recoleta System does not exactly coincide with the political boundaries of these census districts and it is probably smaller, the districts' outer limits are seen as the maximum possible expansion of the Recoleta System. While the water rights available determine that the largest possible spatial expansion are the outer boundaries indicated here (as the largest total volume of water assigned can serve 15.000 hectares), the system can shrink whenever there is not enough water for irrigation encouraging a reduction in the irrigated surface (Figure 14).

Figure 14: Recoleta System, Recoleta channels and reservoirs in LRB
(Elaborated by the author based)

5.1.2 Functional delimitation

Water governance is an important issue in the Recoleta System and the larger-scale Paloma System. Water is distributed according to the total water volume available in the reservoir system, the amount of water consumption rights and the decisions made at the directors' board of the CASEP and ACER about the amount of water assigned to each water action per year.

Each water right is entitled to one water action, which is the amount of water assigned to each water right per hydrologic year. The assigned amount to a water Faction varies depending on water availability in the reservoirs; if there is less water in the reservoir system and the directors' board decides to assign less, each water action per year will receive a reduced amount.

With the *Modelo Operacional Sistema Embalse Paloma* the water distribution is managed at river basin-scale (i.e. the super system), as if the three reservoirs, which together accumulate 1.000 hm^3, were one single distribution center to optimize resource use. This Operational Model is a permanent tool that fixes both allocation and distribution of water, in terms of volume and timing, approved by all Water User Organizations of the Paloma System and supported by the Chilean Hydraulic Works Directorate.

The Operational Model has three alternative system states (Resilience Alliance, 2010): i) abundant water with maximum assignation, ii) low water where the assigned volume equals half of the water stored in the reservoir system and iii) extremely low water (Figure 15). This last condition occurs in case any of the reservoirs does not achieve 40% of the maximum assignation implying that the Paloma System fails. In that case, the system functions as if there was no reservoir infrastructure, i.e. the rivers follow their "natural" flow (Modelo Operacional Sistema Embalse Paloma, n.d.).

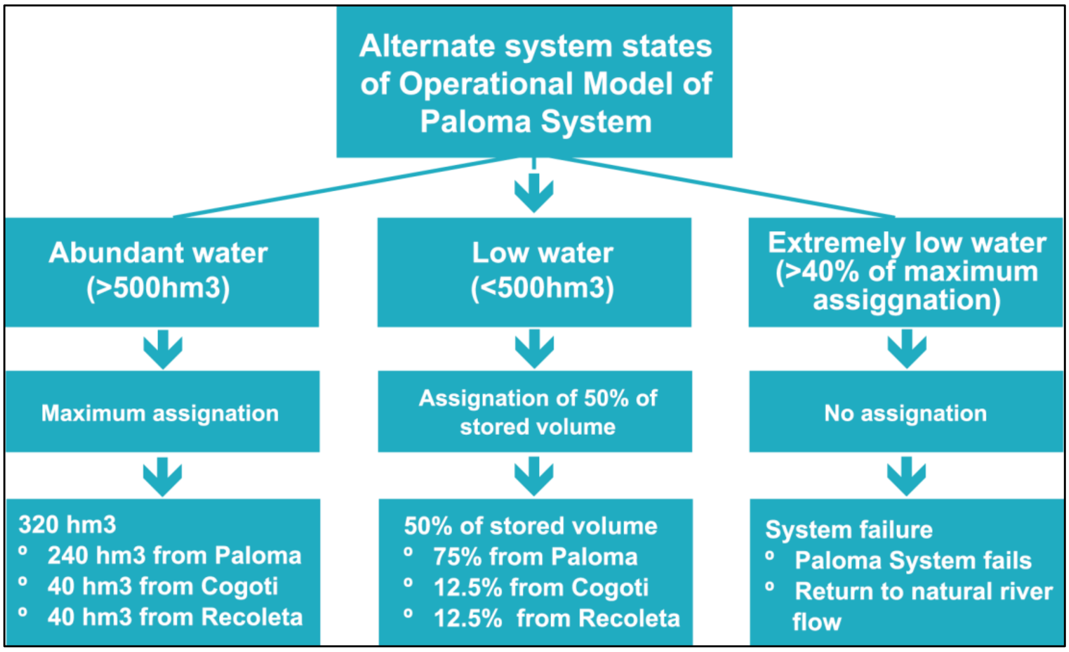

Figure 15: Operational Model of Paloma System
(Elaborated by the author based on Modelo Operacional Sistema Paloma)

Under the condition of maximum assignation, ACER receives 114,4 hm^3 (i.e. 35.75% of the total water volume assigned to the Paloma System with 35% from Recoleta and 65% from Paloma waters). This volume is partitioned into approximately 22.721 water actions. In case of maximum assignation, each ACER water action equals almost 3.675 m^3 per year (Modelo Operacional Sistema Embalse Paloma, n.d.).

For the Recoleta System, the spatial distribution of all ACER water actions coincides with the area irrigated, i.e. one third of ACER actions is dedicated to the so called "upper part" (*parte alta*). Under the condition of maximum assignation, these areas are irrigated with waters directly from the Recoleta reservoir, while the remaining two-thirds of the Recoleta System's surface receive the remaining two-thirds of the water actions, which are served by the Paloma reservoir (Modelo Operacional Sistema Embalse Paloma, n.d.).

In case the Paloma System enters in failure, the Recoleta System continues operating and distributes the waters from the Recoleta reservoir. Also all ACER water actions have to be supplied with waters from the Recoleta reservoir, however with drastically reduced volumes per water action per year.

In case of reduced water assignations in the Recoleta System, ACER provides a schedule with distribution dates for the whole system. This rotational concept is widely known as *turnos de agua*, water turns. The idea is to concentrate the farmers' requests for water volumes on predefined dates in order to guarantee that the water reaches the farmers' gates by reducing losses due to evaporation or conduction and, thus, to optimize water distribution under conditions of a drought (ACER. Vice-president; Díaz, 2008).

The key variable to track changes in the Recoleta System is therefore the total volume of water assigned to the Recoleta System, which is equivalent to the waters stored in the Recoleta and Paloma reservoirs. In addition, decisions made by the directors of the CASEP and ACER on the quantity of water assigned to each water right and certain distribution rules need to be considered.

5.1.3 Temporal delimitation

A glance at the last century illustrates that the Recoleta System has experienced significant changes in its appearance with regard to its ecosystem type, its spatial extent and recently also in its agricultural focus and production systems.

According to the functioning of social-ecological systems, human interventions and actions modify ecosystems (Chapin et al., 2011). This is exactly what holds true for the Recoleta System. This region was characterized by “typical” dryland ecosystems (ODEPA, 2012). However, during the last century they were converted to highly specialized, agricultural systems with intensive agricultural activities including alterations of the natural river courses as a consequence of the construction of the reservoirs and channel networks.

In global terms, more than 40% of the world’s land surface is covered by drylands, which can be subdivided into dry sub-humid, semi-arid, arid and hyper-arid regions where almost 40% of the world’s total population resides (Reynolds et al., 2007; Safriel & Adeel, 2005). Drylands are characterized by water scarcity due to low and variable amounts of rainfall and soil moisture simultaneously facing high evapotranspiration rates. Thus, the main limiting factor in drylands is water (Safriel & Adeel, 2005). Human-induced land degradation (which may lead to desertification) and natural temporary water scarcity associated with drought events may threaten the functioning of dryland ecosystems (Pereira et al., 2002). Also, due to their low productivity these ecosystems do no provide sufficient provisioning ecosystem services contributing to high levels of poverty, especially in rural areas (Dobie, 2001).

Hence, considering the climatic conditions of the Recoleta System one would not come up with the idea that now this area was specialized in agricultural production of highly water demanding crops such as avocado, grapes, citrus fruit and almonds. The reason for this is that the region’s climatic conditions were modified and have practically been equalized for the whole focal system with the help of an extensive irrigation infrastructure in the 20th century, i.e. homogeneity concerning water supply has been established by the regulatory reservoir system. This means that even though there are small differences in annual precipitation amounts, evapotranspiration rate and solar irradiance, all farmers of the Recoleta System are guaranteed the same amount of water per unit of water action no matter where they are located (Modelo Operacional Sistema Embalse Paloma, n.d.).

Figure 16 presents the most important milestones of the last century for the Recoleta System to become what it is today. Large scale influences on the Paloma System or larger scale systems, like the Chilean state or the international scale are also taken into account.

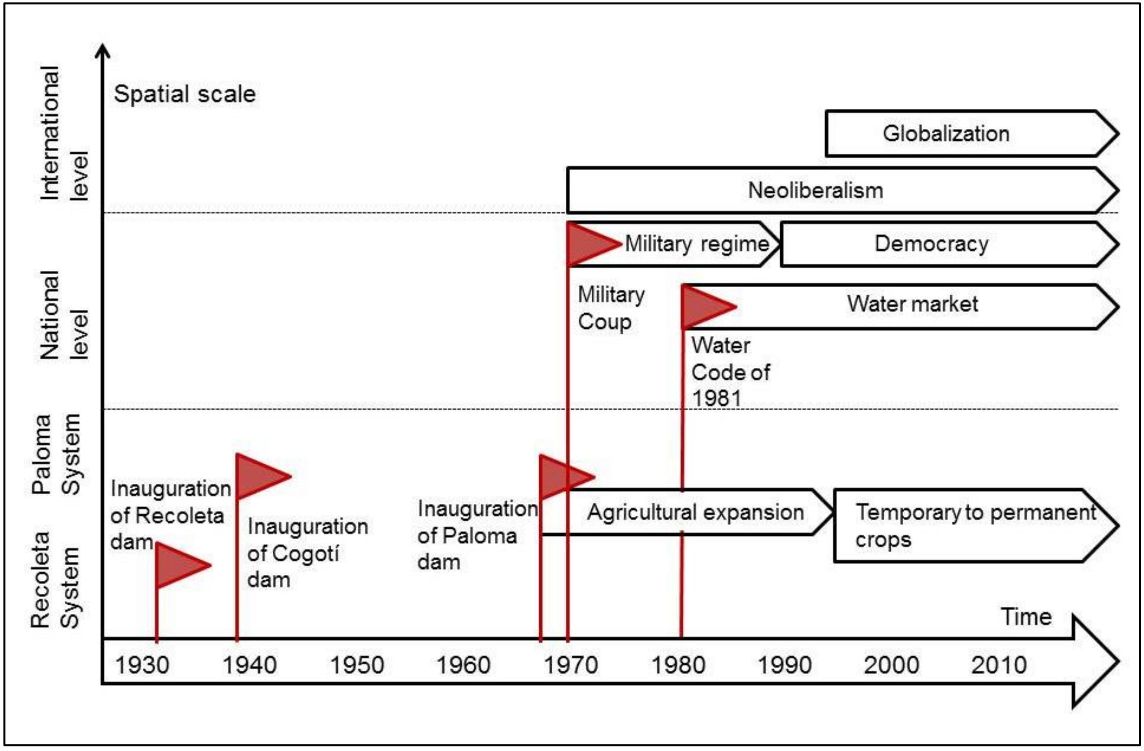

Figure 16: Historical Timeline with milestone for Recoleta System
(Timeline indicating the most important milestones and trends, which defined the shape of the Recoleta System; Elaborated by the author)

Chile was hit hard by the global economic recession, which culminated with the Wall Street Crash in 1929. As a response, the Chilean government channeled funds and gave an impulse promoting the agricultural sector with the construction of the Recoleta reservoir, which was finally inaugurated in 1934 (León, 2008). The Cogotí dam was inaugurated five years later, while Paloma started working in the late 1960s (cf. Embalse Recoleta).

The coup d'état in 1973 by Augusto Pinochet was the start of seventeen years of military regime. Starting in the early 1970s, a new macroeconomic focus changed the Chilean economy substantially (León, 2008). The neoliberal economists of Pinochet's regime fostered the liberalization of the Chilean markets (Tokman, 2010). The agricultural sector received a major boost with the adoption of the 1981 Chilean Water Code influencing substantially the state of the art of water management with the introduction of a water market where water rights can be traded such as any other private commodity and separated from land (Bauer, 2005).

Since 1990, Chile is a democracy and the influence of the military forces has been displaced steadily. Although the country's form of government has changed, the economic focus on neoliberalism has been maintained. With the help of economic instruments and international trade agreements, Chile obtained access to global markets and experienced increases in export and import. For the country's economy the globalization process had positive impacts, however it also induced changes in the economic structure of the country: The agricultural sector, for instance, reduced its share in the country's GDP when comparing the periods 1971-1973 to 2000-2005. The most severely affected by this re-structuring of the national economy were smallholders, as they could not compete in the global markets, while agribusinesses generally profited from these new conditions (Tokman, 2010).

The new force of global players at the markets induced a series of shifts in the traditional Chilean agriculture (Tokman, 2010). In the last twenty years, the Recoleta System has experienced changes in crop patterns: fruits for export markets replaced horticulture and livestock products. Hence, a pronounced shift from horticulture in the late 1990s to an impressive increase in fruit production, vineyard and cereals is observed (Figure 17). Furthermore, the Recoleta System experienced an overall increase in cultivated land.

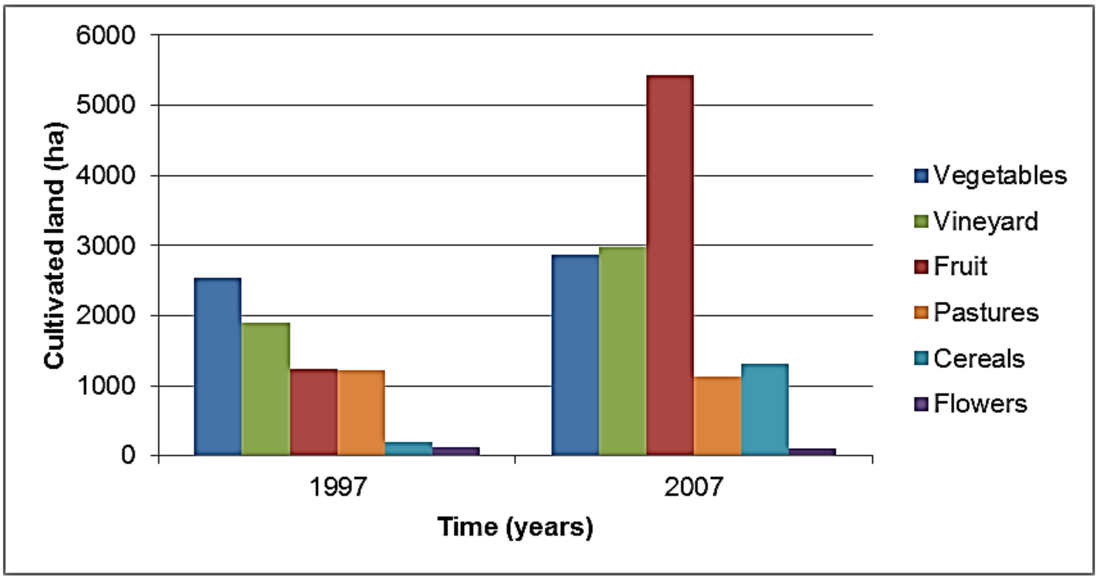

Figure 17: Comparison of main crops in Recoleta System
(Comparison of the main crops cultivated between the Agricultural Censuses of 1997 and 2007; Elaborated by the author based on data for the seventeen census districts of the Recoleta System from the Chilean Agricultural Censuses of 1997 and 2007)

To come back to the denomination of the current geologic epoch as *Anthropocene* (Steffen et al., 2007), the focal Recoleta System with its irrigation infrastructure has, in fact, probably reached maximal distance from the once natural conditions of the dryland ecosystem. The natural dryland ecosystem of the social-ecological system is highly modified due to the agricultural enterprise.

The anthropogenic influence and thus, the changes of the aspect of the Recoleta System can be illustrated in four broad stages: starting with the pre-agricultural phase where there was a natural dryland ecosystem and humans as hunter-gatherers (Steffen et al., 2007). The second stage initiates when humans started cultivating land ten thousands of years ago and thereby alternated the natural water and nutrient cycles. From then, agriculture and agricultural techniques passed several evolutionary sub-stages but for the Recoleta System, the next important landmark is the construction of the Recoleta reservoir and the channel network in the 1930s. Finally, the implementation of the Paloma System with the Paloma dam and the Operational Model probably marks the most important milestone for the Recoleta System as it adds a second water source to the system, which increases irrigation security (ACER. Vice-president). This represents a further step away from the once natural conditions towards a highly modified, human-influenced system with minimized variability in water availability (León, 2008).

5.2 Recoleta stakeholders

The Recoleta System is embedded in the larger-scale Paloma System situated in the Limarí River Basin. The focal system is further split into sub-units represented by several producers and their production units, together making up the organizational structure of the Recoleta System within Paloma super system context (Figure 18).

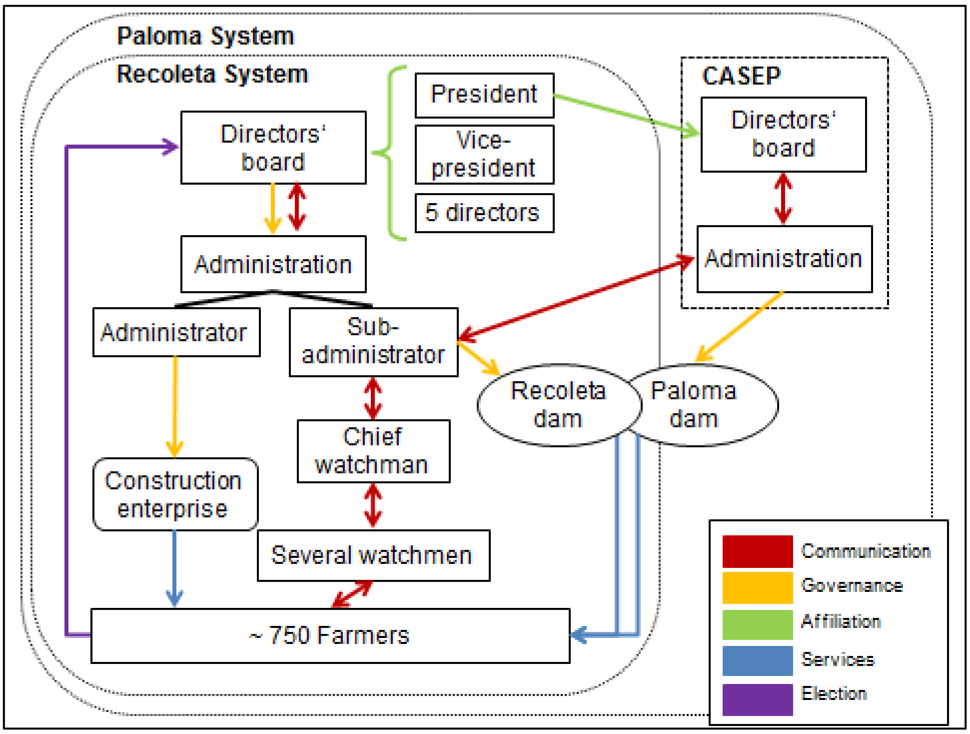

Figure 18: Stakeholders and relationships in Recoleta System
(Recoleta System embedded into larger-scale Paloma System with linkages between stakeholders are portrayed in different colors concerning their nature of relationships; Elaborated by the author based on interview data)

The CASEP is the stakeholder at the highest organizational scale considered in this analysis. This institution was founded in 2012, after various requests from the Paloma System's water organizations in order to optimize the water distribution at the basin level. It represents the super-organization of the river basin, which integrates the focal system's organization ACER as well as seven other water associations, which together form the Paloma System and are benefitted by the water distributed by the Paloma dam. The directory board consists of one representative from each of the channel associations or river organizations. The directory board discusses and decides on the allocation of waters from the Paloma reservoir backed by the Operational Model (Figure 15).

The CASEP also counts with an administrative branch, headed by the administrator who is in charge of the operation of the Paloma reservoir by distributing water to the respective water organizations and of the maintenance of the reservoir infrastructure. The administration has to keep track of all water movements of the whole system, which means that all member organizations have to report to the CASEP (CASEP, 2012).

ACER is the water user organization at the focal system's scale, self-denominated as a bank that distributes water instead of money.[4] It consists of a directors' board with a president, a vice president and five additional directors. All of them are elected every two years by the totality of Recoleta farmers where each water action is entitled to one vote. ACER's president is the official representative of the organization in the CASEP, while the vice-president listens to the Recoleta farmer demands, i.e. the internal communication.

The directors' board supervises the administration, which, in turn, is divided into administration and sub-administration. While the head-administrator supervises the work of the association's construction enterprise *Construcción y Riego S.A.* and postulates for funding for new maintenance projects, the sub-administrator deals with the proper functioning of the Recoleta dam. The sub-administrator is additionally in charge of the distribution of the reservoir waters and the permanent communication with the Recoleta farmers via the watchmen, *celadores*, who are headed by a chief watchman (cf. Embalse Recoleta).

These watchmen are the missing piece of the jigsaw to link the more than 720 Recoleta farmers with their channel organization. The watchmen receive the requests for water volumes from the farmers and forward these demands to the chief watchman who communicates them to ACER's sub-administration. However, the total volume of water to be distributed and the amount of water per water action per hydrological period is discussed and defined at the directors' board, which means that the farmers' water demands cannot always be met. Especially during dry spells, the directors' board of ACER recommends a schedule of the water distribution via their watchmen in order to accumulate water requests at a specific date and by this reduce water losses (ACER. Vice-president).

There are approximately 720 to 750 farmers irrigating with ACER waters. Figure 19 outlines the distribution of Recoleta's irrigated surface among its farmers. According to statistics provided by the Universidad La Serena from 2005, exactly 608 out of the total number of 728, i.e. almost 84 % of the Recoleta farmers cultivate areas smaller than 12 hectares. Thus, the majority of the Recoleta farmers are smallholders.

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[4] "Esta oficina es un banco con la diferencia de que en vez de manejar dinero, se maneja agua" (ACER. Vice-president).

Although the majority of the farmers are concentrated in smallholder group, together they account for only 36% of the total surface cultivated (cf. ULSa).

Seventy farmers who own between 12 and 30 hectares (i.e. one tenth of all Recoleta farmers), cultivate the remaining 20% of the surface. An additional 6% of the farmers, in absolute numbers 46 farmers, own 30 to 100 hectares while only four Recoleta farmers own 100 to 350 hectares. These four farmers own more than 740 hectares of the Recoleta area, which is an 11 % of the total surface considered (cf. ULSa).

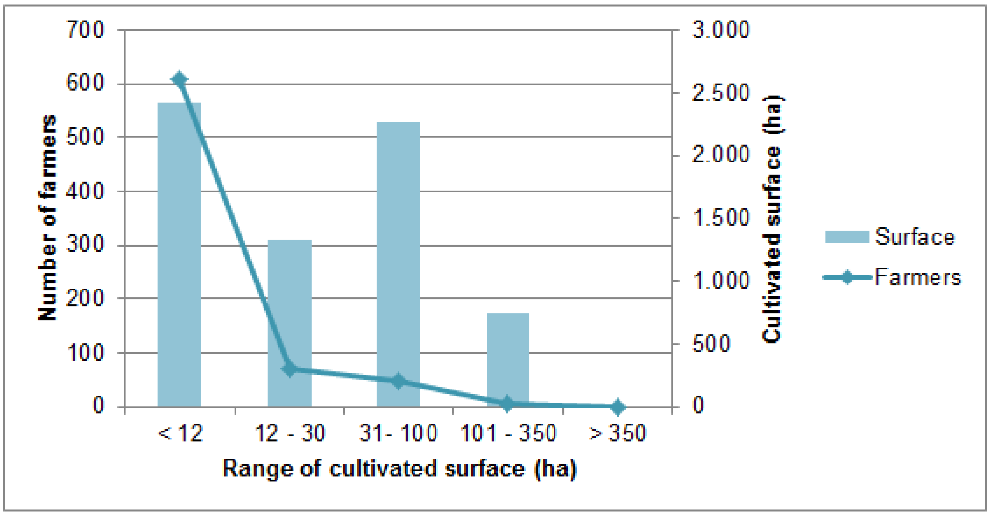

Figure 19: Distribution of cultivated surface among Recoleta farmers
(Numbers indicate the total number of farmers belonging to the respective group of range of cultivated surface; Elaborated by the author based on data provided by P. Álvarez (ULSa))

As each water action gives the right for one vote to elect the directors' board, the distribution of the water actions among Recoleta farmers is of interest as it determines the representation of interests at the board-level.

According to estimates of ACER's vice-president more than 350 of the 720 to 750 Recoleta farmers own between 0 and 9.9 water actions, another 250 farmers own 10 to 20 water actions. In the ranges of 21 to 50 and 51 to 100 water actions there are around fifty farmers each. Twenty Recoleta farmers hold between 100 and 499 water actions. The last group with an amount of 500 to 1000 water actions only counts with two or three farmers, large agro industrial firms.

Even though the majority of Recoleta farmers only hold up to twenty water actions, they are well represented at the directors' board (ACER. Vice-president).

The distribution of water rights is related to the distribution of cultivated surface among Recoleta farmers, as agricultural production requires water for irrigation.

Around 83% of Recoleta farmers hold between zero and 20 water actions, which coincides with the 83.5% of Recoleta farmers that cultivate less than 12 hectares (cf. ULSa).

5.3 Defining a Recoleta drought

The critical disturbances (Resilience Alliance, 2010) affecting the Recoleta System are cyclical drought events. In the considered period, the hydrological year 1996/97 presented a Recoleta drought event whereas, more recently, a trend towards several continuous years of dryspells has negatively affected the Recoleta System, its farmers and the local and regional market.

Water management by the reservoir system has changed the natural water flows and distribution. It provides the chance to increase the overall agricultural production, i.e. an attenuation of the effects of the disturbance regime of the "natural" drought regime (Resilience Alliance, 2010). Nonetheless, this suppressing of the natural disturbance regime also implies negative impacts as it somehow hides the possible impacts of a drought and provides a feeling of security among the farmers due to less temporal variability in water distribution that, in the future, can turn out to be counterproductive.

Given the specific conditions of the Recoleta System situated downstream the Recoleta dam and connected with this reservoir through a network of channels and at the same time connected with the Paloma dam, the sole consideration of time series of precipitation or river discharge is insufficient to detect a drought in the Recoleta System. Precipitation and discharge alone will not indicate sufficiently whether the Recoleta System suffers a drought or not. Besides the meteorological and hydrological data, the reservoir inflows, the stored reservoir volumes as well as their management in terms of the volumes assigned and distributed have been analyzed in order to isolate periods of water deficit that cause drought in the Recoleta System for the period from the early 1990s until today.

The analyzed data of the meteorological, hydrological and regulated system stations shows similar patterns in the evolution of rainfall, river discharge, reservoir inflow and stored reservoir volume, despite being located in different areas and in some cases at different altitudes.

In several cases, considering only precipitation data, as it is done when determining a meteorological drought (Mishra & Singh, 2010), would have led to the erroneous assumption that the Recoleta System had suffered a drought year. For instance, the year 1998 turns out to be one of the driest years of the considered period and, thus, would have been declared an extreme drought when adopting the definition of meteorological drought. However, the analysis of river discharge data partly shows that when adopting the definition of hydrological drought (Mishra & Singh, 2010), this assumption is rejected, as there are no major negative anomalies in river discharge. River discharge – after deducting the volume destined to the *Juntas de Vigilancia* – is a first indicator of what might be the reservoir inflow.

It is eventually the water stored in the respective reservoirs, which guarantees irrigation for Recoleta farmers. Thus, the reservoir inflow, the stored volume in the reservoirs and finally the decisions of ACER and the CASEP determine the quantity of water leaving the reservoir gates.

One single year of no precipitation and little discharge does not lead to a drought in the Recoleta System, while several consecutive years of negative anomalies in precipitation, river discharge and reservoir inflow indicate the reduction of stored reservoir volume as, at the same time, the organizations decide on the maximum volume of water allocation.

This has been the case for the hydrological year 1996/97 where since 1992 or 1993 three to four consecutive years of below-average values in precipitation and river discharge lowered the reservoir inflow. Simultaneously, maintaining the maximum assignation until the hydrological year 1995/96 eventually caused an extreme drought in 1996/97 in the Recoleta System downstream the reservoirs. An extremely rainy winter with several heavy rainfall events in 1997 managed to recover the maximum storage capacity of the reservoirs.

The current situation is the result of an extended period of balances and imbalances since 2002/03 in precipitation, river discharge and reservoir inflows, which did not generate any further positive surpluses in the stored reservoir volumes. At the same time, ACER and the CASEP decided to distribute the maximum volume to each water action as can be seen in Figure 20. It was only in 2009 when the organizations decided on lowering the allocation rates.

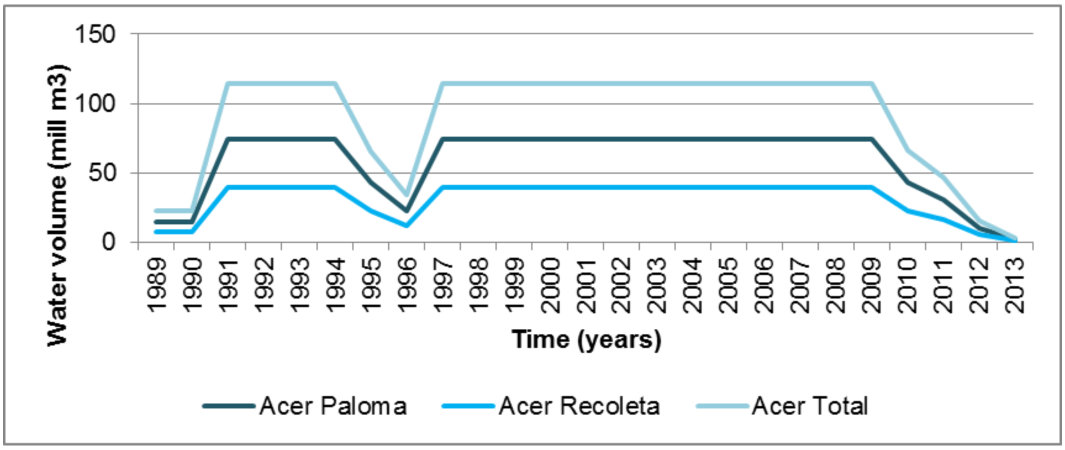

Figure 20: ACER assignments

(Assignments by ACER from Paloma and Recoleta reservoir from 1989 to 2013; The maximum assignment for ACER is 114.4 million m^3 where Recoleta contributes 35% and Paloma 65%; Elaborated by the author based on data from WEAP Limarí)

A drought in the Recoleta System is the result of the decision taken by the CASEP and ACER to maintain maximum allocation during continuous years of reduced precipitation and river discharge leading to reduced reservoir inflows and finally, reduced storage volume of the reservoirs. Hence, apart from the climatic conditions, Recoleta droughts depend highly on water governance decisions.

5.4 Stakeholders' views on drought vulnerability

Field research in the Recoleta System with observations, interviews and expert consultations confirmed the results of the analysis of meteorological, hydrological and regulated system data, which detected a drought in the Recoleta System for the hydrological year of 2013/14.

All stakeholders agreed that the current period 2013/14 is an outstandingly dry one. They equally confirmed that they perceive drought as a hazard, which affects their agricultural production.

From the CASEP's point of view, the Limarí River Basin is increasingly vulnerable to drought when there is little water in the Paloma System's reservoirs. As the CASEP is directly in charge of the distribution of water from the Paloma dam, the storage volume of this reservoir is of interest when determining drought vulnerability. The Paloma dam is primarily fed by water from snowmelt, thus, sufficient snowfall in the mountain ranges, which means upstream water supply to the reservoir, may reduce drought vulnerability. Precipitation downstream the reservoir does not reduce the CASEP's drought vulnerability although these water amounts may be beneficial for individual farmers downstream the reservoir and reduce local drought vulnerability (CASEP. Administrator).

> "Any vulnerability event has to be seen from the reservoirs to the mountain ranges. We cannot evaluate the amount of precipitation downstream the dams for the system as it does not have any relevance. Our most important variable for [measuring] vulnerability is therefore what happens in the mountain ranges[5]" (CASEP. Administrator).

In case of ACER, the water stored in the reservoir equally determines drought vulnerability. However, here, there are two reservoirs, which serve as sources to feed the water demand of the irrigated surface of the Recoleta System. The definitions of drought vulnerability from ACER members vary from a primarily technical definition where the losses in the channel system represent ACER's drought vulnerability – "[…] our main vulnerability are the losses due to conduction."[6] (ACER. Sub-Administrator) – to a definition closely linked to good or bad water governance of the water user organization as it is assumed that expertise in water management may reduce drought vulnerability (ACER. Vice-president).

At the farmer scale, drought vulnerability is represented by insufficient water supply the moment it is needed for irrigation purposes. In case there is no water distributed by the Paloma System because the Operational Model enters into failure due to insufficient water and additionally, ACER distributes water in *turnos de agua*, drought vulnerability is high for Recoleta farmers (Farmer 1).

Drought vulnerability for farmers is a situation, where the water distributed by the water organization is not enough to meet the demands of the farmers' crops, which induces production losses and finally, economic instability. Another definition on drought vulnerability highlights the situation from an agronomic point of view and considers the intolerance of individual crops to hydrologic stress. Drought vulnerability presents itself in economic terms as it leads to lower productivity and therefore, less income than in a normal year (Farmer 2).

The existence of irrigation infrastructure indicates less drought vulnerability when comparing the Paloma System to other agricultural areas in Chile (ACER. Vice-president). For the Paloma System, precipitation in form of snowfall can be seen as

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[5] "O sea, todo evento de vulnerabilidad está visto desde los embalses a la cordillera. No podemos evaluar la cantidad de precipitaciones debajo cortinas de embalse para el sistema. Porque no tendría significancia. Entonces, nuestra variable de importancia de vulnerabilidad es lo que ocurre en la cordillera."

[6] "[…] nuestra mayor vulnerabilidad son las pérdidas por conducción."

an indicator to define drought vulnerability within the Paloma System (CASEP. Administrator).

The variable water management highlights differences in drought vulnerability. For instance, the reduction in losses by improving the conditions of the channel network can reduce drought vulnerability for ACER (ACER. Vice-president). Thus, the losses of the channel system are another proxy to measure drought vulnerability of the Recoleta System (ACER. Sub-administrator).

Productivity as the outcome of reduced water availability can help measure drought vulnerability for Recoleta farmers (ACER. Farmer 2).

In general, drought vulnerability can be measured by the variable of reservoir water available for distribution by the channel system.

6 DIFFERENTIAL DROUGHT VULNERABILITY

6.1 Rejecting hypotheses

Initially, the two hypotheses mentioned in the introductory chapter are analyzed and, immediately, rejected as the variables thought to be decisive for the Recoleta System turned out to be of minor importance for the focal system.

When formulating H1, the phenomenon of solidarity was not considered. This concept describes an integral mechanism of ACER's functioning. The idea is that all losses related to evaporation or conduction are distributed proportionally between all Recoleta farmers. ACER discounts the equal amount of water from each water action in order to jointly bear the losses of the whole system – no matter where they are located (Díaz, 2008).

Another aspect of the concept is that all ACER auctioneers equally share costs for maintenance projects. For every water action, the same amount is paid as a contribution to channel renovations and maintenance. Eventually, the reduction in losses as a result of these improvement works benefits all, as it reduces the amount discounted. In accordance with ACER's vice-president, it is a *solidary saving*[7].

Furthermore, solidarity is maintained during drought when the Paloma System enters into failure and, hence, no assignations occur from the Paloma dam: Under these conditions, the remaining water source, the Recoleta dam waters, are distributed among all ACER auctioneers (ACER. Vice-president).

Thus, the solidarity concept created by ACER provides homogeneity among the system elements concerning the variable location/distance to the reservoir. The spatial distribution of farmers within the Recoleta System does not imply differences in drought vulnerability as all of them receive the same water assigned for each water action. To conclude, the solidarity concept guarantees that all the Recoleta farmers have the same losses and the same benefits.

If the spatial focus is extended to the Paloma System, location leads to differences in drought vulnerability as the three reservoirs are influenced by different climatic conditions: Recoleta is located close to the province of Elquí at higher altitudes, thus, there is more precipitation from snow and therefore more favorable, hydrologic

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[7] "El tema es si ese canal pierde agua, si nosotros estamos entregando las aguas en forma solidaria entonces el ahorrar en ese canal es ahorro solidario porque se va a repartir entre todos" (ACER. Vice-president).

conditions. The Paloma reservoir is directly influenced by the discharge coming from the Grande River, which cyclically presents high drought vulnerability. Cogotí almost borders with the province of Choapa and presents the most critical climatic and geological conditions. Cogotí's channel system is impacted by the northern exposition of the mountains, which leads to fragmentation of the soil and the irrigation infrastructure and therefore, increases conduction losses (CASEP. Administrator; DGA, 2004).

Whereas the Recoleta System can rely on solidarity, other water user organizations, dealing with natural courses, do experience differences in drought vulnerability as the ones located more upstream will always receive first and the farmers more distant from the water source may not even receive water (ACER. Sub-administrator).

According to H2, smallholders are more harmed by droughts than middle scale farmers or agribusinesses, as they are supposed to be less capable to respond to the adverse effects of the hazard in terms of economic resources and technical infrastructure. Recoleta's *pequeños productores* present the broad majority of the system's farmer community.

Nonetheless, findings from field observation, expert consultation and the results of the interviews reject H2 as well. It is probably too simplistic to relate differences in drought vulnerability to farmer type, as more economic resources and a highly technified farm do not necessarily stand for low drought vulnerability. While large agribusinesses count with their own storage infrastructure, ACER provides communal storage tanks, which benefit the totality of farmers (ACER. Sub-administrator).

Some smallholders may actually be less adversely affected by drought, as they do not make large investments in storage infrastructure and crops, which are now – under drought conditions – at risk of failure. The next section will tie up these differences in drought vulnerability and will take a closer look at the situation of Recoleta farmers.

6.2 What makes the difference?

At the larger spatial scale, in comparison to the other water user organizations of the Paloma System, ACER is less vulnerable to drought. This is due to the advanced irrigation infrastructure with two reservoirs as water sources, which provide increased irrigation security and decrease variability in water supply (ACER. Vice-president). At the organizational scale of the focal system, there are no clear differences in drought vulnerability as the channel organization ACER based on the solidarity concept serves each water action with the same amount of water. This means that if there is drought, the whole system suffers the same degree of drought vulnerability (ACER. Vice-president). However, at the individual scale, there are differences in drought vulnerability. So, if it is neither the location within the system nor farmer type, what variables do then lead to differential drought vulnerability among the system's elements?

Individual water management, water actions and crop type are the variables discussed here as they may lead to differences in drought vulnerability among Recoleta farmers.

6.2.1 Individual water governance

Water distribution by ACER is guaranteed as long as water flows through Recoleta's channel system. However, once the water passes the gate of the channel and reaches the farmer's property, it is the farmer's responsibility to manage it. Especially during drought years, the existence of tanks with high storage capacity are of great importance as water volumes are accumulated and reach the property every three weeks in *turnos de agua* and thus, have to be stored to last for the next weeks.

From 42 Recoleta farmers, 41 own tanks with varying storage capacities between 80 m^3 and 85.000 m^3. Almost 30% of them additionally own wells and by this, have access to ground water. Increasingly more technology is applied in irrigation to minimize water losses (cf. ULSb).

Water management at the individual scale includes the decisions of when to demand water, how much water to demand, whether to plant or if it is convenient to cultivate an area jointly with other farmers to divide the costs and risks of losses (ACER. Vice-president).

6.2.2 Water actions

Considering the current situation, according to a Recoleta farmer, there are several cases of agricultural companies, who own thousands of water actions, however, when the reservoir dries out, they do not receive anything.[8]

The simple fact of having many water actions does not immediately mean that the respective farmer is less vulnerable to drought than other farmers with less water actions. As already mentioned, water in the Recoleta System derives from either the Recoleta or the Paloma dam. Under normal conditions, two thirds of the water actions are served with water from the Paloma reservoir and these two thirds also serve two thirds of the Recoleta System's area. This implies that the remaining third is served by the Recoleta dam and represents the remaining third of Recoleta's area (ACER. Administrator). This suggests that although the *Código de Aguas* induced the separation of land and water consumption rights, water rights in the Recoleta System are relatively well distributed and do not accumulate in one area of the system (Código de Aguas, 1981).

However, due to Chilean law, farmers are allowed to trade their water consumption rights such as any other good. Thus, there is the risk of farmers selling their water actions under drought conditions in order to rapidly acquire cash. This has happened to some small producers due to a lack of awareness on the value of water actions. As with ACER's vice-president, these water actions were transformed into jeeps or machinery, which soon diminished in value while the water action itself does not devaluate but receives the assigned amount by ACER each year dependent on the stored volume in the reservoirs[9].

The assumption that purchasing many water actions may decrease one's drought vulnerability is questionable. During drought, farmers receive restricted volumes of water per water action. Thus, the recently purchased water actions will not lead to any outstanding surplus in water supply and therefore, does not reduce substantially drought vulnerability of farmers. On the other hand, the purchase of a water action is generally motivated by the lack in water volume for the farmer's area under

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[8] "Por ejemplo, conozco casos de empresas que tienen mil acciones de agua y no sacan nada si el embalse está vacio" (Farmer 2).

[9] "[…] se produjo un encantamiento en que tenían un número, una cantidad de acciones y la oferta por comprarlas era tan atractiva que cedieron. Y lamentablemente, los derechos accionarios se transformaron en camionetas[…]" (ACER. Vice-president).

irrigation. The purchase of a water action is merely a strategy to increase the irrigation security of the existing production.

In addition to the possibility of trading water actions, there is the option to transfer water volumes. As ACER operates similarly as a financial institution, farmers can decide to transfer a certain amount of their assigned water to another farmer’s water account. This volume is then delivered to the new recipient. While water transfer among farmer is supervised by ACER, the payment for it remains beyond the control of the channel organization (ACER. Vice-president).

As water transfers have reached alarming proportions, ACER has implemented rules to limit system-wide transfer of water actions from one extreme of the Recoleta System to another. The physical infrastructure of the channel network impedes the unrestricted transfer as water actions are inherent to a specific channel, which constrains their transfer only to one channel (ACER. Vice-president).

Acquiring water actions or water volumes does not necessarily reduce drought vulnerability. It can be a strategy of response under drought conditions but for Recoleta farmers, an accumulation of water actions generally coincides with more agricultural production. Consequently, it does not reduce drought vulnerability but is a way to guarantee irrigation security of the existing production.

6.2.3 Crop type

The variable crop type is subdivided into temporary and permanent crops. The Recoleta System’s shift from horticulture, i.e. temporary crops, to permanent crops such as citrus fruits, avocados, vineyard and almonds was presented earlier (Agricultural Census 1997; Agricultural Census 2007) (Table 4).

Table 4: Temporary vs. permanent crops

(Elaborated by the author based on data from 42 Recoleta farmers collected by the Universidad La Serena in December 2013)

Crop type	Cultivated surface (ha)
Temporary crops (total)	107.9
Permanent crops (total)	1765.73
Almonds	179
Avocado	294.5
Mandarin	43
Olives	966.95
Vineyard	206
Walnut	66.28
Other	10
	1873.63

While temporary crops have to be replanted every agricultural season or even throughout one season, permanent crops are plants that last for more than one agricultural year (FAO, 2011).

In this regard, the concept of flexibility arises where flexibility refers to the range of decisions the farmer can take. As with the previous sections, Recoleta farmers differ in drought vulnerability due to their individual decisions on water management. However, certain crops limit the freedom in decisions on water management strategies. Higher flexibility applies for temporary crops, which require low investment and offer the possibility to reduce or eliminate production for a complete agricultural year in case of a drought (ACER. Vice-president).

Farmers with temporary crops can decide to not cultivate during a drought period. They leave their fields in fallow, and thus, reduce their costs, as they do not pay any salaries, fertilizers, seeds, machinery, electricity, etc. Furthermore, they may decide to transfer their water volume to another farmer, which is a legal transaction and receive money for this, which, in turn, is an unofficial movement. In addition, the farmer may decide to work elsewhere and receive further income as an employee.

Permanent crops, instead, make farmers inflexible in their decisions as the decision to plant permanent crops already includes high investments in the crops themselves and in irrigation infrastructure. A farmer with permanent crops cannot decide to leave the field fallow for just one season, as this would imply the loss of the entire production. For permanent crops, irrigating is always the best option; no matter if there is a normal or drought year, as the decision of not irrigating implies the loss of the crops.

In order to be more flexible and reduce the impact of drought, Recoleta farmers with permanent crops have the choice to cut back parts of their crops and paint the trunks with white color so that these do not resprout (Farmer 2). Certainly, the farmer will experience a reduction in the production, but, on the other hand, it reduces the plant water uptake and therefore cuts irrigation costs. Nonetheless, this increase in flexibility is limited temporally, as the plants cannot survive in this state more than one year.

In conclusion, during drought a farmer with temporary crops has more alternatives to decide on than a farmer with permanent crops. The wider range of decisions makes farmers with temporary crops less dependent on water available for irrigation. No irrigation under drought can turn out to be a favorable decision for farmers with temporary crops, while no irrigation for farmers with permanent crops will always imply losses.[10]

6.2.4 Flexibility

In conclusion, differences in drought vulnerability among Recoleta farmers are related to the state of flexibility of farmers.

Flexibility is often related to differences in farmer type (Pereira et al., 2002), where agribusinesses are generally seen as more flexible than smallholders as they have more economic resources to increase flexibility.

In the first place, flexibility is specified by the farmer's decision on crop type where permanent crops always imply less flexibility, i.e. higher drought vulnerability to a Recoleta drought. Partial or total focus on temporary crops makes them more flexible to reduce production and irrigation costs during the drought and resume production once the drought is over. The decision on the crop type defines the degree of dependency on water actions or, more explicitly, the adverse impact reduced water assignation has over the farmer. Thus, diversification to increase flexibility is possible strategy (Folke et al., 2005).

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[10] Farmer 3 who focuses on horticulture states that for vegetable production, it is economically more convenient to leave the fields fallow than producing under drought conditions: "Porque económicamente es mejor dejar secar y volver a entrar después" (Farmer 3).

The investment in storage infrastructure increases flexibility and thus, reduces drought vulnerability as when there are *turnos de agua* farmers do not receive water volumes daily but once every 18 to 20 days so that a tank with enough storage capacity helps to bridge the weeks without water distribution by ACER. The farmer's individual water management determines the success of agricultural production. Flexibility in irrigation scheduling further reduces drought vulnerability (Playán & Mateos, 2006), while the opposite, the inflexibility in irrigation schedules is portrayed in the case of Farmer 2 (cf. sub-chapter 6.4.2).

6.3 Adaption strategies

Enhanced adaptive capacity is supposed to decrease the specific vulnerability of a system and thus, differences in adaptive capacity may lead to differences in drought vulnerability. In this section, several collective and individual strategies at several temporal scales are highlighted (Adger et al., 2007) (Table 5).

6.3.1 Present adaptation

At the level of the Paloma System, the water user organizations who are members of the CASEP cooperate by transferring water from river organizations to channel associations or vice versa in order to reduce the impacts of drought. Longer-term strategies focus on the improvement of the Paloma System's channels and the reservoir. State aid partly funds these projects (CASEP. Administrator).

At present, ACER's short-term strategy to reduce drought vulnerability focuses on reducing water losses in form of water distribution via *turnos de agua*, the concentration of water demands in short time frames. Additionally, the permanent communication between ACER's administration, watchmen and farmers as well as the distribution of irrigation schedules are mechanisms to provide better planning (ACER. Vice-president).

As long-term adaptations, the organization postulates for maintenance projects and the ACER-owned construction enterprise *Construcción y Riego S.A.* continuously works on improvements of the channel network (ACER. Administrator). These maintenance projects are partly funded by the Chilean state, however, water user organizations discovered that in many cases it is more convenient to take a bank loan rather than postulating for state aid (CASEP. Administrator).

Farmers count on a series of strategies to reduce the adverse effects of drought and as already stated in the previous sections these differ concerning crop type. While crop management targeted at reducing water demands of a crop species is a common strategy for permanent crops, farmers with temporary crops often opt for leaving their fields in fallow for the time hydrologic stress remains, while they have the choice to transfer their water to another person's water account.

In general, improved water management in terms of water distribution, increased application of irrigation technologies, the realization of maintenance work of the existing distribution and storage infrastructure as well as the construction of new storage infrastructure are farmers' long-term responses to drought. Active crop management with selection of drought-resistant species and pruning increase the preparedness of a crop to a drought.

On the short term, as an immediate response to drought, i.e. as an action of coping capacity (Berman et al., 2012), farmers with temporary crops decide to reduce their productive surface, while farmers with permanent crops also have the choice to concentrate their waters on a limited area and cut down the rest in order to mitigate the costs and losses.

Table 5: Adaptation strategies to reduce drought vulnerability
(Elaborated by the author based on SSI's data; Includes potential future strategies for CASEP and ACER)

Stakeholder	Short-term adaptations	Long-term adaptations
CASEP	- Water transfer between user organizations	- Maintenance of channels and reservoir
		- Update of Operational Model - Cloud seeding - Renovation of Matriz channel
ACER	- Water distribution in *turnos de agua*	- Maintenance of channels and reservoir - Active communication and information network
		- Enlarge Recoleta dam
Individual	- Acquisition/ Sale of water volumes - Leave fields fallow - Cut down part of production - Drill wells	- Selection of crop type (e.g. drought-resistant variety) - Acquisition additional water rights - Investment in irrigation technology and infrastructure

6.3.2 Future strategies

Recoleta stakeholders were additionally asked whether they had any specific strategies to face future drought events.

At the CASEP scale, transversal projects, which benefit not only one water user organization, but the whole river basin was mentioned in order to reduce drought vulnerability. ACER's vice-president asked for maintenance works of the Matriz Channel, which is the primary channel of the Paloma dam and a reduction in conduction losses would therefore bring a benefit to the whole Paloma System

(ACER. Vice-president). Another highly-discussed topic at the basin scale is cloud seeding (CASEP. Administrator). There are discussions on committing the Universidad La Serena with this task.

ACER's future strategy is to maintain the current focus on loss reduction with the help of maintenance works of the channel network, the reservoirs, better monitoring and management as well as the promotion of highly efficient irrigation technology among all Recoleta farmers (ACER. Sub-administrator). A further step may be to enlarge the Recoleta dam's storage capacity, as it has already spilled over several times during heavy rainfall events (ACER. Vice-president).

Another point of concern for the CASEP and also ACER is a revision of the Operational Model as this was written and implemented in the 1970s, where the Paloma System's reality was a different one from the current situation when looking, for instance, at the crop patterns and the switch to permanent crops with higher water requirements (ACER. Vice-president).

When asked about future strategies, Recoleta farmers responded to maintain what has been done until now, as all of them are actively engaged in activities to reduce their specific drought vulnerability.

6.4 A glance inside the system

To get an impression on the reality of how Recoleta farmers face drought, three individual cases are presented, which introduce the diversity in differential drought vulnerability of the elements of the Recoleta System.

Farmer 1 is located in Samo Bajo, close to the Recoleta reservoir, while Farmer 2 and Farmer 3 are located in a part called Llanos de Limarí (Figure 21).

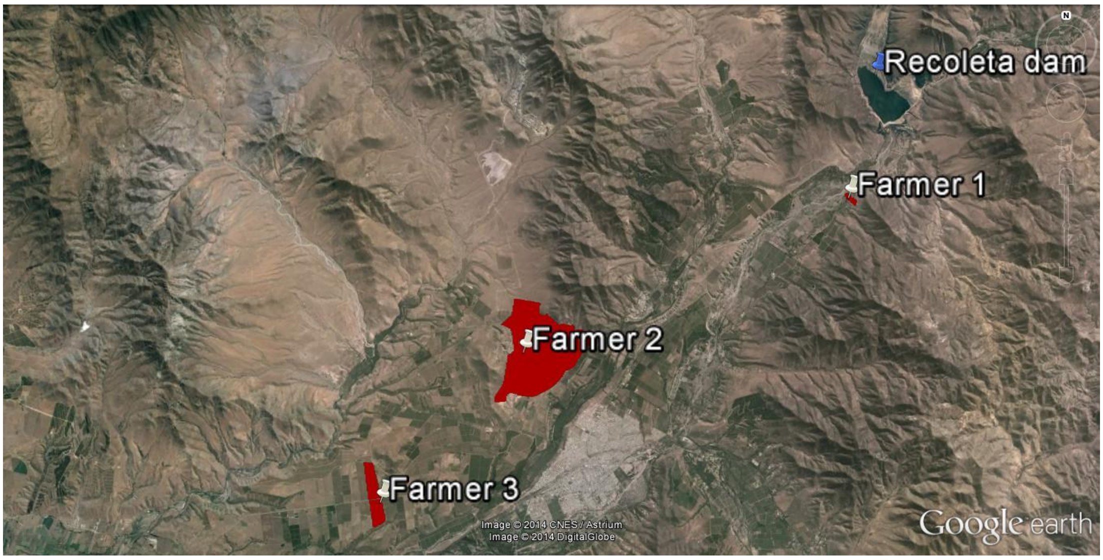

Figure 21: Farmers' location in the Recoleta System
(Farmers' locations are marked in white and their cultivated areas in red, respectively; Elaborated by the author with Google Earth and data from ArcGis)

6.4.1 Farmer 1: Irrigate the total area... poorly.

Farmer 1 owns 9.9 water actions with which – under normal conditions – he is able to satisfy the water needs of his six hectares of avocado plantations. However, in the agricultural year 2013/14 the amount assigned to each water right has only been 400 m^3, while during normal years Farmer 1 receives around 3500 m^3 per action and year.

The current agricultural year is already the second one without harvesting a single avocado, which implies no income but at the same time costs for water, labor force and energy represent an additional burden. One part of Farmer 1's fields is located above the channel, thus, a considerable amount of energy for bombing the water uphill is needed. However, the property has no access to a high-voltage energy source, thus, water bombing is slow and expensive.

There is no elaborated strategy, how situations faced by Farmer 1 are tackled during drought situations: Currently, this farmer irrigates the total planted area – but poorly. He applies deficit irrigation with the small amount of water distributed by ACER and additionally, with ground water accessed by a well. Subsequently, the avocado trees suffer permanent water stress.

He decided to irrigate the whole planted area because cutting down the trees and painting them white to reduce water demands would have implied more costs. Besides, there would not be any harvest for the next three years as it takes several years until the avocados will produce fruits again.

Spatially, Farmer 1 does not perceive any differences in drought vulnerability but compared to the past, the current situation is more extreme as it is already three years that he is experiencing adverse impacts. Nonetheless, when looking at the future the single option he sees is praying for rain and waiting for better times to come, as his advanced age of 67 years and lack of formation do not allow him to work elsewhere (Farmer 1).

Farmer 1 is highly vulnerable to the current drought due to his limited economic resources, the inflexible situation of having permanent crops and the lack of other income sources.

6.4.2 Farmer 2: Continues to improve water management.

Farmer 2 represents the perception of drought vulnerability of a Spanish agribusiness cultivating almost 700 hectares of olive trees for olive oil production for to the European market, primarily to Spain, and most recently also to the Chilean market. Permanent crops face water scarcity, but the situation in the current agricultural year is less severe than the previous one due to improved water and crop management techniques and strategies. As a result, although the water allocation in 2013/14 is lower, the company can maintain the whole cultivated area.

A threat to the company's planning is that ACER did not respect the provided schedule of the *turnos de agua* in several situations, which, in turn, affected the programming of the company. Nonetheless, the company can rely on a well, water actions for the river and two water tanks with a total storing capacity of 85.000 m^3 as additional water sources.

Compared to the directly surrounding neighbors who cultivate both, permanent and temporary crops, the agribusiness is less vulnerable to current droughts. Their great advantage lies in cultivating a permanent crop, which is a species already adapted to water stress and salts, with low hydrological demand in comparison to other permanent crops. Additionally, this Spanish enterprise has permanent contact with its Spanish partners and the purchase of the whole production is guaranteed.

For twelve years now, the company resides in Chile but there has not been a single dry spell comparable to the current one. Future strategies are not made yet, as they still wait for the rain to come (Farmer 2).

6.4.3 Farmer 3: Reduce and maintain.

While Farmer 1 and 2 plant permanent crops, Farmer 3 is an example for a production unit with a focus on horticulture although the middle-scale family business recently initiated cultivating a small area with citrus fruits and avocado.

From the 500 hectares of arable land, only 80 hectares are planted, which is a remarkable reduction of the productive surface to reduce drought impacts. Although Farmer 3 owns 830 water actions, ironically, during the current drought period it is more convenient to sell the water than to plant vegetables. Thus, there is almost no horticulture and water is exclusively applied to the limited area with permanent crops. Other horticultural producers nearby act similarly: selling their water and leaving their fields fallow, which gives the region the aspect of an extraordinarily dry one.

Reduce the productive surface, sell water and maintain the enterprise is Famer 3's adaptation strategy to cope with the drought event. New technologies, improvement in water management and the construction of new and maintenance of existing storage infrastructure slightly improve the harsh conditions.

In the history of the family business, there is no comparable drought period to the current one, - probably related with the change in land use and the increase in the total planted surface nowadays.

If it does not rain in the near future, current practices will be maintained (Farmer 3).

7 DISCUSSION

7.1 Paradox: The advantage of "not having"

Apparently, the reduction in variability in water availability as a result of the homogenization of the climatic conditions due to the construction of the reservoirs has increased irrigation security for the Recoleta System. This induced the shift from temporary to permanent crops, as the latter are economically more profitable. At least, for those who were able to afford high investments.

But what happens next? Under drought conditions, the situation is reverse: Those who invested high amounts into their plantations are less flexible and thus, highly affected by and vulnerable to drought hazards. Their capacity to respond to droughts is low compared to farmers with temporary crops, as these have a broader range of possible alternatives and, in case of selling water and leaving the system for the current period, do not depend exclusively on incomes from their production.

The advantage of *not having* permanent crops, an expression adopted from ACER's vice-president, refers to those farmers who do not have "trees" (permanent crops).[11]

Ironically, the reservoir system planned as an adaptation to drought and dry spells and most of the time also working as such, finally turns out to be a trap. The reduction of variability in water availability, i.e. the artificial irrigation security provided by the reservoirs encouraged changes in crop types towards highly water-demanding permanent crops. In a situation of a Recoleta drought, farmers with permanent crops are highly vulnerable to this stress, whereas farmers with low-investment crops can exit the system temporally and return whenever the climatic conditions favor it.

However, it should be stressed that there are farmers who had to leave the Recoleta System, not only spatially but in their function as farmers, as they were not able to maintain their agricultural activities under the current drought period. These producers by leaving the Recoleta System crossed a *threshold* into a new *system state*; the words in italics are terminology taken from resilience literature, which links up to the next discussion topic (Resilience Alliance, 2010).

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[11] "Yo creo que los que menos sufren son los que menos tienen. Increíblemente. Los que menos tienen, menos sufren. […] asumamos un cultivo permanente ya es *tener*" (ACER. Vice-president).

7.2 Bridging the gap: From vulnerability to resilience

Gallopín (2006) emphasizes that the

> “fundamental distinction between vulnerability and resilience lies in that vulnerability refers to the capacity to preserve the structure of the system while resilience refers to its capacity to recover from non-structural changes and dynamics” (Gallopín, 2006: 295).

Resilience is a competing concept to vulnerability and the terms are sometimes seen as two sides of a coin (Gallopín, 2006). Thus, the decision of not incorporating it into the study’s conceptual framework is due to the risk of mixing up concepts and resulting in more confusion than understanding. Nonetheless, to approach the Recoleta System’s boundaries, it was made use of the Resilience Alliance *Workbook for Practitioners* to assess social-ecological systems. Besides, the research community working on social-ecological systems particularly focuses on resilience of these systems (Resilience Alliance, 2010). Hence, resilience is worth a discussion and may be of help for further studies on the Chilean case study.

As with vulnerability, there is no universally accepted definition for the term resilience and on its constituent parts (Folke, 2006). However, according to Walker and colleagues (2004), resilience can be considered as

> “[…] the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks” (Walker et al., 2004: 5).

Beyond the conceptual differences of vulnerability and resilience it becomes clear that in order to understand the dynamic nature of social-ecological systems, both approaches are of relevance and research on their linkage is desirable. There are voices which see adaptive capacity as the concept that may bridge the gap between vulnerability and resilience research, which is an interesting starting point for further studies (Engle, 2011). Gallopín (2006) discusses the differences between capacity of response and adaptive capacity to make an intent to link vulnerability and resilience via adaptive capacity.

Adopting the abovementioned definition by Walker and colleagues (2004), it can be asked whether the Recoleta System is a resilient system. The disturbance event is unmistakably the drought, which leads to modifications in the system’s functioning (Resilience Alliance, 2010). Still, the Recoleta System retains its identity as an agricultural ecosystem although its system components suffer under the disturbance. When looking at the broader system scale, the Paloma System enters into failure state. However, it has to be expected that, once the reservoirs return into functioning, the system resumes works.

As a conclusion, further studies on the Recoleta System can focus on the resilience of this system and analyze the thresholds crossed as well as potential thresholds to be crossed in the future.

7.3 Reflection on visualization of drought vulnerability

Initially, one of the main objectives of this study was the visualization of the differences in drought vulnerability among Recoleta system's elements in form of a map because the graphical presentation via maps highlights these differences in an appealing way.

Nonetheless, this task turned out to be unfeasible in the limited amount of time available for field research. Besides, the attempts to make stakeholders indicate areas which are more or less vulnerable, failed as they referred to the organization's solidarity concept, which provides homogenous conditions for the whole system (ACER. Vice-president; ACER. Sub-administrator).

Consequently, for future studies, it is of great interest to perform walking interviews with the farmers of the Recoleta System in order to assess their specific drought vulnerability and reference these findings to a certain place in the system. The walking interview is a mixture of interview and participant observation where questions and explications are made along the walked transect. It helps to understand and "access people's attitudes and knowledge about the surrounding environment" (Evans & Jones, 2011:850). The recorded information can be geo-referenced to specific places with the help of a GPS device. Finally, with the help of a Geographic Information System, differences in drought vulnerability can be highlighted in a map. The disadvantage of this type of interview is that it is extremely time-consuming and, just as with any other forms of drought vulnerability mapping, it will only show a snapshot of one specific situation.

As maps only depict a certain moment of the social-ecological system's vulnerability to drought, the dynamic nature and multi-scalar relations of these systems remain unnoticed. For instance, the Recoleta System's boundaries are not fixed but soft boundaries (Resilience Alliance, 2010); the system's spatial extent experiences intra- and interannual changes, as the irrigated area is dynamic in time and space depending on the water available and on farmer decisions about planting. Mapping these changes is a challenging task.

A way to approach the visualization of the Recoleta System’s differential drought vulnerability is to compare the planted with the non-planted areas making use of a satellite image of the hydrological year 2013/14. The problem here is that some of the fields might just have been cut down as crops were harvested. Furthermore, temporary and permanent crops should be distinguished as the non-planted area of a farmer with temporary crops does not make him more drought vulnerable, in contrast, not planting is probably a management decision to reduce losses.

An approach to highlight temporal differences in drought vulnerability is to compare satellite images of a past Recoleta drought year, such as the agricultural year 1996/97, with a normal year, as well as the current drought year 2013/14 with a normal year by using the Normalized Difference Vegetation Index and highlighting the differences. The products will be several maps which indicate the changes in vegetation cover.

8 CONCLUSION

Assessing drought vulnerability, as the aim of this work, includes as term itself at least two expressions with no universally accepted definition and concept. However, a stepwise approach based on a combination of qualitative and quantitative data to assess drought vulnerability of a social-ecological system is accomplished.

The analysis of the agricultural Recoleta System characterized by its irrigation infrastructure and active water governance institution ACER resulted in the rejection of the hypotheses on variables, which were thought to induce differences in drought vulnerability within the focal system.

Recoleta drought vulnerability is closely related to water stored in the reservoir system: a Recoleta drought can be defined as an event determined by the storage volume of the reservoirs and decisions made on water allocation by the respective water organizations. During field research, the Recoleta System suffered an extraordinarily impacting drought.

Drought vulnerability differs among several organizational scales. At the super system-scale of the CASEP, there are differences in drought vulnerability among the eight water user organizations. ACER, the focal system organization, appears to be less vulnerable due to the irrigation infrastructure, two reservoirs as water sources and an internalized mechanism called solidarity concept, which is supposed to guarantee an equal distribution of losses among all farmers of the association.

Yet, drought vulnerability differs between Recoleta farmers, a fact closely related to the decision to plant permanent or temporary crops. While farmers are more flexible during a drought event when focusing on temporary crops, permanent crops predominate the system's agricultural surface as they economically more profitable – unless a drought occurs.

An insight on specific drought vulnerability of Recoleta's farmers highlights the different faces drought vulnerability assumes. In short, drought vulnerability is a transversal topic for Recoleta farmers and water user organizations, which affects all.

Adaptations to drought vulnerability are realized at all spatial scales in the Recoleta System and its related super system and system components; unplanned and in direct response to water scarcity as well as in form of long-term strategies. The expertise of ACER in water governance is supposed to enhance adaptive capacity to drought of the Recoleta System. However, ACER's water management approach is rather top-down, although communication between the organization and its members is both-way. Long-term adaptations including changes in institutional functioning are supposed to reduce drought vulnerability of the focal system (Hurlbert & Diaz, 2013).

8.1 Recommendations, shortcomings and outlook

Enhancing long-term adaptive capacity rather than mitigating short-term impacts is the recommended focus for the Recoleta System's water user organization ACER as well as for the super system organization CASEP. Interview results showed the need for readdressing and modifying the functioning of the Operational Model as the permanent rule for water distribution.

When referring to the WEIN project with its German and Chilean partners, like in most international projects, more frequent communication may improve cooperation, facilitate the research of several institutions and thus, generate more added value to the project's aims. Additionally, for future master theses a common database – alongside RBIS Limarí – can contribute to better prepare the three months of field research.

Future research on the Recoleta System may focus on visualization of drought vulnerability by using walking interviews to geo-reference farmers' perceptions with the specific places and thus, allow the creation of drought vulnerability maps. Flexibility of farmers as a variable to induce differences in drought vulnerability is another interesting topic for further research. Finally, beyond the Recoleta System also in the field of the theoretical background of drought vulnerability, still gaps remain and offer a wide variety of topics to be investigated.

The closing remark is a statement on the most frequently pronounced wish of Recoleta farmers and water organization representatives for water in form of precipitation, which highlights the borders of human influence on natural, climatic conditions:

> "Concerning the future, I think if you ask any farmer here, they hope that it will rain, nothing else, it *has* to rain. If there is no water, there is no life."[12]

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[12] "El futuro […] Yo creo que si le preguntas a cualquier agricultor, tienen la esperanza que llueva. No hay otra cosa, tiene que llover. Si no hay agua, no hay vida" (Farmer 2).

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ACER. Sub-administrator. Marco Tirado. Realized: 07.05.14 in Office of ACER, Ovalle, Chile.

ACER. Vice-president. Guillermo Farr. Realized: 14.05.14 in Office of ACER, Ovalle, Chile.

Farmer 1. Francisco Rodriguez. Realized: 22.05.14 in El Quiscal, Samo Bajo, Ovalle, Chile.

Farmer 2. Jorge Rojas (Agronoble S.A.). Realized: 22.05.14 in Llanos de Limarí, Ovalle, Chile.

Farmer 3. Alex Valdivia. Realized: 22.05.14 in Llanos de Limarí, Ovalle, Chile.

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[13] For the complete transcription of the interviews, please contact the author.