ADAPTIVE CO-MANAGEMENT FOR LOCAL WATER RESILIENCE: THE CASE OF COMMUNITY-LED ECOSYSTEM-BASED ADAPTATION IN THE PERUVIAN ANDES

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Abstract

Ecosystem-based adaptation (EbA) champions the use of biodiversity and ecosystem services to help people adapt to the adverse effects of climate change. Moreover, EbA presents an exemplary opportunity to confer social-ecological resilience. But how can such initiatives be effectively implemented and managed towards a resilient supply of key ecosystem services? Through case study research on community-led water sow and harvest (WSH) – a traditional form of EbA in the Peruvian Andes – this thesis explores social-ecological conditions for self-organization, collaboration and learning for the adoption of the practice, as well as the emergence of adaptive co-management (ACM) and its potential for building local water resilience. Qualitative data collected from interviews and participatory observations were thematically coded, and analysed for self-organization using the Multilevel Nested Framework (Ostrom 2009) and subsequently for social learning using ACM literature. This study found that self-organization for the adoption of WSH was primarily influenced by strong leadership, the importance of the water resource to the community, and users bonded by formal institutions of collective choice and social norms rooted in Andean culture. In addition, four types of collaboration and five learning activities were found to conform a social learning process and result in social learning outcomes for enhanced adaptive capacity, indicating the emergence of ACM around community-led WSH. By supporting knowledge exchange through a social network, ACM allows the practice to be scaled-up to create enabling legislation, scaled-out to increase the number of communities adopting WSH, and scaled-deep to support cultural internalization of the practice. Such scaling can potentially enable community-led WSH to build local water resilience through: 1) implementation at the landscape level to match the scale of ecological processes that sustain water ecosystem services; and 2) continuous management over time to support adaptive forms of water resource governance in the face of change and uncertainty.
I. Introduction

1.1. A Resilience Approach to Ecosystem-based Adaptation

The Andean region currently faces strong climate change impacts on its water resources, including a decrease in average annual precipitation due to alterations in the water cycle and changing precipitation patterns (MINAM 2016). Water scarcity in the semi-arid Andes is further aggravated by changes to the hydrological regime and/or loss of ecological integrity in the highland wetland ecosystem as a result of overgrazing, deforestation and land-use change (Vásquez et al. 2014). To respond to climate shocks and changing conditions in water supply, ecosystem-based approaches for water management are increasingly being implemented. Ecosystem-based adaptation (EbA), in particular, “integrates the use of biodiversity and ecosystem services into an overall strategy to help people adapt to the adverse impacts of climate change” (Colls et al. 2009), where ecosystem services are the direct or indirect benefits people derive from nature (MEA 2005).

In the context of sustainable development\(^1\), a social-ecological resilience approach views humans and nature as “intertwined and interdependent social-ecological systems, where human actions shape ecosystem dynamics from local to global scales” (Biggs et al. 2015:5). A social-ecological system “consists of an ecosystem, the management of this ecosystem by actors and organizations, and the formal and informal institutions (e.g. rules, social norms and conventions) underlying this management” (Hahn et al. 2008:120). Resilience of a social-ecological system refers to its capacity to reorganize and adapt (or transform) in response to abrupt or unexpected change (Walker et al. 2004; Folke et al. 2005), and “to continue to provide a valued set of ecosystem services” (Biggs et al. 2015:17). Focused on the conservation, restoration and sustainable management of an ecosystem’s capacity to supply ecosystem services, EbA presents an opportunity to confer social-ecological resilience in a climate change context.

EbA is increasingly integrated with community-based adaptation (hereafter referred to together as community-led EbA). Through a ‘bottom-up’ process, communities lead adaptation initiatives based on their own needs, priorities, knowledge and capacity to deal with climate variability (Reid

\(^1\)“Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland Report – Our Common Future, 1987).
2016). Relevant to community-led EbA is ecosystem stewardship, which refers to human agency to respond to and shape change in order to sustain the supply of key ecosystem services (Chapin et al. 2009). Thus, a social-ecological resilience approach to community-led EbA involves stewards navigating optimal ecosystem function and securing the provision of ecosystem services in the face of climate change (Chapin et al. 2009; Biggs et al. 2012).

1.2. Ecosystem-Based Adaptation for Local Water Resilience

In the Peruvian Andes, a locally conceived form of EbA is water sow and harvest (WSH). This practice is centered around the protection and sustainable management of highland wetland ecosystems in response to climate change-induced rain variability and water insecurity. Local water resilience – the sustained provision of water ecosystem services, recognizes the critical “role of water in safeguarding and sustaining a particular desired state of a social-ecological system” (Falkenmark et al. 2019:2). Building local water resilience with community-led WSH thus involves ecosystem stewardship of the local land component (i.e. highland wetland ecosystem) of the hydrological cycle. By managing ‘hydrological flow regulation’ and ‘water retention in watersheds and aquifers’, stewards can enhance water-regulating and-provisioning ecosystem services, respectively (Costanza et al. 1998).

Similar forms of this practice exist around the world, more commonly referred to as rainwater harvest (Pandey et al. 2003; Colls et al. 2009). In the Andes, however, the use of a composite term for water sow-and-harvest is akin to the local belief that people play a key role in nurturing water resources (M Morvelli. Personal communication. 7 December 2018). Water sow traditionally refers to the ‘planting of water’ using natural infrastructure (Fig. 1) to capture rainfall in the upper or middle basin for increased ground-water recharge and provision of water during the dry season (Vásquez et al. 2014). In turn, water harvest refers to the collection of water from natural springs (known locally as manantes or ojos de agua), integrated with hard-engineered infrastructure used to transport and store the resource.
Fig 1. Images of water sow and harvest in the highland wetland ecosystem of Curahuasi district, Apurimac region, Peru. Top – the main work site where several different practices are integrated. Bottom left – reinforcement of Qocchas (i.e. lakes) with rustic dams made from natural materials. Bottom center – afforestation, hole excavation in preparation for tree planting; complemented with infiltration trenches. Bottom right – native grass conservation, placement of wooden poles in preparation for fencing to protect the area from overgrazing.

1.3. Collaboration and learning for community-led adoption of WSH

WSH is based on traditional ecological knowledge developed by pre-Columbian societies in the Andes, yet this knowledge has been lost or eroded in many local communities (MINAGRI 2016). The recovery of this practice as a promising adaptation measure for local water resilience in the face of climate change will depend on its long-term management, underscored by continuous investment in collaboration and learning. Moreover, new knowledge will have to be developed to modify WSH practices in response to climate conditions different to those under which the practices were historically developed.

1.4. Knowledge gap and research questions

The current climate crisis calls for increased knowledge of approaches that deliver resilient natural resource governance. Existing literature propose that EbA can support overall system resilience and increased adaptive capacity (CBD 2009; Colls et al. 2009; Reid 2016; Lafortezza et al. 2018). However, knowledge is limited on how to operationalize these initiatives at the local level
(Wamsler et al. 2016), and more so, towards building key resilience attributes. As EbA and community-based adaptation approaches are relatively new disciplines, there is a need to better understand what institutional and social contexts make them successful. To this end, more evidence is needed on management approaches that enable community-led EbA to provide a resilient supply of ecosystem services.

Resilience theory proposes adaptive co-management (ACM) as a collaborative and adaptive approach that nurtures social learning for natural resources governance and social-ecological resilience (Plummer and Armitage 2007). ACM has previously been applied to ecosystem-based initiatives, including Biosphere Reserves (Olsson et al. 2007; Schultz et al. 2011; Plummer et al. 2017), ecosystem-based management of fisheries (Berkes 2012), and conservation or protected areas (Plummer and Fennell 2009; Sandström and Rova 2010). However, adaptive management is not well captured in the principles established for ecosystem-based approaches (Cohen-Shacham et al. 2019). In addition, there is need for “measuring and monitoring the conditions from which ACM may emerge” (Armitage, Berkes and Doubleday 2007:9), and information is limited on how the governance dimension of ACM can be addressed to strengthen local stakeholders’ capacity to deal with uncertainty and change (Olsson et al. 2007).

With interest growing in WSH across communities in the region, more information is needed to direct such initiatives on true resilience pathways. One way forward is to explore how community-led WSH can be effectively implemented and managed towards building local water resilience. Through case study research on community-led WSH in the community of Puca Puca, this thesis aims to empirically assess the emergence of ACM, and its potential for building local water resilience. To this purpose, two specific research questions are posed: (1) What social-ecological conditions enabled the community of Puca Puca to self-organize around the adoption of water sow and harvest? and (2) What is the relationship between collaboration and learning in community-led water sow and harvest?
II. Theoretical Framework: Adaptive Co-Management for Resilience

ACM combines adaptive management’s focus on iterative learning-by-doing through experimentation and monitoring with collaborative management’s focus on participatory and inclusive decision-making for the allocation and use of resources (Plummer 2009). This management approach emphasizes the exchange of diverse knowledge sources between multiple stakeholders and involves the sharing of power between communities and government at different scales (Olsson et al. 2004a; Berkes 2007; Plummer and FitzGibbon. 2004).

Central to this study, is the idea that ACM develops through self-organization, allowing local communities to actively adapt to and shape change. Such self-organization has been described to arise under conditions of good leadership, social capital, multiple sources of knowledge, social networks and arenas of collaborative learning, and enabling legislation, as well as in response to environmental crisis (Olsson et al. 2004a; Ostrom 2009). ACM has further been described as a continuous process (i.e. iterative cycle) of institutional change, by which society tests and revises institutional arrangements and builds ecological knowledge in a dynamic, ongoing, self-organized process of trial-and-error (Folke et al. 2002; Plummer and Armitage 2007). Olsson and colleagues (2004a:87) propose that the “self-organizing process of ACM development, facilitated by rules and incentives at higher levels, has the potential to make the social-ecological system more robust to change”.

Social learning is a key component of ACM (Plummer and Armitage 2007) and refers to a “change in understanding that goes beyond the individual to become situated within wider social units of communities of practice2 through social interactions between actors within social networks” (Reed et al. 2010:5). Self-organized social learning for ecosystem management thus provides a platform for collective action and learning in response to environmental feedback (Olsson et al. 2004a). In particular, it can play a “key role in developing ecological knowledge and creating, reevaluating and reshaping management practices, rules and organizational structures” (Olsson et al. 2004a:77).

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2 “A ‘community of practice’ refers to a group or groups of people who share a concern for something that they do, and learn how to do it better through regular interaction” (Cundill 2010).
Thus, the literature on ACM describes social learning as a relevant attribute of resilience (Biggs et al. 2015).

Social-ecological systems are complex and adaptive in nature (i.e. complex adaptive systems) and their governance, especially during periods of abrupt change, requires flexibility and ability to respond to environmental feedback (Olsson et al. 2004a; Folke et al. 2005). Such adaptive capacity refers to the ability of the resource governance system to alter processes and structural elements in response to change (Pahl-Wostl 2009). Social learning builds the adaptive capacity of actors within that governance system to influence resilience by developing knowledge to shape ecosystem dynamics, respond to change (Walker et al. 2004), and enhance “fit between institutions and ecosystem dynamics” (Olsson et al. 2007:2). In this regard, social learning is considered “essential for governing social-ecological systems during periods of abrupt change” (Pahl-Wostl 2009:355).

Based on the literature presented above, the working premise for this thesis is that EbA, operationalized with ACM, can enhance social-ecological resilience in the face of climate change. The dynamics underpinning this premise are englobed in the ‘ACM for Resilience’ conceptual framework (Fig. 2) constructed for this thesis (see methods section 3.4), where self-organization, social learning and adaptive capacity form the iterative cycle of ACM towards building resilience of key ecosystem services over time.
Fig 2. The ‘ACM for Resilience’ conceptual framework links three key components of ACM: self-organization, social learning and adaptive capacity, in an iterative mechanism towards building ecosystem service resilience. The blue sphere represents the ‘Adoption of WSH’, a phase in which all three framework components begin to emerge. The blue-to-green spirals represent the transition towards ‘Continuous management of WSH’, in which all three framework components continue to feedback over time towards securing a resilient supply of key ecosystem services. Regarding these feedbacks, arrow n.1 corresponds to the social-ecological conditions that support self-organization; arrow n.2 corresponds to knowledge exchange through a social network, which supports the process of social learning; and arrow n.3 corresponds to social learning outcomes that build adaptive capacity in the social-ecological system; adaptive capacity then feedbacks into self-organization by strengthening social-ecological conditions needed in community-led management of WSH. Overall, this figure is a descriptive representation of the social sphere of natural resources governance, and is embedded within the natural sphere (not portrayed) involving multiple ecosystem components to be managed.
III. Methods

3.1. Research approach & epistemological background

Case Study Research (CSR) was conducted to empirically investigate community-led WSH within its real-world context (Yin 2014). The aim was to build a narrative account of WSH based on a qualitative understanding of stakeholders’ perspectives (Newing et al. 2011), decision-making and implementation processes and their results (Yin 2014). Thus, the focus of this study is on the social dimension of the WSH social-ecological system. “By utilizing in-depth insights of empirical phenomena and their context”, this case study provides an opportunity to further develop ACM theory based on unique “theoretical insights gained during the [research] process” (Dubois and Gadde 2002:555). In order to empirically ground theory, abductive reasoning (Straus and Corbin 1990; Timmermans and Tavory 2012; Bryman 2012) was used for analytical inference to appropriately match reality to theoretical constructs (Dubois and Gadde 2002).

3.2. Case study description

The case study was conducted in the Andean rural community of Puca Puca. The study area (Fig. 3) is located in Abancay province, Apurimac region of Peru, and encompasses the district town of Curahuasi, the community of Puca Puca (13°36’29.5" S; 72°41'01.7” W), and the community’s WSH work site in the upper water basin (part of the Chalhualloc micro-basin). Puca Puca was selected (as per recommendation of the regional WSH expert) for demonstrating strong self-organization around the adoption of WSH, which was of interest for empirical analysis of ACM theory. The community began practicing WSH in early 2017, and at the time of study was finishing its second year of implementation. Thus, this study focuses on the ‘adoption phase’ of community-led WSH, which considers both the decision to use an EbA approach for water management and its implementation. It allows an in-depth view into the social dynamics around the adoption of the practice, as well as on the prospective for long-term management under a resilience lens.
Though Puca Puca’s WSH was the primary subject of study, complementary information on WSH experiences in four neighboring communities\(^3\) (i.e. Ccochua, Ccecceray, Antilla and Collpa) was included for the following reasons. It was found that communities practicing WSH in the district (and beyond) were connected, whereby information collected for Puca Puca also included information for other communities. This connectivity was valuable for studying present learning and collaboration among communities, as well as the far broader social-political context in which community-led WSH takes place. In addition, it allows for a comparative assessment of Puca Puca’s WSH’s unique features.

\(^3\) Members of these five communities converge within the district city of Curahuasi. These communities have also collaborated, or are collaborating with the regional WSH expert.

**Fig. 3.** A) Map of Peru showing the location of Apurimac Region in red. B) Map of case study sites, including (1) District town of Curahuasi, (2) Community of Puca Puca, (3) Work site for Puca Puca’s water sow practice, (4) Community of Ccochua and (5) Community of Ccecceray: Communities of (6) Antilla and (7) Collpa are not pictured. C) Zoom map of the area. Items 1-3 represent the main case study on Puca Puca, and items 4-7 represent the communities included as complement.
Field research was conducted between November-December 2018, just before the start of the ‘rain season’ – when water sow activities end and water harvest activities predominate. During this period, Puca Puca conducted one community assembly and two full-day WSH work trips to their upper mountain territory, which the researcher attended. The researcher also participated in a series of ‘daily life’ activities in the district of Curahuasi (e.g. radio programs, one municipal assembly, informal gatherings, and more) where information on the social dynamics around WSH could be gathered. This research was approved by the Ethics Committee of the Stockholm Resilience Centre (see Ethical Review, Appendix 2).

3.3. Methods for data collection and data sources

The primary method for qualitative data collection was semi-structured interviews, which allowed insight into diverse stakeholder perceptions and experiences around the adoption of WSH. Three types of interviews were conducted: individual interviews (n = 38 participants), focus group interviews (n = 11 participants) and survey interviews (n = 16 participants). The participant sample size was constrained by the number of attendees to WSH activities, but was large and diverse enough (Yin 2014) to gather adequate information on the case study. A questionnaire (Table 1) was used as the main ‘verbal line of inquiry’ for all interviews; it was constructed based on literature review, preliminary topics linked to self-organization (research question 1), and consultation with the regional WSH expert. The survey component of the questionnaire was conducted separately to ask for a qualitative ‘measure’ – high, medium, low – of social capital indicators identified by Pretty (2003): trust (i.e. in leaders and each other), reciprocity (i.e. equal exchange of effort), rule compliance (i.e. upholding formal institutions, and the application of sanctions) and connectedness (i.e. relationships among WSH participants).

Participatory observations were a secondary method for qualitative data collection, enabling the researcher to piece together non-verbal evidence on social conditions relevant to the adoption of WSH. These occurred through the researcher’s immersion in all “daily life” activities relevant to WSH taking place during the stage of fieldwork. Participants were observed to obtain information on social interactions, attitudes and behaviours (Marshall and Rossman 1989; Yin 2014); some case-specific characteristics were captured with photographs for detail.
Table 1. Presentation of questionnaire topics A-C used in qualitative interviews, including a description of their pre-set objective and the relevant data sources.

<table>
<thead>
<tr>
<th>Questionnaire topic</th>
<th>Pre-set objective</th>
<th>Data source(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A WSH practice</td>
<td>Characterization of the water sow and water harvest practices.</td>
<td>Individual interviews; Focus group interviews</td>
</tr>
<tr>
<td>B Social conditions of WSH</td>
<td>Characterization of social conditions that led to the adoption of WSH, with a focus on learning and social capital.</td>
<td>Individual interviews; Focus group interviews; Survey interviews on social capital</td>
</tr>
<tr>
<td>C Local perspectives around WSH</td>
<td>Context-specific views, opinions and experiences on climate change challenges, the value of water, objectives and motivation for work and results observed.</td>
<td>Individual interviews; Focus group interviews</td>
</tr>
</tbody>
</table>

3.4. Methods for data analysis and discussion of results

For the systematic analysis of data, this study follows abductive reasoning, which uses logical inference to make sense of unstructured data. To this purpose, interview transcripts were thematically coded (Strauss and Corbin 1990; Bryman 2012) with the assistance of computer software NVivo12. A first stage of ‘open coding’ was applied to tag, or assign descriptive codes to salient ideas and concepts connected to ACM theory, as they emerged from case study data. A second stage of ‘axial coding’ was applied to connect conceptual codes within themes; for example, all data related to leadership were placed within Data Theme 7. Themes were developed based on common data characteristics, and were not “forced to fit preconceived or preexistent categories”, which is important in the process of grounding theory (Dubois and Gadde 2002:556). In order to answer the two specific research questions, a third stage of ‘selective coding’ was applied to arrange 21 core themes on social-ecological system characteristics, collaboration and learning (Table 2, Fig. 5i); these themes were subsequently analyzed using two analytical frameworks on self-organization and social learning (described below), respectively. Finally, findings were interpreted following an ‘ACM for Resilience’ conceptual framework, which was constructed by sub-setting parts of the wider ACM theory umbrella, as evidenced by case study data on community-led WSH, and emphasizing relationships between key components for building resilience.
Table 2. Presentation of three results categories, their corresponding data themes and analysis frameworks applied.

<table>
<thead>
<tr>
<th>Results Category</th>
<th>Data Themes</th>
<th>Analytical Frameworks</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Key characteristics of the social-ecological system</strong></td>
<td>(1) Climate change impact on water availability</td>
<td>The social-ecological system was analyzed using the ‘Multilevel Nested Framework’</td>
</tr>
<tr>
<td></td>
<td>(2) Water sow practices</td>
<td>and its 10 self-organization variables (Ostrom 2007; 2009) to assess the social-</td>
</tr>
<tr>
<td></td>
<td>(3) Water harvest practices</td>
<td>ecological conditions for self-organization.</td>
</tr>
<tr>
<td></td>
<td>(4) WSH results</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(5) Value of water</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(6) Motivation &amp; goals for WSH adoption</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(7) Leadership</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(8) Knowledge source and development</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(9) Social capital indicators</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(10) Cultural values, traditions and beliefs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(11) Formal institutions (rules)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(12) Informal Institutions (norms)</td>
<td></td>
</tr>
<tr>
<td><strong>Collaboration types in community-led WSH</strong></td>
<td>(13) Collaboration within community</td>
<td>‘Collaboration types’ and ‘Learning activities’ were analyzed using a ‘Social</td>
</tr>
<tr>
<td></td>
<td>(14) Collaboration with knowledge holders</td>
<td>learning in ACM’ framework (constructed based on Reed et al. 2010, Cundill and</td>
</tr>
<tr>
<td></td>
<td>(15) Collaboration with government</td>
<td>Rodela 2012, Plummer et al. 2014) to assess the social learning process and outcomes in</td>
</tr>
<tr>
<td></td>
<td>(16) Collaboration across communities</td>
<td>the context of ACM.</td>
</tr>
<tr>
<td><strong>Learning activities in community-led WSH</strong></td>
<td>(17) Internship visit</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(18) Capacity building</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(19) Faena</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(20) Radio diffusion</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(21) Monitoring of springs</td>
<td></td>
</tr>
</tbody>
</table>

The ‘Multilevel Nested Framework’ (Ostrom 2007; 2009) was used to analyse ‘key characteristics of the social-ecological system’ (data themes 1-12). This framework provides a structure for presenting the social-ecological system as four interacting sub-systems: resource system, resource units generated by the system, users of the system, and governance system. Sub-systems are composed of second-level variables, which can be analyzed based on their relevance to the research question (Ostrom 2009). For this study, a group of 10 variables across all subsystems that affect the likelihood of stakeholders self-organizing for sustainable resource management (Table 3; Fig. 4.ii), were used to identify the social-ecological conditions that enable community-led adoption of WSH (research question 1).
Table 3. The 10 self-organization variables (Ostrom 2009) assessed, and their corresponding subsystems

<table>
<thead>
<tr>
<th>Sub-system</th>
<th>Self-organization variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resource System (RS)</td>
<td>Size of resource system (RS3)</td>
</tr>
<tr>
<td></td>
<td>Productivity of system (RS5)</td>
</tr>
<tr>
<td></td>
<td>Predictability of system (RS7)</td>
</tr>
<tr>
<td>Resource Unit (RU)</td>
<td>Resource unit mobility (RU1)</td>
</tr>
<tr>
<td>Users (U)</td>
<td>Number of users (U1)</td>
</tr>
<tr>
<td></td>
<td>Leadership / entrepreneurship (U5)</td>
</tr>
<tr>
<td></td>
<td>Norms / social capital (U6)</td>
</tr>
<tr>
<td></td>
<td>Knowledge of social-ecological systems / mental model (U7)</td>
</tr>
<tr>
<td>Governance System (GS)</td>
<td>Importance of resource (U8)</td>
</tr>
<tr>
<td></td>
<td>Collective-choice rules (GS6)</td>
</tr>
</tbody>
</table>

The social-ecological system representation constructed with the Multi-Level Nested Framework is used to provide a setting for the analysis of ACM. Such context\(^4\) provides a base – in terms of the biophysical, social and social-ecological elements – for what is desirable and feasible in resource management (Plummer et al. 2014). ACM literature focused on social learning (Reed et al. 2010, Cundill and Rodela 2012, Plummer et al. 2014) was then used to construct a ‘Social learning in ACM’ analytical framework (Fig. 5iii;) for the analysis of collaboration (data themes 13-16) and learning (data themes 17-21).

\(^4\) “Context, as applied to natural resources, encompasses the dynamic forces at various scales that define what is both desirable and feasible” (Plummer et al. 2014).
Fig. 4. The research process: Twenty-one core data themes (i) were selected for analysis. Data themes 1-12 representing the ‘Key Characteristics of the social-ecological system’ were analysed using ten self-organization variables proposed by the Multilevel Nested Framework (ii). Themes 13-16 representing ‘collaboration types’ and Themes 17-21 representing ‘learning activities’ were together analysed as the social learning process around community-led WSH using existing ACM literature on social learning (iii); Learning activities were further analysed for social learning outcomes with this literature.
IV. Results

4.1. Social-ecological conditions for self-organization

The community of Puca Puca demonstrates self-organization around the adoption of WSH, a characteristic described as ‘exemplary’ by the regional WSH expert. To determine what social-ecological conditions enabled such self-organization (research question 1), data themes 1-12 were analyzed to present the social-ecological system’s 4 sub-systems (Fig. 5) within the scope of Ostrom’s (2009) 10 self-organization variables (Table 4).

The Social-Ecological System

![Diagram](image)

*Fig. 5. Adapted from Ostrom 2007 & 2009, showing the four interconnected sub-systems of the social-ecological system relevant to WSH in the community of Puca Puca. Key aspects of data themes 1-12 are provided in each sub-system box.*

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5 For a detailed presentation of data themes 1-12, see Appendix 1.
The Resource System (RS) is composed of the páramo highland wetland ecosystem located in the upper basin headwaters above 4000masl, and the water sow practices implemented in this area that contribute to the generation of water-regulating ecosystem services.

The Resource Units (RU) correspond to water flow (measured in liters) obtained through water harvest; these are the water-provisioning ecosystem services that directly benefit users. The water emerging from manantes is transported using irrigation channels towards reservoirs where the resource is stored (CM 181130_1627); the community takes turns to use water from these reservoirs, whereby “each [geographic] sector is assigned only one day of the week to irrigate their fields” (PP_JUR_P 181130_1627).

The Users (U) include the main and secondary beneficiaries of the resource. The main beneficiaries are the 235 agricultural land owners registered as members of the local resource administration Board of Users for Irrigation (JUR); JUR members are the ecosystem stewards implementing water sow practices. The secondary beneficiaries are the 19,000<sup>6</sup> residents of Curahuasi district, who use water primarily for domestic purposes.

The Governance System (GS) is integrated by the JUR, the local government (i.e. municipality) and the national government (i.e. Ministry of Agriculture and Irrigation, through Agro Rural<sup>7</sup>), as well as the informal institutions (e.g. social norms) and formal institutions (e.g. rules and sanctions) that regulate WSH and the decision-making processes by which these institutions are made. WSH is conducted under the JUR, whereby the National Government via the General Law for Rural Communities (N. 24656), has devolved decision-making power to local resource users. This grants the community the right of property to its territory, as well as the competence to regulate members’ access to natural resources and to organize the work regime around their use.

Key social-ecological conditions for community-led WSH

Eight out of the ten self-organization variables identified by Ostrom (2009) were evidenced in the current adoption phase of WSH (Table 4). Among these, four were observed to be of fundamental importance in the community’s adoption of the practice: ‘leadership / entrepreneurship’ (U5),

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<sup>7</sup> Agro Rural: National Program for Productive Rural Agrarian Development (i.e. implementing body).
of resource’ (U8), ‘collective choice rules’ (GS6), and ‘norms / social capital’ (U6)
rooted in Andean culture. These key characteristics are all within the “Users” and “Governance”
sub-systems, demonstrating the importance of the social dimension of the social-ecological system
in the adoption of WSH.

Leadership: “Three main leaders (Theme 7) act as driving agents in Puca Puca’s adoption of WSH,
where leadership has been key to successfully organize around the idea (CM 181130_1127). The
‘catalytic leader’ is Puca Puca’s JUR President, who proposed and saw through the adoption of
WSH during his two-year term. He is motivated by the community’s need for water because
“Curahuasi’s population is growing, but the opposite is happening with water” (PP_JUR_P, RH
291118), as well as by the opportunity to increase agricultural productivity. The ‘enabling leader’
is the regional WSH expert, devoted to mainstreaming the recovery or adoption of WSH and
playing a key role as the main repository of knowledge on the practice. He is respected across
communities for supporting WSH implementation, providing “technical advice to [guide]
community leaders on what to do and where” (RE_WSH 181206_0750) and mobilizing regional
and national resources to make it possible. The ‘supporting leader’ is the local radio host,
disseminating information on the challenges of water scarcity and the opportunity of WSH; he also
monitors and exposes any failed WSH commitments by the municipality. His radio station
provides a platform for communication and coordination on WSH among communities in the
province and beyond.

Importance of resource: “Water is life” and of great value (Theme 5) to Puca Puca because the
community needs the resource to “drink and feed their families, and to work their fields and raise
their animals” (CM 181130_1127; _0737; 1159). Puca Puca’s economy is fully dependent on
agriculture, and this provides strong motivation (Theme 6) for heavy investment in WSH
(REWSH, 181206_0750). In addition, action to protect water resources was prompted by a severe
drought in 2015 (FG 181201). Puca Puca’s goals with WSH are to attain water security through
the protection of the water-provisioning ecosystem, and to increase water flow for enhanced
agricultural productivity and economic development (RE_WSH 181206_0750; PP_JUR_P
181130_1610).
Collective-choice rules: The community’s work around WSH is governed by rules, “through a community by-law in which the community stipulates formal agreements”, including “what actions will be taken” (ARD 181130_1028). JUR members approve these agreements “in community assemblies led by JUR directors”, a process that “builds trust, which is important for organization” (CM 181130_1127; REWSH 181201_2239). There is “participatory community democracy” because “all is debated in assemblies, and community members approve agreements with an Act, which then serves as a work plan” (CM 181130_1127). Sanctions and penalties are imposed for failure to comply with faenas and respect irrigation turns (CM 181130_1127, _1214).

Norms: Putting formal agreements into practice, however, strongly depends upon the existence of social norms (Theme 12), or “the agreements by which people live”. Such norms play a key role in regulating behavior by dictating “what is correct or incorrect, what is good or bad, what is sacred and what is profane” (LS 181207_0945). Thus, “when one [looks] at organization, one must [consider] customs, which are the ‘true’ law of the people” (LS 181207_0945). In fact, national government “laws on water and land [-use] don’t work because customs have regulatory power” (LS 181207_0945). These ‘codes of conduct’ are deep-seated in Andean culture “around how resources should be used” (LS 181207_0945). Norms linked to Andean values, traditions and beliefs (Theme 10) are fundamental to the adoption of WSH because they “allow [communities] to work together with nature” (LS 181207_0945). Values identified as important for WSH include “responsibility, respect, cooperation (and helping each other), unity, honesty and unselfishness” (CM 181208_1230; _1242; _0127). Ancestral traditions of Minka and Ayni play a key role in WSH. Puca Puca’s faenas follow the “Minka tradition of ‘we all work together’”, underpinned by strong social capital that enables WSH to be carried out collectively. In addition, Puca Puca’s work on WSH is enhanced by collaboration between communities with the “Ayni tradition of ‘I help you, you help me’” (ARD, 181130_1028). New traditions are also forming around WSH, whereby “culture is changing” because the community is “building a tradition where [their] children will know about this work” (CM 181130_1127, 181208_1230). Local beliefs, like the view of mountains as Apu deities, evidence that “there is a deep respect for natural resources – water and land above all” (LS 181207_0945).
Social capital: indicators of trust, rule compliance, reciprocity and connectedness were assessed as social capital (Theme 9). Regarding trust among community members, 75% of respondents evaluated it as medium, indicating that trust is present because they carry out the work together, and because “every person, big or small is respected”. However, trust is reduced when people don’t attend mandatory work trips (i.e. faenas) (CM 181130_1127, _1242; 181202_1228). Regarding trust in JUR leader(s), 50% of respondents evaluated it as medium; they trust the JUR President, but rule enforcement (i.e. not imposing the agreed sanctions) is insufficient (CM 181202_1228; 181208_1230). Regarding rule compliance, 59% of respondents evaluated it as medium, and 41% as low – making it the lowest ranked social capital indicator. Faenas are missed because of the effort and time (3-4 hours walking) required to carry materials and access the work site, and because heads of households are busy working for income to meet immediate needs (CM 181208_1230). If the municipality provided transportation and a road (two commitments yet unmet by Curahuasi’s Mayor), more people would participate (RH 181129; FG 181201; CM 181130_1127, _1214). Regarding reciprocity in WSH, it was ranked highest with 81% of respondents evaluating it as medium, acknowledging that everyone puts equal effort into practice implementation (CM 181130_1127). Regarding connectedness amongst WSH faena participants, 70% of respondents evaluated it as medium, because users are linked by family relationships that strengthen participation (CM 181208_1230).

Table 4. Summary of key case-specific evidence for the 10 self-organization variables within the 4 social-ecological sub-systems.

<table>
<thead>
<tr>
<th>Self-organization variable</th>
<th>Relevance to adoption of WSH</th>
</tr>
</thead>
<tbody>
<tr>
<td>RS3 Size of resource system</td>
<td>✓ The community implements water sow practices within its legal territory. Political delimitations make the areas manageable in size and reduce costs of organization, while maintaining connectivity of the broader Paramo ecosystem to supports ecological processes for water provision.</td>
</tr>
<tr>
<td>RS5 Productivity of system</td>
<td>✓ At present, the system is moderately productive in terms of water provision (i.e. water is neither exhausted nor abundant). The adoption of WSH enhances productivity.</td>
</tr>
<tr>
<td>RS7 Predictability of system dynamics</td>
<td></td>
</tr>
<tr>
<td>RU1</td>
<td>Resource unit mobility</td>
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<tr>
<td>-----</td>
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</tr>
<tr>
<td></td>
<td>The resource unit is ‘stationary’, as water is ‘harvested’ from springs and stored in reservoirs, allowing for self-organization in terms of equitable distribution of water.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>U1</th>
<th>Number of users</th>
<th>✓</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>235 JUR members implement water sow practices and are direct users of water harvest. This (relatively) small group size represents lower costs of self-organization for the implementation of the practice. However, it also implies higher costs per individual, in terms of labor and time commitment.</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>U5</th>
<th>Leadership / entrepreneurship</th>
<th>✓</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Puca Puca’s JUR Directors are the local leaders for the implementation of WSH. Their condition as community-elected leaders to oversee all matters on water for irrigation, however, precedes the WSH initiative.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>U5</th>
<th>Leadership / entrepreneurship</th>
<th>✓</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Puca Puca’s JUR President is the catalytic leader who manages resources and navigates challenges to successfully implement WSH. The regional WSH expert is the enabling leader who provides knowledge to guide the community in the implementation of the practice, and mobilizes key resources to scale WSH across the region. The local radio host is the supporting leader who disseminates information and provides a platform for broader communication and coordination within and across communities.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>U6</th>
<th>Norms / social capital</th>
<th>✓</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Social capital indicators reveal medium levels of trust, reciprocity, rule compliance and connectedness around community participation in WSH. However, social norms linked to Andean values, traditions, and beliefs contribute to social cohesion for WSH implementation.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>U7</th>
<th>Knowledge of social-ecological system / mental model</th>
<th>✓</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Learning is currently focused on how water sow practices should be carried out. Knowledge on social-ecological system dynamics in the community is not yet evidenced, because the WSH system is designed and guided by external knowledge holders (i.e. regional WSH expert and Agro Rural).</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>U8</th>
<th>Importance of resource</th>
<th>✓</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>‘Water is life’ for Puca Puca. A severe drought in 2015 (i.e. system shock) motivated the community to work together to secure water resources for irrigation. The common goal with WSH is to increase agricultural productivity and economic diversification, as the local economy is ‘fully dependent’ on agriculture. The broader community also relies on water from local ecosystems for household use.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>GS6</th>
<th>Collective-choice rules</th>
<th>✓</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Formal institutions (i.e. community by-laws) relevant to WSH are crafted, continuously modified and enforced by collective choice (through the JUR). These rules serve as base agreements for the implementation of WSH, and include sanctions for non-compliance.</td>
<td></td>
</tr>
</tbody>
</table>
Considering the medium-to-low level of rule compliance, Andean culture is valuable for upholding community involvement in WSH. *Faenas*, in particular, have a strong foundation in *Minka* and *Ayni* traditions, and on key values of reciprocity and cooperation. However, there is a risk that over time, weak rule enforcement could jeopardize the commitment of JUR members to WSH all together, despite the strength of social norms.

Self-organization variables not evidenced, ‘predictability of system dynamics’ (RS7) and knowledge of social-ecological systems / mental model’ (U7), will likely be met through continuous management of WSH. In order to fulfill all 10 self-organization variables, the community will need to continue to learn and collaborate towards improving their knowledge of the social-ecological system.

### 4.2. Collaboration in community-led WSH

The adoption of WSH required Puca Puca to work with multiple actors and develop knowledge for the implementation of the practice. Four different types of collaboration were evidenced: collaboration within community, collaboration between community and knowledge holders, collaboration between community and government, and collaboration across communities.

**Collaboration within community** (Theme 13) in Puca Puca, entails shared decision-making processes and collective action for the implementation of WSH. All JUR members participate in assemblies, attend work *faenas*, contribute to a collective fund that covers miscellaneous expenses, and respect weekly irrigation turns for the equitable distribution of water harvested. Inclusive participation is important in Puca Puca, where women, children and the elderly are encouraged to take part in WSH.

**Collaboration between community and knowledge holders** (Theme 14), involves the community acquiring knowledge on WSH and receiving technical assistance on the implementation of the practice from knowledge holders. In Puca Puca, the regional WSH expert became involved in the design of the community’s WSH and in monitoring the effective implementation of the practice, upon request of the JUR President (RE_WSH 181201_1927).
Collaboration between community and government (Theme 15), is based on a common interest in securing water resources. The National Government provides support to Puca Puca through Agro Rural which delivers capacity building and materials for WSH. Agro Rural’s engagement depends on the community showing committed to WSH (ARD 181130_1028, _1022), and demonstrating a capacity to “be organized for implementation” (RE_WSH 181206_0750). At the local level, Puca Puca collaborates with the Municipality, which provides resources (e.g. transportation vehicles and machinery for road construction) through formal request (and insistence) of the community (RH 181129). In addition, the community plans to “work with the provincial and district municipalities, and with the regional government to declare the [WSH] area as a reserved zone for water recharge” (PP_JUR_P in RD 291118); a municipal ordinance will help protect the water-provisioning ecosystem and recognize the importance of the community’s work on WSH (RE_WSH 181206_0750).

Collaboration across communities (Theme 16) on WSH is underpinned by Andean traditions, as well as a shared need to secure water resources. Following the tradition of Ayni, the neighbor community of Ccocchua attended Puca Puca’s faena to support the implementation of WSH (ARD 181130_1028, _1015; CM 181130_1127). Such collaboration increases implementation efficiency and overcomes issues arising from non-attendance, in order to meet important deadlines established for resource provision by external cooperators (PP_JUR_P 181130_1627). Aynis are coordinated by JUR leaders in both communities, and are usually reciprocated (ARD 181130_1028). However, it is not [all] about Ayni, but rather that every community has the obligation to do the work […] because they share the same water source” (RE_WSH 181206_0750). “Water is the core element over which people gather”, and the problem of “water scarcity in the region prompts communities to work together” (ARD 181130_105; FG 181201). “Collaboration across communities could also improve WSH through the creation of a joint Reserve Zone spanning several communities’ territories, operationalized through the Irrigation Commission, which integrates JURs of all communities within a micro-basin (RE_WSH 181206_0750).
4.3. Knowledge exchange in community-led WSH

Five complementary learning activities were evidenced: internship visit, capacity building, faena, radio diffusion, and monitoring of springs. In order to understand the relationship between collaboration and learning in community-led WSH (research question 2), or how different actors participated in and/or contributed to knowledge exchange, learning activities were crossed with collaboration types (Table 5).

Table 5. Relationship between learning activities and collaboration types, based on an indication of which actors participate in each learning activity, as well as what is learned.

<table>
<thead>
<tr>
<th>Learning Activities</th>
<th>Collaboration within community</th>
<th>Collaboration with knowledge holders</th>
<th>Collaboration with government</th>
<th>Collaboration across communities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internship visit</td>
<td></td>
<td>(Regional WSH expert facilitates opportunity for leaders to learn about the potential of WSH)</td>
<td>(Agro Rural facilitates opportunity for leaders to learn about the potential of WSH)</td>
<td>(Communities exchange knowledge on the potential of WSH)</td>
</tr>
<tr>
<td>Capacity building presentation</td>
<td>(Regional WSH expert facilitates; community learns how to implement WSH)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Faena</td>
<td>(Minca tradition promotes collective learning on WSH implementation)</td>
<td>(Regional WSH expert may attend to guide community’s learning for WSH implementation)</td>
<td>(Agro Rural may attend to guide community’s learning for WSH implementation)</td>
<td>(Ayni tradition promotes knowledge exchange on WSH implementation)</td>
</tr>
<tr>
<td>Radio diffusion</td>
<td>(Community learns about the importance of WSH and when WSH activities will take place)</td>
<td></td>
<td>(Community learns about and monitors Municipality commitments)</td>
<td>(Communities exchange knowledge on water challenges and successful WSH experiences)</td>
</tr>
<tr>
<td>Monitoring of springs</td>
<td>(Community evaluates results form WSH)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Learning activity: internship visit**

Internship visits (Theme 17) involve community leaders visiting a community with a mature WSH system (commonly Ccecceray) to observe the practices in use and the results obtained (FG 181201). Internship visits are arranged by Agro Rural and/or by the regional WSH expert (ARD 181130_1028). Puca Puca’s JUR President evidenced increased water provision and economic diversification (ARD 181139_1426): “water flow had increased, and that motivated me more, because they increased the amount of irrigation days, from once a month to once a week!” (PP_JUR_P 181130_1610). He also learned where Ccecceray conducted afforestation, and how big their plantation had “grown in 10 years, creating a habitat for flora and fauna” (181130_1610). Knowledge exchanged through internship visits serves to generate understanding of WSH results: “only after seeing the work did we understand; We did not trust the idea of ‘sowing water’, but results are clear in *manantes*” (CM 181130_1127). However, visitors don’t learn ‘how’ WSH works, in terms of the ecological processes involved; this type of knowledge is managed by knowledge holders like the regional WSH expert.

**Learning activity: capacity building**

Capacity building (Theme 18) is provided to community members during assemblies and on the work site (before the start of *faenas*); they are facilitated by Agro Rural officials and/or by the regional WSH expert, who serve as sources of knowledge. Knowledge exchanged through capacity building allow community members to learn about the overall goal of WSH, the specific objectives of the individual practices (ARD 181130_1022), as well as how to implement them (e.g. the depth and diameter of a hole required for afforestation; where to place the infiltration trenches; etc.) and where to monitor their results (ARD 181130_1015, _1022). This collaboration between community, government and knowledge holders represents the integration of multiple sources of knowledge, albeit, sometimes conflicting, as seen with debate around afforestation with native versus non-native species. However, community members don’t learn ‘how’ WSH works, in terms of the ecological processes involved.

**Learning activity: faena**

*Faenas* (Theme 19) promote ‘learning-by-doing’, whereby JUR members collectively learn about individual *water sow* practices by participation in their implementation (ARD 181130_1028; CM
181130_1127), thereby also gaining experience on interacting with the water-provisioning ecosystem. However, the community is not yet learning about the ecological processes involved, though *faenas* can potentially provide a stage for such learning with continuous management of the practice. In addition, *faenas* are linked to collaboration within and across communities through Andean traditions. *Minka* promotes dynamic group learning within a community, as all community members work together, whereas *Ayni* supports the exchange of experiences in WSH through the participation of neighbor communities in one community’s *faena* (CM 181130_1426; ARD 181130_1028). On occasion, *faenas* are attended by Agro Rural and/or the regional WSH expert for additional capacity building (ARD 181130_1015, _1028).

**Learning activity: radio diffusion**

Radio diffusion (Theme 20) enable residents of the district of Curahuasi and communities in the area to learn about successful WSH experiences in neighbor communities. “We’ve heard [about WSH] through radial emissions, [which] spread information and help us get organized to work” (CM 181130_1127). In addition, communities learn about the importance of the practice for safeguarding water resources in the context of climate change, as well as about Municipal commitments not being upheld (RH 181129). JUR leaders also use the radio to communicate and coordinate logistics for upcoming WSH faenas (RH 181129). The radio serves as a communication channel to connects multiple communities across a landscape, ultimately allowing more communities to follow in the example of those already implementing WSH with successful results (CM 181130_1127). This is important, as often good experiences led by government or international cooperation are not communicated broadly, especially with other actors on the ground; for example, Ccecceray’s 10-12 year successful WSH practice is only just being known by neighbor communities in the same region and even in the same district (FG 181201). As more communities adopt WSH, the radio can also become a strong platform for the sharing and integration of diverse knowledge, based on the different experiences of participating communities.
Learning activity: monitoring of springs

The monitoring of springs (Theme 21) is key for community members to observe the results of their work on WSH. The community can assess how well WSH is working through the observation of increased water flow volumes in the springs (RE_WSH 181206_0750), increased or maintained water volume in highland lakes (ARD 181130_1028), the appearance of new manantes (RE_WSH 181206_0750), as well as increased vegetation in the bofedal (CM 181130_1127) and the arrival of new species of grasses and fauna (RE_WSH 181206_0750). “Monitoring in the manantes allows us to say that water is effectively increasing, in connection to the afforestation practice [in the páramo ecosystem]” (RE_WSH 181201_1927). “We learn through the results that our work gives us that year”; “we’ve seen greater infiltration with [WSH], water flow in manantes increased. This year we’ve had water to irrigate all our lands, unlike the past when water [sources] dried out” (CM 181130_1127). “The community refers to [such monitoring] as ‘follow-up’, focusing on “evaluating or qualifying results” (RE_WSH 181206_0750) to assess whether the practice is delivering. The long-term monitoring of results holds potential for the community to learn about social-ecological dynamics, based on the relationship between the addition, expansion or modification of individual WSH practices and results generated.
V. Discussion

This study captures the richness and complexity of the social dimension of community-led WSH. Puca Puca’s self-organization for the adoption of the practice was found to be primarily influenced by strong leadership, the importance of the water resource to the community, as well as users bonded by social norms and formal institutions of collective choice (research question 1). Such self-organization supported four types of collaboration and five learning activities, which this study found to be extensively linked (research question 2). Below, these results are interpreted within the scope of social learning to assess the emergence of ACM (section 5.1). WSH with ACM is then evaluated on its potential for building local water resilience in the face of climate change (section 5.2).

5.1 Assessment of ACM as Social Learning

Social learning is a key component of ACM (Plummer and Armitage 2007) through which “stakeholders learn to work together, build relationships and ultimately undertake collective actions around common environmental concerns” (Cundill and Rodela 2012:11). The assertion of social learning as both a process and an outcome provides a strong basis for examining how learning occurs around Puca Puca’s adoption of WSH, and the learning outcomes that ensue.

The process of social learning, or ‘how learning takes place’, involves on-going deliberation through “sustained interaction between individuals, and the sharing of knowledge and perspectives in a trusting environment” (Cundill and Rodela, 2012:11). Thus, social networks and knowledge exchange are two key components of the social learning process in ACM. The 4 types of collaboration evidenced in this study represent a social network, which connects communities, knowledge holders and government in a common social arena for learning, deliberation and goal-setting (Ostrom 2007, Olsson et al. 2004b; Plummer et al. 2017). A connection to other communities and to government authorities allows Puca Puca to engage with social and administrative institutions operating at the watershed management scale (Reid 2016). This network also supports a diverse governance system around WSH, with multi-level learning processes and flexible institutions that build adaptive capacity for the sustainable management of water resources (Pahl-Wostl 2009; Carlisle and Gruby 2017).
Social learning within a network fosters “the generation of new knowledge and facilitate[s] knowledge exchange” (Plummer et al. 2014:5-6). Each of the collaboration types were found to be linked to three or more learning activities (Table 5). The greater number of links to learning activities (i.e. 4 out of 5) occurred in collaborations between community and knowledge holders and between community and government. This reflects the importance of external support in the initial adoption phase of the practice, suggesting that the community does not hold sufficient knowledge (i.e. eroded or not traditionally held) and/or other resources to implement WSH. Furthermore, the greater number of links to collaboration types occurred in internship visit, faena and radio diffusion learning activities, with three, four and three links, respectively. This indicates that the social network is most active (i.e. greater number of collaboration types involved) within these three learning activities. Interestingly, collaboration across communities appears to be fundamental to these three learning activities, suggesting that the social network plays an important role in linking communities for collective action in terms of knowledge sharing and working together for scaling implementation. Altogether, these links indicate a significant relationship between collaboration types and learning activities, that is, the existence of a social learning process around community-led WSH.

The outcomes of social learning, or ‘what is learned’, involves “improved decision-making by increasing awareness of human-environment interactions and by building relationships and the problem-solving capacity of stakeholders”, as well as “stakeholders exposing their own values and sharing knowledge about the issue at stake” (Cundill and Rodela 2012, 11). Social learning outcomes can thus be conceptualized as relational, normative and/or cognitive changes in understanding (Plummer et al. 2014; 2017) that occur as a result of learning activities (Table 6) underpinned by collaboration. As Puca Puca is currently in the adoption phase of WSH, learning outcomes are only beginning to emerge, but the contribution of different learning activities to these three changes in understanding are already observable.
Table 6. Qualitative assessment of social learning outcomes during the adoption phase of Puca Puca’s WSH (i.e. status after 2 years of practice), in terms of relational, normative and/or cognitive changes in understanding (adapted from Plummer et al. 2014 and Reed et al. 2010). Each learning activity’s contribution to the different learning outcomes is indicated with ‘✓’; ‘(Potential)’ indicates that the learning activity is expected to contribute to the learning outcome over time; Blanks correspond to unavailable data due to limitations in the scope of the study.

<table>
<thead>
<tr>
<th>Learning Activities</th>
<th>Social Learning Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Relational change in understanding, or perception, about others and their learning to work together</td>
</tr>
<tr>
<td>Internship visit</td>
<td>✓</td>
</tr>
<tr>
<td>Capacity building</td>
<td>✓</td>
</tr>
<tr>
<td>Faenas</td>
<td>✓</td>
</tr>
<tr>
<td>Radio diffusion</td>
<td>✓</td>
</tr>
<tr>
<td>Monitoring of springs</td>
<td>✓</td>
</tr>
</tbody>
</table>

After just two years of practice, Puca Puca is developing a relational change in understanding, with four out of five learning activities supporting this learning outcome. For example, faenas and radio diffusion provide a stage for cooperation that helps develop actors’ relational ability, trust and social cohesion, and supports the sharing of different perspectives on water issues; internship visits also involve cooperation, in particular among knowledge brokers and leaders. Evidence on relational change in understanding occurring during the adoption phase suggests that social learning first develops or strengthens relationships between communities, knowledge holders and government; thereby, it establishes a base social network structure to support further knowledge exchange. Between communities in particular, this learning outcome is likely supported by social norms, rooted in deep-seated Andean cultural values of trust, reciprocity and cooperation. A relational change in understanding is key to developing adaptive capacity, as it can help Andean communities build “social memory, enabling legislation, and social incentives for collaboration” as well as “flexible institutions and a multilevel governance system” (Hahn, et al. 2008:121). Social memory in particular, “provides insight into the alternatives for responding to disturbance
and change” (Chapin et al. 2009:69), which in the case of the Andean culture may already exist (but has not yet been broadly accessed) or can be developed collectively based on the experiences of multiple neighbor communities conducting WSH across the region. With flexible institutions within a multi-level governance system allowing for context-specific resource management (Pahl-Wostl 2009), the community of Puca Puca is able to strengthen its adaptive capacity by making local choices in response to locally felt changes.

Puca Puca is developing a normative change in understanding, with four out of five learning activities strengthening human-nature interactions. For example, both internship visits and faenas, combined with the monitoring of springs, allow WSH participants to shift viewpoints on the relevance and effectiveness of using natural infrastructure to manage the ecosystem for increased water flow. In addition, radio diffusion can provide a platform for the convergence of similar views on the importance and need for communities to become stewards of the water provisioning ecosystem, especially in the climate change context. As more and more communities evidence the benefits of WSH, this could potentially elicit a shift in values, regarding the significance of working alongside nature to face climate change challenges, and ultimately, in the natural resource governance paradigm that considers a pluralistic approach for co-management (Rashid et al. 2016). A normative change in understanding occurring in the adoption phase of WSH might reflect the compatibility between the practice and the Andean worldview, drawing upon the culture’s long-held millennial connection to nature, as well as from the daily interaction of rural agrarian societies with the land. By “increasing awareness of human-environment interactions and by building […] the problem-solving capacity of stakeholders” (Cundill and Rodela. 2012:11), this learning outcome supports ecosystem stewardship and the development of adaptive capacity.

Puca Puca is not yet developing a cognitive change in understanding in terms of ecological knowledge, since knowledge exchanged in learning activities are focused on the development of operational skills around ‘how’ each practice should be implemented, and at most, ‘when’ in the season. However, faenas and the monitoring of springs combined, over time can potentially support increased understanding of the social-ecological processes that maintain ecosystem function by using monitoring to assess the work conducted in faenas. By continuously testing, monitoring and modifying (Hahn et al. 2018:120-121) the different WSH practices (in terms of
location, magnitude, etc.), the community can restructure or create new knowledge, enhance skills and develop best practices on how to manage the ecosystem for enhanced water provision. Strengthening the ability to interpret and respond to environmental feedback, and develop ecological knowledge on ecosystem processes and resource dynamics (Folke et al. 2005; Hahn et al. 2008) allows stewards to build complex adaptive systems thinking, a key cognitive learning outcome that supports adaptive capacity. Developing such ecological knowledge, however, requires considerable time investment. In Andean society, cultural heritage “provides information about how people coped with past environmental and social-ecological challenges” (Chapin et al. 2009:46), and may accelerate its development. It is likely that the traditional ecological knowledge that is imbedded within such cultural heritage is present within the region, but sparsely available. ACM can play an important role in the recovery and dissemination (and subsequent modification) of this knowledge.

Regarding the order in which these different learning outcomes emerge, and how they interconnect, it is not possible to discern within the scope of this study. It is reasonable to deduce that a relational change in understanding would precede cognitive and normative changes. It is also likely that cognitive and normative changes would occur in tandem since ecological knowledge and human-nature connection outcomes are linked. In the case of Puca Puca, however, a normative change preceded cognitive for three reasons. First, cognitive change in understanding is expected to take time to develop, because acquiring the ability to both accurately interpret and respond to environmental feedback requires ample experience with trial-and-error. Second, the strength of the human-nature connection imbedded within Andean culture may have hasten normative learning needed for WSH. Third, cognitive learning is not crucial while external knowledge holders ‘stand in’ to support the adoption of the practice; yet, these actors cannot accompany the community forever, and more so, their knowledge is limited on how WSH will respond with future climate change. Essentially, all three learning outcomes are needed and feedback between each other. Facing water challenges in a climate change context would most reliably depend on a vast network of communities actively experimenting with and developing the practice further. Thus, the ultimate goal would be for social learning to result in an active, extensive and self-sustained process among communities over time.
5.2. Potential for building local water resilience with ACM: scaling up, out & deep

The contribution of social learning to enhanced adaptive capacity highlights the potential of ACM for building social-ecological resilience. By developing flexible institutions, social memory, human-environment interaction and ecological knowledge, the social-ecological system can “accept uncertainty, be prepared for change and surprise, and […] deal with disturbance” (Hahn et al. 2008:121) in the face of climate change. This is possible because ACM enables the practice to be scaled up, out and deep (Fig. 6).

![Fig. 6. Representation of scaling-up WSH to influence the creation and/or modification of policy, laws and rules (i.e. formal institutions of governance); scaling-out WSH for adoption across communities at the landscape level; and scaling-deep WSH to adapt values and worldviews within the community for cultural internalization of the practice.]

**Scaling up** WSH refers to impacting a change in policy, laws and rules (Riddell and Moore 2015) to create enabling legislation for these initiatives to increase in number, in the speed of adoption and in the scope of their ambition (Wigboldus et al. 2016). The broader social context is important to scaling up the practice because “governments can help or hinder local self-organization” (Ostrom 1999:281) by providing or limiting opportunities. Such opportunities include the validation of WSH initiatives by national, regional and/or local governments, and the creation of programs to secure funding and other resources. ACM allows the practice to be scaled up by
facilitating cross-scale communication and collaboration between community, government and national organizations. At the community level, the ACM process was seen to modify existing rules (under JUR) to formally adopt the practice, and its successful results to be communicated among neighbors. As more communities learned about the practice and petitioned support from local authorities, a new work program on WSH was developed by the regional government. This exemplifies a bottom-up process by which community-led action delivering increased water security and human well-being, prompted government to take notice and prioritize (and potentially mainstream) such ecosystem-based initiatives.

Scaling out WSH refers to impacting a greater number of people and communities through the replication and dissemination of the practice over a wider geographic area (Riddell and Moore 2015; Wigboldus et al. 2016). By sustaining a social learning action arena (e.g. internships and faenas) and communities of practice (e.g. radio diffusion) for the exchange of knowledge and experiences, ACM can readily and rapidly enable WSH to ‘catch on’. This process may be facilitated by communities across the region sharing one common Andean culture already compatible with the practice. Such scaling would result in multiple communities managing smaller areas linked spatially, to ultimately attain watershed-level implementation. According to literature on EbA, implementation at the landscape level supports ecological connectivity and matches the scale at which ecological processes can be maintained (Andrade Pérez et a. 2010; Lafortezza et al. 2018) to secure water –provisioning and –regulating ecosystem services. This is key because just one community conducting the practice cannot effectively sustain the integrity of the ecosystem as a whole, beyond its political territory where the practice is conducted. The ecosystem may also not deliver water specifically to manantes within the territory of the WSH-implementing community, which is why many neighbour communities must work together to ensure the resource is delivered equitably. Furthermore, as ACM supports the scaling-out of WSH across the region, it is possible that a diversity of knowledge and resources will be integrated into the network, resulting in a collective repository of best practices, adaptive strategies/institutions, and resource capacity to respond to change, uncertainty, and even, ecological crises.
Scaling deep WSH refers to impacting cultural roots by transforming values, worldviews and the quality of relationships (Riddell and Moore 2015) to enable the cultural internalization of the practice. Andean culture, values and traditions are already compatible with WSH, and in fact play a key role in the successful adoption of the practice. This is because a strong human-nature connection is at present part of the Andean cultural identity, which “links to the past through cultural heritage, i.e., the stories, legends and memories of past cultural ties to the environment” (Chapin et al. 2009:46). A cultural connection to the environment is a “powerful social force that can foster stewardship and social ecological sustainability” (Chapin et al. 2009:46). Rather, scaling deep would be conducive of the community continuing to invest time, effort and resources in the management of the practice, which is key to successful ecosystem stewardship in the face of change and uncertainty. ACM as a process allows the practice to be scaled deep, by supporting iterative experimentation and learning by which the community tests and ascertains the effectiveness of the practice to validate such investment. Although the iterative nature of learning and collaboration of the ACM process can incur costs to stakeholders, the case-specific context of strong Andean values of reciprocity and connectedness, and the locally conceived institutional structures and processes for natural resource management (supported by national institutions), present ideal conditions for the continuous management of the practice.

Ultimately, the scaling-up, -out and -deep of WSH through ACM (Fig. 7), enables the scale of institutional, ecological and worldview processes, respectively, to be matched to the spatial and temporal scales at which the EbA initiative can support local water resilience. Regarding the spatial scale, implementation of WSH at the landscape level supports “the maintenance of ecosystem structure and functioning” (Andrade Pérez et al. 2010:29) and thereby, the ecological processes that deliver ecosystem services. The temporal scale is also important, since the continuous management of the practice supports adaptive forms of natural resource governance (Plummer and Armitage 2007) to deal with present and future climate change. With key values of cooperation and reciprocity, local and collective decision-making, and ancestral worldviews founded in strong human-nature interconnection, the Andean region presents inherent adaptive capacity for resilient ecosystem stewardship.
Fig. 7. Representation of the ACM mechanism linking self-organization, social learning and adaptive capacity in an iterative process that supports, and is supported by, the scaling-up, -out, and –deep of WSH. Scaling-up and scaling-out through ACM strengthen the adoption of WSH across other communities (represented by the small blue spheres) and the continuous management of the practice (represented by the blue-to-green spirals. Scaling-deep through ACM strengthens the continuous management of WSH.

5.3. Limitations of the study and future research

Single-case study: Conducting a single case-study, despite the inclusion of complementary information from other communities, carries an important limitation regarding the generalizability of the findings. It would be suitable to conduct a comparative analysis between various cases of community-led WSH at 1) similar stages of implementation to assess different social-ecological conditions for self-organization, and 2) different stages of management to assess the time factor of ACM. In addition, it would be interesting to compare between community- and government-led WSH initiatives. Future research with a multiple-case study approach will allow greater understanding on how initiatives in different contexts can be managed towards building social-ecological resilience, and what common denominators are found to be significant to this end. As a
contribution, this thesis has puzzled together a comprehensive methodology that lends itself for use in comparing different cases of community-led WSH.

**ACM approach:** There is substantial variation in the definition of ACM, and on how it can be operationalized (Plummer et al. 2012). This study addresses the emergence of ACM based on social learning, where further limitations exist. According to Plummer and colleagues (2014:6), “how to assess learning in environmental governance and resource management broadly, and ACM specifically, is not well established”. In addition, both the evidence about “the importance of learning and the mechanisms by which it enhances the resilience of ecosystem services remain somewhat unclear” (Biggs et al. 2012:440), requiring systematic analyses on “what type of learning is most appropriate or inappropriate to build ecosystem service resilience and under what conditions” (Biggs et al. 2015:186). Furthermore, “monitoring social learning and the formation of communities of practice remains a significant challenge”. The work conducted in this thesis managed some of these limitations, particularly in the context of social learning for the ACM of water-provisioning ecosystems, but further research is needed.

**Social learning network:** A limited account of the social network supporting social learning is provided. Puca Puca’s WSH social network should be further explored with a formal social network analysis of its structure, social relationships and key players performing critical functions. Regarding the latter, this thesis gathered and assessed data on key network players, including leaders, knowledge holders and ecosystem stewards, and how they are connected. Data on network actors can be further developed and explored as functional groups, and for diversity and redundancy, in order to assess social network conditions that could best increase social capital, strengthen collaboration for resource transfer, and promote the exchange and integration of diverse knowledge systems towards resilient natural resource governance with WSH.

**Social learning outcomes:** This case study was temporally bounded to the adoption phase of community-led WSH; extensive research periods are required to assess the continuous management of the practice over time. In particular, further assessments of relational, normative and cognitive learning outcomes for adaptive capacity are needed. Latent changes in understanding not yet observable are bound to have been missed by the design and scope of the study, and even
so, it is likely that these will not be easy to assess. Future work on this topic would help gauge the effectiveness of EbA with ACM in developing adaptive capacity in the face of ongoing change.

**ACM for building resilience:** This thesis approaches ACM’s potential for building resilience from the social dimension, primarily focused on the governance aspect. Following the 7 resilience principles proposed by Biggs and colleagues (2012; 2015), this study can be linked to resilience principles concerning the governance system: learning, participation and complex adaptive systems thinking. However, other principles (e.g. polycentricity, diversity and redundancy, connectivity and slow feedbacks) that are critical to building social-ecological resilience were not assessed, due to limitations in the research scope. Thus, this thesis is a partial assessment of resilience elements needed to build local water resilience with community-led WSH. Future studies on WSH should provide an integrated assessment of all seven principles. In addition, it would be valuable to develop guidelines for incorporating the seven resilience principles within the design, implementation and management of EbA initiatives in general, as a way to secure the resilient supply of ecosystem services.
VI. Conclusion

In community-led WSH, iterative feedbacks between self-organization, social learning and adaptive capacity make up a mechanism for ACM. Self-organization is primarily supported by strong leadership, the high value of the water resource to the community, institutions of collective choice and social norms rooted in Andean culture. Collaboration and learning are linked in a social learning process that facilitates knowledge exchange between communities, knowledge holders and government actors. Social learning outcomes in Puca Puca are linked to relational and normative changes in understanding; however, a cognitive change in understanding (i.e. the development of ecological knowledge), requires further experimental and experiential investment over time. Adaptive capacity in Puca Puca and other communities is expected to build gradually over time through social learning, as ACM enables WSH to be scaled up, out and deep. Such scaling can build local water resilience, when multiple community-led WSH initiatives are integrated as one landscape-level intervention, and when enabling legislation and cultural internalization support the continuous and adaptive management of the practice. In this regard, this thesis speaks to the importance of the Andean culture as both a source and catalyst of ACM for operationalizing ecosystem-based initiatives. Understanding how the self-organization, social learning and adaptive capacity components of the ACM mechanism enable community-led WSH to be scaled, provides insight into which process components require further investment to navigate the social-ecological system towards local water resilience.
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