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Corresponding author:
Shelley MacDonell;
Email: shelley.macdonell@canterbury.ac.nz

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Snow and ice in the desert: reflections from a decade of connecting cryospheric science with communities in the semiarid Chilean Andes

Shelley MacDonell[1,2], Paloma Núñez Farías[1], Valentina Aliste[1], Álvaro Ayala[1], Camilo Guzmán[1], Patricio Jofré Díaz[1], Nicole Schaffer[1], Simone Schauwecker[1], Eric A. Sproles[3,4] and Eduardo Yáñez San Francisco[1]

[1]Centro de Estudios Avanzados en Zonas Áridas (CEAZA), La Serena, Chile; [2]Waterways Centre for Freshwater Management, University of Canterbury and Lincoln University, Christchurch, New Zealand; [3]Department of Earth Sciences, Montana State University, Bozeman, Montana, USA and [4]Geospatial Core Facility, Montana State University, Bozeman, Montana, USA

Abstract

Citizen science and related engagement programmes have proliferated in recent years throughout the sciences but have been reasonably limited in the cryospheric sciences. In the semiarid Andes we at the Centro de Estudios Avanzados en Zonas Áridas have developed a range of initiatives together with the wider community and stakeholder institutions to improve our understanding of the role snow and ice play in headwater catchments. In this paper we reflect on ongoing engagement with communities living and working in and near study sites of cryospheric science in northern Chile as a strategy that can both strengthen the research being done and empower local communities.

1. Introduction

Science as a global public good recognises that scientific information gives power at individual to collective levels, and is a right for all (Aarhus Convention, 1998; Escazú Agreement, 2018; Boulton, 2021). As knowledge, and scientific information is the most powerful of all public goods, access to knowledge is also a right that everyone should hold (Gaventa and Barrett, 2012; Boulton, 2021). However, often there is a disconnect between knowledge generation and the community it serves for reasons including political realities, ineffective communication practices of scientists with the population at large (Schmidt, 2009) or the focus on scientific publication over public dissemination (Wilson and others, 2010). Disconnects may also be due to educational or cultural disparities or when science is not grounded in the society it impacts (Boulton, 2021). In cryospheric science additional barriers to connecting science with communities are often the geographic reality as communities are commonly located far from study sites, and many scientific pursuits have global impact that appear to be less applicable to day to day issues. One step towards addressing concerns regarding community understanding and knowledge transfer, has been in the development of citizen science and engagement programmes (Bonney and others, 2014).

Whilst citizen science and related engagement programmes have proliferated in the last decade (e.g. Buytaert and others, 2014; Le Coz and others, 2016; Wood and others, 2022), relatively few programmes have focussed on cryospheric topics (e.g. Dickerson-Lange and others, 2016; Yeeles, 2018; Arienzo and others, 2021). One region that has bucked this trend is the Canadian Arctic, which has a growing body of integrated, interdisciplinary work programmes where researchers and communities can benefit through collaboration (e.g. Wilson and others, 2021; Sadowsky and others, 2022). Comparatively, in northern Chile, citizen science programmes have mostly focussed on biodiversity (e.g. Garcia-Cegarra and others, 2021) or local issues (e.g. Eastman and others, 2014), some of which have been organised by community members with support from researchers and/or research institutions (e.g. Núñez-Farias and others, 2019). To date, there is very limited community based monitoring of hydrological processes, such that a few water user associations (Juntas de Vigilancia) do snow and hydrological monitoring, but it is limited in scope and coverage. Data limitations are concerning given that in the semiarid Andes of Chile, very few people reside in the mountains, but everyone is impacted by the hydrological variability of the cryosphere, as it provides most of the water used in the region (Masiokas and others, 2006). Whilst few people who live in cities may recognise this, inhabitants in the foothills and upper valleys have observed through time how water security, means of subsistence, and their livelihoods, are connected to and conditioned by 'good' and 'bad' snow years (Fundación Superación de la Pobreza, 2020). Since 2010 this relationship has intensified as both researchers and communities have recognised the impact of the central Chile mega drought which has played an important role in increasing water-related insecurity in the wider region (Garreaud and others, 2020). Additionally, the inclusion of glaciers in several legislative initiatives over the last decade including: Environmental Impact Assessment processes; the modification to water legislation; the ongoing constitutional reform processes; and heavily debated glacier protection laws indicates an increasing level of citizen concern to changes in the mountains. However, due to logistical constraints there has traditionally been a dearth of information in the foothills and mountainous regions of the dry regions of Chile, which limits analyses of cryospheric and hydrological response to environmental forcings. Some constraints are due to access, as many mountain regions are privately owned, and closed to the wider public, and others are related to the rugged and harsh terrain of a large expanse of the Andes. Therefore, to gain access to these regions, it is necessary to work together with local landowners, and wider stakeholder groups to create projects of mutual interest.

Due to the ongoing severe drought (Garreaud and others, 2020), both the public and private sectors are highly motivated to invest in better information to inform decision making, and to be more resilient to water shock. However, as there are mixed levels of education and relatively low level of information available about the cryosphere across socio-economic groups in Chile (OECD, 2021), to generate and disseminate quality information there is a need to invest time into training, education and to generate general excitement about cryospheric processes. It is within this backdrop that in 2013, cryosphere researchers at the Centro de Estudios Avanzados en Zonas Áridas (CEAZA) began to actively question how they could better engage and work together with the wider community to help support knowledge transfer for bettering livelihoods and decision-making at all levels. However, to support these efforts we needed to become better communicators, actively work with others outside of the traditional research institutions, and address our own biases and perspectives to undertake science with real impact in our local community. In this paper, we will reflect on what we have learned from working with communities in the semi-arid Coquimbo Region (29.0–32.3°S) over the last decade.

2. Connecting local populations to the cryosphere in Chile

In central Chile, the cryosphere is the main source of water, with snow accounting for 85% of streamflow variance (Masiokas and others, 2006) and generally being more important than glaciers the further north one travels in the region (Masiokas and others, 2020). Whilst Chile contains approximately 84% of glaciers in South America (Masiokas and others, 2020), only 10% of ice bodies in Chile are found in semiarid and arid regions (Barcaza and others, 2017), but here the cryosphere provides water for over 10 million inhabitants. However, very few people are aware of these glaciers found high in the Andes, and in such dry environments. The apparent lack of connection between inhabitants and snow and ice is not a new phenomenon. Whilst likely not the first to identify this disconnection, Lliboutry (1956) lamented in the introduction to his work on Chilean snow and glaciers that whilst the snow-capped mountains were front and centre in the national anthem, they were not often in the daily consciousness of the general population. One might argue that over the last two decades, this has started to change (Fernández and others, 2021). Firstly the threat of mining impacts brought glaciers into a general conversation (e.g. Brenning, 2008), and then as impacts of climate change became more evident (e.g. Masiokas and others, 2020), those discussions became more urgent. They have led to the ongoing development and debate of glacier protection and preservation (Iribarren Anacona and others, 2018), and even to the mention of glaciers in the proposed new constitutional texts, voted down in 2022 (Mendoza, 2022). These debates have often been polarising, and whilst much can come from debate, inclusive decision-making requires information exchange, a willingness to listen and to accept difference or uncertainty. In the spirit of open communication, dialogue and collaboration, for the last decade, cryosphere scientists and outreach teams at CEAZA have been working together with local communities and stakeholders to break down knowledge transfer barriers and to work towards more informed decision-making at all levels. This move was largely precipitated by the ongoing mega drought in northern and central Chile which began in 2010 and which has severely impacted the primary sector, as well as potable water for rural households. As well as prolonged period of low precipitation amounts, problems were exacerbated by a lack of necessary information to take informed decisions at both national and local levels. This work has spanned much of Chile, but the core programmes have focussed primarily on the Coquimbo Region.

3. The Coquimbo Region

The Coquimbo Region straddles the southern margin of the Atacama Desert and extends towards the central region of Chile (Fig. 1). Mining, agriculture and fishing are significant industries in the region and sources of conflict with respect to water and environmental concerns (Carranza and others, 2020), but also help to explain many of the current and original distribution of settlements by the Diaguitas peoples and more recent arrivals.

The region is designated semiarid, and has a mean precipitation rate of approximately 167 mm a^{-1} in the upper headwater catchments (Robson and others, 2022). Precipitation is seasonal, falling principally in the austral winter (May – August) and follows a strong orographic gradient. Annual rates are mainly conditioned by ENSO patterns, such that larger precipitation events are generally experienced during El Niño periods (Kinnard and others, 2020; Réveillet and others, 2020). The cryosphere drives streamflow in most catchments, with snow melt augmenting flows during spring and summer, and glaciers providing additional flow principally during late summer and autumn (Masiokas and others, 2020).

Following the 2022 update of the Chilean national glacier inventory, there are ca. 900 glaciers (including mountain, debris-covered and rock glaciers) in the region and they can be found along the length of the mountain chain (Dirección General de Aguas, 2022). Rock glaciers cover the largest total area, but the largest individual, and most studied, glacier complex is the Tapado Glacier (1.25 km^2, 30.1°S, Robson and others, 2022), which also contains two rock glacier tongues (0.85 km^2). Tapado Glacier has shown significant retreat of the clean ice section (−28.4%) and expansion of the debris-covered area over the last 50 years (Robson and others, 2022), which is likely due to changes in precipitation rates (Kinnard and others, 2020).

4. Reflections on undertaking community based programmes in the Coquimbo Region

As the cryosphere plays such a fundamental role in providing water in this region, we have worked with the wider community to gather data and information to improve early estimations of the regional water balance (Favier and others, 2009). To that end, at CEAZA we have worked together with community groups, public and private sector entities, as well as individuals to enhance connections with scientific information, support local development and to improve the science we do. Shared work has included the co-creation of projects, the execution of citizen science programmes and the facilitation of logistical support as well as information (Table 1). The impulse behind these programmes has been to develop continuous interactions, that enhance the ongoing relationships between the community and researchers.

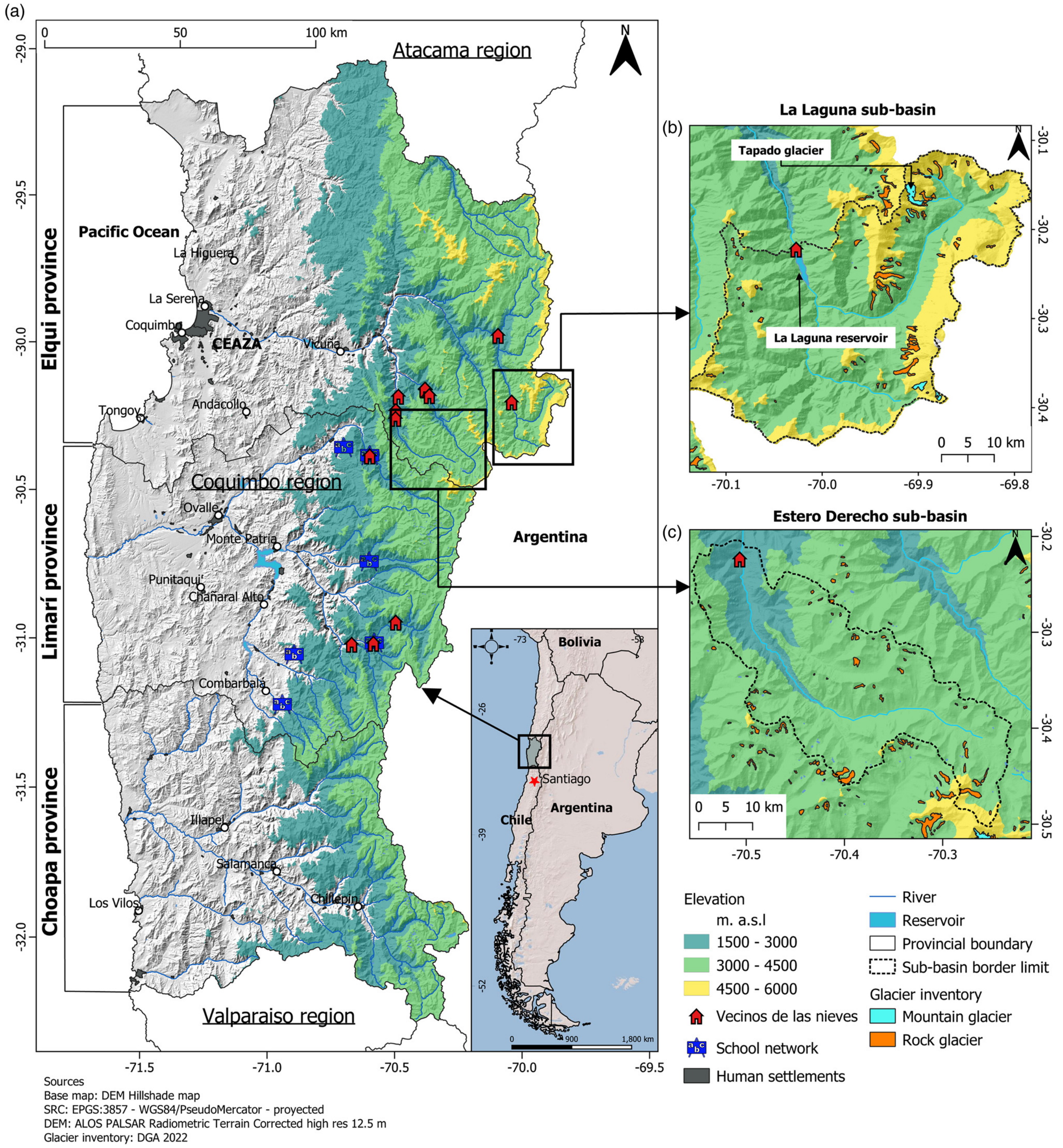

Figure 1. Map of the Coquimbo Region showing sites of interest used in community-based programmes: (a) shows the whole region with an inset of Chile in South America; (b) shows the La Laguna catchment in the upper Elqui Valley, where the Tapado Glacier and La Laguna station are located; (c) shows the Estero Derecho catchment. The DEM is from ASF DAAC (2015), and the glacier inventory is from Dirección General de Aguas (2022).

Some programmes or products have been picked up by the local community after development and subsequently led or implemented by locals (e.g. Water Academy and Andesita), which means that in some cases whilst CEAZA may not be directly involved in leading the programme anymore, the initiative does not end. Some programmes also morph into a new state of relationship, for example, CEAZA has provided information for the applications by local communities to have parts of their territories designated as nature sanctuaries. In these cases, once the application is approved, the relationship morphs into one of advising, or of undertaking science that links to the aims of the nature sanctuary. For this reason, Table 1 indicates the start date of each initiative but not a fixed end date.

In our programmes we have found that the main first steps of successful engagement come down to respectful communication, identifying issues that are of common interest, honesty and time. Breaking these down further means that allowing time and space to listen, to be wrong and to have to try again is part of the process. The investment in time is what will lead to the development of trust which is necessary for the success of any collaboration.

Whilst not a new idea, we soon realised that the way we communicate directly relates to the success of an engagement initiative (Heffner and others, 2003). Approaching conversations with an attitude of humility and reciprocity when sharing knowledge and learning to listen to people, promotes closeness, horizontality and empathy, valuing the stories of the observers of the

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Table 1. Main programmes that connect cryosphere research with community partners

Start year	Programme	Main partners
2013	Support private nature sanctuary development	Agricultural and indigenous communities
2013	Glacier protection law contributions	Ministries and Central Government
2015	Water Academy	NGO Tierra y Valle, school aged children in the Elqui Valley
2016	Use of snow fences for water management	Coquimbo Regional Council, regional water stakeholders
2016	Materials for CEAZA Science Vehicle	School aged children, rural schools and general public
2017	Glacier management plan	Coquimbo Regional Council, regional water stakeholders
2018	Vecinos de las nieves	Residents in headwater sites
2018	Children's book 'Andesita'	Schools and children in rural and headwater areas
2018	Training of cryosphere concepts and methods	Regional private and public water stakeholders
2019	Fixed monitoring of Tapado Glacier	Ministry of Public Works
2021	Snowline observations	Social media users
2022	Snow water equivalent forecasting	Regional water stakeholders

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environments and that, at the same time, the communities are interested in the interpretations given by science observations of snow, mountain range and climate in general. Using a language that is understandable by the entire group, considering language, culture, level of education and accessibility of the people who participate, is essential so that the actions for exchanging knowledge and establishing work agreements are horizontal and accessible. Enabling knowledge transfer in all directions engenders respect, and leads to the development of trust. One example of this was when we were exploring possibilities of developing a package of programmes including the 'Vecinos de las Nieves' (Snow Neighbours) snow measurement programme, the children's book and glacier management plan initiatives. To facilitate interactions with community members in the foothills, we organised a series of 'mateadas' that we held within senior citizen clubs in each locality. These sessions had 'mate' (traditional herbal drink) and food at their centre and senior members of the community came to share their experiences and stories with us, and we shared our scientific insights with them. Through these conversations we found many points of intersection, but also realised the wealth of knowledge these people held.

When choosing modes of communication we have had to often adapt to how the community partners want to communicate as opposed to how we as scientists might be most comfortable. For example, in the citizen science programme 'Vecinos de las Nieves', as well as filling in their provided booklets, the collaborators enjoy contributing to a phone based messaging platform WhatsApp group, where they can post photos, chat about how much or little precipitation was received at their house, or how terrible the forecast was! In this group, members interact freely and openly, and it has created a safe space for people to share with others in the programme, who might be in another province in the region and would otherwise be unlikely to meet. This has enabled us to break down political and other divides which are generally marked in Chile, around a common area of interest. Additionally, during the COVID-19 pandemic, a new initiative was developed to encourage people to send in old and new photographs of snow-covered mountains. This development was launched and run completely via social media platforms, and a gallery of images was created. Using these images, we were able to validate empirical snowline height estimations from Sentinel-2 NSDI imagery and improve our understanding of the typical range of the 0°C isotherm altitude during precipitation events (Schauwecker and others, 2022). Without the use of social media platforms, we could not have created and maintained direct communication with study collaborators or received these datasets.

Ongoing communication also enables the continuous evaluation of programmes, including whether they are still fulfilling requirements. For example, in the snow fence programme, we worked together with the Regional Government and water user associations to install four fences to manage snow accumulation for water resource enhancement in different catchments (see barreras.ceaza.cl for more information). The pilot fences reduced sublimation rates and extended the time that snow was on the ground, but had varied success depending on location (see barreras.ceaza.cl), which is similar to experiments in other places (Harrison, 1986). In ongoing conversations, at one site it was decided that the fences were not suitable, one site sustained significant damage which demoralised the local stakeholders, and the final two partners have maintained the original sites, and are exploring using different approaches to expand the network (e.g. using vegetation and customary building practices to create wind breaks for snow management). Whilst still in discussion, this has enabled project partners to take original results and make decisions for their location as appropriate. Through the open dialogue in this space, we have also connected these original participants to other groups in Chile who are interested in implementing their own snow fences.

Additionally, to set the foundation to build an honest relationship between members of the community and scientists it is necessary to agree on the scope of the scientific work, what the collected information will be useful for, and how any funding will be allocated. Whilst sharing information about funding can sometimes seem intimidating, in our snow fence pilot study, water users associations ended up financially contributing to the project once they understood how their investment could improve outcomes for their catchment above what we were able to achieve with regular funding.

Community based projects sometimes require methodologies to be modified and made more flexible, based on previous agreements, improvement and/or simplification of processes or the interests of the participants (Bonney, 2021). Within this context, many question the quality of obtained data, however, studies have shown that data generated by the local community can be as good as that collected by experts if the appropriate protocols and training are provided (Fore and others, 2001; Bonney and others, 2014; Danielsen and others, 2014). To try and minimise errors in our citizen science datasets, we retrain our volunteers each year before the winter season begins and keep in constant contact throughout the precipitation period. This is part of the agreement we have with our partners.

Long-term initiatives to monitor the Cordillera need to establish collaborative agreements between the participants, community managers and scientists. This includes generating spaces to discuss who is going to participate, their interests, joint objectives of monitoring, design of methodologies and their application, the time that the participants will dedicate and how to record the information. These agreements will build trust between scientists and volunteers, by making interests transparent, eliminating the assumptions and uncertainty of the entire group, and promoting teamwork. After some time, these agreements must be evaluated, renewed and updated to the reality of the participants. One example of the need for ongoing agreements was in the Vecinos de las Nieves programme when the lack of snowfall events meant that people started to lose motivation. Following

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conversations, we added distributed rain gauges to facilitate rainfall measurements and asked the volunteers to take photos of upper mountain slopes where snow had fallen following precipitation events. These photos served to estimate the snowline altitude and led to a scientific publication (Schauwecker and others, 2022). A change in focus has important impacts on the success of such a programme, as already described in e.g. Dickerson-Lange and others (2016), and should be constantly evaluated based on the volunteers needs, interests and questions (Bonney and others, 2016).

Another relevant agreement to be reached is the storage, administration, access and availability of the data and information generated. In addition, deciding what will be done with the results should be defined together and possible applications to the participants daily lives discussed. It is important to always keep in mind that the data is collaborative and belongs to all the participants. For this reason, all authors should be recognised and acknowledged, and periodic reports should be generated to make information readily available. One example is that in the Vecinos de las Nieves programme, in which participants were keen for their data to be shared publicly so they could have access and share with others. This led to the publication of the first years of data on a data sharing platform (Aliste and others, 2022).

Community-based initiatives require the dedication and time of individuals and researchers. The time of the participants is as valuable, or more, than the time of the research teams, since the volunteers give time of their lives, share daily moments and intimate experiences that inhabiting the mountain range offers them. Due to the intimacy of being connected to the daily lives of community members, food and informal experiences can often be a great catalyst for constructive partnerships (Brunet and others, 2014). Leading from this, one important lesson we have learnt is about our own attitude and approach to spending time with community collaborators. As researchers, we often feel pressed for time, and so it is easy to think of long meetings, meals or excessive travel to meet with people in their locality as a cost, but it really should be considered as an investment. For example, it was after spending hours with members of senior citizen clubs in the remotest parts of our region, that we were alerted to the importance of the snow-rain interface and its connection with landsliding in the area. This provided the platform for new research lines (e.g. Schauwecker and others, 2022) that were previously unknown. By spending hours listening and sharing food with those who had spent their lives in the mountains, we also discovered local terms for snow types, timings of stream activation and how ENSO had impacted their lives. By meeting people face to face you also have the chance to build respect, trust and ongoing relationships that will be more likely to continue through hard times.

Commitment also needs to come from both individuals as well as institutions. Our programmes have benefited by incorporating ‘Participatory Science Managers’ within the wider team, one who focuses on stakeholder institutions, and one on our citizen science programme. These people can come from within a community or from the world of science, but they should coordinate actions, open spaces for dialogue and exchange of information, as well as apply motivational strategies with people from the community and science. As this is a large commitment, we strongly recommend that the institution responsible for the programmes either hires that person internally, or supports them in the wider community. For example, in the first iteration of our Water Academy programme for 8-12 year olds, we hired and trained a member of the Pisco Elqui village community in Estero Derecho to run the sessions. This decision led to the possibility of having three sessions with the group each week, as well as access to the Estero Derecho Nature Santuary which would have otherwise been closed to the children and researchers. The contracted person went on to fully lead the programme through their NGO Tierra y Valle and link it into the curriculum of local schools.

Finally, through these programmes we have shown that it is possible to do community-based, locally-relevant science that is still useful for the cryosphere community. For example, from our direct and indirect interactions, we have made advances in understanding snow processes (Réveillet and others, 2020; Voordendag and others, 2021; Schauwecker and others, 2022), glacier and rock glacier processes (Schaffer and others, 2019; de Pasquale and others, 2022; Schaffer and MacDonell, 2022) and catchment hydrology (Valois and others 2020a, 2020b, 2021). In addition, these interactions, linkages and new perspectives garnered from working with the wider community has produced new questions and areas of study in Andean cryospheric science. For the wider community, as well as increasing awareness, our partnerships have led to both tangible and intangible outcomes. These include: the naming of two community based private nature sanctuaries by the Environment Ministry (Santuario de la Naturaleza Estero Derecho and Santuario de la Naturaleza Río Cochiguaz); changes to school curriculum including the inclusion of snow and water monitoring programmes; training of Environmental Impact Assessors from the identification of a significant knowledge gap in the regional glacier management plan; and the inclusion of snow information in decision-making processes of water user associations.

4.1 Difficulties and challenges

Whilst our experience has been overwhelmingly positive, it has not been a straight path. Despite all of our experiences and ongoing adjustments, one of the greatest challenges and gaps in citizen or community science is that the information generated is fully appropriated by the participants and linked to decision-making in the territories, promoting their educational, economic and social development in a sustainable way. This is an issue we have encountered many times during this process and are still evaluating ways to address. However, it is not our only challenge, others include:

Scientific communication must be developed in a simple and understandable language for isolated communities. However, scientists and professionals usually do not have pedagogical training and/or skills to communicate science, which sometimes results in a loss of transparency and understanding when sharing generated information.

Sometimes participants expect rapid results from science and immediate impacts on their territories and daily lives. Many times there are differences in the work rhythms of science, governments and communities, especially when it comes to responding to the needs of communities. Additionally, most of our initiatives have had an impact at a community or regional level, rather than national, which makes it difficult to influence policy change which is a common issue (Carlson and Cohen, 2018). However, through the dissemination of our work programmes in national and international level working groups, we have managed to include these areas of interest in research strategy documents which should ultimately have policy implications (e.g. CNID, 2016; González and others, 2019).

Internet connectivity in the Cordillera is poor and this makes it difficult to use citizen science digital platforms, which are

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widely used in other disciplines such as bird watching and flora and fauna recording.

The vulnerability of some Andean communities is reflected in the little access to education, low self-esteem, handling of technological tools and poor discipline for keeping records makes it difficult to record high-quality information continuously.

With respect to the management of participatory science, the development of continuous programmes that need long-term contracted professionals is needed and many times these initiatives are interrupted due to lack of funding.

Only in some instances have we had the possibility to involve social scientists and other disciplines within our initiatives, which has sometimes limited the connections we have made with programme partners. It has also limited our ability to both judge the impact our collaborations are having within the local community, as well as assessments for applying our programmes elsewhere. We are currently working together with sociologists to better assess the merit of programmes and to make recommendations for necessary changes.

The allocation of water rights in Chile bestow different levels of access to water. In this political and legal context, we have worked to provide information in an open, accessible way to all users, so they can contribute to discussions and work through issues at various spatial and temporal scales. However, there is still much work to do in this space.

5. Conclusions and future directions

Often we think of transformative change as being big, provoked by large scale actions that have an immediate impact on delivery. But we have learned that to make sustained, transformative change in our local communities, that it takes time, trust, communication and commitment. For us it has also meant handing over 'ownership' of ideas, and acting as support as and when required, rather than expecting to always be in control.

Our programmes are based on a relationship of trust that involves people in the generation of scientific knowledge for a better understanding of issues associated with water in arid zones. As all actors in the mountains depend on each other, there is an inherent need to work together. Together we can generate information that would not be possible otherwise.

These collaborations have enabled the production of both locally relevant outputs, as well as results available to the wider scientific community (Réveillet and others, 2020; Schauwecker and others, 2022; Schaffer and MacDonell, 2022). In the presentation of community based data collection, participants have been acknowledged (Aliste and others, 2022; Schauwecker and others, 2022) and included in the presentation of results. Their interest keeps the programmes moving forward.

In our initiatives, both scientists and partners benefit from participation: learning opportunities; sense of identity and belonging to the territory; and the satisfaction of contributing to science and society for decision-making. These outcomes promote reciprocity.

Following from what we've learnt and developed over recent years, we plan to continue nurturing and growing our programmes following a set of collective goals:

To connect and continue to build trust with actors within in the Coquimbo Region to propose strategies based on cooperative work programmes;

To cultivate and support the formation of local capacity with respect to the characteristics and functions of mountain systems;

To co-design research programmes around questions the community wants answered;

To support the development and implementation of public policy and local governance based on collaborative work.

Finally, we would like to leave with these closing remarks. The experience and learning acquired through interaction with Andean communities gives us greater responsibility in future community-based programmes and information management. Also, we firmly believe that cryospheric science can improve and benefit society much more, if we integrate local communities in its development. Whilst every community has its own culture, ways of doing, being and communicating, we hope that the underlying lessons learned here are useful for those interested in beginning community engagement programmes elsewhere.

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