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Future of proglacial landscape:
Alpine ecosystems and deglaciation in the Tropical Andes and French Alps

Overview

Mountain glaciers are melting worldwide, and their ecosystem services are declining, impoverishing local ecosystems and downstream communities. These emerging ice-free lands, however, represent an opportunity for plant and microbe colonization and therefore for the development of new alpine ecosystems. Despite extreme environmental condition, alpine ecosystems present important biodiversity and endemism that adapt along biophysical gradients. We still know very little about the rates of these biophysical processes and their ecological outcomes. Studying these hotspots, therefore, provides key insights into the adaptive capacity of high mountain systems. Indeed, there is an urgency for studying these time limited open-field laboratories.

We hypothesize that species range shifts and possible species extinctions occur in alpine regions influenced by the increasing time lag between relatively fast global warming and slow primary succession –i.e., colonization of newly exposed area. Mountain communities thus face new challenges to ensure water provisions, slope stability, and essential ecosystem services for life. This research aims to assess how physical, ecological, and social processes interact to drive ecosystem changes in alpine proglacial landscapes. Our approach is explanatory and experimental science. First, we study in tandem the processes of primary succession and geomorphological dynamics of seven proglacial landscapes. Our study sites include the Peruvian Tropical Andes and the French Alps, setting up a biogeographical comparison between the two continents. Second, our experimental approach examines the Andean Camelid as a possible ecosystem engineer to enhance ecosystem formation following glacier retreat in the Cordillera Blanca in Peru. We use a multiscale and multidisciplinary approach combining field surveys, experiments, and remote sensing techniques to build an integrated understanding of postglacial ecosystem development.

Methodology & Research activities

The time scale of our analysis is the acceleration of global warming (since 1950-1970) and considering a likely control zone in the Little Ice Age (LIA). The LIA term refers to the glacial maximum extension between the 1600s and 1800s when glaciers advanced. Considering a LIA control zone provides information about well-established alpine communities and allows comparison with very recently deglaciated zones. We used satellite imagery, aerial photographs, and direct in-situ observation to delimit the chronosequences (i.e. space for time substitution approach) of our seven glacier forelands: Uruashraju, Yanamarey, and Broggi in the Cordillera Blanca in Peru, and the Gébroulaz, Glacier Blanc, Tour, and Pélerins in the French Alps.

In parallel, we study the geomorphic surfaces which depends on the topography —slope orientation, degree and position on slope—, roughness —differentiating zones with large blocks, rocks, and fine sediments—, and general geomorphological characteristics, which include disturbed or undisturbed moraines, bedrock surfaces, fluvial systems, and hillslopes.

Last summer for four months, I led research teams to both the Andes and Alps and carried out the major part of the field work. We performed floristic and geomorphological inventories in our seven glacier forelands (Fig. 1 &2).

Figure 1: Floristic evaluation at the Broggi Glacier Foreland, Cordillera Blanca. Credits: Anaïs Zimmer

The field sampling approach consisted of (1) listing and characterizing all the vascular species and presence of biological soil crust —biotic data, and (2) measuring geomorphic settings —abiotic data. At each site, around 10 and 20 square plots of 4 m^2 were selected randomly in each deglaciated zone. We surveyed a total of 396 plots. Within each plot, we listed all the vascular species observed in our sampling and measure the ground cover, plant height, specie fertility, and spatial association with rock, plants, or biological soil crust (Fig. 2).

Figure 2: Floristic evaluation at the Uruashraju Glacier Foreland, Cordillera Blanca. Credits: Carlos Ly (@ly_carlos)

In addition, we took a Near infra-red (NIR) photograph of each plot, which will allow us to study plant functional traits at a larger scale and calibrate our aerial images. Additionally, for each plot, we collected soil moisture, slope degree, position and aspect, granulometry, landform, geomorphic process — i.e. debris flow, avalanche, debris slide, rill and interrill erosion, wash, solifluction, cryoturbation, gullying, aeolian deflation, and geomorphic dynamism — i.e., high, moderate, low or absence. Then for a subsample of 25 plots per site, we analyzed essential soil properties in the laboratory: temperature, moisture, pH, bulk density, magnetic susceptibility, texture, SOM, CHNPS, and microelement content. We also buried 15 temperature sensors —Data logger — per glacier foreland to obtain a complete energy budget along the chronosequences. Additionally, we measured air temperature, wind speed and direction, atmospheric pressure, and relative humidity. This species-and-community-based approach yielded data at different levels: individual, species, and ecosystem, and allowed us to understand the role played by the species on the structure and properties of the global ecosystem.

In parallel, in the Cordillera Blanca, we carried out a preliminary aerial survey using a UAV to test and validate the methodology. We used a multirotor UAV Platform (Phantom 4 Pro DJI) equipped with two sensors, a normal color Red-Green-Blue (RGB) and the Red-Green-Infrared (RGN) bands (Fig. 3). The RGB sensor was the UAV camera and the RGN sensor was a Mapir Survey3W Camera. Because of harsh weather conditions we will reprogram these surveys for next year. However, we built the 20 wood plates as highly visible targets for use as Ground Control Points (GCP – Fig. 3) and organize some other important components of the survey that will be very helpful for the next field campaign planned in 2020. The GCPs serve to georectify the photogrammetric point cloud and to generate a set of “checkpoints” for accuracy assessment of the derived digital elevation models. This work requires the use of a differential GPS and a total station. To do so, we worked in collaboration with the Glaciological and Hydrological Resources Unit (UGRH) in Huaraz who helped us to survey the GCPs in the fields.

Figure 3: UAV survey at the Uruashraju, Yanamarey and Broggi Glacier Forelands, Cordillera Blanca. Credits: Carlos Ly (@ly_carlos)

Lastly, in the valley of the Uruashraju glacier, we worked with the Llama 2000 Association, an association of local farmers who own llamas and live in the village of Canrey Chico, downstream from the Uruashraju glacier. The farmers helped us in constructing the 4 fences and their respective control areas (Fig. 4). Inside each delimited zone, we established the 8 permanent plots and carried out the floristic evaluations. Moreover, we sampled the soils and buried the data loggers. Additionally, we sampled plant leaves for laboratory analysis of nitrogen and phosphorus, setting up the baseline of our experiment. A grazing calendar was established to ensure the llama rotation every month. Next summer, between May and July 2020, we will use the UAV photogrammetry technique to monitor this experiment. We already have preliminary UAV RGN images which constitute our baseline for the research.

Additionally, next to the llama grazing experiment we also have implemented a similar protocol to test the effect of nutrient addition on proglacial soil and biodiversity. This complementary experiment will help us to understand the biophysical processes observed — or not— in the llama fence. We installed 5 replications of a series of 3 permanent plots (1x1m) and consider the following treatments: (1) nutrient addition using a commercial NPK solution —Nitrogen, Phosphorus, and Potassium, (2) nutrient addition using a dilution of llama feces, (3) watering –i.e., no treatment, as control plots. We analyzed the llama feces at the National University Agraria La Molina in Lima to ensure the same nutrient addition that in the llama fence. This work is carried out in collaboration with Pier Smith Cisneros, a master’s student in Ecology at the National University of San Marcos, Lima.

Figure 4: Building the grazing fences and introduction of the llama in the fences for the first time at the Uruashraju, Glacier Foreland, Cordillera Blanca. Credits: Anaïs Zimmer

Conclusion y Broader impact

The landscape that emerges after deglaciation is the nexus for the consequences of climate change. These changes are not restricted to the proglacial area but propagate downstream. Therefore, the geoecological, hydrological, and geomorphic consequences of climate change scale up, and affect densely populated mountain areas, entailing challenges for risk management, natural resources supply, and economic activities (Carey et al., 2017; Milner et al., 2017).

Moreover, these issues are also alarming for the conservation of biodiversity and ecosystem functioning at a global scale. High Alpine ecosystems are key providers and regulators of water resources to human societies (e.g., water towers; Harden et al., 2013; Körner, 2003). They provide fodder for livestock grazing (Jacobsen and Dangles, 2017) and capacity to efficiently sequester carbon pools (Segnini et al., 2010; Tarnocai et al., 2009). In the Andes and Alps, shifts in the locations of wetlands, tree line altitudes, and modification in woody plant abundance are ongoing ramifications of climate change and glacier retreat (Carlson et al., 2017; Huggel et al., 2015; Young et al., 2017). Estimating and anticipating these impacts is crucial for the wellbeing of actual and future mountain communities but also for downstream populations.

Over the last 6 years working in high alpine environments, the Co-PI came to realize that the lack of scientific knowledge about periglacial ecosystems hinders decision-making, both in the Alps and in the Andes. Very few studies have experimentally tested the mechanisms underlying the biodiversity response to glacier retreat, yet functional approaches identifying the physical and biological processes are crucial for ecological predictions—of wetland, grassland, and alpine forest distribution—and land management. The Andes are facing such difficulties as securing water quality and quantity and Glacial Lake Outburst Floods (Carey et al., 2012; Huggel et al., 2015). While in the Alps decision-makers are more concerned with mass wasting hazards like rockfalls and landslides (Deline et al 2014, Ravanel et al. 2011; Huggel et al. 2015; Temme and Lange 2014) and changes in tourism (Mourey and Ravanel 2017; Salim et al. 2019). However, policymakers need scientific output and recommendations based on scientific findings to enhance land management of these emerging and fragile areas.

First, this research permits to understand the future of proglacial landscapes at a local scale to enhance decision-making and land use management, generating scientific reports for municipalities, regional or national governments. Second, this proposal aims to develop applied solutions to respond to actual and future problems in mountain regions. Our grazing experiment in Peru tests a local solution that can be implemented at a larger scale and in other mountain systems to respond to regional problems. Third, our results from both continents will advance complementary studies worldwide in such regions as the Central and Southern Andes, the Arctic and Scandinavian Mountains, the Himalayan region, and Africa.

In addition, this research provides the groundwork to create awareness and promote international policies for the conservation of deglaciated landscapes. We aim to influence the broader community of international organizations that work on conservation (such as the IUCN, UNESCO, Mountain Research Initiative, ICIMOD, The Nature Conservancy, among others) in a call for the protection and restoration of proglacial landscapes. Up until now, there is no specific effort on this.

The project will contribute to the academic development of undergrad and graduate students. Last summer we worked in collaboration with two students in Peru, both from the National University of San Marcos. At UT Austin, we are mentoring three undergraduate students who are helping the research through laboratory work and starting their theses. Through this formative experience, they have the possibility to learn scientific methods in the field and laboratory and be in contact with the different partners of the research project. Overall, we apply the same methodology in the Alps and Andes and consequently train all the local partners in both continents with the same methods. Finally, as we integrate the local community in the research activities such as our llama grazing experiment in Peru, we seek to benefit local people by increasing awareness and socioeconomic and professional development.

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