CLIMBING FOR SCIENCE AND ICE: FROM HANS KINZL AND MOUNTAINEERING-GLACIOLOGY TO CITIZEN SCIENCE IN THE CORDILLERA BLANCA

Escalando por la Ciencia y el Hielo: De Hans Kinzl y Montañismo-Glaciología a Ciencia Ciudadana en la Cordillera Blanca

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ABSTRACT

Observing and monitoring glacier changes and glacier-related risks is challenging given the rapid rate of environmental and societal changes in mountain regions, such as the Peruvian Andes and, in particular, the Cordillera Blanca with a deadly history of glacial lake outburst floods (GLOFs) and ice/rock avalanches. It is crucial not only to analyze these dynamic conditions through remote sensing, but also through fieldwork and glaciological research on the ice itself. However, with the relatively few professional researchers and the still-limited resources of the Peruvian government—particularly its National Institute for Research on Glaciers and Mountain Ecosystems (INAIGEM) and Glaciology and Hydrologic Resources Unit (UGRH)—it is not always possible to monitor and study in detail all of the country's dynamic glacial environments. Examining both the historical practices of combined mountaineering and glaciology activities, as exemplified by Dr. Hans Kinzl's work in Peru from the 1930s to the 1960s, and recent advances in citizen science, this paper shows how the combination of mountaineering and glaciology has yielded useful information about glacier change and glacier-related hazards. Observations and even data collection from the mountaineering community that includes climbers, guides, and porters has contributed to glaciological research and diversified glacier knowledge, with the ideal end result being increased knowledge generation and sharing, expanded public awareness, reduced risk of glacier-related disasters, and improved environmental management to help a broad range of stakeholders.

Keywords: *History of glaciology, environmental history, mountaineering, climbing, citizen science, glacial lake outburst flood (GLOF), Peru*

RESUMEN

Observar y monitorear cambios glaciares y riesgos relacionados a glaciares constituye un reto dada la rápida velocidad de los cambios ambientales y sociales en regiones montañosas, tal como en los Andes peruanos, y en particular la Cordillera Blanca, con una historia mortífera de aluviones (flujos por desbordes violentos de lagunas glaciares, o GLOFs por sus siglas en inglés) y por avalanchas de hielo y roca. Es crucial analizar estas condiciones dinámicas no solamente por percepción remota, sino también por estudios de campo e investigaciones glaciológicas en el hielo mismo. Sin embargo, con los relativamente pocos investigadores profesionales y los recursos todavía limitados del gobierno peruano, particularmente de su Instituto Nacional de Investigación en Glaciares y Ecosistemas de Montaña (INAIGEM) y de la Unidad de Glaciología y Recursos Hídricos (UGRH), no siempre es posible monitorear y estudiar en detalle todos los dinámicos ambientes glaciales del país. Examinando las prácticas históricas de actividades que combinaron el montañismo y la glaciología, como el trabajo del Dr. Hans Kinzl en el Perú en las décadas entre 1930 y 1960, y los avances recientes en la ciencia ciudadana, este artículo muestra cómo la combinación del montañismo y la glaciología ha producido información útil acerca de los cambios en glaciares y los peligros relacionados a ellos. Las observaciones e incluso los datos recogidos por la comunidad de montañistas, que incluye escaladores, guías y porteadores, han contribuido a la investigación glaciológica y han diversificado el conocimiento de los glaciares, cuyo resultado final ideal es el aumento y el compartir del conocimiento generado, la ampliación de la conciencia pública, la reducción del riesgo de desastres relacionados con glaciares, y la mejora en el manejo ambiental para ayudar a un amplio rango de grupos interesados.

Palabras clave: *Historia de la glaciología, historia ambiental, montañismo, andinismo, ciencia ciudadana, aluvión, Perú*

INTRODUCTION

Glacier change in mountain regions creates environmental hazards such as landslides and glacial lake outburst floods (GLOFs), hydrologic changes, unstable terrain for climbing and tourism, and other dynamic conditions that affect nearby societies and visitors (Vuille et al., 2008; Huggel et al., 2015; Haeberli and Whiteman, 2014). These changes can be difficult to monitor, thereby endangering people and triggering, at times, deadly consequences. In Peru, efforts to study and monitor high-mountain glacierized areas have long been carried out by a variety of government agencies, from the Control Commission of Cordillera Blanca Lakes (CCLCB) established in 1951 to the Glaciology and Hydrologic Resources Unit (UGRH) created in 1986 and ongoing today. Since the formation of the National Institute for Research on Glaciers and Mountain Ecosystems (INAIGEM) in December 2014, glacier research and monitoring work has been further centralized and significantly bolstered throughout the country. These agencies have played a particularly important role in Cordillera Blanca glacier monitoring given the long history of deadly GLOFs in the region: in 1941 (Huaraz), 1945 (Chavín de Huantar), and 1950 (Los Cedros/Huallanca), as well as catastrophic rock/ice avalanches in 1962 (Ranrahirca) and 1970 (Yungay), among others (Ames Marquez and Francou, 1995; Carey, 2014; Evans et al., 2009; Portocarrero, 1995; Zapata Luyo, 2002; Carey, 2010).

Glacier instability continues to the present day and requires consistent research and monitoring (Emmer, Vilímek, and Zapata, 2016; Portocarrero et al., 2016), such as at Lake Palcacocha which has been repeatedly declared a state of emergency during the last five years and now has more water in it than it had when its moraine dam burst catastrophically in 1941, sending a flood downstream that killed approximately 1,800 people (Carey, 2014; Wegner, 2014; Somos-Valenzuela et al., 2016). Individual scientists and engineers have also been studying the Cordillera Blanca and other Andean glaciers for decades, with research devoted generally to glacier and glacial lake hazards, glacier hydrology, glacier melt dynamics, and past glaciations. The Glaciers Project, for example, run by the University of Zurich and CARE, focuses on resolving glacier hazards through integrated approaches involving scientific studies, an early warning system, and community outreach and education in Carhuaz and at Laguna 513 in the Cordillera Blanca, and in other high-mountain Andean regions of Peru. Additionally, many local populations living near glaciers have developed their own understandings of glaciers and environmental change in mountain regions. Whether urban residents who have understood GLOF and avalanche risks to their communities (Drenkhan et al., 2015; Carey, 2014; Jurt et al., 2015), or Quechua-speaking peoples who conceive of "enchanted lakes" that help influence human behavior with some glacierized landscapes (Walter, 2003), or indigenous ice collectors who analyze glaciers to cut blocks of ice for the flavored ice drinks called *raspadillas* (Dunbar and Medina Marcos, 2012), or farmers who understand water flowing out of Andean glaciers to utilize for crops, pastures, and drinking (Brugger et al., 2010; Paerregaard, 2013; Rasmussen, 2015; Bury et al., 2011)—these diverse local populations have also been involved with analyzing glacier change and evaluating risks in the Andes, as elsewhere (e.g., Brugger et al., 2013; Drew, 2012; Nüsser and Baghel, 2014; Williams and Golovnev, 2015). Despite all these and other efforts to investigate and monitor glacier conditions in Peru, buttressed by technologies like GPS and satellite imagery, the high-mountain environment can still change fast enough to generate uncertainty and risks.

This paper provides historical perspective on knowledge production and glacier-related risks in the Cordillera Blanca to show how mountaineering and glaciology have at times provided useful information about glacier change and glacier-related hazards. The mountaineering community's observations and data collection have historically and up to the present—in fact, increasingly so in recent years through "citizen science" programs—contributed to glaciological research and diversified glacier knowledge. Ideally, the end results of these contributions are increased knowledge generation and sharing, expanded public awareness, reduced risk of glacier-related disasters, and improved environmental management to help a broad range of stakeholders and groups. This paper focuses on these contributions from the mountaineering community, recognizing that many types of local knowledge are also important but are beyond the scope of this study. There is a long history of merging mountaineering and glaciology—from the nineteenth-century European foundations of the scientific discipline of glaciology, to twentieth-century mountaineering-glaciology research expeditions, to more recent programs in citizen science among mountaineers. In Peru, joint mountaineering-glaciology expeditions occurred in the Cordillera Blanca beginning in the 1930s, as exemplified by University of Innsbruck geography professor Hans Kinzl. He conducted extensive Cordillera Blanca glacier research, among other studies and in other regions. Kinzl's early maps of the Cordillera Blanca and Cordillera Huayhuash were notable accomplishments as some of the first detailed maps of those mountain ranges (see Figure 1)—not to mention the mountaineering accomplishments, such as the first ascent of Mount Huascarán South in 1932, by his German and Austrian Alpine Club team members (Byers, 2000; Carey, 2012; Neate, 1994). But then, by the 1960s, even as mountaineer-scientists kept climbing and studying glaciers, glaciology and mountaineering became more divided—with deadly consequences. More recently, citizen science initiatives from climbing organizations have helped rekindle a connection between mountaineering and glacier knowledge production. These new developments in citizen science, as researchers investigating other regions and topics have indicated (Buytaert et al., 2016; Gura, 2013), have the potential moving forward to help uncover and chronicle dynamic landscape changes, collect useful environmental data, and provide timely reports about hazards to protect people and to help support effective global change adaptation.

On the one hand, those who travel, climb, and work among the world's glaciers—particularly mountaineers, guides, and porters who experience the ice directly—can add a great deal of information about these mountains and glaciers. Yet, on the other hand, these mountaineers and other high-mountain visitors are not automatically scientists simply because they spend time in the mountains. Moreover, it is important to consider that knowledge production—including the co-production of scientific and vernacular knowledge about glaciers (Sörlin, 2011)—is always embedded in societal contexts (including inequalities among social groups) and often-unequal power dynamics. The mountaineers in Peru, who are mostly foreigners, frequently come with expensive equipment and resources unattainable for most segments of Peruvian society. Peruvian porters, by contrast, generally participate in mountaineering not for recreation but rather for the job, out of economic necessity for employment rather than during free time or for leisure, thereby revealing differences in motivation and capacity for citizen science programs. The contrasts between mountaineers and local groups are thus crucial considerations in citizen science programs because of several factors: mountaineers' unique access to both equipment and free-time for recreation and citizen science projects, the different type of knowledge and information they can collect that contrasts with local knowledges, their access to particular constituencies such as policymakers and NGOs in Peru and internationally, and the fact that local porters and guides work with and assist most mountaineers, thereby co-producing the data and environmental observations even when porters and guides do not necessarily write the reports, compile the data in Excel, or give public lectures in Huaraz or Lima (Driver, 2000; Konishi, Nugent and Shellam, 2015; Livingstone, 2003; Raj, 2007; Ortner, 1999). Finally, the type of knowledge from the mountaineering community is only one aspect of the many knowledges created and circulated, but it can nonetheless contribute to broader understandings of glacier change and mountain hazards.

Glaciology and Mountaineering Roots

Hans Kinzl and his three German-Austrian Alpine Club expeditions to Peru during the 1930s stemmed from a long trend of linking mountaineering and science that began with early origins of both mountain climbing and the field of glaciology in the eighteenth century (Fleming, 2000; Hansen, 2013). Horace-Benedict de Saussure was one of the early advocates and practitioners of mountaineering-glaciology. A Swiss aristocrat, naturalist, botanist and geologist, de Saussure was obsessed with Mont Blanc and put up a reward for its first ascent. He would eventually summit Mont Blanc in 1787, a year after its first ascent. He did not just climb the peak though: he hired eighteen guides to transport bulky scientific equipment and lavish provisions to the top. De Saussure's scientific observations and description of the region's glaciers and complex geology were published in *Voyages dans les Alps* (1779-96). The book laid the foundation for his reputation as the father of alpinism, also making Mont Blanc a fertile field for the study of glaciers. De Saussure was the first of the climber-scientists marrying mountaineering with glaciology.

From the end of the eighteenth century until the middle of the nineteenth century, before mountaineering took off as a sport, it was primarily Swiss, Italian, and a few French and British scientists who climbed peaks and studied glaciers in Europe. In particular, the Swiss-born and European-trained biologist and geologist Louis Agassiz studied the glaciers of the Chamonix Valley. He, too, combined climbing with science. In 1840, he set up a camp on the Unteraar Glacier in Switzerland, under an overhanging slab of rock, wedged next to some large boulders, at the end of a three-hour hike on the glacier (Steiner, Zumbühl and Bauder, 2008). When it became Agassiz's summer field camp for glacier research—and with a steady stream of visiting scientists—it became known as the "Hôtel des Neuchâtelois." Agassiz measured the hut's voyage down the mountain on top of the glacier. In two years, it had moved 486 feet downhill. He also hauled a host of instruments and tools out to his "hotel" to systematically study and measure the glacier, particularly its motion. He bored holes into the ice to test flow at different depths, and he pounded wooden stakes all over the glacier to measure its pace. Living on the ice at the Hôtel des Neuchâtelois proved that innovative glaciological research stemmed from personal interactions with glaciers, time at high elevation, and expertise in mountaineering. Mountaineering and glaciology had been linked, and even reinforced each other, by the mid-nineteenth century (Hevly, 1996).

Those first ascents of Mont Blanc—and the broader link between mountaineering and glaciology—had another dimension to them beyond science and recreation: they were inextricably linked to the political climate of the time and the struggle over sovereignty in Chamonix and Geneva. Mountaineering and exploratory sciences would subsequently maintain and strengthen these connections, demonstrating that nineteenth- and twentieth-century mountaineering and geographical research were often tied to government expansion, economic agendas or imperial projects (Driver, 2000; Ellis, 2001; Ortner, 1999; Lefebvre, 2005; Poole, 1998). Knowledge acquired by mountaineer-scientists, after all, facilitated the understanding of glaciology and made landscapes legible (that is, governable and exploitable) through science. When the first German and Austrian Alpine Club expedition arrived in Peru in 1932, Germany was sending exploratory mountaineering-science expeditions to other regions as well. As Harald Höbusch (2002) explains, "between 1928 and 1939 German expeditions repeatedly traveled to such remote locations as the Andes, the Pamir and, most importantly, the Himalayas. Alpine historians have attributed this shift from a local to a global focus in German mountaineering to two related causes: first, to a chauvinist attitude of competition fueled by British attempts at Mount Everest . . . ; second, and more importantly, to the desire among German mountaineers for the reconstitution of their nation as a recognizable European (and even world) power in the decade immediately following World War I" (Höbusch, 2002: 50). Despite these contexts for mountaineering-glaciology in the Andes, when Kinzl arrived on his first expedition in 1932, he followed a different path and worked more closely with the educated, urban, and wealthier classes of Peruvians—as well as with local and regional authorities—to generate useful glaciology studies and successful mountaineering accomplishments.

Hans Kinzl and the German-Austrian Alpine Club in Peru

Hans Kinzl was born in 1898 in St. Florian, Austria, where he could gaze out at the Alps on the horizon—a view that drew him to high mountains for the rest of his life. After serving in World War I, during which he was ambushed and shot in the right hand on Christmas Eve of 1917, he was able to combine his passion for mountains and intellectual rigor through graduate work in geography. By the time the first German Alpine Club expedition of 1932 was taking shape under the leadership of German mountaineer Philipp Borchers, Kinzl had become a professor at the University of Heidelberg (he subsequently moved to the University of Innsbruck). Upon returning from a trip to the North Sea with his students in 1930, Kinzl received a letter asking if he wanted to join the Andean Expedition—which he was thrilled to do to see and study some of "the most beautiful high mountains in the world" (Kinzl, 1935; Penz, 1997-98).

The three German-Austrian Alpine Club expeditions of the 1930s to the Andes showcased what was so valuable about the link between mountaineering and science (Carey, 2012). During the 1932, 1936, and 1939 expeditions, the teams made first ascents of 15 peaks above 6,000 meters, including Huascarán (6,768 meters) in the Cordillera Blanca and Siulá (6,344 meters) in the Cordillera Huayhuash. As a professional geographer, Kinzl was doing more in the Andes than climbing peaks—producing some of the first maps of these ranges (see Figure 1), studying Andean flora and fauna, evaluating the causes and consequences of a glacial lake outburst flood, analyzing the dynamics of glacier retreat (long before the general public and even most scientists starting paying attention to global warming), and taking 16,000 photographs of the Cordillera Blanca (Kinzl, 1940c; Kinzl and Schneider, 1950; Kinzl, Schneider and Awerzger, 1954). Kinzl and his companions—including the famous mountaineer Erwin Schneider, one of Europe's top climbers—had won significant acclaim in both Peru and Europe. But Kinzl was most proud of his beautiful maps and scientific studies of glacier forms, movement, and positions. His glacier research, it turned out, continued to be useful for documenting long-term Cordillera Blanca glacier change (e.g., Georges, 2004). Kinzl's teams also mapped the northern and southern Cordillera Blanca. Twenty years later, Heinrich Klier, the leader of an Austrian expedition to the Cordillera Huayhuash, was still fawning over these maps, saying "Our whole expedition had been based on this map [of Kinzl's], which, according to Prof. Arnold Heim, is the best of its kind in South America, and really constituted a scientific and touristic accomplishment of the first order" (Klier, 1955: 169)

Kinzl's research is notable because he provided one of the first detailed scientific descriptions of a GLOF, which occurred in 1938 at Lake Pakliashcocha in the Ulta Canyon of the Cordillera Blanca (Kinzl, 1940b). The flood killed livestock and damaged bridges, irrigation canals, crops, and pastures, but there were no fatalities. Kinzl noted that "glacial lakes represent certain dangers for the Cordillera [Blanca] valleys and the people directly at the foot of the mountain range," thereby offering one of the earliest warnings about GLOF risks in Peru, even before the catastrophic 1941 Huaraz outburst flood from Lake Palcacocha. But at the same time, in 1940 he did not see practical ways to prevent GLOFs and protect the exposed populations because he believed that retaining walls in valley towns were the only disaster prevention option, something he saw as expensive and potentially ineffective. At that point, the Peruvian government had not yet started draining glacial lakes and building artificial dams to reinforce moraine dams (Carey, 2014).

While Kinzl was studying Peruvian glaciers and glacial lakes, he also faced other risks personally. In one case, in 1939, he barely escaped an avalanche that engulfed part of his climbing team on Mount Huaytapallana in central Peru. Three days after the avalanche, while Kinzl was still mourning the loss of his companions, Germany invaded Poland to start the Second World War. Peru immediately broke diplomatic ties with Germany, turning Kinzl into a virtual political refugee, unable to take public transportation back to Innsbruck to reconnect with his wife, Hedwig. After a year of plotting clandestine escapes from his exile in Peru, he was finally able to slip onto a Japanese freighter, taking whatever gear, photographs, and scientific records he could carry on his own. From Japan he made it to China, then into the Soviet Union, onto the Trans-Siberian Railway, and eventually, in spring 1941, back to Innsbruck (Leidlmair, 2003-2007; Penz, 1997-98; Neate, 1994). After the war, Kinzl came under the scrutiny of the Denazification Commission for his mountaineering activities between 1938 and 1945. The Commission evaluated whether his Andean mountaineering and scientific studies had been an arm of Nazi expansion and Democratic Socialism. Kinzl was cleared of any wrongdoing.

Kinzl had managed to escape from Peru just in time because mountaineers were coming under increased scrutiny in Peru during the war. As he was traveling back to Innsbruck, the U.S. military attaché stationed in Peru became agitated about two other German mountaineer-scientist-photographers, the brothers Franz and Edgar Eichorn, who had been traveling around Peru, and even into the jungle along the banks of the Amazon River, far from any glacier-clad peaks. The German government had helped pay customs duties for the climbers' photographic equipment and scientific instruments, which raised significant concerns among authorities—and in particular for Mr. Ent, the U.S. military attaché in Peru. He wondered in a military intelligence report why "two technical experts in good health, in their 50's, have to circle the globe with equipment for taking photographs and to study mountain climbing—in Iquitos—during a time when their country is engaged in a struggle of life and death and is in need of men, young and strong, and above all technical experts?" (Carey, 2012: 123). For Mr. Ent and other authorities, the mountaineer-scientists such as the Eichorn brothers—and likely Kinzl, if he had not already escaped—were "dangerous" because climbing mountains was more than just sport and recreation. It was the information, records, photographs, maps, studies of the natural world (and natural resources), and their information about inhabitants and their relationships with the high mountains that concerned the authorities. In other words, it was the integration of climbing and science that made them truly valuable, unique, and—for Mr. Ent— so threatening to U.S. national security and the Allied forces.

Within Peru, Kinzl became for some a legend for his studies of glaciers and glacial lakes—as exemplified in the many laudatory newspaper editorials and engineering reports, and by regional authorities who invoked Kinzl in their pleas for help from Lima to understand and contain glacial hazards. Kinzl's 1940 analysis of the Pakliashcocha GLOF recognized that Cordillera Blanca glacial lakes threatened residents and infrastructure in the region (Kinzl 1940b). A year later his worries became reality: glacial Lake Palcacocha, which he had photographed in 1939 (see Figure 2), burst over and through its moraine dam, generating a tsunami-like flood that killed 1,800 people in the city of Huaraz (Carey, 2014; Wegner, 2014). Within days of the catastrophe, many Callejón de Huaylas residents were complaining in newspapers and town meetings that authorities had ignored Kinzl's warnings. But local residents' veneration of Kinzl as the prescient sage was also somewhat misplaced. He had, after all, concluded in his pre-1941 publications that the

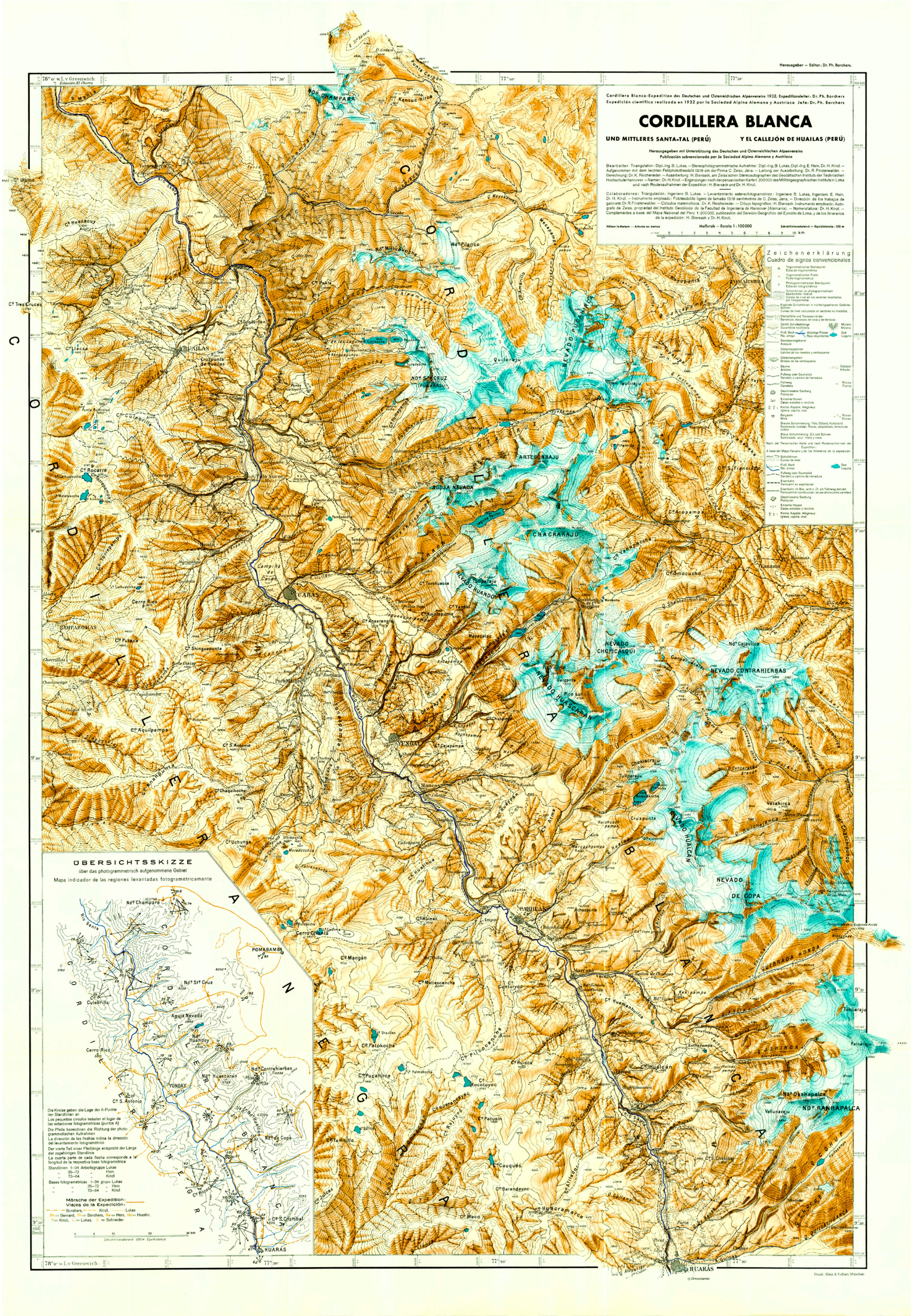

Figure 1. Map of the Cordillera Blanca and Callejón de Huaylas, Northern Section, scale 1:100,000. German-Austrian Alpine Club, 1934.

floods were rare, that it was largely impossible to protect the populations without constructing enormous retaining walls in the valleys, and that the "economic value" of the upper valleys was "not sufficiently large to justify such high costs" of disaster mitigation (Kinzl, 1940b: 164). His comment about the insufficient economic value could suggest a dismissive view of the regional population. He had not yet seen, however, that it was possible for outburst floods to extend out of upper valleys and into the densely populated lower valleys of the Callejón de Huaylas. Thus, he was not necessarily saying human lives were not worth the economic investment. Rather, he could not yet even foresee that GLOFs on the scale of the 1941, 1945, and 1950 events—which killed a total of perhaps 3,000 people, destroyed towns, and obliterated the nearly-completed Cañón del Pato hydroelectric station (Carey, 2014)—could even occur. After the 1941 Huaraz disaster, Kinzl took a very different view and was by then repeatedly warning residents about outburst floods and calling for disaster prevention works at unstable glacial lakes (Kinzl and Schneider, 1950).

What had made Kinzl such a hero among the urban non-indigenous populations who wrote so eloquently about him was his combination of mountaineering feats, his systematic scientific studies, and his diplomacy and outreach to Peruvians. For one, he actually ventured into the Andean canyons, climbed on the glaciers, and reached the peaks. Other scientists at the time did not do that—some in fact refused to do it. Kinzl was not only doing both mountaineering and science, but he was also communicating and interacting directly with local and regional residents living in Yungay and Huaraz, or those owning haciendas further up toward the glaciers. Kinzl was, however, interacting primarily with the non-indigenous population, and particularly the wealthier and more educated scientific communities, as well as regional policymakers. The Innsbruck professor became famous because he happily camped at glacial lakes, spent years traversing glaciers, learned Spanish and even some Quechua, and came to understand the Andean landscape in ways that non-mountaineering scientists never did. It is difficult to know much depth about his relationship with guides, porters, and Quechua-speaking inhabitants of the upland areas of the Cordillera Blanca. But he and his Alpine Club companions wrote about the indigenous populations favorably, offering significant praise and respect for the porters who worked with them during the 1930s expeditions—but that is praise and respect during the 1930s, in which the porters were largely invisible background labor compared to hacienda owners. Nevertheless, Kinzl published in Spanish (e.g., Kinzl, 1940a, b, c, d), gave lectures in Huaraz and Lima, and had even planted Peruvian flags on mountain summits to show respect for Peruvian policymakers and government leaders (Carey, 2012). Many indigenous residents could have held other views, of course, as they have over time had very different relationships with glaciers and mountain peaks. Some have noted how mountaineers can trespass when they go into the mountains, can violate sacred protocols, make spiritual transgressions against mountain spirits, cause glacier shrinkage by tromping on the glaciers, and, in some cases, be linked with the pishtaco, the mythical, evil, white-man monster roaming the mountains to suck body fat from indigenous people to grease industrial machinery in the United States and Europe (Bode, 1990; Carey, 2012; Oliver-Smith, 1969; Gose, 1994; Walter, 2003).

Figure 2. Lake Palcacocha in 1939. Photo: H. Kinzl.

Kinzl distinguished himself in the eyes of authorities, scientists, and the urban and wealthy classes he interacted with by being both a mountaineer and a "man of German science," as one resident referred to him in a March 1, 1956, *El Departamento* newspaper editorial. Other newspapers welcomed Kinzl's expeditions not only because of the "conquests" of mountains such as Huascarán, but also because they had calculated peaks' height, studied geography, analyzed the geologic history of the region, and produced their "very important" maps (e.g., *El Comercio*, June 1, 1936). In a January 21, 1945, article in Lima's *El Comercio* newspaper, a local Huaraz resident complaining about the government's neglect of glacial lake disaster prevention programs contrasted Kinzl's devotion and systematic analysis to what he deemed neglectful government research: "It is important to remember," the resident proclaimed, "that more than ten years ago a German scientific commission—the most extensive and capable that has ever been in the region—lived in and explored the entire Cordillera Blanca of Ancash for a year." Others in the government gave even higher praise to Kinzl: a decade later, in 1956, the Innsbruck professor received the Peruvian Order of Merit for his "distinguished services" to the country over two and a half decades. There were clearly benefits to spending time in the Cordillera Blanca itself, in the mountains and communities, not only for successful scientific studies about glacier retreat and GLOF threats to regional populations, but also for research diplomacy, outreach, and education.

Other Mountaineers and Glacier Research

By 1962, mountaineer-scientists were still venturing into the Cordillera Blanca but they received a rather different reception in one notable case. In 1962, there was a catastrophic rock/ice avalanche from Mount Huascarán, which destroyed several communities, including Ranrahirca in the Callejón de Huaylas, and killed thousands (Carey, 2014; Evans et al., 2009). Later that year, the U.S. mountaineer-scientists David Bernays and Charles Sawyer spent several weeks climbing and researching on Huascarán, focusing especially on Glacier 511 that had generated the fatal 1962 avalanche. Bernays was known primarily for his mountaineering accomplishments, including a first ascent of Mount Tullparaju in the Cordillera Blanca with Charles Sawyer (Bernays, 1963). Sawyer was a graduate student in geophysics at the Massachusetts Institute of Technology (MIT). But when they reported that the badly-fissured Glacier 511 could trigger yet another and even more deadly avalanche, authorities silenced the mountaineer-scientists, forced them to leave the region, and told residents to "return to your homes with your faith placed in God," threatening anyone who spoke in favor of the mountaineers' conclusions to be charged under the Penal Code for "disrupting public tranquility" (Guzmán Tapia, 2002). The director of the Control Commission of Cordillera Blanca Lakes, Miguel Elías Pizarro, referred to their research in a letter printed in *El Departamento* on October 2, 1962, as "a sporting adventure," not science. Sadly, Bernays and Sawyer had been exactly right in their prediction: on May 31, 1970, a rock/ice slide from Glacier 511 on Huascarán killed nearly 8,000 people (Evans et al., 2009; Oliver-Smith, 1986). For some engineers and regional authorities during the 1960s, the value of these mountaineer-scientist perspectives had plummeted since the time of Kinzl, even though the climbers had offered a critical—and correct—analysis of Glacier 511 and its unstable bedrock. Thousands of people paid the price for the political shift with their lives.

As mountaineering became a popular and valued form of recreation internationally, the climbers arriving in Peru no longer needed to rely on science for credibility, justification or prestige (as Kinzl had achieved), though of course glaciologists still needed mountaineering skills to keep them out of the crevasses they were studying. And at the same time, satellites, remote sensing, and GIS were gaining significant momentum after the 1970s, which some would say reduced the amount of time glaciologists spent in the mountains. At the same time in Peru, with the rise of the Sendero Luminoso (Shining Path) insurgence by the 1980s, and more specifically the Tupac Amaru Revolutionary Movement in the Callejón de Huaylas, there was a decline in scientific research and mountaineering in remote places such as the Cordillera Blanca. Further, whereas Peru's Glaciology and Lakes Security Office was large and actively monitoring and containing unstable glacial lakes during the 1970s, by the 1980s the office had shrunk considerably and shifted its focus away from glacier hazards and toward glaciers as hydrological resources (Carey, 2014). Kinzl's era, when "men of science" climbed mountains and studied wglaciers at the basecamp, had given way to limited glacier monitoring and more politicized glacier knowledge—with potentially dangerous consequences.

Mountaineers and Citizen Science

While satellite observations have monumentally increased understanding of mountain glaciers and Alpine regions in general, they have some limitations. If the images are not ground-truthed and coupled with first-hand fieldwork analysis of environmental conditions, they can lead to misinformation—as revealed by the 2003 debacle over Lake Palcacocha in the Cordillera Blanca. In April 2003, NASA issued a press release warning about an "ominous crack" in the glacier above Lake Palcacocha (see Figure 3). "Should the large glacier chunk break off and fall into the lake," the NASA report warned, "the ensuing flood could hurtle down the Cojup Valley into the Rio Santa Valley below, reaching Huaraz and its population of 60,000 in less than 15 minutes" (Steitz and Buis, 2003). The press release sent shock waves through Peru as worried residents, scientists, and authorities demanded details about their fate—and while tourists cancelled their plans to visit Huaraz. The lost tourism revenue was estimated in the millions as only 6,000 visitors arrived in Huaraz for the Semana Santa holiday, instead of the projected 18,000 (*El Comercio*, April 21, 2003). Kinzl had warned that these glacial lakes could trigger catastrophe, and Palcacocha had a deadly record ever since its horrendous 1941 flood. But in 2003, NASA based its analysis on satellite imagery alone, not the kind of eyewitness account that de Saussure, Agassiz, Kinzl, Bernays, Sawyer, or other scientists could have offered through observations at Palcacocha. In the end, on-the-ground analysis of Palcacocha within days of the NASA press release proved the report was wrong. The supposed crack in the glacier was a rock, Peruvian experts discovered as soon as they reached the glacier (Kaser and Georges, 2003; Carey, 2014; Kargel et al., 2011; Vilímek et al., 2005). Without on-the-ground glaciological analysis, misrepresentations of hazards and environmental change,

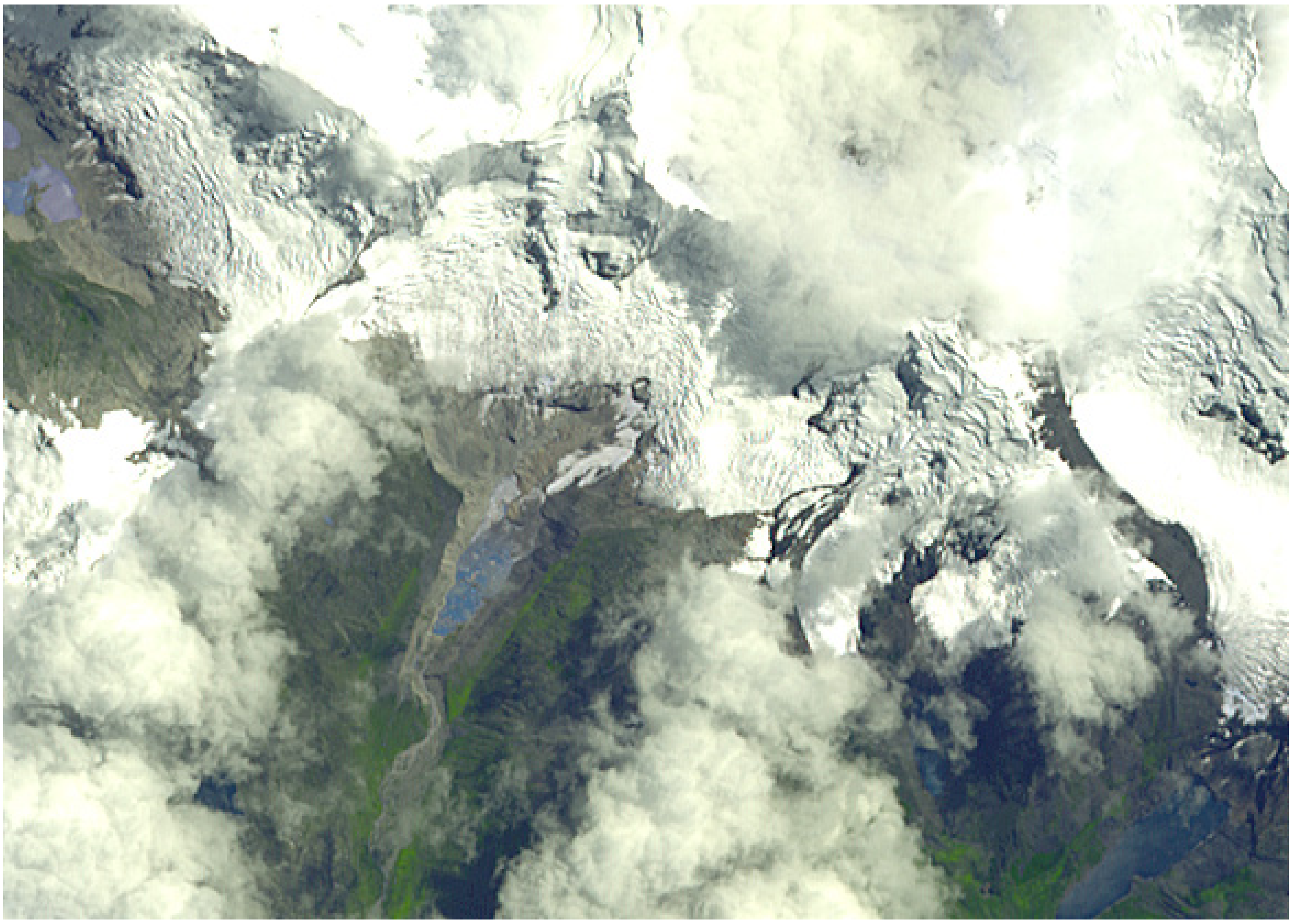

Figure 3. NASA's ASTER satellite image of Lake Palcacocha, April 2003. Note the supposed "crack" in the glacier above Palcacocha at the center of the image. Source: Steitz and Buis, 2003; http://photojournal.jpl.nasa.gov/catalog/PIA03899.

such as at Palcacocha, can occur with far-reaching negative consequences. Kargel et al. (2011) explain that satellite image analysis, ground and aerial observations, and ground-based instruments—all combined together—provide the most comprehensive glacier hazard monitoring.

Another way to increase glacial lake, glacier, and other mountain and environmental observations is through climber-scientist programs and the kind of work that both motivated Kinzl in the 1930s and fed the foundations of glaciology in the nineteenth century. Such a link between mountaineering and what is increasingly referred to as citizen science has the potential to help with glacier change observations and educational outreach. Local knowledge from diverse residents is obviously another source of knowledge about environmental change (e.g., Jurt et al., 2015; Walter, 2003), but here we focus on the role of citizen science among the mountaineering community, which includes not only the climbers but also guides and porters. Scientists are relatively few and cannot study and monitor every glacier system; moreover, remote sensing can fulfill important roles, but even so, as in the case with Palcacocha, cannot discern every potential threat. On the other hand, many mountaineers, and especially guides and porters, spend significant time in mountain regions and can acquire detailed environmental knowledge about rapidly changing landscapes. Even if they only have limited time or experience, mountaineers involved in citizen science programs can benefit from the educational component for themselves, learning about dynamic global environmental change in the mountains where they climb and then sharing that information with others, whether locally or back in their home communities and countries. Kinzl was, after all, successful in the Cordillera Blanca because of his outreach, lectures, publications in Spanish, and community relations in the Callejón de Huaylas and Lima. He did not simply extract the information for himself and then leave the country, an important lesson for mountaineers and citizen science programs today.

Citizen science is a growing trend that relies on the general public—people who spend time in the outdoors—to collect and share observations about environmental conditions (e.g., Silvertown, 2009; Buytaert et al., 2014). It is frequently done in collaboration with professional scientists, thereby being part of or guided by a larger scientific project to help ensure consistency. Citizen science is motivated by the belief that people who are not technically professional scientific researchers can also collect data or report conditions to augment scientific knowledge. Furthermore, participation and data sharing can increase public awareness and engagement, leading in an ideal outcome to constructive contributions not only for knowledge production but also for government policies and environmental management (Weitkamp, 2016). Citizen science is gaining momentum, as evidenced by the creation of a new open-access journal in 2016 called *Citizen Science: Theory and Practice*. In one case of citizen science research on snow conditions in mountains, the professional scientist overseeing the program found it most productive to build a formal relationship with an outdoor education school because it created more data and more consistent and better results than simply inviting anyone going to the mountains to contribute (Dickerson-Lange et al., 2016).

Overall, citizen science has the potential to diversify and augment scientific and local knowledges by including more participants and more fields of expertise, which can have benefits for environmental management (Buytaert et al., 2016).

In places such as Peru, there is great need for glacier and high-mountain observations, data, monitoring, and other information. For one reason: glacier hazards persist. A few weeks before the 2003 NASA announcement about Lake Palcacocha, for example, the lake had overflowed due to a landslide from the lateral moraine. The lake's security dam built in 1974 was partially destroyed (see Figure 4), but the dam served its purpose: it prevented the overflow from turning into a full-blown GLOF that could have had deadly consequences downstream in Huaraz. Experts in 2003 believed the lake was safe, but they were using data from 1974, which indicated the lake only had about a half million cubic meters of water. They also did not have in 2003 the kinds of lake observations that would have shown significant lake expansion due to the retreating glacier terminus. Recent studies show Palcacocha now has more than 17 million cubic meters of water, compared with 10-12 million cubic meters when it triggered the 1941 GLOF (Unidad de Glaciología y Recursos Hídricos, 2003; Carey, 2014; Somos-Valenzuela et al., 2016; Vilímek et al., 2005). Experts thus vastly underestimated the amount of water in Palcacocha before the 2003 overflow. The lake today is being drained very slowly with siphons (see Figure 5), which is not necessarily a permanent solution to prevent a Palcacocha GLOF but one that is at least helping to reduce risk by removing lake water. In 2010, another glacial lake, Laguna 513 in the Cordillera Blanca, triggered a GLOF when an avalanche crashed into the lake and generated 30-meter-high waves that overtopped its rock dam. The lake surface had been artificially lowered in the 1990s and was, up until 2010, believed to be secure (Carey et al., 2012; Schneider et al., 2014). That previous work likely prevented a major GLOF in 2010. In 2015, a rock/ice avalanche into Lake Huallcacocha occurred, but fortunately engineers had lowered the lake level and constructed an artificial dam during the 1970s, which likely averted a GLOF in 2015 (Portocarrero et al., 2016). There is concern today that a new lake is forming above the city of Caraz, at a site called Artesoncocha Alta, upstream of Lake Artesoncocha, which generated two GLOFs in the early 1950s that drained into and were barely contained by Lake Parón, nearly causing a cataclysmic GLOF given that Parón is the largest lake in the Cordillera Blanca (Carey, 2014). No deadly GLOF events have occurred in Peru in recent decades, but conditions are changing rapidly—as these examples demonstrate. Glacier and glacial lake changes are occurring constantly in Peru and elsewhere, and they cannot always be monitored or predicted, even with satellite imagery and remote sensing.

Figure 4. Lake Palcacocha security dam in 2003 that was partially destroyed when a landslide fell into the lake and created waves that overtopped the dam. Photo: M. Carey.

Worldwide, efforts are increasing to get climbers involved with science and environmental observations. The "snow and ice collection" program of Adventure Scientists (http://www.adventurescience.org/), for example, trains mountaineers to collect scientific data and give back to society by sharing it with scientists. They give the data to scientific partners, who are using data to study environmental issues such as glacier melt and climate change. Since 2012, Adventure Scientists' snow and ice collection project has coordinated the collection of vertical columns of snow from the top surface of glaciers by mountaineers above 6,000 meters in the central Himalaya for the Byrd Polar and Climate Research Center at Ohio State University. The data have contributed to high-elevation glacier mass and glacier melt studies and have led to some surprising observations about top-down glacier melt. In the last few years, Adventure Scientists has recruited and trained volunteer adventurers worldwide with help from mobile apps that give users the ability to contribute to Adventure Scientists projects. Further incorporating mobile apps and other technology will be a key factor in advancing the goal of Adventure Scientists to enhance conservation by providing hard-to-obtain environmental data.

The American Climber Science Program (http://www.mountainscience.org/) also engages mountaineers through scientific projects, including in recent years in Peru's Cordillera Blanca. Beginning in 2011, the program's annual expeditions have called upon the expertise of volunteer climbers to collect snow and ice samples on some of the tallest, most challenging peaks in the region. Their efforts, along with their commitment to train and support local guides and students, have resulted in a substantive black carbon glacier pollution database for the entire Andean region, produced through monthly sampling on peaks such as Vallunaraju. The data are currently being processed through multiple international labs to uncover the primary sources of heat-trapping carbon, potentially leading to socio-political solutions. Schmitt et al. (2015) have published some of the results of the American Climber Science Program studies on black carbon and heat absorption on glaciers. This past summer (2016), a citizen science group with this program in the Cordillera Blanca discovered empty subway-sized tunnels

Figure 5. Palcaraju Glacier and Lake Palcacocha in 2013, with siphons removing water to reduce the possibility of a GLOF. Photo: Paribesch Pradhan, from the Glacier Photograph Collection, National Snow and Ice Data Center, Boulder, Colorado, USA.

under the seemingly intact Mount Andavite (Chopiraju). The insights raise questions about glacier dynamics that cannot be answered solely through satellite imagery and remote sensing. The American Climber Science Program's coordination and collaboration with mountaineering experts in Huaraz suggests yet another productive aspect of citizen science: guides and porters go repeatedly to the mountains, often on the same routes and returning frequently to the same glaciers. By working more regularly with local climbers—including guides, mountaineers, and porters—new data can continue to be revealed.

Girls on Ice (http://girlsonice.org/) is another type of citizen science program focusing on glacier research by the general public. University of Alaska Fairbanks glaciologist Erin Pettit founded the Girls on Ice program that offers a unique opportunity for teenage girls without professional training in glaciology to do glaciological research, to be inspired by glacierized mountains, and to share results with various communities afterward, such as their home schools. In addition to learning mountaineering skills, the students use cameras, timers, measuring tapes, thermometers, handheld GPS, and simple filters for examining snow conditions during their field experience. A key outcome of the program is to teach the young women broadly about the scientific process: they engage in research and data collection related to glaciers but also develop a larger appreciation of science and scientific knowledge.

Other programs linking mountaineering and glaciology focus more specifically on glacier hazards, such as the Office de Haute Montagne (Mountain Information Office) and the Pôle Montagne Risk (Mountain Risk Center) in the Chamonix Valley (http://www.chamoniarde.com). Few alpine regions provide such an exhaustive database of mountain data due in part to the advent of new information and communication technologies. Though largely devoted to search and rescue operations in this glacier-covered region of the Alps, the Mountain Risk Center also studies snow and ice conditions to help prevent damage to life and property in the event of avalanches. Alp-Risk (http://www.alp-risk.com/) is another program in Europe to help link mountaineering and science by observing and reporting alpine environmental changes, especially hazards and risks posed to populations and climbers.

A major reason for the emergence of such citizen science efforts is the facilitating role of technology. The Internet in particular has led to growing availability of scientific results for large groups of people. This greatly improves coordination of efforts, exchange of information, and communication between scientists and non-scientists (Karpouzoglou et al., 2016). As a consequence, the involvement of the general public in science is increasing and will likely become more important with the emergence of well-informed knowledge societies and the ever-growing information and communication technologies. For example, mobile applications for smartphones, tablets and other gadgets can automate data collection. These technologies may also be able to incorporate important data-gathering functions, such as digital photography combined with GPS that generates photographs with geographical coordinates, time stamps, and orientation included in the metadata. The increased availability of low-cost, robust and more integrated data collection technologies gives interested people the possibility to participate in science projects (Buytaert et al., 2014). Such participation and effective use of available technologies not only advances data collection and knowledge production, but also contributes to education and awareness among the general public. The website Scistarter (http://scistarter.com) lists more than 600 active citizen science projects around the world, one third of which are powered by mobile apps.

As these active programs in the Cordillera Blanca and elsewhere illustrate, citizen science conducted by mountaineers, guides and porters could be useful on a number of levels in Peru. For one, INAIGEM and UGRH experts cannot observe and monitor every glacier and glacial lake. Photographs of these glacial features could be enormously helpful if they were consolidated in a central database, especially if the precise GPS coordinates, photographic orientation and time stamp could be extracted and uploaded from climber photographs. Other information could also be collected, such as data related to temperature and precipitation, ice and snow stability, water quality and quantity, glacier and glacial lake positions, ice melt rates, vegetation cover, and flood evidence. The diverse observations would be most beneficial if they could be transferred into a single database through a smartphone app that includes photographs, videos, GPS data, hydrophone recordings, weather conditions, typed notes, and other types of information that provide evidence of environmental change in high mountains. This information and data would not replace scientific studies or supplant local knowledge produced by residents living near glaciers, who have, in many cases, developed glacier-related understandings over many generations. Foreign mountaineers often lack the kind of awareness about long-term environmental change that local residents maintain. Nor are mountaineers working in citizen science programs always trained as scientists in data collection. Further, the contrasts between the diverse local populations (including but not limited to porters and guides) and the foreign mountaineers' access to equipment, leisure time for recreation, and political authority must be recognized. As demonstrated in this paper, glacier knowledge has politics and power, from Kinzl's unheeded warnings about GLOFs to Bernays' and Sawyer's conclusions about Mount Huascarán's instability, to more recent events at Lake Palcacocha. And given the deep so-called neo-imperial roots of mountaineering and geographical knowledge (Driver, 2000; Ellis, 2001), there is a need to recognize the politics of mountaineering and glaciology today, including for successful citizen science programs.

Even in cases when citizen science mountaineering-glaciology projects do not directly benefit scientists or threatened communities living with glacier hazards and glacier runoff variability, there is still an educational value because climbers learn about key issues facing Andean residents and policymakers. Climbers in the Cordillera Blanca often complain, for instance, about the "ugly" glacial lakes that have been artificially dammed or partially drained, which thus tarnish what many of these foreigners think should be a pristine alpine environment. They often think (erroneously) that these are reservoirs for hydroelectricity generation. Instead, they are mostly disaster prevention security dams that do not regulate streamflow, but simply maintain a low water level in glacial lakes so they do not acquire too much water and overflow dangerously in a GLOF. Teaching mountaineers, in this one example, about the history of GLOFs and glacier avalanches—and particularly about the successful efforts to drain and dam 35 dangerous and supposedly ugly Cordillera Blanca glacial lakes—illustrates quite vividly to the generally foreign mountaineers how climate change and glacier retreat are playing out in Peru, with deadly and ongoing consequences requiring decades of vast engineering projects to protect the population.

CONCLUSION

Hans Kinzl argued that glaciology, geology, and the natural sciences were central to mountaineering. His point was that being in the mountains for extended periods, often with a need to evaluate ice conditions to stay alive, yielded important observations and tremendous knowledge about mountain processes. For early climbers, reaching the summit was key. But so was collecting meteorological and glaciological information, for intellectual curiosity and also survival. Bagging the peak was not enough for them—not for the founders of glaciology in the nineteenth century or for Kinzl. As such, Kinzl can be considered an early champion of citizen science in the Cordillera Blanca. The Stockholm University glaciologist Hans Ahlmann reached similar conclusions to Kinzl during the same period, realizing in the 1930s that his scientific studies in the Arctic would advance significantly by working closely with Lapland Sami, Greenland Inuit, and Icelandic farmers, who also collected data for Ahlmann's research on "polar warming" (Sörlin, 2011). Today, in the era of remote sensing and satellite imagery—corresponding with a period of incredibly fast glacier changes—it remains crucial to do "muddy boots" fieldwork and glaciological research on ice. But with the relatively few professional researchers and the still-limited resources of the expanded INAIGEM, it is not possible to monitor and study all the dynamic glaciers in Peru. Mountaineering and citizen science projects can be useful for the natural sciences, environmental management, and global environmental change monitoring—which can all benefit from those who spend significant time on and around glaciers. The diverse range of local populations—from Quechua-speaking farmers living near glaciers and irrigating their crops with glacier runoff to urban residents who have experienced the long history of GLOFs and avalanches—also possess crucial environmental knowledge. Citizen science programs among mountaineers do not replace or threaten those other diverse knowledges, but rather add another dimension of information about rapidly changing glaciers and mountain environments. There is a persisting opportunity for mountaineers, guides and porters to provide input into this knowledge production. As Ohio State University glaciologist Lonnie Thompson reflected about the need to spend time working on glaciers, "mountains are interesting places. . . . There are a lot of words in the world of science and everyday affairs, but words don't work on mountains; you have to experience them" (Bowen, 2005: 332).

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