Field Trip Guide for Ensenada/Calbuco
Post-Conference tour for Wood in World Rivers 4 Conference – Jan 10-11, 2019

Calbuco volcano during the April 2015 eruption. Photo from the city of Puerto Varas looking to the east, with the Osorno volcano to the left (source, Gutierrez, 2015)

Field Trip Schedule in Brief

Jan 10, 2019
0830. Leave Valdivia
1200. Arrive at restaurant in the Ensenada area for set lunch
Afternoon: three stops

1. Blanco-Este River: upper site. Eruption impacts, fluvial geomorphic dynamics, including large wood.
2. Blanco-Este River: lower site formerly occupied by a hydropower station. Valley floor and channel dynamics downstream of Stop 1. Sedimentology and large wood of the streambed.
3. (time permitting) Petrohue River on the flank of Osorno Volcano. View of volcanoes, Osorno debris flow tracks, big river draining Todos los Santos Lake.

Evening: Group dinner – a classic Chilean asado at Parque Valle Los Ulmos on Calbuco

Jan. 11, 2019
Morning: two stops

4. At the Domo of Parque Valle los Ulmos. Brief overview of the park objectives, tephra fall experienced here during the eruption, state of ecological and social responses.
5. Tepú River valley floor. Deposits left by pyroclastic flows, their impact of inundated forest, subsequent fluvial erosion and downstream sediment transport, effects on large wood in the river.

Midday: Arrive in Puerto Varas for lunch and after lunch dispersal to Valdivia, Puerto Montt airport, Puerto Montt city, or other destinations.

Introduction

The field trip will provide biogeographic and cultural views of this fascinating part of the world, and will feature findings from current research on wood in rivers impacted by various volcanic processes (a map with general information for the WWR4 conference is found at https://www.wwr4.cl/session-program/). As with the northwest coast of North America, the geography of this part of western Patagonia is characteristic of a tectonically active continental margin where an oceanic plate plunges beneath a plate of continental crust. A low mountain range hugs the coast and is separated from the high volcanic mountain range of the Andes by a broad, lush interior valley that supports agriculture. South of Puerto Montt this geography gives way to an archipelago extending to Tierra del Fuego, just as the interior valleys of the Pacific Northwest give way to an archipelago that extends northward from Seattle and the Puget Sound area in Washington. Climate of the region is similar to the Pacific Northwest, with 80% of precipitation falling in the austral winter, and a shift from rain to snow-dominance with increasing elevation and latitude.

Human occupation of this Patagonian landscape has evolved through many stages. The indigenous Mapuche people and other groups descend from among the earliest arrivals in the Americas – one of the oldest sites of human origin (radiocarbon-dated at approximately 14,000 yr BCE) in the New World was found at Monte Verde along the coast just to the west. Europeans arrived in the early 1500s, but native people resisted subjugation by the Spaniards and by the Incas from the north through great skill and the protection provided by the ruggedness of their native homeland. In 1835 a noted European visitor, Charles Darwin, stood on the deck of the *Beagle* anchored near Puerto Montt and observed the eruption of a lava flow onto the southwest flank of Osorno (the outline of this flow is still evident in the vegetation pattern). The arrival of German, French, Italian, and others in the beginning in the mid 19th century is evident in the styles of farms, food (signs for "kuchen"), beverages (beer brands), and architecture.

Our trip takes us east from Valdivia through the coastal mountains and then south down the interior valley. The Andes are marked by a series of stratovolcanoes with summit elevations generally ranging from ca. 2000 to 3500 m. Glaciers issuing from the Andes left terminal moraines that created a series of large lakes along the east side of this interior valley. Note the large rivers we cross along Highway 5 (Ruta 5) which drain these big lakes, whose large volumes buffer runoff, creating rather stable hydrographs. This stable flow regime moderated by the lakes results in lack of sediment and large wood in downstream river channels and the presence of riparian vegetation down to the water's edge, even at the low flow stage we will encounter in mid-summer. We encounter the largest lake, Llanquihue Lake, as we approach the tourist town of Puerto Varas. Turning east from Puerto Varas along the southern shore of the lake, the road (Highway 255) to Ensenada passes through 50 km of mixed woodland and dairy farming. This area was originally forested, but land, especially along the lake shores, was cleared for dairy farming by European (predominantly German) settlers in the late 1800s, which may have reduced wood contributions to the lake. An interesting historical feature of the Puerto Varas-Llanquihue Lake-Ensenada area is its historic use as part of a route of train-boat-overland travel across the continent before the Panama Canal opened. Today the Puerto Varas-to-Ensenada area is undergoing a second phase of land use transformation, in which the dairy farms are undergoing rapid development as second homes and vacation spots by individuals and corporations from Santiago, Europe, North America, and elsewhere. Extensive national and private park lands have been designated recently for conservation purposes in southern Chile, yet this process attracts more visitors and new residents, which in some ways complicate achieving conservation objectives.

This field trip focuses on the southeastern part of Llanquihue Lake area in the neighborhood of Osorno (2652 m) and Calbuco (2003 m) volcanoes, two of the most active volcanoes of the very active southern Chilean Andes. Osorno is a beautifully symmetrical cone composed dominantly of basalt to basaltic-andesite rocks. The 1835 lava flow Darwin observed was one of five eruptive events in the 19th century – four of Volcano Explosivity Index (VEI) = 2 and one of VEI = 3. Osorno frequently sheds debris flows which travel from above treeline high on its south flank downslope through the fringing forest all the way to Petrohue River ("place of flies" in Mapuche – watch out for the tabanos! It is best to wear a long-sleeved white shirt and hat – dark colors like black, red, and brown seem to attract them). However, the delivery of large wood to the river is limited by the high frequency (every few years – note the dips in the highway to let them pass) of events traveling along common flow paths, so the forest does not have time to regenerate and produce new wood sources. Large wood that does reach the Petrohue River is quickly swept downstream by this large river.

Calbuco also has a history of vigorous eruptive activity with 11 recent events of VEI = 2 or greater observed beginning with the 1893 eruption. The 1893 and 2015 eruptions were the largest of this period at VEI = 4 (the 1980 eruption of Mount St. Helens was barely VEI = 5). These events have included tephra fall, lahars, pyroclastic flows, and production of a dome and lava flows of basalt to basaltic-andesite composition. The 2015 event involved several phases during 22-23 April with the eruption column reaching a height of >15 km and delivering ca. 0.27 km^3 (dense rock equivalent) of basaltic-andesite tephra initially to the northeast and then east across Patagonia and ultimately circling the globe (Romero et al. 2016). More than 40 cm of coarse-gravel tephra blanketed the terrain high on the cone and about 20 cm of tephra up to 2-cm diameter fell in Ensenada. Pyroclastic flows were triggered by two processes: partial collapse of the eruption column and by the fall of hot, highly porous tephra (scoria, density ca. 1.5 g cm^{-3}) into the heads of steep drainages originating on the upper flanks of the cone. This immediately formed pyroclastic flows that raced down the steep, narrow channels. Where the tephra fell onto snow and ice fields, meltwater mixed with tephra and entrained alluvium to form cool lahars that moved rapidly down many channels radiating from the cone (Mella et al 2015, Russell and Dussaillant 2018), as they have in other recent eruptions (Moreno et al 2006). The northeast flank of Calbuco received a higher proportion of hot flows than other quadrants around the cone, and the south side appears to have experienced more cold lahars, perhaps because tephra ejection was directed somewhat to the northeast, the wind was blowing the hot tephra in that direction, and snow and ice fields were more extensive on the poleward-facing south side of the cone.

Despite this long history of eruptive activity, extensive tracts of native, centuries-old, Valdivian rainforest blanket the upper flanks of the volcano, which is now “protected” within a national park. The oldest trees on the northeast flank have survived more than a dozen eruptions, including pelting with hot, gravel- to boulder-sized tephra. Dominant tree species include *Dasyphyllum diacanthoides* (trevo), *Laureliopsis philippiana* (tepa), *Nothofagus dombeyi* (coigue), and *Eucryphia cordifolia* (ulmo), with individual trees of trevo and tepa exceeding 300 to 400 years. Native forest at lower elevation on Calbuco, such as in the vicinity of the Domo we visit on January 11, was removed long ago for farming, pasture, and tree plantations. Remnant old forests are confined to planar slopes at high elevations and the extremely steep slopes of stream channels, where they escaped logging and removal by volcanic flow processes.

Land use history has greatly altered the conditions of wood in rivers in this landscape, but field studies elsewhere in Chile indicates that conditions are similar to volumes, piece size distributions, and dynamics observed elsewhere in the world (Iroume et al 2010, 2017, 2018). For example, in a third-order section of a river (channel width approximately 10 m) flowing through native, old Valdivian rainforest in Reserva Costera Valdiviana near Valdivia, they observed wood loadings of approximately 110 m^3ha^{-1}. The rivers draining Calbuco, however, had much younger valley floor vegetation at the time of the 2015 eruption, because of the history of frequent hot and cold flow events associated with eruptions. For example, Klohn (1963) reports that the 1961 eruption of Calbuco left 1.5-2 m of steaming deposits on the Highway 255 bridge delivered by hot flows down the Tepú River, suggesting that valley floor forest date from that event.

This field trip draws on research and collaborative work of Andres Iroumé, his many students and colleagues, especially Hector Ulloa, as well as Fred Swanson and Julia Jones, concerning the effects of volcanic processes on forests in general (Swanson and Crisafulli 2018) and wood in rivers in particular. Our combined experiences at Chaiten, Calbuco, and Mount St. Helens demonstrate that the great variety of volcanic and associated hydrologic processes have a wide range of effects on the abundance and function of wood in rivers (Swanson et al 2013). In some cases, volcanic and associated hydrologic processes deliver and transport large volumes of wood into and down rivers (e.g., Ulloa et al 2015; 2016); in other cases, volcanic processes greatly reduce near-term and long-term wood supply to rivers. The field stops on this Calbuco trip display two cases along this continuum of effects of eruption-related wood delivery to rivers.

Field trip stops on Jan 10.

The first visit of this day will be at the Blanco-Este River (Fig.1), affected by the 2015 eruption of Calbuco volcano.

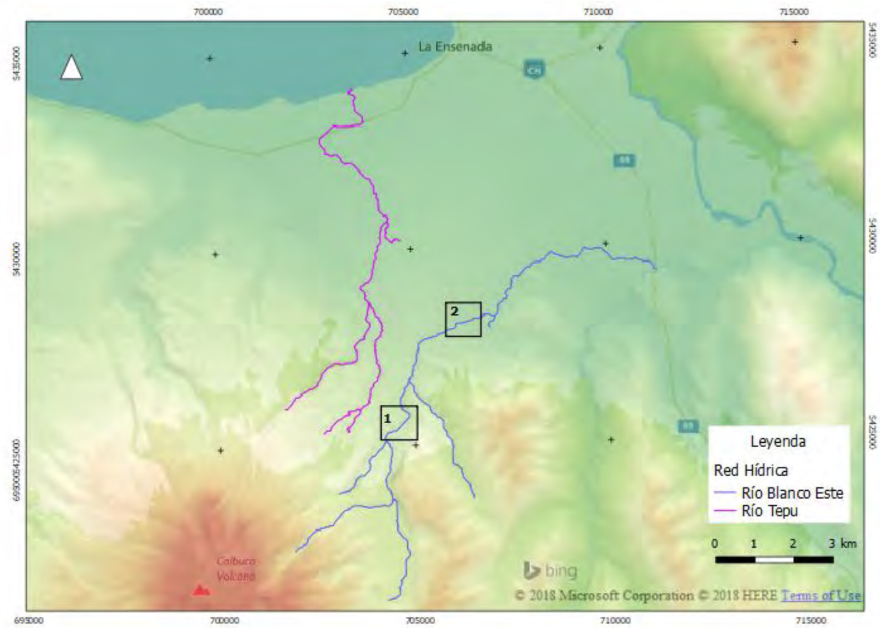

Fig. 1. Blanco-Este River and Tepú River

Valley floor dynamics from 1961 to 2018 are revealed in aerial photographs (Fig. 2, Valeria Zingaretti, UACh). The fluvial system experienced dramatic vertical and lateral changes in response to the 1961 and 2015 eruptions. Various methodologies and instruments are deployed in this area to observe system dynamics. Remote images, drone images, field work with differential GPS (dGPS), terrestrial laser scanner, grain size, and geophysical surveys are used to observe sediment deposit characteristics, and time lapse cameras are deployed to investigate flood patterns. In the upper site of the Blanco-Este River, Andy Russell and colleagues installed a solar-powered monitoring system in January 2018.

Stop 1. Blanco-Este River upper site (Fig. 1). Initial eruption impacts and fluvial geomorphic dynamics, including large wood (Fig. 3). Viewed from this location the Calbuco cone is quite irregular in form, complicating the pattern of rivers draining its summit area. Main presenters: Andres Iroumé (UACh, Chile), Andy Russell (Newcastle, UK), and Alejandro Dussaillant (U Aysen, Chile).

- Setting the stage. The general setting and structure of Calbuco cone, the 2015 eruption impacts at this site, including deposition of hot flows (pyroclastic flows) and cold flows (lahars), the rapid reworking of that material and deposition of alluvium from the upper watershed.

- Note the contrast between the two valleys that come together at this point. The smaller valley on the right (west) has a tongue of the 1961 lava flow at this head, which has limited water and sediment movement into and down this channel, but more voluminous hot and cold flows in the 2015 eruption were able to enter this short valley segment just below the 1961 lava flow. The larger channel and watershed on the left (east) has a much larger drainage area that extends to the summit area, and, therefore, has delivered much more water, sediment, and wood to the upper Blanco-Este River.
- Research program and findings.
  - Fluvial geomorphology. Field observations indicate that river bed incision dominates fluvial processes in this upper reach, suggesting that the channel is a massive source of sediments. Grain size is highly varied and no final river configuration (i.e., step-pool, riffle-pool) has yet been established. The river is still far from reaching a *quasi*-equilibrium state.
  - Effects on wood in the river. There is little wood on the recently emplaced sediment at this site, perhaps because upstream sources are limited, and wood delivered to this site may have been transported through this reach and delivered to downstream reaches, such as at Stop 2.

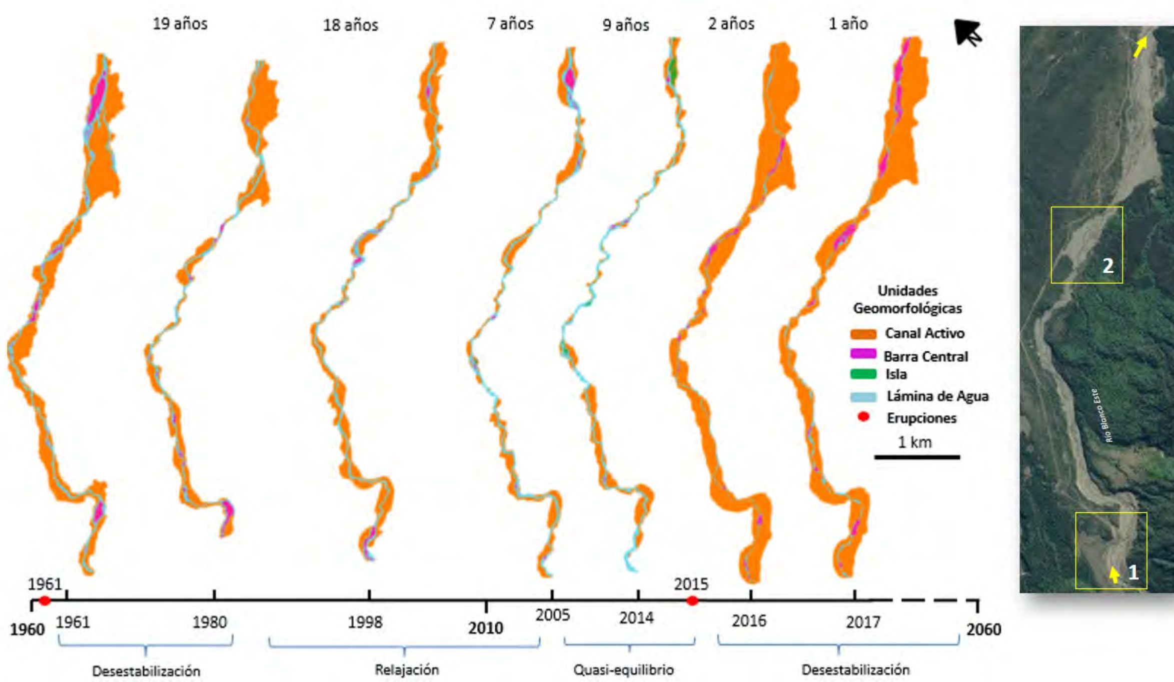

Fig. 2. The Blanco-Este River from a sequence of remote images, from 1961 (just after the 1961 eruption) to 2017 (after the 2015 eruption). (From Valeria Zingaretti, MSc Thesis).

Fig. 3. The upper Blanco-Este River site. Above left, few days after emplacement of pyroclastic flows and lahars showing vigorous fumarole activity (May 2015) and above right after extensive fluvial erosion of the flow deposit (Jan. 2016). (photos by J. Romero). Above, drone image of Stop 1 (A. Iroume, December 2017).

Stop 2. Blanco-Este River hydropower station site (Fig. 1). Sedimentology of the streambed. Main presenters: Andres Iroumé and colleagues.

- Setting the stage. Earlier history of river channel change and revegetation is revealed in a sequence of photographs beginning after the 1961 eruption (Fig. 2). This site is downstream of the extent of hot and cold volcanic flows, but they left a large volume of readily mobilized material upstream, so aggradation and channel widening has been dramatic. These processes overwhelmed a hydropower plant constructed at this site before the eruption (Fig. 4).
- Research program and findings.
    - Fluvial geomorphology. This site is characterized by the enormous sedimentation that has occurred since the eruption, which is shown by the braiding and the rapidly changing character of the channel, as well as by the poor sorting of the sediments. Channel morphology and sedimentary characteristics may suggest that this reach is accommodating a large part of the sediments eroded and transferred from upstream that are circulating through the river mainstem since the eruption took place. A big sediment pulse is moving along the river's longitudinal profile, with this middle reach acting as a large sediment sink, hence aggradation mainly occurs. For example, in the period 11 April 2017 to 2 August 2017 the bed aggraded by up to 3 m and the channel eroded laterally by up to 30 m (Fig. 5). Thanks to the on-going, long-term analysis that we have undertaken, we can hypothesize that it will take decades until the river re-attains a *quasi*-equilibrium state, especially in highly dynamic reaches such as this one.
    - Effects on wood in the river. Large wood is moderately abundant in some sections of Blanco-Este River and nearly absent in other parts. More wood occurs in this section of the river than at Stop 1 (from 36 m^3/ha in April 2017 to 9 m^3/ha in November 2017, with an increase to 13 m^3/ha in January 2018). Some of this wood may be derived from valley floor forest, lateral tributaries, landslides from the adjacent hillslopes, and sediment deposits between the Stop 1 site and this site.
    - River ecology (work of Eduardo Jaramillo, UACh). In June 2015, i.e., 2 months after the eruption, species richness and abundance of aquatic insects were clearly low in the Blanco-Este as compared with the un-affected Tronador River. In this sampling period no fishes were found at the Blanco-Este while rainbow trout was in the Tronador. In January 2018 no aquatic insects and fishes were found at the Blanco-Este, but in February 2018 aquatic insects characteristics of severely affected rivers or rivers in constant perturbation were found.

Fig. 4. Above, drone image of Stop 2 channel conditions (A. Iroume, April 2017). Below, Blanco-Este River before (left, DigitalGlobe, 2014) and after (right, Google) the 2015 eruption.

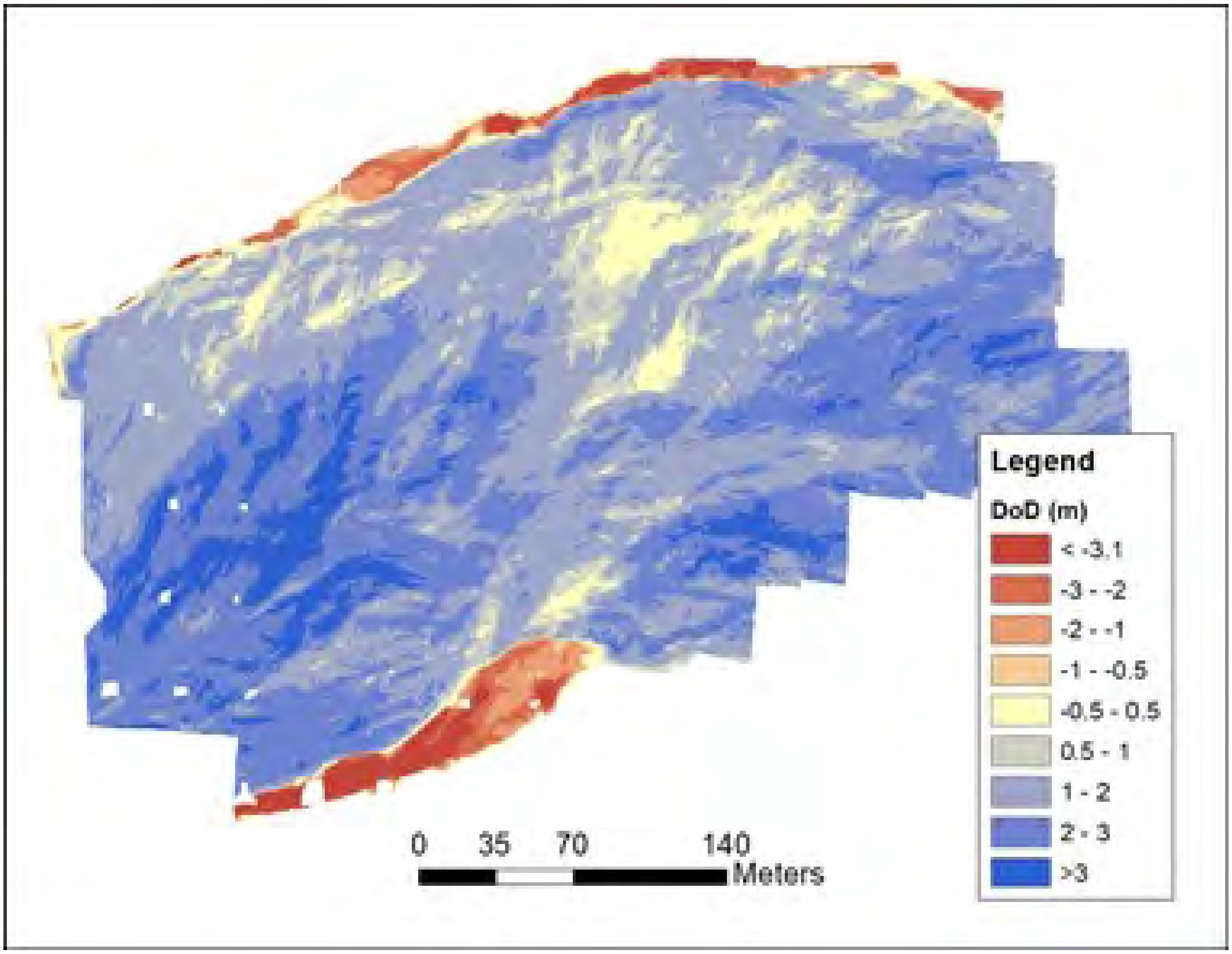

Fig. 5. Raw difference of DEMs (DoD) between 11 April 2017 and 2 August 2017 of the Stop 2 site. The colors displayed represent net change in elevation (meters). Negative values represent erosion (nearly entirely bank erosion in this case), while positive values represent deposition. The figure was produced using structure from motion photogrammetry processed in Agisoft Photoscan® and GCD 6 for ArcGIS®. This DoD has not been classified to separate out vegetation or water and it has not been yet adjusted to account for uncertainty (i.e. minimum level of detection threshold of 0.5 m).

Stop 3. Petrohue River on flank of Osorno Volcano – view of volcanoes – if our schedule permits.

- Setting the stage. Interaction of debris flows from Osorno volcano and the big Petrohue River. Lava flows from Osorno create waterfalls on the Petrohue River upstream of this point and control the level of Todos los Santos Lake, from which the Petrohue River issues.
- Wood in this river. The river has a substantial drainage area and high discharge, so it has high capacity to transport large wood. The rate of large wood input appears to be quite limited, despite debris flows entering from Osorno volcano along the north side and from streamside forest and landslides from steep mountain slopes bordering the lake and some sections of the river. Also, the large Todos los Santos Lake upstream moderates discharge

and wood and sediment delivery to this downstream reach. Therefore, the Petrohue River has very low large wood loading.

Field trip stops on Jan 11.

Stop 4. The Domo of Parque Valle los Ulmos in the Tepú River watershed just west of the Blanco-Este River watershed visited yesterday. A brief overview of this site and the park objectives, tephra fall experienced here during the eruption, and the state of ecological and social responses in the immediate area. Presenters: Pablo Saumann (personal coach, consultant, community organizer) and Barbara Corrales (landscape architect), leaders of a group of 15 families creating a private park with conservation and education objectives here on the northeast flank of Calbuco.

Stop 5. Tepú River valley floor at the downstream extent of deposits left by pyroclastic flows of the 2015 eruption. We observe the deposits, their impact on inundated forest, subsequent fluvial erosion, and effects on large wood in the river. Main presenters: Andy Russell, Alejandro Dussaillant, Fred Swanson (US Forest Service), Julia Jones (Oregon State U).

- Setting the stage (Fig. 6). Multiple pyroclastic flows came down the valley and left deposits of 2-8+ m total thickness on the valley floor, partially burying young forest which probably date from similar events in the 1961 eruption. Unlike the broad head of the Blanco-Este River watershed, the Tepú River heads in a very narrow, bedrock-lined, and steep basin, so eruption column collapse and hot scoria that fell on the slopes mobilized immediately, forming pyroclastic flows that ran down the valley. In the first few years after the 2015 eruption, fluvial erosion has removed a large fraction of these 2015 flow deposits, exposing the pre-eruption channel, stream banks, and pre-eruption soil surface in some areas. There has not been the massive influx of alluvium from upstream sources which we observe in the Blanco-Este River, so the channel in this reach appears to be in its pre-eruption location (note root systems of killed, pre-eruption streamside vegetation marking the location of the stream banks).
- Research program and findings.
    - Eruption processes. Jorge Romero (U Atacama) has been characterizing flow processes, their deposits, and their timing in terms of the eruption phases described in his tephra fall paper (Romero et al 2016).
    - Fluvial erosion. Reports from local residents Saumann and Corrales indicate that several weeks passed before the channel cut substantially into the new deposits. Precipitation leading up to the eruption was low and several weeks passed before substantial precipitation occurred in the area. The subsequent progressive erosion and redistribution of flow deposits are evident in fluvial landforms and deposits along the valley floor. Note abrasion on the upstream side of dead trees where both the primary hot flows and subsequent bedload transport abraded the tree boles.
    - Effects of hot flows on trees. The hot flows bent over small trees (diameter less than ca. 12 cm) and the ends of these stems were cooked to charcoal (Fig. 7). It appears that the upper parts of these small trees were removed by abrasion by bedload transport as the river eroded and transported the new flow deposits. In some areas, larger trees (diameter greater than ca. 15 cm) extended above the top of the deposits (Fig. 7). Some of those trees burned at the top of the deposits and the tree tops generally fell in the down-valley direction (possibly in response to

slight down-stream tipping by the hot and cold flows). Sections (cookies) cut from the standing trees reveal a pattern of increasing heat damage (charring, radial cracking) with height above the pre-eruption forest floor to the top of the new deposits (Fig. 8), suggesting that evaporation of water from the buried soil, tree stems, and streambed may have created a thermal gradient with more rapid cooling close to the base of the deposits.

- Wood in the river. Overall, many pieces of large dead wood are on the valley floor of the lower km of the channel in this zone of hot flow deposits; however, an inventory of wood revealed very few free-to-move pieces in the channel. In some areas, the hot flows toppled many trees in the downstream direction, but most of these wood pieces are still partially rooted and suspended above the valley floor, so they do not perform the geomorphological and ecological functions we typically expect of large wood in rivers (Fig. 9). Will eventual decomposition of the root systems result in delayed wood input to the river? Since the eruption, landslides from outside the reach of the hot flows have been important sources of large wood to the river and valley floor more generally.
- Downstream transport of sediment. The hot flows extended downstream and stopped at the upstream end of the island partially covered by living trees, where the very steep section of our trail reaches the valley floor. Downstream of this island the floodplain is covered with several meters of fluvially-emplaced sediment derived from erosion of the flow deposits. The downstream and lateral extents of this remobilized sediment decrease over a kilometer or two below the island; downstream of that point the channel gradient is sufficiently steep over several additional kilometers to transport sediment derived from the flow deposits without leaving significant, post-eruption deposits in the channel or on the floodplain. As the Tepú River approaches within a few kilometers of Llanquihue Lake, its gradient decreases, making possible extensive deposition into floodplain forest, endangering the Highway 255 bridge, and constructing a small delta into Llanquihue Lake (Fig. 10). We can view the conditions of the river and floodplain in the transportation zone (a few hundred meters downstream of the small bridge into the Parque Valle los Ulmos) and at the Highway 255 bridge as we depart the Ensenada area. We have not surveyed the Tepú River for large wood, but it is extremely sparse in the sites we have visited.

Fig. 6. Tepú River looking upstream in January 2017. Note flat, primary deposit surfaces.

Fig. 7. Tepú River. The hot flows bent over small trees (foreground) and the ends of these stems were cooked to charcoal and abraded; the large tree remained upright, but burned at the top of the hot deposits and its top fell downstream after fluvial erosion of the new deposits.

Fig. 8. Sections of a standing tree with increasing heat damage higher above the pre-eruption forest floor (lower left is 20 cm above ground level) to the top of the new deposits (right side, center row); upper left section is base of the fallen top; upper right section is 100 cm higher.

Fig. 9. Tepú River hot flows toppled many trees in the downstream direction, but most of these wood pieces are still partially rooted and suspended above the valley floor.

Fig. 10. Tepú River extensive deposition into floodplain forest and constructing a small delta into Llanquihue Lake.

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