<u>Project title</u>: ***“Ecosystems in the sky: dynamic processes of old-growth tree canopies in Chile and the Pacific Northwest”***

<u>Short project description</u>: We propose to initiate a multi-year research program focused on better understanding old-growth forest canopy ecological processes in collaboration with Chilean scientists at varying career stages from Universidad Austral de Chile (Valdivia), Instituto de Ecología y Biodiversid at the Universidad de Chile (Santiago), and Pontificia Universidad Católica de Chile (Santiago). This project will focus on cross-continental comparisons of old-growth tree canopy ecology. These comparisons include studies of water and nutrient dynamics in old-growth Alerce (*Fitzroya cupressoides*) and western redcedar (*Thuja plicata*) tree canopies, along with detailed biodiversity surveys. Our sites will span a wide range of climates and soils, with a coastal and montane site in each country. We have chosen two iconic trees in each country, and have tried to minimize confounding phylogenetic differences by choosing species in the same plant family (Cupressaceae).

**PERSONNEL**

***Christopher Still*** (lead PI), Department of Forest Ecosystems and Society

***Dave Shaw*** (co-PI), Extension Forest Health Specialist and Director, Swiss Needle Cast Cooperative, Department of Forest Engineering, Resources and Management, Oregon State University

***Steve Perakis*** (co-PI), Research Ecologist, USGS Forest and Rangeland Ecosystem Science Center, Courtesy Faculty, Department of Forest Ecosystems and Society

***Camila Tejo*** (co-PI), postdoctoral scholar at Universidad Austral de Chile, received her Ph.D. in 2013 from the University of Washington for her research on nutrient dynamics and decomposition of canopy soils in big leaf maple and Sitka spruce trees on the Olympic Peninsula of Washington.

**<u>Additional Chilean collaborators</u>** (please see their letters of support)

Juan J. Armesto (Pontificia Universidad Católica de Chile), Cecilia A. Pérez (Universidad de Chile)

## PROJECT NARRATIVE

### Type of project (e.g. research, education, exchange, combination)

This is primarily a research project, though there are obvious linkages to a separate educational initiative (the 'Mountains to the Sea' field course) based partly in the Valdivia area of Chile. Indeed, in this proposal we have budgeted trips to Chile in March 2016 by PI Still and co-PI Shaw. We would leverage those trips for a scouting visit and 'dry run' of the field course at the same time.

### Project Objective

The overall goal of this research is to compare canopy biology, biogeochemistry, and microclimates between old-growth Alerce trees in Chile and old growth western redcedar trees in Oregon and Washington. To meet this overarching goal, the project will focus on the following objectives: (1) to establish new canopy observations for ecological, ecophysiological, and biogeochemical applications such as monitoring the response of forest tree canopies to climate variations, including heat and drought stress; and (2) to demonstrate how measuring canopy processes and properties can be used to advance fundamental biological understanding of canopy processes, including canopy flora and fauna, in iconic old-growth tree canopies in Chile and the USA.

### Contribution to College internationalization goals

This project explicitly links CoF researchers with Chilean researchers by setting the science within a comparative framework that leverages ongoing research and infrastructure investments in both countries. This work builds on a long and rich history of comparative ecology between the US West Coast and Chile that has played a key role in the development of convergent evolution theory and plant biogeography and ecology. Importantly, a central person working on this project is a Chilean (co-PI Tejo) who received her PhD working in old-growth canopies in WA and who is currently studying canopy ecology in Chile for her postdoctoral research.

### Project Deliverables

The primary deliverables of the project will be the new knowledge we gather on canopy ecological processes and their connections to overall forest ecology in Chile and the

USA. This information will be shared in peer-reviewed publications, along with technical and management reports for a wide variety of organizations, ranging from forest management agencies to NGOs to indigenous groups. We also plan to include outreach activities for the general public, such as small workshops (possibly joined with other Chile Initiative-funded proposals to create a session for local communities in Corvallis and in Chile). Additional opportunities to communicate and promote our activities outside academia include co-PI Tejo making a bilingual video, along with a webpage in Spanish and English, highlighting the research we'll be conducting. Other, less tangible deliverables include new partnerships and the generation of new collaborations and research funding opportunities.

**Role of Partner(s)**

Our Chilean partners are absolutely fundamental to this effort. Without their participation, we would not be able to accomplish any of our research goals. The participation of co-PI Dr. Camila Tejo, a Chilean postdoctoral scholar, will be particularly key to this project given her research experience in canopies in WA (big leaf maple and Sitka spruce) and in Chile (Alerce), along with her background in ecology, biogeochemistry, and hydrology. In most ways, Dr. Tejo will be the lead on this project, and will lead the authoring of resulting publications, with significant input and advising from our other Chilean partners. The participation of Dr. Juan Armesto (Full Professor and senior scientist) and Dr. Cecelia Perez (mid-career scientist) is also critically important, as both are experienced in international collaborations in the study of Chilean ecosystems, and can effectively participate in the Chilean research and help advise Dr. Tejo. Please see the letters of support from each Chilean partner.

**Sources of external support (including from Chilean partners)**

We will leverage the extensive infrastructure at the HJ Andrews LTER and Experimental Forest for the montane site in this country. In addition, PI Still is in charge of a new canopy processes initiative as part of the LTER7 grant, and funds from this initiative (~30K/year) will be leveraged to help support the proposed work during the next 5 years. Additionally, Dr. Tejo has applied for a postdoctoral fellowship from the Chilean government, which would be used to leverage this research. Our Chilean partners would also help facilitate our in-country travels and fieldwork logistics, and some of the canopy analyses will be done at Chilean universities (Univ. Austral de Chile, and PUC). In addition to these sources of support, we plan to submit a proposal to the National Geographic Research and Exploration fund in summer 2015. This program previously funded co-PI Shaw's trip to study Alerce canopy structure in Alerce Andino National Park (Clement et al. 2001). Finally, the long-term, large-scale funding goal for this research would be to include a robust educational component and apply with our Chilean partners for support through the NSF Partnerships for International Research and Education (PIRE) program.

**Questions and Objectives**

***Our overarching objective is to compare forest canopy microclimate, biology, and ecological function in two long-lived conifers that occupy climatically similar regions of Chile and the Pacific Northwest. We will focus on comparisons of forest canopies in Alerce (Chile) and western redcedar (PNW) in both wet-coastal and moist-inland montane (Andes and Cascades) habitats of both regions.***

<u>Microclimate</u>: How do vertical gradients in canopy microclimate (temperature, moisture) compare in Alerce and western redcedar trees? Are similarities and differences consistent across both wet-coastal and moist-inland forests of Chile and the PNW? What are patterns of fog inputs, and to they cause similar effects on canopy microclimate?

<u>Biology</u>: How do canopy flora, fauna, and leaf and soil microbes compare between these forests types (diversity, composition)? What are their functional differences? How do canopy structures and biomass differ? How do epiphytic canopy soils of these regions compare?

<u>Ecological function</u>: Does the phylogenetic relation between western redcedar and Alerce, and the influence of epiphytes and arboreal soil on microclimate, lead to convergent canopy ecophysiological and biogeochemical function? How does fog chemistry and its processing by forest canopies compare? Does the characteristically high calcium content of *Cupressaceae* (Kiilsgaard 1987) lead to convergent

biogeochemical and physiological function? How do patterns of biological nitrogen fixation compare in forest canopies in wet coastal vs. moist inland sites?

**Rationale and background**

The canopy of old-growth trees is in many senses the last frontier of forest ecology. The forest canopy integrates the entire vertical profile of forests, from the ground level to the topmost point of the tallest tree (Lowman and Rinker 2004). Epiphytes, plants that live on another plant but are not parasitic, form a carpet-like layer that covers the trunk and large limbs of canopy trees. When these epiphytes die and decompose on branches and trunk surfaces within the canopy, they create a distinctive layer of canopy organic matter (a.k.a. canopy soils) (Enloe et al. 2006, Haristoy et al. 2014). Epiphytes and canopy soils can become quite important in terms of biomass in old-growth forests: in tropical cloud forests of Colombia can accumulate up to 44 Mg ha-1, whereas a single *Picea sitchensis* tree can harbor over 10 Mg of epiphyte material (Naiman et al., 2010).

Ecological roles of epiphytes and their associated canopy soils include capturing and retaining fog and rainwater, providing habitats for organisms, increasing total forest diversity and increasing the inputs of nutrients from the canopy to the ground (Coxson and Nadkarni 1995, Lowman and Rinker 2004, Enloe et al. 2006). Because of their position in the canopy, epiphytes capture water from the mist and precipitation that is retained by canopy soils, which then provide moisture to canopy-dwelling organisms (Bohlman et al. 1995, Rhoades 1995, Enloe et al. 2006). Coastal ecosystems in the Pacific Northwest and Chile are often covered by clouds or immersed in fog during the largely rain-free summer months. Ecosystems in these regions typically harbor a number of rare and endemic plant and animal species, presumably because of the moderate maritime climate and the large modifications to the environment driven by clouds. Cloud cover greatly reduces solar irradiance and evapotranspiration, increases humidity levels, and strongly buffers daily air temperature variations. Fog immersion further enhances ecosystem water status by providing direct water inputs through fog drip and possibly foliar uptake, and maintains wet canopies during an otherwise dry period. Fog enhances ecosystem fertility and productivity, by directly delivering oceanic nutrient subsidies to the land, and by facilitating the activity of nitrogen-fixing species that increase availability of this limiting nutrient.

When not immersed in fog, the upper-canopy of these forests is known to experience a very different microclimate than the rest of the forest: it is often simultaneously brighter, hotter, windier, and drier. The upper canopy also contains most of the leaf area, and because it absorbs most of the solar radiation, it accounts for the great majority of carbon and water exchanges. Critically, this is also the zone where most climate variations and stress likely manifest. This function of the canopy environment could be critical for the survival and activity of epiphytic organisms, especially when there is a dry period, or under many climate change scenarios (Bohlman et al. 1995, Coxson and Nadkarni 1995, Anderson 2009). Finally, the upper canopy is the region of the forest that is sampled by satellite imagery. With intensive canopy microclimate monitoring, we can provide connections to satellite-based imagery at varying temporal and spatial scales in order to scale across these landscapes.

A focus on canopy biology and microclimate would thus yield large dividends in our understanding of old-growth forest function and its response to climate change in both countries. It would complement and leverage ongoing, long-term climate measurements collected across the PNW experimental forests and in Chilean counterpart sites. Finally, by establishing new microclimate measurements in adjacent old-growth and second-growth canopies, this research could help shed light on the differing responses seen in air temperature measurements beneath these forest types. Both Alerce and western redcedar are relatively understudied compared to other commercially valuable conifers, and we seek to supplement our understanding of these iconic species.

Alerce (*Fitzroya cupressoides* (Mol.) Johnst., Cupressaceae) is an endemic and long-lived conifer from southern Chile and Argentina. Alerce is the second longest-living tree in the planet and reaches monumental dimensions with heights above 60 m and diameters over 5 m. (Fravet et al., 1999; Clement et al., 2001). In southern South America, Alerce populations are currently threatened and distributionally restricted due to its historical exploitation since the 16th century leading, in the late 1970's, to Chile declaring the species as a national monument (Lara et al., 1995; Veblen et al., 1995; Clement et al., 2001). Numerous ecological studies of Alerce have focused on regeneration, genetics, population dynamics, and conservation efforts (Donoso et al., 1993; Lara et al., 1995; Armesto et al., 1996; Allnut et al., 1999; Fravet et al., 1999). And yet, little is known about the biophysical processes and contributing biodiversity and relevant ecosystem functions occurring within the canopy of this massive South American conifer. Due to its complex architecture, Alerce can support a great abundance of vascular and non-vascular epiphytes as well as invertebrate populations (Clement et al., 2001, Perez et al., 2005). In old-growth Alerce forests from Chiloé island, canopy soils formed along the main trunk to near the base of Alerce trees, account for ca. 6% of the N cycled in that ecosystem (Perez et al., 2005). This added N may be disproportionately important to sustaining the productivity of Chilean forests, which display extremely tight N cycling and only very low losses of bioavailable N (Perakis et al., 2001, 2002).

There is a long-standing history of scientific research examining cross-continental convergence of ecological and evolutionary processes across the west coasts of the Americas.  Despite very different biogeographic histories of Northern and Southern hemisphere flora and fauna, these regions nonetheless support many functionally similar species and ecosystems that reflect broad similarities in climate and geology. The amounts and seasonality of precipitation are particularly important in shaping broad distributions of vegetation types. Modern comparative studies of Northern and Southern hemisphere ecosystems started in the 1970s with Mediterranean-type semi-arid regions (Mooney 1977; comparing California to northern-central Chile), and continued through the 1990s with comparative studies of temperate rainforest regions (Alaback 1991; comparing SW Alaska to southern Chile). Among forest types, broad analogues between the continents tend to track summer rainfall patterns, making the study forest canopy microclimate of special interest. In addition, some trees of these regions are among the massive and long-lived on Earth. Notably, despite hemispheric differences in tree species composition and diversity, both regions support regionally important members of the *Cupressaceae* (for example, Alerce in Chile and western redcedar in Oregon and Washington). These *Cupressaceae* share several broad-based similarities, including massive potential size, longevity, climatic tolerance, and decay resistant wood. This similarity provides a basis well-constrained cross-continental comparisons of canopy processes in trees across regions sharing broadly similar climate. Interestingly, both Alerce and western redcedar are also considered especially important trees to indigenous people in both hemispheres, and provide similar attributes when used in wood products, which opens the possibility of broadening our proposed ecological comparisons into future cultural, social, and ecosystem services dimensions.

## Methods

*Coastal forest canopies*

One objective of this project is to better understand how clouds and fog influence Chilean and Pacific Northwest coastal forests dominated by western redcedar and Alerce trees, something which has never been fully characterized for these species. To assess the role that clouds play in ecosystem processes across our coastal forest sites in PNW and Chile, we will measure and synthesize a wide range of physical and biological processes and patterns and relate them to our cloud and fog patterns. We hypothesize that low clouds (shading) and fog (immersion and drip) exert important influences on canopy-atmosphere interactions in both Chile and the PNW, with impacts on ecosystem water balance, tree growth, and the spatial extent and severity of foliar diseases disease. Our proposed coastal sites in each country are:
(Chile) Valdivian Temperate Rainforest, (USA) Olympic Experimental State Forest.

*Moist-inland montane forest canopies*

A second objective of this project is to understand how site climate affects canopy processes. Since both species occur in coastal and moist-inland montane settings, this offers a strong contrast on site climate and how it affects the processes and properties of interest. Our proposed montane sites in each country: (Chile) Alerce Andino National Park, (USA) HJ Andrews LTER and Experimental Forest.

The following methods will be used for collecting data at each forest site.

<u>Canopy access:</u> To access to the canopy we will use standard arboreal climbing and canopy access techniques. 5 trees will be rigged at each study site. After a tree is rigged, it will be climbed and a complete description of the structure will be done (height, azimuth, and angle  of each branch over 2 cm diameter will be measured and foliated

volume of the branch estimated). This canopy structural survey will provide a reference for all other measurements (e.g., Clement et al. 2001).

Water holding capacities and temperature patterns of aerial soils: Within each tree we will select the main branches with large loads of epiphytic material. Information about branch height, aspect, tree diameter, depth and density of canopy soil will be recorded. After selecting the branches, a moisture and temperature sensor will be installed in each selected branch. Sensors will be connected with a data logger that will be attached to the main trunk. Information collected by the data loggers will be retrieved every 3-4 months to minimize impacts produced by the ropes on the trees and epiphytes, collecting data for a minimum of 12 months. To understand the patterns of water retention and temperature overtime can illuminate potential processes occurring within the treetops such as decomposition of organic matter and microbial activity, both key processes for forest productivity.

Canopy biodiversity of plants (lianas and epiphytes): This important aspect of canopy ecology will be quantified along the vertical axis using the crown structural organization as a framework. Canopy soils will be quantified along the vertical gradient, and canopy soil arthropods will be sampled by taking collections from perched soils along the vertical axis and taking them to the lab for extraction using Burlese funnels. Arthropods will be identified to family for functional group analysis, with a subsample taken to genus and species depending on abundance of specific taxa. If possible and other funding sources are found, microbial biodiversity of foliage and canopy soils will be measured by sampling and processing at OSU. To our knowledge, these would be pioneering measurements of canopy microbes, whose composition and ecological function are completely unknown. We anticipate that the microbial composition will be quite distinct between these tree canopies (redcedar vs Alerce), but that there will be functional convergence just as there is with vegetation.

Biogeochemical function of forest canopies: We will evaluate the degree to which arboreal soils track the climate and chemistry of the atmosphere and of host plants. Whereas ground soils can strongly reflect soil mineralogy of underlying bedrock, arboreal soils are formed from organic matter produced by the host plant, and of aerosols trapped in the forest canopy. We will evaluate major element nutrient chemistry (C, N, P, S, Ca, Mg, K, etc) of arboreal soils, and relate its composition to that of host plants and of fog and rainfall (the latter being derived marine aerosols with similar composition to seawater). We will also estimate nutrient transformation rates, including biological nitrogen fixation, in arboreal soils.

**Anticipated outcomes**

We anticipate that this project will produce not just new knowledge about these unique canopy ecosystems, but importantly it will provide new and actionable information for resource managers and conservation planners. This is especially critical as climate change is expected to produce new threats for coastal and inland ecosystems alike.

*Relevance to forest resource managers and conservation NGOs*

The proposed research has important implications for improving our knowledge base to address multiple natural resource management and conservation challenges in both countries. These challenges include: biological carbon sequestration, fish and wildlife (threatened and endangered species) response to climate change and hydrologic changes, forest resilience, wildfire, water availability and quality, and forest disease. Specifically, because canopy-atmosphere interactions and dynamics strongly impact forest health, hydrology, nutrient cycling, and tree growth, knowledge and new understanding from this project should be useful for resource managers in both countries. This project will quantify and characterize various aspects of canopy biodiversity in Alerce and western redcedar in Chile and the USA. Biodiversity is very important to ecosystem function and if these systems are functionally equivalent, then some very similar patterns should emerge regarding vertical patterns in functional groups. In addition, climate change is predicted to influence the vertical patterns of biodiversity by increasing heat in the upper canopy and potentially reducing the height within the canopy of various organisms.

We will strive to make our project results available and useful as quickly as possible for managers tasked with managing and conserving these unique forests in a time of rapid global change. We also note that our focal study tree species (Alerce and western redcedar) are both considered especially important trees to indigenous peoples in both hemispheres, and provide similar attributes when used in wood products, which opens the possibility of broadening our proposed ecological comparisons into future anthropological, cultural, social, and ecosystem services dimensions.

*Opportunities provided to young researchers and post-docs:*

This project will provide the opportunity for a postdoctoral scholar (co-PI Tejo) to design and conduct studies on: (1) existing spatial and temporal dynamics of coastal and montane old-growth canopy processes in the Pacific Northwest and Chile, with a specific focus on hydrological, biological, and biogeochemical dynamics in these canopies; (2) linkages between these canopy processes and ecosystem services important for local communities such as maintenance of streamflows in the dry season (the canopy sponge effect), and the capture, storage and transformation of organic matter (C) and key nutrients (N, P, Ca, Mg) that sustain forest productivity and biodiversity, and (3) predicting future dynamics of canopy processes and ecological integrity based on climate change predictions for these forests.

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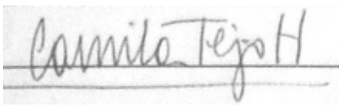
Valdivia, June 5th 2015

Dear Chris:

I am pleased to provide this letter of support for the proposal ***“Ecosystems in the sky: dynamic processes of old-growth tree canopies in Chile and the Pacific Northwest”*** ***s***ubmitted by Steve Perakis, Dave Shaw, and yourself as part of the Chile Initiative at Oregon State University.

My research interest are focused on the relevance of the canopy environment on forest conservation and resilience. During my doctoral research I worked in the canopy of bigleaf maple (*Acer macrophyllum*) and Sitka spruce (*Picea sitchensis*) at the Olympic National Park, and my current interest are focused on the canopy of the long-lived Alerce. Your comparative proposal on canopy dynamics would be very relevant to highlight the importance of above-ground processes on forest functioning. Moreover, since very few scientist have done comparative studies in northern and sourthern hemispheres, this will be an incredible opportinity to develop synergic interactions among Chilean and USA scientist.

Please no not hesitate in contact me if you have any further questions or comments.
Sincerely yours,



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# Institute of Ecology and Biodiversity

DEDICATED TO SCIENCE AND ITS APPLICATIONS TO SOCIETY

Santiago 8 June 2015

Dr. Steve Perakis
Professor
USGS Forest and Rangeland Ecosystem Science Center
& Dept. Forest Ecosystems and Society, Oregon State University
Oregon, U.S.A.

Dear Dr. Perakis:

I write to confirm my full support and that of the **Institute of Ecology and Biodiversity** (IEB) for the proposal entitled: *"Ecosystems in the sky: dynamic processes of old-growth tree canopies in Chile and the Pacific Northwest."* This proposal is of interest to us because of its potential for building a collaborative partnership among scientists based at the University of Oregon, the IEB-Chile, and the Department of Ecology, Universidad Católica de Chile, where I work. In the past, we have been able to undertake novel and fruitful research collaboration with Dr. Steve Perakis, on the subject of forest ecosystem science, contributing to better understanding nutrient cycles in Chilean forests.

The present proposal will address biodiversity, hydrology, and biogeochemistry of canopy soils and ecosystems, using as subjects of study long-lived trees in the family Cupressaceae. Such studies will offer insights into the maintenance of biodiversity and ecosystem function in conifer-dominated forests occupying mirror climatic regions on the western margins of North and South America. The study will also provide opportunities for further comparative studies, developing new research questions, and student training.

We commit our participation and logistic support to this research, and wish you the best luck with your application for funding.

Sincerely,

Juan J. Armesto

Dr. Juan J. Armesto
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# Corporación Instituto de Ecología y Biodiversidad IEB

IEB CHILE
INSTITUTO DE ECOLOGÍA Y BIODIVERSIDAD

Dear Steve,

I am happy to provide this letter of support for your proposal ***"Ecosystems in the sky: dynamic processes of old-growth tree canopies in Chile and the Pacific Northwest"*** submitted by Chris Still, Dave Shaw, and yourself as part of the Chile Initiative at Oregon State University.

Currently I am doing research on the biogeochemistry of Chilean forests focusing on nitrogen cycling with ecosystem development. I find that your proposal on canopy processes is a key topic to develop in Chile because it may be a key component in incorporating new nitrogen to the ecosystem via biological nitrogen fixation, either by the diverse cryptogamic flora or as epiphylles in tree-leaves. The comparison with northern temperate forest will help to elucidate at a broad global scale the importance of canopy processes to nitrogen economy in old-growth unpolluted temperate forests.

With kind regards,

Cecilia Peréz

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Santiago, June 4th, 2015

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