Austrocedrus forests of South America are pivotal ecosystems at risk due to the emergence of an exotic tree disease: can a joint effort of research and policy save them?

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Introduction

Human expansion, global movement, and climate change have led to a number of emerging and re-emerging diseases. The decline of biodiversity due to emerging plants pathogens may cause habitat and wildlife loss and declines in ecosystem services. This, in turn, often results in lower human well-being. Reports of emerging plant diseases are constantly on the rise, and often they appear to be linked to the commercial trade of plants and plant products. While there are several examples of decimation or extinction of plant hosts affected by invasive forest diseases, there are no known cases of invasive forest diseases successfully eradicated.

Austrocedrus chilensis represents a keystone tree species in most of the austral montane regions of Argentina and Chile. This species, endemic to South America, grows between the 32°39' and 43°35 parallels and between altitudes of 250 to 2,200 m. The most conspicuous forests are between 34°45' S and 38° S in the western slope of the Andes mountains (Chile) and between 39° 30' S and 43° 35' S in the eastern slope of the Andes (Argentina). It is a dominant or co-dominant species, it grows in pure stands or intermixed with *Nothofagus* spp. and other species as *Lomatia hirsuta*, and *Maytenus boaria*, among others.

The species is able to grow in a wide range of environments and soils. It is present in a rainfall gradient from 1500 mm/y on the West to 500 mm/y on the East, and soils that vary from very poor, even rocks in steep slopes, to plane and shallow clayish soils in the valleys or deep soils of volcanic ash.

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A. chilensis covers today a total estimated area of 185,000 ha in South America. As a dominant forest species, its role in supporting biodiversity, generating shelter for wildlife, as well as preventing soil erosion and preserving water quality is well understood. Along with *Araucaria araucana*, it is the tree species that grows furthest into the ecotone zone within the Patagonia steppe, where it plays a key role preventing desertification. There are however additional functions this tree provides, including the production of valuable timber and the generation of an environment ideal for cattle grazing, recreational and touristic activities and for human settlement. As one moves South, this species becomes more and more important, and it is often one of only three dominant native tree species in forests. Due to its ecological importance and to its role in fostering human activities, *A. chilensis* can be regarded an essential element of the agro-forest society of both Chile and Argentina.

Silvics and ecology.

A. *chilensis* can grow to be 25 m in height and 2 m in diameter. Its life span can be upward of 1,000 years, but the age of most surviving forests is below 400 years old. Its productivity can reach more than 400 cubic meters per hectare. However these figures do not take into account its absolute importance in harsh steep sites and in providing an ideal habitat for human activities. It is estimated that about 60% of pure forests of this species occur in hazard sites and that most areas forested by this species are used for cattle grazing in Argentina. Regeneration of A. *chilensis* occurs naturally in many sites but this species is rarely artificially planted, records indicate that less than 100 hectares have been replanted with this species as of 2014.

A. chilensis threatened by an emergent pathogen

Starting in 1948, significant mortality of A. *chilensis* was reported in several areas. Disease progression appeared to be fast leading often to 50% mortality, or more, of trees of all ages and size classes. The symptoms included withering, defoliation, and root rot. Patterns of spread of mortality suggested an infectious disease, and the term "Mal del Ciprés" (Cypress disease) was coined to describe the phenomenon. Its causal agent though remained unresolved for over 57 years, despite the several attempts by groups of scientists, including one FAO-sponsored expedition whose participants suggested to continue the studies and to investigate the possible participation of a root pathogen. The lack of understanding of the causes behind the *Mal del ciprés*, greatly hindered any significant advancement in the formulation of preventive and disease control measures. In 2005, a collaboration between Argentine and US scientists led to the discovery of the causal agent of the disease, since then named "Austrocedrus root disease (ARD)". The causal agent was found to be an undescribed soilborne pathogen belonging to the genus *Phytophthora*, soon to be named *P. austrocedri* (Greslebin et al. 2007). Although research on novel organisms is extremely complex and demanding, the discovery has led to the understanding of the disease cycle, including some key epidemiological aspects. Currently it is understood that higher infection rates are associated with abiotic factors that favor *Phytophthora* proliferation (La Manna & Rajchenberg 2004, La Manna et al. 2008) and with the proximity to roads and streams, and intensity of grazing (La Manna et al. 2014). Nine years after the initial discovery, there is little evidence of natural resistance in populations of the tree host, while it has become apparent that humans are responsible, through cattle grazing, vehicular and foot traffic, and construction, for the spread of the disease both in areas adjacent to older infestations and in new areas. Natural preserves and national parks with limited access show no or limited disease. In infested areas, though, mortality can reach 90%, and it has been estimated that *P. austrocedri* is now present in many sites in at least 3 Argentine states. In 2011, an apparently identical pathogen surfaced in the United Kingdom, where it appears to be causing widespread mortality of a key species of heath and moorlands, *Juniperus communis*. Although it is still unclear whether the causal agents of the two outbreaks are really the same, the extremely simplified genetic structure of pathogen populations in the two areas suggest both outbreaks are caused by an introduced exotic pathogen, and not by an emergent native one (Vélez et al. 2013).

According to it exotic origin, mitigation measures for ARD should be directed to both the protection of healthy areas, avoiding the introduction of the pathogen, and to the mitigation of disease impact in affected areas.

Measures to protect healthy areas include:

- Avoid road opening and vehicular movement in these areas.
- Avoid plant introduction unless verified it is clean from pathogens.
- Wash vehicles, feet, tools, equipment, etc. before they enter uninfested areas
- Use only pathogen-free water for dust abatement and fire fighting
- Educating forest users about the risks of accidentally transporting the pathogen.
- Apply preventive chemical control in healthy areas threatened by the disease (for example sides of the roads, path and trails).

In diseased areas, mitigation measures include:

- Avoid actions that generate conditions favorable to the pathogen as artificial irrigation and changes in natural watercourses.
- Confine activities as forestry, road maintenance and other activities involving heavy equipment, as well as tourism and cattle raising to the summer dry season.
- Regulate harvest of timber and boughs to reduce chances of spread of the pathogen on feet and equipment.
- Reduce inoculum source by burning residues of basal trunk and root systems of dead and up-rooted trees.
- Develop a breeding program of disease tolerant A. chilensis, to restore diseased areas. This program should include searching for resistant individuals, vegetative reproduction and planting of these individuals.

Policy and scientific needs

This brief is authored by a few individuals, but it summarizes concerns collectively expressed at the 7th international meeting of an IUFRO working group dedicated to the study of Forest Phytophthoras. Although this document focuses on *Phytophthora austrocedri*, similar outbreaks caused by exotic introduced forest pathogens are common in several continents. Considering *Phytophthora* spp. alone, the list includes jarrah dieback in Western Australia and oak decline in the Iberian Peninsula, Sudden oak death and port orford cedar root disease in Oregon and California, Kauri die back in New Zealand, and a devastating foliage disease of planted pines in Chile, among others. In many cases, the introduction of these exotic pathogens has been clearly proven to be associated with the international trade of plants, and as in the case of Sudden Oak Death, outbreaks in natural forests has highly impacted the international plant trade due to the regulations imposed on such trade by the international community. The emergence of a putatively identical pathogen to *P. austrocedri* in the UK, could again be the result of the international plant trade.

There is a dramatic need to generate a more effective approach to link the scientific community to governmental agencies and policy makers and to stakeholders. There is increasing knowledge on how to curtail further introductions and on how to mitigate current ones, but this knowledge generated by research –ironically often financially sponsored by the same governmental agencies- only rarely makes a significant impact in the regulatory world, at least in a time frame to actually be useful.

ARD represents an ideal situation to generate a sustained relationship between the scientific community and local and national governments, as well with international organizations. Intense research has already been completed and many options are available to mitigate the disease and to prevent its spread in new areas in South America. Equally important is to include the plant trade industry in this dialogue to ensure the pathogen is not spread elsewhere. Currently, research findings are locally communicated with a local valiant grass root effort, often resulting in valid disease management efforts (e.g. ensuring construction is done with clean machinery and workers and visitors alike clean their shoes in areas free of the pathogen), but a broader approach mediated by governmental agencies is urgently needed. The Austrocedrus Root Disease or Mal del Ciprés is present in more than one State in Argentina (Greslebin & Hansen 2010) and is present in Chile as well (Greslebin unpublished), and it impacts significant economic enterprises. We need:

(1) analyses to convincingly show the long term economical effects of loosing *Austrocedrus chilensis* to a diverse audience;
(2) a way to publicly share mitigation efforts through general policy and education;
(3) economical intervention to offset the damages caused by the change in practices of the industry that will be necessary to slow the spread of the disease,
(4) funds to help the most promising research efforts,
(5) an immediate adoption of all proven disease mitigation efforts by publicly run land holders (State and National Parks, Preserves, Open Spaces, etc.).

At the 7th IUFRO meeting on Forest Phytophthoras in Argentina and at the IUFRO world congress in Salt Lake City, it has been clear that many scientists have renounced the hard line of an "all or nothing" approach, and times are ripe for a constructive and inclusive joint effort between the scientific community, government or NGOs, and stakeholders: what is needed now is an opportunity to sit together at the table and help to identify the most productive approaches. We urge governments to invest resources into generating a "working approach", an "operational module" of sorts to consistently deal with the emergence of these devastating tree diseases: this approach requires not only immediate funding to identify causal agents and ecological conditions favoring outbreaks, but also a way to turn the findings into disease mitigation policies that are shared with stakeholders and employed by them. Analysts need to prove these disease mitigation policies are cost-effective in the long term, thus increasing buy-in from stakeholders. In the case where such cost-benefit analysis showed a disproportionate cost on stakeholders, offsets need to be provided to protect the affected natural resources.

In the case of ARD, key issues for policy-makers are:

- Mapping carefully the distribution of the disease along *A. chilensis* forest in order to delimit healthy and diseased areas.
- Develop and apply a good practices guide for forestry and other activities in the forest.
- Stimulate *A. chilensis* production in nurseries for restoration purposes.
- Promote and support research on *A. chilensis* resistance to the disease.
- Establish, together with institutions of research and management, integrated programs of research, monitoring and management of *A.chilensis* diseased forests.
- Establish measures to protect healthy areas avoiding the introduction of the pathogen.

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