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ORIGINAL ARTICLE

The role of "forensic" dendrochronology in the conservation of alerce (*Fitzroya cupressoides* ((Molina) Johnston)) forests in Chile

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Abstract

Dendrochronological techniques have proved to be an effective tool in the investigation of illegal cutting of *Fitzroya* because it is illegal to trade and cut wood coming from living individuals or from trees that were killed after 1976 either by natural or anthropogenic causes. Accurate cross-dating of death or burn dates provides strong evidence for prosecution in the legal enforcement of the ban and an important defense in the protection of this and other endangered species. Some examples illustrate the application of these dating techniques and discuss potential difficulties.
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Keywords: Illegal cutting; Law enforcement; Alerce; Forensic; Dendrochronology

Introduction

Fitzroya cupressoides (alerce) is one of the most outstanding species of the temperate rainforests of southern Chile and adjacent Argentina, due to its beauty, cultural, historical and scientific importance. *Fitzroya* is an endemic evergreen conifer that can live for more than 3600 years (Lara and Villalba, 1993) and is thus the second longest-lived tree species in the world after *Pinus longaeva* (D.K. Bailey), which grows in the south-western United States. *Fitzroya* can attain heights of up to 50 m and 5 m in diameter, usually growing on thin and poor soils along the Andean (41–43°30′S) and the Coastal (39°50′–42°35′S) Ranges in Chile (Donoso, 1993). Recently, several small young *Fitzroya* stands in the Central Depression near the city of Puerto Montt have been described (Fraver et al., 1999). *Fitzroya* grows extremely slowly with average diameter increments ranging between 0.6 and 6 mm/year, depending on site conditions and age (Lara et al., 2003).

Fitzroya has been over-exploited for the beauty and durability of its wood for over four centuries, reducing its original distribution from 617,077 ha in 1550 to 264,993 ha in 1997 (Lara et al., 1999, Fig. 1). The burning and clearing of these forests was especially intense in the Central Depression during the 19th century when these populations were completely eliminated by European colonisation of southern Chile between Valdivia and Puerto Montt (Veblen et al., 1976). During the 20th century these activities continued and *Fitzroya* was extensively logged by clear-cuts or high-grading and high-quality timber exported until the 1970s (Lara, 2000; Lara et al., 2003). Due to the threats to *Fitzroya* forests, legal protection for this species was necessary.

In 1976 *Fitzroya* was legally declared a National Monument (National Decree 490) and its exploitation was forbidden throughout Chile. However, an exemp-

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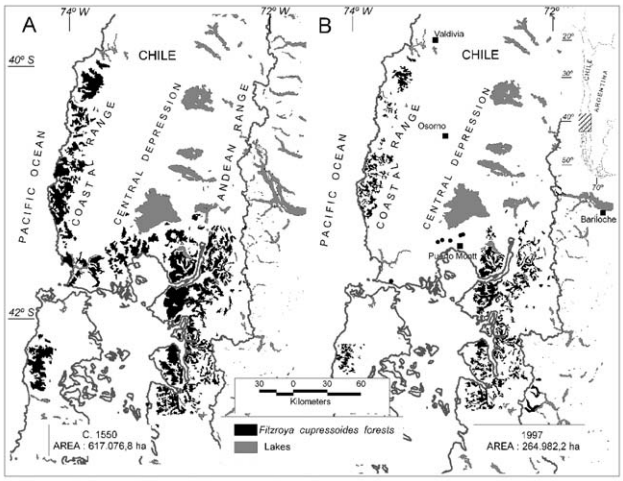

Fig. 1. Original distribution of *Fitzroya cupressoides* forests around 1550 and its present distribution. (adapted from Lara et al., 1999).

tion within this Decree allows the cutting and utilisation of "dead *Fitzroya*" (i.e., trees killed before 1976 either by fires, logging or that are buried in the forests, Lara et al., 2003), which has stimulated illegal cutting and intentional burning of these forests to generate "dead *Fitzroya* wood" that can be "legally" used and sold. Apart from this national "protection", in 1973 *Fitzroya* was included under Appendix I of Convention on International Trade of Endangered Species (CITES), forbidding its international commerce. Chile became a member of the Convention in 1975. Despite this international protection, *Fitzroya* timber is still exported. These legal exports correspond to dead *Fitzroya* wood that owners declared to have in stock in 1975 when Chile joined the Convention, and are known as "pre-CITES" wood. In addition, at the Ottawa CITES Conference of the Parties in 1987, Chile requested an exception to allow the continued export of dead *Fitzroya* wood from the Coastal Range (see Fig. 1). This means that *Fitzroya* forests in the Coastal Range are not "officially" considered to be sufficiently threatened with extinction to warrant a total ban on international trade. This exception, in combination with the National Decree that allows the exploitation of *Fitzroya* individuals or forests that died before 1976 in Chile, has stimulated the intentional killing of *Fitzroya* individuals and forests, mainly through fire, and leaves *Fitzroya* populations in the Coastal Range completely unprotected (Lara et al., 2003; Poblete, 2003). Therefore, human-set fires are another important threat to *Fitzroya* forests, as thousands of hectares are affected. In the 1997–1998 austral summer, 9477 ha of these forests were destroyed by five human-set fires in the Coastal Range (Lara et al., 2003).

Despite the continued exploitation of *Fitzroya* forests, only 47,400 (17.9%) of 264,993 ha of *Fitzroya* forests are protected within National Parks and Reserves. The remaining 82% are mainly on private land (Reyes and Lobos, 2000). In the special case of the Coastal Range, which is the most affected area by fires and illegal cutting, only 2.6% of the *Fitzroya* forests are protected within a single National Monument and a Reserve.

The National Forest Corporation (CONAF) is charged with the protection of the native forests in Chile but has insufficient funds or human resources to carry out law enforcement effectively (Lara, 2000; Lara et al., 2003; Poblete, 2003). CONAF personnel cannot distinguish between legally and illegally felled *Fitzroya* wood in the field except by using subjective criteria such as the colour of the wood or the presence of green leaves or bark on the logs (which are generally removed by the loggers to eliminate the evidence of illegal cutting). Dendrochronological techniques were adapted and utilised to determine the year and season of death and/or felling of *Fitzroya* trees to address this problem.

Dendrochronology as a "forensic" tool.

Chronology quality

Patton carried out the first collection of *Fitzroya* samples in Chile in 1943 (Schulman, 1956). However, the development of tree-ring chronologies was not successful until 1985, when Boninsegna and Holmes (1985) developed a 1534-year chronology for Río Cisne, Argentina. This slow development of *Fitzroya* chronologies was mainly due to cross-dating problems caused by the presence of groups of micro-rings and a high percentage of missing rings (Lara and Villalba,1994; Lara, 2000). The percentage of living *Fitzroya* samples from a site that cross-date varies between 43% and 90% depending on the site (Lara, 2000). Most of the samples that do not cross-date come from trees whose growth has been strongly influenced by local conditions (fire, competition, etc.). Chronologies from the Coastal Range present lower values of mean sensitivity and of common variance in the 1st eigenvector compared to those from the Andean Range (Table 1). A possible explanation is that tree growth in the Coastal Range has been more strongly affected by anthropogenic disturbances (e.g., repeated fires and wood exploitation) altering the growth patterns of the trees (Lara, 2000).

Methods

Dendrochronology has been used as a very effective tool in Chile since 1989 to determine whether the cutting of *Fitzroya* has been carried out legally (Lara and

Table 1. Descriptive statistics for selected *Fitzroya cupressoides* chronologies

Location	Coastal Range		Andean Range	
Chronology	Pelada	Pabilos	Lenca	Ayacara
Interval	448 BC–1992 AD	350–1996 AD	1637 BC–1987 AD	354 BC–1993 AD
Length (years)	2441	1647	3625	2348
Trees	40	38	38	23
Radii	57	43	43	56
Mean sensitivity	0.222	0.223	0.275	0.311
Average series intercorrelation	0.415	0.409	0.465	0.49
Total rings	28404	17125	37 260	22 180
Total missing rings	27	27	57	61
% Missing rings	0.095	0.158	0.153	0.275
Variance in 1st eigenvector (%)	23.12	23	30.57	38.10

Fig. 2. This *Fitzroya* stump in the Coastal Range was illegally cut just a few weeks before the photo was taken on January 30, 2002. The heartwood/sapwood boundary is clearly visible (photo by Carlos Poblete).

Cortés, 1991; Lara and Aravena, 1992). In many cases cross-dating can establish the year and season (summer or winter) when a tree was felled or killed by fire (Fig. 2). For trees that are suspected of being illegally cut we take at least three samples (increment cores and/or sections) from each stump, including, if at all possible, well-preserved sapwood and bark. This is fundamental to determine the exact year when the tree was cut. Where stands have been killed by fire, we sample the best-preserved individual trees, preferably with some trace of bark and sapwood, to determine the year and season the fire took place. Core samples are taken from living *Fitzroya* at adjacent sites to develop a reference chronology for cross-dating.

The dating of the last ring of the "suspicious" samples enables us to determine the year and season when each tree was cut and/or burned. Rings are dated using Schulman's (1956) convention where calendar dates of annual rings are assigned to the year in which ring formation begins. In these trees the 2000 annual ring would normally represent growth from September 2000 to March 2001. Therefore a tree with a complete 2000 ring year was cut between March and September 2001 (winter 2001). If the 2000 ring year is incomplete the tree was cut during the 2000–2001 growing season, i.e., between spring (September) 2000 and late summer (April) 2001.

In general, the cross-dating of samples to determine if the tree was illegally cut has been quite successful. Table 2 summarises results from several studies carried out at the Dendrochronology Laboratory of the Universidad Austral de Chile (UACH), where this technique has been applied since 1992. The success in dating samples from cut trees can range from 0% to 100%, depending on several factors relating to the site and the condition of the stump or tree. Two main types of problems make cross-dating difficult (and in some cases impossible). The presence of extremely narrow and/or missing rings in the outer, formerly living, tissue of the dead trees or stumps due to repeated disturbances (fire, high-grading, etc.), or the damage/removal of the outer tissue by rot or during logging. In cases where the most recent tissue is damaged, absent or could not be measured due to micro-rings, only a minimum death date can be given (i.e., the tree was cut after a given year). According to our studies, most of the illegal cutting of *F. cupressoides* occurs during winter (April–October), when climatic conditions make access to the sites very difficult for CONAF personnel to carry out monitoring and law enforcement, mainly due to heavy rainfall.

Case studies

The Dendrochronology Laboratory of the UACH has been continually working in the monitoring and dating of illegal cutting of *Fitzroya*, since it was established in

Table 2. Studies performed at the Dendrochronology Laboratory of the Universidad Austral de Chile to detect illegal cutting of *Fitzroya cupressoides* during the period 1992–2000 in the Xth Region, Chile

Authors and year of the study	Dates of illegal cutting [a]	% of samples from illegal cutting that cross-dated		Legal outcome
		Range	Average	
Vergara et al. (2000)	Apr. 1993–Sept. 1993 Apr. 1999–Sept. 1999		16.18	Case in progress
Lobos et al. (1999)	Oct. 1987–March 1988 Apr. 1998–Sept. 1998		100	No information
Díaz et al. (1998)	Apr. 1985–Sept. 1986 Oct. 1997–March 1998	0–63	29.3	No information
Díaz et al. (1997)	Oct.1982–March 1983 Oct. 1996–March 1997	8–67	32.7	No information
Ramírez (1996)	Oct. 1979–March 1980 Oct 1990–March 1991		33.3	Dismissed
Lara and Wolodarsky-Franke (1996)	Oct. 1983–March 1984 Apr. 1987–Sept. 1987		52.3	Fined; *Fitzroya* products were confiscated
Leal and Ramírez (1994–1995)	Oct. 1990–March 1991 Apr. 1994–Sept. 1994	7–37	19.6	No information
Lara and Aravena (1992)	Oct. 1988–March 1989 Oct. 1990–March 1991		66.7	Dismissed

[a]Only the dates of the oldest and the most recent cuttings are given out of a set of samples that were cross-dated.

1992. Additionally, we have provided dating results to several legal cases, to establish scientifically whether the trees were cut illegally. In the first case in 1996 we were asked by the Judge to evaluate and report on the cutting of *Fitzroya* in a country estate in the area of Lake Chapo in the Andean Range (Lara and Wolodarsky-Franke, 1996). Sixty-two samples were collected from 21 "suspicious" stumps and logs, plus increment cores from living trees to develop the reference living tree chronology. We determined the cutting year and season of 11 of the 21 trees sampled (52% success). All were cut after 1976, mainly during winter 1987. The primary difficulty in dating these trees was that the loggers had destroyed the outer living tissue in the stumps. In this case the property owner was charged with illegal cutting of *Fitzroya* and assessed a fine of $40,000,000 Chilean pesos (approx. US$63,500) and the *Fitzroya* products were confiscated. Unfortunately, a legal loophole allowed the owner to serve a maximum of 15 days in jail in lieu of the fine, and, on the presentation of a medical certificate, this was commuted to 30 days in a hospital in Puerto Montt.

The second example relates to a devastating fire that took place in February 1998 on a large country estate located in the Coastal Range. This intentionally set fire affected 2339 ha of *Fitzroya* forests within the estate,

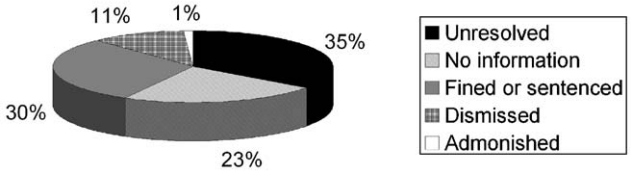

Fig. 3. Resolution of the 83 legal cases of illegal cutting of living *Fitzroya cupressoides* trees presented by CONAF (National Forest Corporation) for the period 1990–2001, in the Xth Region, Chile. (*Source*: Poblete (2003) based on data provided by CONAF.)

representing 76% of the total burned area (Neira and Díaz, 1998). In this case, the State Defence Council (SDC) initiated a legal action against the owner of the estate for setting an intentional fire. The SDC asked the Dendrochronology Laboratory at UACH to determine the dates of the fire and cutting of *Fitzroya* for this case (Vergara et al., 2000). The samples taken from burned snags showed an incomplete outer ring dated 1997, indicating that the trees died between October 1997 and March 1998, which coincides with the date of the fire. However, samples taken from stumps yielded cutting dates between 1992 and 1998, indicating that living *Fitzroya* trees had been illegally cut both before and after the fire. This case is still under review.

Fig. 3 shows the outcome of 83 legal cases relating to the illegal cutting of living *Fitzroya* trees brought for trial by CONAF during the period 1990–2001. Less than half of the cases (42%) have been adjudicated by the Local Police Judge, out of which 11% were dismissed. The remaining 58% are either unresolved (35%) or there is no available information on the result (23%).

Conclusions

For most dendrochronologists cross-dating is the basic tool that underlies much of our science. However, in other milieux these simple tools (and training individuals to use them) can be an effective way of monitoring illegal harvesting of protected species. The dendrochronological techniques developed for the dating of illegal cutting of protected trees have become a very useful, quick and precise tool in law enforcement in Chile, and are recognised as an objective and conclusive proof in legal cases. Unfortunately, these efforts are insufficient to stop this illegal activity, as inadequate economic resources are devoted to policing that could provide efficient and effective law enforcement. It is necessary that both the authorities and the citizens become conscious of the enormous cultural, historical, scientific and aesthetic value, not only of *F. cupressoides*, but also of all the rare, vulnerable and protected species of the native forests in Chile.

In addition to illegal logging, there are many other needs and challenges that must be faced to stop the future destruction of *Fitzroya* forests. Alternative uses for these forests should be developed, such as the management and use of other tree species for timber, recognition of the economic value of non-wood forest products (fungi, medicinal plants, fruits, etc.), ecotourism and ecological restoration. The local communities should be involved in these activities, supported by the Government with economic incentives, capacity-building, provision of access to international funding, etc. New protected areas, principally in the Coastal Range and Central Depression should be established. More resources should be given to the maintenance and enforcement of the national and international protection of *F. cupressoides* and other endangered species. The major change that should be made is the modification and improvement of the laws that protect these species, by restricting or eliminating the permits that allow the use of dead wood, and also banning the commercialisation of dead *Fitzroya* wood in general. This might necessitate providing owners of *Fitzroya* forests who depend economically on this resource with assistance in developing other management or land use alternatives to maintain this resource.

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