Forest Ecology and Management 177 (2003) 131–143

Forest Ecology and Management

www.elsevier.com/locate/foreco

Subtropical dendroecology—dating disturbances and forest dynamics in northwestern Argentina montane ecosystems

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Received 1 February 2002; accepted 10 June 2002

Abstract

The use of dendroecological techniques to describe temporal patterns of disturbances and forest dynamics has been largely restricted to high-latitude ecosystems. In this review, we present the results of recent developments in subtropical northwestern Argentina (22–28°S). The area is characterized by a subtropical monsoonal climate (wet summers, dry winters) which implies that some species respond to climatic seasonality by producing annual tree rings. *Alnus acuminata*, a deciduous species that dominates the upper montane forests (1700–2700 m), has been successfully used to describe patterns of forest regeneration, fire, landslides, and floods by dating scars, establishment events and changes in growth patterns and to relate these patterns with climate and land use during the twentieth century. Establishment dates, growth releases, and resprout dates of species with annual tree rings (e.g. *Cedrela lilloi*, *Solanum riparium*, *Cinammomum porphyria*) have been used in lower montane forests to describe regeneration dynamics in relation to treefall gaps. These results indicate that dendroecology is a feasible and promising research line that needs further exploration in this geographical area. Among the research priorities we identified are: (1) exploration of the use of these species in forests of lower latitudes (e.g. southern Peru and Bolivia), (2) increase of sample sizes and target species, in order to extend the temporal and spatial domains of these studies, (3) explore the use of other species in the same area to study other ecological processes or the same ones in different environments.

Keywords: *Alnus acuminata*; Dendroecology; Disturbances; Montane forests; Tropical ecology

1. Introduction

Dendroecology—the use of tree rings to date and describe temporal patterns of forest dynamics, disturbances and other ecological events—has been widely used in temperate ecosystems of Europe (Schweingruber, 1996), North America (Lorimer, 1985; Fritts and Swetnam, 1989), New Zealand (Duncan and Stewart, 1991) and southern South America (Kitzberger et al., 2000; Villalba, 2000). In these environments, dendroecology is an important tool to study ecological process at multidecadal to centennial temporal scales. Contrarily, at tropical and subtropical latitudes, the small number of species with annual tree rings due to the reduced thermal seasonality limits the use of dendrochronology. However, studies in the tropics of Asia (e.g. Chowdhury and Rao, 1948; Bhattacharya et al., 1992), Indonesia (e.g. Jacoby and D'Arrigo, 1990), Australia (e.g. Ogden, 1981), Africa (e.g. Wyant and Reid, 1992), and South America (e.g. Detienne, 1989; Seitz and Kanninen, 1989; Worbes, 1989, 1995; Botosso et al., 2000; Roig, 2000; Stahle et al., 2000; Tomasello Fo et al., 2000) showed

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0378-1127/02/$ – see front matter
PII: S0378-1127(02)00316-X

the potential of several species for dendrochronological dating in regions with precipitation seasonality. In the western subtropics of South America (associated with a marked rainfall seasonality) several species show annual tree rings, which suggests that they have potential to be used in dendroecological work. However, dendrochronological research initiated during the 1980s have been mostly restricted to descriptions of anatomical characteristics and methodological potential (e.g. Villalba et al., 1985; Villalba and Boninsegna, 1989; Tomasello Fo et al., 2000; Morales et al., 2001), assessments of growth rates in relation to site quality (Villalba et al., 1987; Sidan and Grau, 1998), and reconstructions of past climatic conditions (Villalba et al., 1992, 1998a,b).

During recent years, we started using dendrochronological techniques in the subtropical montane forests of NW Argentina to explore long-term patterns of

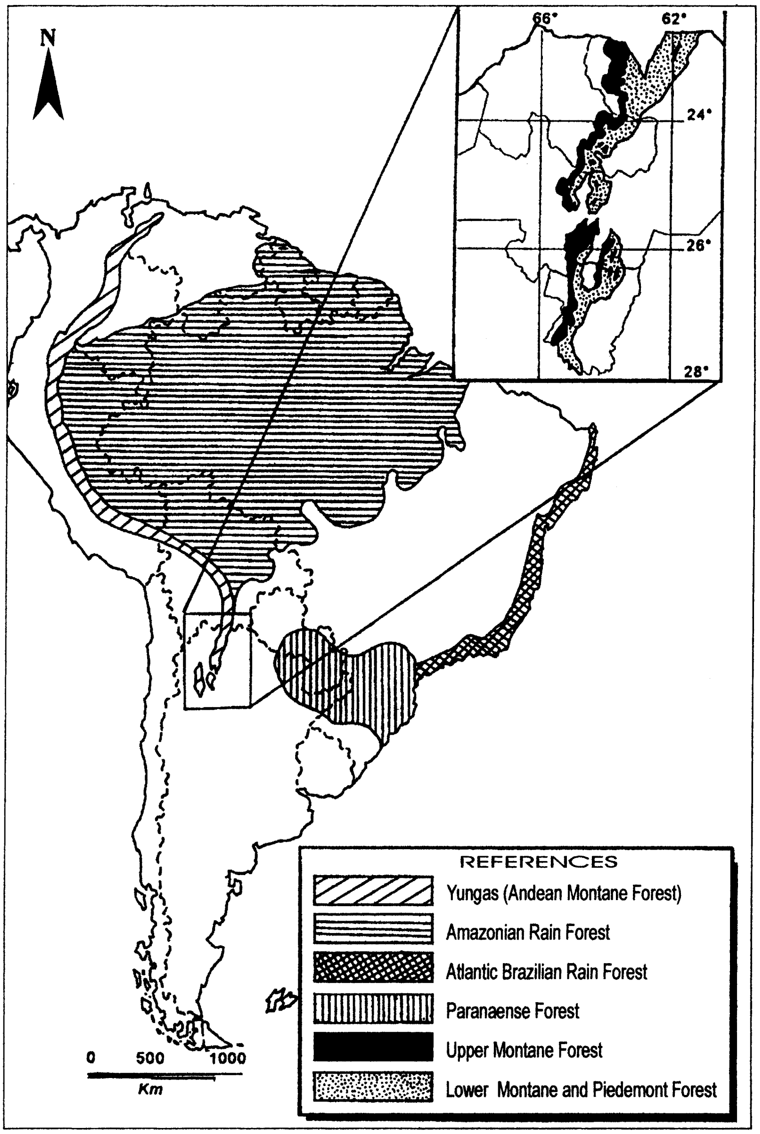

Fig. 1. Relative location, distribution and vertical zonation of humid subtropical montane forests (Yungas) in NW Argentina, in relation to other neotropical humid forests.

forest dynamics in relation to disturbances. Humid montane subtropical South American forests are characterized by a diverse disturbance regime (Grau, in press). In this paper, we present examples of the use of dendroecology to study temporal patterns of disturbance regimes (fire, floods, landslides, treefall gaps), and we discuss the potential in the region to study other disturbances and to expand the range of potentially useful species. The methods here discussed represent an important tool for studying and managing these very dynamic forested ecosystems of high conservation priority and management potential.

2. Study area

In this revision we present results and examples of research conducted at different elevational levels in the subtropical montane humid and mesic forests of Northwestern Argentina (Fig. 1). This biogeographic unit corresponds to the "Yungas" biogeographic province that extends along the tropical Andes, reaching its southern limit in northern Argentina (Cabrera and Willink, 1980). The vegetation types considered in this paper extend from 28 to 22°S in Argentina and continue northward into Bolivia approximately to 19°S (Brown et al., 2001). Several species considered here extend their distribution towards lower latitudes in the Andes of Bolivia and Peru (Killeen et al., 1993).

The climate of the region is subtropical monsoonal, with a marked dry winter season (Fig. 2). Both rainfall and temperature are strongly influenced by topography. The *Yungas* extend along the eastern slopes of mountain ranges that are mostly north–south oriented, and both forest composition, diversity, and disturbance regime vary along the elevational range from 400 to 3000 m (Grau and Brown, 1995a; Brown et al., 2001; Grau, in press). In a simplified scheme, two forest types can be differentiated along the elevational gradient. The lower montane forest extends from 400 to 1700 m of elevation. This is a relatively diverse (20–30 tree species/ha) semi-evergreen forest, where the dominant natural disturbances are landslides and treefall gaps. Wind, fire, insect attacks and bamboo mass flowering are other components of the disturbance regime. The upper montane forest (1700–2700) is a mosaic of relatively simple forests largely dominated by *Alnus acuminata*, grasslands, and shrublands, and dominant

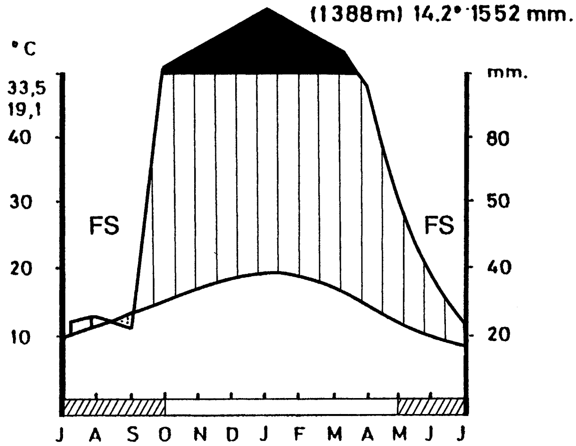

Fig. 2. Climatic diagram (Walter and Leith) of Villa Nougues, a locality representative of the climatic conditions of the Argentine Yungas. GS = growing season (which also corresponds to floods, landslides and treefalls season). FS = fire season (winter).

disturbances are fire, landslides and grazing. On valley bottoms at different elevational levels, floods are also important components of the disturbance regime.

3. Fire and forest dynamics in the upper montane forests

The use of fire scars to develop fire chronologies is based on the dating of fire events by counting backwards from the outermost ring (corresponding to the sampling date in living trees) to the ring at which the fire signal is observed (usually a scar partially covered with reaction tissues) (Arno and Sneck, 1977; Mc Bride, 1983; Kitzberger et al., 2000; Smith and Kennedy-Sutherland, 2001). In order to describe fire regimes based on fire scar records three characteristics of the system are desirable: (1) fire must damage external tissues but not kill the affected trees, (2) fire recording trees should be abundant, and (3) fire scars should be reliably dated. *A. acuminata* forests in NW Argentina upper montane forests meet these conditions. In this ecosystem, the fire regime is largely dominated by surface fires which do not kill large trees. Although there are no quantitative records, most fires appear to be human ignited (Grau and Veblen, 2000). *A. acuminata* is by far the dominant species along an elevational range from 1700 to 2700 m and a latitudinal range from 22 to 28°S. It is a deciduous tree that produces reliable annual tree rings clearly visible (Sidan and Grau, 1998). Trees larger than 20 cm DBH affected by surface fires typically produce fire scars that are readily datable. Fire scars in *A. acuminata* appear as triangular-shaped scars in the base of the tree (more often facing uphill) and as longitudinal scars facing down on perpendicular low-height branches. The usual technique to sample fire scars is the extraction of wedges (typically with a chainsaw) at the base of the scar, which, if done carefully do not kill the tree (Mc Bride and Laven, 1976; Kitzberger et al., 2000). Fire dates obtained from *A. acuminata* fire scars showed perfect matching with fire dates observed in landsat TM images. Recent fires (i.e. less than 20 years old) show good agreement among the fire dates of different trees seemingly affected by the same event. The vast majority of the fires in this region occur during the winter dry season, when *A. acuminata* has no leaves. Consequently, fire dates are typically assigned to the dry season which precedes the growing season corresponding to a complete ring. However, *A. acuminata* starts regrowing at the end of the dry season (October) when some fires can still occur. Therefore, in some cases, very narrow rings preceding a scar should be assigned to the growing season following the fire season. In order to discriminate if narrow rings are annual (for example, occurred during a climatically unfavorable year) or sub-annual rings produced by fire after a short time of spring re-growth, visual cross-dating with neighboring trees not affected by the fire is recommended. Due to the short life span of the

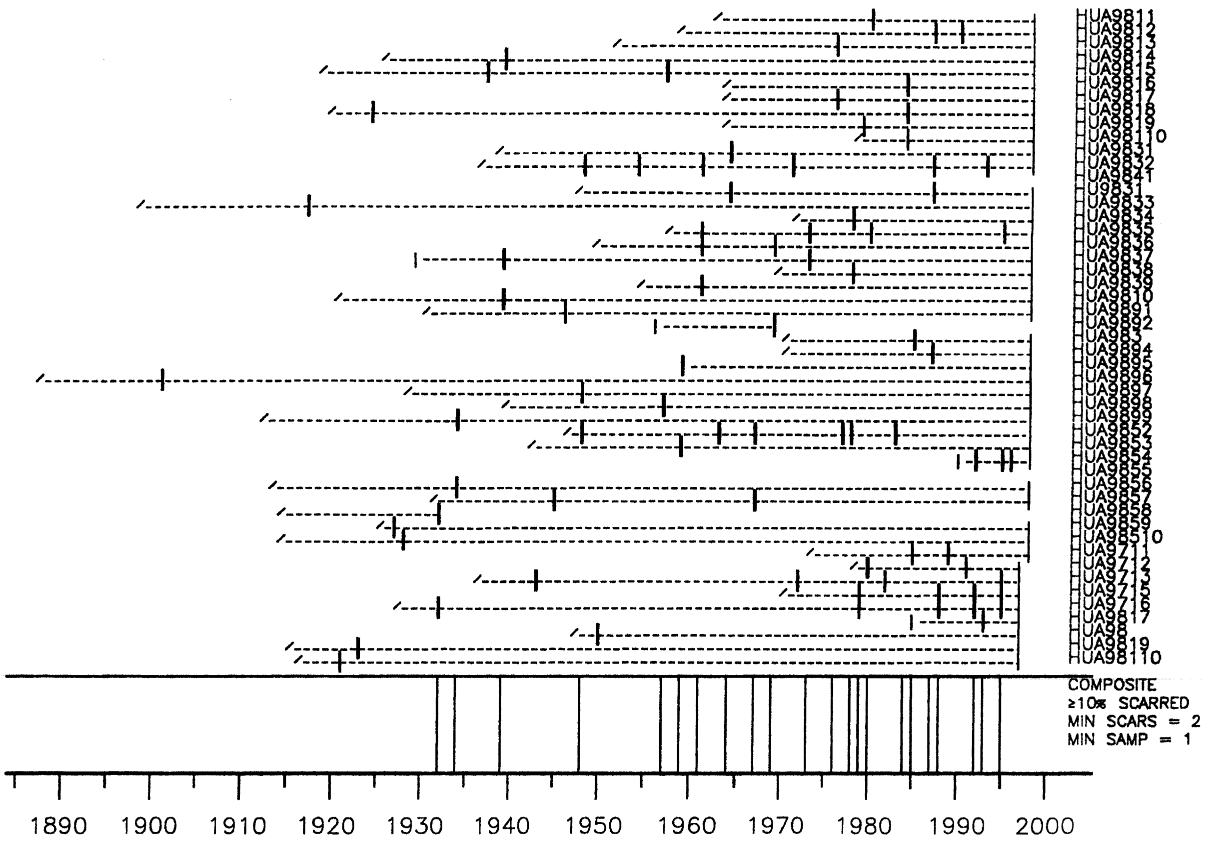

Fig. 3. Fire chronology based on fire scars of *A. acuminata* in the site ‘‘Hualinchay’’, Tucuman province, NW Argentina. Horizontal dotted lines represent individual samples (trees). Vertical short lines are fire scars dated for each tree using dendroecological methods in *A. acuminata* (see text). In this case, fire events (vertical bars in the figure bottom) are defined as events in which at least two trees and 10% of the sampled trees existing for each date recorded fire.

species, quantitative cross-dating based on long time series (e.g. Mc Bride, 1983) is usually not feasible.

Longevity of *A. acuminata* typically does not exceed one century, although record individuals reach 170–180 years old. As time in the past increases, the number of potential fire-recorder trees decreases rapidly and the number of rotten fire scars increases. These problems can be partially overcome by doing extensive sampling of large (presumably old) trees which are frequently available due to the abundance of the species in the landscape, making it possible to produce fire chronologies several decades long (e.g. Fig. 3).

Grau and Veblen (2000) used these techniques based on fire scars of *A. acuminata* to develop fire chronologies in sites of contrasting moisture conditions in the upper montane forests of NW Argentina, and establish relationships with climatic conditions at interannual and seasonal scales (Fig. 4). Since establishment dates of *A. acuminata* are also easily datable by taking increment-borer cores at the base of the tree, it was feasible to establish relationships between fire and patterns of invasion of *A. acuminata* into montane grasslands (Fig. 5). Fast initial growth (20–40 cm height, 3–10 mm radius in the first year) reduces the errors on age determination due to time to reach the sampling height and to not hitting the pith (Grau and Veblen, 2000).

Due to methodological limitations, previous studies of the relationship between fire and vegetation dynamics in neotropical mountains have been restricted to non-quantitative descriptions (e.g. Ellenberg, 1979; Young, 1993; Kessler, 1995), short term (less than 3 years) local assessments or experiments (e.g. Williamson et al., 1986; Verweij and Budde, 1992; Keating, 1998), or multi-century records of pollen and charcoal sediments (e.g. Chepton-Lusty et al., 1998). Our work allowed the study of fire–climate–vegetation dynamics during several decades, a temporal scale that includes significant climatic and land use changes at the regional scale.

The wide distribution of *A. acuminata* provides the opportunity to use the species for studying fire patterns in a variety of ecological and land-use conditions. Other species with potential for developing fire chronologies based on fire scars are *Zanthoxylum coco* and *Jacaranda mimosifolia* in mesic-drier areas of *Yungas*, *C. lilloi*, *Juglans australis*, *Ilex argentina*, *Cletra*

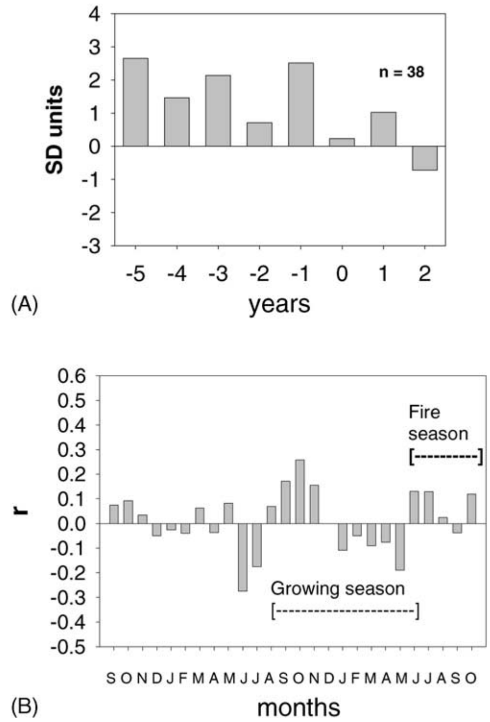

Fig. 4. Temporal relationships between fire events dated using dendroecological techniques in *A. acuminata*, and (A) rainfall during the 5 years previous to the fire event, based on superposed epoch analysis (Monte Carlo simulations on the time series, Grissino-Mayer, 1995), (B) monthly water balance (de Martonne's, 1926) during the 2 years prior to the fire event. Both analyses are modified from Grau and Veblen (2000), performed for La Banderita site, NW Argentina.

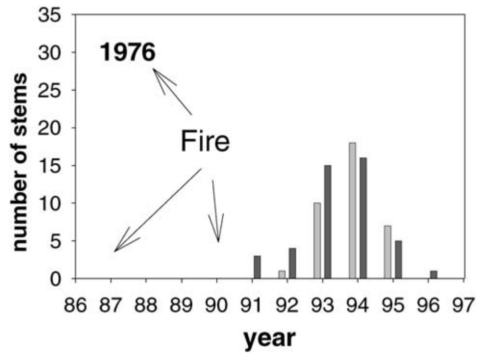

Fig. 5. Age structure of seedlings (open bars) and crown resprouts (solid bars) after fire (dates indicated by arrows) at one location in La Banderita site, NW Argentina.

Table 1
Species with potential for dendroecological work in NW Argentina subtropical montane forests[a]

Species	Botanical authority	Botanical family	Dendroecological use					Elevational range	Latitudinal range	Estimated longevity
			Fire	Treefalls	Floods	Land-slides	Distribution[b]			
A. acuminata	H.B.K	Betulaceae	x		x	x	UMF	600–3000	10°N–28°S	100
C. lilloi	C. DC.	Meliaceae	x	x			LMF, mesic-humid	500–2000	15–28°S	200
C. porphyria	(Griseb) Kosterm	Lauraceae	x	x			LMF, mesic-humid	400–1700	21–28°S	200
Clethra scabra	Meissnet, Sleumer	Cletraceae	x				LMF, mesic-humid	1400–1800	14–24°S	80
H. americanus	L.	Tiliaceae				x	LMF, mesic-humid	400–1000	5–28°S	60
I. argentina	Lillo	Aquifoliaceae	x				LMF, humid	1300–2000	15–27°S	150
J. mimosifolia	D. Don	Bignoniaceae	x			x	LMF, mesic-dry	400–1000	16–28°S	40–50
J. australis	Griseb	Juglandaceae	x	x	x		LMF, UMF	400–2100	16–28°S	300
M. pubescens	Humb. & Bomp. ex Willd	Myricaceae	x				LMF, mesic-humid	1400–1800	10°N–24°S	50
P. excelsa	(Griseb) Burkart	Fabaceae				x	LMF, mesic-dry	400–1700	15–28°S	200
S. riparium	Pers.	Solanaceae		x		x	LMF	400–1300	15–28°S	40
S. humboldtiana	Willd	Salicaceae			x	x	LMF, riparian	400–1000	8°N–30°S	30
T. integrifolia	Ruiz & Pavon	Asteraceae			x	x	LMF, riparian	400–1000	5°N–27°S	30
Z. coco	Gill ex Hook & Arn.	Rutaceae	x	x	x	x	LMF, mesic-dry	600–1800	15–30°S	60

[a] Botanical nomenclature and descriptions, species distributions and further references are provided in Digilio and Legname (1967), Legname (1982), Killeen et al. (1993) and Morales et al. (1995).

[b] LMF: lower montane forest; UMF: upper montane forest.

scabra, and *Myrica pubescens* in humid areas (Table 1). Of these species, *Z. coco* and *I. argentina* have good potential due to their high density in some areas; however, the quality and reliability of their annual rings still need to be better assessed. *J. australis* and *C. lilloi* are long living species that show fire scars and excellent tree ring quality (Villalba et al., 1985) but they tend to occur in relatively low-densities in diverse forests. *J. mimosifolia* shows clear annual rings but its life span is short, limiting its use to records no longer than two decades.

4. Floods and riparian forest dynamics

Floods affect vegetation by producing physiological stress, mechanical damage, and changes in soil and geomorphology. Tree ring analysis of riverbed forest stands can be used to estimate duration, magnitude and frequency of hydrological events, and provide information concerning associated changes in geomorphic and ecological conditions such as vegetation dynamics, sediment deposition, rates of channel migration, riverbank stability, or drainage (Hupp, 1988; Baker, 1990). Tree age, scars, age of new roots and shoots, and suppression–liberation patterns may serve as indicators of these hydrological events. Most riparian dendroecological studies have been conducted in lowland temperate river dynamics which are mainly affected by inundation and meandering erosion–deposition patterns (e.g. Harrison and Reid, 1967; Begin et al., 1991; Martens, 1993). Montane NW Argentina riparian forests growing in mountain cobble-bed braided rivers, are likely to have a very different dynamic than lowland rivers because of topographic channel constriction, steep relief, and coarse debris size, which in turn affect water velocity, lateral and vertical channel fluctuations and sediment deposition patterns.

Besides its wide distribution on mountain slopes, *A. acuminata* grows in almost pure stands on river terraces over the Andes of South America (Grau, 1985) and mountains of central America. Intensive coring and mapping of trees in riparian forest plots at Tucuman, Argentina, allowed the reconstruction of post-flood *A. acuminata* regeneration patterns and the exploration of the effects of floods on riparian forest structure (Easdale, 1997). Age distribution showed distinct tree cohorts with an age span of up to 8 years and with most individuals corresponding to a 4 years settling period following an intense flood event in 1984–1985 rainy season, which is reflected in the high number of flood scars and also in gauge records (Fig. 6). In the mentioned study (Easdale, 1997), the combination of the spatial distribution of stems and age structure information by means of spatial autocorrelation analysis (Moran's I, Duncan and Stewart, 1991), verified the occurrence of spatially discrete even-aged tree patches. As suggested by the relatively good fit between establishment peaks and river gauge records, even-aged patches result from massive regeneration following catastrophic summer river floods, which partially destroy preexisting stands and originate bare fluvial terraces. Analysis of flood scars in association with forest age structure suggests that regeneration initiates one hydrologic year after catastrophic floods (Fig. 6). This could be explained by the fact that seeding and dispersal of *A. acuminata* occurs during the winter and early spring. Since floods in the area typically occur during summer, seeds are not available to colonize flood-affected areas until the following growing season. Given that riparian environments are not limited by water deficit colonization is, however, faster than in other microenvironments.

Flood scar dating should be made with caution in these monsoonal environments. Floods occur mostly during the growing season. Consequently, radial growth occurs both right before and right after the disturbance. Damage produced by the flood may result in a double annual ring, and visual cross-dating with neighboring trees not affected by the flood is recommended. Flood plains are very dynamic environments. Recurrent floods frequently eliminates previous evidence, and longevity of trees is typically shorter than in other environments. Nevertheless, *A. acuminata* has potential for the reconstruction of flood regimes for at least half a century. Given the monsoonal climatic regime, floods occur almost every year and to record floods of unusual intensity, it is necessary to conduct extensive sampling to quantitatively identify years with a large number of flood scars (e.g. 1985 in Fig. 6). Other species with reliable tree rings, commonly growing on riparian environments, and that show flood scars are *Salix humboldtiana* and *J. australis* (Table 1). *J. australis* may complement *A. acuminata* records in the high-elevation montane

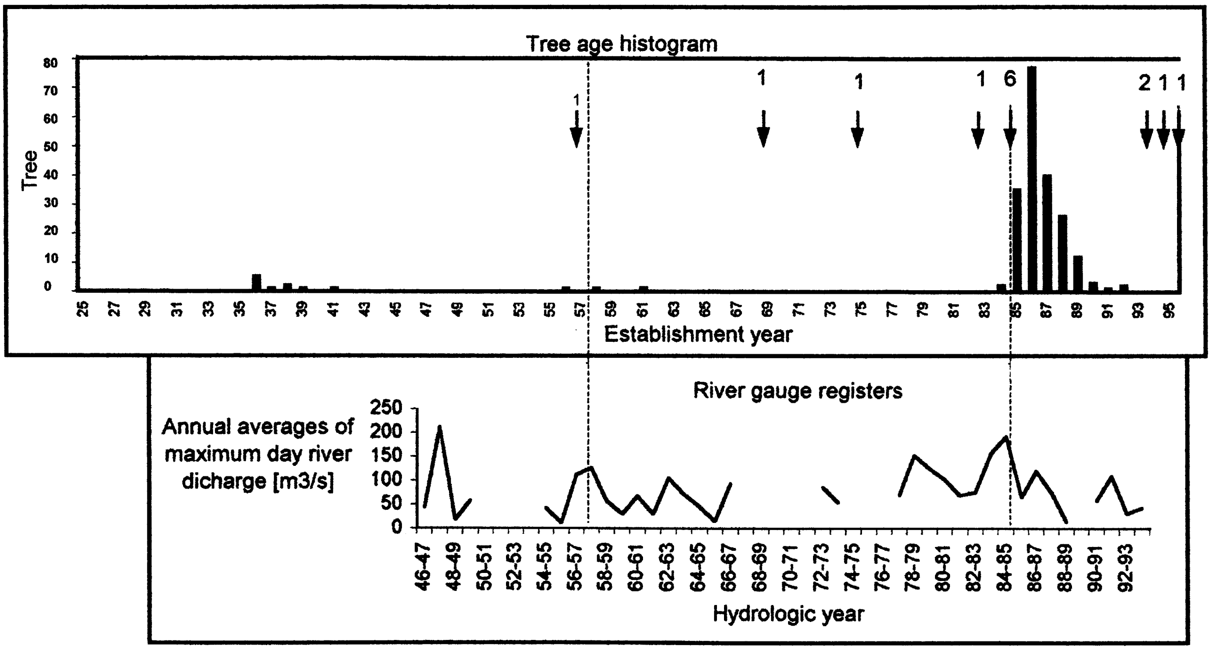

Fig. 6. Age distribution of *A. acuminata* trees in flood plains, flood dates in Potrero river, Tucuman, NW Argentina. Arrows indicate dates of flood scars (number of scars for each date are indicated on top). Gauge registers correspond to the Lules river, close to the study site. Dotted vertical lines are hypothetical flood years which originate tree cohorts.

forests. In the northern extreme of Argentina (22°S) we have preliminarily dated a flood terrace which occurred between 1815 and 1820 using *J. australis* (R. Villalba and H.R. Grau, unpublished information). *S. humboldtiana* could be used for studies at lower elevations where it becomes very abundant. *Tessaria integrifolia* shares the environment with *S. humboldtiana* (both extend their distribution through most riparian environments of South America) and has cambium bands and flood scars, but the use of these rings for dating still needs to be assessed.

5. Landslide dynamics

Dendroecological dating of landslides has been successfully done in high-latitude environments of the northern hemisphere. Slow and continuous land movements can be dated by analyzing changes in tree rings eccentricity, while sudden mass movements are dated by analyzing trees directly or indirectly affected by these movements (e.g. Alestalo, 1971; Braam et al., 1987; Denneler and Schweingruber, 1993; Fantucci and McCord, 1995; Corominas and Moya, 1999; Fantucci and Sorriso-Valvo, 1999; Lang et al., 1999). These analyses include combination of different approaches.

Minimum landslide age. Age of the oldest tree can be used as an estimator of landslide age. In tropical and subtropical environments, landslides are surrounded by abundant seed sources, and this colonization is expected to be relatively fast. For example, in the Bolivian montane forests *A. acuminata* trees usually establish during the first or second year following the landslide occurrence (Blodgett, 1998). However, it must be recognized that after a landslide event, severe erosion and falling debris may continue for several years limiting forest establishment, and therefore, tree establishment may underestimate the age of the actual landslide event.

Growth patterns in trees surrounding the landslide. Trees with stem or root damage produced by the land movement may show growth suppression. On the other hand, trees located in the surroundings of the landslide which were not affected by it can show growth increase (releases) due to decreased competition with the damaged trees. The combination of these growth changes reflected in tree ring widths can be used for dating the events with precision.

Landslide scars. When external stem tissues are directly removed or killed by mechanical effects of falling debris, wood re-growth over the scar can be dated in the same way as fire or flood scars.

Landslides are a major component of the disturbance regime in the *Yungas* of Argentina and southern Bolivia (Grau, in press). Above 1500 m elevation, *A. acuminata* is a typical landslide colonizer. To test the potential of *A. acuminata* for dendrogeomorphology in the area, we sampled a landslide with a documented date of occurrence in the summer of 1983. Increment-borer cores were extracted from trees growing over the landslide surface. Two to three samples were taken for each individual. Due to difficulties in reaching the pith at the base of the tree, only 11 (out of the 25) samples were finally included for the analysis. Additionally, 11 trees were sampled in the border of the landslide. In order to discriminate growth patterns due to the landslide event from the climatic signal on ring widths, the standardized width chronology of these trees (Cook et al., 1989) was compared to a master ring chronology developed for *A. acuminata* in the region. In this particular example, no landslide scars were found.

Fig. 7 illustrates how the different samples contribute to the landslide dating. Most dated trees established in 1986, lagging 2 years the growing season following the landslide. Note that since *A. acuminata* seeds in spring, it cannot colonize the landslide surface until the following growing season. Growth suppression occurred in 1984, which suggests that root damage is not reflected as a reduction in stem radial growth until the year following the landslide. While the age structure cannot be used to precisely date the landslide event, it may be used to discriminate growth suppression due to the landslide from other years of relatively slow radial growth (e.g. 1972 and 1993 in Fig. 7). Landslide scars would be a useful complement for a more accurate dating. Since landslides typically occur during the growing season (rainy summer) the scars may result in a double annual ring and visual cross-dating with neighboring trees not affected by the landslide may be useful, in the same way as described for flood scars. Other species that are typical colonizers of landslides (Grau and Brown, 1995b) and have tree rings are *S. riparium*,

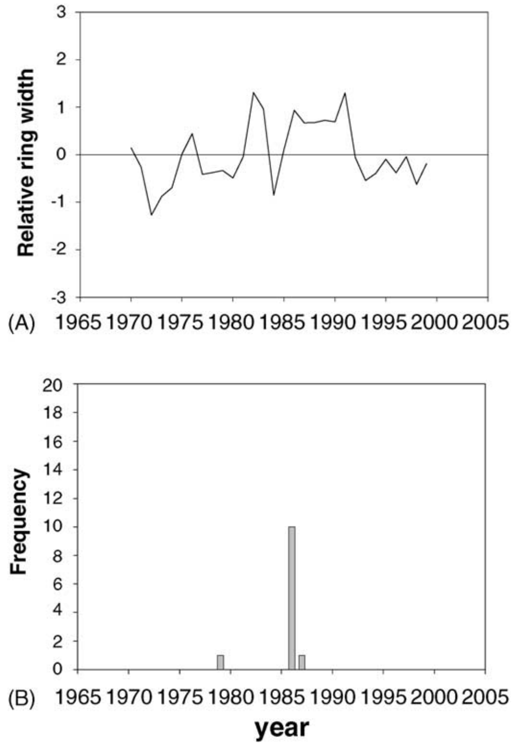

Fig. 7. (A) Difference between standardized (minus mean, divided by standard deviation) of annual ring width of *A. acuminata* growing in the border of the landslide and a master chronology for the region. (B) Age distribution of *A. acuminata* trees on a landslide in Quebrada de Los Sosa, Tucuman, Argentina.

Heliocarpus americanus, *T. integrifolia*, *Parapiptadenia excelsa* and *Zanthoxylum coco* (Table 1). However, they have not been used for dendroecological studies and their reliability for quantitative studies needs further testing.

6. Treefall gaps and diverse forest dynamics

Treefall gaps are a dominant type of disturbance in mature forests of different latitudes. Treefalls regime have been studied in temperate forests by dating establishment of gap-dependent species, growth releases of juveniles growing inside the gap or adult trees limiting the gap, and falling dates of the gap-maker (e.g. Henry and Swan, 1974; Oliver and Stephens, 1977; Veblen et al., 1981; Lorimer, 1985; Fritts and Swetnam, 1989). In tropical forests, treefall regime is almost exclusively studied by means of permanent plots (for a description of procedures see Dallmeier, 1992). Subtropical forests of NW Argentina provide the opportunity to combine both methods to describe forest dynamics and disturbance regimes at multi-decadal scales.

Increment-borer cores of *S. riparium* (a gap dependent species) taken in 1997 in a treefall gap occurred in 1992 (according to direct observations in forest permanent plots) showed five cambial bands in 1997. Establishment dates of *S. riparium* in other treefalls coincided with growth release dates in increment-borer samples of *C. lilloi* and *J. australis*, two species with reliable annual rings (Villalba et al., 1985). *C. porphyria*, a common multistemmed canopy tree with reliable annual tree rings (Villalba, 1995), has a high capacity to produce vertical resprouts when a main stem falls, and these resprouts can be accurately dated.

The potential for dendroecological reconstructions of treefalls patterns largely depends on the availability of species producing annual tree rings at each particular location. For example, in a forest where *S. riparium* and *C. porphyria* are very abundant, Grau (2002) was able to reconstruct the history of treefalls during the last 30–40 years by combining dendroecology with permanent plot-observations over a 5-year period in the subtropical forests of the Sierra de San Javier (27°S). Growth releases were also used to study the response to treefalls of *C. lilloi* (a valuable timber species) in the forests of El Rey (24°S) and assess its potential for management in selective logging systems (Grau, 2000).

Dead stem dating is very difficult due to the fast rate of decay of the dead wood, and has not been used. The use of other species, as well as the extension of treefall chronologies is an important research challenge to understand treefalls dynamics in this region.

7. Discussion

Through this review we have shown the possibility of using dendroecological techniques for describing disturbance regimes and forest dynamics in Andean subtropical forests (22–28°S), with potential for expansion of geographic range to latitudes as low as 15°S. This group of techniques has been historically restricted to temperate ecosystems (Lorimer, 1985; Fritts and Swetnam, 1989; Duncan and Stewart, 1991; Schweingruber, 1996; Kitzberger et al., 2000; Villalba, 2000), while more recent studies have shown some potential for work in subtropical ecosystems dominated by conifer taxa which do not exist in the Neotropics (e.g. Enright and Goldblum, 1998; Heyerdahl and Alvarado, 2002). Our paper serves to expand the geographical range of potential uses of tree rings for ecological studies in South America. The methods and examples here reported are the result of a few years of research of a small group of scientists, but they suggest a strong potential of these methods for further research. The use of the dendroecological methods described here provides the opportunity to study a variety of ecological processes at multidecadal scales. The comparatively shorter life span, and the accelerated dead wood decay rate due to the subtropical climatic conditions, preclude the use of the methods here reported for multi-century studies, as has been done in temperate forests (Cook and Kairiukstis, 1989; Fritts and Swetnam, 1989; Schweingruber, 1996; Kitzberger et al., 2000). However, multidecadal dendroecological accounts of disturbances and forest dynamics represent a substantial extension of the time scales explored by most ecological studies in the tropics (e.g. permanent plots, repeated observations, experiments). On the other hand, the annual resolution provided by tree rings is substantially more accurate than that achievable by other long-term methods such as historical and sediment studies (e.g. charcoal, pollen). We expect our results will stimulate the development of further methods. Among the most promising research lines are the following: (1) develop fire chronologies with useful species in environments where fire is an important component of the disturbance regime, but *A. acuminata* is not abundant, (2) explore the use of the species here described for studies at lower latitudes, (3) explore the use of other species to study treefall regimes in a larger variety of mature diverse forests; including relatively short living species (e.g. a few decades) that respond to canopy openings by means of establishment, resprout or growth releases, (4) explore the use of dendroecological techniques to describe disturbances not studied to the present such as mortality events, wind, insect attacks, grazing, bamboos flowering, agriculture and post-agriculture succession.

Acknowledgements

This paper was founded by grants from PROYUNGAS (Argentina), CONICET (Argentina), and International Foundation for Science (Sweden). The development of these methods was improved and stimulated by the guidance of Ricardo Villalba (CRICYT, Mendoza, Argentina), and Thomas Veblen (University of Colorado at Boulder). Alfredo Grau and two anonymous reviewers provided helpful comments on the manuscript.

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