

Biomass Burning and Global Change

Volume 2

**Biomass Burning in South America, Southeast Asia,
and Temperate and Boreal Ecosystems,
and the Oil Fires of Kuwait**

edited by Joel S. Levine

The MIT Press
Cambridge, Massachusetts
London, England

One Thousand Years of Fire History of Andino-Patagonian Forests Recovered from Sediments of the Rio Epuyén River, Chubut Province, Argentina

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The Andino-Patagonian forests of southern Argentina occur between 37° and 55°S in elevation up to 1800 m a.s.l. A distinct East-West gradient in annual precipitation ranges from 200–500 mm in the Patagonian shrub steppe (eastern foothills of the Andes cordillera), via 500–1200 mm in the tree-grass steppes of the pre-cordillera, up to 4000 mm in the high altitudes. The dry season is between November and the end of March. The Andino-Patagonian forests are dominated by broadleaved trees of *Nothofagus* spp. The most important conifer in this region is *Austrocedrus chilensis*.

Volcanism

This forest region is one of the few in the world where volcanism may have played an important role as a natural fire source because 24 volcanoes are found between 37° and 45°S. Historic records of eruptions are given in table 62.1 (Simkin 1981). Besides their potential role for starting fires, volcanic activities and tectonic instability cause landslides, an important disturbance factor that helps to explain forest composition and dynamics (cf. Veblen and Ashton 1978; Heusser et al. 1988).

Historic volcanic activities during the main active postglacial periods ca. 7000, 2300, and 1000 years before present (B.P.) are manifested in thick ash layers with subsequent formation of andosols. (Auer 1933).

Lightning Fires

Lightning is one of the other important sources of wildfires, particularly on the eastern mountain-steppe ecotones (Knoch 1930). Large-scale die-back of local bamboo (*Chusquea culeou*) in intervals of up to several decades provides periodic fuel for lightning fires (Veblen and Lorenz 1987). Litter production in Chilean *Nothofagus* forests of ca. 5 t ha⁻¹ yr⁻¹ (Burschel et al. 1976) provides sufficient fuel for the build up and spread of lightning fires. Veblen and Lorenz (1987) quote unpublished statistics from the Argentinian Park Service revealing that 14 lightning fires were recorded

between 39° and 41°30'S from 1938–82 and burned a total of 4085 ha of forests.

Human-Caused Fires

Pre-Columbian fire practices in this region are not yet known in detail. Archeological data from caves or descriptions of historic fires along the southern tip of the continent (*Tierra de los Fuegos*) by seafarers like Magellan clearly show that fire has been in the hands of humans for a long time. Early travel reports indicate that nomadic tribes used fire for hunting guanaco, cougar (puma), and ostrich (Musters 1871, in Eriksen 1972). Volcanic ash layers contain well-preserved information on pre-Columbian human cultures that date back to at least 10 000 B.P. (Menghin 1955; Vitale 1990). Only a few palynological analyses with age dating of charcoal are available, such as a study by Heusser et al. (1988) that shows fluctuating charcoal particle frequencies for the last 3 000 years.

The consequences of changed regional climate on natural fire regimes in South Patagonia during the last centuries is not clear. Regional climate change was manifested by a decrease of precipitation and the westward shift of the forest zone towards the cordillera (Auer 1933; 1939; 1958; Kalela 1941; Eriksen 1972). However, no reliable data are available that indicate a change of natural fire regimes because of the increasing influence of post-Columbian forest clearing activities that began at the end of the sixteenth century.

The earliest detailed descriptions of forest fires date back to the late nineteenth century during when forests were increasingly converted into rangeland (Lauer 1961). Historic fire maps produced by Rothkugel (1916) show that extended forest fires had occurred in the area of today's Nahuel Huapi National Park. An even-aged 150-year-old stand of *Nothofagus dombeyi* is described as the result of a forest fire caused by indigenous people or by missionaries. Seibert's (1979) statement that in the 1970s about 10% of all forest fires were caused by lightning may still be valid today. In the 1980s, fires in the Andino-Patagonian

Table 62.1 Eruptions of volcanoes in the Andes between 37°S and 40°S (Simkin 1981)

Volcano	Geographic location	Eruption years
Tromen (Argentina)	37°12'S–70°10'W	1822
Antuco (Chile)	37°40'S–71°37'W	1750, 1752, 1820, 1828, 1839, 1845, 1852–53, 1861, 1863, 1869, 1929, 1972
Callaqui (Chile)	37°92'S–71°42'W	1850
Copahues (Chile)	37°85'S–71°17'W	1750
Lonquimay (Chile)	38°37'S–71°58'W	1853, 1887, 1889
Llaima (Chile)	38°70'S–71°70'W	1640, 1751, 1852, 1862–66, 1869, 1872, 1876, 1877, 1883, 1887, 1889, 1892, 1893, 1895–96, 1903, 1907–08, 1912, 1914, 1917, 1927, 1929, 1930, 1941, 1945, 1949, 1955, 1956–57, 1964, 1972, 1979
Villarrica (Chile)	39°42'S–71°95'W	1558, 1777, 1806, 1822, 1852, 1860, 1869, 1874, 1875–76, 1883, 1893, 1897–98, 1906–08, 1908, 1915–18, 1920, 1929, 1933, 1935, 1938, 1948–49, 1959–61, 1964, 1971, 1980
Quetrupillan (Chile)	39°48'S–71°70'W	Holocene
Rinihué (Chile)	39°93'S–72°03'W	1864

mountain forests affected between 1000 and 3500 ha per year, however, there were also extremely dry years like 1988 when 218 000 ha of forest were burned (Goldammer 1993).

Ecological Consequences of Forest Fires

Because of recent forest fires the characteristic features of vegetational post-fire development can be seen in many places of the Cordillera. Little research has been done, however, to explain the consequences of fires on the composition and dynamics of the Andino-Patagonian *Nothofagus* forest.

In this study we present the findings of a case study of the recovery of fire history data and present the hypotheses of Goldammer (1993) on the eco-historical role of fire in this forest region.

Reconstruction of Historic Fire Events

The first systematic collection and radiometric age determination of charcoal was conducted in 1991 (Goldammer 1993). The study sites given in table 62.2 are in the Argentinian provinces Chubut and Rio Negro near 43°S/71°W, and thus are in the North of the volcano zone described in table 62.1.

A second sampling series was conducted in March 1993. The target site was a river sandbank in the Rio Epuyén estuary at Lago Puelo, Province of Chubut. This sandbank was up to 6 m high and contained charcoal pieces, predominantly in the lowest tow meters of the sedimented material (figure 62.1). The purpose of the study was to reconstruct a time sequence of

historic fire dates transported from a watershed area of ca. 1000 km² and deposited in the river sandbank.

The sampling site is located in the Province of Chubut (GPS Position: 42°07.68'S, 71°34.84'W), in a river valley between the *Cordón de los Derrumbes* and the *Corrón de Churrumahuida*. Elevation of the bottom is 200–220 m asl. The geological material is plutonic (paleo-mesozoic) and volcanic (tertiary). Hydrologically the site is in the Cuenca Pacifica watershed (sub-cuenca Lago Epuyén and Lago Puelo).

The morphological characteristics of the fluvio-glacially shaped river valley are steep slopes with high-relief dynamics and high morphogenetic potential (slopes >35% and mean annual precipitation of ≥1000 mm yr⁻¹ lead to high erosion rates).

Post-glacial volcanism nearby (30–50 km) produced thick volcanic ash layers. Dry slopes are stocked with *Austrocedrus chilensis* (particularly on N exposition), mesic-wet foothill/low elevation sites with *Nothofagus dombeyi* (S exposition), high elevations (wet sites) up to tree line with *Nothofagus pumilio* (S exposition), and wet sites on the valley floor with *Nothofagus antarctica*, with *Salix* spp. along creeks and rivers, and *Festuca pallens* and *Carex goyana* grasses.

The river sand bank consisted of up to 6-m high sandy silt loam accumulation. ¹⁴C dates of charcoal pieces embedded between the base and 2.2 m are given in table 62.3.

Impact of Fires on Forest Vegetation Composition

The most important tree species in this region occurring both in pure and mixed stands, are *Nothofagus*

Table 62.2 Locations and ^{14}C -ages of soil charcoal recovered on various Andino-Patagonian *Nothofagus* forest sites in South Argentina

Sample no. Date of sampling	^{14}C Age (yrs B.P.)	Location	Forest type Main tree species	Soil type Sampling depth
HAM 2855 — 3/1991	1360 \pm 70	Los Alerces National Park, Chubut	<i>Nothofagus dombeyi</i>	Andosol 30 cm
HAM 2856 — 3/1991	4740 \pm 100	Forest S. of El Bolsón, Rio Negro	<i>Nothofagus dombeyi</i>	Andosol 30 cm
HAM 2857 — 3/1991	1060 \pm 70	Forest near Lago Rosario, Chubut	<i>Nothofagus pumilio</i>	Andosol 30–50 cm
HAM 3151 — 12/1991	2760 \pm 280	Forest near Huemules Sur, Chubut	<i>Nothofagus antarctica</i>	Andosol 70–85 cm
HAM 3152 — 12/1991	810 \pm 180	Forest near Huemules Sur, Chubut	<i>Nothofagus pumilio</i>	Andosol 15–30 cm

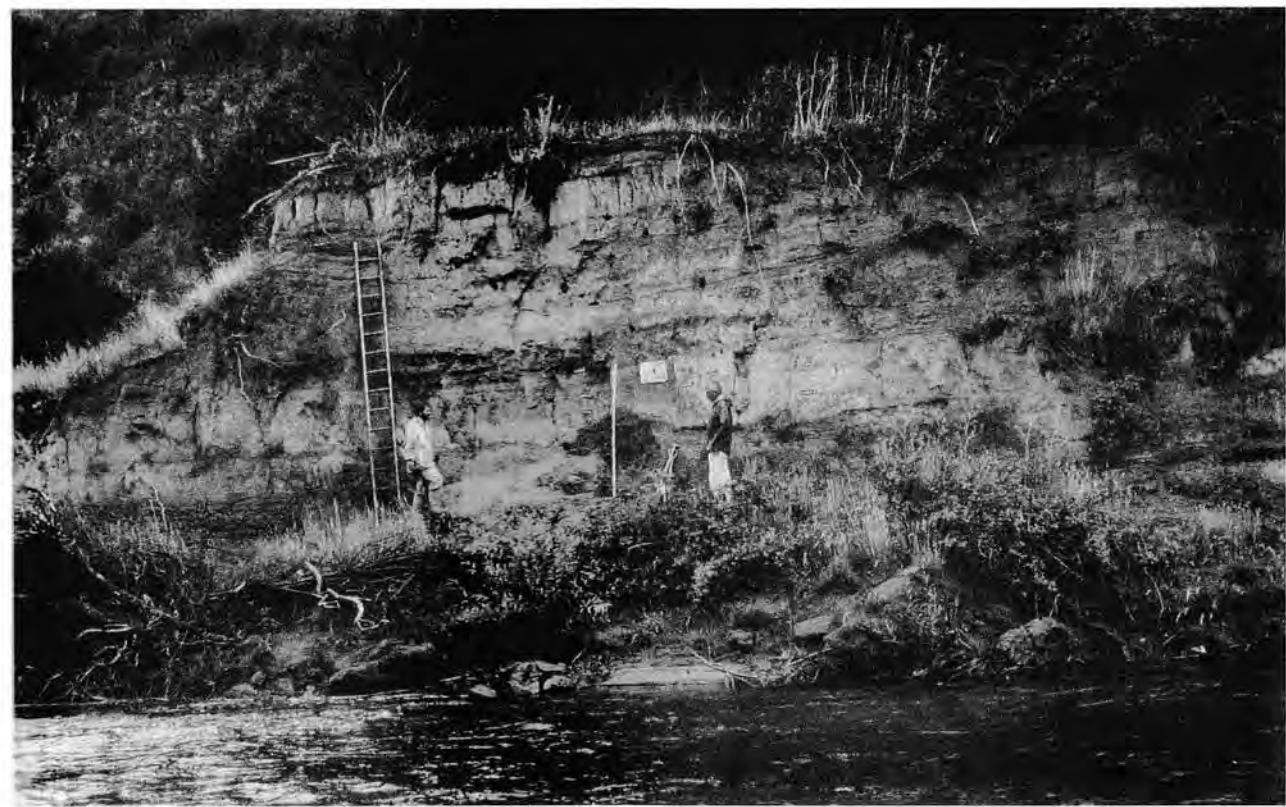
**Figure 62.1** Sampling site of sediments along Rio Epuyén

Table 62.3 Location of charcoal within a sandbank profile of Rio Epuén Valley, Province of Chubut, Argentina (GPS Position: 42°07.68'S, 73°34.84'W). ^{14}C dates were provided by Peter Becker-Heidmann, Isotope Dating Laboratory, Institute for Soil Sciences, Hamburg University (Germany)

Location of charcoal within Sandbank profile		
Height above boulders (cm)	^{14}C Age (years B.P.)	Laboratory number (HAM)
+220	105.21 ± 097% (modern)	3189
+200	480 ± 60	3193
+180	830 ± 110	3195
+160	840 ± 220	3197
+140	1020 ± 180	3196
+110	1120 ± 110	3194
+50	1180 ± 50	3188
Base	950 ± 210	3192

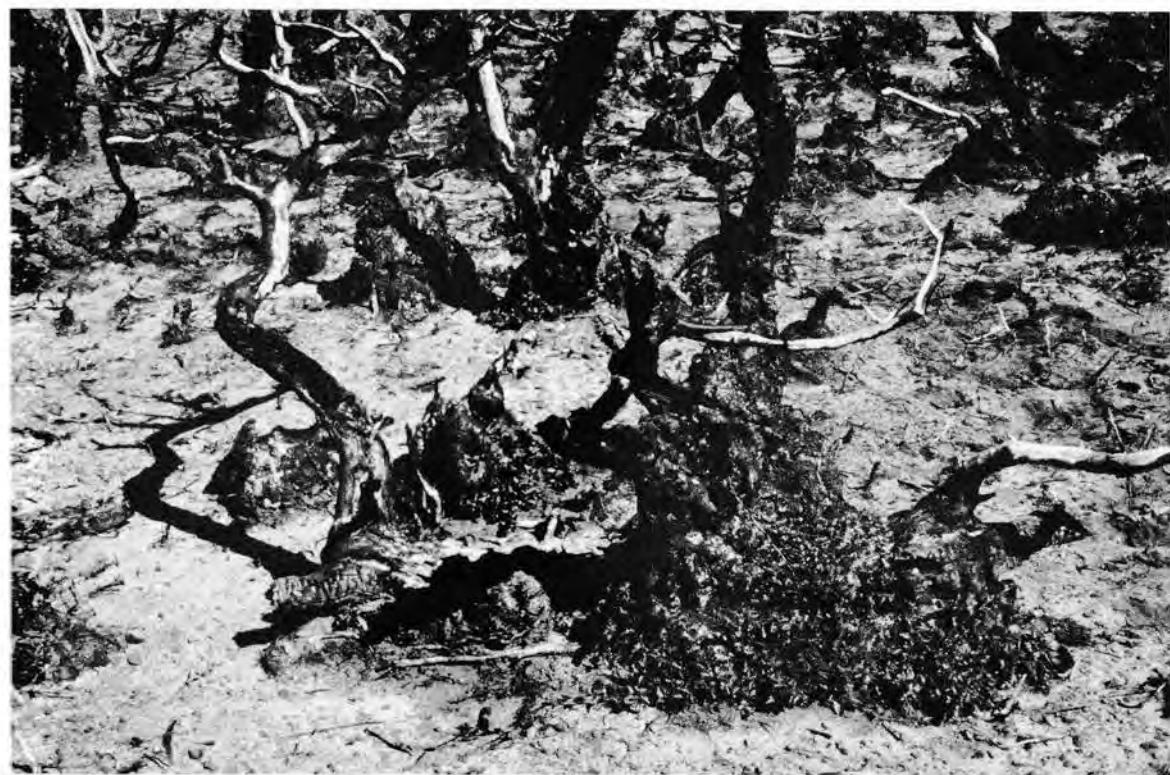
pumilio, *Nothofagus dombeyi*, *Nothofagus antarctica* and *Austrocedrus chilensis*. The typical occurrence of *Nothofagus* spp. in altitudinal belts as described earlier (e.g. Hueck 1966; Seibert 1979) is not found everywhere. One presumable reason for this is fire.

1. Of all Patagonian tree species, *Nothofagus pumilio* covers the largest area. Its altitudinal range is restricted to 500–600 m asl. in the South (Tierra del Fuego) and to 1700 m asl. in the North (Province of Neuquén). Like the Northern Hemispheric beech species (*Fagus* spp., particularly *Fagus silvatica*), *N. pumilio* is very intolerant to fire due to its thin bark. Forest dieback as a consequence of increasing aridity in the Patagonian region results in high fuel loads, which were estimated to range between 30–50 t ha⁻¹ (Goldammer 1993). In selectively harvested stands, the nonexploitable trunks and other debris provide additional fuel that contrib-

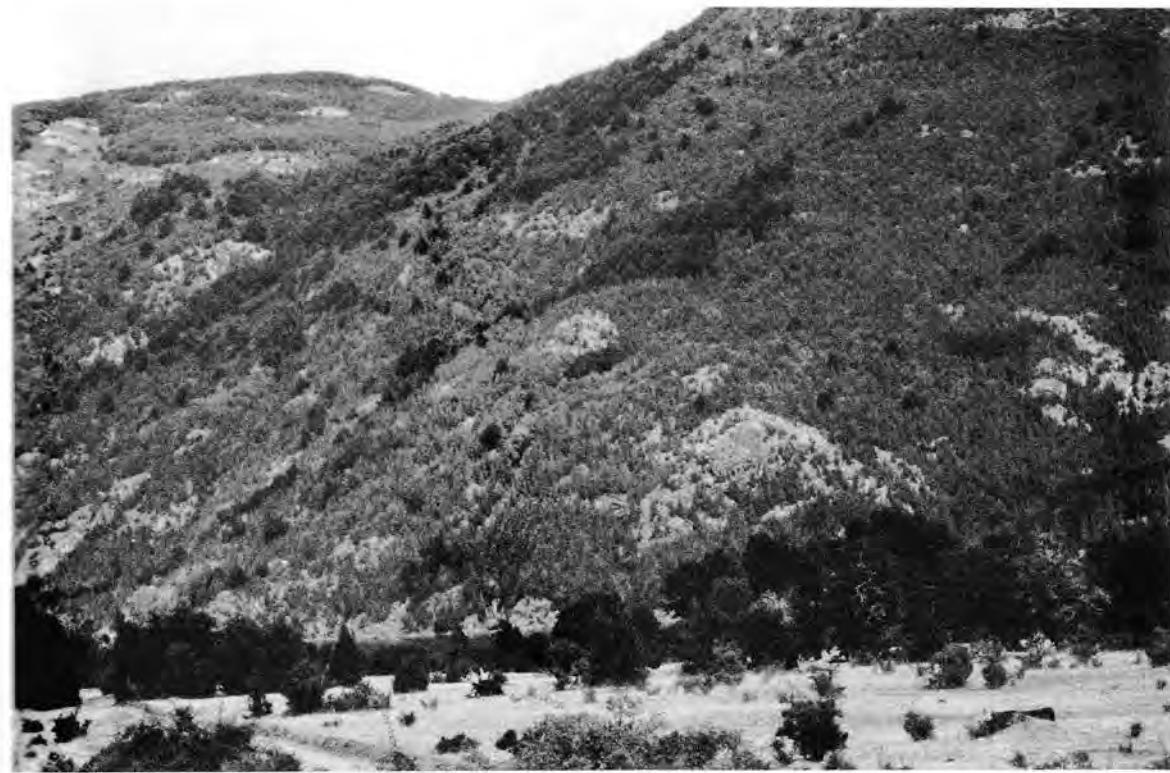


(a)

Figure 62.2 Effects of fire in Andino-Patagonian *Nothofagus* forest in South Argentina, (a) a *N. pumilio* stand affected by fire in 1987 and showing no regeneration in 1991; (b) resprouting from *Nothofagus antarctica* on same site; (c) forest mosaic near Los Alerces National Park. Dark forest patches indicate groups of *Nothofagus pumilio* and *Nothofagus dombeyi* in a formerly burned area occupied by *Austrocedrus chilensis* (all photographs: J. G. Goldammer).



(b)



(c)

Figure 62.2 (continued)

utes to the high intensity of wildfires. Post-fire regeneration through seeds is very slow. Since this species requires shade in its seedling and sapling stage, regeneration is particularly slow on large burned sites (figure 62.2a).

2. *Nothofagus dombeyi* grows on sites with a better moisture supply and is often associated with other species. *N. dombeyi* is as intolerant to fire as is *N. pumilio*, but regenerates faster on burned-over sites (more and lighter seeds are produced by this species).

3. *Nothofagus antarctica* has a larger ecological amplitude and is sometimes described as a light-demanding pioneer species. The capability to resprout from roots after fire enables this species to remain on burned sites. Short-return interval fires may eliminate competing tree species, allowing *N. antarctica* to dominate (figure 62.2b).

4. *Austrocedrus chilensis* is a drought-tolerant conifer. Crown fires often occur in *A. chilensis* stands, leading to high-stand mortality. Since seeds are light and easily transported by wind over long distances, this species occupies burned sites much easier than does *Nothofagus* spp. (figure 62.2c).

Discussion

The radiocarbon dates of the first investigation series (table 62.2) must be interpreted carefully. All radiocarbon dates are pre-Columbia. Only one location can be identified clearly as an ancient fire-place dating back 4740 years b.p. All other charcoal may be from forest fires. However, there is no indication whether the fires were set by humans or caused by lightning. Since all charcoals were embedded in volcanic ash layers, it is assumed that fires took place in periods of volcanic activity.

The radiocarbon dates given in table 62.3 for the first time allow the reconstruction of a sequence of fire events in a limited watershed area of 1000 km². We assume that the fires on the predominantly steep terrain had severe consequences on surface runoff and erosion. The eroded materials carried the fire-charred parts of incompletely burned forest fuels. Finally, the materials were deposited in the river sandbanks or in the Lago Puelo. However, this time series does not allow us to conclude that there were on fires between the dated events. Thus, the database is too small to derive a complete picture of fire-return intervals.

Natural and human-caused fires have had considerable influence on forest composition. *Austrocedrus chilensis* behaves like a pioneer species and occupies fire-disturbed sites easier than does *Nothofagus* spp.

Many of the large stands of *A. chilensis* may have originated after fire and successfully competed with *Nothofagus* spp.

The fire tolerance (resprouting capability) of *N. antarctica* and the susceptibility of the other thin-barked *Nothofagus* spp. to fire may help to explain contemporary forest mosaics in the Andino-Patagonian vegetation. The edges between distinctly different forest stands do not always follow horizontal lines. Many stand edges follow vertical lines uphill. While these edges could also be explained by landslides, fires typically tend to run uphill with high intensity and spread slowly to the flanks, thus creating sharp edges between burned and unburned forest.

Other disturbances have been intermixing since human first occupied the area some 10 000 years ago, and they intensified with the beginning of European settlement. With the settlers, domestic and wild animals (e.g. the hare *Lepus europaeus*) were introduced that increasingly exerted highly selective grazing and browsing pressure on the Andino-Patagonian forest. The influence of this exotic fauna on forest species composition and dynamics is one of the major problems in contemporary forest resource management.

Conclusions

The field research and observations presented in this paper give some initial insights into the possible historical role of fire in the Andino-Patagonian *Nothofagus* forest. The collection of a larger dataset of soil and sedimented charcoal is required in order to obtain more reliable information on historic fire regimes. Forest soils and river sediments in South Argentina contain abundant charcoal and woody biomass that are easily accessible for radiocarbon dating. Sediments in the Andino-Patagonian lakes (e.g. Lago Puelo) will provide a possible source for charcoal recovery.

Acknowledgments

¹⁴C dates were provided by Peter Becker-Heidmann Isotope Dating Laboratory, Institute for Soil Sciences Hamburg University (Germany). The expeditions were financed by the Max Planck Institute for Chemistry and Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ).

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