Dynamics of North Patagonian rainforests from fine-resolution pollen, charcoal and tree-ring analysis, Chonos Archipelago, Southern Chile

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Abstract Fine-resolution palaeoecological and dendrochronological methods were used to investigate the impacts of climate change, and natural and anthropogenic disturbances on vegetation in the North Patagonian rainforest of southern Chile at decadal to century timescales during the late Holocene. A lake sediment mud–water interface core was collected from the northern Chonos Archipelago and analysed for pollen and charcoal. Dendrochronological analysis of tree cores collected from stands of Pilgerodendron uviferum close to the lake site was incorporated into the study. The combined analysis showed that the present mosaic of vegetation types in this region is a function of environmental changes across a range of timescales: millennial climate change, more recent natural and anthropogenic disturbances, and possibly short-term climatic variations. Of particular interest is the spatiotemporal distribution of Pilgerodendron uviferum dieback/burning in the Chonos Archipelago region.

Key words: pollen, charcoal, dendrochronology, Late Holocene, Chonos Archipelago, Chile.

INTRODUCTION

In recent years there has been an increasing integration of neo-ecological and palaeoecological studies of vegetation dynamics. Traditionally, neo-ecological studies have been carried out on timescales of months to years, and on spatial scales of individuals to communities. Palaeoecological investigations have normally focused on timescales of centuries to millennia, and spatially on the scale of landscapes or greater (Delcourt & Delcourt 1991). The spatial and temporal gaps between these two fields are narrowing. Landscape ecological studies, for instance (Noble & Gitay 1996), have made use of remote sensing and geographic information system (GIS) technologies to address ecological questions on spatial scales equivalent to those of traditional palaeoecology. Improved sampling and dating techniques have allowed for the development of palaeoecological records of stand or population dynamics at annual to decadal timescales (Sugita et al. 1997). Such records have proven very useful in studies of climate change and natural and anthropogenic disturbance in the southern temperate rainforests of Tasmania, Australia (Dodson et al. 1998; Dodson 2001), and the northern temperate and boreal forests of the United States (e.g. Foster et al. 1998; Long et al. 1998) and Sweden (Bjorkman & Bradshaw 1996).

Palaeoecological studies that bridge the spatial and/or temporal gap with neo-ecological records, however, have been restricted primarily to the Northern Hemisphere. There is a strong need for such studies in other regions, and this is particularly true for southern South America (Veblen & Alaback 1996). Neo-ecological work in the temperate forests of south-western South America has emphasized the importance of disturbance as a driving factor behind vegetation change at annual to decadal timescales (Donoso 1993; Veblen et al. 1999). Both fine-scale gap dynamics and large-scale catastrophic disturbances affect patterns of vegetation change. Major disturbances in these forests include earthquakes, volcanic activity, windstorms, avalanches, insect outbreaks, and natural and anthropogenic fires (Veblen & Markgraf 1988; Veblen et al. 1999). To date, most palynological research from this region has emphasized the importance of climatic change, migrational lags and palaeoindian burning in driving large-scale vegetation change during the late Quaternary (Heusser 1987; Markgraf 1989; Villagrán et al. 1996; Moreno et al. 1999), but the importance of natural disturbances at century or longer timescales is less well understood. Recent palynological (Szeicz et al. 1998; Haberle et al. 2000) and dendroecological (Veblen et al. 1992; Kitzberger et al. 1995; Szeicz 1997) studies are, however, beginning to address this deficiency.

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In a recent study of the impact of European occupation of the Coyhaique region of northern Patagonia (Fig. 1), Szeicz et al. (1998) showed that the intensive clearance of forests for cattle and sheep grazing since the 1930–1940s has produced a much more open landscape that is now dominated by pastureland, exotic conifer plantations and second-growth Nothofagus forest. The fine-resolution study of environmental change using fossil pollen, charcoal and sedimentological analysis from Lake Venus (45°32′S, 72°01′W), located approximately 5 km north of Coyhaique at an elevation of 600 m a.s.l. (Fig. 1), showed that a major peak in charcoal accumulation rate was directly related to the anthropogenic clearance of Nothofagus during the 1930–1940s and resulted in the expansion of grasslands and introduced species (Rumex and Plantago). Reduced burning activity after approximately 1960 resulted in partial recovery of the local forest community; however, the composition of local native forests had changed from Nothofagus betuloides dominated to Nothofagus pumilio dominated (Szeicz et al. 1998).

In a region remote from the impact of European occupation, some 140 km to the south of Coyhaique and adjacent to the active Liquiñe–Ofqui fault, a pollen record from Lake Miranda (46°08′S, 73°27′W) and dendrochronological data from Pilgerodendron uviferum growing around the lake, showed a rapid expansion of Pilgerodendron uviferum within the past 300–400 years at the expense of trees such as Weinmannia and Podocarpus (Haberle et al. 2000). In the absence of any evidence for substantial human impact, these changes are most likely related to long-term millennial-scale trends associated with periodic tectonic activity and associated changes in the local water table. These results highlight the need to consider long-term changes in natural disturbance regimes in the study of short-term ecological change.

In the present paper we present new pollen, charcoal and dendrochronological data from an ongoing multidisciplinary project that aims to investigate vegetation dynamics in the North Patagonian rain forest of southern Chile during the late Holocene (Bennett et al. 2000). Fine-resolution palaeoecological data from a lake in the Chonos Archipelago are compared with dendrochronological data from the same locality to investigate the potential of combining these data sets to reconstruct the impacts of climate change, and natural and anthropogenic disturbances on vegetation at decadal to century timescales. In this study, botanical nomenclature follows Marticorena and Quezada (1985).

METHODS AND STUDY AREA

Study area

The Chonos Archipelago makes up the northern part of the Chilean Channel region between latitudes 44°00′S and 45°45′S and longitudes 73°20′W and 74°30′W (Fig. 1). The region lies within a zone of high precipitation, which is produced by the Southern Polar Front that migrates seasonally between 50°S (austral summer) and 40–45°S (austral winter). In general the climate is strongly oceanic, with annual precipitation approximately 3000 mm, although at higher altitudes where the mountainous islands can reach up to 1300 m a.s.l. (e.g. Cerro Cuptana, Isla Cuptana), orographic effects significantly increase the precipitation (Fujiyoshi et al. 1987). Annual average temperatures at sea level range from 8 to 10°C, and decrease further to the east with increasing continentality and with increasing altitude. The geology of the region is highly complex Cretaceous granites overlain by Quaternary tills and volcanics (Niemeyer et al. 1984). Extensive Late Quaternary glaciation has left numerous small lake basins, which make ideal sites for palaeoecological study (Bennett et al. 2000; Haberle & Bennett 2001). Southern Chile is very tectonically active, and some of the largest earthquakes on record have occurred in this region (Lomnitz 1970). Several active volcanoes are located directly to the east of the region, with the most active being Volcán Hudson, which erupted most
recently in 1991 (Naranjo et al. 1993) and has had a long history of eruptive activity during the Holocene (Haberle & Lumley 1998). Tectonic activity is centred around the Liquiñe–Ofqui fault system, with the main north–south aligned fault passing through the San Rafael Glacier embayment and north along the eastern margin of Canal Moraleda.

The Chonos Archipelago lies within the range of North Patagonian rainforest. In general, North Patagonian rainforest is dominated by evergreen broadleaved and conifer taxa (Veblen et al. 1983; Gajardo 1995). Lowland coastal areas support a dense forest of Nothofagus dombeyi, N. nitida, N. betuloides, Weinmannia trichosperma, Podocarpus nubigena, Drimys winteri, Caldcluvia paniculata and Pseudopanax laetevirens. Poorly drained sites are dominated by Pilgerodendron uviferum and Tepualia stipularis. This same association, often with an understorey dominated by Philesia magellanica, Astelia pumila and Lepidothamnus fonkii, is found on the interiors of many islands that appear to have been burned during the last one to two centuries. Such sites are often dominated by a high density of dead standing Pilgerodendron uviferum with fire scars present on the remaining stems. At high elevations, Nothofagus betuloides increases in dominance, with Drimys winteri and Pilgerodendron uviferum also present. Nothofagus betuloides, N. antarctica and P. uviferum occur as krummholz at and above the upper tree line, which at this latitude occurs at between 650 and 700 m a.s.l. Several tree species in the region reach considerable age, allowing for the development of long dendrochronological records. Of particular interest is the Cupressaceous conifer Pilgerodendron uviferum, which attains ages of well over 500 years (Cruz & Lara 1981; Szeicz 1997), and has been the focus of much timber extraction activity in the past.

Despite a long history of European exploration along the southern Chilean coast dating from the voyage of Ferdinand Magellan in AD 1520, some of the first detailed descriptions of the forests of the region around the island of Chiloe and the Chonos Archipelago come from Charles Darwin’s observations in AD 1834 during the voyage of the Beagle. In his accounts, Darwin emphasized the rugged and impenetrable nature of the region: 

...the wood is so intricate that a person who has never seen it will not be able to imagine such a confused mass of dead and dying trunks. I am sure oftentimes for quarter of an hour our feet never touched the ground, being generally from 10 to 20 feet above it; at other times, like foxes, one after the other we crept on our hands and knees under the rotten trunks... We ultimately gave up the ascent in despair. (Keynes 2001: p.273)

Darwin also noted the absence of Native American populations in the islands, despite there being ample food sources from marine (particularly fur seals, Arctocephalus australis) and terrestrial (southern limit of the potato, Solanum tuberosum ssp. tuberosum, and the ‘avellano’ nut, Gevuina avellana) environments, suggesting that the population may have already been displaced by disease and exploitation under Spanish colonial rule. From the limited archaeological evidence available, occupation of the channel islands by Native Americans (Chono or Wayteca), whose subsistence was based primarily on fishing and coastal resource exploitation, appears to be relatively late in southern South American prehistory with archaeological remains dating to no earlier than 5100 BP in the region (Cárdenas et al. 1993). Earlier evidence of human occupation may have been destroyed by rising sea levels as Native American impact is likely to have been focused on the coastal margins with only occasional excursions to the interior of the islands.

Human settlement remains very sparse in the island region today, and clearance for grazing or agriculture is non-existent. Some areas, however, have apparently been burned for the purposes of timber extraction over approximately the last 150 years (Donoso & Lara 1995). The result is a patchy landscape, with extensive areas of open Pilgerodendron uviferum – Tepualia stipularis woodland, and an abundance of dead Pilgerodendron stems. This is particularly evident in the lowlands of the islands in the northern Chonos that lie closest to the permanent fishing settlement of Melinka in the Guaytecas Islands. In the southern Chonos, where the islands are generally higher and steeper, the vegetation is more continuous and is reminiscent of the descriptions given by Darwin approximately 170 years ago.

**Study site: Lake Facil**

The lake coring site selected for the present study lies at the north-western margin of the Chonos Archipelago.

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**Fig. 2.** Lake Facil surrounded by disturbed coastal vegetation dominated by Pilgerodendron uviferum, Nothofagus betuloides and Tepualia stipularis. Donatia fascicularis, Astelia pumila and Sphagnum moss are common in the open foreground areas.
Lake Facil (44°19′30″S, 74°17′00″W, Fig. 2) is a small (1.2 ha, 3 m deep) ombrotrophic lake, at an altitude of 10 m a.s.l. on the northern slopes of a small island (Isla Chacona) in the north-western Chonos Archipelago, some 120 km north-west from Puerto Aysen. The waterlogged margins of Lake Facil are dominated by Pilgerodendron uviferum, Nothofagus betuloides and Tepualia stipularis. Donatia fascicularis, Astelia pumila and Sphagnum moss are common in the open wet areas. Potamogeton sp. is also found around the margins of the lake. Extensive patches of dead Pilgerodendron uviferum are found across the island, some showing evidence of fire scars and ring-barking, which is presumably associated with the timber extraction practices of the late 1800s and early 1900s.

Methods

Fieldwork was carried out in March–April 1996. A core of the uppermost sediment was obtained from the centre of the basin using a clear plastic piston corer. This method allows for undisturbed recovery of the mud–water interface. The core was sectioned in contiguous 1-cm intervals on-site. In the lab the core was analysed for loss-on-ignition (%LOI) by combusting dried sediment at 500°C for 5 h. Magnetic susceptibility was measured using a Sapphire Instruments S12B meter.

Chronological control of the record was provided using a combination of 14C and 210Pb dating. Conventional 14C dates were obtained on two bulk organic sediment samples and one accelerator mass spectrometry 14C from Nothofagus leaves in the lower half of the core. These dates were calibrated using the CALIB4.2 program (Stuiver et al. 1998). Fourteen sediment samples from the upper 25 cm of the core were dried overnight at 75°C, then finely ground and analysed for 210Pb by Flett Research (Winnipeg, Manitoba). Sedimentation rates were derived from the analysis of 210Pb activity using the constant rate of supply (CRS) model (Appleby & Oldfield 1983).

Pollen analysis followed standard procedures (Faegri & Iversen 1989). Pollen counts are expressed as percentages of the total pollen sum (excluding pollen of aquatic vascular plants and spores), which reaches a minimum of 200 in all samples. Macroscopic charcoal (particles >150 μm) was analysed to investigate the occurrence of fires at this site. This technique of charcoal analysis provides a better record of local fire activity than microscopic or pollen-slide charcoal enumeration (Clark & Royall 1995; Millsap & Whitlock 1995), because the large particles do not tend to be carried long distances by atmospheric transport. Principal components analysis (PCA) was performed only with major taxa whose percentage values exceeded 2% at least once. Principal components analysis is used

![Fig. 3. Sediment analysis of Lake Facil core including lithology, magnetic susceptibility and loss-on ignition (LOI). MS, magnetic susceptibility.](image)

![Fig. 4. Results of radiometric dating of Lake Facil sediments. (a) 210Pb activity in samples from the upper 26 cm of the core. (b) Age–depth curve based on a combination of 210Pb results (●) and 14C dating (error bars). Preferred age–depth model shown with solid line.](image)
to reduce the pollen and spore data to a 2-D plot and the resulting data set is displayed as a biplot for samples and taxa (Birks & Gordon 1985). All numerical analyses, including PCA, have been implemented within PSIMPOLL, a C program for plotting pollen data, which was developed by Bennett (1994).

Dendrochronological sampling of 20 living *Pilgerodendron uviferum* trees that were double cored provided a well-replicated chronology. Ring-width chronologies have been being produced using a conservative negative exponential/straight line detrending standardization method (Fritts 1976; Cook & Kairiukstis 1990; Szeicz 1997). Cores and sections from living *Pilgerodendron* next to Lake Facil provide a record of stand dynamics in recent centuries, with a focus on the recent burning/dieback.

**RESULTS**

The mud–water interface sediment core was composed entirely of dark organic gyttja (Fig. 3). The magnetic susceptibility of the core was consistently low except for two peaks at 56–57 cm and 71–71 cm. Low %LOI values at 56–57 cm suggested that this may be associated with a catchment erosional event or a tephra deposition event. The latter is more likely, because Haberle and Lumley (1998) showed that a tephra (Fac-3) identified in the upper 1-m of a separate Livingstone core taken from Lake Facil was derived from Hudson Volcano.

In the upper part of the core, $^{210}$Pb activity dropped to background levels at a depth of 23 cm (Fig. 4a). Constant rate of supply modelling indicates that dry sediment accumulation was relatively constant at 0.006 g cm$^{-2}$ year$^{-1}$, giving a sedimentation rate of 0.144 cm year$^{-1}$. Radiocarbon dating indicates that the 75-cm-deep core extends back to approximately 2000 BP (Fig. 4b). The bulk organic sediment samples at 71–73 cm depth and 36–40 cm depth gave calibrated ages of AD 80 (1910 ± 80 14C BP, WAT-3090) and AD 660 (1350 ± 70 14C BP, WAT-3089), respectively. An AMS 14C sample from *Nothofagus* leaves extracted at 56–57 cm depth gave a calibrated age of AD 1160 (900 ± 50 14C BP, TO-6320).

The combined $^{210}$Pb results and 14C dating (Fig. 4b) showed that there are several possible age–depth models in the lower part of the core. The most reliable model was considered to be based on the AMS 14C age from a *Nothofagus* leaf and WAT-3090, as it was.

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**Fig. 5.** Pollen percentages of selected taxa and macroscopic charcoal concentrations from the Lake Facil core. Dates at left in calendar years AD are based on $^{210}$Pb (0–20 cm) and 14C (lower two dates). The 14C dates have been calibrated using CALIB 4.2 (Stuiver et al. 1998). Undiff., undifferentiated.
more likely that the younger bulk sediment sample WAT-3089 was erroneously old because of contamination of old carbon derived from the catchment (lower %LOI from 30 to 40 cm depth indicated increased allochthonous inputs). Based on this model the sedimentation rates in the lower part of the core are

0.014 cm year\(^{-1}\), increasing to 0.049 cm year\(^{-1}\) between 57 and 23 cm, and then to 0.144 cm year\(^{-1}\) in the upper part of the core. We use this combined age–depth model to interpret the pollen and charcoal results, emphasizing the upper portion of the core where dating was considered to be most reliable.

The pollen record from Lake Facil (Fig. 5) was dominated by *Nothofagus dombeyi*-type which includes all *Nothofagus* species found south of approximately 41°S in South America (Heusser 1971). *Nothofagus dombeyi*-type pollen maintained levels of 40–60% throughout the record, although this type tends to be over-represented in pollen records from the Northern Patagonian rain forest (Haberle & Bennett 2001).

*Pilgerodendron uviferum*-type and *Teucrium* pollen are subdominant and show greater fluctuations in percentage representation over the last 2000 years. The most significant declines in *Pilgerodendron uviferum*-type occur at approximately 40–30 cm depth (AD 1500–1700) and in the uppermost 10 cm (AD 1920 to present). At the same levels in the core, *Teucrium* pollen shows significant percentage increases. These changes follow major peaks in macroscopic charcoal at 45–40 cm depth (AD 1400–1500) and 17–10 cm depth (AD 1880–1920). The shrub and herb pollen taxa are poorly represented throughout the record, with the exception of Cyperaceae which tends to increase from approximately 40 cm (AD 1500) depth to the top of the core.

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**Fig. 6.** Principal components analysis (PCA) of the lake core pollen sequence only using pollen taxa representing 2% or greater of the total pollen sum. Samples shown as numbers (depth cm) and taxa shown as vectors. Axis 1 contrasts the dominant tree taxa with herbaceous taxa.

**Fig. 7.** First two axes of the principal components analysis (PCA) for Lake Facil pollen data plotted against macroscopic charcoal shows the negative shift in PCA axis 1 after the major fire episode of AD 1400–1500 ($r^2 = 0.49$ for PCA axis 1 and macroscopic charcoal). The *Pilgerodendron* growth trends (ring-width index) at Lake Facil since AD 1464 are at the right, showing the link between increased radial growth between 1896 and AD 1901 and fire in the early 1890s.
The first component (axis 1) of the PCA (Fig. 6) was defined by high positive loadings for *Teucrium* and high negative loadings for Cyperaceae, *Misodendron* and *Weinmannia*, reflecting the difference between forested and herbaceous/disturbed forest conditions. The shift from positive to negative loadings along axis 1 occurs from 39 to 31 cm depth immediately after the period of peak macroscopic charcoal concentration (Fig. 7). The correlation coefficient between PCA axis 1 and macroscopic charcoal concentration was high \( r^2 = 0.49 \). The second component (axis 2) was defined by high positive loadings for Cyperaceae and high negative loadings for *Pilgerodendron*, possibly reflecting changes in lake margin vegetation. The radial growth record of living *Pilgerodendron* at this site spanning the period from AD 1460–1998 (Fig. 7) showed that a major increase in ring-widths took place in 1896–1901 coincident with the rise in charcoal between 17 and 10 cm depth (AD 1880–1920).

**DISCUSSION**

The fine-resolution palaeoecological–dendrochronological analyses of the Lake Facil catchment, summarized in Figs 5–7, provide a clear record of vegetation change over the last 2000 BP and allow us to address several questions in the Aysén region of southern Chile concerning vegetation dynamics at time scales much longer than can be examined using neoecological or dendroecological data alone.

First, are changes due to European colonization discernible in records from unsettled regions such as the Chonos Archipelago? There are many reports of widespread forest burning by Europeans in this area during the 19th and 20th centuries, primarily for the purposes of extracting *Pilgerodendron* for the timber trade (Silva 1983; Innes 1992; Donoso & Lara 1995; Veblen & Alaback 1996). It has been presumed that the extensive areas of open *Pilgerodendron uviferum* – *Teucrium stipularis* woodland, with an abundance of dead *Pilgerodendron* stems, resulted from this relatively recent anthropogenic disturbance (Innes 1992). The palaeoecological and dendroecological results from Lake Facil suggest that the episodes of burning that took place within the last 600 years were a major factor in the dieback of *Pilgerodendron* and the opening up of the forest canopy (Figs 5–7). By incorporating the radial growth record from living trees at this site with the palaeoecological record it is clear that the most recent fire period recorded between AD 1880–1920 in the macroscopic charcoal record is compatible with a fire, or series of fires, which opened up the forest canopy and increased soil nutrient levels in the mid-1890s, resulting in a major growth increase in surviving trees. In contrast to the Lake Facil record, the pollen and charcoal records from the heavily settled and cleared pasturelands around Coyhaique show much more abrupt changes in the vegetation. Before clearance in the early 20th century, for example, the forests of this region were subject to very occasional natural fires and possibly tectonic disturbances (Szeicz et al. 1998). Following the arrival of European settlers, however, massive fires and livestock grazing altered the landscape dramatically, rapidly changed species dominance in the remnant *Nothofagus* forest and provided an opportunity for exotic species to invade open areas. There is no evidence for the introduction of exotic species to the Lake Facil catchment as yet; however, the trend towards a more open landscape over 100 years may have increased the susceptibility of the archipelago to future invasion of exotic plants. These records suggest that the susceptibility of island floras to invasion by exotic plants may persist well after a major disturbance event, such as the extensive burning of the late 19th century, has occurred.

Second, what is the role of natural disturbance on vegetation dynamics? Results from Lake Facil and
other sites including Lake Miranda (Haberle et al. 2000) and Lake Venus (Szeicz et al. 1998) suggest that fires have occurred in the period before European colonization. The most prominent fire episode to be recorded in the Lake Facil record occurred between about AD 1400–1500 and may have resulted from burning by Chono Native Americans, or from natural ignition sources such as lightning. The resultant decline in Pilgerodendron uviferum and expansion of Tepualia is not sustained because Pilgerodendron uviferum recovers in the absence of further major burning until increased burning after the arrival of Europeans in the late 19th century results once again in population declines. However, there is a sustained increase in open vegetation communities in the catchment after the AD 1400–1500 fire episode from which the forest community does not appear to have recovered at present (Figs 6,7). Rapid and catastrophic declines in Pilgerodendron have also been noted at sites on the Taitao Peninsula at around 2650 bp, possibly as the direct or indirect result of volcanic activity (Lumley 1993) or a period of regional aridification (Van Geel et al. 1996).

In contrast to these records, the Pilgerodendron tree-ring analysis and pollen results from the southern Chonos Archipelago site of Lake Miranda, which span the last 400 years, show a recent expansion of Pilgerodendron at the northern and eastern margins of this site. This expansion might be either a response to periodic tectonic-induced water table changes, or might be part of a long-term trend in gymnosperm growth around a shallowing lake margin (Haberle et al. 2000). Fluctuations in pollen taxa percentages over this time suggest that periodic disturbance still plays an important part in local vegetation dynamics, despite the lack of erosion or tephra events evident in the lake sediment record. Indeed, the decline of shade-intolerant trees such as Weimannia and Podocarpus within a Nothofagus-rich forest community and an increased presence of Pilgerodendron and Poaceae (likely Chusquea bamboo), that began more than 2000 bp, may have been due more to catchment processes such as a change in the disturbance regime resulting in the development of waterlogged soils, rather than to an episode of climate change. Pilgerodendron uviferum appears to be particularly susceptible to fire, eruption events and water table fluctuations and may represent an important indicator of environments that have been sheltered from frequent (decadal to century scale) major disturbance during the late Holocene.

Finally, have climatic changes over the past one to two millennia affected vegetation dynamics in this region? Analysis of Pilgerodendron uviferum tree-ring samples from the Lake Valentin and Trailtop sites in the southern Chonos region has led to the development of a set of temperature-sensitive chronologies for the study region (Fig. 8, Szeicz 1997). Most prominent is a marked increase in ring widths since the 1940s. A chronology from lowland Pilgerodendron at Lake Miranda is very similar to that from Lake Facil and those from sites in Chiloé to the north (Roig 1991), and is considered to contain a strong regional moisture signal (Szeicz 1997). In order to address this question, we first need to develop reliable records of climatic change. Results of dendrochronological sampling in this project (Fig. 6, Szeicz 1997) and many other studies (Boninsegna 1992; Villalba & Veblen 1998; Lara et al. 2000) have begun to improve our understanding of recent climatic change in south-western South America. The close correspondence between Pilgerodendron growth trends at Lake Facil and Lake Miranda (Szeicz 1997) and trends in precipitation-sensitive chronologies from Chiloé (Roig 1991) indicates that there is potential to develop a long-term record of precipitation or soil moisture from low and mid-elevation sites in coastal areas of southern Chile. Dendrochronological analyses at high elevation sites (Fig. 6, Szeicz 1997) suggest that in areas close to the coast with very high levels of precipitation and weakly developed seasonality, the growth of trees at the upper treeline is limited primarily by temperature. These trees are therefore suitable for the development of long-term proxy temperature records. Climatically sensitive chronologies developed in this region fill a major geographical gap between those from farther south (Boninsegna et al. 1989) and from farther north (Roig 1991; Lara et al. 2000). Additional long-term climatic information can be derived from records of glacial activity (Warren & Rivera 1994; Winchester & Harrison 1994), although temporal resolution is generally decadal at best, and the relationships between climate and glacial advance/retreat are not always clear. An improved understanding of late Holocene climatic variation should aid in the interpretation of palynological and dendroecological records of vegetation dynamics at both low-elevation and high-elevation sites. Climate may have a direct impact on vegetation through its influence on establishment and mortality patterns (Szeicz & MacDonald 1995) and an indirect impact through its influence on disturbance regimes. Fire frequency, for example, is highly dependent on both long and short-term climatic conditions (Johnson & Larsen 1991; Kitzberger et al. 1997).

Conclusions

Our results indicate that an integrative multiproxy approach can be used successfully in investigations of late Holocene vegetation dynamics in south-western South America at decadal to century timescales. The present mosaic of vegetation types in this region is a function of environmental changes at millennial timescales, more recent natural and anthropogenic disturbances, and possibly short-term climatic variations. Of
particular interest is the spatiotemporal distribution of *Pilgerodendron uviferum* dieback/burning in the Taitao-Chonos region. The development of more detailed palaeoecological and dendroecological records should address the question of whether the disturbance events in different areas were synchronous, time-transgressive across the region, or randomly distributed.

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