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A blast from the past: A dendroecological reconstruction of forest windthrow, North Island, New Zealand

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ABSTRACT: Strong winds are a major natural disturbance agent in New Zealand's indigenous forests, and a suite of native tree species utilize major forest disturbance events for recruitment. Cohorts of several conifer and beech species such as kaikawaka (*Libocedrus bidwillii*) and mountain beech (*Nothofagus solandri* var *cliffortioides*) appear to mark past storm events temporally and spatially. This paper presents the methodology and preliminary results from a research project which aims to identify windthrow-initiated cohorts and, by determining their disturbance histories as accurately as possible, develop a fine resolution record of past storm events. The relationship between recruitment, suppression, and release was investigated within 400 m^2 plots at Whakapapanui, Mt Ruapehu, and Deadman's Track, Ruahine Range, central North Island, New Zealand. A site of known storm date (Cyclone Bernie AD 1982) was studied at Whakapapanui in order to assess interspecies differences between storm damage and tree ring response. The results provide a clear indication of storm events, with suppression and release being temporally coincident with windthrow, and storms initiating periods of recruitment.

1 INTRODUCTION

Strong winds, often of extra-tropical origin, are one of the dominant agents of natural forest disturbance in the indigenous forests of North Island, New Zealand. Major cyclones have a recurrence interval of c. 10 years and have a key role in modifying North Island forest structure and pattern (Shaw 1983). Recent storm events, such as Cyclone Bernie (AD 1982), caused widespread catastrophic windthrow, with complete canopy destruction in some areas (Shaw 1983, Hosking & Hutcheson 1998, Steel 1989).

A suite of native tree species utilize major forest disturbance events for recruitment, and cohorts appear to temporally and spatially mark past storm events. The relationship between disturbance and recruitment has been well documented for kaikawaka (*Libocedrus bidwillii*) and species of southern beech (*Nothofagus* spp.) (Norton et al. 1988, Ogden et al. 1996, Stewart & Veblen 1982). Montane forests of central North Island tend to be dominated by *Nothofagus* species, and the conifers *Libocedrus bidwillii*, mountain toatoa (*Phyllocladus aspleniifolius*) and Hall's totara (*Podocarpus hallii*) (Elder 1965, Ogden et al. 1993, Rogers 1989, Steel 1989).

Strong winds are likely to be the primary disturbance agent in areas not prone to fire, flooding, or mass movement, for example elevated high rainfall areas with gentle slopes. In these areas past storm events initiating tree cohorts can be pinpointed dendrochronologically, particularly where evidence of windthrow still exists. Potential exists for the reconstruction of past disturbance history where these tree cohorts are dominated by species suitable for dendrochronological study.

Within New Zealand, dendrochronological techniques have successfully dated events such as earthquakes (Vittoz et al. 2001, Wells et al. 1998) and insect epidemics (Norton & Ogden 1987). Storm events have been approximately dated using tree rings (Grant 1963, Jane & Green 1983, Ogden 1971), and several periods of increased storm frequency have been postulated (Grant 1985). However, no fine resolution record of past storm events has been reconstructed within New Zealand forests. Internationally, the longest disturbance histories have been reconstructed for areas subject to fire (Hemstrom & Franklin 1982), but histories for storm dominated regions in the order of 300 years have been achieved (Abrams & Orwig 1996). Successful methodologies focus on the analysis of radial growth patterns (Abrams & Orwig 1996, Nowacki & Abrams 1997, Payette et al. 1990), and the correlation of recruitment and release dates (Lorimer 1980, Rebertus et al. 1997), to identify and correctly date canopy disturbance events.

The aim of this study was to develop a methodology for the reconstruction of forest windthrow history in North Island indigenous forests. A site of known storm date was included in order to test the method, and to investigate any potential delay period or interspecies differences, between storm events and tree ring response. This paper outlines the methodology, and the preliminary results from the first two sites.

2 STUDY AREA

The Whakapapanui site (WHAK) is on the northern slopes of Mount Ruapehu at 1020 m (Fig. 1). The vegetation is dominated by *Nothofagus solandri* var *cliffortioides*, with *Libocedrus*, *Phyllocladus*, and *Podocarpus* as common associates. The area has been subject to several major disturbance events, including periods of stand dieback in the 1740's, c. 1904, and the 1960's (Ogden et al. 1993), and windthrow of stands by Cyclone Bernie in 1982 (Steel 1989).

The Deadman's Track site (DEAD) is in the Ruahine Range at 1200 m, approximately 90 kilometres south east of WHAK. *Libocedrus* is the dominant component of the vegetation, and is found in association with *Phyllocladus* and *Halocarpus biformis*. The disturbance history of this site is unknown.

3 METHODS

3.1 *Site selection*

Topographical maps on a scale of 1:50 000 were overlaid with vegetation maps to select gently sloping elevated areas dominated by *Nothofagus* or *Libocedrus*. Each area was then searched on foot to locate a site with one or more cohorts of the study species. Plots were preferentially located in sites with the following characteristics;
(1) direct evidence of past windthrow in the form of pit and mound topography or uprooted trees,
(2) more than one of the selected species present;
(3) tree establishment on surfaces created by the fall of the previous cohort.

One 20 x 20 m plot (0.04-ha) was laid out along the contours at each site.

3.2 *Canopy and emergent trees*

All canopy or emergent trees >5 cm diameter at 1 m height had the following recorded; species, tier (canopy or emergent), substrate (ground, mound, pit, stump, root plate, or log), and suitability for coring (presence or absence of visible rot). A tree was defined as in the canopy if its crown received direct overhead light, without regard to tree height. All suitable trees within the plot were cored at c. 1 m height. This core height conforms to that used by Xiong (1995). If >30 suitable trees occurred within the plot, the size frequency distribution of trees was plotted, and cores taken from trees within each size-class frequency peak.

3.3 *Woody debris*

All logs >10 cm in diameter and 2 m in length were assigned consecutive letters and the following recorded; species (if known), length, fall type (uproot, snap, branch fall, unknown), fall direction (compass bearing), and whether the log was above or below any other recorded fallen material (to aid relative dating). Cross-sections were sawed from all suitable material within the plot.

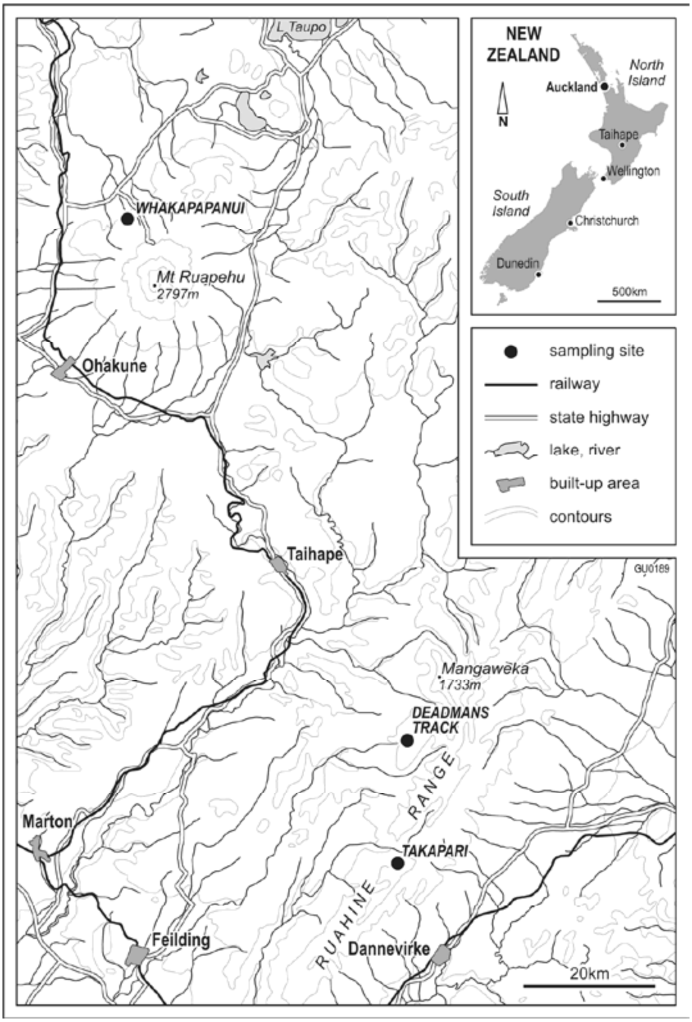

Figure 1. Location of study sites mentioned in the text

3.4 *Stand structure*

To investigate the degree to which stand structure within the plot represented the surrounding area, additional tree diameters at 1 m height were taken outside the plot until a minimum of 100 trees had been measured.

3.5 *Sample preparation and data analysis*

Cores and cross-section surfaces were regarded as suitable for measurement when cell boundaries were clearly visible under a binocular microscope (Stokes & Smiley 1996). Tree ring widths were measured to the nearest 0.01 mm and recorded and stored using Dendro for Windows (Tyers 1999).

Where cores failed to intercept pith, tree age was estimated using methods described by Norton et al. (1987). Years to grow to coring height was compensated for by adding 65 years for *Libocedrus* (Norton 1983), 71 years for *Halocarpus* (Wardle 1963), 29 years for *Phyllocladus* growing on raised surfaces (Barker & Kirkpatrick 1994), and 54 years for *Phyllocladus* growing on the ground (Barker & Kirkpatrick 1994). *Nothofagus* seedlings can attain one metre in height one to two years after germination (Wardle 1984). No additional years were therefore added to *Nothofagus* ages. Ages for *Libocedrus* not cored were estimated using the age-diameter relationship determined by Horrocks (1994).

Ring-width sequences in tree-cores and radii from cross sections were cross matched and a site chronology made using standard procedures (Stokes & Smiley 1996). Site chronologies were cross-checked to other *Libocedrus* chronologies from the central North Island (Xiong 1995).

Calendrically dated ring-width series were analysed for the presence of release and suppression events using a method described by Nowacki and Abrams (1997). Sequential five and ten year running means were compared using the formula:

$$\%GC = [(M_2 - M_1)/M_1] \times 100 \qquad (1)$$

where %GC = percentage growth change between preceding and subsequent five or 10 year means, M_1 = preceding five or 10 year mean, and M_2 = subsequent five or 10 year mean. A $\%GC \geq 100$ was regarded as a release event and $\%GC \leq -50$ as a suppression event (Fenwick 2003). Using the same criteria, the 10 year running mean analysis was used to pinpoint event years recorded in the Takapari chronology of Xiong (1995). The Takapari chronology was built using *Libocedrus* at a site approximately 20 kilometres to the south of DEAD.

4 RESULTS

4.1 *Tree ring dating*

At WHAK the ring-width series from one log (Log A) was calendar dated 1733-1978. At DEAD one log and two living trees were calendar dated 1632-1902, 1764-2001, and 1683-2002 respectively. The ring-series for all calendar dated material cross-matched between DEAD, WHAK, and the Takapari and Hauhungatahi chronologies constructed by Xiong (1995).

4.2 *Description of the forest at the Whakapapanui Cyclone Bernie site*

Twenty tree falls were located within the plot at WHAK. Ten trees were uprooted, five were branch falls, three were bole snapped, and two were classified as unknown. 14 of the trees fell between 245 and 330˚, and three fell at a bearing of 280˚. Uprooted *Libocedrus* had a mean diameter of 34.4 ±5.8 cm and a mean height of 9.2 ±5.1 m (± standard error). Only two *Nothofagus* were uprooted, with heights of 6.1 and 13.1 m, and diameters of 15 and 55 cm respectively.

A tree mean was constructed from WHAK Log A. This cross-matched with a *Libocedrus* chronology from Hauhungatahi (Xiong 1995) and the chronology constructed from DEAD, for the period 1733-1978. Three additional rings were found on the outer circumference near one of the measured radii, dating the last ring to 1981. As Cyclone Bernie occurred in March 1982, the 1981-1982 season ring would be the expected ring if the cyclone was responsible for this tree fall. Ages of *Nothofagus* growing on fallen logs, and the relative vertical positions of logs, provided seven minimum log ages. Thus log ages were obtained for eight of the twenty logs. Three dated to or before 1981, four to or before 1986, and only one definitely before Cyclone Bernie (Log G, 1931). The remaining 12 logs were unable to be dated, either due to significant rot, or the lack of dateable trees growing upon them.

The *Nothofagus* size frequency distribution within the WHAK plot was strongly unimodal with 50% of individuals in the 5-9.9 cm size class (Fig. 2 a). The size frequency distribution for *Libocedrus* was weakly bimodal with peaks in the 10-14.9 and 20-24.9 cm size classes. Sampling of tree diameters in the surrounding area indicated that the within plot tree size distributions were representative of the surrounding area for both species (Fig. 2 b).

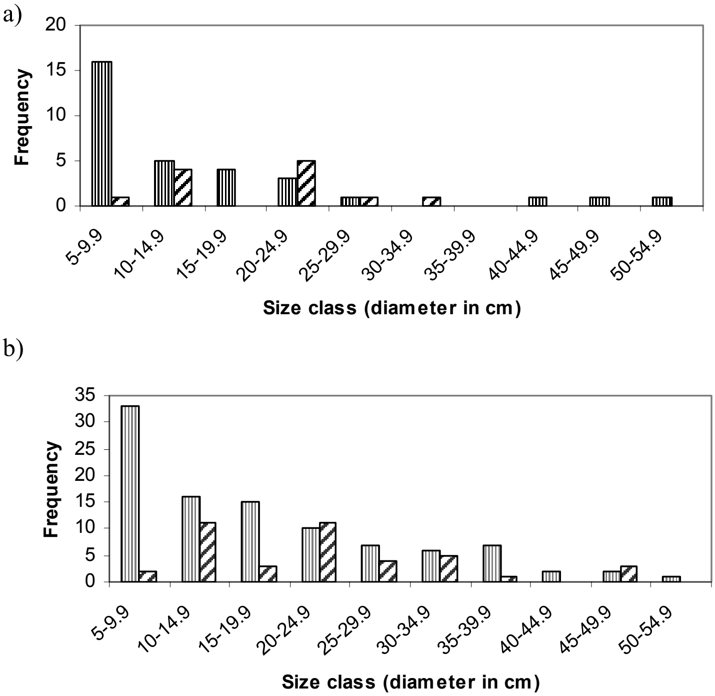

Figure 2. Size f Nothofagus solandri var cliffortioides Libocedrus bidwillii *Nothofagus solandri* var *cliffortioides* and *Libocedrus bidwillii*, Whakapapanui, Mount Ruapehu

Trees at WHAK recruited prior to 1982 responded to Cyclone Bernie in one of four ways; suppression, suppression followed by release, resprouting, or no noticeable response. A *Nothofagus* that was partly uprooted by Cyclone Bernie and knocked into the subcanopy, initially exhibited suppression, but regained the canopy by vigorously resprouting (Fig. 3). A *Libocedrus*, attached to the same root plate, was knocked into the subcanopy resulting in a reduction of mean ring width from 0.17 ±0.02 to 0.09 ±0.008 mm (±standard error). Cyclone Bernie also initiated a period of *Nothofagus* recruitment and epicormic shoot production. Recruited individuals exhibited rapid initial growth.

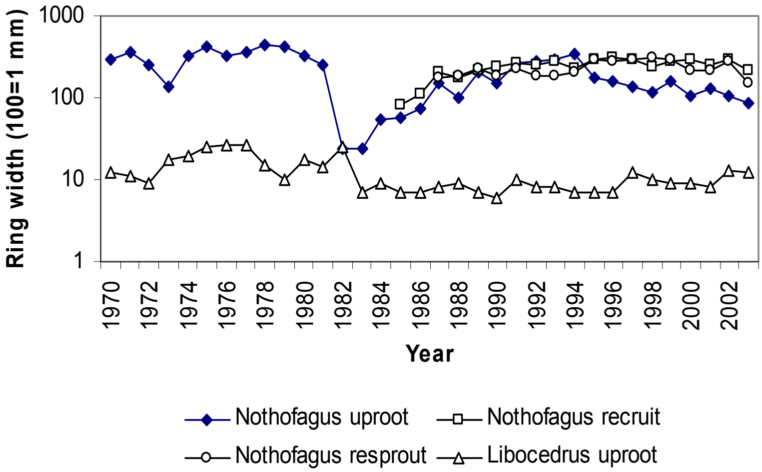

Figure 3. Examples of *Nothofagus* tree ring response to Cyclone Bernie (AD 1982)

Table 1 Release and suppression events detected using 5 and 10 year running means

Sample	Period	Date	5yrm %GC	Date	10yrm %GC	Date of Takapari event (% of trees)
WHAK	1733-1978	1808	-55.1			
Log A		1814	110.4	1815	132.4	
		1827	-50.1	1828	-50.4	
				1898	-51.6	
		1937	-50.8			
DEAD	1632-1902	1639	116.4			
Log A		1651	-54.0	1651	-50.9	
		1664	114.0	1663	100.7	
		1666*	228.6	1666*	202.3	1666 14.3%
		1717	105.7			
		1881	-52.4			1881 9.5%
DEAD	1764-2001	1903	-52.5	1903	-54.0	1903 28.6%
Tree 1		1939	100.7			
DEAD	1683-2002	1778	-52.3	1776	-50.1	
Tree 2						

* mid 1660s regarded as one event, two years are shown to indicate progressive strengthening of growth change

4.3 *Suppression and release events*

Suppression and release events were detected using both a five year and ten year running mean (Table 1). A ten year running mean detected 54% of events detected by the five year running mean, but the ten year running mean also detected events not identified by the five year running mean. No calendar dated cores or log cross sections shared common events. However, if the suppression threshold was lowered to %GC≤-40 both DEAD Log A and DEAD Tree 1, show suppression in AD 1881. Event years in the mid 1660s, 1881, and 1903 correlated with suppression or release years for the Takapari chronology.

Recruitment at WHAK was periodic (Fig. 4). All *Libocedrus* recruitment within the WHAK plot occurred between 1740 and 1839, with a possible recruitment peak occurring in the 1820s. Two suppressions and the release event detected for Log A occurred between 1800 and 1829. All *Nothofagus* were recruited since 1900, with a minor recruitment peak in the 1930s and a major peak in the 1980s. The only *Libocedrus* suppression event detected post 1900 occurred in 1937.

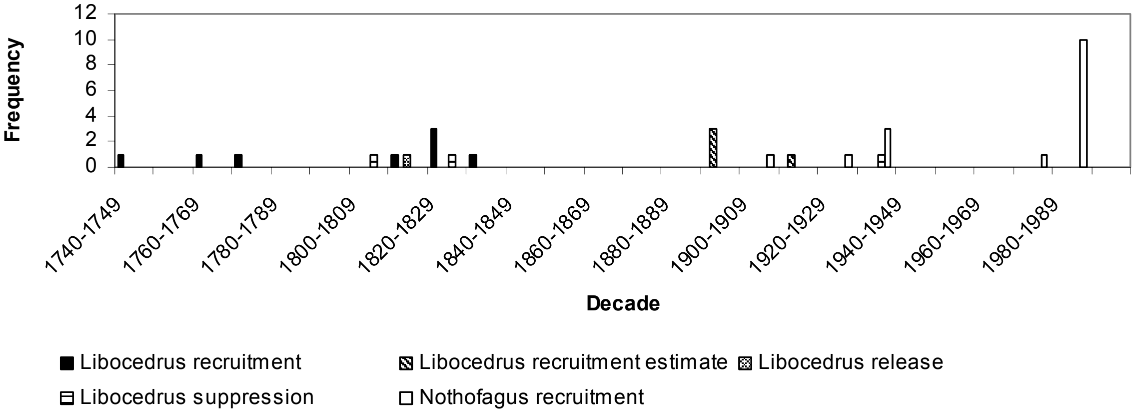

Figure 4. Frequency of recruitment, release, and suppression events for *Libocedrus* and *Nothofagus*, Whakapapanui, Mount Ruapehu

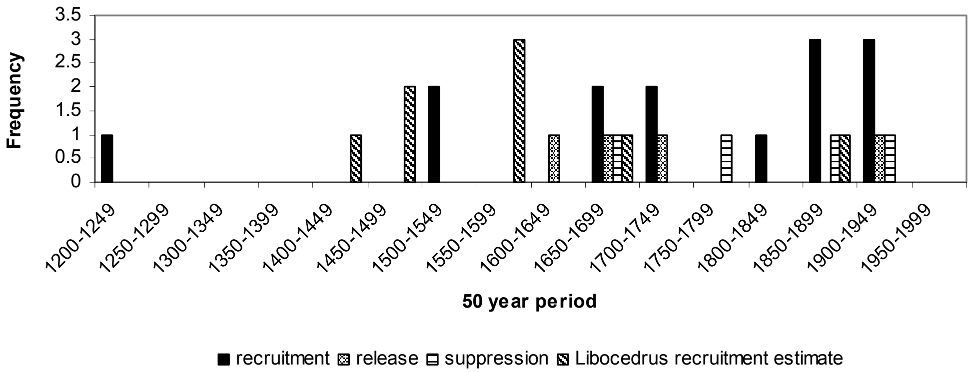

Figure 5. Frequency of recruitment, release, and suppression events for *Halocarpus*, *Libocedrus*, and *Phyllocladus,* Deadmans Track, Ruahine Range

Few trees within the DEAD plot were successfully cored due to heart rot. Recruitment within the plot occurred sporadically from c. 1216 to 1933 (Fig. 5). Release and suppression events occurred throughout the time period analysed (1632 to 2002). The event years in common for DEAD and Takapari, 1666, 1881, and 1903, coincided with three of the four possible recruitment peaks.

5 DISCUSSION

The interpretation of the WHAK stand structure from size frequency alone would suggest that *Nothofagus* has an all-aged distribution, and *Libocedrus* has a distribution with two main age peaks (Fig. 2 a,b). Age frequency distributions however reveal distinct recruitment peaks for both species, which have significantly different age – diameter relationships. The results highlight the danger of relying on size frequency distributions alone for the interpretation of stand disturbance history, and the differential growth rates for canopy species within a stand (Ogden 1985b).

At WHAK no cored trees were older than 260 years, despite *Libocedrus* having a possible life-span of 800 – 1000 years (Ogden 1985a) and *Nothofagus* of 300 years (Wardle 1984). This suggests that the plot area was subject to a major disturbance prior to the mid 1700s. Ogden et al. (1993) discuss a dieback event that affected the area in the 1740s, and c. 1740 is also postulated as the date for a major regional storm event (Ogden et al. in review). The 1810 – 1840 peak in *Libocedrus* recruitment, coincident with suppression and release, needs further investigation as it is not additionally supported by other known studies. A distinct peak in *Nothofagus* recruitment occurred following Cyclone Bernie. The older cohort, established between 1900 and 1939, may be linked to recruitment following the 1904 dieback event (Ogden et al. 1993). At DEAD, no distinct periodicity in recruitment was evident and it is possible that no catastrophic event has occurred in this area during the period 1200 to 2003.

At WHAK, Cyclone Bernie initiated a period of increased *Nothofagus* recruitment from 1982 until 1988. *Nothofagus* gained dominance of the canopy through epicormic shoot production from partly uprooted trees, and the recruitment of new canopy trees. The rapid initial growth of the cored saplings indicates that they germinated after the disturbance event, rather than being released from suppression. *Nothofagus* germination and epicormic shoot production has been recorded only nine months after a storm in the Tararua Range (Thomson 1936). *Nothofagus* recruitment peaks in areas of past windthrow are likely to occur in the decade following a storm event, and the oldest trees in the cohort may have germinated within a year of a storm. The ring-width series from the uprooted *Nothofagus* suggests that cores from surviving uprooted trees have the potential to date storm events to the exact year.

Libocedrus suppression, such as that caused by non-fatal uprooting, can also indicate the timing of past storm events. The problem with dating storms using suppressed *Libocedrus* lies in the difficulty in cross-matching severely suppressed ring-width series (Cherubini et al. 1996).

Tree release exhibits more gradual change in ring width than suppression (Cherubini et al. 1996), thus determining the exact year in which release occurred can also be problematic. Other studies have found release events to occur one to five years (Cherubini et al. 1996), three years (Dynesius & Jonsson 1991), and five to ten years (Foster 1988b) after known disturbance events. With successful cross-matching *Libocedrus* releases may date windthrow events to within a few years of their occurrence.

As successive disturbances cause the death of the most vulnerable, usually the oldest, trees, the information contained within the rings of those individuals begins to literally decay. Although *Libocedrus* are typically long lived, old trees are often hollow. Thus, the constructed release and suppression history for a site may cover only a fraction of the time since the oldest trees were recruited. Old log falls with minimal wood to ground contact may substantially increase the period for which disturbance can be reconstructed, for example DEAD Log A extended the chronology back in time by 51 years to 1632.

In dense canopied stands dominated by *Libocedrus*, a long-lived light demanding species, and *Nothofagus solandri* var *cliffortioides*, a species capable of rapid recruitment following disturbance, the conditions for accurate disturbance history reconstruction are well met. A dense canopy, in combination with rapid recruitment in disturbed areas, ensures that recruitment is periodic, and temporally tied to canopy disturbance events (Lorimer & Frelich 1989). Thus at WHAK, the *Nothofagus* recruitment peak initiated by Cyclone Bernie was less than 10 years in duration. This rapid colonisation of gaps also shortens the temporal window within which other light demanding species can recruit. In contrast, at DEAD the canopy is more open and dominated by slow growing species. Following a disturbance event, canopy gaps are likely to provide recruitment sites for several decades, and this is further exacerbated by recruitment on stumps that protrude above the scrub layer.

Increment cores from partly uprooted trees and trees established on windthrow surfaces, and cross sections from sound fallen material, have proven particularly valuable for both accurately dating storm events and increasing the potential length of the disturbance history. Further sampling needs to focus on collecting material from these three sources, in conjunction with cores from old sound trees. Comparison of release and suppression dates, with abrupt growth changes detected in other *Libocedrus* chronologies, has the potential to both verify events detected and indicate their regional significance. Regional correlation of abrupt growth changes and recruitment peaks may then provide further evidence for catastrophic storm events.

6 CONCLUSION

Central North Island forests are well suited for the reconstruction of forest windthrow history. Sites with the greatest potential with regard to both the length and accuracy of record are gently sloping elevated areas with a dense canopy of *Libocedrus* and *Nothofagus*. *Libocedrus* contributes to the length of the record and has proven dendrochronological potential, and the presence of fast growing *Nothofagus* ensures that recruitment peaks are closely tied to disturbance events. Further work needs to cover more sites, and focus on clarifying the relationship between storms and tree ring response, increasing sample depth and the quantity of calendar dated material, and investigating regional correlations of suppression, release, and recruitment events.

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