The impact of recent climate on fire danger levels in New Zealand

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Mt Cook Station – January 2008 fire

Abstract

Have changes in weather conditions impacted on the day-to-day management of fires in the New Zealand forest and rural landscape? The aim of this paper is to look at the impacts of climate over the past four to five decades and to use an assessment of past and present fire danger levels in New Zealand to assess what changes, if any, have occurred. The objective is to evaluate the question as to whether a change in the availability of fuel for combustion has taken place between the periods pre-2000 and 2000 to 2020. This study looked to analyse three key components of the daily outputs from the NZ Fire Danger Rating System (NZFDRS) for 15 representative fire weather stations located throughout New Zealand. These historical datasets range in length from 24 to 59 years. The results from this largely qualitative analysis show a trend that fuel availability for combustion prior to the year 2000 generally does not appear to have increased in the past 20 years. A general overall decrease in regional fire danger levels was seen for South Island stations, apart from a minimal increase for Queenstown. For the North Island, regional fire danger levels indicated no overall change, but a nominal increase for the Central North Island, Auckland, Whanganui and Northland. Despite these differences between regions and islands, this study shows that outputs from the NZFDRS indicate a marginal overall downward trend in fire danger levels across New Zealand for the past 20 years compared to the period prior to 2000.

Background

From a forest and rural fire standpoint, a fire danger rating system is the cornerstone for the day-to-day management of fire risk. These systems integrate the effects of weather and other fire environment factors, fuels and topography, to indicate the ease of ignition, rate of fire spread, difficulty of control and potential fire impact (Merrill & Alexander, 1987). Such systems provide a metric in the form of a fire danger rating or index(es) that can be used to support many daily operational decisions (such as suppression resource needs, alert levels, mobilisation and positioning), and longer-term strategic planning (e.g. defining burn prescriptions, justifying financial requirements, assessing future fire risk, etc). Fire danger rating is a mature science with almost a century of research, development and applications behind it.

All fire danger rating systems have the common objective of obtaining a relatively simple and comparable measure of fuel flammability from day-to-day (Chandler et al., 1983). In this study, the tool available to assist in providing the evidence to determine whether the levels of fuel availability for combustion in New Zealand have changed or not over the past 60 years is the NZ Fire Danger Rating System (NZFDRS) (Anderson, 2005; Alexander, 2008).

The NZFDRS is a New Zealand branded version of the Canadian Forest Fire Danger Rating System (CFFDRS) (Stocks et al., 1989). The CFFDRS, or at least its major subsystem (the Fire Weather Index (FWI) System), is extensively used both nationally and internationally to aid operational wildland fire decision-making (Taylor & Alexander, 2006). The CFFDRS has undergone considerable development since its introduction in Canada in 1971. Today it is one of the most comprehensive and scientifically-based rural fire land management decision support systems in the world. The CFFDRS enables fire managers to predict fire behaviour in most of their major fuel types and it is used extensively for fire protection planning and operations. The system is modular, computer and manually-based, and can be used in other countries by incorporating additional fuel types, provided the underpinning research is done to validate or extend the relationships between observed fuel moisture and the fire danger ratings (Wagner, 1988; Fogarty, et al., 1998; Anderson & Anderson, 2009). The FWI System was introduced into New Zealand in 1980 following a review of the main fire danger rating systems available around the world at that time (Valentine, 1978), and has undergone only minor modifications for change of latitude and season (Alexander, 1992; NRFA & NZFRI, 1993). This was followed by the adoption of the broader CFFDRS, including the empirical approach to developing a Fire Behavior Prediction (FBP) System using experimental burns (Anderson, 2005, 2009; Pearce et al., 2012). In the NZFDRS, this allows the fire danger indices from the FWI System (Figure 1) to be supported by fire danger classes for three fuel types, i.e. forest, grassland and scrubland (Anderson, 2005; Alexander, 2008).

Figure 1 illustrates that the components of the FWI subsystem of the NZFDRS. Calculation of the components is based on consecutive daily observations of temperature, relative humidity, wind speed and 24-hour rainfall (Van Wagner, 1987). The six standard components provide numerical ratings of relative potential for vegetation fires.

For the purposes of the fire climate trend analysis undertaken here, three components from the FWI System were chosen. The Build Up Index (BUI), Drought Code (DC) and Initial Spread Index (ISI) referred to in Figure 1 are defined as:

- The BUI is a numeric rating of the total amount of fuel available for combustion. It combines the Duff Moisture Code (DMC) and the DC
- The DC is a numeric rating of the average moisture content of deep, compact organic layers within the forest floor. This code is a useful indicator of seasonal drought effects on forest fuels and the amount of smouldering in deep duff layers and large logs
- The ISI is a numerical rating of the expected rate of fire spread. It combines the effects of wind and the Fine Fuel Moisture Code (FFMC) on rate of spread without the influence of variable quantities of fuel.

The ISI, BUI and FWI are each designed to represent some aspect of fire behaviour after ignition has taken place. The FFMC, DMC and DC, on the other hand, represent fuel moisture in different size classes of fuels and should therefore be related to the ease of ignition and availability for combustion. None of the FWI System components says anything about the presence or level of activity of fire-starting agents, in other words, fire ignition risk. Any comparison between actual fire occurrences and the FWI System combines both flammability (i.e. the relative ease with which a substance ignites and sustains combustion) and risk of ignition. The FWI System components can measure flammability but cannot account for ignition risk.

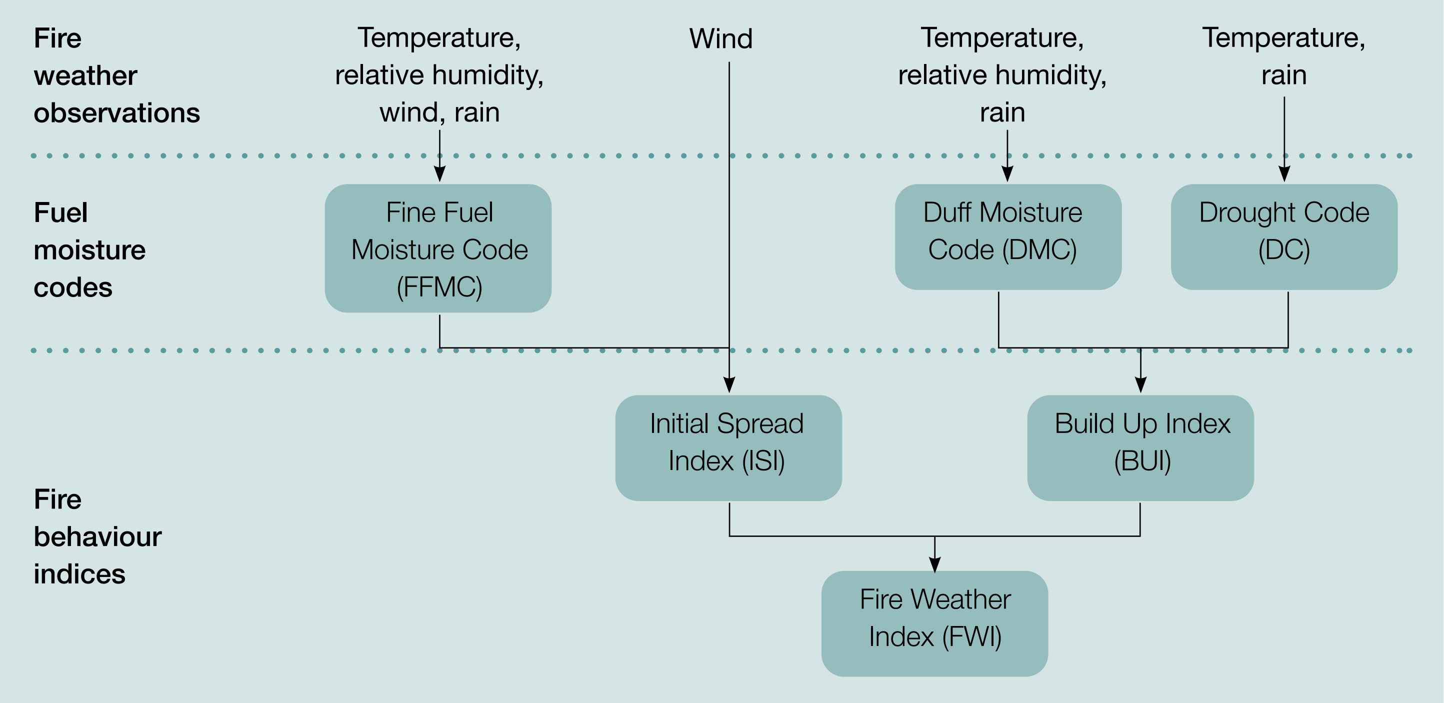

Figure 1: Inputs and outputs of the Fire Weather Index (FWI) System

Since a fire start depends most of all on the flammability of the fine surface fuel, the FFMC is the FWI System component most likely to compare well with vegetation fire occurrence. In addition, this paper has not considered whether there have been changes in fuel loadings in our forest and rural landscape over the past five decades.

The impacts of climate change on New Zealand and our environment is front and foremost in most people's minds. From a forest and rural fire perspective, is climate change already occurring, and has this had an impact on increasing periods of elevated fire danger, or is it leading to little change or even a reduction in fire danger levels for some parts of the country?

Fire danger level regional assessment methodology

This study uses daily climatology records from 15 weather stations located within different regions throughout New Zealand. Data was obtained from the Fire Weather System managed for Fire and Emergency New Zealand by the National Institute of Water and Atmospheric Research (NIWA), and records for discontinued Meteorological Service of NZ stations updated to June 2020 with synoptic data provided by MetService.

The study looked at two groups of fire danger indicators. These included:

- The monthly maximum BUI, DC and ISI values from historical datasets for the 15 weather stations ranging in length from 24 to 59 years. For stations with data available for more than 20 years prior to 2000, this was trended against the 20-year period following 2000. For those stations with historical indicators covering a 24-year period only, this data was split to compare two 12-year periods
- The number of days with DC greater than 300, BUI greater than 60 and ISI greater than 10 were identified, and a five-year rolling average was then applied to each station.

For the BUI and DC, most of the 15 weather stations selected took into account an extended length of available daily data, with 11 of the stations having daily data history ranging back more than 40 years. The analyses for each of the 15 weather stations involved nearly one million daily data records for the BUI, DC and ISI. The full datasets and detailed results for each station are available as supplementary data from both the NZ Institute of Forestry (www.nzif.org.nz) and Scion Rural Fire Research (www.scionresearch.com/rural-fire-research) websites. However the lack of ISI data history for the Napier, Masterton and Blenheim stations prior to 1996 meant the monthly maximum ISI data for this first part of the study covered only a period of 24 years.

The second part of the study took account of the number of days each year with values above recognised thresholds – for DC above 300, BUI above 60, and ISI above 10. For the 15 weather stations, the daily data history ranged from 24 to 59 years.

Mt Torlesse Station – research burn site in Canterbury 2008

To aid the simple assessment of overall changes from the historical trend period to current, one of five change categories was identified for each of the six indicators of change in fire danger values for each of the 15 stations:

- A notable increase in fire danger values
- A nominal increase
- No overall change
- A nominal decrease
- A notable decrease.

No formal statistical analysis was undertaken, and the difference between a 'notable' and 'nominal' change was based on a visual assessment of graphical comparisons of annual or monthly values for each station (e.g. see Figure 2 – Taupo and Figure 3 – Gisborne). For frequency of days above the identified threshold values, assessment of change was based on the slope of a line for the five-year moving average of annual frequency counts over each comparison period. For maximum values, assessment of change was based on the difference in maximum monthly values for each comparison period, with strength of change being based on the number of months values were above or below and the difference in maximum values.

Results

The high level-results of this assessment are outlined in Table 1. For the 90 fire danger indicators across the 15 weather stations, 68 (77%) of the indicators showed a no change to a nominal or notable decrease, versus 22 (23%) of the indicators showing a nominal to notable increase.

In fact, more stations showed decreases in fire dangers for the period since 2000 compared to the period prior to 2000, whether nominal or notable. Gisborne, Nelson, Blenheim and Christchurch mainly showed decreases, including many notable decreases, with Invercargill and Paraparaumu also showing no change or decreases. Only two stations (Taupo, Whanganui) showed notable increases, with significant increases for the number of days of DC >300 and maximum monthly BUI and DC values since 2000. The remaining stations showed more variable trends, with a mix of increases, decreases and/or no changes in fire danger indicators for the two comparison periods.

In general, increases occurred in the north (Kaitaia, Auckland) and central (Taupo, Whanganui) North Island, and also for Queenstown in the South Island. Decreases occurred on the East Coast of the North Island (Gisborne) and in the northern South Island (Nelson, Blenheim and Christchurch).

It should be noted, however, that even though Taupo and Whanganui showed notable increases for the number of days with BUI greater than 60 and DC greater than 300 during the period 1996–97 to 2019–20. Figure 4 shows that the annual number of days for Taupo and Whanganui do not regularly meet levels experienced at the Gisborne and Napier weather stations over that same 24-year period.

Discussion

A recent study by Meridian Energy (2019) could assist in understanding why there may have been a decrease in fuel availability to burn in the past 20 years compared to the period prior to 2000. If we look at the current and future impacts on fire weather in our forest and rural landscapes, especially in the South Island, a key component is annual rainfall trends. The Meridian Energy study has suggested that climate change may result in more rainfall impacting the West Coast and Southern Alps. In their May 2019 'Meridian Climate Change Impacts on NZ Renewable Electricity Generation to 2050' presentation to the Major Electricity User Group, they flagged that:

- An increase in air temperature of 1°C results in an 8% increase in the moisture carrying ability of the air
- Increasing wind speed (projected in coming decades) will enhance orographic uplift in the South Island in particular, enhancing both precipitation amounts and spillover over the Southern Alps and in the Waitaki, Clutha and Manapouri catchments (and likely others further north as well)
- For their modelling purposes, they estimated that each rain event would be 8% wetter by 2050.

The Ministry for the Environment (MfE, 2008) also previously stated that they expect annual mean rainfall out to 2040 to increase in the Tasman, West Coast, Otago, Southland and Chatham Islands regions. These areas are also likely to get more heavy downpours. Northeastern districts – Northland, Auckland, Gisborne and Hawke's Bay – are predicted to get less rain. Such an increase in rainfall, either as an increase in rain days or

Taupo Weather Station BUI

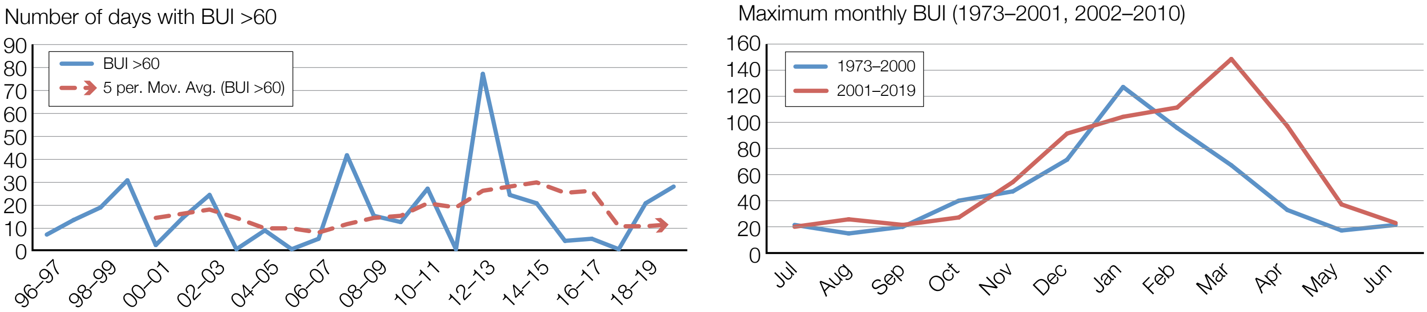

Figure 2: Example graphs for Build Up Index (BUI) from the Taupo weather station. Above left: Annual number of days with BUI values >60 for the period 1996–97 to 2019–20. Above right: Monthly maximum BUI values for the period 1973–2000 compared to 2001–2020. (In this case, the trends identified were 'No change' for days with BUI >60 and 'Notable increase' for monthly maximum BUI over the past 20 years when compared with the 27 years prior to 2000)

Gisborne Weather Station BUI

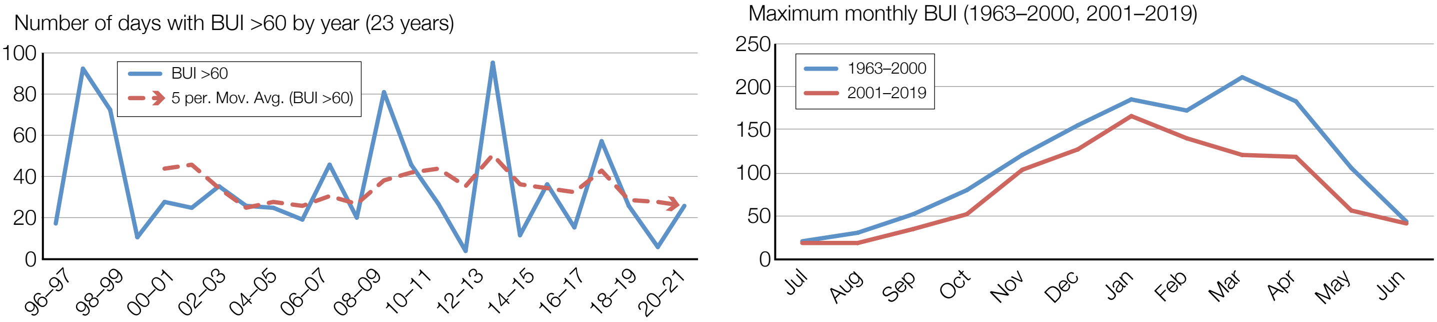

Figure 3: Example graphs for Build Up Index (BUI) from the Gisborne weather station. Above left: Annual number of days with BUI values >60 for the period 1996–97 to 2019–20. Above right: Monthly maximum BUI values for the period 1973–2000 compared to 2001–2020. (In this case, the trends identified were 'Nominal decrease' for days with BUI >60, and 'Notable decrease' for monthly maximum BUI over the past 20 years when compared with the 27 years prior to 2000)

in the amount associated with each rain event, would result in lower BUI and DC values in areas along and just east of the Southern Alps, such as seen here in this study for Nelson and Christchurch in the South Island. Predicted decreases in rainfall for northern areas would result in increased fire dangers, as also seen here for Kaitaia and Auckland. However, findings for Gisborne are at odds, with strongly decreased fire dangers shown here, compared to the increased levels expected under the MfE (2008) projections of reduced rainfall.

Similarly, a 2011 study by NIWA on 'Scenarios of Storminess and Regional Wind Extremes Under Climate Change' (Mullan et al., 2011) found that extreme winds are likely to increase over this century in almost all regions in winter, but decrease in summer, especially around Wellington and across the South Island. However, they also stated that the projected increase in wind speeds was not expected to be large, but just a few percent (i.e. <1 km/h) by the end of the century under a middle-of-the-range emissions scenario. The wind element has a strong impact on the daily ISI output value from the NZFDRS. The findings from this study are therefore supported by the NIWA predictions for similar or even reduced wind speeds for the first part of the century. This is because this study has shown that both the frequency of days with ISI above 10 and the maximum monthly ISI values over the past 20 years have not changed, and in fact in many cases have decreased compared with the period prior to the year 2000.

Short and longer-term climate drivers, such as sea-surface temperature changes around New Zealand and across the Pacific and Indian Oceans (including the Madden-Julian Oscillation, El Nino-Southern Oscillation (ENSO), Indian Ocean Dipole and Interdecadal Pacific Oscillation) also have a significant effect on atmospheric pressure patterns across the country (e.g. see NIWA, 2019), and therefore changes in weather and fire dangers. These changes over seasonal, interannual to decadal timescales are contributing to both increases and reductions in fire dangers in different parts of the

Table 1: Summary of changes in fire danger for 15 weather station locations across New Zealand

	Kaitaia	Auckl.	Gisbor.	Napier	Rotorua	Taupo	Wangan.	Parapar.	Mastert.	Nelson	Blenh.	Christch.	Queenst.	Dunedin	Invercar.
No. of years/ period:	59	54	24	24	24	24	24	24	24	24	24	24	41	55	58
Days of Build Up Index >60	🟧	🟧	🟢	🟢	🟧	⬜	🟥	⬜	🟧	⬜	⬜	🟢	🟧	⬜	⬜
Days of Drought Code >300	⬜	⬜	⬜	🟧	🟧	🟥	⬜	🟢	⬜	🟢	🟩	🟢	🟧	⬜	⬜
Days of Initial Spread Index >10	🟩	⬜	🟩	⬜	⬜	⬜	⬜	⬜	🟢	🟢	🟢	⬜	⬜	🟢	🟩
No. of years/ period:	59	54	56	28	54	46	41	56	28	56	27	58	41	55	58
Maximum BUI by month for period	🟧	🟧	🟩	⬜	⬜	🟥	🟥	🟢	⬜	🟢	🟩	🟩	🟧	🟢	⬜
Maximum DC by month for period	🟧	🟧	🟩	🟧	🟧	🟧	🟥	⬜	⬜	🟩	🟩	🟩	⬜	🟧	⬜
Highest ISI per month for the period	🟩	🟢	🟩	⬜	🟢	⬜	🟢	⬜	🟩	🟩	🟩	🟩	⬜	⬜	🟩

Key	**Indicator spread**	
Notable increase	🟥	5
Nominal increase	🟧	17
Overall no change	⬜	34
Nominal decrease	🟢	16
Notable decrease	🟩	18
		90

Each colour generally shows the movement between the cluster of years prior to 1999 compared with the 2000 to 2020 cluster of years.

The BUI, DC and ISI referred to above are defined as:

1. The Build Up Index (BUI) is a numeric rating of the total amount of fuel available for combustion. It combines the Duff Moisture Code and the DC.
2. The Drought Code (DC) is a numeric rating of the average moisture content of deep, compact organic layers. This code is a useful indicator of seasonal drought effects on forest fuels and the amount of smouldering in deep duff layers and large logs.
3. Initial Spread Index (ISI) is a numerical rating of the expected rate of fire spread. It combines the effects of wind and FFMC on rate of spread without the influence of variable quantities of fuel.

country that may be masking increases in fire dangers due to the slower effects of climate change.

New Zealand's climate is also very diverse, with significant differences in fire climate severity due to microclimate effects associated with topography (Pearce & Clifford, 2008; Scion, 2011a, 2011b). Findings from this study are based on only a small subset of stations that have the long-term records required for such analyses. The analysis of trends in fire dangers is also based on a relatively simple, principally qualitative and non-statistical assessment only, and there is a need for more robust analyses of whether changes are occurring. To this end, work is currently underway to update long-term fire weather records (Pearce et al., 2003) for the wider set of weather stations across the country. This will provide a greater number of stations to undertake more formal statistical analyses of changes over time (e.g. Pearce & Whitmore, 2009), as well as comparisons between stations in the same regions (Pearce et al., 2011) and links to fire climate drivers such as ENSO and longer-term decadal variability (Heydenrych et al., 2001; Pearce et al., 2007), and fire occurrence data (Anderson et al., 2008).

Conclusions

The purpose of this study was to assess whether values of fire danger ratings that indicate the fuel availability to burn in forest and rural landscapes across New Zealand have increased over the past 20 years when compared with a similar period prior to 2000. The NZFDRS provides a sound scientific basis for answering this question, as well as supporting fire management decision-making. What has emerged is that the number of days with fuel available for combustion at an intense level – as indicated by elevated values of the BUI and DC components of the NZFDRS – has remained the same or actually reduced since 2000 for almost all of the weather station locations analysed. Similarly, indicators of increased fire spread potential (based on the ISI component of the NZFDRS) show even more widespread decreases. Along with the BUI and DC changes, this may be explained in part by changing wind patterns and associated increases in rainfall along the Southern Alps associated with natural seasonal climate variability, as well as longer-term climate change.

Based on this study, involving up to 60 years of weather data for a range of locations across the country, it will take a major swing in current weather patterns to suggest that the average annual frequency of elevated fire danger levels across New Zealand will increase dramatically over the next 20 to 40 years.

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References

Alexander, M.E. 1992. *Standard Specifications for Fire Weather Index System Computer Calculations*. Paper prepared for the 3rd Advisory Committee on Forest and Rural Fire Research held at the NZ Fire Service National Headquarters, Wellington, NZ, 21 October 1992.

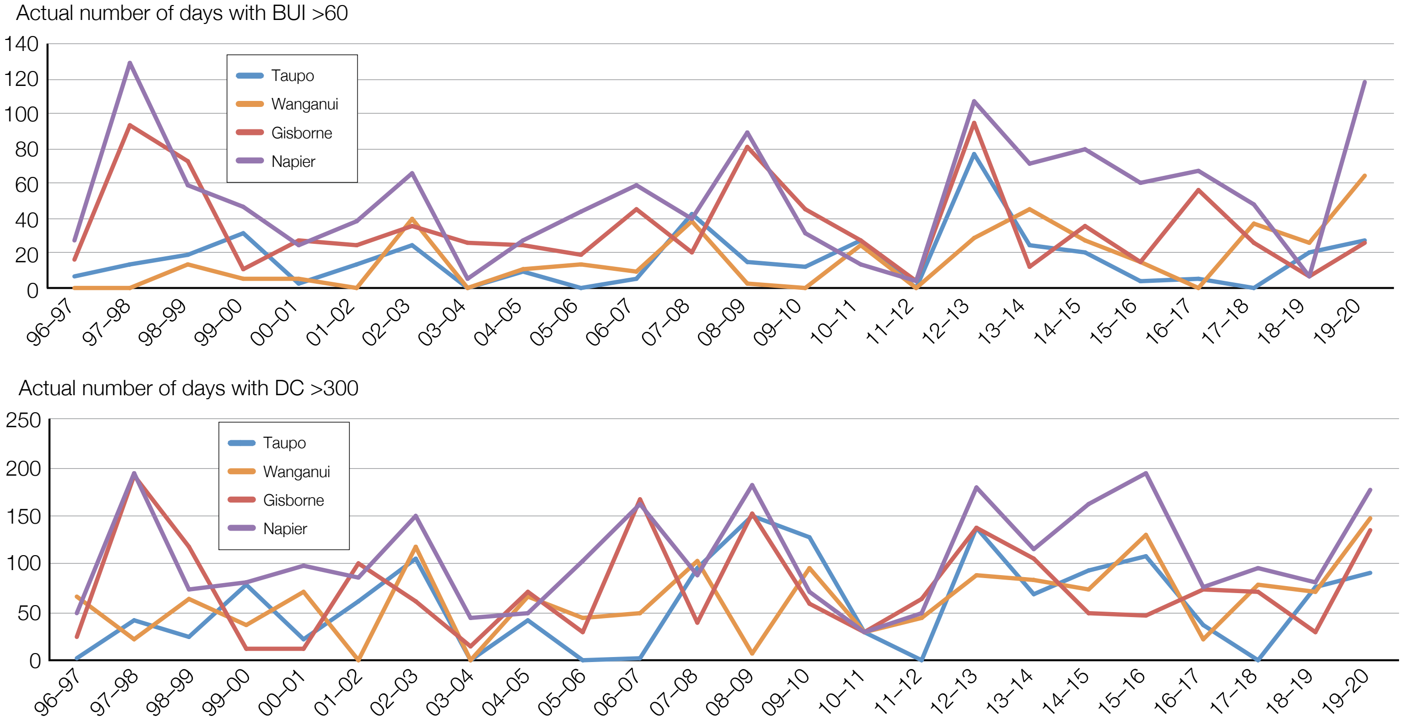

Figure 4: Comparison of annual number of days with BUI greater than 60 (top) and DC greater than 300 (bottom) for the Taupo, Wanganui, Gisborne and Napier stations

Alexander, M.E. 2008. *Proposed Revision of Fire Danger Class Criteria for Forest and Rural Areas in New Zealand* (2nd Ed.). National Rural Fire Authority, Wellington, NZ, in association with the Scion Rural Fire Research Group, Christchurch, NZ.

Anderson, S. 2005. Forest and Rural Fire Danger Rating in New Zealand. In Colley, M. (Ed.), *Forestry Handbook*. Christchurch, NZ: New Zealand Institute of Forestry.

Anderson, S.A.J. 2009. Future Options for Fire Behaviour Modelling and Fire Danger Rating in New Zealand. *Proceedings of the Royal Society of Queensland*, 115: 119–127.

Anderson, S.A.J. and Anderson, W.R. 2009. Predicting the Elevated Dead Fuel Moisture Content in Gorse (*Ulex europaeus L.*) Shrub Fuels. *Canadian Journal of Forest Research*, 39(12): 2355–2368.

Anderson, S.A.J., Doherty, J.J. and Pearce, H.G. 2008. Wildfires in New Zealand from 1991 to 2007. *New Zealand Journal of Forestry*, 53(3): 19–22.

Chandler, C.C., Cheney, P., Thomas, P., Trabaud, L. and Williams, P. 1983. *Fire in Forestry, Volume 1: Forest Fire Behavior and Effects*. New York, US: John Wiley and Sons.

Fogarty, L.G., Pearce, H.G., Catchpole, W.R. and Alexander, M.E. 1998. Adoption vs. Adaptation: Lessons from Applying the Canadian Forest Fire Danger Rating System in New Zealand. In Viegas, D.X. (Ed.), *Proceedings, 3rd International Conference on Forest Fire Research and 14th Fire and Forest Meteorology Conference*. Luso, Coimbra, Portugal, 16-20 November 1998.

Heydenrych, C., Salinger, J. and Renwick, J. 2001. Climate and Severe Fire Seasons: A Report on Climatic Factors Contributing to Severe Fire Seasons in New Zealand. *NZ Fire Service Commission Research Report No. 11*. Wellington, NZ: NZFSC.

Meridian Energy. 2019. *Meridian Climate Change Impacts on NZ Renewable Electricity Generation to 2050*. Presentation to the Major Electricity User Group, May 2019. Wellington, NZ: Meridian Energy.

Merrill, D.F., Alexander and M.E. (Eds.). 1987. Glossary of Forest Fire Management Terms (4th Ed.). *Publication NRCC No. 26516*. Ottawa: Ontario: National Research Council of Canada, Canadian Committee on Forest Fire Management.

Ministry for the Environment (MfE). 2008. *Climate Change Effects and Impacts Assessment: A Guidance Manual for Local Government in New Zealand* (2nd Ed.). Wellington, NZ: MfE.

Mullan, B., Carey-Smith, T., Griffith, G., and Sood, A. 2011. Scenarios of Storminess and Regional Wind Extremes Under Climate Change. *NIWA Client Report WLG2010-31*. Wellington, NZ: National Institute of Water and Atmospheric Research.

National Rural Fire Authority (NRFA) and New Zealand Forest Research Institute (NZFRI). 1993. *Fire Weather Index System Tables for New Zealand*. NRFA, Wellington, NZ, in association with NZFRI, Rotorua, NZ.

Pearce, H.G., Anderson, S.A.J. and Clifford, V.R. 2012. *A Manual for Predicting Fire Behaviour in New Zealand Fuels* (2nd Ed.). Christchurch, NZ: Scion Rural Fire Research Group.

Pearce, H.G. and Clifford, V. 2008. Fire Weather and Climate of New Zealand. *New Zealand Journal of Forestry*, 53(3): 13–18.

Pearce, H.G., Douglas, K.L. and Moore, J.R. 2003. A Fire Danger Climatology for New Zealand. *Fire Service Commission Research Report No. 39*. Wellington, NZ: NZFSC.

Pearce, H.G., Kerr, J., Clark, A., Mullan, B., Ackerley, D., Carey-Smith, T. and Yang, E. 2011. Improved Estimates of the Effect of Climate Change on NZ Fire Danger. *MAF Technical Paper No. 2011/13*. Wellington, NZ: Ministry of Agriculture & Forestry.

Pearce, H.G., Mullan, A.B., Salinger, M.J., Opperman, T.W., Woods, D. and Moore, J.R. 2005. Impact of Climate Change on Long-term Fire Danger. *NZ Fire Service Commission Research Report No. 50*. Wellington, NZ: NZFSC.

Pearce, H.G., Salinger, J. and Renwick, J. 2007. Impact of Climate Variability on Fire Danger. *NZ Fire Service Commission Research Report No. 72*. Wellington, NZ: NZFSC.

Pearce, H.G. and Whitmore, M.A. 2009. Analysis of Seasonal Trends in the Drought Code in New Zealand. *Scion Client Report No. 12788*. Christchurch, NZ: Scion Rural Fire Research Group.

Scion. 2011a. Future Fire Danger. *Rural Fire Research Update 9* (November 2011). Christchurch, NZ: Scion Rural Fire Research Group.

Scion. 2011b. *Fire Climate Severity. Rural Research Update 8 (July 2011)*. Christchurch, NZ: Scion Rural Fire Research Group.

Stocks, B.J., Alexander, M.E., Van Wagner, C.E., McAlpine, R.S., Lynham, T.J. and Dube, D.E. 1989. The Canadian Forest Fire Danger Rating System: An Overview. *Forestry Chronicle*, 65: 450–457.

Taylor, S.W. and Alexander, M.E. 2006. Science, Technology and Human Factors in Fire Danger Rating: The Canadian Experience. *International Journal of Wildland Fire*, 15(1): 121–135.

Valentine, J.M. 1978. Fire Danger Rating in New Zealand: Review and Evaluation. *Forest Establishment Report No. 123*. Rotorua, NZ: New Zealand Forest Service, Forest Research Institute.

Van Wagner, C.E. 1987. Development and Structure of the Canadian Forest Fire Weather Index System. *Forestry Technical Report 35*. Ottawa, Ontario: Canadian Forestry Service.

Van Wagner, C.E. 1988. *Note on the Use of the Canadian Forest Fire Weather Index System in Other Countries*. Canadian Forestry Service, Petawawa National Forestry Institute, Chalk River, Ontario. Unpublished filenote, April 1988.

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