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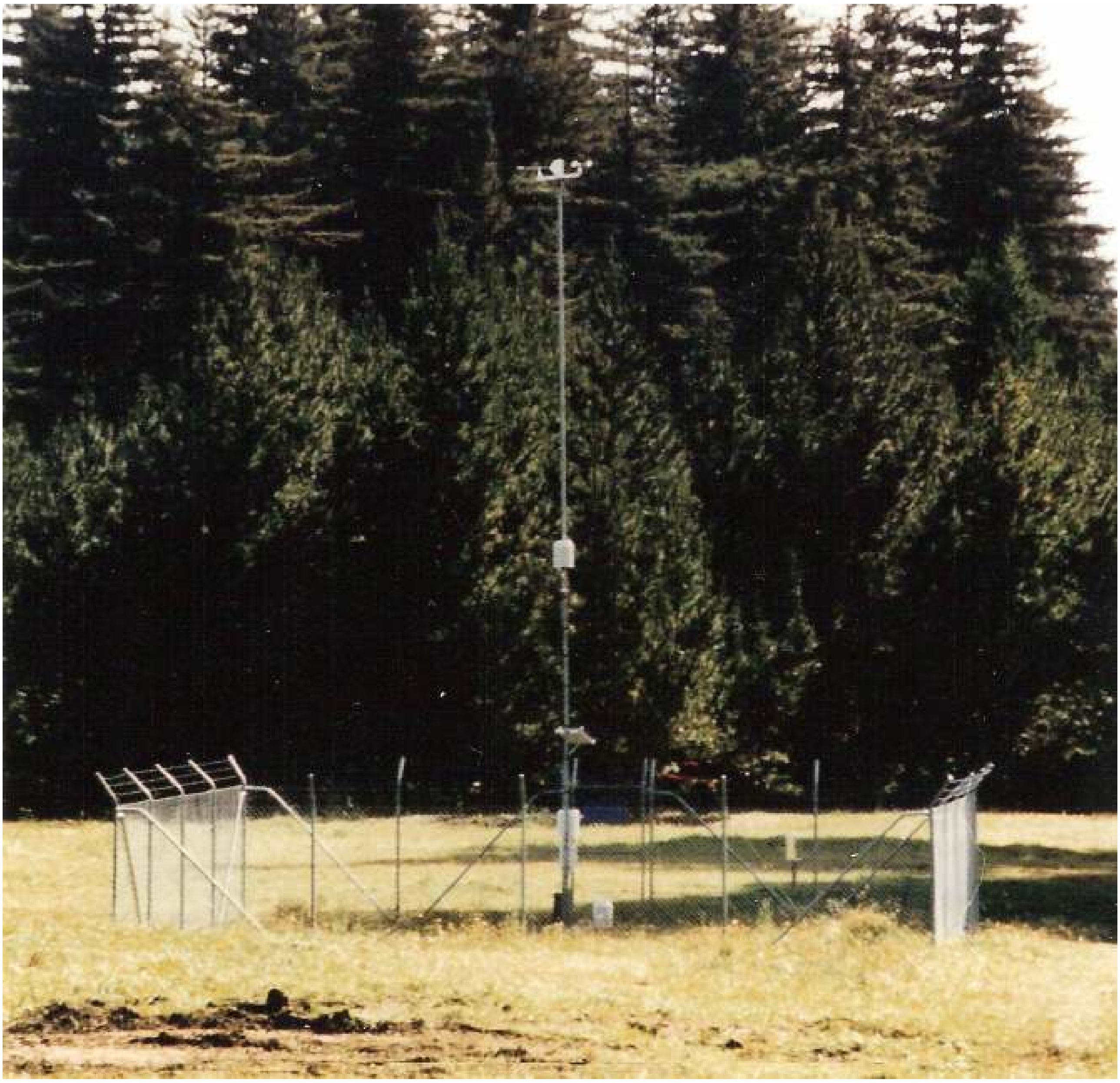

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H. Grant Pearce and
Meredith A. Whitmore

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EXECUTIVE SUMMARY

The Drought Code (DC) component of the Fire Weather Index (FWI) System provides a measure of the effect of long-term drying on the moisture content of deep, compacted organic layers within the soil profile. One of the FWI System's three fuel moisture codes, the DC tracks the drying and wetting of the compact organic layers and large woody fuels, and provides an indicator of seasonal drought and potential fire mop-up problems.

In New Zealand, fire weather monitoring stations are run all year round, and the data collected are used to calculate the daily values of the FWI System components employed to assess fire danger. Fire managers have expressed concern that values of the DC component are increasing over time in New Zealand due to calculation issues, particularly a lack of annual re-setting, or possibly climate change. Trends in DC values for a number of stations from several regions of the country were investigated to determine whether these concerns were justified. The study also forms part of the broader validation of the FWI System to New Zealand conditions.

While increasing values of the DC were apparent for a number of months at most stations investigated, very few of these observed trends were statistically significant due to the high variability in DC values from year-to-year. In addition, corresponding decreases were also observed in other months at many of the same stations. More significant increases in DC values were found for several stations for the last 5-10 years than indicated by the general trend over the full length of record. However, these rapid increases in DC values appeared to coincide with the occurrence of consecutive severe fire seasons with higher than average DC values.

The mix of both increasing and decreasing trends, and relatively frequent recovery of DC values to near zero at least every few seasons at most stations, suggests that rather than a general increase in DC values associated with climate change, the observed increases (and decreases) in DC values are related to other factors. The length and period of record used to determine trends had a major impact on the strength and direction of the trends identified. Increases in DC values over the last 10-15 years, particularly for the months July to September, may also be associated with normal longer-term climate variability such as described by the Interdecadal Pacific Oscillation (IPO). Therefore, rather than indicating annual DC re-setting or calculation problems, these results highlight the influence of the length of data record and climate patterns on rainfall variability, and thus DC values/trends.

Trends in DC values should continue to be regularly reviewed to determine whether the recent upward trend observed at many stations continues, possibly as a result of climate change, or is reversed due to the changes in the prevailing climate pattern. The effect of IPO (and ENSO) on the DC should also be investigated. Use of soil water-balance, drought indices and direct soil moisture measurements should be examined as means of calibrating calculated DC values. The established procedure for adjustment of DC start-

up values based on over-winter precipitation should also be assessed as an operational tool for validation of DC values at the start of the fire season. As a part of the more general validation of the FWI System to New Zealand conditions, investigation of the validity of the underlying moisture relationships contained within the DC equation is also required to determine whether these are in fact applicable to New Zealand soil profiles.

Perhaps most importantly, fire managers should not over-focus on the DC component of the FWI System, but should utilise all the codes and indices within the System to guide fire management decision-making.

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Information for Scion abstracting:

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INTRODUCTION

New Zealand experiences around 3000 rural vegetation fires each year, covering some 6500 ha of rural lands and the number of fires is increasing by about 200-300 fires per year (Doherty *et al*. 2008). However, the risk of fires varies greatly from year-to-year and within different parts of the country in response to seasonal climate patterns and local microclimates. Fire managers therefore need to have accurate information about the risk of fire in the environment to target fire prevention activities, and to prepare for and respond to fires when they occur.

In New Zealand, fire managers utilise the Fire Weather Index (FWI) subsystem from the Canadian Forest Fire Danger Rating System to monitor daily and seasonal changes in fire danger conditions (Anderson 2005). Adopted in 1980, the FWI System was originally implemented for rating fire danger in exotic pine plantations but its use has now been extended across a range of New Zealand fuel types (Alexander 1994, Fogarty *et al*. 1998). Despite recommendations to do so (Valentine 1978), the applicability of the FWI System to New Zealand conditions has not been properly validated [although this has been identified as a priority for the current research programme and work has commenced in an effort to rectify this situation].

This lack of validation of the FWI System, and of the underlying relationships for the System's fuel moisture codes in particular, has lead to doubts being expressed by some fire managers regarding the validity of the FWI System to the New Zealand environment and especially in non-forested fuel types (Anderson 2005, 2006). These concerns extend to the Drought Code (DC) component of the FWI System, which tracks the drying and wetting of the deep, compact organic layers and large woody fuels, and provides an indicator of seasonal drought and potential fire mop-up problems. Fire managers have expressed concern that DC values may be increasing from year to year due to possible calculation issues. An increased awareness of the climate change issue has also resulted in growing concerns that conditions in some parts of the country are becoming drier and more drought-prone over time.

The potential for problems with calculation of DC values in New Zealand is exacerbated by the fact that fire weather monitoring stations are run all year round, due to the lack of winter snow cover. In Canada, where the FWI System was developed, calculations are halted over the winter period and restarted the following spring using a standard procedure that takes account of over-winter precipitation (both rainfall and the water-equivalent from snow). All-year round calculation has the potential to contribute to increases in DC values through a lack of "re-zeroing" of values over the winter and carry-over of elevated values from the end of the previous fire season to the start of the next. While this occurs naturally as a result of low rainfall or drought conditions that cause elevated DC values to persist through the winter period, values are normally re-set by the next wet season and would not be expected to persist indefinitely. Ongoing carry-over of elevated DC values is therefore more likely due to issues in calculation, possibly resulting from the use in New

Zealand of the standard Canadian wetting and drying relationships or soil water storage capacity value contained in the DC equations.

New Zealand fire managers need to have faith that the FWI System provides an accurate and reliable basis for assessing and comparing fire danger between years and stations/regions. This study therefore sought to undertake an initial investigation of trends in seasonal DC values to determine whether the concerns expressed were justified, and if further research was required. Providing a better understanding of the trends in the DC would also aid in evaluating the performance of this component under New Zealand conditions and, more broadly, assist in validating the FWI System's applicability to the local fire environment.

Scope of Study

This report describes an initial investigation into the performance of the Drought Code (DC) component of the FWI System under New Zealand conditions. The study forms a key part of the broader research objective to review the validity of the FWI System to New Zealand conditions, by indicating priority areas for further research, and of the DC component in particular. However, the primary objective of the study was to identify whether the concerns expressed by fire managers, that fire season starting values of the DC are increasing over time, were valid. The intent of this initial investigation was therefore to determine whether there was evidence that seasonal DC values have increased over time and, if there was, to highlight whether there was a need for further, more detailed research into aspects of the DC, including possible issues with all-year round calculation and/or a lack of re-setting.

The study therefore aimed to address the following questions:

(1) Are seasonal DC values changing over time (and, if so, are these changes statistically significant)?
(2) If DC values are changing, are values at the start of the fire season increasing from year to year?
(3) What, if any, are the possible causes of fire season DC value increases, and are DC calculation issues (e.g., re-setting, soil moisture capacity) a contributing factor?
(4) What additional research is required to more clearly define and, where possible, resolve any issues identified?

BACKGROUND

Fire Danger Rating in New Zealand

In New Zealand, assessment of the influence of the fire environment factors on fire danger and fire behaviour potential is carried out through use of the New Zealand Fire Danger Rating System (NZFDRS), which is based on the Canadian Forest Fire Danger Rating System (Stocks *et al*. 1989, Anderson 2005). The Fire Weather Index (FWI) System forms the core of the NZFDRS (Fig. 1a), and this component has been in use in New Zealand since 1980 (Valentine 1978). Originally implemented for rating fire danger in exotic pine plantations, its use has now been extended across a range of vegetative fuel types, including grass and scrubland (Fogarty *et al*. 1998, Anderson 2006).

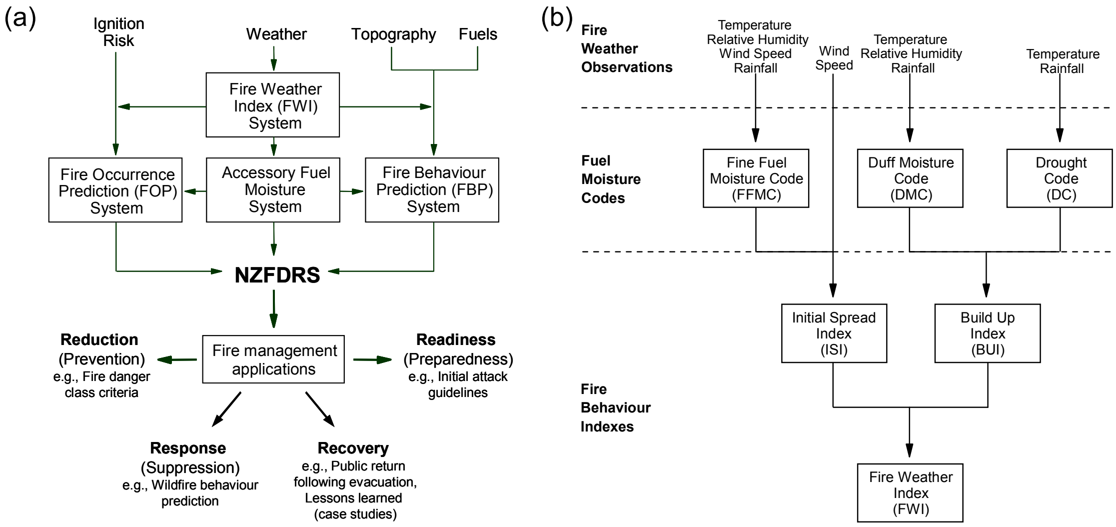

Figure 1. Structure diagrams for **(a)** the New Zealand Fire Danger Rating System (NZFDRS), illustrating the linkage to fire management actions (after Fogarty *et al*. 1998); and **(b)** the Fire Weather Index (FWI) System (after Anon. 1993).

The six components of the FWI System (Fig. 1b) account for the effects of fuel moisture and weather on ignition potential and probable fire behaviour. The System is based solely on weather inputs (dry bulb temperature, relative humidity, 10-metre open wind speed and 24-hour accumulated rainfall, recorded daily at 1200 NZST) for a reference fuel type (a mature pine stand[1]) on level terrain (Anderson 2005). The fuel moisture codes (Fine Fuel Moisture Code, FFMC; Duff Moisture Code, DMC; and Drought Code, DC) act as bookkeeping systems, adding moisture after rain and subtracting moisture for each day's drying to provide numerical ratings of the moisture content of their characteristic fuel layers (Alexander 1992). The FFMC is indicative of the moisture content of the litter layer of the forest floor, while the DMC reflects the moisture content of the moderately deep duff and the DC the deep,

[1] Of jack (*Pinus banksiana*) or lodepole (*P. contorta*) pine, although data from red (P. resinosa) and white (*P. strobus*) pine stands were also used in the development of the FWI system (Van Wagner 1987).

Table 1. Comparative properties of the FWI System fuel moisture codes (adapted from Van Wagner 1987).

Code Property	FFMC	Fuel Moisture Code DMC	DC
Value range	0 to 101	0 to ~150	0 to ~800
Required inputs*	T, RH, WS, R	T, RH, R, mo	T, R, mo
Timelag² (days)	2/3	15	53
Rain threshold (mm)	0.6	1.5	2.8
Water capacity (mm)	0.6	15	100
Nominal layer depth (cm)	1.2	7	18
Nominal fuel load (kg/m^2)	0.25	5	25

* T = temperature, RH = relative humidity, WS = wind speed, R = rainfall, mo = month.

compacted organic layers (Table 1). Higher values of these three fuel moisture codes correspond to lower moisture contents and hence greater flammability (CFS 1984, Stocks *et al*. 1989). As the name suggests, the fire behaviour indices are indicators of fire behaviour potential, with the Initial Spread Index (ISI) representing the rate of fire spread and the Buildup Index (BUI) the amount of fuel available for combustion. These are then combined in the final FWI value, which indicates the intensity of a spreading fire on flat terrain. Again, values of the fire behaviour indices increase as fire weather severity worsens, indicating the potential for more severe fire behaviour. A detailed description of the development and structure of the FWI System is contained in Van Wagner (1987).

Whilst the FWI value itself is a good indicator of general fire danger across broad areas and of key aspects of associated fire activity, it is impossible to summarise daily fire potential in a single number. All six components of the FWI System provide useful information on fuel moisture (and flammability) and expected fire behaviour. For example, the Fine Fuel Moisture Code (FFMC) is a useful indicator of ignition potential (i.e., the likelihood of fire starts), the Drought Code (DC) and Buildup Index (BUI) provide indicators of the potential for deep-seated burning, and the Initial Spread Index (ISI) indicates the potential rate of fire spread (Anderson 2005). FWI calculations are carried out daily for more than 170 weather stations across the country[2], providing managers with up-to-date fire assessments of fire danger and fire behaviour potential.

The Drought Code

The Drought Code (DC) component of the FWI System provides a measure of the effect of long-term drying on the moisture content of deep, compacted organic layers within the soil profile. In the reference pine forest fuel type on which the FWI System is based, the DC relates to duff layers which generally lie between 10-20 cm below the surface, with a nominal fuel load of 25 kg/m² and water holding capacity of 100 mm (after Van Wagner 1987; see Table 1);

[2] See http://nrfa.fire.org.nz/fire_weather/Index.htm

that is, the deep humus (H) layer, which lies above the mineral soil but below the litter (L) and fermentation (F) layers (represented by the FFMC and DMC components, respectively).

The DC originated from the Stored Moisture Index (SMI), which was first developed as an index of water stored in the soil (Turner 1966. However, the exponential drying rate of the index made it well-suited to tracking the moisture content of slow-drying forest fuels (Turner 1972), including compact soil organic layers and large woody fuels. The DC also provides a useful general indicator of drought, including the availability of water in small streams and swamps (Van Wagner 1987). From a fire management perspective, it is also a useful indicator of seasonal drought effects on forest fuels, and the amount of smouldering that might be expected in deep duff layers and large logs (CFS 1987).

DC values are obtained through simple equations which are calculated daily from noon temperature (local standard time), 24-hour rainfall to noon, and the month of observation; the latter taking into account the changing day length in the calculation of the drying phase (Van Wagner 1987). Daily rainfall amounts up to 2.8 mm are ignored for the purposes of DC calculation, as this amount is assumed to be intercepted by the forest canopy and overlying litter and loose duff layers. Like the other FWI System components, the DC scale is structured so that higher values represent drier (i.e., more severe) conditions, and the scale is open ended, so that a higher value is always possible if fire weather worsens (i.e., higher temperature, or extended dry spell or drought) (Alexander 1992). The theoretical maximum for the DC is 800, although values in excess of 1000 have been recorded in New Zealand (Pearce and Moore 2004) and internationally (Alexander and Pearce 1993).

The fuels represented by the DC dry only very slowly through the process of evaporation, and a long period of weather with low rainfall is needed to dry out these fuels and greatly increase the DC value. Generally, several days of heavy rain (or equivalent snow melt) are required to reduce the DC significantly to zero (Turner 1972). The associated timelag[3] for this component is 53 days[4], considerably longer than those for the other moisture codes (see Table 1). The DC output scale ranges from zero (fully saturated soil) to >800 (the driest condition normally encountered). The “standard” DC fuel layer with the properties outlined above has a theoretical maximum moisture content of 400% when fully saturated (i.e., a weight of water four times the oven-dry weight of the compact organic material holding it), decreasing to less than 50% moisture content at DC values greater than 800. Although the water capacity of the “standard” DC layer is 100 mm, it is generally considered that more than 200 mm (8 inches or 800 points) of precipitation is required to

[3] The exponential drying time “under stated conditions of temperature, relative humidity, wind speed, and time of year, required for dead fuels to lose about two-thirds (2/3) of the difference between their initial moisture content and their equilibrium moisture content” (Merrill and Alexander 1987).

[4] Timelag values for the DMC and DC components quoted here may differ from those referenced in earlier publications, due to values being updated following reanalysis of the original Canadian data (Lawson and Dalrymple 1996, Lawson *et al*. 1997).

"re-set" the DC (Lawson 1977, McAlpine 1990)[5]. However, McAlpine *et al*. (1999) caution that any station receiving less than 250 mm in over-winter precipitation warrants review of seasonal start-up values.

The appropriate equation linking oven-dry moisture content (MC%) and DC is not the rearranged form of Van Wagner's (1987) standard DC equation

$$DC = 400 \ln(800 / Q) \quad [1]$$

as quoted by some authors (e.g., Lawson and Dalrymple 1996)

$$Q = 800 \exp(-DC / 400) \quad [2]$$

(where Q = moisture equivalent of the DC). It is in fact (after Lawson and Armitage 2008)

$$MC\% = 400 \exp(-DC / 400) \quad [3]$$

which produces the theoretical maximum moisture content of 400% (after Van Wagner 1987) (*cf*. 800% using equation [2]).

While the standard DC equation [1] is used across Canada, the equivalent moisture equation [3] is not expected to accurately reflect moisture content at all locations and in all forest types due to differences in soil types, forest floor depth, climate and other factors (such as soil drainage rates, and presence of permafrost). As a result, a number of site- or species-specific relationships have been derived for moisture content as a function of DC (e.g., Lawson and Dalrymple 1996, Abbott *et al*. 2007; Otway *et al*. 2007). Lawson and Dalrymple (1996), who developed DC calibration equations for a number of different forest types (see Fig. 2), in particular noted that "the standard curve of the DC moisture equivalent would not be expected to relate closely to sampled forest floor moisture content on well-drained sites". This suggests that moisture contents derived from the equivalent DC moisture equation [3] may not accurately reflect the moisture content of New Zealand soils, particularly non-forested or shallow, free-draining soils, and that one or more New Zealand-specific DC calibration equations may also need to be developed for New Zealand soil types. Similarly, it could also suggest that changes in DC values calculated using the standard equation [1] may not adequately represent changes in the dryness of subsurface fuels in these "non-reference" situations.

Although DC values vary significantly from location to location and year to year, some commonly recognised threshold values ("trigger points") for the DC are (Alexander 1983a, De Groot 1988, NRFA 2004):

- 200: fire managers need to be aware soils are beginning to drying out;
- 300: likely involvement of deep sub-surface and heavy fuels, and consideration should be given to suspending prescribed burning;
- 350: potential for mop-up and control problems; and
- 500: subsurface and other heavy fuels are extremely dry, and will present significant fire control problems.

[5] The predecessor to the DC, the Stored Moisture Index (SMI) of Turner (1972), in fact referred to a "water reservoir" with a capacity of 200 mm; however, this was subsequently revised to 100 mm for the 'standard' forest floor layer defined by Van Wagner (1987).

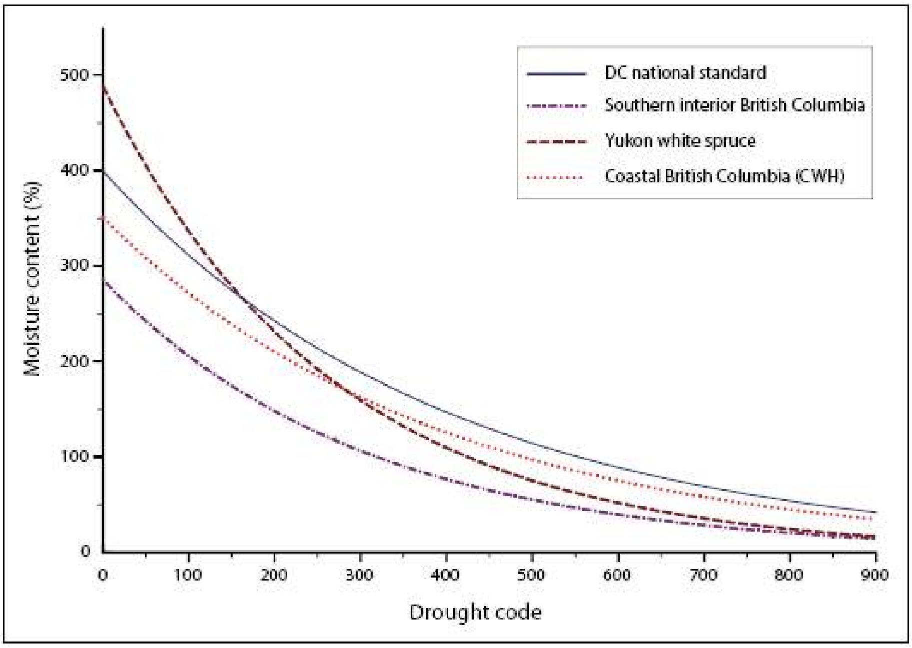

Figure 2. Calibration curves for forest floor moisture content as a function of the Drought Code (DC), for the standard Canadian DC equation (solid blue line) and the site-specific forest types described by Lawson and Dalrymple 1996). (Source: Fig. 15 from Lawson and Armitage 2008).

These trigger points provide general benchmarks for a range of fire management applications, including issue of fire permits and authorisation for prescribed burning, as well as fire suppression requirements. However, they do not apply universally, and will require adjustment up or down in some parts of the country to fit the range of seasonal values normally encountered at a particular location[6]. The DC should also be interpreted in conjunction with other FWI System components, particularly the FFMC and the DMC, as the fire potential may be low due to low values of FFMC and DMC even though the DC is high.

Compared to other components of the FWI System (e.g., FFMC, ISI and FWI), the DC is not influenced to the same extent by day-to-day variability. In a study of the seasonal trends of all the codes and indices within the FWI System, Nikleva (1973) found the DC was the only index to show a consistent seasonal trend, with a generally steady rise in values throughout the fire season interspersed by drops and rebuilding phases associated with infrequent rain events. The average trend for Christchurch Aero (Fig. 3), for example, shows a minimum Dc value in September and a maximum value in April. The DC has therefore been used to review and compare seasonal trends (Nikleva 1973, McAlpine 1990, McAlpine *et al*. 1999, Pearce and Moore 2004, Lavoie *et al*. 2007) and to highlight potential problem fire seasons (Muraro and Lawson 1970, Pearce 1998).

[6] Fire danger climatology summaries for 127 weather station locations across New Zealand are contained in Pearce *et al*. (2003).

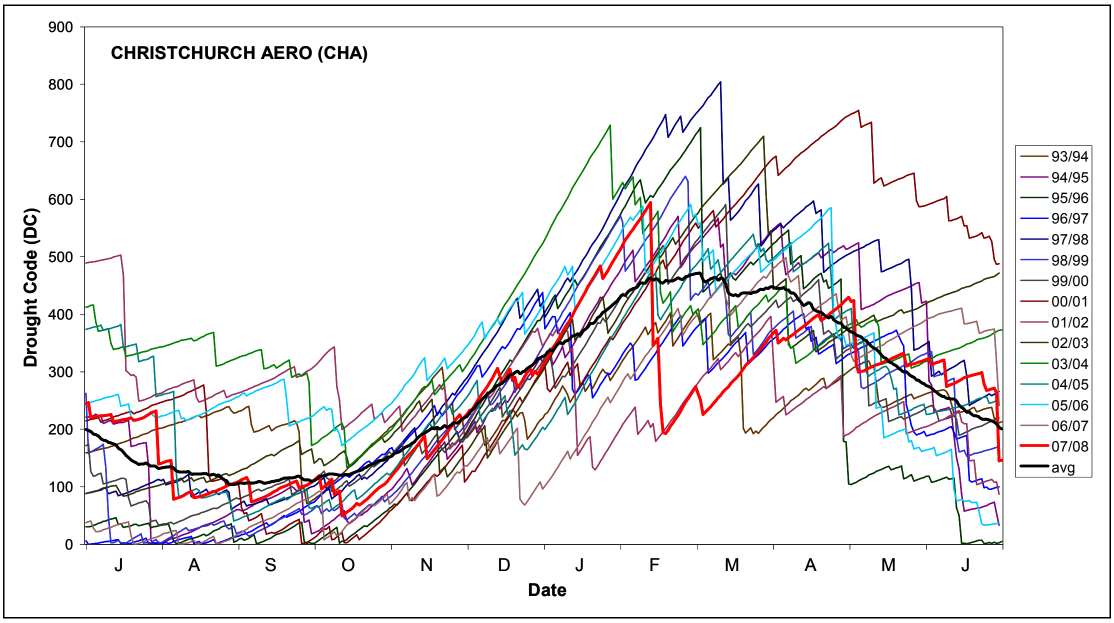

Figure 3. Annual Drought Code (DC) patterns for Christchurch Aero (CHA) from July 1993 to May 2008. The average trend is highlighted in bold.

Over-wintering of the DC Component

In Canada where the FWI System was developed, calculations are not usually continued year round, but are stopped over the winter period when snow cover and frozen ground in many parts of the country remove any appreciable fire danger. Calculations typically start in spring[7] (generally in April), and continue through to late autumn/fall when snow cover returns (typically September/October). Normally there is sufficient precipitation (in the form of rain and water-equivalent contained in snow) over the winter months to saturate forest fuels, and moisture code calculations start in early spring from close to zero using the standard start-up values (FFMC 85, DMC 6 and DC 15; after CFS 1987).

However, occasionally in some regions in some years, over-winter precipitation falls short of the 200 mm required[8] to saturate the deep, heavy fuels represented by the DC. Autumn rains may be insufficient or unable to saturate heavy fuels before winter freeze-up occurs, or spring snowpacks may be too light so that snowmelt occurs before deep organic layers have fully thawed, resulting in runoff rather than percolation (Lawson 1977). In these instances, procedures are available for adjusting seasonal start-up values (Turner and Lawson 1978, Alexander 1982, 1983a,b), with some regional modification in some cases (e.g. Ricketts 1991, Frech and McAlpine 1999).

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[7] Calculations begin on the third day following snow melt or, in regions where snow cover is not a significant feature, on the third successive day that noon temperatures of 12 ºC or higher have been recorded (CFS 1987).

[8] In contrast with other authors (e.g., Lawson 1977, McAlpine 1990, Lawson and Dalrymple 1996), McAlpine *et al*. (1999) suggest that 250 mm of over-winter precipitation is actually required, depending on the final fall DC value.

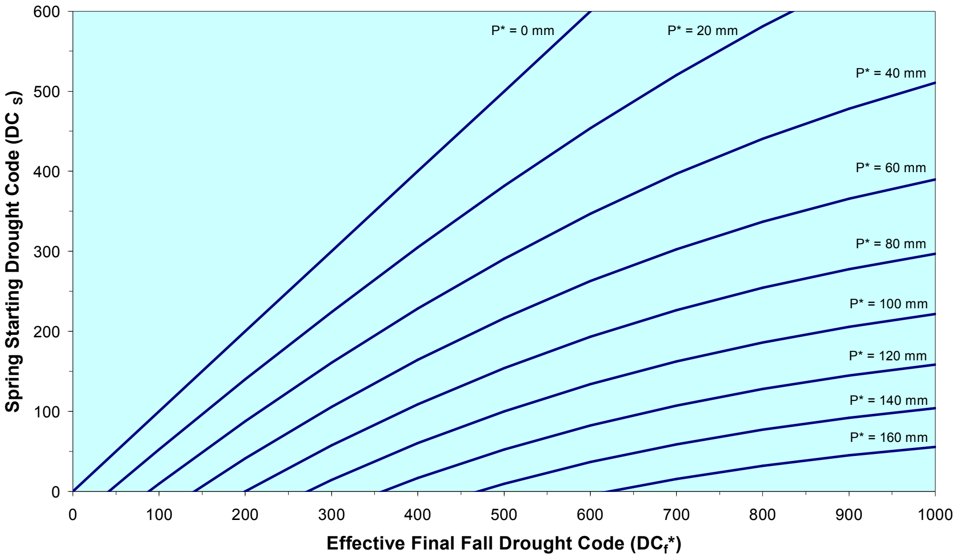


Figure 4. Relationship between effective final fall Drought Code (DC_f*) and spring starting Drought Code (DC_s) for different effective overwinter precipitation amounts (P*) (after Fig. 25 from Turner and Lawson 1978). Note that DC_f* is obtained by adjusting the final fall DC value (DC_f) for the carry-over fraction of fall moisture (a), and P* is obtained by multiplying the overwinter precipitation amount (P) by the precipitation effectiveness fraction (b).

These procedures calculate the spring starting DC value (DC_s) from user-defined inputs (*a* and *b*)[9] for the carry-over fraction of last fall's moisture (Q_f, calculated from the final fall DC value, DC_f) and the effectiveness of winter precipitation (P) in recharging moisture reserves in the spring, which vary regionally depending on climate, soil type and other ecosystem characteristics. The relationship between the final fall DC value, overwinter precipitation amount and spring starting DC value is shown in Figure 4, and is based on the following equations:

$$Q_f = 800 \exp(-DC_f / 400) \quad [4]$$

$$Q_s = a\, Q_f + b\,(3.94\, P) \quad [5]$$

$$DC_s = 400 \ln(800 / Q_s) \quad [6]$$

Field sampling procedures for ground-truthing of DC values based on sampling of actual moisture contents of soil organic layers are also available (Lawson 1988, Lawson and Dalrymple 1996) for use in verifying values at the start of the fire season or any other time of year.

Lawson and Armitage (2008) note that "in areas where normal winter precipitation exceeds 200 mm, the DC overwintering exercise tends to be unnecessary". Over-winter adjustment of the DC is commonly applied in the drier parts of western and northern Canada (Alexander 1983a, Rickets 1991), but has variously been reported as being "almost never" (Van Wagner 1987) or "only rarely" (Stocks 1979) required in eastern Canada. In the latter case,

[9] Values range from 0.5 to 1.0 for the carry-over fraction of last fall's moisture (*a*), and 0.5 to 0.9 for the effectiveness of winter precipitation in recharging moisture reserves in spring (*b*) (Turner and Lawson 1978, Alexander 1983b).

McAlpine *et al*. (1999) note that it can be easy to fall into the trap of never evaluating the over-winter DC situation when it may be necessary from time to time. They also suggest that it may in fact be necessary to reassess and, where required, adjust DC values more frequently as the climate of the planet changes.

In contrast, in New Zealand, the lack of continuous winter snow cover or ground freeze, even at inland, high elevation sites, has resulted in fire weather stations (now exclusively monitored using automatic weather stations) and associated FWI System calculations being continued all year round. DC values are known to vary widely from location to location (Pearce 1996, Pearce *et al*. 2003) and from season to season (Pearce and Moore 2004), due to differences in annual precipitation and temperature. Occasionally, periods of elevated values occur as result of rainfall deficits or drought associated with interannual or longer-term climate variability (Pearce *et al*. 2007). In such dry years and with below-average winter rainfall, it is recognised that DC values at the start of the fire season can commence at higher than normal values and contribute to a more severe fire season. However, it is generally believed that weather stations in New Zealand receive enough rainfall during winter in an "average" year to recharge soil moisture and re-set DC values at or close to zero by the beginning of each fire season.

Hence, evidence that this is not the case and that DC values are in fact gradually increasing over time, whether due to issues with code calculation (including a lack of re-setting resulting in values building over winter) or climate change, would have significant impacts for rural fire management in New Zealand. Inaccurate calculation and reporting of DC values would result in misrepresentation of fire danger conditions and, in the case of inflated values, could lead to unnecessary expenditure on fire prevention and readiness. Even worse, the under-estimation of actual fire danger conditions due to dismissal of high reported DC values (potentially resulting from climate change), could lead to underestimation of fire behaviour potential and threats to life and property. Such issues would also seriously undermine the faith of fire managers in the FWI System and, together with the general public, of the fire danger rating system in general.

METHODS

Study Regions and Stations

Analyses were conducted using historical DC records calculated from fire weather observations collected by the network of weather stations across the country. These automatic weather stations comprise the fire weather network used to monitor fire danger conditions (Majorhazi 2003), and that has formed the basis for development of a fire danger climatology database used to describe the fire climate of New Zealand (Pearce 1996, Pearce *et al*. 2003) and effects of climate variability (Pearce *et al*. 2007) and future climate change (Pearce *et al*. 2005) on fire danger. The stations used were a mix of Meteorological Service of New Zealand (MetService), National Institute of Water and Atmospheric Research (NIWA) and rural fire authority weather stations from which data are downloaded and archived by the National Rural Fire Authority (NRFA).

Rather than attempt to investigate trends for all of the 170+ weather stations in the fire weather network, it was decided to focus on stations in drier regions of the country which were considered to be more likely to have experienced increases in DC values due to a lack of annual re-setting or carry-over issues. Areas identified were the Eastern North Island, Wairarapa, Marlborough, Canterbury, South Canterbury and Otago, where drought or elements of drought, including over-winter rainfall deficiencies, were thought more likely to occur and therefore to have contributed to possible increases in DC values.

A limited number of long-term stations in these regions with record lengths greater than 20 years meant that a number of additional stations with lengths of record between 10 and 15 years were also included. These shorter-term stations provided increased coverage within the regions being investigated, and also aided in determining whether any trends identified for the longer term stations were representative of the trends across each region. Within the six regions, 31 stations (of the 85 potentially available) were used in the subsequent DC analyses (see Table 2 and Fig. 5). Although not a drought-prone region, the West Coast station of Hokitika Aero (HKA) was also included in the analysis for comparative purposes. It is located in a known high rainfall region where soil layers would be expected to be recharged each year, and therefore annual DC values would not be expected to show an increase over time due to carry-over issues.

Like previous studies (Pearce and Moore 2004, Pearce *et al*. 2007), it was also assumed for the purposes of this investigation that the ‘fire year’ runs from July 1st to June 30th, and monthly analyses commenced from July as month 1.

Table 2. Weather stations included in the analysis of Drought Code (DC) trends, with comparative lengths of record, annual rainfall and fire climate severity rank (from Pearce *et al.* 2003). (Long-term stations with 20+ years of record are highlighted in bold).

Station	Name	Region	Length of Record (years)	Annual Rainfall (mm)	Fire Climate Severity Rank
GSA	**Gisborne Aero**	**Eastern**	**44**	**1012**	**8**
MGF	Mangatu Forest	Eastern	12	1349	85
NRA	Napier Aero	Eastern	12	907	7
WPK	Waipukurau	Eastern	12	751	16
NMU	Ngaumu	Wairarapa	13	1061	28
STO	Stoney Creek	Wairarapa	11	1238	57
HWT	Holdsworth Station	Wairarapa	12	1655	94
MSX	East Taratahi	Wairarapa	15	1072	34
KIX	**Kaikoura**	**Marlborough**	**42**	**824**	**45**
OSN	Opua Bay	Marlborough	13	1277	91
WBA	Woodbourne Aero	Marlborough	15	792	2
AWN	Awatere Valley	Marlborough	12	583	1
MLX	Molesworth[10]	Marlborough	14	611	4
RAI	Rai Valley	Marlborough	10	2041	80
CHA	**Christchurch Aero**	**Canterbury**	**46**	**629**	**3**
SDN	Snowdon	Canterbury	13	1056	31
FPL	Darfield	Canterbury	13	661	10
BTL	Bottle Lake	Canterbury	13	520	37
HAN	Hanmer	Canterbury	10	915	30
BML	Balmoral	Canterbury	12	542	9
ASH	Ashburton Plains	Canterbury	12	697	47
TUA	Timaru Aero	South Canty	15	770	24
CAN	Cannington	South Canty	12	559	62
THE	Tara Hills	South Canty	15	533	13
OUA	Oamaru Aero	South Canty	15	804	56
QNA	**Queenstown Aero**	**Otago**	**28**	**827**	**55**
WFA	Wanaka	Otago	12	778	14
LAE	Lauder	Otago	15	463	15
DNP	Dansey Pass	Otago	12	555	6
RNP	Rock and Pillar	Otago	10	518	12
DNA	**Dunedin Aero**	**Otago**	**43**	**700**	**42**
HKA	**Hokitika Aero**	**West Coast**	**42**	**2852**	**123**

[10] Molesworth (MLX) station records exclude periods of missing data from Sept. 1994 to July 1997. Despite this, the station still has a length of record of 10 years.

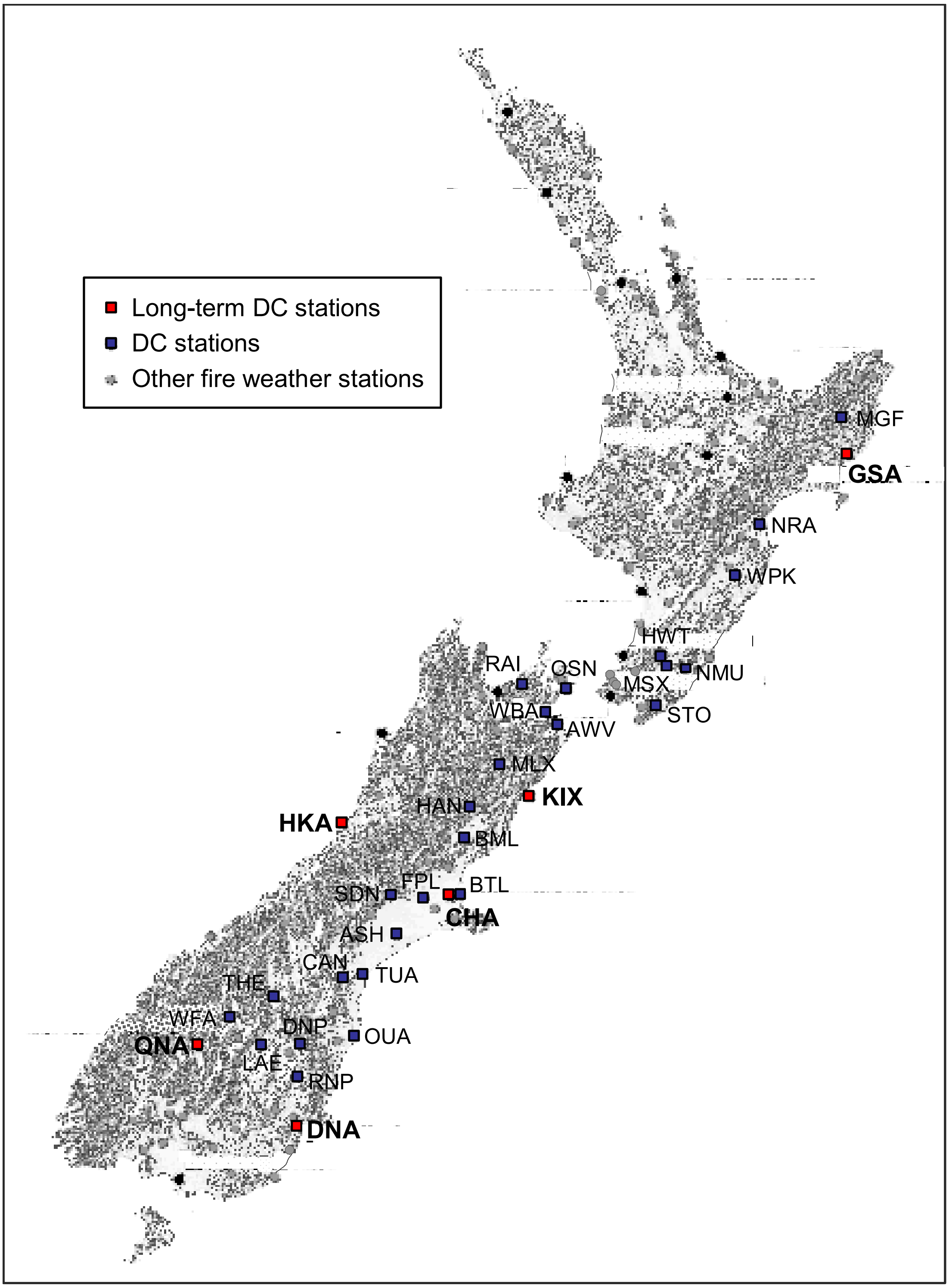


Figure 5. Weather station coverage (●) included in the national fire weather monitoring network, and long- and shorter-term (■) stations included in the current Drought Code (DC) analysis. See Table 2 for station details.

Graphical Trend Analysis

To gain an initial appreciation of whether DC values were changing over time, the annual cycle of DC values at each of the long-term stations was reviewed. This included six stations (see Table 2): Gisborne Aero (GSA), Kaikoura (KIX), Christchurch Aero (CHA), Queenstown Aero (QNA) and Dunedin Aero (DNA), in addition to Hokitika Aero (HKA). Linear trend lines were fitted through plots of the annual cycles in daily DC values for each station to identify whether a trend was apparent.

It was recognised from the outset that such general analyses of annual cycles in daily DC data were insufficient to provide statistical evidence of identified trends, and that more detailed analyses of average monthly (or perhaps 3-month climate season) DC values were necessary. Maximum DC values could also provide a means of indicating whether DC values are changing over time, by highlighting whether higher DC values are becoming more common. Due to the interest in this particular study in whether DC values are "re-zeroing" each year, another approach was to use minimum DC values for subsequent trend analyses rather than averages. Mean, maximum and minimum values of the DC for a particular location follow very similar annual trends (Fig. 6), although can vary significantly from place to place. For the purposes of this study, where the focus was on comparing the DC for a particular period with values for the same period in subsequent years, it was considered that the mean DC value provided a sufficiently representative value to enable comparison of trends across years. Use of monthly data (over 3-month climate seasons) was also favoured due to the simplicity of computation (using pivot tables within Microsoft Excel).

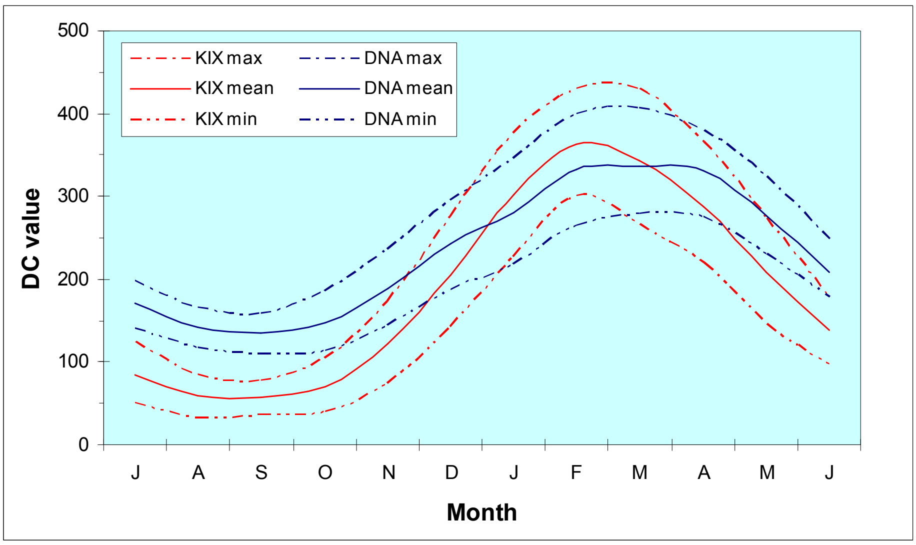


Figure 6. Comparison of monthly mean, maximum and minimum Drought Code (DC) values for two stations – Dunedin and Kaikoura.

However, due to the advantage of providing additional information on possible DC carry-over or re-setting issues, analyses of maximum and minimum monthly DC trends for the six long-term stations were also included for comparison with the broader trends identified using mean monthly DC values. [The minimum DC values for each long-term station were also subsequently used to investigate if and when DC values fell below recognised fire season start-up values. Maximum DC values were also used to investigate whether the frequency of above-average values of the DC was changing over time].

Linear trend lines were used to highlight any trends occurring in the monthly DC values. This approach fits a straight line to the data with the form:

$$\mathrm{DC} = a + b\,(\mathrm{year}) \qquad [7]$$

where DC = monthly Drought Code (i.e., mean, maximum or minimum), a = the y-intercept, and b = the slope of the fitted trend line. The b value, in particular, shows how much the slope of the trend line is changing, with a positive value indicating an increase and a negative value a decrease in monthly DC over time.

Statistical Analysis of Observed Trends

Testing of the statistical significance of trends observed from the graphical analyses was carried out using an analysis of variance (ANOVA) to test whether monthly means for each month at each station were changing over time. In addition to providing a value for the slope *(b*), the y-intercept (*a*) and an R^2 value describing the goodness of fit of the fitted trend line, the ANOVA also provides a *p*-value describing the probability that the fitted trend line describes the observed trend in the data. In this instance, trends were deemed statistically significant when $p < 0.05$.

The Durbin-Watson test (Durbin and Watson 1950) was also used to detect the occurrence of autocorrelation between subsequent mean monthly values within the DC record. Autocorrelaton describes whether a value is dependent on those that come before it (i.e., X_t dependent on X_{t-1}); in this case, whether the average monthly DC value for a particular year is dependent on the previous year's average DC value for the same month. In data sets of this type, temporal autocorrelation can be an issue affecting statistical testing. The presence of temporal autocorrelation leads to underestimation of regression coefficient standard errors, invalidating normal statistical hypothesis tests (West *et al*. 1984). Daily DC values are temporally autocorrelated as the daily value is calculated from the DC value for the previous day. Due to the long (53 days) timelag for the DC, values in subsequent months, and perhaps years, could also be expected to show some auto-correlation. However, analyses using the Durbin-Watson test showed that temporal autocorrelation in monthly DC values was absent at all sites with the exception of Woodbourne Aero and Wanaka. As a result, temporal autocorrelation was not deemed to be a major factor affecting the statistical testing of the fitted trend lines and was not considered in subsequent analyses.

Fire Season Maximum Values

In addition to determination of trends in maximum monthly values at each of the six long-term stations, fire season maximum values were also investigated to determine if the frequency of above-average DC values was changing over time. For each station, a count was made of the number of days in each fire season that DC values exceeded threshold values of 300, 400 and 500. These thresholds were chosen based on the range in DC values observed at the long-term stations, and for simplicity. However, the values also have some correspondence with recognised fire management “trigger points” for the DC (see p. 6). Linear trend lines were then fitted through plots of the seasonal “frequency of exceedance” for each threshold at each station.

Fire Season Minimum Values

Minimum monthly DC values were also used to identify possible trends in DC values using the same approach as for mean and maximum DC values. However, in addition, the minimum DC values for each long-term station were also used to investigate in which months the lowest minimum values occurred, and for how many years minimum DC values fell below the recognised fire season start-up value (of 15; after Anon 1993). This was done by determining the minimum DC value and date of occurrence for each year of record at each long-term station.

The dates of minimum DC occurrence were then used to compare the most common months in which these minimum values occurred at each station, and whether there was any evidence that this was changing over time. The minimum DC values were also used to determine how frequently, if at all, DC values fell below the standard DC start-up value (of 15) recognised as representing complete recharge (i.e., saturation) of the deep, compacted organic layer within the soil profile represented by the DC.

RESULTS

General Trends in DC Values

Graphing of the seasonal trend cycles in daily DC values for each of the stations with long-term records (Fig. 7) shows that, even at the most general level, there is some evidence that DC values are increasing over time. However, these increases are very small, and are not likely to be statistically significant. [Statistical testing was not undertaken due to the autocorrelation between daily DC values, and limitations of fitting a linear trend line to this highly variable, cyclic DC data.]

The rates of increase were different for each station, but in all cases were relatively small at less than 0.01 points of the DC per day (or at most, 2.7 points per year) (Table 3). Queenstown (QNA) had the greatest increase, with a slope value of 0.0073 points per day, whereas Gisborne (GSA) showed the least increase with 0.00004 points per day. However, even these increases are noteworthy, as they equate to rises in DC values by 0.015 to 2.66 points per year or, in the case of Kaikoura (KIX), an increase of 103 points over the 42 years of record for this station. Interestingly, Hokitika Aero (HKA) showed a decreasing trend over its period of record, although the rate of decrease was again very small and unlikely to be significant.

Table 3. Summary of observed trends in daily Drought Code (DC) values for stations with long-term records.

Station	Region	Length of record	Slope (b)	R^2-value	Points per year*
QNA	Otago	28	0.0073	0.0301	2.6645
KIX	Marlborough	42	0.0067	0.0358	2.4455
CHA	Canterbury	46	0.0015	0.0017	0.5475
DNA	Otago	43	0.0010	0.001	0.3650
GSA	Eastern	44	0.00004	0.0000002	0.0146
HKA	West Coast	42	-0.0003	0.0019	0.1095

* Calculated by multiplying the slope by 365 days in a year.

The low R^2 values, which indicate the “goodness of fit” of the fitted trend line, are not unexpected due to the variability of the annual cycles of DC values compared to the straight line trend. The use of annual or shorter term averages for each year of record (as opposed to daily values in the case of annual cycles) would be expected to show a better fit (i.e., with R^2 values closer to 1.0); however, previous analyses have shown that it is difficult to describe the “average” for fire danger ratings (Pearce 1996, Pearce *et al.* 2003). Therefore, more detailed analyses of monthly data were conducted.

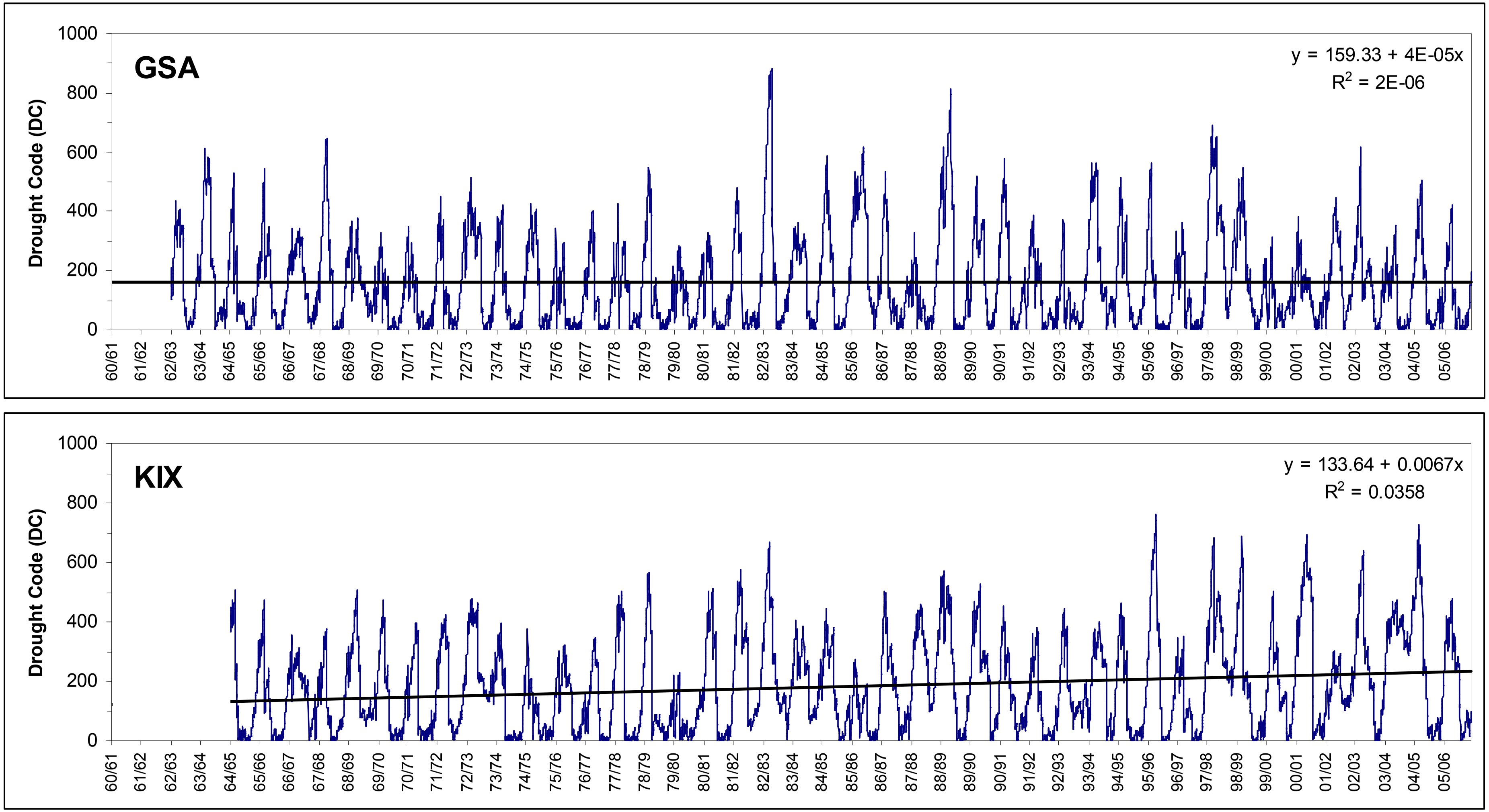


Figure 7. Trends in daily DC values over time for the six stations with long-term records (cont. over).

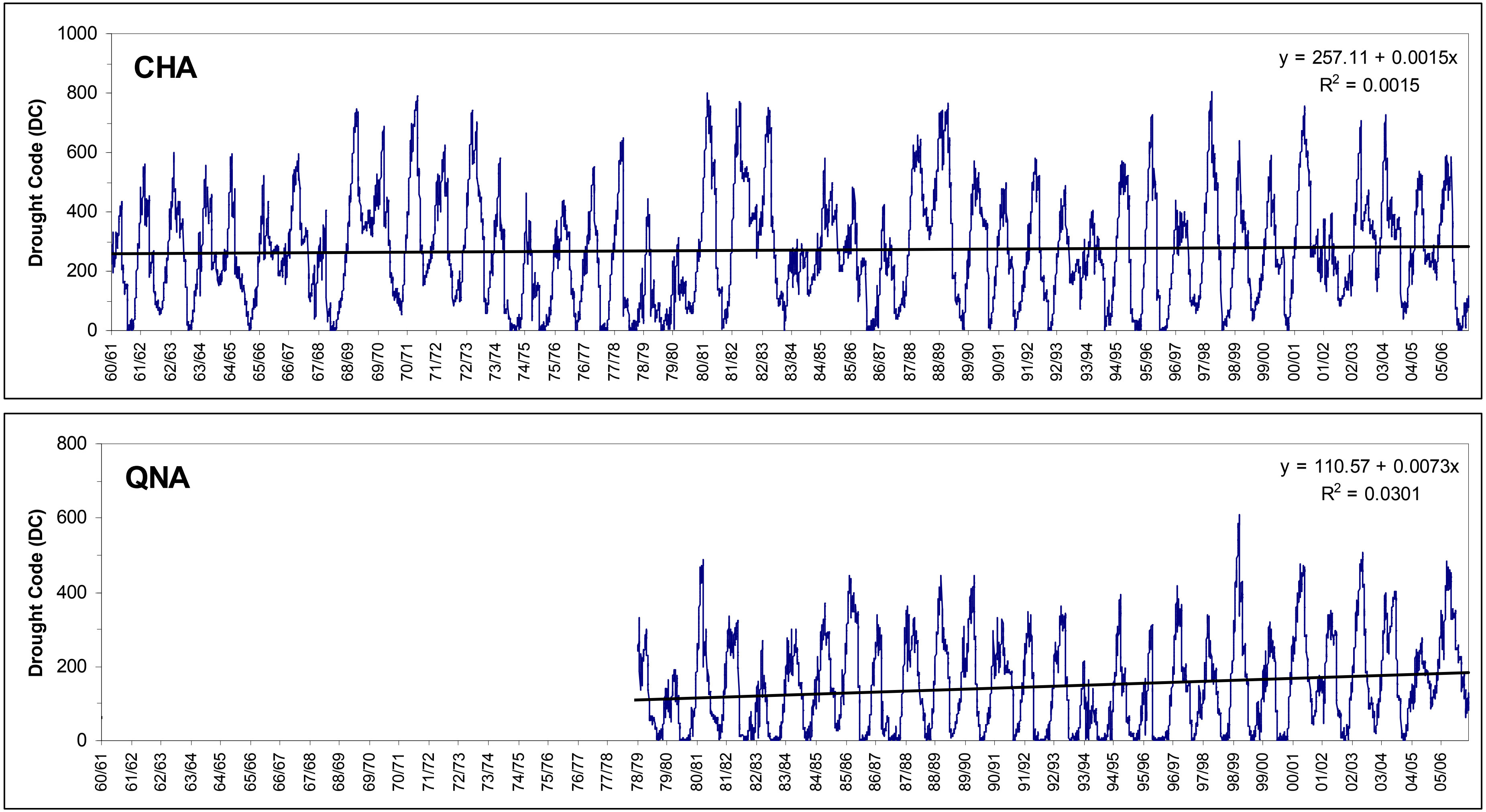


Figure 7. Trends in daily DC values over time for the six stations with long-term records (cont. over).

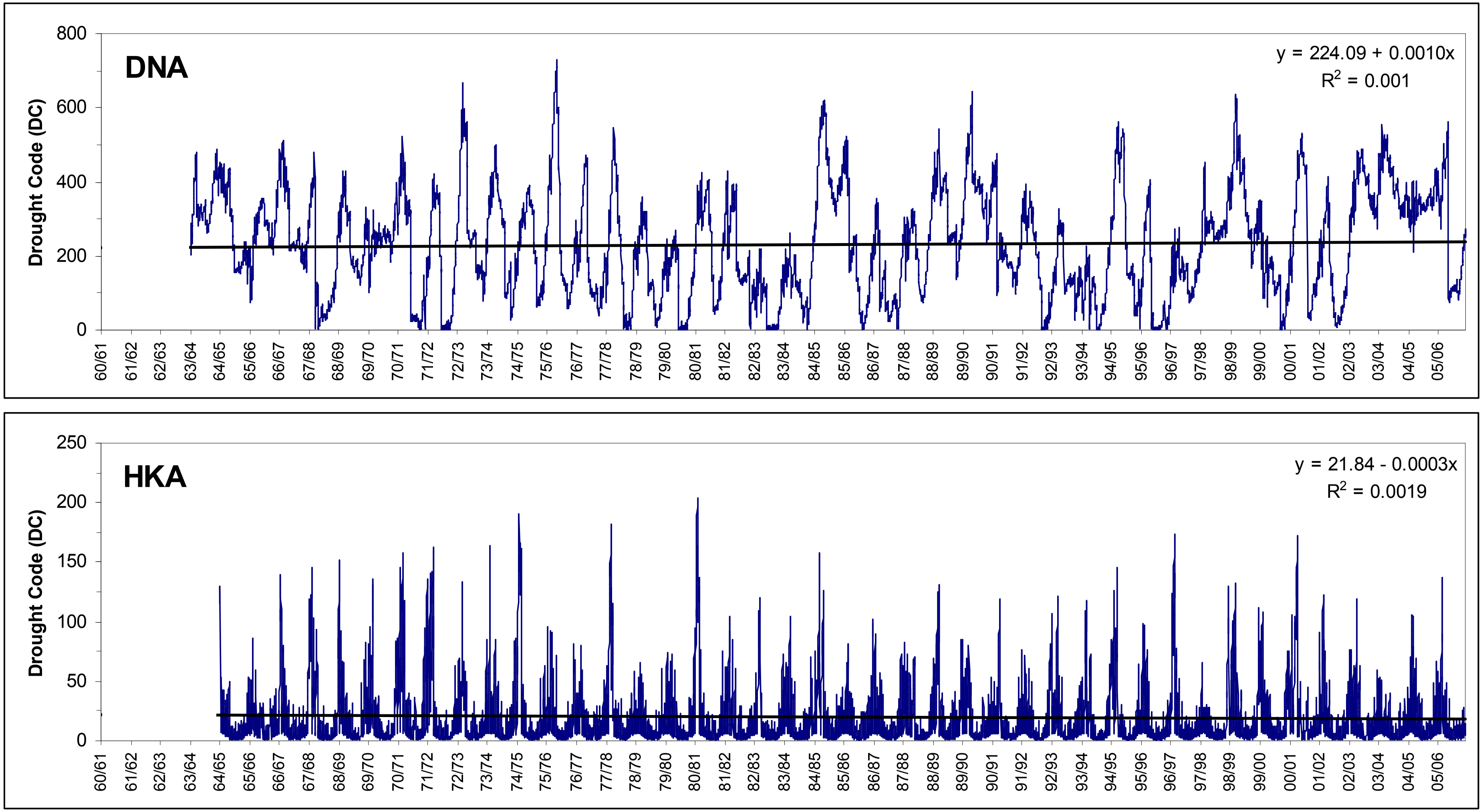


Figure 7. Trends in daily DC values over time for the six stations with long-term records.

Trends in Monthly DC values

Mean monthly DC values

Analysis of trends in the DC values using monthly mean values for each month produced more variable results than indicated by the general trends in daily values. In addition to the long-term stations, analyses were conducted on a further 26 stations with record lengths between 10 and 15 years from the five regions of the country investigated (see Table 2). These stations were not included in the previous analysis due to insufficient lengths of record, but were added here to gain better coverage of the regions being investigated and to ascertain whether any trends identified for the longer term stations were representative of the broader trend within each region.

Trends in monthly DC values from the additional 26 stations were compared to those observed at the long-term station(s), where present. Results again indicated that there is some evidence that DC values are changing over time. However, the observed trends (Figs. 8-14)[11] varied greatly from region to region, between stations from the same region, and from month to month for individual stations. In some cases, DC values were observed to increase over time, while in others they were found to decrease. Very few months were found to have trends that were statistically significant at the 5% level ($p < 0.05$), and those that were are highlighted in Appendix 1. As such, it is extremely difficult to be conclusive about general trends for a particular station or region, or even for the DC as a whole.

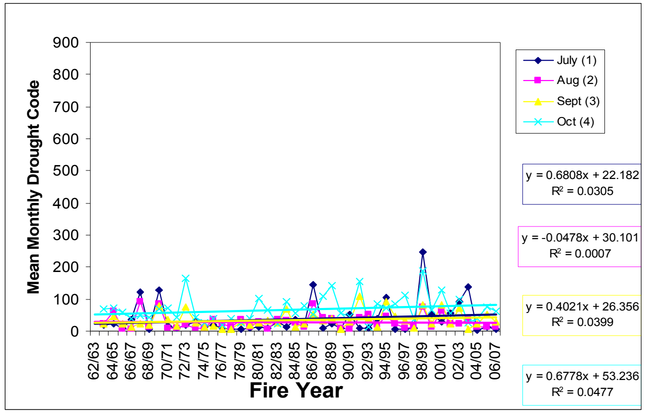
In the Eastern North Island region, all four stations included months where DC values both increased and decreased over time. However, only three months (out of the possible 48) were found to be statistically significant (see Appendix 1). These included November and December for Waipukurau (WPA), where DC values decreased over time (Fig. 8), and September for Mangatu Forest (MGF), where DC values have increased. Both Gisborne Aero (GSA) (Fig. 8) and Napier (NRA) had months where values variously increased and decreased, but none of these trends were found to be statistically significant. For winter months and those leading up to the start of the fire season (i.e., June through October), although not statistically significant, DC values tend to have increased over time in the north of the region (GSA and MGF) but decreased in the south (NRA and WPK), so that there is no clear trend for the region as a whole.

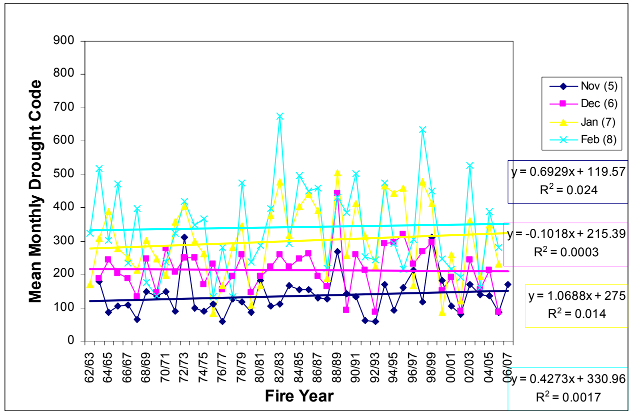
Within the Wairarapa region, the graphical analyses indicated differences in observed trends between stations close to the coast and those further inland. The coastal stations of Ngaumu (NMU) (see Fig. 9) and Stoney Creek (STO) had months where DC values mainly decreased over time. However, NMU was the only station in the region to have months indicating statistically significant trends, in November and December (see Appendix 1), similar to WPK in the Eastern region. For the more inland stations of East Taratahi (MSX, located near Masterton) (Fig. 9) and Holdsworth Station (HWT), DC

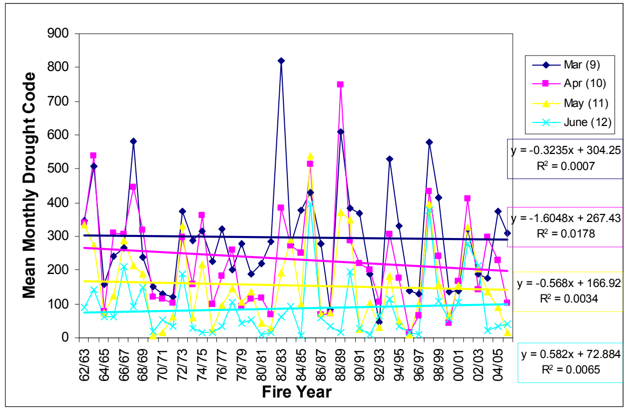
[11] Note that the graphs for all stations are not included, and trends for only two stations are included for illustrative purposes for each region.

Months – Jul/Aug/Sep/Oct	Months – Nov/Dec/Jan/Feb	Months – Mar/Apr/May/Jun

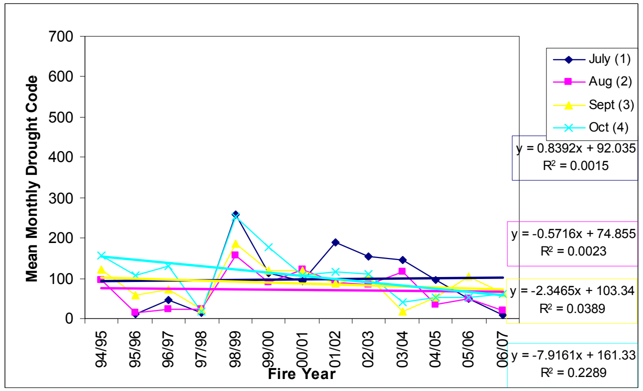
Gisborne Aero (GSA)

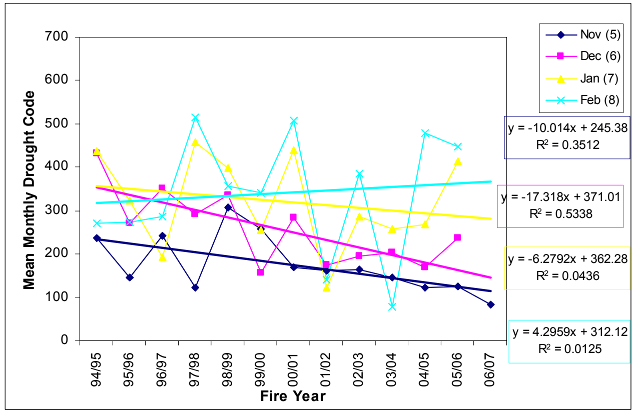






Waipukurau (WPK)





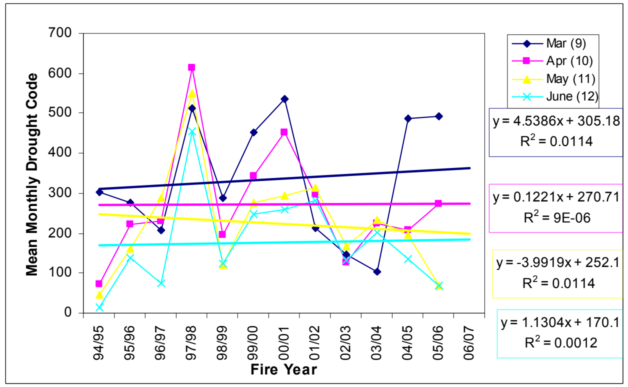


Figure 8. Observed trends in mean monthly DC values for two stations in the Eastern North Island region – Gisborne Aero (GSA) and Waipukurau (WPK). Each graph contains the data and fitted trend lines for four months of the year (grouped for convenience).

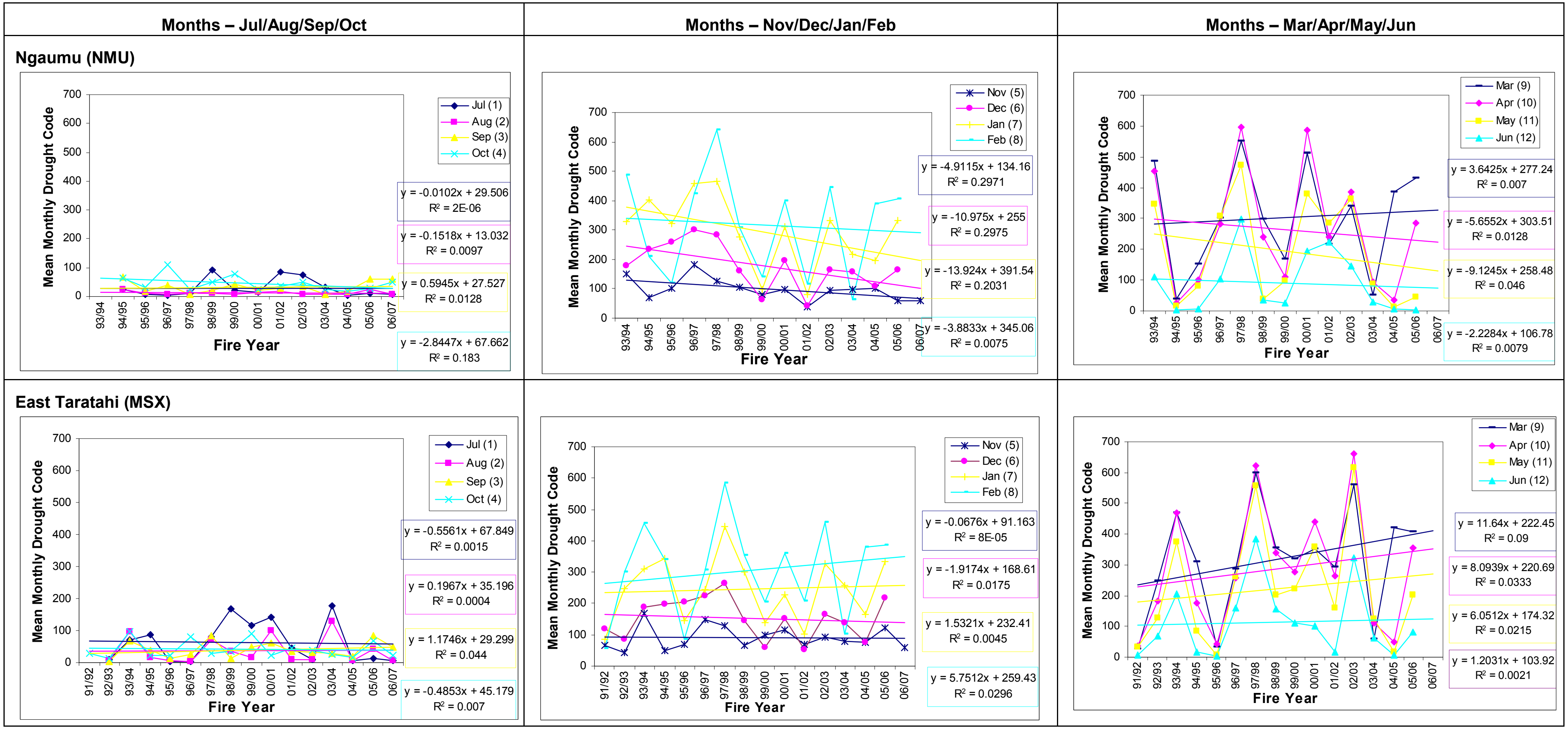


Figure 9. Observed trends in mean monthly DC values for two stations in the Wairarapa region – Ngaumu (NMU) and East Taratahi (MSX). Each graph contains the data and fitted trend lines for four months of the year.

values in most months increased over time, but trends were not statistically significant. For months over winter and leading up to the start of the fire season, DC values in this region have decreased over time in coastal areas (NMU and STO), but don't show any definitive trend in inland areas (HWT and MSX) where values have decreased in some months but increased in others.

In the Marlborough region, most of the stations showed significant increases in mean monthly DC values for several months (see Appendix 1). This was particularly the case for Kaikoura (KIX), where 6 months showed statistically significant increases and the remaining months also indicated increasing DC values over time (Fig. 10). Molesworth (MLX), which had 9 months with significant trends, and Woodbourne Aero (WBA) with 5 significant months (Fig. 10), also both showed general increases across all months. Opua Bay (OSN), Awatere Valley (AWV) and WBA demonstrated increases for months during winter and/or spring (as also did KIX and MLX). Rai Valley (RAI), however, which is located more west than the other stations investigated in the region, did not show any months with statistical increases and had an equal number of months with non-significant decreasing and increasing trends. April was the only month not to be statistically significant across all stations in this region.

The potential for high summer DC values to be carried through into the following winter and next fire season is apparent in the data for Woodbourne Aero (WBA) (Fig. 10), where high DC values during summer (Nov-Feb) 2000/01 (middle graph, were carried through the subsequent winter period (Mar-Jun 2001) (right-hand graph) and into the following spring (Jul-Oct 2001) (left hand graph). This season was associated with the 2000 Boxing Day fires near Blenheim, when daily DC values at the nearby Awatere Valley station (*cf*. monthly averages for WBA shown in Fig. 10) exceeded 1000 and reached a maximum of more than 1200 later in the summer. These elevated values continued through into July, August and September 2001, when DC values were still averaging around 400.

The Canterbury region was unusual in that it was the only one in which no stations had months with statistically significant trends (Appendix 1), perhaps as a result of the greater variability in the monthly DC values from year to year (e.g., CHA in Fig. 11 *cf*. GSA in Fig. 8). Stations in the region also demonstrated a mix of non-significant increasing and decreasing mean monthly DC trends. Balmoral (BML) (Fig. 11) with 9 months, followed by Hamner (HAN) with 6 months, had a majority of months trending downwards; this included December which was found to be decreasing for six out of seven stations in the region. For Christchurch Aero (CHA) (Fig. 11), DC values in the months October to December tended to decrease, whereas other months increased. In general, DC values at most stations in the region tended to increase slightly over time for the months over winter and leading up to the beginning of the fire season (i.e., July to October).

In the South Canterbury region, trends in mean monthly DC values at most stations were again not statistically significant (Appendix 1). The exception was Oamaru Aero (OUA) (Fig. 12), which showed significant increases in

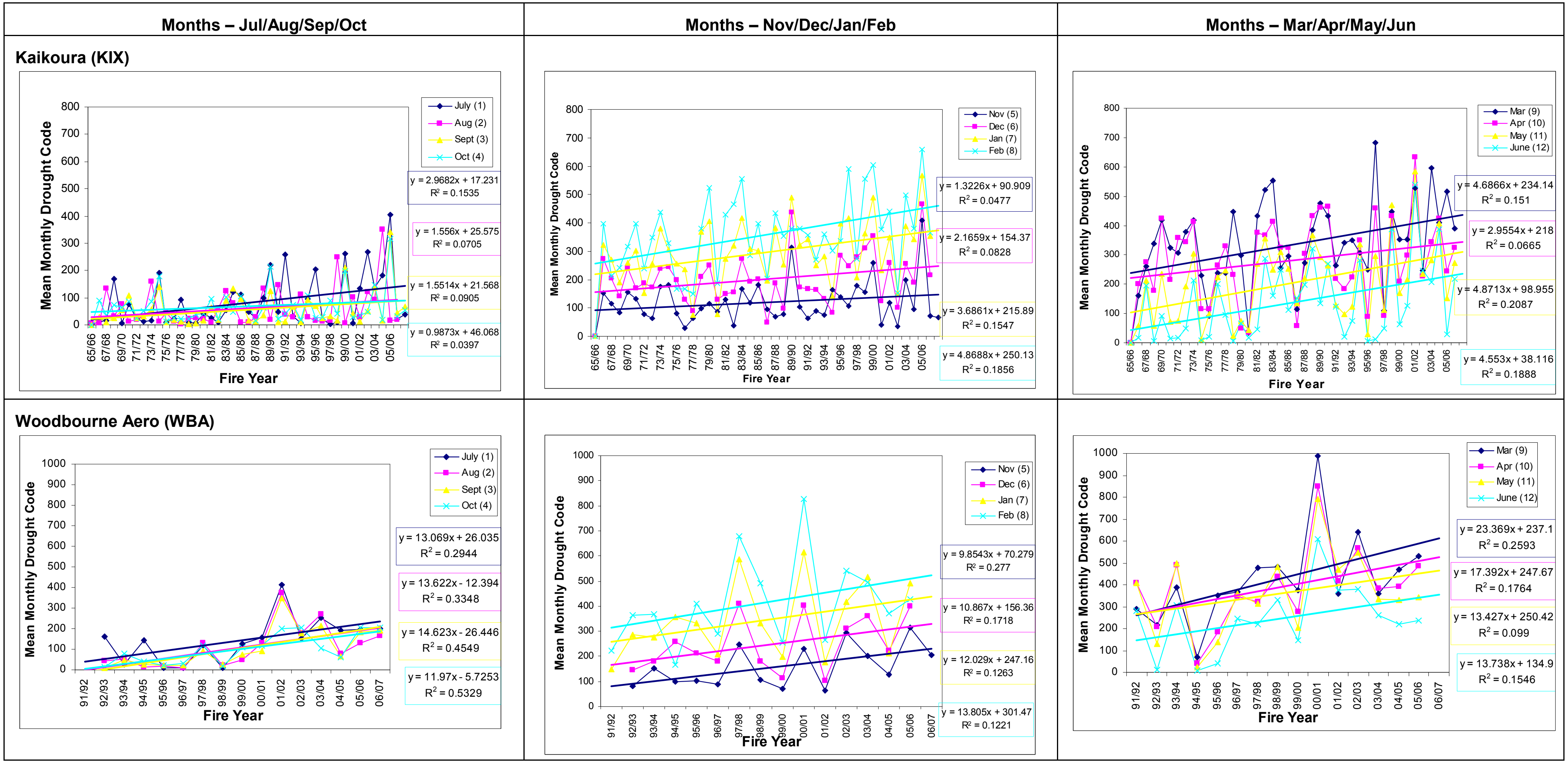
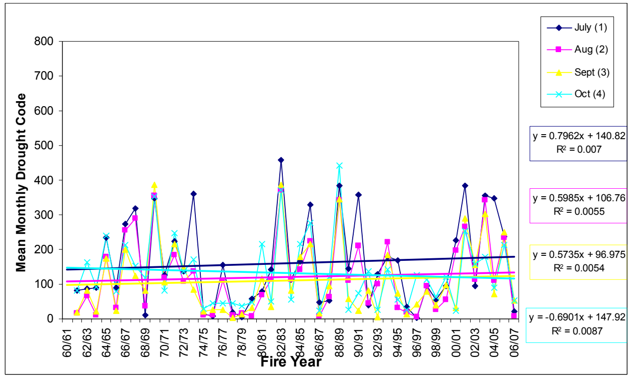
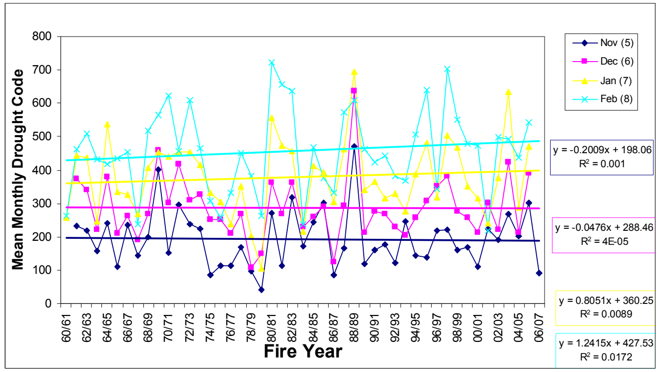


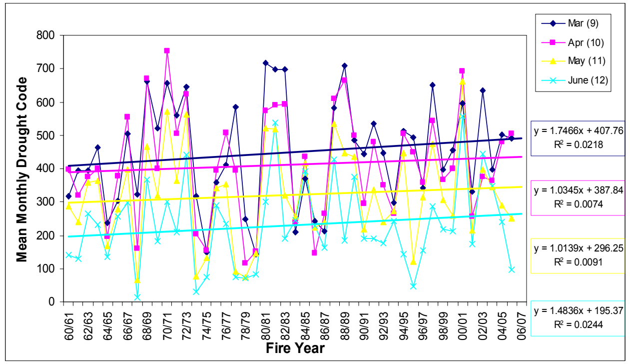
Figure 10. Observed trends in mean monthly DC values for two stations in the Marlborough region – Kaikoura (KIX) and Woodbourne Aero (WBA). Each graph contains the data and fitted trend lines for four months of the year.

Months – Jul/Aug/Sep/Oct	Months – Nov/Dec/Jan/Feb	Months – Mar/Apr/May/Jun

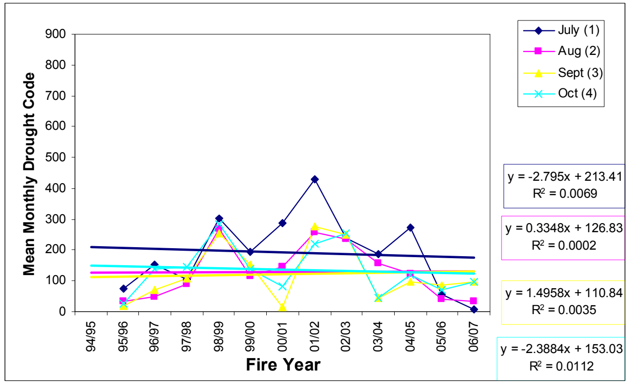
Christchurch Aero (CHA)

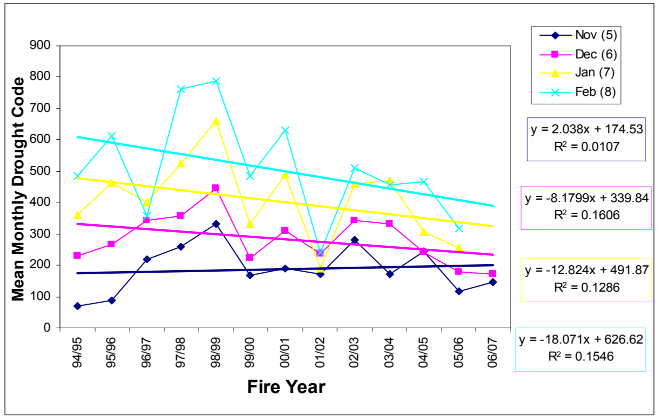






Balmoral (BML)





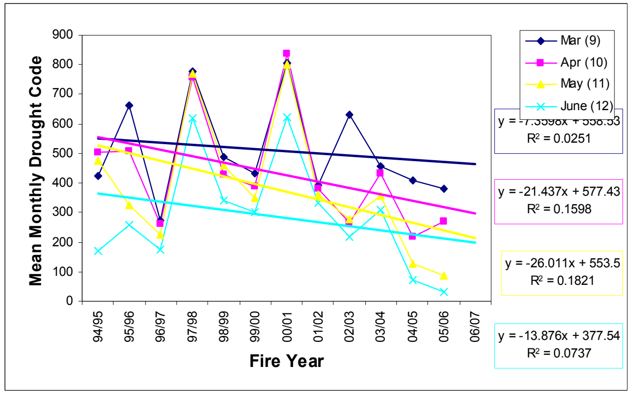


Figure 11. Observed trends in mean monthly DC values for two stations in the Canterbury – Christchurch Aero (CHA) and Balmoral Forest (BML). Each graph contains the data and fitted trend lines for four months of the year.

monthly DC values in all months except May. April had the greatest increase, with a slope of 29 DC points per year, while the minimum increase for the rest of the months was 14 DC points per year at this station. Tara Hills (THE) showed significant increases over time for November and December, while Timaru Aero (TUA) and Cannington (CAN) did not show any evidence of significant trends in any months. CAN was the only station in the region to have months (December, January and February) with decreasing trends and, while not significant, DC values for all months at the other stations generally increased.

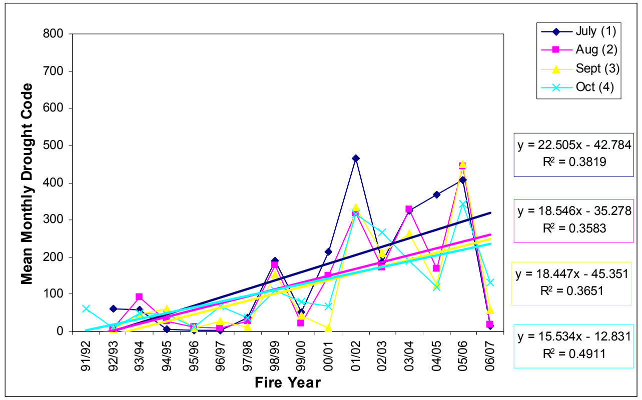
The Otago region also generally showed increases in mean monthly DC values in most months at most stations, with the exception of Rock and Pillar (RNP) which showed decreases in 8 out of the 12 months (Appendix 1). Queenstown Aero (QNA) and Dunedin Aero (DNA) also showed slight decreases during January and/or February (Fig. 13). However, these trends were only statistically significant for the inland stations (QNA, Wanaka (WFA) and Lauder (LAE)), and the more costal stations (DNA, RNP and Dansey Pass (DNP)) did not show significant trends in any month. January and February were the only months for this region not to show significant changes.

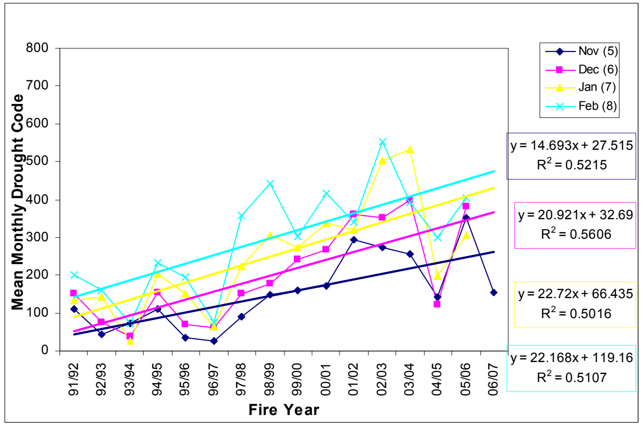
There was also some evidence from several of the stations in the Otago region of more significant increases in DC values over the last 4-6 years than indicated by the general trend over the full length of record. For example, QNA (Fig. 13) showed evidence of a significant upward trend for the months July to September, with mean monthly DC values increasing by more than 100 points in each case over the last four years. There is also a suggestion that the upward rate of change in mean monthly DC values is increasing with each additional year of record over this period (2002/03 to 2006/07). This sudden increase within the last decade can also be seen in the Marlborough region at, for example, Kaikoura (KIX; see Fig. 10) and Opua Bay (OSN; not shown), as well as at Oamaru (OUA; see Fig. 12) in the South Canterbury region, albeit for a slightly earlier period (1997/98 to 2001/02).

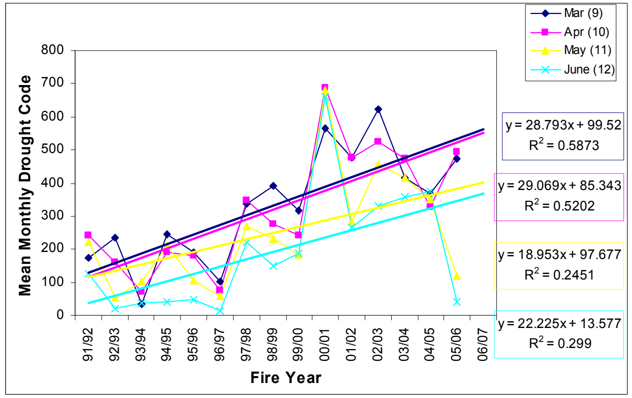
The Hokitika (HKA) station was also included in the analysis as a high rainfall station for comparison against stations from predominantly drier parts of the country. It was expected to show little, if any, evidence of either increasing or decreasing trends due to the high rainfall ensuring "re-setting" of DC values in most years. The majority of trends indicated were not statistically significant, although the slight decrease observed for June was highly significant ($P = 0.0006$) (Appendix 1). Mean monthly DC values for July and the autumn period (March, April and May) did show very small (but non-significant) upward trends, whereas remaining months showed (non-significant) decreases over time (Fig. 14). Results for HKA were not unlike stations in the Eastern and Wairarapa regions, where individual months showed both increasing and decreasing trends, although the changes indicated for HKA were generally smaller. This may be due to the smaller range in DC values and generally more consistent annual pattern (less seasonal variability, with fewer peaks and troughs) seen at HKA (see Fig. 7) compared with other stations.

Months – Jul/Aug/Sep/Oct	Months – Nov/Dec/Jan/Feb	Months – Mar/Apr/May/Jun

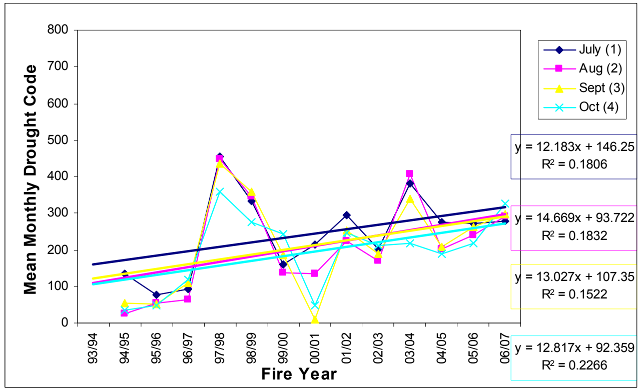
Oamaru Aero (OUA)

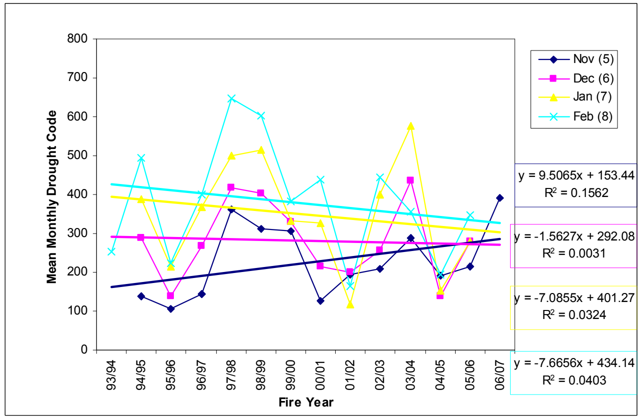






Cannington (CAN)





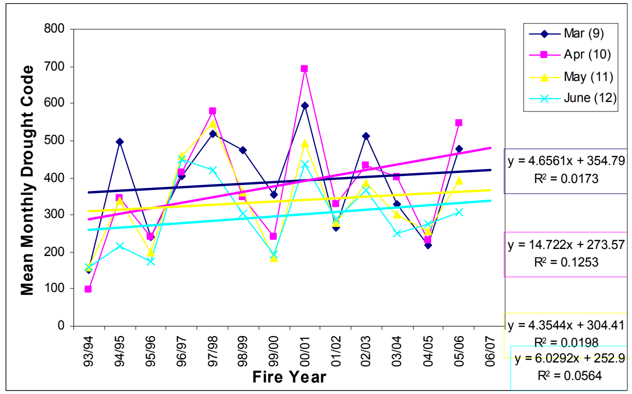


Figure 12. Observed trends in mean monthly DC values for two stations in the South Canterbury region – Oamaru Aero (OUA) and Cannington (CAN). Each graph contains the data and fitted trend lines for four months of the year.

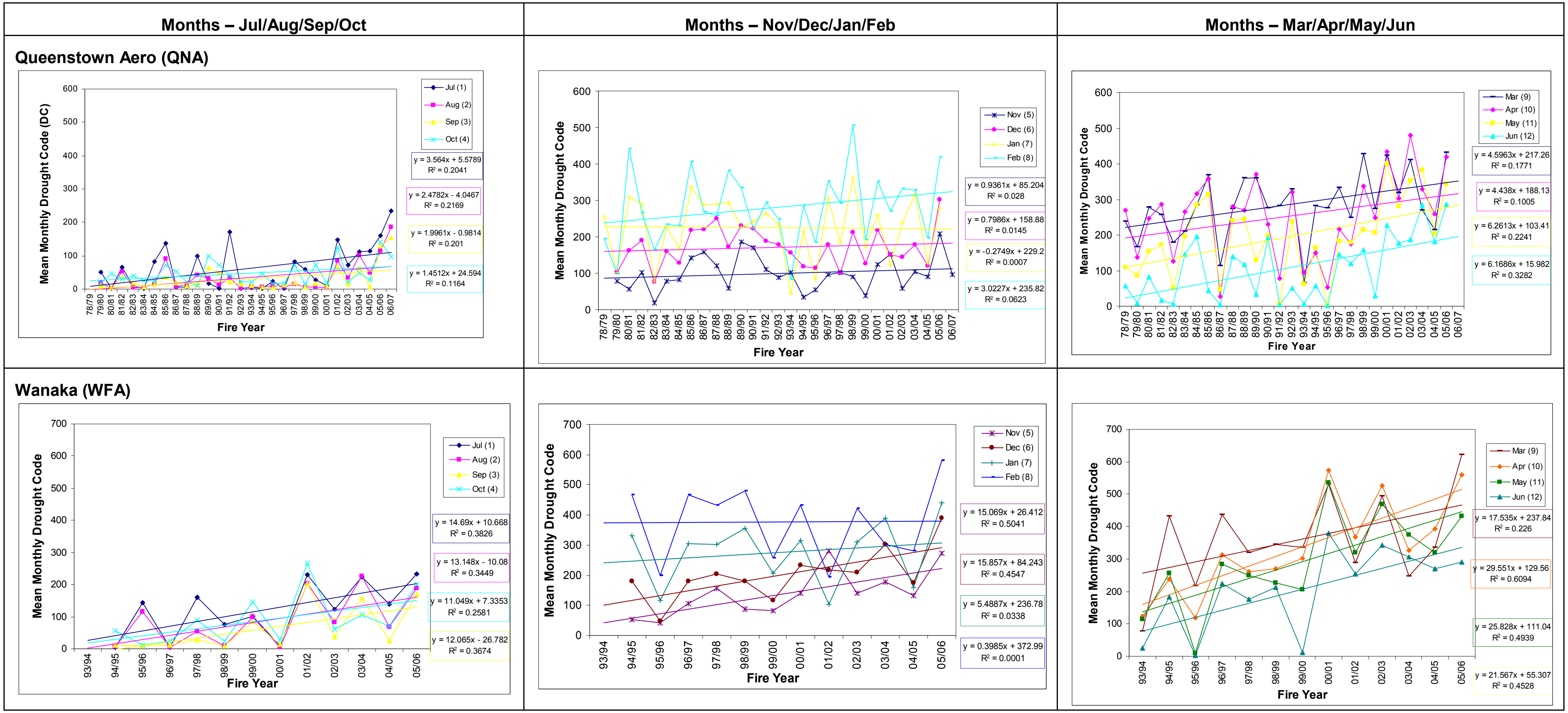
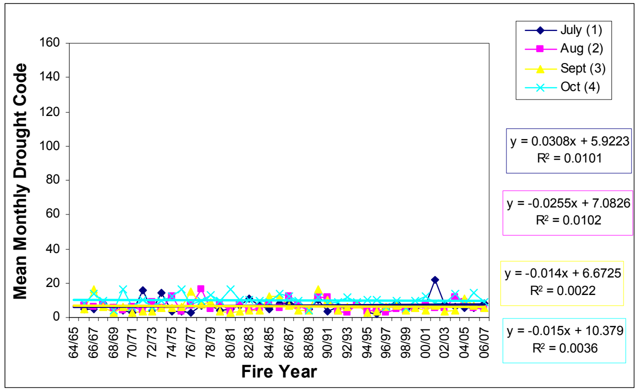
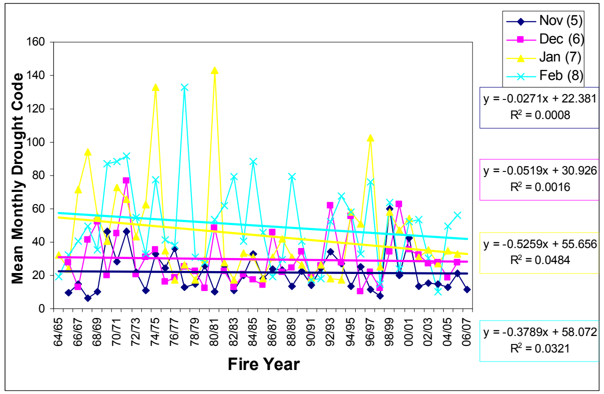


Figure 13. Observed trends in mean monthly DC values for two stations in the Otago region – Queenstown Aero (QNA) and Wanaka (WFA). Each graph contains the data and fitted trend lines for four months of the year.

Months – Jul/Aug/Sep/Oct	Months – Nov/Dec/Jan/Feb	Months – Mar/Apr/May/Jun

Hokitika Aero (HK)





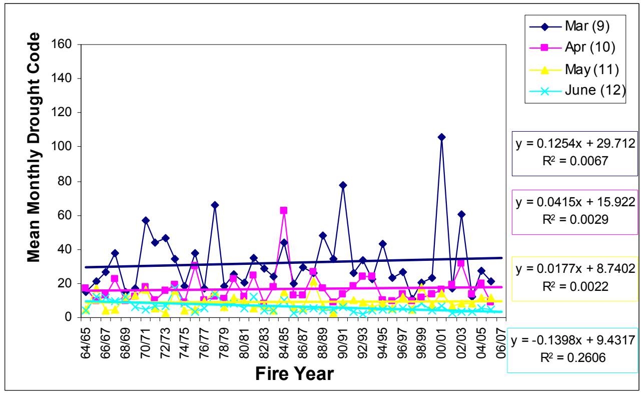


Figure 14. Observed trends in mean monthly DC values for the Hokitika Aero (HKA) station on the South Island's West Coast. Each graph contains the data and fitted trend lines for four months of the year.

Maximum monthly DC values

Observed trends in the maximum (as opposed to mean) monthly DC values for the six long-term stations are shown in Appendix 2. In general, the trends were very similar to those observed for mean monthly DC values (Fig. 15; also see Appendix 1), with only minor differences in the slope of the fitted trend lines and number of months indicating statistically significant trends.

For Gisborne Aero (GSA), slopes of trend lines observed for maximum monthly DC values were generally similar to those for monthly means although, like means, none of these were statistically significant (at $p < 0.05$). Both maxima and means showed the same mix of negative (i.e., decreasing) and positive (i.e., increasing) slopes, although the months with each trend direction were slightly different (see Fig. 15).

Kaikoura (KIX) also showed similar trends for maxima as found for means, again indicating increases (positive slopes) in all months. However, in the case of maxima, only 5 months showed significant trends compared with 6 for mean monthly values (with the increase indicated for January no longer significant).

For Christchurch Aero (CHA), slope values were generally slightly lower for maxima than for mean values, although again none of these were statistically significant. In both cases slopes were generally positive (increasing), although the months October to December showed decreasing trends in both instances.

Queenstown Aero (QNA), which had shown strong upward trends for mean monthly DC values, demonstrated very similar trends for maximum values (see Fig. 15). However, the increasing trend was statistically significant for one less month using maxima and the months showing these significant trends were slightly different (April and June-September *cf*. March and May-September for means).

The slopes of the trend lines for maximum monthly values at Dunedin Aero (DNA) were also generally very similar to those for mean values, but were generally low and again not statistically significant. However, the direction of the trends using maxima was different in some months, with 3 months indicating decreasing trends (*cf*. 2 for mean values).

Hokitika Aero (HKA) also indicated a mix of increasing and decreasing trends, although one fewer month had a negative slope for maximum values than for means. However, 2 months showed statistically significant trends using maxima (January and June), compared with just one for mean values, although these were still decreasing trends in both cases.

The similarity of trends observed for maximum versus mean monthly DC values therefore indicated that there was nothing to suggest that monthly trends for maximum values at other short-term stations would be any different than those illustrated for monthly mean values.

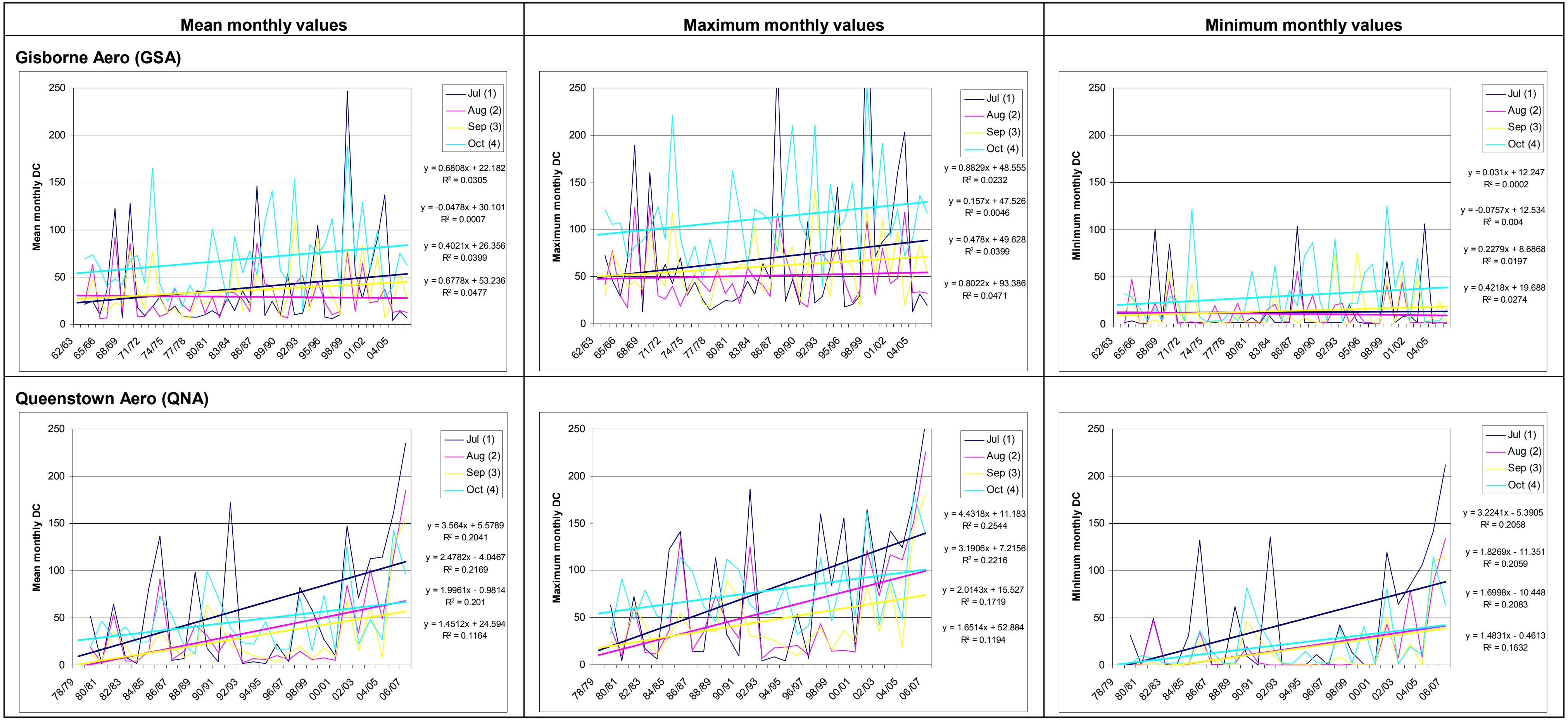


Figure 15. Comparison of observed trends for mean monthly DC values for the months July to October with trends in the same months for maximum and minimum monthly values at two stations – Gisborne Aero (KIX) and Queenstown Aero (QNA).

Minimum monthly DC values

The trends for minimum monthly DC values were also very similar to those for mean (and maximum) values (Fig. 15), and again demonstrated only minor differences in slope and number of months with significant trends. Observed trends in minimum monthly DC values for the six long-term stations are shown in Appendix 3 (along with those for monthly means in Appendix 1, and maxima in Appendix 2).

At Gisborne Aero (GSA), which showed a mix of increasing and decreasing trends, the trend directions using minimum and monthly values were the same in all cases (see Fig. 15). However, positive slopes all tended to be slightly lower for minima than for means (i.e., increasing slower), and negative slopes were generally higher for minima (decreasing faster). Apart from August which showed a very slight decrease in both instances, slopes for the build-up period prior to the start of the fire season (June-October) were mainly increasing in both cases (see Fig. 15), although slopes were small and not statistically significant.

For Kaikoura (KIX), trend directions were again all the same for minima and means, both indicating that all months showed increasing trends at this station for monthly DC values. However, many of the trends which were statistically significant for mean values were no longer significant when monthly minimum values were used (only the trends for May and June remained significant *cf*. 6 months using means). Increases indicated for July using means (and August for maximum values) were not significant for minimum values.

At Christchurch Aero (CHA), the trends for minima and means were very similar, increasing over the June-September period and decreasing during October-November. The exception was December, where a small decreasing trend for means became a slight increase for minimum DC values. The slopes of the trend lines were generally small however, and none were statistically significant for means, minima (or maxima).

Queenstown Aero (QNA), showed similar trends for monthly mean and minimum values. However, the slight decrease found for January using monthly values became an increase when minimum values were used. The number of months illustrating significant trends also increased (from 6 to 7), with the increase indicated for October becoming significant when minima were used. This station had some of the highest slope increases of any of the stations, including increases that were statistically significant (for means, minima and/or maxima) for both the end of (March-June) and build-up (July-October) to the fire season.

Trends for minimum and mean monthly values at Dunedin Aero (DNA) were similar, although use of minima resulted in an increase in the number of months showing decreasing (as opposed to increasing) trends. Slope values did increase during the build-up period prior to the start of the fire season (for monthly minimum, mean and maximum DC values). However, slope values were generally low in all cases, and were not statistically significant.

As it had for mean monthly DC values, Hokitika Aero (HKA) also showed a mix of increasing and decreasing trends when monthly minima were used. The trends for individual months varied from those indicated for mean values, and one more month demonstrated an increase for minima compared with means. However, the slope values were very small, and the decreasing trend for June found to be statistically significant using means was no longer significant when minimum values were used.

Again, the similarities in trends for minimum monthly DC values with those found for means suggested that the monthly trends for minimum values at other short-term stations were unlikely to be very different from those already identified using monthly mean values. Therefore no further efforts were made to analyse trends in monthly minimum values for these short-term stations.

Trends in Fire Season Maximum DC Values

Maximum fire season DC values were also used to determine if DC values were increasing, buy investigating whether the frequency of above-average DC values was changing over time. Counts of the number of days in each fire season that DC values exceeded threshold values of 300, 400 and 500 were made for each of the long-term stations. These were then used to investigate trends in the seasonal “frequency of exceedance” for each threshold at each station.

Resulting trends in the number of days each fire exceeding these threshold DC values for the six long-term stations are illustrated in Figure 16. Statistical tests of these trends are summarised in Appendix 4.

The analyses confirm that some stations do show trends of increasing DC values over time. Kaikoura (KIX) and Queenstown Aero (QNA) again showed statistically significant increases in the frequency of elevated DC values, whereas the smaller increases indicated for Gisborne Aero (GSA), Christchurch Aero (CHA) and Dunedin Aero (DNA) were not significant. In contrast, Hokitika Aero showed evidence of decreases in the frequency of elevated DC values, although these trends were not statistically significant.

KIX, in particular, showed strong increasing trends in the number of days each fire season with DC values above all three DC thresholds, with that for DC values greater than 300 particularly strong (slope = 2.23, $p = 0.0041$). This showed the frequency of DC values above 300 increasing from around 40 days/fire season in 1965/66 to 130 days/season in 2005/06 (i.e., an increase of 90 days/season over 41 years). The trend for days with DC values above 500 was also strongly significant (slope = 0.95, $p = 0.0044$), showing an increase from zero to more than 30 days/season in 2005/06. Similarly, QNA showed a significant increase in the number of days with DC values greater than 300 (slope = 2.34, $p = 0.0449$), which increased from less than 20 days/fire season in 1979/80 to around 80 in 2005/06 (i.e., an increase of some 60 days/season over 27 years). The increasing trends for other DC thresholds at QNA were not statistically significant.

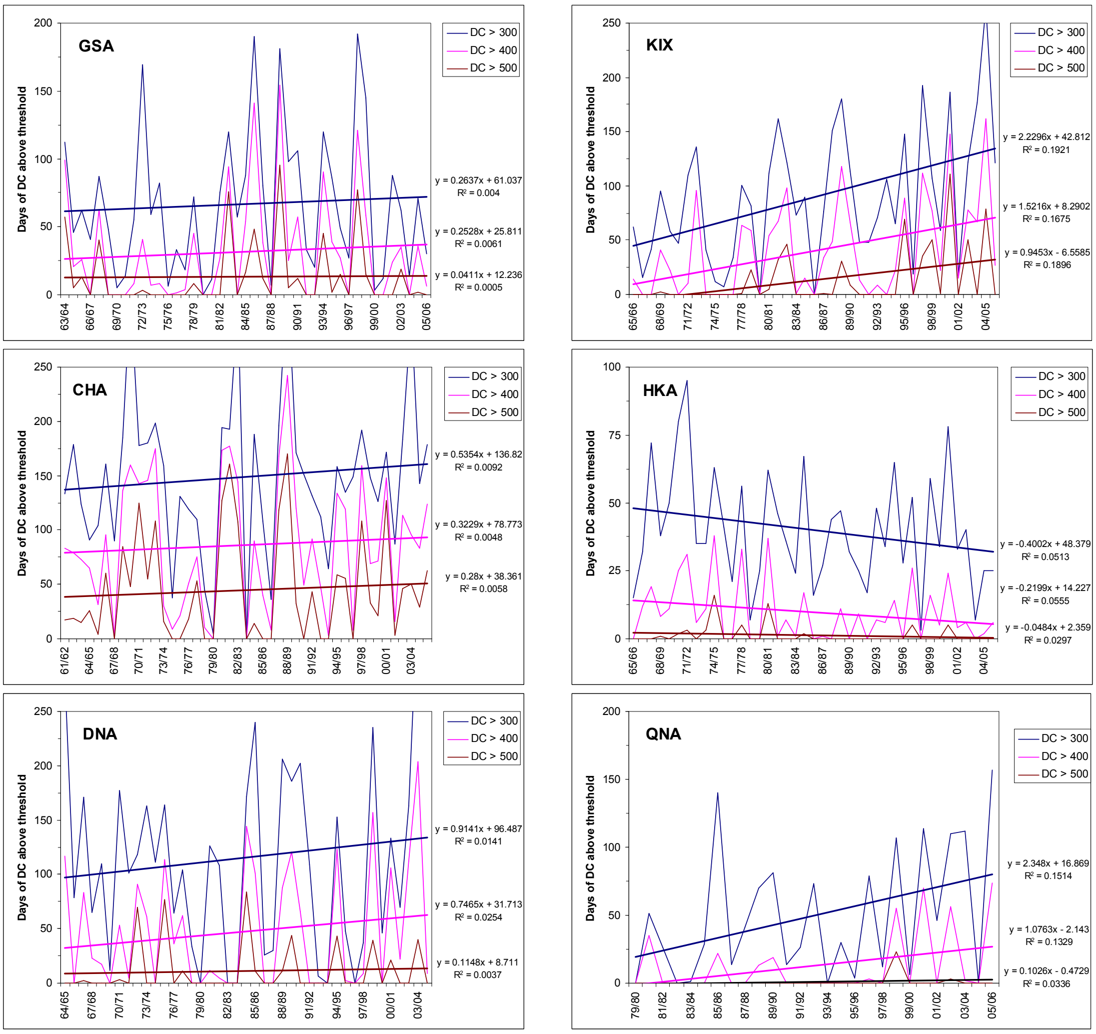


Figure 16. Trends in the "frequency of exceedance" of Drought Code thresholds (for DC values > 300, 400 and 500) at the 6 long-term stations.

Fire Season Minimum Values and Over-winter DC Recovery

Fire season minimum values of the DC were also used to investigate trends in DC values over time, and whether there were potential issues with the over-winter recovery of DC values (back to near zero) due to a lack of soil moisture recharge.

For each of the long-term stations, the dates of minimum DC occurrence in each year of record were used to compare the most common months in which these minimum values occurred, and whether there was any evidence that this was changing over time. The minimum DC values at each station were also used to determine how frequently, if at all, DC values fell to zero (or at least below the standard DC start-up value of 15; after Anon 1993) recognised as representing adequate recharge (i.e., saturation) of the soil layers represented by the DC.

Trends in the annual cycle of monthly minimum DC values at each of the six long-term stations (Fig. 17) were similar, with most stations reaching their seasonal minimum in August or September and then values climbing through the spring and summer before beginning to fall away again in the autumn. However, while this general pattern is similar, there are some significant differences in the values for average monthly DC minima reached at different stations. For example, minimum DC values for Christchurch Aero (CHA) range from around 80 in September to 380 in February, whereas those at Kaikoura (KIX) range from 30 in August to 280 in February. The average seasonal profile of minimum DC values for Dunedin Aero (DNA) is somewhat "flatter", climbing from a low of 110 in September to peak at around 280 later in the fire season, in March/April. With a higher rainfall, Hokitika (HKA) has a much narrow range in average minimum DC, ranging from around 1 to just 12 in February. With the exception of HKA, there is also some evidence of a trend in peak minimum DC values with latitude, with stations further north (i.e., Gisborne Aero, GSA), followed by KIX then CHA, peaking earlier (in January/February) than those further south (i.e., QNA in March, and DNA in April), although more detailed analysis with a larger number of stations is required to demonstrate whether this is in fact due to latitude or to other factors (such as rainfall or temperature effects).

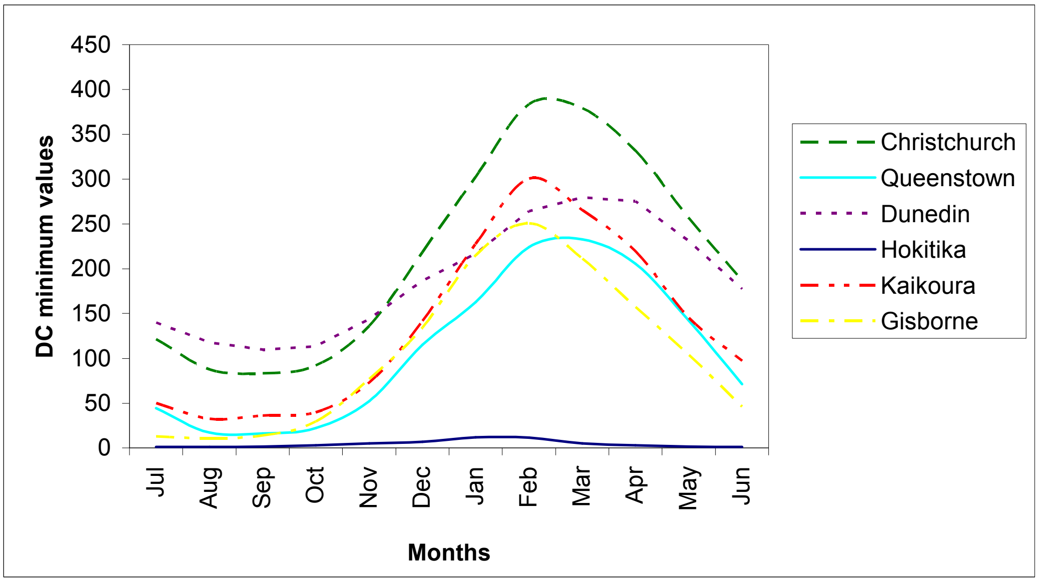
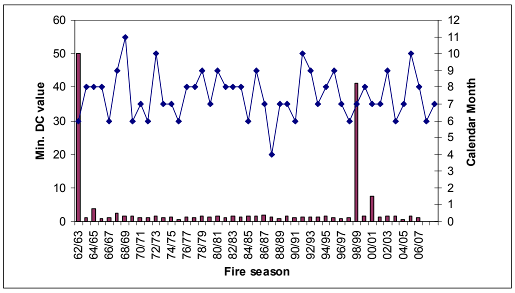


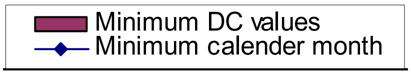
Figure 17. The seasonal trend of Drought Code minimum values for long-term stations (with greater than 20 years of record).

From Figure 17, it is apparent that, on average, minimum DC values at many stations would not appear to fall to the levels expected for recharge of the deep, compacted organic layers in the soil represented by the DC (i.e., down to, or at least, close to zero). Of the six long-term stations studied, only HKA and QNA would appear to regularly fall below a DC value of 15 and, in the latter case, then only within the months of August and September. However, more detailed analysis of the variation in seasonal DC minimum values showed that this potential lack of re-setting of DC values indicated in Figure 17 may be more related to problems with averaging minimum values than an actual lack of regular DC recovery.

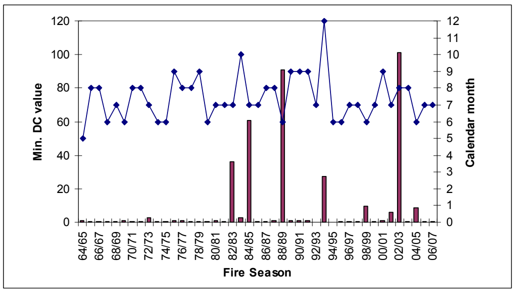
Each of the long-term stations in fact showed a much greater frequency of years in which minimum DC values did in fact fall below required recovery values (Fig. 18; also see the annual cycles illustrated in Fig. 7). At GSA, DC values fell below 15 in all but two years, with minimum values generally occurring in June, July or August (calendar months 6, 7 or 8) or occasionally September or October (months 9 or 10). Similarly, DC values at KIX also fell to close to zero in the majority of years, with only five of 22 years showing DC minimum values greater than 15. These minima also typically occurred in June, July and August, or occasionally September. DC values at QNA also generally appear to return to close to zero in most years, although values have remained high in four out of the last six years.

Gisborne Aero (GSA)

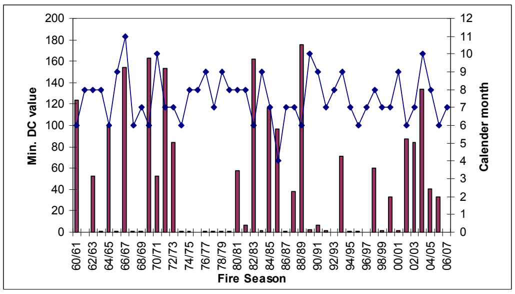




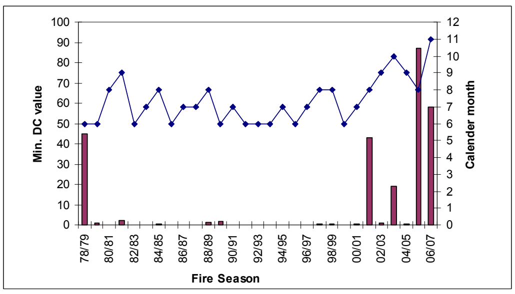
Kaikoura (KIX)



Christchurch Aero (CHA)



Queenstown Aero (QNA)



Dunedin Aero (DNA)

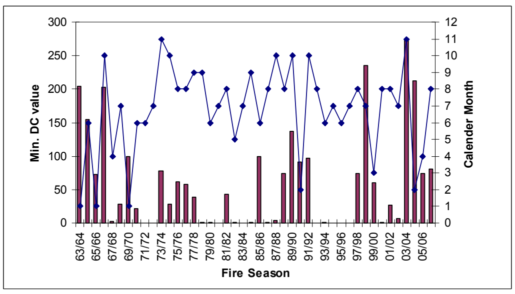


Figure 18. Plots of minimum seasonal Drought Code (DC) values and month of occurrence for long-term stations. (Note the varying Minimum DC scales and number of Fire Seasons in each case).

Minimum DC values at CHA and DNA were much more variable (Fig. 18), with alternating periods of low and elevated values; however, they still returned close to zero in about half the years of record in each case. The month of occurrence of these minimum values was more consistent for CHA, generally occurring in June-August and occasionally September (months 6-9), whereas this varied considerably at DNA from January to November (months 2-11) although was most typically between June and September (months 6-9).

Investigation of the trend in the month of occurrence (by fitting a linear trend line through the data for calendar month for each station in Fig. 18) suggests that there is little evidence that minimum DC values have occurred later in the fire season in more recent years. While there were very slight increases over time at the majority of these long-term stations, the slopes of these trends lines were very low (typically <0.01 to 0.03) and not statistically significant. The exception was QNA, where minimum DC values in latter years do appear to be occurring several months later than during the first part of the station's record (slope = 0.0773, p = 0.0070), in August-November (months 8-11) compared with June-August (months 6-8) previously. In contrast, the month of occurrence showed evidence of a very slight decrease (to earlier) at CHA, the only station of the five investigated to show a downward trend.

DISCUSSION

Results from this initial investigation into possible trends in DC values do show some limited evidence that DC values have increased over time at some stations. Statistically significant increases in mean (as well as maximum and minimum) monthly DC values over time were found for several of the long- as well as short-term stations, and for a number of the months for stations in several regions. There was also some evidence of more significant increases in DC values over the last 5-10 years than indicated by the general trend over the full length of record for several of the stations. For example, Queenstown Aero (QNA) in the Otago region, and Kaikoura (KIX) in Marlborough, demonstrated significant upward trends over the past few years during the months of July to October. Wanaka (WFA), also in Otago, and many of the stations in the South Canterbury region, also showed increases in mean monthly DC values that exceed 25 points per year over the latter part of their record. Some long-term stations also showed an increase in the frequency of occurrence of elevated fire season DC values. Minimum seasonal DC values at several of the long-term stations also showed some evidence of increases over time, and also of shifts in the month of occurrence of these seasonal minimums to later in the season. However, these shifts often also coincided with the occurrence of more severe fire seasons with higher minimum DC values in the past few years. Stations in many regions also showed statistically significant decreases in DC values in some or all months, so that there was no clear evidence of a general upward trend in DC values over time.

Regional differences in DC trends probably reflect to some degree the differences in regional climates, particularly with regard to general rainfall and temperature patterns. However, the regions as described here (based on regional council (and NZ Fire Service) boundaries) do not adequately capture the broad regional differences in climate, or range of microclimates within a region, compared with other possible classifications (e.g., NZMS 1983, Heydenrych and Salinger 2002). The grouping of stations from different microclimates could therefore explain some of the differences in DC trends observed between stations from the same geographic region. However, differences in the length of record available for individual stations could also have been a factor (see the more detailed discussion of the impact of length of record on observed trends that follows).

Despite these apparent increases in DC over time at some stations, DC values did appear to be being “re-set” every few years (at the long-term stations at least). This was even the case at stations with more variable fire climates, where DC values returned to close to zero in at least half (i.e., 1 in 2) of the fire seasons studied. This would tend to suggest that there is not a widespread problem with DC calculation, or with over-wintering issues resulting in the more common occurrence of elevated DC values at the start of the fire season due to DC carry-over. There is some suggestion that the observed trends are influenced by periods of more severe fire years, especially in the latter part of the record for several stations.

Possible explanations for observed trends

The anomaly of decreasing trends in DC values in some months at many of the stations, combined with the evidence of relative frequent recovery of DC values to near zero at least every few seasons, suggests that rather than a general "across the board" increase in DC values, as perhaps associated with global warming and long-term climate change, the observed increases (and decreases) in DC values are related to other factors. Some possible explanations for these differences in the trends found for various stations and/or regions include the impact of the length of data record used for analysis, or shifts in climate circulation patterns and associated changes in prevailing weather conditions in different parts of the country.

Dependence on length of record

A key feature of the trends observed in DC values over time at the various stations is the apparent dependence on the length of record used for analysis. The strongest trends are generally observed at stations with shorter records, whereas the longer records have more variability and show periods where DC values both increase and decrease. The following figures (Fig. 19 and 20) show the influence of length of record on the trends for the neighbouring stations of Christchurch Aero (CHA) and Bottle Lake (BTL) in Canterbury. Figure 19 has the DC values for BTL from 1993-2007 overlaid on to those for CHA from 1960-2007. The DC values at both stations follow very similar patterns for the fire seasons from 1993/94 onwards; however, while similar, the resulting trend lines for the two stations are not the same. The CHA trendline has a slope of 0.0014 (p = 1.04E-06), whereas the BTL line has slope of 0.0077 (p = 1.19E-04).

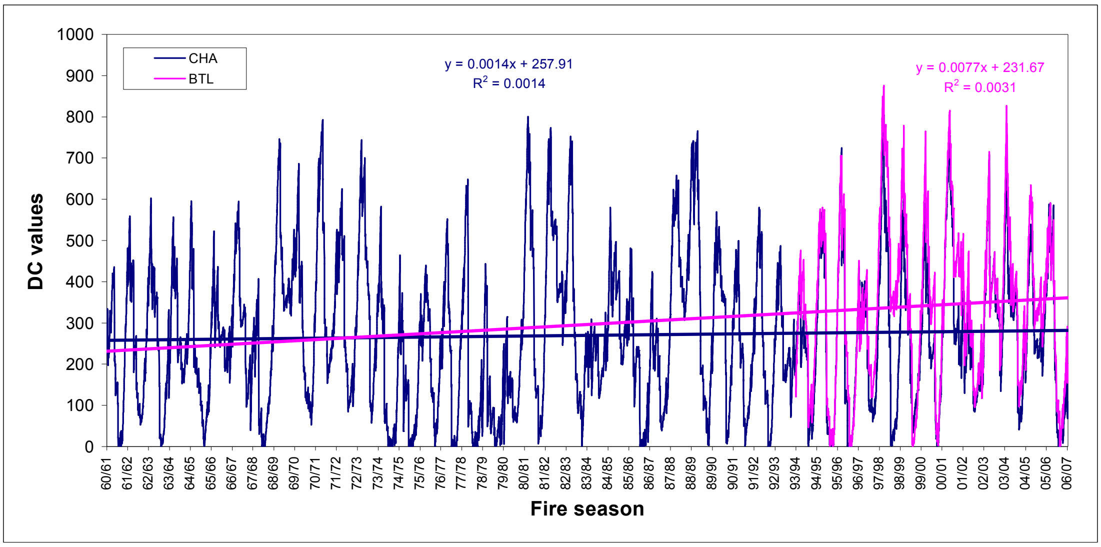


Figure 19. Trends in daily Drought Code (DC) values for Christchurch Aero (CHA) [from 1960-2006] and Bottle Lake (BTL) [from 1993-2006].

The effect of using a different period on the resulting trend lines (in this instance, the same period for CHA as available for BTL) is shown in Figure 20. Here, the slope of the CHA trend line changes from 0.0014 for the full period to 0.0103 (p = 2.91E-08) for the period 1993-2006, indicating a much greater increase (by a factor of more than 10) in DC values at CHA over this shorter timeframe.

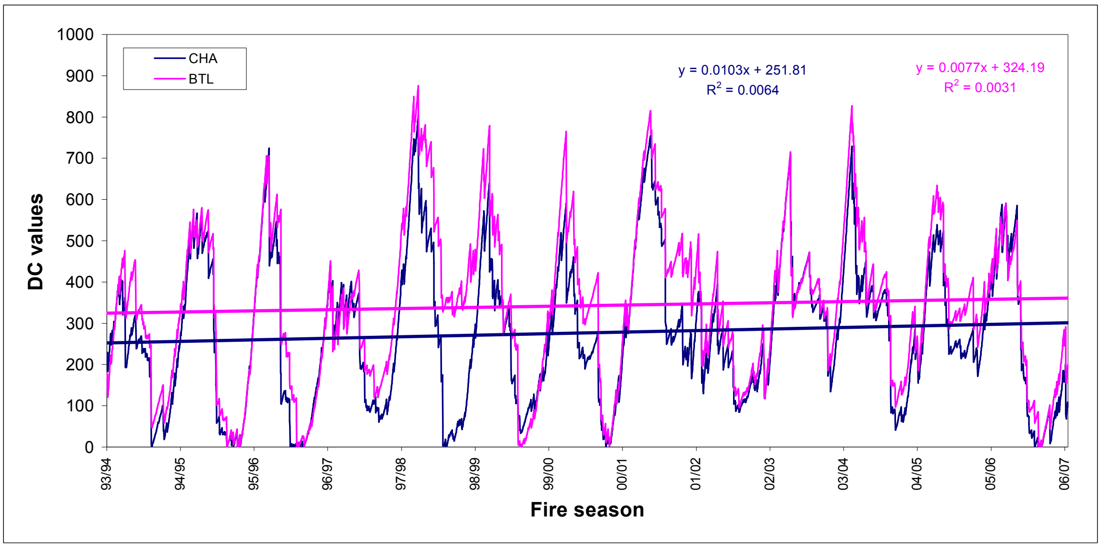


Figure 20. Trends in daily Drought Code (DC) values for Bottle Lake (BTL) [from 1993-2006] and Christchurch Aero (CHA) for the same period.

The effect of using a shorter length of record on trends for mean monthly DC values is even more apparent. For CHA (Fig. 21), slopes of the trend lines for the months July-October change from showing very little difference over time (with trend line slopes of -0.69 to +0.80, and p-values of 0.53-0.63) to showing much greater increases over time (with slopes from 4.7 to 11.2, and p-values of 0.20-0.32) for the shorter period of record. In the case of October, the trend also goes from a slight decrease over the longer period to a moderate increase over the shorter timeframe.

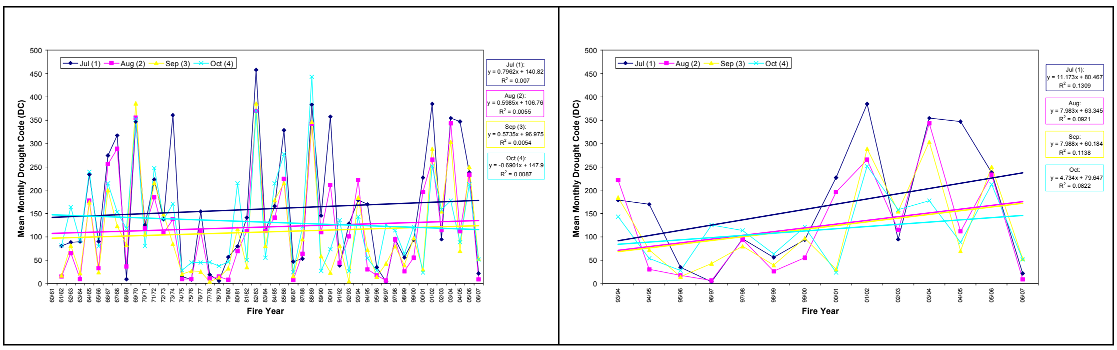


Figure 21. Trends in mean monthly Drought Code (DC) values for July, August, September and October at Christchurch Aero (CHA) from (left) 1960-2006, and (right) 1993-2006.

The use of trend line forms such as polynomial types (e.g., cubic) rather than linear relationships (i.e., straight lines) also suggests that the slope of the fitted trend lines is changing over time, and that the longer lengths of record may in fact be able to be separated into periods which demonstrate quite different trends. For example, a cubic-form trend line fitted to the long-term (46 year) record for CHA shows that the slope (in this case of the mean monthly DC trend line) initially increases then decreases, before increasing more dramatically over the 8-10 years (Fig. 22a). More to the point, it is possible to recognise phases where the mean monthly DC actually increases more steeply then decreases and, in the case of CHA (Fig. 22b), then repeats this pattern at least once if not twice again prior to the end of 2006. Wherever possible, comparative analyses of trends in DC values (or values of other components of the FWI System or its weather inputs) should therefore be undertaken using historical records for the same period. The recommended length of record for climatological analyses is generally 20-30 years, but as few fire weather stations are likely to have this length of record available, a minimum of 10 years and preferably longer (i.e., 15-20 years) is advisable for such comparative studies (Simard 1973, Pearce and Hawke 1999).

(a) **(b)**

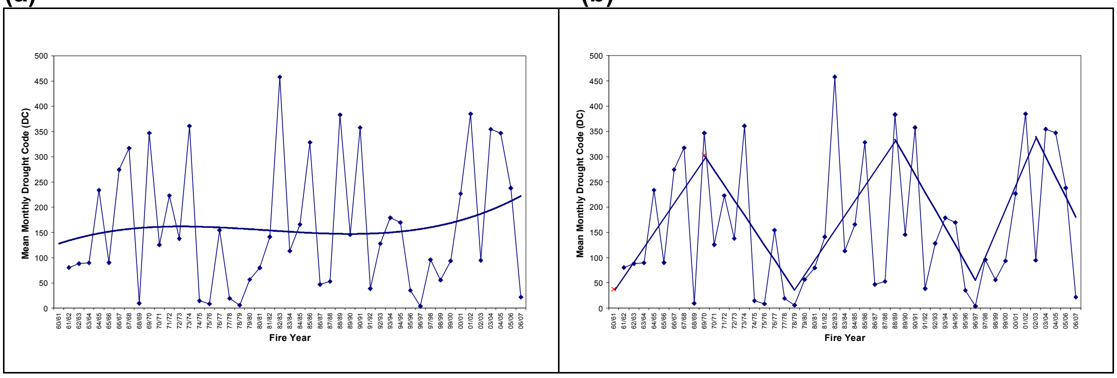


Figure 22. (a) A cubic-form polynomial trend line, and (b) short-term linear trend lines fitted to mean monthly Drought Code (DC) values for July at Christchurch Aero (CHA).

Climate circulation patterns

This pattern of increasing and decreasing values for the stations with long-term records suggests that rather than a single trend, perhaps resulting from global warming or climate change, DC values may in fact be responding to shorter term “cycles” and that these cyclical trends are not apparent for the short-term stations due to insufficient lengths of record. If this is the case, it is likely that these cyclical trends are in fact the result of normal climate cycles, such as the Interdecadal Pacific Oscillation (IPO). It is widely recognised that occasional severe fire seasons can result from shorter-term “interannual” climate variability such as the El Nino/Southern Oscillation (ENSO) (e.g., Pearce 1998, Pearce *et al*. 2007), and recent studies have also shown that the IPO (on its own and in combination with ENSO) can produce higher than normal fire dangers in many parts of New Zealand (Pearce *et al*. 2007)[12]. The IPO demonstrates cycles of 20-40 years (Fig. 23), and most recently underwent phase changes around 1976/77 and 1999/2000, so could be responsible for the cycles of DC values observed in the records of the long-term stations used here (Girardin *et al*. 2004). The positive phase of the IPO is similar to El Niño and is associated with periods of stronger westerly winds and more anticyclones over northern New Zealand, with generally drier conditions in the north and east. In contrast, the negative phase is more like La Niña and is associated with weaker westerlies and more easterly/northeasterly winds over northern New Zealand, and drier conditions in the west of both islands, central regions and the south of the South Island. The most recent change in the IPO to its negative phase in 1999/2000 is therefore likely to have resulted in changes to atmospheric circulation patterns across the New Zealand region, and to changes in rainfall and temperature patterns in different parts of the country. This may explain the increases in DC values observed at some stations and decreases at others, especially the significant increases seen at several stations (e.g., QNA, OUA) over the past few fire seasons.

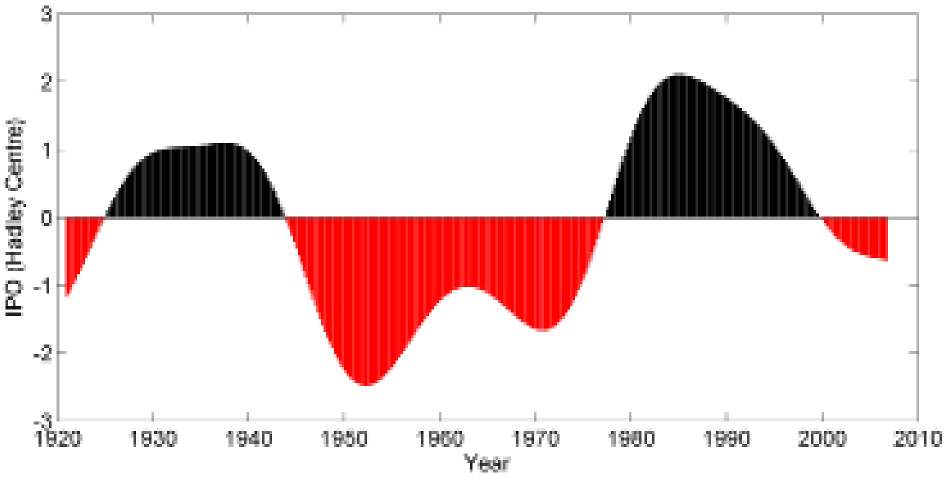


Figure 23. Phases of the Interdecadal Pacific Oscillation (IPO). Positive values indicate periods when stronger westerlies occur over New Zealand, and more anticyclones over northern New Zealand. Negative values indicate periods with more north-easterlies in northern regions. (© NIWA 2007).

Therefore, fire managers need to be aware that even though the records for a station may show a particular trend for that period of record, this trend is very dependent on the length of record used and use of a different period could significantly alter the subsequent trend. It also ignores the effects of historical factors which may influence the overall trend, such as climate patterns like IPO and ENSO.

[12] The study by Pearce *et al*. (2007) did not specifically investigate changes in DC with IPO and ENSO, but did look at changes in the Buildup Index (BUI) as a measure of seasonal dryness, as well as changes in temperature, rainfall, Fine Fuel Moisture Code (FFMC), and fire season severity (using the Daily Severity Rating, DSR, and number of days in the Very High and Extreme forest fire danger classes, VH+E FFDC).

Again, the normal length of record for climatological analyses is typically 20-30 years, and use of longer records is advisable where long-term (e.g., decadal) changes in climate patterns are suspected. Where possible, station records should also be separated for analysis into known periods associated with opposing phases of such climate cycles (such as the IPO; Pearce *et al*. 2007), if meaning conclusions are to be drawn from any trends identified.

Further Research

While increasing trends in DC values were found at many stations, it is believed that these may be the result of issues associated with the length of data record used to analyse trends and/or the influence of changes in patterns of climate circulation (such as IPO and/or ENSO) on the key weather inputs affecting the DC (i.e., rainfall and temperature), as opposed to underlying problems with DC calculation or fire season carry-over. However, trends in DC values should continue to be monitored to determine whether the recent upward trend in values observed at many stations continues, possibly as a result of long-term climate change, or is in fact reversed due to a shorter-term shift in the prevailing climate pattern (e.g., of the IPO). In addition to repeating the analyses undertaken here to identify trends in DC values over time, more detailed investigation of the effects of IPO and ENSO on DC values should also be undertaken (e.g., Girardin *et al*. 2004, Pearce *et al*. 2007). Where possible, longer-term datasets (e.g., 100+ years) should also be utilised to investigate longer term trends at a representative set of weather stations[13].

The Canadian procedure for over-winter adjustment of DC start-up values could also be investigated as a means of validating DC valuations at the start of each fire season. The procedure (after Turner and Lawson 1978, Alexander 1982, 1983a,b, Lawson and Armitage 2008) provides a method for determining whether the amount of precipitation received over the winter period is sufficient to "re-set" the DC. Even in the absence of winter snow and ground-freeze as occurs in Canada, this methodology could be used to validate DC values in New Zealand. DC values occurring in September or October, for example, could be validated using DC values from the end of May or June, together with the amount of rainfall received in the intervening period. A key factor in these computations would be the establishment of appropriate values of the constants for the carry-over fraction of moisture from autumn and effectiveness of winter precipitation in recharging moisture reserves in spring. However, this methodology could provide a useful addition to both research (into trends in DC values and DC component validation) and operational validation of fire season start-up values.

Detailed investigation of the validity of the underlying moisture relationships contained within the DC equation is also required[14], to determine whether relationships derived for Canadian conifer forests with their deep organic

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[13] This will require derivation of historic estimates of noon weather inputs and FWI System components from synoptic climate records (as done by Pearce and Alexander 1994).
[14] Similar validation studies are also required for the other FWI System fuel moisture codes – the Duff Moisture Code (DMC) and Fine Fuel Moisture Code (FFMC).

layers are in fact applicable to New Zealand soil (including duff and litter layers, where present) profiles, especially the shallower, stony soil types common in arid areas. This would require soil moisture sampling studies to be conducted at a range of sites across the country, preferably over several seasons. Lawson and Dalrymple (1996) describe a “standard” methodology for ground-truthing the over-winter recharge of DC fuel moisture in Canada that could also be applied to New Zealand DC validation studies. The methodology involves field sampling of organic layers within the soil profile by cutting and collecting a series of 2-cm deep layers from each profile for determination of moisture content by oven-drying. Moisture content by depth can then be compared to that estimated using the standard DC equation or the various Canadian site-specific “ground-truthing” models available for different Canadian forest and soil types. Identifying and, where necessary, validating through sampling, the water capacity for a range of local soil types is also a key part of determining the applicability of the standard DC equation for use in New Zealand.

The use of other drought or soil moisture indices (e.g., Mullan et al. 2005), soil water-balance calculations (e.g., McAlpine and Eiber 1985), or direct measurements of soil moisture (e.g., NZ Fire Research 2002) as are now routinely undertaken at a number of sites around the country for agricultural purposes, should also be investigated for use in validating DC values at the start of each fire season. It may well be possible to derive relationships between the DC (and other FWI System moisture codes) and such approaches for a range of soil types and climatic regions that can be used to calibrate or potentially even predict DC values.

CONCLUSIONS AND RECOMMENDATIONS

This study aimed to undertake an initial investigation into the performance of the Drought Code (DC) component of the FWI System under New Zealand conditions. In particular, it sought to establish whether there was any validity to the concerns expressed by New Zealand fire managers that values of the DC are increasing over time. Concerns that DC values have increased due to the lack of re-setting of values over the winter have arisen as a result of New Zealand fire weather monitoring stations being run all year round. Long-term climate change may also be resulting in increases in DC values.

While evidence of increases in DC values was found, many of them statistically significant, corresponding decreases in DC values were also found at many stations. Evidence of more significant increases in DC values over the last 5-10 years was also found at several stations. However, these periods tended to coincide with the occurrence of more severe fire seasons with higher minimum DC values. These drier fire seasons are potentially linked to variation in prevailing climate patterns, such as ENSO and IPO. The length and period of record used to summarise trends was also found to have major impact on the strength and direction of trends identified.

Analyses of the frequency and timing of seasonal DC minimum values also showed some evidence of slight increases in minimum values over time at some stations, and possible shifts in the timing of minimum DC occurrence to later in the fire season. However, concerns regarding the lack of re-setting of DC values prior to the start of each fire season appear unfounded, with DC values recovering to near zero in at least half (and usually, many more) of the years studied for all the stations investigated.

The mix of both increasing and decreasing trends, combined with evidence of the re-setting of DC values to near zero at least every few seasons at most stations, suggests that the observed increases (and decreases) in DC values are related to other factors. Rather than a general increase in DC values as perhaps associated with global warming and long-term climate change, or problems with over-winter recovery or calculation of the DC, it is more likely that these increases and decreases are the result of the limited length of data record available for many stations, and the effect of climate variability on DC values. In particular, the increases in DC values seen over the last 10-15 years at many stations, especially in the months prior to the fire season (i.e., July to September), are likely to be associated with changes in seasonal rainfall (and temperature) patterns in various parts of the country under the different phases of the IPO.

However, trends in DC values should continue to be monitored to determine whether the recent upward trend observed at many stations continues, possibly as a result of climate change, or is reversed due to the changes in the prevailing climate pattern. The effect of IPO (and ENSO) on DC values should also be specifically examined. Research should also be undertaken into the validity of the underlying moisture relationships contained within the standard DC equation, to determine whether relations derived for Canadian conifer forest are in fact applicable to New Zealand soil profiles. This includes quantification of the water capacity for the range of New Zealand soil types. Use of soil water-balance, drought indices and direct soil moisture measurements should also be investigated as means of calibrating calculated DC values. The established procedure for adjustment of DC start-up values based on over-winter precipitation should also be explored for use to support research into DC trends and validation, and as a possible operational tool for validation of DC values at the start of the fire season. Perhaps most importantly, fire managers should not over-focus on the DC component of the FWI System, but should utilise all the codes and indices from within the System to guide fire management decision-making.

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Appendix 1. Summary of observed trends in mean monthly Drought Code (DC) values for individual stations, based on linear regression. Months highlighted in bold indicate significance ($p < 0.05$).

Eastern North Island

Station	Regression	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Gisborne Aero (GSA)	**Slope b (x)**	0.6808	-0.0478	0.4021	0.6778	0.6929	-0.1018	1.0688	0.4273	-0.3235	-1.6048	-0.568	0.582
	Intercept	22.182	30.101	26.356	53.236	119.57	215.39	275	330.96	304.25	267.43	166.92	72.884
	R^2	0.0305	0.0007	0.0399	0.0477	0.024	0.0003	0.014	0.0017	0.0007	0.0178	0.0034	0.0065
(n = 44)	***p***	0.2568	0.8658	0.1937	0.1543	0.3158	0.9070	0.4440	0.7910	0.8663	0.3880	0.7090	0.6021
Mangatu Forest (MGF)	**Slope b (x)**	3.4779	6.61	**5.0959**	-0.4383	-2.2619	-9.3636	-10.005	-10.348	-5.8982	-0.9004	-4.5246	-3.5808
	Intercept	-3.954	-24.154	**-13.17**	41.546	97.24	189.83	303.4	311.46	197.4	126.56	128.61	82.611
	R^2	0.1731	0.2371	**0.3825**	0.0044	0.0681	0.2397	0.1095	0.0405	0.0175	0.0004	0.0088	0.0093
(n = 12)	***p***	0.2031	0.1287	**0.0425**	0.8472	0.4382	0.1062	0.2935	0.5308	0.6817	0.9554	0.7833	0.7778
Napier Aero (NRA)	**Slope b (x)**	-5.7615	-1.8056	-0.3128	-2.3324	-0.756	-8.5177	-5.3724	2.113	4.4869	3.2256	-1.9343	-5.5107
	Intercept	106.52	56.542	55.523	104.01	155.1	293.21	354.17	326.91	316.37	264.13	205.31	158.52
	R^2	0.1064	0.0415	0.0012	0.0502	0.0032	0.1347	0.0396	0.004	0.0118	0.0064	0.0025	0.0369
(n = 12)	***p***	0.2355	0.4663	0.8967	0.4042	0.8341	0.1783	0.4770	0.8237	0.6999	0.7761	0.8596	0.4929
Waipukurau (WPK)	**Slope b (x)**	0.8392	-0.5716	-2.3465	-7.9161	**-10.014**	**-17.318**	-6.2792	4.2959	4.5386	0.1221	-3.9919	1.1304
	Intercept	92.035	74.855	103.34	161.33	**245.38**	**371.01**	362.28	312.12	305.18	270.71	252.1	170.1
	R^2	0.0015	0.0023	0.0389	0.2289	**0.3512**	**0.5338**	0.0436	0.0125	0.0114	9.0E-06	0.0114	0.0012
(n = 12)	***p***	0.9050	0.8758	0.5182	0.0981	**0.0328**	**0.0070**	0.5150	0.7298	0.7415	0.9926	0.7412	0.9166

Wairarapa

Station	Regression	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Ngaumu (NMU)	**Slope b (x)**	-0.0102	-0.1518	0.5945	-2.8447	**-4.9115**	**-10.975**	-13.924	-3.8833	3.6425	-5.6552	-9.1245	-2.2284
	Intercept	29.506	13.032	27.527	67.662	**134.16**	**255**	391.54	345.06	277.24	303.51	258.48	106.78
	R^2	2.0E-06	0.0097	0.0128	0.183	**0.2971**	**0.2975**	0.2031	0.0075	0.007	0.0128	0.046	0.0079
(n = 13)	***p***	0.9968	0.7491	0.7132	0.1448	**0.0438**	**0.0539**	0.1223	0.7786	0.7854	0.7130	0.4816	0.7734
Stoney Creek (STO)	**Slope b (x)**	-0.1667	0.2503	1.4049	-0.7938	-2.6884	-9.2405	-7.5699	-3.4728	4.0245	-5.8576	-8.0105	-2.9504
	Intercept	13.851	6.4247	11.769	29.161	91.305	188.46	253.98	274.59	225.55	228.37	186.5	73.826
	R^2	0.0016	0.027	0.212	0.1385	0.116	0.2096	0.0612	0.006	0.0062	0.0079	0.0273	0.0184
(n = 11)	***p***	0.9074	0.6294	0.1320	0.2335	0.2787	0.1568	0.4635	0.8216	0.8173	0.7954	0.6271	0.6911

Holdsworth	**Slope b (x)**	0.3473	-1.6584	1.4774	-0.2316	2.0727	1.4622	2.3248	10.353	16.264	12.591	6.9647	1.7091
(HWT)	**Intercept**	3.541	26.867	11.413	18.292	22.071	65.659	122.57	117.01	83.57	53.678	39.104	10.189
	R^2	0.2002	0.0676	0.0663	0.0344	0.1453	0.0108	0.0191	0.161	0.2583	0.1735	0.112	0.0878
(n = 12)	***p***	0.1447	0.3908	0.3958	0.5441	0.1987	0.7476	0.6681	0.1961	0.0916	0.1780	0.2877	0.3498
East Taratahi	**Slope b (x)**	-0.5561	0.1967	1.1746	-0.4853	-0.0676	-1.9174	1.5321	5.7512	11.64	8.0939	6.0512	1.2031
(MSX)	**Intercept**	67.849	35.196	29.299	45.179	91.163	168.61	232.41	259.43	222.45	220.69	174.32	103.92
	R^2	0.0015	0.0004	0.044	0.007	8.0E-05	0.0175	0.0045	0.0296	0.090	0.0333	0.0215	0.0021
(n = 15)	***p***	0.8903	0.9409	0.4528	0.7587	0.9742	0.6384	0.8117	0.5398	0.2773	0.5151	0.6020	0.8702

Marlborough

Station	Regression	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Kaikoura	**Slope b (x)**	**2.9682**	1.556	1.5514	0.9873	1.3226	2.1659	**3.6861**	**4.8688**	**4.6866**	2.9554	**4.8713**	**4.553**
(KIX)	**Intercept**	**17.231**	25.575	21.568	46.068	90.909	154.37	**215.89**	**250.13**	**234.14**	218	**98.955**	**38.116**
	R^2	**0.1535**	0.0705	0.0905	0.0397	0.0477	0.0828	**0.1547**	**0.1856**	**0.151**	0.0665	**0.2087**	**0.1888**
(n = 42)	***p***	**0.0151**	0.0892	0.0749	0.3031	0.2972	0.1720	**0.0384**	**0.0182**	**0.0372**	0.2329	**0.0064**	**0.0077**
Opua Bay	**Slope b (x)**	25.007	**26.032**	**20.187**	**9.5582**	4.9898	3.7261	-1.3531	-5.4426	4.6048	6.4817	11.621	18.65
(OSN)	**Intercept**	-119.72	**-128.19**	**-94.965**	**-28.512**	30.559	104.17	209.86	286.62	222.03	169.03	97.811	-20.364
	R^2	0.2755	**0.312**	**0.3427**	**0.326**	0.158	0.0264	0.003	0.0335	0.0175	0.0215	0.0634	0.1731
(n = 13)	***p***	0.0655	**0.0472**	**0.0356**	**0.0415**	0.1786	0.5956	0.8578	0.5492	0.6668	0.6330	0.4065	0.1574
Woodbourne Aero	**Slope b (x)**	**13.069**	**13.622**	**14.623**	**11.97**	**9.8543**	10.867	12.029	13.805	**23.369**	17.392	13.427	13.738
(WBA)	**Intercept**	**26.035**	**-12.394**	**-26.446**	**-5.7253**	**70.279**	156.36	247.16	301.47	**237.1**	247.67	250.42	134.9
	R^2	**0.2944**	**0.3348**	**0.4549**	**0.5329**	**0.277**	0.1718	0.1263	0.1221	**0.2593**	0.1764	0.099	0.1546
(n = 15)	***p***	**0.0366**	**0.0238**	**0.0058**	**0.0020**	**0.0438**	0.1406	0.1936	0.2017	**0.0525**	0.1190	0.2534	0.1471
Awatere Valley	**Slope b (x)**	14.137	13.908	**15.582**	12.6	10.121	7.4665	8.8287	12.197	21.265	22.104	12.528	5.9052
(AWV)	**Intercept**	131.99	105.33	**86.478**	96.156	167.22	286.12	384.06	444.95	410.45	364.91	403.76	333.95
	R^2	0.152	0.1508	**0.3135**	0.2983	0.133	0.0393	0.0313	0.0372	0.1242	0.1444	0.0403	0.0118
(n = 12)	***p***	0.2103	0.2122	**0.0466**	0.0580	0.2204	0.5367	0.5825	0.5480	0.2612	0.2230	0.5314	0.7369
Molesworth	**Slope b (x)**	**15.319**	**14.526**	**14.528**	**14.816**	**15.764**	**25.039**	**22.342**	**10.808**	**17.878**	7.2264	10.117	13.914
(MLX)	**Intercept**	**24.591**	**8.6807**	**17.366**	**7.7171**	**47.177**	**59.293**	**167.11**	**350.67**	**317.21**	346.36	258.32	127.62
	R^2	**0.4847**	**0.4381**	**0.4065**	**0.4345**	**0.4825**	**0.6731**	**0.6381**	**0.2121**	**0.3681**	0.0959	0.089	0.2113
(n = 14)	***p***	**0.0040**	**0.0070**	**0.0071**	**0.0061**	**0.0021**	**0.0005**	**0.0012**	**0.0340**	**0.0169**	0.0871	0.1489	0.0556

Rai Valley (RAI)	**Slope b (x)**	-0.1715	0.1117	0.4299	-0.2681	-0.6105	5.5563	1.0492	-5.083	5.5607	5.2946	-0.0423	-0.5716
	Intercept	10.275	8.2461	10.479	24.152	67.02	72.553	120.64	185.32	162.94	105.89	75.424	23.133
	R^2	0.0173	0.0364	0.0441	0.0075	0.0013	0.0669	0.002	0.0132	0.0093	0.0127	0.000002	0.0025
(n = 10)	***p***	0.7175	0.5976	0.5603	0.8005	0.9149	0.4705	0.9024	0.7520	0.7912	0.7567	0.9969	0.8912

Canterbury

Station	Regression	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Christchurch Aero (CHA)	**Slope b (x)**	0.797	0.599	0.574	-0.690	-0.201	-0.048	0.805	1.242	1.747	1.035	1.014	1.484
	Intercept	140.82	106.76	96.975	147.92	198.06	288.46	360.25	427.53	407.76	387.84	296.25	195.37
	R^2	0.007	0.0055	0.0054	0.0087	0.001	4.0E-05	0.0089	0.0172	0.0218	0.0074	0.0091	0.0244
(n = 46)	***p***	0.5817	0.6232	0.6261	0.5386	0.8339	0.9650	0.5325	0.3855	0.3276	0.5698	0.5286	0.2995
Snowdon (SDN)	**Slope b (x)**	3.512	4.5077	5.5205	3.6487	1.7374	-3.195	0.658	-3.760	4.2093	5.3752	3.5434	3.0702
	Intercept	-5.1743	-14.735	-15.421	1.0838	42.897	138.62	180.29	257.94	181.5	115.86	79.962	25.811
	R^2	0.1147	0.1905	0.2669	0.1563	0.0229	0.0372	0.0006	0.0147	0.0261	0.0265	0.0154	0.0404
(n = 13)	***p***	0.2576	0.1359	0.0707	0.1812	0.6216	0.5086	0.9346	0.6931	0.5981	0.5952	0.6867	0.5101
Darfield (FPL)	**Slope b (x)**	5.8578	7.5085	7.1056	3.8081	1.3872	-0.149	6.0804	3.1864	10.561	5.5291	-3.743	0.4416
	Intercept	81.058	16.863	21.228	56.612	134.15	215.94	268.99	357.71	308.29	300.14	307.29	203.14
	R^2	0.0583	0.1432	0.1288	0.0565	0.0108	5.0E-05	0.0374	0.0088	0.132	0.0202	0.0121	0.0002
(n = 13)	***p***	0.4266	0.2022	0.2284	0.4342	0.7349	0.9809	0.5268	0.7602	0.2224	0.6431	0.7205	0.9635
Bottle Lake (BTL)	**Slope b (x)**	12.264	25.519	12.079	8.207	5.1048	2.4776	6.8466	0.5129	4.6207	-3.6974	-5.1608	3.9127
	Intercept	146.76	7.3844	80.29	115.21	220.48	319.97	388.58	524.84	502.19	523.72	443.77	293.63
	R^2	0.1071	0.3515	0.1004	0.0637	0.036	0.0086	0.0314	0.0002	0.0221	0.0112	0.0195	0.0116
(n = 13)	***p***	0.2750	0.2320	0.2915	0.4055	0.5349	0.7523	0.5622	0.9652	0.6283	0.7306	0.6495	0.7261
Hanmer (HAN)	**Slope b (x)**	1.3103	1.6897	4.015	0.3952	-3.3135	-9.4058	-3.7151	-7.8297	14.181	2.3908	-11.421	-8.6825
	Intercept	39.824	14.363	11.48	45.118	111.83	208.23	249.79	353.08	224.06	204.08	240.9	162.79
	R^2	0.0039	0.0259	0.1625	0.0013	0.1001	0.2604	0.0124	0.0314	0.0774	0.002	0.0417	0.0375
(n = 10)	***p***	0.8548	0.6363	0.2189	0.9161	0.3432	0.1087	0.7591	0.6241	0.4364	0.9015	0.5717	0.5919
Balmoral (BML)	**Slope b (x)**	-2.795	0.3348	1.4958	-2.3884	2.038	-8.1799	-12.824	-18.071	-7.3598	-21.437	-26.011	-13.876
	Intercept	213.41	126.83	110.84	153.03	174.53	339.84	491.87	626.62	558.53	577.43	553.5	377.54
	R^2	0.0069	0.0002	0.0035	0.0112	0.0107	0.1606	0.1286	0.1546	0.0251	0.1598	0.1821	0.0737
(n = 12)	***p***	0.7973	0.9655	0.8559	0.7433	0.7368	0.1747	0.2523	0.2061	0.6231	0.1979	0.1665	0.3935

Ashburton Plains (ASH)	**Slope b (x)**	13.406	10.618	10.232	7.1019	5.5995	-0.3585	4.9101	1.3968	15.107	11.688	-0.762	9.3372
	Intercept	58.171	39.27	38.461	70.786	140.08	251.13	309.02	389.22	301.65	294.92	312.3	163.17
	R^2	0.1422	0.1782	0.1963	0.1436	0.1276	0.0003	0.0254	0.0019	0.1999	0.0713	0.0003	0.0571
(n = 12)	***p***	0.2268	0.1716	0.1295	0.2016	0.2309	0.9588	0.6205	0.8929	0.1451	0.4014	0.9542	0.4546

South Canterbury

Station	Regression	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Timaru Aero (TUA)	**Slope b (x)**	12.0	11.253	11.154	10.802	5.8867	4.99	11.733	6.9337	13.675	14.879	12.115	12.35
	Intercept	118.81	93.073	87.975	84.318	171.87	238.59	234.38	330.63	283.56	261.68	222.63	173.44
	R^2	0.1596	0.1641	0.1658	0.1896	0.0726	0.039	0.1418	0.039	0.1362	0.1588	0.1146	0.14
(n = 15)	***p***	0.1401	0.1342	0.1320	0.1048	0.3314	0.4985	0.1666	0.4804	0.1759	0.1412	0.2172	0.1695
Cannington (CAN)	**Slope b (x)**	12.183	14.669	13.027	12.817	9.5065	-1.5627	-70855	-7.6656	4.6561	14.722	4.3544	6.0292
	Intercept	146.25	93.722	107.35	92.359	153.44	292.08	401.27	434.14	354.79	273.57	304.41	252.9
	R^2	0.1806	0.1832	0.1522	0.2266	0.1562	0.0031	0.0324	0.0403	0.0173	0.1253	0.0198	0.0564
(n = 12)	***p***	0.1477	0.1445	0.1876	0.1001	0.1813	0.8630	0.5758	0.5107	0.6684	0.2354	0.6469	0.4348
Tara Hills (THE)	**Slope b (x)**	1.7212	6.8482	10.31	11.488	**11.744**	**12.777**	4.5785	-0.8546	2.9926	6.9397	3.7892	1.2121
	Intercept	212.06	128.13	85.744	96.978	**148.65**	**217.0**	320.47	443.86	439.35	393.78	366.66	308.22
	R^2	0.0033	0.056	0.1266	0.1773	**0.277**	**0.322**	0.0265	0.0006	0.0091	0.053	0.0147	0.0013
(n = 15)	***p***	0.8383	0.3958	0.1931	0.1043	**0.0362**	**0.0274**	0.5624	0.9313	0.7348	0.4093	0.6668	0.8997
Oamaru Aero (OUA)	**Slope b (x)**	**22.505**	**18.546**	**18.447**	**15.534**	**14.693**	**20.921**	**22.72**	**22.168**	**28.793**	**29.069**	18.953	**22.225**
	Intercept	**-42.784**	**-35.278**	**-45.351**	**-12.831**	**27.515**	**32.69**	**66.435**	**119.16**	**99.52**	**85.343**	97.677	**13.577**
	R^2	**0.3819**	**0.3583**	**0.3651**	**0.4911**	**0.5215**	**0.5606**	**0.5016**	**0.5107**	**0.5873**	**0.5202**	0.2451	**0.299**
(n = 15)	***p***	**0.0141**	**0.0184**	**0.0170**	**0.0025**	**0.0016**	**0.0013**	**0.0031**	**0.0028**	**0.0009**	**0.0024**	0.0606	**0.0349**

Otago

Station	Regression	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Queenstown Aero (QNA)	**Slope b (x)**	**3.564**	**2.4782**	**1.9961**	1.4512	0.9361	0.7986	-0.2749	3.0227	**4.5963**	4.438	**6.2613**	**6.1686**
	Intercept	**5.5789**	**-4.0467**	**-0.0981**	24.594	85.204	158.88	229.2	235.82	**217.26**	188.13	**103.41**	**103.41**
	R^2	**0.2041**	**0.2169**	**0.201**	0.1164	0.028	0.0145	0.0007	0.0623	**0.1771**	0.1005	**0.2241**	**0.3282**
(n = 28)	***p***	**0.0158**	**0.0125**	**0.0167**	0.0756	0.3950	0.5499	0.8932	0.2002	**0.0257**	0.1002	**0.0109**	**0.0014**

Wanaka (WFA)	**Slope b (x)**	**14.69**	**13.148**	**12.065**	11.049	**15.069**	**15.857**	5.4887	0.3985	17.535	**29.551**	**25.828**	**21.567**
	Intercept	**10.668**	**-10.08**	**-26.782**	7.3353	**26.412**	**84.243**	236.78	372.99	237.84	**129.56**	**111.04**	**55.307**
	R^2	**0.3826**	**0.3449**	**0.3674**	0.2581	**0.5041**	**0.4547**	0.0338	0.0001	0.226	**0.6094**	**0.4939**	**0.4528**
(n = 12)	***p***	**0.0320**	**0.0447**	**0.0367**	0.0917	**0.0097**	**0.0162**	0.5671	0.9716	0.1007	**0.0016**	**0.0074**	**0.0117**
Lauder (LAE)	**Slope b (x)**	1.0247	0.9295	**1.0918**	**0.7698**	**14.238**	**16.066**	11.68	11.106	12.156	13.937	7.286	6.5084
	Intercept	146.4	120.51	**109.47**	**129.65**	**178.7**	**210.87**	278.73	329.96	340.38	321.6	315.79	278.87
	R^2	0.0115	0.01	**0.0159**	**0.0081**	**0.5155**	**0.3142**	0.0881	0.1078	0.1811	0.1984	0.0621	0.0609
(n = 15)	***p***	0.2702	0.1391	**0.0457**	**0.0030**	**0.0017**	**0.0297**	0.2827	0.2321	0.1138	0.0961	0.3705	0.3753
Dansey Pass (DNP)	**Slope b (x)**	14.549	14.082	12.727	9.0645	5.8158	5.3017	3.7431	6.7169	14.01	17.35	8.265	12.37
	Intercept	134.58	111.41	112.05	147.37	205.15	260.85	316.9	341.31	311.98	295.11	292.77	215.35
	R^2	0.2539	0.3069	0.3045	0.287	0.1607	0.0579	0.0095	0.0418	0.2573	0.2861	0.0515	0.121
(n = 12)	***p***	0.0948	0.4950	0.1065	0.0592	0.1747	0.4511	0.7635	0.5238	0.0923	0.0731	0.4779	0.2679
Rock and Pillar (RNP)	**Slope b (x)**	-1.7885	-1.2723	1.1666	-0.9264	-2.5795	2.9919	-3.3921	-1.5218	4.5955	4.8512	-3.211	-3.1871
	Intercept	277.24	248.39	230.65	262.77	297.34	300.02	381.91	413.33	391.89	382.51	365.12	328.96
	R^2	0.0041	0.002	0.0018	0.0014	0.0113	0.0083	0.0041	0.0009	0.018	0.0157	0.0061	0.0079
(n = 10)	***p***	0.8508	0.8968	0.9009	0.9145	0.7560	0.8028	0.8602	0.9285	0.6940	0.7137	0.8193	0.7953
Dunedin Aero (DNA)	**Slope b (x)**	1.0247	0.9295	1.0918	0.7698	0.6064	0.0965	-0.053	-0.807	0.2157	0.2639	0.2419	1.214
	Intercept	146.4	120.51	109.47	129.65	175.64	241.4	281.6	349.95	331.74	325.09	271.29	181.07
	R^2	0.0115	0.01	0.0159	0.0081	0.0054	0.0002	4.0E-05	0.0084	0.0005	0.0006	0.0005	0.0141
(n = 43)	***p***	0.4942	0.5234	0.4206	0.5668	0.6406	0.9386	0.9681	0.5580	0.8923	0.8759	0.8851	0.4477

West Coast

Station	Regression	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Hokitika Aero (HKA)	**Slope b (x)**	0.0308	-0.026	-0.014	-0.015	-0.027	-0.052	-0.526	-0.379	0.1254	0.0415	0.0177	**-0.14**
	Intercept	5.9223	7.0826	6.6725	10.379	22.381	30.926	55.656	58.072	29.712	15.922	8.7402	**9.4317**
	R^2	0.0101	0.0102	0.0022	0.0036	0.0008	0.0016	0.0484	0.0321	0.0067	0.0029	0.0022	**0.2606**
(n = 42)	***p***	0.5255	0.5235	0.7658	0.7076	0.8595	0.8043	0.1616	0.2561	0.6073	0.7345	0.7667	**0.0006**

Appendix 2. Summary of observed trends in maximum monthly Drought Code (DC) values for long-term stations, based on linear regression (months highlighted in bold indicate a statistically significant trend, and those highlighted in blue indicates months where monthly mean values were also found to be statistically significant).

Station	Regression	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Gisborne Aero (GSA)	**Slope b (x)**	0.8829	0.157	0.478	0.8022	0.5921	0.4854	1.1467	-0.6618	-0.4003	-1.3698	-0.8771	-0.3715
	Intercept	48.555	47.526	49.628	93.386	182.72	280.06	358.84	447.45	401.1	352.63	229.29	149.05
	R^2	0.0232	0.0046	0.0399	0.0471	0.0158	0.0061	0.0153	0.0044	0.0012	0.0088	0.0054	0.0017
(n = 44)	***p***	0.3232	0.6635	0.1939	0.1570	0.4158	0.6183	0.4241	0.6697	0.8265	0.5449	0.6343	0.7916
Kaikoura (KIX)	**Slope b (x)**	**3.6454**	2.0184	1.5754	1.1447	0.7492	1.8199	2.417	**3.1921**	**3.9116**	2.907	**3.8796**	**5.4208**
	Intercept	**41.496**	39.355	41.066	78.838	155.9	234.72	326.92	**363.2**	**347.58**	298.18	**184.35**	**58.981**
	R^2	**0.1435**	0.0846	0.0822	0.0456	0.0132	0.0548	0.0697	**0.0936**	**0.1254**	0.0552	**0.1052**	**0.2517**
(n = 42)	***p***	**0.0134**	0.0616	0.0657	0.1744	0.4696	0.1409	0.0912	**0.0488**	**0.0214**	0.1341	**0.0361**	**0.0007**
Christchurch Aero (CHA)	**Slope b (x)**	0.9305	0.9086	0.6563	-0.6337	-0.354	-0.0933	1.2306	0.8354	1.6179	0.5925	0.7863	2.031
	Intercept	186.79	131.09	120.87	187.2	255.26	361.97	432.06	509.21	490.92	473.6	372.0	235.11
	R^2	0.0085	0.0102	0.0069	0.0065	0.003	0.0022	0.021	0.007	0.0197	0.0022	0.0038	0.0431
(n = 46)	***p***	0.5431	0.5040	0.5832	0.5947	0.7187	0.9350	0.3362	0.5793	0.3516	0.7566	0.6841	0.1664
Queenstown Aero (QNA)	**Slope b (x)**	**4.4318**	**3.9106**	**2.0143**	1.6514	0.5738	0.3633	0.0112	3.6034	3.6033	**5.0735**	5.1238	**7.5827**
	Intercept	**11.183**	**7.2156**	**15.527**	52.884	137.29	220.11	294.83	285.43	291.04	**237.82**	165.53	**42.729**
	R^2	**0.2544**	**0.2216**	**0.1719**	0.1194	0.0084	0.0024	1.0E-06	0.092	0.0797	**0.1513**	0.1275	**0.3071**
(n = 28)	***p***	**0.0062**	**0.0115**	**0.0283**	0.0717	0.6436	0.8096	0.9957	0.1166	0.1456	**0.0408**	0.0621	**0.0072**
Dunedin Aero (DNA)	**Slope b (x)**	1.3358	1.0305	1.2119	0.7516	0.2128	0.0135	0.1204	-0.4796	-0.5069	0.8832	-0.3958	0.9905
	Intercept	166.59	142.18	129.99	168.23	231.2	295.1	342.56	409.69	417.93	359.31	332.07	225.69
	R^2	0.0164	0.0117	0.0186	0.0073	0.0007	3.0E-06	0.0002	0.0028	0.0025	0.0061	0.0013	0.0088
(n = 43)	***p***	0.4130	0.4898	0.3831	0.5864	0.8684	0.9917	0.9287	0.7339	0.7525	0.6181	0.8154	0.5500
Hokitika Aero (HKA)	**Slope b (x)**	0.0613	-0.0205	-0.0182	0.0686	-0.1093	-0.1551	**-1.1053**	0.6571	-0.0346	0.1317	0.3083	**-0.3092**
	Intercept	16.436	17.699	18.271	26.925	55.931	72.713	**115.71**	116.16	78.949	44.297	19.994	**24.199**
	R^2	0.0084	0.0013	0.0006	0.0080	0.0033	0.0041	**0.0937**	0.0372	0.0001	0.0056	0.0752	**0.2581**
(n = 42)	***p***	0.5646	0.8206	0.8773	0.5724	0.7162	0.6984	**0.0487**	0.2213	0.9432	0.6381	0.0788	**0.0006**

Appendix 3. Summary of observed trends in minimum monthly Drought Code (DC) values for long-term stations, based on linear regression (months highlighted in bold indicate a statistically significant trend, and those highlighted in blue indicates months where monthly mean values were also found to be statistically significant).

Station	Regression	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Gisborne Aero (GSA)	**Slope b (x)**	0.031	-0.0757	0.2279	0.4218	0.7386	-0.567	0.8905	0.3198	-0.8392	-1.1163	-0.9272	0.9882
	Intercept	12.247	12.534	8.6868	19.688	59.738	147.21	194.86	243.49	230.3	182.35	124.6	24.094
	R^2	0.0002	0.004	0.0197	0.0274	0.0256	0.0112	0.011	0.0009	0.004	0.009	0.0104	0.0229
(n = 44)	***p***	0.9305	0.6835	0.3634	0.2828	0.2992	0.4991	0.4988	0.8482	0.6842	0.5408	0.5108	0.3268
Kaikoura (KIX)	**Slope b (x)**	2.0177	1.2745	1.1404	0.6549	1.1343	1.4643	2.1699	2.9497	2.9542	3.4676	**5.0461**	**3.6864**
	Intercept	4.8416	4.2154	10.867	25.179	47.46	109.4	180.75	237.1	201.81	145.2	**36.478**	**18.214**
	R^2	0.0852	0.0614	0.0569	0.0189	0.0377	0.0376	0.0624	0.082	0.0608	0.0915	**0.2463**	**0.1425**
(n = 42)	***p***	0.0607	0.1135	0.1283	0.3853	0.2179	0.2242	0.1105	0.0660	0.1155	0.0515	**0.0008**	**0.0137**
Christchurch Aero (CHA)	**Slope b (x)**	0.5378	0.4596	0.0705	-0.5798	-0.0861	0.0987	0.3031	1.5041	1.8293	0.9004	1.3252	0.9786
	Intercept	108.02	76.631	81.717	106.14	138.27	215.68	294.89	348.34	336.23	310.36	225.22	163.98
	R^2	0.0036	0.0036	9.0E-05	0.0073	0.0002	0.0002	0.0013	0.0273	0.022	0.0051	0.0188	0.0097
(n = 46)	***p***	0.6906	0.6915	0.9500	0.5727	0.9277	0.9286	0.8155	0.2725	0.3251	0.6382	0.3638	0.5144
Queenstown Aero (QNA)	**Slope b (x)**	**3.2241**	**1.8269**	**1.6998**	**1.4831**	1.1395	1.2876	0.2199	2.4792	**4.94**	4.6852	**7.2518**	**4.5704**
	Intercept	**-5.3905**	**-11.351**	**-10.448**	**-0.4613**	34.687	95.865	159.48	188.29	**161.3**	137.78	**36.824**	**4.9848**
	R^2	**0.2058**	**0.2059**	**0.2083**	**0.1632**	0.0496	0.0397	0.0005	0.0413	**0.1864**	0.1166	**0.3081**	**0.2662**
(n = 28)	***p***	**0.0153**	**0.0153**	**0.0147**	**0.0330**	0.2546	0.3190	0.9108	0.2996	**0.0218**	0.0754	**0.0022**	**0.0049**
Dunedin Aero (DNA)	**Slope b (x)**	0.9496	0.8711	0.7822	0.8508	0.9582	0.2415	-0.0634	-1.096	0.4794	-1.2399	0.6876	1.3754
	Intercept	118.01	97.656	91.728	93.673	121.49	181.22	218.35	288.46	269.0	302.53	215.61	147.49
	R^2	0.0103	0.0092	0.0083	0.0099	0.013	0.0009	6.0E-05	0.015	0.0021	0.0128	0.0042	0.0185
(n = 43)	***p***	0.5173	0.5413	0.5620	0.5624	0.4674	0.8508	0.9619	0.4337	0.7716	0.4697	0.6798	0.3842
Hokitika Aero (HKA)	**Slope b (x)**	0.0045	-0.0048	-0.0002	0.0014	0.0033	0.0484	-0.1687	-0.1763	-0.0281	0.0048	-0.004	-0.0037
	Intercept	0.9723	1.2279	1.2679	2.7442	4.916	5.775	15.53	15.197	5.5223	2.6779	1.4601	1.1116
	R^2	0.0097	0.0329	4.0E-06	0.0033	0.0003	0.0164	0.0135	0.018	0.0134	0.0304	0.0144	0.0247
(n = 42)	***p***	0.5340	0.2501	0.9700	0.7168	0.9073	0.4255	0.4363	0.3971	0.4655	0.2694	0.4498	0.3199

Appendix 4. Summary of observed trends in fire season maximum Drought Code (DC) values for stations with long-term records (months highlighted in bold indicate a statistically significant trend).

Station	Regression	DC threshold value		
		> 300	> 400	>500
Gisborne Aero (GSA)	**Slope b (x)**	0.2637	0.2528	0.0411
	Intercept	61.037	25.811	12.236
	R^2	0.004	0.0061	0.0005
(n = 44)	***p***	0.6883	0.6186	0.8911
Kaikoura (KIX)	**Slope b (x)**	**2.2296**	**1.5216**	**0.9453**
	Intercept	**42.812**	**8.2902**	**-6.5585**
	R^2	**0.1921**	**0.1675**	**0.1896**
(n = 42)	***p***	**0.0041**	**0.0079**	**0.0044**
Christchurch Aero (CHA)	**Slope b (x)**	0.5354	0.3229	0.2800
	Intercept	136.82	78.773	38.361
	R^2	0.0092	0.0048	0.0058
(n = 46)	***p***	0.5310	0.6509	0.6159
Queenstown Aero (QNA)	**Slope b (x)**	**2.3480**	1.0763	0.1026
	Intercept	**16.869**	-2.143	-0.473
	R^2	**0.1514**	0.1329	0.0336
(n = 28)	***p***	**0.0449**	0.0615	0.3602
Dunedin Aero (DNA)	**Slope b (x)**	1.4394	0.8891	0.1629
	Intercept	88.957	29.526	8.022
	R^2	0.0345	0.0385	0.0079
(n = 43)	***p***	0.2389	0.2132	0.5765
Hokitika Aero (HKA)	**Slope b (x)**	-0.4002	-0.2199	-0.0484
	Intercept	48.379	14.227	2.359
	R^2	0.0513	0.0555	0.0297
(n = 42)	***p***	0.1544	0.1381	0.2812