Forest Sciences Project Y09-2200:

Assessing ecosystem vulnerability to climate change from the tree- to stand- to landscape-level

Analysis of climate data from Smithers, BC: can we expect an increase in conditions favourable to dothistroma reproduction?

Project Report

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Introduction

Anticipated increases in maximum daily temperatures and rainfall for British Columbia's northern regions could potentially bring about an increase in conditions favourable to *Dothistroma* reproduction; a form of needle blight that mainly attacks lodgepole pine. This report provides a method analyzing daily maximum temperatures and daily precipitation to identify the expected frequency of environmental events that are favorable for *Dothistroma* populations. Analyses were performed on data obtained from the airport near Smithers, BC.

The underlying assumption of this analysis is that the link between climate change and a change in the *Dothistroma* population is defensible. Woods *et al.* (2005) provide evidence to support this link. Information obtained from Woods et al. (2005) and other peer reviewed literature on the subject of *Dothistroma* were pooled and assessed. From this assessment, it was determined that *Dothistroma* reproduction was most likely to occur under a specific set of environmental conditions. These conditions included a period of at least 3 days with temperatures between 16 and 20 C, which was then followed by a week of temperatures between 12 and 20 C and which also included periods of precipitation. This report presents a specific set of climate criteria that are considered to be favourable conditions for *Dothistroma* reproduction. Temperature and precipitation data from Smithers, BC were then queried using the specific climate criteria. Results of the query and a brief discussion of the analyses are presented in this report.

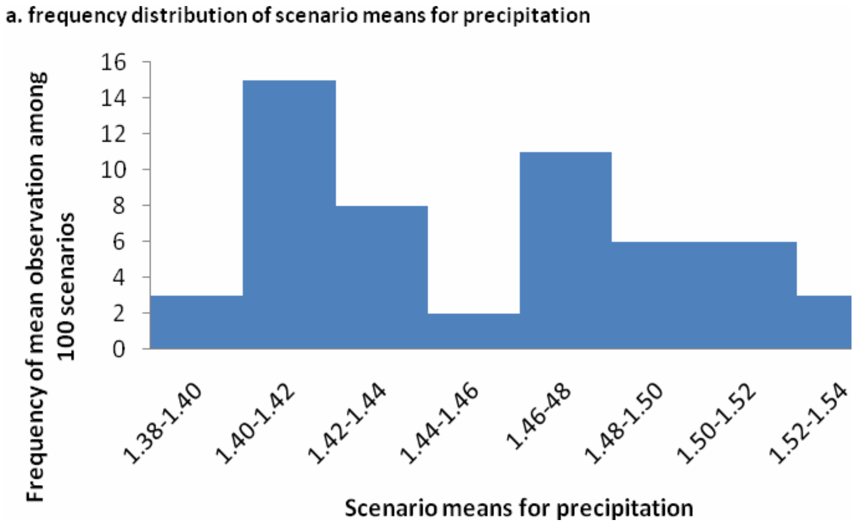
Methodology

Data for analyses

The dataset used in the analyses included daily temperature and precipitation values for the period between January 1st 1971 and December 31st, 2090. The data was derived from two sources. For the period between January 1st, 1971 and December 31st, 2000, actual daily temperature and precipitation measures were obtained from the airport in Smithers, BC. For the period between January 1st, 2001 and December 31st, 2090, daily temperature and precipitation values for the Bulkley Valley area were generated using an ensemble of Global Circulation Models (GCMs). To test the likelihood that future climate conditions in the Bulkley Valley would provide conditions favourable to the reproduction of *Dothistroma*, a Monte Carlo approach was used. For each predictor variable used in the GCM, an upper and lower bound was established for the associated parameter, based on the literature. Parameter values were then randomly selected from the defined upper and lower bounds associated with each predictor variable. The parameter selection process was repeated until a total of 1000 scenarios were generated, each containing daily temperature and precipitation values for the period between 2001 and 2090.

Description of data

The first step in the analysis was to understand the distribution of temperature and precipitation values from the 1000 scenarios. To do this, the means for temperature and precipitation of 100 scenarios were plotted on a frequency table (means were from the period between 2001 and 2090). Figures 1 and 2 show the frequency distributions of the scenario means for temperature and precipitation, respectively. The scenario means for precipitation and temperature do not appear to follow any obvious distributional patterns. This was somewhat unexpected, as the random parameter selection process should have created a clear uniform distribution. Under a uniform distribution, each scenario has equal likelihood of occurring. A closer look at the process used to generate the temperature scenarios appears warranted; however, for now I will assume that each scenario has equal probability of occurring.



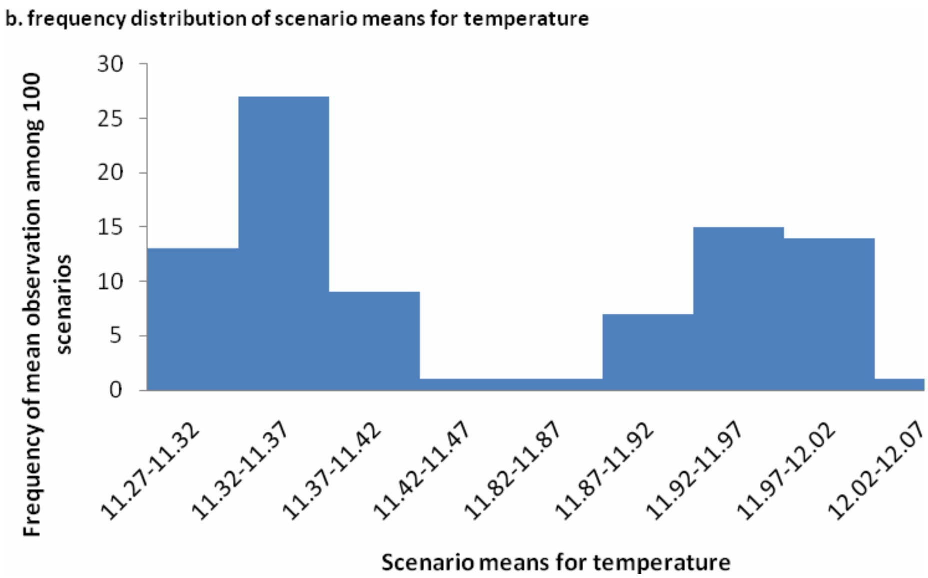


Figure 1 a-b. Frequency distribution of means of maximum temperature and precipitation from the 1000 GCM-generated scenarios.

The average for total annual precipitation was calculated from the 1000 scenarios for four time periods (Table 1). On average, the total annual precipitation increases over the 120 year period for the 1000 scenarios. Furthermore, the maximum and minimum annual precipitation predicted by individual scenarios also increase, on average. Averages of the annual mean maximum temperature from the 1000 scenarios for the four time periods, shows that the annual mean maximum temperature increases over time. The highest and lowest values for annual maximum mean temperature predicted from individual scenarios also increases over time, on average.

Table 1 Average of total annual precipitation, and average of the maximum and minimum total precipitation from the 1000 GCM scenarios.

Time Period	Total precipitation	Std.	Max	Min
1970-2000	510.4	83.3	760.7	312.4
2001-2030	512.6	88.4	698.4	294.9
2031-2060	521.6	89.9	718.4	300.0
2061-2090	534.6	90.1	724.9	312.2

Time Period	Mean Max. Temperature	Std.	Max	Min
1970-2000	9.2	0.90	10.6	6.8
2001-2030	9.6	0.34	10.7	8.5
2031-2060	11.8	0.44	13.3	10.5
2061-2090	12.9	0.60	14.8	11.4

A time series plot of the average of the annual mean maximum temperature for the 1000 GCM-generated scenarios shows two distinct jumps, noticeable at 2029 and 2061; the latter being a smaller increase (Figure 3). During the period between 2001 and 2090, the highest and lowest average maximum annual temperature reported by any one scenario remains constant, relative to the annual mean maximum temperature.

Figure 3 Actual annual total precipitation and average annual maximum temperature for the period between 1971 and 2000. For the period between 2001 and 2090, the figure shows the mean annual total precipitation (solid green line) and the annual maximum and minimum (blue dots above and below green line) total precipitation calculated from the 1000 scenarios. For the same period, the figure shows the mean of the average annual maximum temperature calculated from the 1000 scenarios (solid red line). Maximum and minimum average max. temperatures are shown in yellow dots above and below the red line.

The total annual precipitation and average maximum temperatures for the period between January 1st, 1971 and December 31st, 2000 show wide fluctuations from year to year (Figure 3). The mean total annual precipitation calculated from the 1000 GCM-generated scenarios remains relatively stable over the next 90 years. However, the GCM-generated scenarios show a clear cyclical pattern where total annual precipitation increases and then decreases over a 5 to 6 year period. The maximum total precipitation predicted from individual scenarios for this period stays relatively stable. In contrast, the minimum total precipitation varies widely from year to year. During the period between 2001 and 2090, six different scenarios predict that the minimum total precipitation will drop to as low as 200 mm.

Average seasonal trends in precipitation and maximum temperature from the 1000 scenarios are presented in Figure 4 a-d. Seasonal trends are presented in 10-year time periods. The seasonal trends were calculated by summing daily precipitation values and averaging maximum daily temperatures over intervals of three months (e.g., to get total precipitation in spring, I summed total daily precipitation values for March, April, and May). These Figures show that the mean seasonal maximum temperatures generated by the GCM (Figures 4 c and d) mimic the cyclical fluctuations in maximum temperatures observed in the period prior to 2001 (Figures a and b). However, the actual fluctuations in precipitation observed prior to 2001 are noticeably different from the precipitation patterns generated by the GCM (particularly for the period between 1991 and 2001).

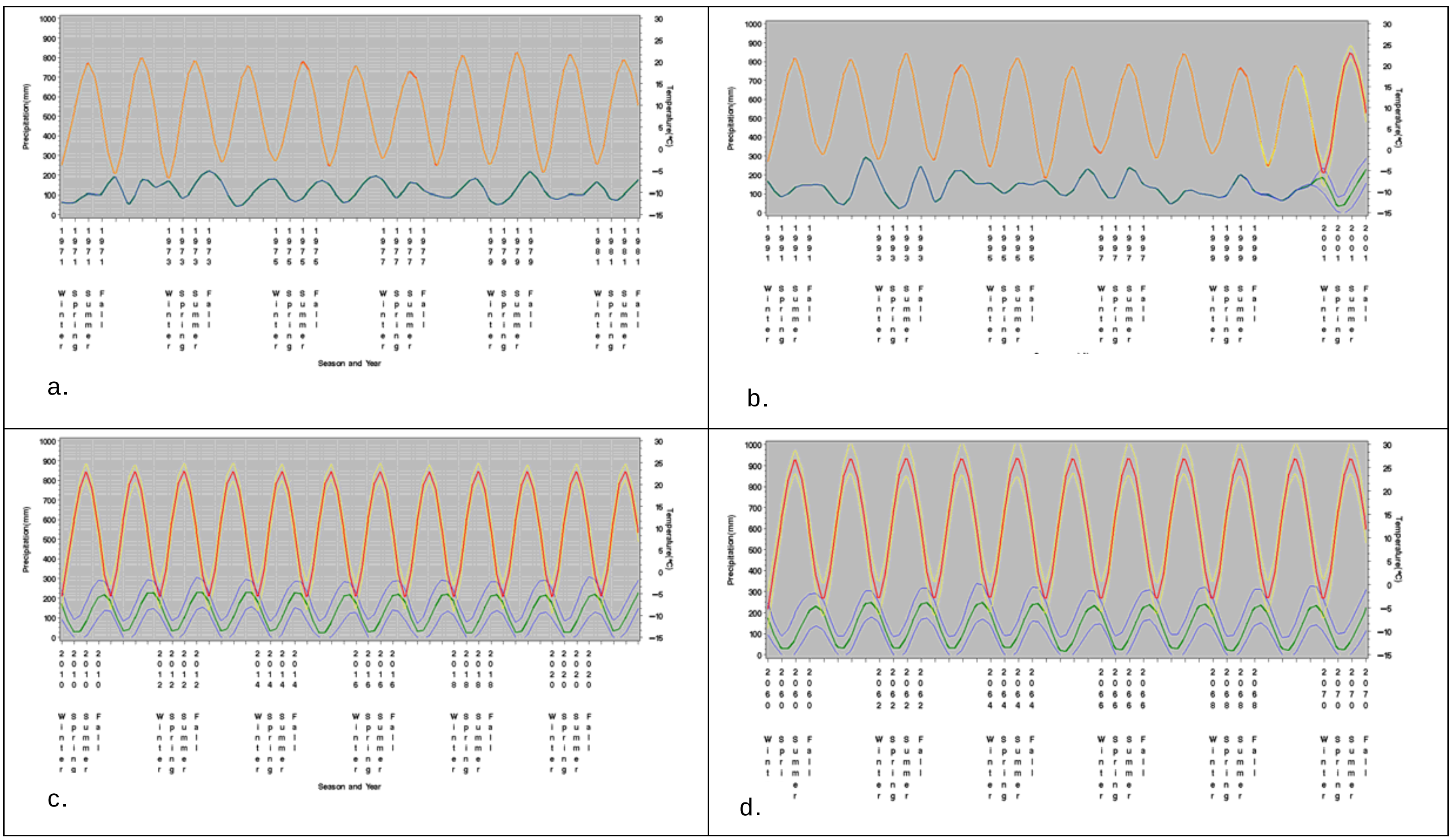


Figure 4 a – d. Averaged seasonal trends for total precipitation (right axis) and maximum temperature (left axis) from the 1000 scenarios for four 10-year time periods (a = 1971-1981; b = 1991-2001; c = 2010-2020; d = 2060-2070).

Query for climatic ‘events’

To assess if actual and predicted temperature and precipitation values for the Bulkely Valley area were favourable to the reproduction of *Dothistroma*, the analysis dataset was queried for a specific range of temperatures and precipitation values. Periods favourable to *Dothistroma* reproduction were identified using criteria obtained from the literature. The following criteria were use:

1. A minimum of 3 days where maximum temperatures ranged between 16 and 20 C. Dates that met this criterion were then grouped into 3 categories (high, medium, and low) based on the number of consecutive days that temperatures fell within this range. These were defined as:

    a. High: > 7 consecutive days

    b. Medium: 8 > consecutive days > 4

    c. Low: 5 > consecutive days > 2

2. Consecutive days where maximum temperatures ranged between 12 and 20 C, and which coincided or followed immediately after a period defined by criteria 1. The classification of criteria 2 was conditional upon the criteria 1. Periods identified as ‘Low’ in criteria 1 had to be immediately followed by a minimum of 3 days that met criteria 2 (e.g., if a period of 4 consecutive days met criteria 1, the 5^{th}, 6^{th}, and 7^{th} days had to meet criteria 2). Periods identified as ‘medium’ in criteria 1 had to be immediately followed by a minimum of 1 day meeting criteria 2. Periods identified as ‘High’ in criteria 1 could either coincide or be followed by any number of consecutive days meeting criteria 2.

3. A minimum total precipitation of 5 mm over a 5-day period and which immediately follows the last consecutive day in the period classified under criteria 1.

Periods meeting all three of these criteria were classified as an ‘event’ favourable to the reproduction of *Dothistroma*. Climatic ‘events’ were then grouped based on the ‘High’, ‘Medium’, and ‘Low’ classes defined in criteria 1. The results for the period between 1970 and 2000 were compared to the results of querying the 1000 scenarios between 2001 and 2090.

Analysis of new scenario set

A second Monte Carlo analysis was performed by generating 250 temperature and precipitation scenarios using a normal cumulative distribution function. Generating the new set began by selecting a single scenario from the original set of 1000, which was of average maximum temperature and total precipitation. Selecting a single scenario of average temperature and precipitation avoided the possibility of removing the correlations between temperature and precipitation; this would have occurred if a single scenario was create by averaging daily values across the 1000 original scenarios. Next, the inverse of a normal cumulative distribution was returned using the following equation:

$$x = F^{-1}(p|\mu,\sigma) = \{x : F(x|\mu,\sigma) = p\}$$

where

$$p = F(x|\mu,\sigma) = \frac{1}{\sigma\sqrt{2\pi}}\int_{-\infty}^{x} e^{\frac{-(t-\mu)^2}{2\sigma^2}}$$

and where μ is the daily temperature or precipitation and σ is 15% of the value for temperature or precipitation on any given day. The result, x , is the temperature or precipitation for the probability (p)

specified. Using this approach allowed for the creation of 250 temperature and precipitation scenarios of known probability. Thus, the number of climate 'events' queried in a given scenario have an associated probability. To simplify the analysis, scenarios were grouped into probability classes of 0.2 (e.g., $p =$ 0-0.2; 0.21-0.4; 0.41-0.6; 0.61-0.8; 0.81-1). The same set of criteria used to query the original data was used for the new scenario set. The generation of scenarios using this approach was limited to 250 due to lengthy processing times. However, 250 scenarios were considered to be sufficient for the purposes of this research. Comparisons of results from the new scenario set to the original 1000 scenarios were on a proportional scale (e.g., comparing the proportion of scenarios in the new data set in which at least one 'event' was recorded to the proportion recorded for the original data set).

Results and Discussion

Query for 'events' from Original Scenario Set

During the period in which actual measures of temperature and precipitation were recorded (i.e., dates prior to 2001), a total of 15 'events' were returned from the query. Of the 15 'events', six were ranked as 'High risk' based on criteria 1. That is, on these six 'events', temperatures ranged between 16 and 20 C for a period of 8 days or more in succession, and coincided with or were followed by periods of rain and temperatures ranging between 12 and 20 C. Four 'events' were classified as 'medium risk', meaning that temperatures ranged between 16 and 20 C for 5 to 7 days and were followed by periods of rain and temperatures ranging between 12 and 20 C. The remaining five 'events' were classified as 'Low risk'. On average, the total precipitation in the week that followed or coincided with periods fitting criteria 1 was 7.28 mm. Eleven of the 'events' were recorded in the summer months, two in the fall and two in the spring.

Reports from the literature have indicated that there was an increase in the frequency of conditions favourable to Dothistroma reproduction in the 1990's. This trend was not evident with the data used in this study. Here, seven of the 15 'events' recorded prior to 2001, occurred between 1971 and 1980, while only five were recorded in the 1990's. However, out of the five 'events' that were queried from the time period between 1990 and 2001, four were ranked as 'High risk'. The discrepancy with previous reports could be a result of different criteria used to identify conditions favourable to Dothistroma. For example, Woods *et al.* (2005) considered the frequency of three-day rain events above a critical temperature. In their query, it was not specified if a six-day rain event above a critical temperature was classified as a single 'event' or as two separate 'events'. For our study, the high number of 'High risk' 'events' in the 1990's could also be interpreted as several three-day 'events' in succession. If the results are interpreted this way, then they appear more similar to previous reports from the literature.

Querying from the 1000 GCM-generated scenarios between 2001 and 2090, a total of 527 'events' were observed in 409 scenarios (40.9% of 1000 scenarios); meaning that 591 scenarios (59.1%) had no 'events'. The frequency with which the 'events' occurred between 2001 and 2090 is presented in Figure 5. Roughly 70% of the 'events' were classified under a 'moderate risk' level. Most of the 'events' with a moderate rank had a sequence of six days with temperatures between 16 and 20 C coinciding or immediately followed by periods of rain. Just under 4% of the 527 'events' were classified as 'High risk', while 27% were classified as 'Low risk'. The highest number of 'events' recorded in a single scenario during this time period was 4. This frequency of 'events' was observed in only one scenario. Overall, the majority (74%) of the 409 scenarios were observed to have only one 'event' (or 30.2% of all 1000 scenarios), 22% had two 'events' (or 9.0% of all 1000 scenarios), and 3% of scenarios had three 'events' (or 0.01% of all 1000 scenarios).

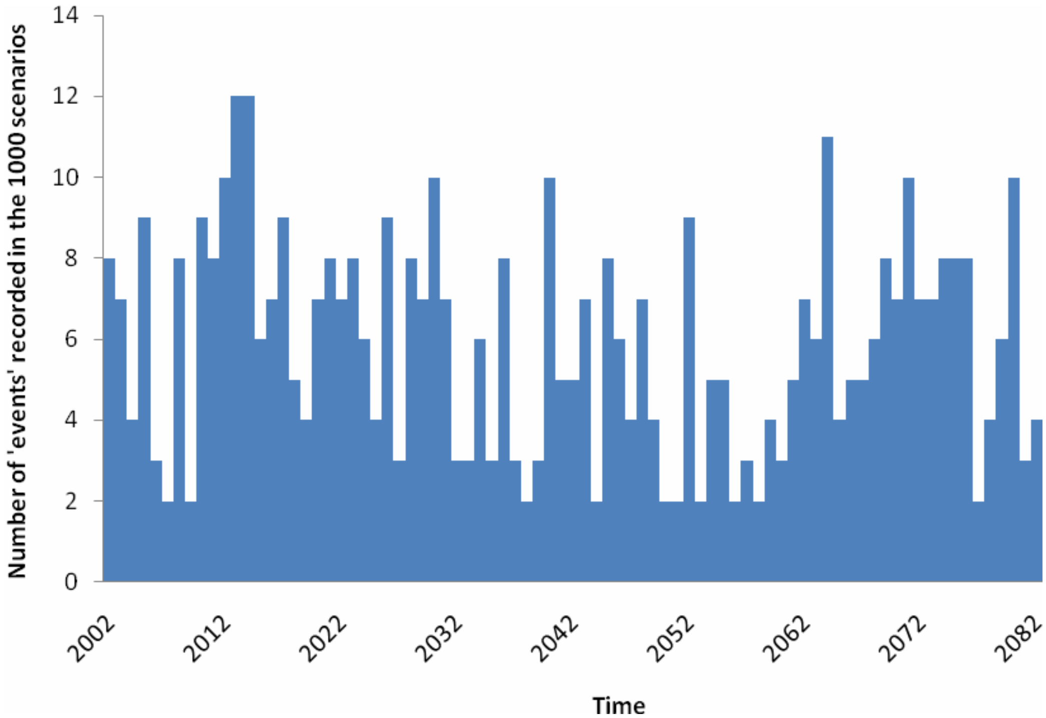


Figure 5 Frequency of recorded ‘events’ from the 1000 GCM-generated scenarios between 2002 and 2090.

Among the 527 ‘events’ recorded, 33% were observed during the summer months, 49% of ‘events’ were recorded during and fall months 18% during the spring months between 2001 and 2090. There was a clear shift over time in the frequency of ‘events’ recorded per season (Table 2). For example, 50% of the recorded ‘events’ between 2001 and 2031 were in the summer and only 33% in fall months. However, between 2061 and 2090, the proportion of ‘events’ recorded in summer months dropped to 23%, while the proportion of ‘events’ in the fall months increased to 54%.

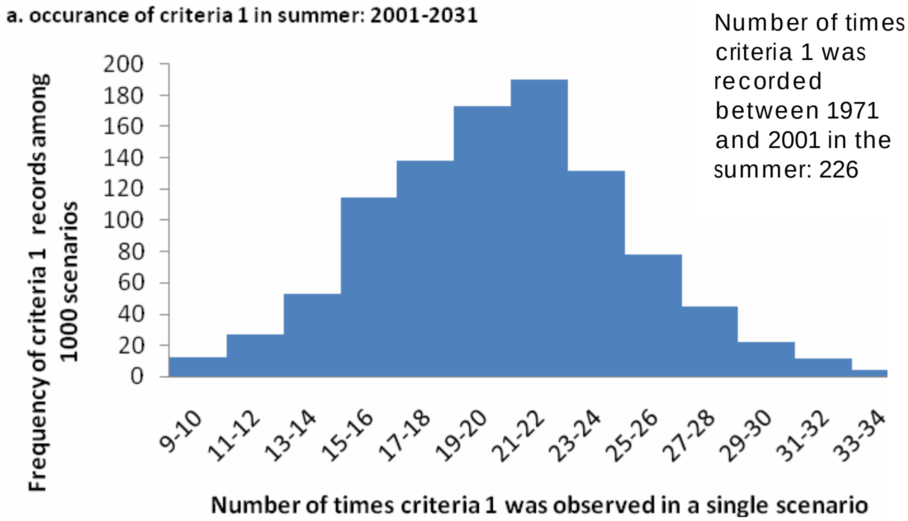
Table 2. Frequency of 'events' recorded per season, listed for three 30-year time periods.

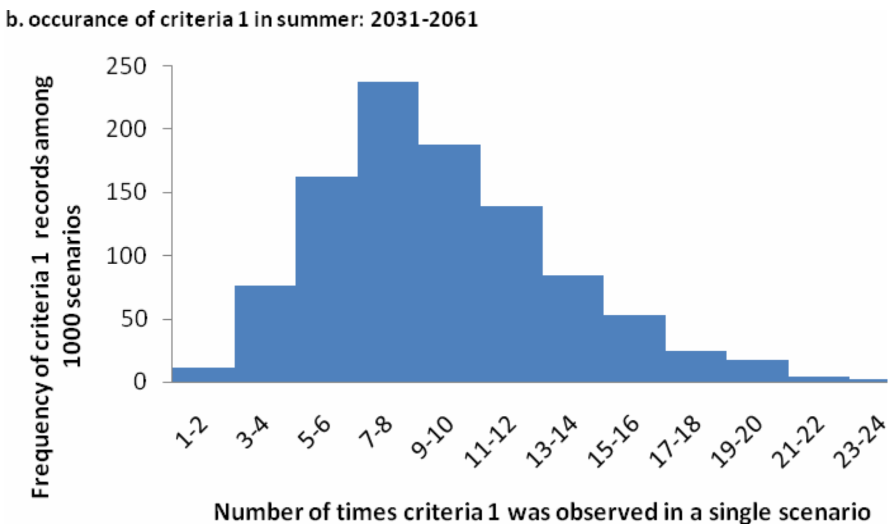
2001-2031		2031-2061		2061-2090	
Season	**Count of Event**	**Season**	**Count of Event**	**Season**	**Count of Event**
Fall		***Fall***		***Fall***	
Low	27	Low	28	Low	33
Moderate	39	Moderate	60	Moderate	62
High	2	High	2	High	2
Spring		***Spring***		***Spring***	
Low	15	Low	6	Low	12
Moderate	21	Moderate	11	Moderate	32
High	1	High		High	
Summer		***Summer***		***Summer***	
Low	23	Low	1	Low	
Moderate	77	Moderate	24	Moderate	39
High	4	High	1	High	3
Grand Total	**209**	**Grand Total**	**133**	**Grand Total**	**178**

The main cause for the shift from summer to fall appears to be mainly due to an increase in summer and fall temperatures. Based on the 1000 GCM-generated scenarios, mean summer temperatures are between 2001 and 2031 are 22.8 C. For this same period, the lowest maximum temperature recorded in any single scenario seldom dropped below 18 C, meaning that we were unlikely to have a sequence of days with temperatures between 16 and 20 C. Comparatively, the period between 2061 and 2090 has a mean summer temperature of 26 C, and the lowest maximum daily temperature recorded from any one scenario was rarely below 20C. Between 1971 and 2001, mean summer temperatures were 20.5 C, with maximum daily summer temperatures dropping down to 17 C frequently within from year to year. Thus, the predicted increase in temperatures post-2001 appears to have moved maximum daily temperatures above the range of temperatures favourable to Dothistroma reproduction.

To get an idea of how temperatures pre- and post-2001 are affecting Dothistroma reproduction, we can examine the likelihood of finding criteria 1 (that is, a minimum of three consecutive days with temperatures between 16 and 20 C). Plotted in Figures 6 a – c and 7 a – c are the frequency distributions of periods matching criteria 1 from the 1000 GCM-generated scenarios. The frequency distributions are plotted for summer and fall, over 30-year intervals (Figure 6 and 7, respectively). The peak of a distribution marks the frequency with which criteria 1 was observed the most often across all 1000 scenarios. For example, in Figure 6 a, we see that the distribution peaks on the x-axis at 21-22, corresponding with 180 on the y-axis. Thus, criteria 1 occurred 21 times in 180 different scenarios. We can them compare the peaks, the means of the distributions, and the upper and lower limits to actual results from the period between 1971 and 2001. For example, between 1971 and 2001, criteria 1 was observed 226 times in the summer months. This is well above the upper limit of the distribution from the 1000 scenarios in Figure 6 a.

A second factor contributing to the seasonal shift in the frequency of ‘events’ as well as the overall decrease in ‘events’ over time were precipitation levels. Figures 8 a – c and 9 a – c plot the frequency distributions of 5-day rain periods in the summer and fall, over 30-year intervals. Between 1971 and 2001, there were 121 five-day rain events in the summer. Over the next 30 years, the results from the 1000 scenarios suggest that there will be an increase, on average, in the number of five-day rain events. However, this increase in precipitation does not seem to coincide with temperatures favourable to Dothistroma reproduction, hence the overall decrease in ‘events’ over time.





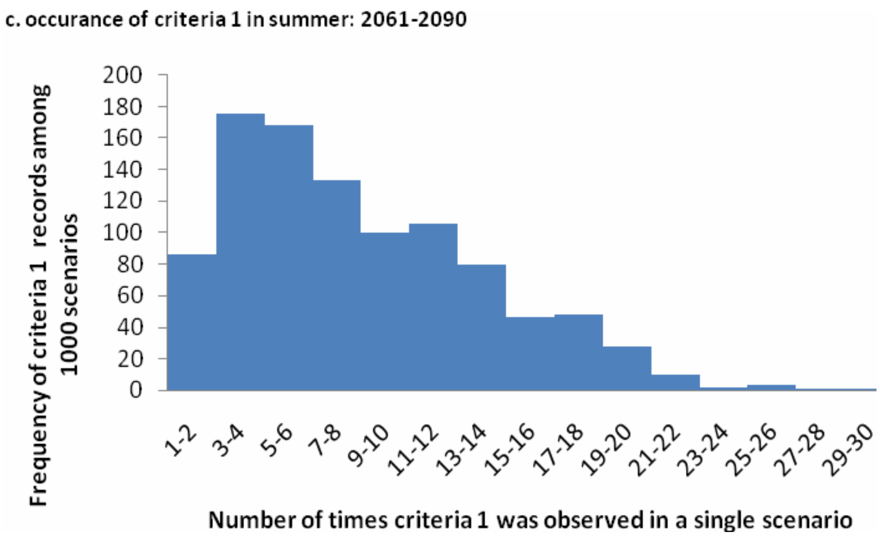
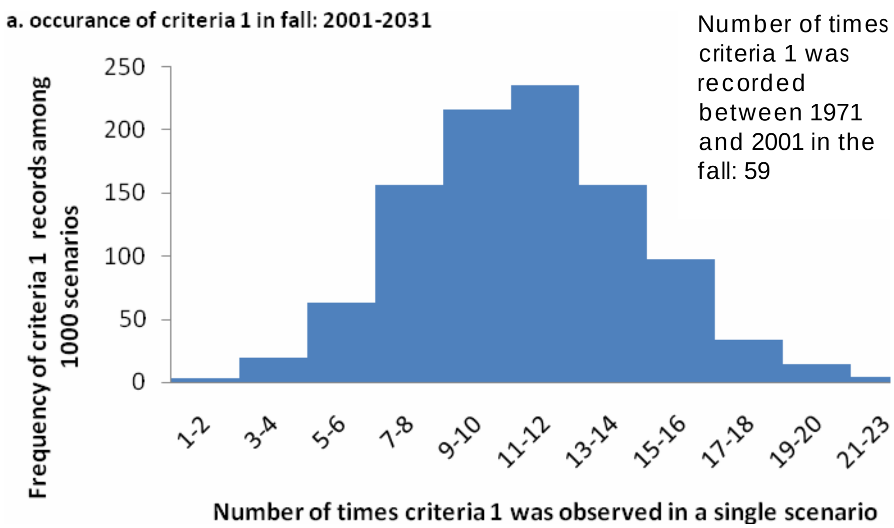
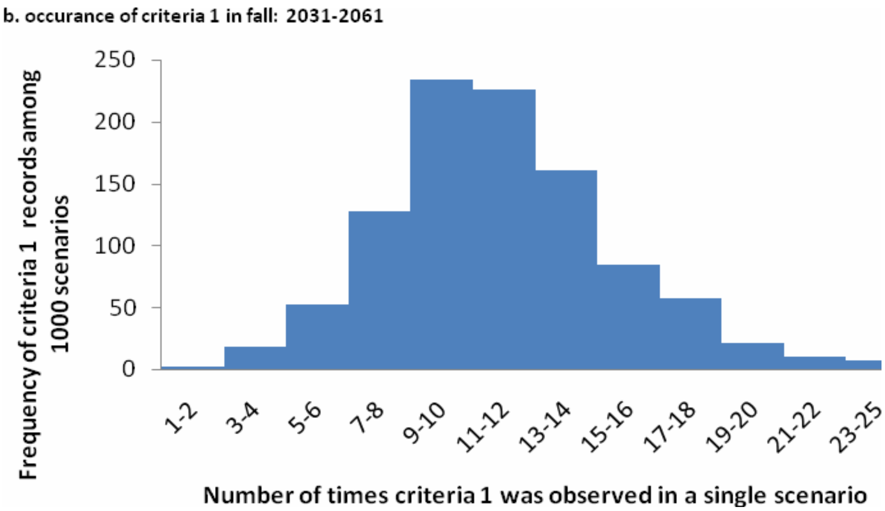


Figure 6 a – c. Frequency distribution of the number of times criteria 1 was recorded in a single scenario during the summer months after querying 1000 scenarios, reported for 30-year intervals.





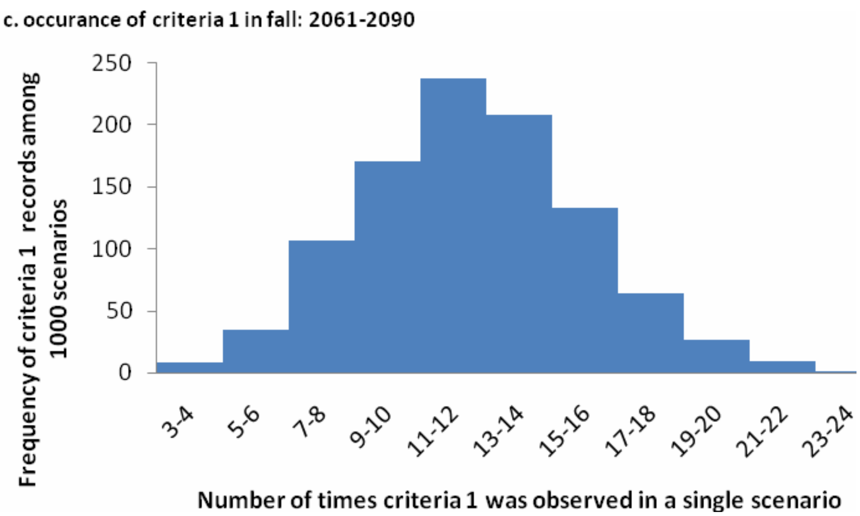
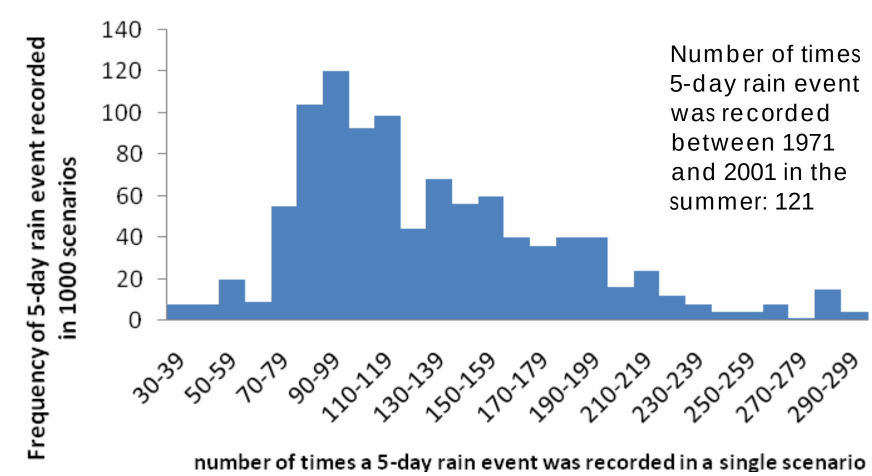
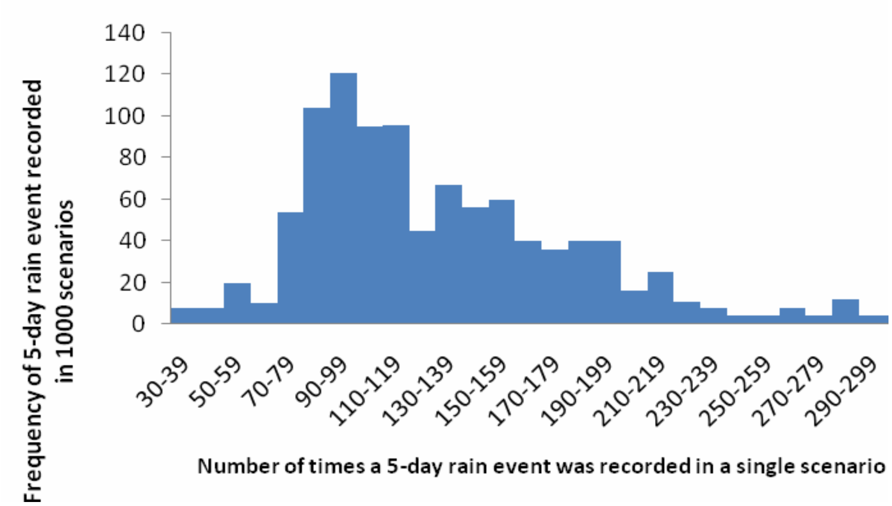


Figure 7 a – c. Frequency distribution of the number of times criteria 1 was recorded in a single scenario during the fall months after querying 1000 scenarios, reported for 30-year intervals.

a. occurrence of 5-day rain events in summer: 2001-2031



b. occurrence of 5-day rain events in summer: 2031-2061



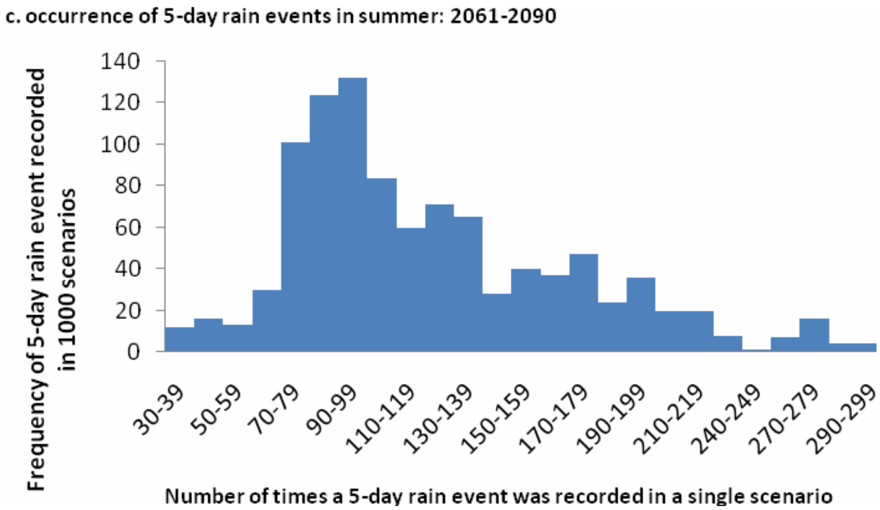
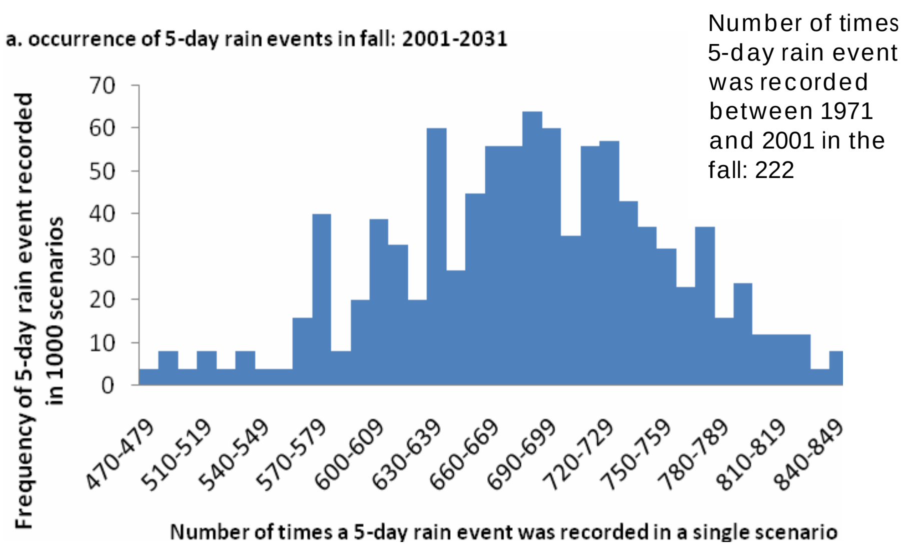
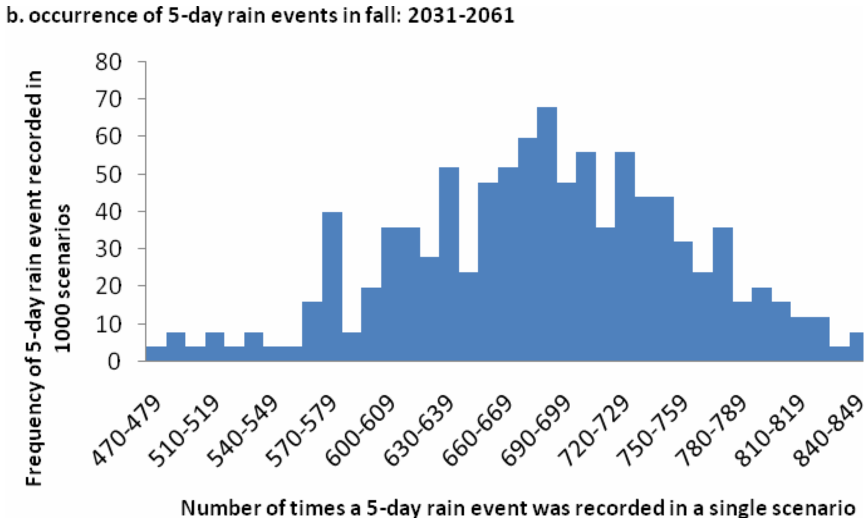


Figure 8 a – c. Frequency distribution of the number of times a 5-day rain event was recorded in a single scenario during the summer months after querying 1000 scenarios, reported for 30-year intervals.





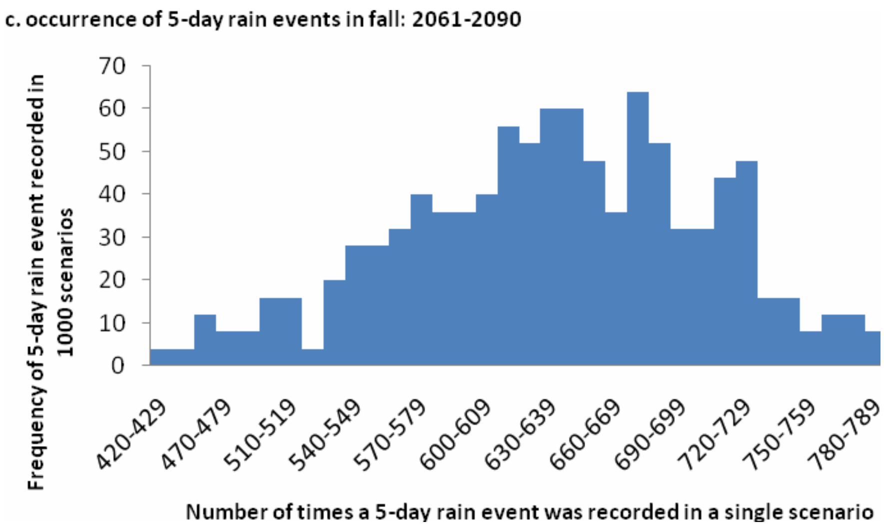


Figure 9 a – c. Frequency distribution of the number of times criteria 1 was recorded in a single scenario during the fall months after querying 1000 scenarios, reported for 30-year intervals.

Query for 'events' from New Scenario-Set

Querying for 'events' in the new scenario-set resulted in a greater proportion of 'events' recorded. From the 250 scenarios queried, 155 had a least one 'event' (62%); compared to 41% in the query of the original dataset. The distribution of maximum and minimum values of temperature and precipitation recorded in a single scenario (yellow and blue lines in Figure 10, respectively) was much wider than in the original scenario-set; hence the greater chance of observing 'events' favourable to *Dothistroma*.

Figure 10 Mean annual total precipitation (solid green line) and the annual maximum and minimum (blue dots above and below green line) total precipitation calculated from the 250 scenarios generated using a normal distribution. The figure shows the mean of the average annual maximum temperature calculated from the 250 scenarios (solid red line). Maximum and minimum average max. temperatures are shown in yellow dots above and below the red line.

The 'moderate risk' classification remained the most frequently observed 'event' type. Among the scenarios with at least one 'event' 38% had only one event (compare to 74% in original scenario set), while 25% had two events. Furthermore, a greater proportion of the scenarios had four or more 'events'; one scenario had 10 'events' recorded, another 9 'events', while 9 scenarios had four 'events' recorded. However, scenarios with the greatest frequency of 'events' tended to have the lowest probability of occurring (e.g., the scenarios with 9 and 10 events were in the 10th percentile of a standard normal distribution). In the scenarios that were most likely to occur (i.e., between the 40th and 60th percentile of a standard normal distribution), two 'events' were recorded on average (ranging from a high of 4 and low of 1 'event' per scenario). The distribution of the number of 'events' recorded per scenario is presented in Figure 11. Scenarios with a probability between 0-0.1 and 0.8-0.9 and least likely to occur (e.g., fall within the 10th and 80th percentiles, respectively, of a standard normal distribution)

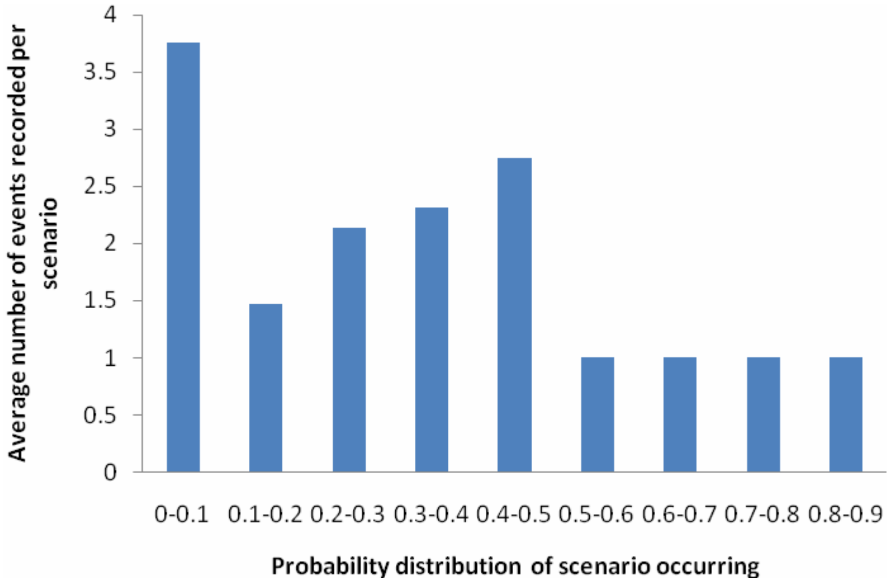


Figure 11 Average number events recorded in a scenario plotted by the probability that the scenario will occur (probability distribution follows that of a standard normal distribution).

The frequency with which criteria 1 was observed in a single scenario tended to be slightly higher in the new scenario set than in the original. Furthermore, the frequency range was much wider. For example, between 2031 and 2061 the number of times criteria 1 was observed in the original scenario-set ranged from 1 to 24 (x-axis on Figure 6 b). In the new scenario-set, the range was between 1 and 79 (Figure 12). Plotted over time, the frequency of 'events' between 2002 and 2090 recorded in the new scenario set did not resemble that of the original scenario set (Figure 13).

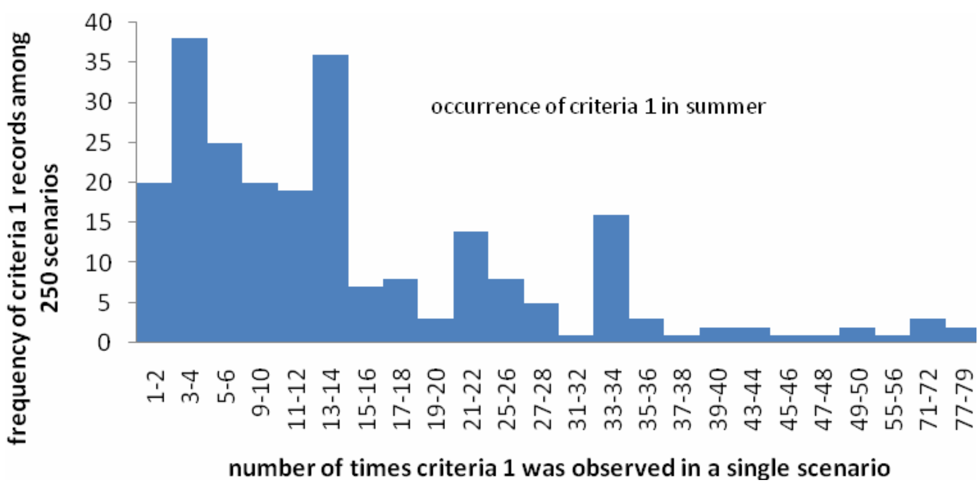


Figure 12 Frequency distribution of the number times criteria 1 was recorded in a single scenario in the summer months for the period 2031-2061; queried from 250 scenarios generated using a normal distribution function.

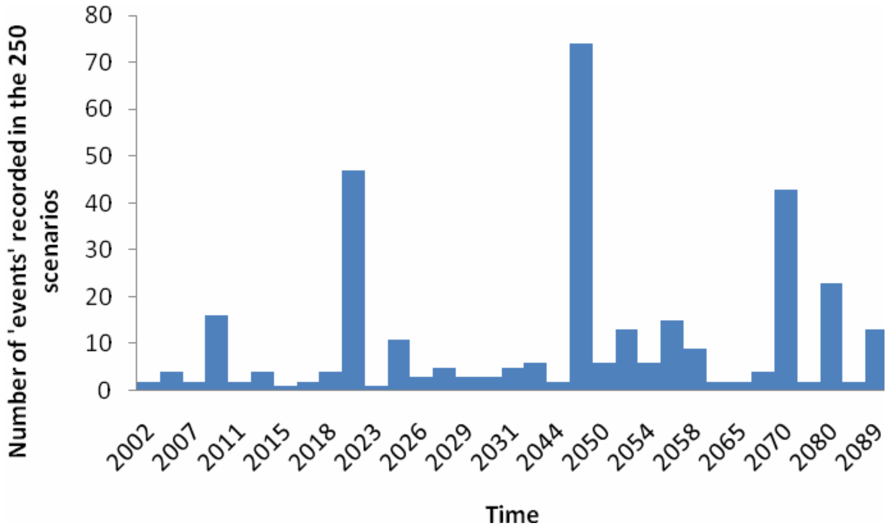


Figure 13 Frequency of 'events' over time, as queried from the 250 scenarios generated using a normal distribution function.

Conclusions

Queries from the original scenario-set as well as the new scenario-set suggested that the predicted increase in temperature combined with a shift in seasonal precipitation will result in climatic conditions that will likely be less favourable for *Dothistroma* reproduction in the but summer more favourable in the fall. The primary hindrance to *Dothistroma* reproduction in the summer appears to be related to the predicted increase in summer temperatures. Based on the GCM predictions, summer temperatures are likely to be above the preferred threshold range for reproduction. Meanwhile, longer periods of no precipitation during the summer months further diminish the opportunity for *Dothistroma* to reproduce. However, the effects of the predicted precipitation patterns on *Dothistroma* are secondary to the changes in temperature. In the fall season, the increase in temperatures and shift in seasonal precipitation may have the opposite effect with seasonal temperatures shifting towards the preferred threshold range for reproduction.

The analysis that was performed on the new scenario set was useful in that it allowed probabilities (from a standard normal distribution) to be associated with individual scenarios. However, this is different than selecting parameters for the GCM from standard normal distribution and should not be confused. It is recommended that future research focus on estimating the parameters for the GCM from various types of distributions. The results could then be queried and compared to the results presented in this report.

Literature cited

Woods, A., Coates, K.D., and Hamann, A. 2005. Is an unprecedented Dothistroma needle blight epidemic related to climate change? Bioscience 55: 761-769