A Seasonal Forest Fire Index Using NCEP Forecast Model Data

Jared Anderson

1. Introduction

This seasonal forecasting index has come from self-interest in forest fires and fire weather forecasting. In parts of the country outside of the Midwest, especially the West, fire weather forecasting is a large concern during the fire season (July, August and September). When a forest fire does flare up, it has the potential to affect many people. This could include the people that live within the forest itself, tourists to the area, fire fighters and their equipment.

At the current time a seasonal forecast for forest fires does not exist. Fire weather centers from the Storm Prediction Center (SPC) to local National Weather Service (NWS) forecast offices offer a wide range of one- and two-day forecast products. These are specifically designed to provide precise information about fire in the near future so that firefighters and fire equipment can be rerouted to hot spots. But for more long-term forecasts, many of the forecast centers only provide a link to the Climate Prediction Center (CPC) website for the 30- and 90- day forecast for temperature and precipitation.

A seasonal forecasting index based from long-range ensemble forecast model runs from the National Center for Environmental Prediction (NCEP) could provide the answer to the lack of long-term forecasts. Specially, homeowners in woodlands could use the index to determine the threat of evacuation for the fire season. Likewise, tourists would be able to use the index to determine if a vacation to the forests would be advisable or if it could be a possibly dangerous situation. Fire fighters would be able to use the index to see what portions of the country would be especially vulnerable to forest fires and necessitate the need for moving fire fighters and equipment into the area before any fires break out.

2. Forecast Output

The NCEP global circulation model runs were utilized for the forecasting data. Both the hindcast and forecast runs for temperature and precipitation were used in the analysis of this project. The temperature output was given in degrees Kelvin and the precipitation output was given in millimeters per second (mm/s). The temperature output was used in its given form, but the precipitation output was converted to centimeters per month (cm/month). This was done to make the model data more manageable and realistic. These hindcast model runs, or retrospective forecasts, consisted of ten model runs for the period of 1979-1999. Each model run was run with globally observed sea-surface temperatures and initial conditions separated by twelve hours from the atmospheric analysis field. The forecast model output consisted of twenty model runs using initial atmospheric conditions that were also twelve hours apart. The actual grid points of the model were specified at 1.87° apart from each other.

Using this model and the fact that this study is dedicated to forest fires, it was decided to construct an index for the state of Wyoming because it had a great deal of forest coverage and ensuing forest fires. There were eight different model grid points found within the state, four to the north of the state along constant latitude and four in the southern half of the state on a different constant latitude. When looking at the topography and vegetation of the state, only the western six model points were found in forested areas of the state. Thus, these six points were given the names southwest, south central, southeast, northeast, north central and northwest to represent the model grid point found in the general location of the forested area of Wyoming.

Special notification needs to be made to the regions of southwest/south central and northwest/north central. When the NCEP forecast model output was obtained, these two pairs of regions elicited the same temperature and precipitation data. The model grid points were double-checked to make sure that the correct points were being outputted and indeed they were. The analysis was performed with the two pairs of unique data sets. This did not create a double set of results because different average conditions were used for the individual domain areas. But it does confuse the author as to why two pairs of completely different model grid points outputted the same data. This circumstance could definitely introduce some amount of error into the results, but it is unsure of how much and in which region the error is contained within.

3. Data Sources

The Wyoming State Climatologist was consulted via its homepage for average monthly temperatures and precipitation amounts for the state of Wyoming. A list of over 100 weather stations in the state was obtained from the website. Along with the temperature and precipitation values, each station also reported its latitude-longitude location. From this list and the known location of the six points used in the forecast data, six weather stations were chosen to represent the six model points used in the study. While the six chosen weather stations were all relatively close to the model grid points, none of them were exact by any means. This most likely imparted some error into the difference between what the model was reporting and what the weather station actually observed. Another source of error could be the difference in elevation between the model grid points and the weather stations used for the average monthly temperature and precipitation data. The model output did not reveal the elevation of the model grid point calculations. If a notable elevation difference exists between the model output and the weather stations used in the study, significant errors could result.

To compare the utility of the index, actual forest fire data was pursued for Wyoming to cover the years from 1979-1999. After a lengthy search on the Internet forest fire data was still not found to meet these criteria. After being directed to Dr. Eugene Takle, contact was made with Dr. Peter Brown, head of Rocky Mountain Tree-Ring Research, Inc. Dr. Peter Brown suggested that Dr. Tim Brown, researcher at the Desert Research Institute, might be of further assistance. Dr. Tim Brown had worked with forest fire data in the past and had a forest fire data set that consisted of the number of fires and acres burned from lightning only by state for the period 1970-1996 and only on Forest Service land. After a fire is extinguished, fire crews determined the cause and then tabulated the number of acres that the fire consumed. This data set is not exactly what would be necessary for a complete seasonal forecast index because it only looks at lightning caused fires and only on Forest Service land, but it was the only data set available for use. A special thanks goes to Dr. Tim Brown for sharing his data set for this project, which otherwise would not have been possible.

4. Analysis Procedure

a. Initial Index

The initial index varied quite a bit from the final index that was used in the procedure. In the initial index, the current state of the atmosphere was weighted with current weather conditions to take into consideration the state of the atmosphere. More emphasis was given to higher temperatures and lower precipitation in the thought that these types of conditions would lead to an increase in forest fires. Several indicies constructed by the Forest Service and the National Interagency Fire Center were also added to the initial index. These included: the Palmer drought index, Haines stability index, lightening ignition efficiency and the 10-hr, 100-hr and the 1000-hr fuel moisture levels. It was hoped that these indices would add information regarding the extent of the environment related to the forest area. The purpose of the Palmer drought index is to take into account the drought conditions of the area. The stability index evaluates how much instability there is in the atmosphere. The lightning ignition efficiency index details the probability that lightning will strike the earth causing an increase in potential for new fires to be started. The fuel moisture levels detail the amount of moisture found in the forest timber, thus helping to determine how susceptible the woodlands are to fire.

The mean temperature and precipitation values for each of the model points were subtracted from the model output. Then the differences were weighted to place emphasis when the temperature was expected to be above average and when the precipitation was expected to be below normal, thus indicating the increased potential for forest fires. The consecutive anomalies were also considered. If the temperature stayed above normal and the precipitation was below normal for consecutive months, then the index would be increased further to represent the continual warm and dry conditions that would result. It was hoped that this index would lead to a representation of the number of fires and the number of acres burned in a given month.

b. Shortened Initial Index

When it came time to begin the data analysis of the hindcasts, it was realized that much of the back data and indicies were not available for use. These included the initial weather conditions, Palmer drought index, Haines stability index, lightening ignition efficiency and the 10-hr, 100-hr and 1000-hr fuel moisture levels. It was also discussed with peers that having this many variables in an index could be difficult to calibrate. This many variables could also focus only on the data that it was calibrated on. Given these suggestions it was decided to omit the additional indicies, initial weather conditions and the consecutive anomalies in the interest of time, reduced complexity, lack of data and the hope for overall better results.

This left the monthly anomalies as the only method to evaluate the forecast for an increase in forest fires. Initially the precipitation coefficients were positive but it was soon concluded that when the precipitation anomalies were below normal, negative anomalies would result. The coefficients for precipitation were then changed from positive to negative to correct for this difference. The initial coefficients are shown below in Table 1:

	April	May	June	July	August	September
Temperature (K)	1	2	3	4	6	7
Precipitation (cm)	-1	-2	-4	-6	-8	-10

Table 1. Initial Coefficients

As Table 1 shows there is special emphasis place on the months of July, August and September. This was done for both the temperature and precipitation coefficients because these months marked the fire season for Wyoming. Also of special emphasis were the precipitation coefficients. These magnitudes were higher because it was hypothesized that the precipitation anomalies would have a larger impact on forest fires than the temperature anomalies did.

c. Data Computations

To begin calculation of the index the mean monthly temperature and precipitation values for the six points in Wyoming were converted to correspond to the model output. The average temperatures were given in degrees Fahrenheit, so these were converted to degrees Kelvin to match the data output of the model. The average precipitation values were listed in inches per month, so these were changed to centimeters per month to also be compared to the model output. The converted average values for the six points were then subtracted from the model output data. The differences were then multiplied by the corresponding coefficients for each month. Since each month had ten different model runs, ten different index values for each month for each region were created. These ten runs were averaged together to arrive at a mean index value for each month for each domain region. The temperature and precipitation index values were then added together to come up with the overall index value for each month.

All six model grid points were graphed together to try and determine which region of the state was performing the best at representing the forest fire season. These index values were then graphed along with the number of fires and acres burned for each year as a function of time. This produced a problem in graphing the number of fires and acres burned because the original forest fire data was on an annual basis, not a monthly basis. This means that the number of fires and acres burned were only reported for each year and not for the individual months of each year. To compensate for this problem the assumption was made that most of the fire occurred in the fire season itself, namely July, August and September. It was further assumed that 1% occurred in April, 3% occurred in May, 6% occurred in June, 25% of the fires occurred in July, 30% occurred in August and 25% occurred in September. Using these estimates the yearly totals for the number of forest fires and acres burned were multiplied by these percentages to come up with monthly estimates for the number of forest fires and acres burned. Obviously this introduces a great deal of error as the estimates cannot completely reproduce the actual monthly forest fire numbers and acres burned.

As reported earlier, the forest fire data covers the time period of 1970-1996. The NCEP forecast model data covers the period of 1979-1999. This means that only the years 1979-1996 were available for study since those years were represented in both sets of data. This time period was divided in half so that the first half of the data, 1979-1987, could be used to calibrate the index. This calibration procedure consisted of trial and error experiments to determine which months need special emphasis to the temperature and precipitation anomalies. The second half of the data set, 1988-1996, was used to test the index for utility.

5. Results

a. Forecast Behavior

To get an idea of the forecast model accuracy, the temperature and precipitation runs were plotted against the observed monthly mean states of the regions from the Wyoming State Climatologist. Overall, the temperature output for the ten different model runs was relatively consistent. All model runs tended to follow an increase leading up to July and August with a decrease in temperature for the month of September. The model output seems to be quite precise by not very accurate. For the temperature trends all the models produced monthly temperatures that were above normal for the southwest, south central and northwest region of the domain. The model output in these regions ranged from 5-7° K above the mean values. The other three regions showed the model output temperatures to start out 5° K below normal for the months of April, May and June and then switch to being above normal for the final three months of the time period. This could possibly suggest that the index for the northwest, southwest and south central areas of the domain might differ substantially from the southeast, northeast and north central portions of the domain.

The precipitation output from the models differed from each other much more than the temperature output did. Generally speaking, the precipitation output tended to range above normal for the six domain regions. The output was especially high in the beginning of the time period when some of the model runs were running as much as twelve centimeters of precipitation above normal. Part of the problem was the assumption that all of the months had 31 days in them. As stated earlier, the original units were given in millimeters per second and these were then converted to centimeters per month by multiplying the number of seconds in each month. To make calculations easier, it was assumed that each month had 31 days in it, even though the months of April, June and September have 30 days. This could lead to an over-estimation of the precipitation in these months. Additional analysis of the precipitation field reveals that initially the model output follows the trend of the observed mean precipitation by being high in April and May and then decreasing after that. Although, in the southwest, south central, northwest and north central areas of the domain, the model precipitation then increases again in August and September when the observed precipitation does not. This suggests that the precipitation output is not as precise as the temperature output as well as being inaccurate.

b. Index Behavior

Initially the index did a somewhat reasonable job of capturing the general trend of the forest fires and the number of acres burned. Overall, April, May and June tended to be the months with the minimum amount of fires and acres burned. Then in July, August and September the index increased to match the increased forest fire consumption during the fire season. However, the index did not decrease in the month of September as is assumed what would happen in the fire season. The index also did not capture the increase in fires and acres from season to season. For instance, in 1987 when the number of acres burned was between ten and twelve and the number of forest fires was near eighteen, the index ranged from 5 to 60, as Figure 1 shows. But, Figure 2 demonstrates that when the number of acres was near 2000 and the number of fires was around 30, the index ranged from -5 to 65. This obviously cannot represent the forest fire season well if the index changes slightly for a large increase in the size of the fire season.

After much trial and error, an adjustment to the initial index was formulated that hopefully represented the data somewhat well. Table 2 shows the adjusted coefficients:

	April	May	June	July	August	September
Temperature (K)	1	2	3	4	6	10
Precipitation (cm)	-1	1	2	4	6	3

Table 2. Adjusted Coefficients

These adjusted index coefficients produced better results in compensating for the decrease of forest fires and acres burned in September. The adjusted index for 1986, Figure 3, shows that all six areas of the project domain follow the increase and decrease of the number of forest fires and acres burned over the entire time period. Figure 4 shows that the year 1984 highlights this fit even better than 1986 does. However, Figure 5 demonstrates that the year 1982 argues against this index. In that year there was wide variability among the six regions of studied. While this adjusted index does indeed show the seasonal trend of the forest fire numbers and the acres burned, it still does not reveal the nature of the overall increases of the fire season. In 1984, Figure 4, when the maximum amount of acres burned in August was just over the 30, the index reached a peak value for the south central region of nearly 100. Contrast this with 1986, Figure 3, when August fires burned close to 1800 acres but the highest index value didn't even break 60. Through the repeated use of trial and error, this type of relationship was never attained. It is hypothesized that the temperature and precipitation anomalies will not produce this characteristic in the index, but that the straight model output might be able to perform this task.

In the third phase of the data analysis the index coefficients were tested over the period of forest fire data from 1988-1996. This yielded some promising results. Most of the years studied followed the general trend of the forest fire data with increasing index values toward August with a decrease of values into September. There was some wide variety in the data regions as the years 1991 and 1992 show (Figures 6 and 7). Figures 8 and 9 show the years 1988 and 1996. These years reflect a tighter association of the domain regions indicating a closer fit to the number of forest fires and acres burned. More importantly than this, 1988 showed a definite increase in the index to 105 when the number of forest fires and acres burned was at a maximum. Similarly in 1996, the number of forest fires and acres burned was also quite large and the resulting index was near 85. In the years of 1991 and 1992, the number of fires and acres was much smaller and the index reflected this with results closer to a maximum index value of 45 and 50, respectively.

Also worth noting is the relative position of each of the index domain regions through the calibration and the testing portions of the analysis. The south central region tended to have the highest index values of the group of six domain areas. The next highest index values tended to be the southwest and the northwest region. The other three regions, southeast, northeast and north central tended to have the least index values and all spent equal times at the bottom of the graph. This could suggest that the south central region would be the best predictor of the acres burned in a fire season since it had the highest index for much of the time studied. The southwest and northwest regions could be the best indicators for the number of forest fires as these two regions were found most often near the actual number of forest fires in a given year.

6. Conclusions

The goal of this project was to develop a seasonal forecasting index to compliment the NCEP forecast model output. It is concluded that the index behaves somewhere between good and bad. The results of this study have shown that the overall trend of the forest fire season can be reflected in the forecast model output for the state of Wyoming. The index coefficients to the temperature and precipitation anomalies were able to produce a peak in the month of August when the fire season was at its height. However, at this point in the index the variability among the six regions was at its highest, and was consistent through the calibration and the testing of the data. This suggests that certain regions were better apt to predict acres burned and number of forest fires. It was found that the south central region had the highest index so it is inferred that this region would do the best job of predicting acres burned. The southwest and northwest regions were found to be consistently near the number of forest fires so these regions might be best used as a predictor for the number of forest fires.

The basis for this project was on the anomalies of the forecast output from the average temperature and precipitation values for the six domain regions. At the time of development of the index, this seemed like a logical method to predict the condition of the environment for the threat of forest fires. However, when put into application, this proved to be difficult and time consuming. The subtraction of the average regional values for monthly temperature and precipitation from the model output produced both positive and negative anomalies. These values had to be structured so that they would increase the threat for forest fires by above normal temperatures (positive anomalies) and below normal precipitation (negative anomalies). As shown earlier in Table 1, this was taken care of with the positive temperature coefficients and negative precipitation coefficients. However, as the coefficients were adjusted, Table 2, most of the precipitation coefficients were adjusted to be positive indicating that the above normal precipitation was associated with a more positive index and thus a higher representation of the number of forest fires and acres burned. Thus, it is implied that more precipitation leads to more forest fires. This directly contradicts the beginning assumptions made in this study. Given this and the fact that precipitation output data tended to yield a much more variable nature than the temperature data did, it is reasonably deduced that the precipitation output has a smaller effect on the forest fire threat than the temperature does. A temperature-weighted index might achieve better results than one that has precipitation included along with it. It is also inferred that anomalies may not achieve the best results. Applying the coefficients directly to the model output is thought to produce better results in a manner that is easier and much less confusing to the researcher.

It is also worth repeating some of the limitations of this study. The forest fire data that was obtained for this procedure was, in itself, somewhat limiting. The data was for lightning induced forest fires on Forest Service land only. Other types of forest fires on other types of land started by careless campers and arsonists, etc. could alter the conclusions found by this study. This fire data set was also on an annual basis only. The monthly average number of fires and acres burned had to be inferred from the author's knowledge of the forest season. To perform a complete study, an extensive data set of fire data for the state of Wyoming would need to be compiled in order to undertake a more thorough study of the forest fire index.

7. Future Index

In addition to the hindcast model runs, the future forecast model runs were also obtained for the six regions of the domain. The adjusted index was then applied to the model output and the results are shown in Figure 10. Looking at the graph, it is noted that if the southwest and northwest regions are assumed to be indicative of the number of fires expected over the next few months, then there is likely to be 9-12 fires in July, 25-30 in August and 35-55 fires in September. If the index values for the south central region are extrapolated against the previous trends in the forest fire data, then July could see 80 acres burned, 120 acres burned in August and 160 acres burned in September. These are far removed from the widespread fire outbreaks of 1985, 1986, 1988, 1994 and 1996, but are still a significant number of fires and acres to warrant attention by homeowners, tourists and fire fighters.

REFERENCES

Brown, Peter N.: Rocky Mountain Tree-Ring Research, Inc. [E-mail Correspondence] pmb@rmtrr.org

Brown, Tim,: Desert Research Institute [E-mail Correspondence] tbrown@dri.edu

Takle, E. S.: Iowa State University [Personal Communication]

Wyoming State Climatologist, 2002: http://www.wrds.uwyo.edu/wrds/wsc/

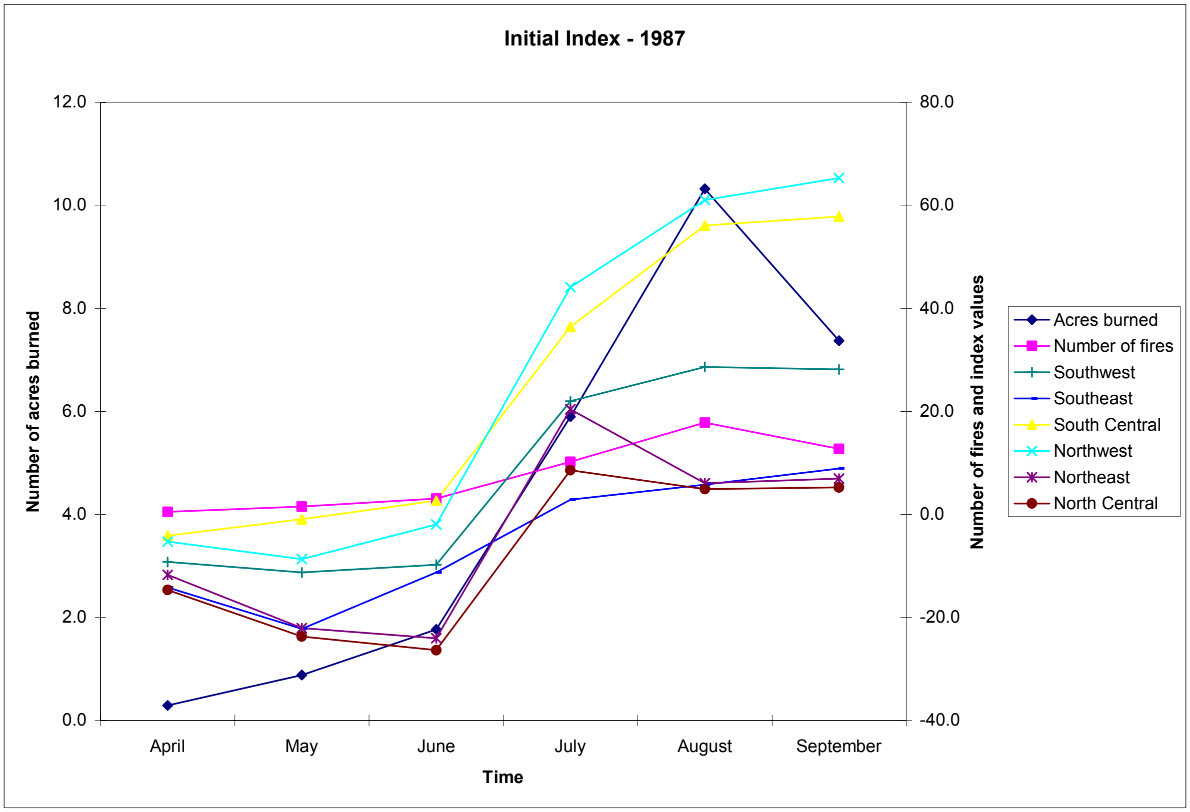

Figure 1. 1987 Initial Index Values

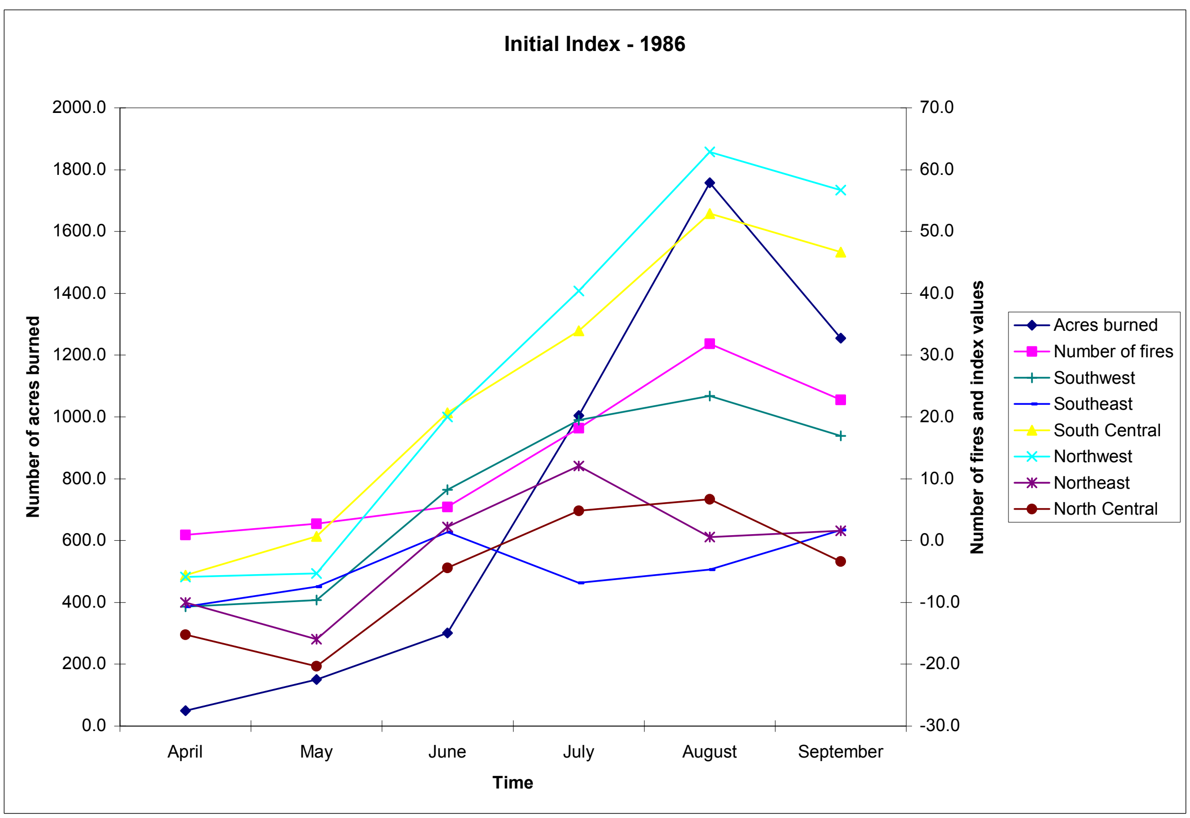

Figure 2. 1986 Initial Index Values

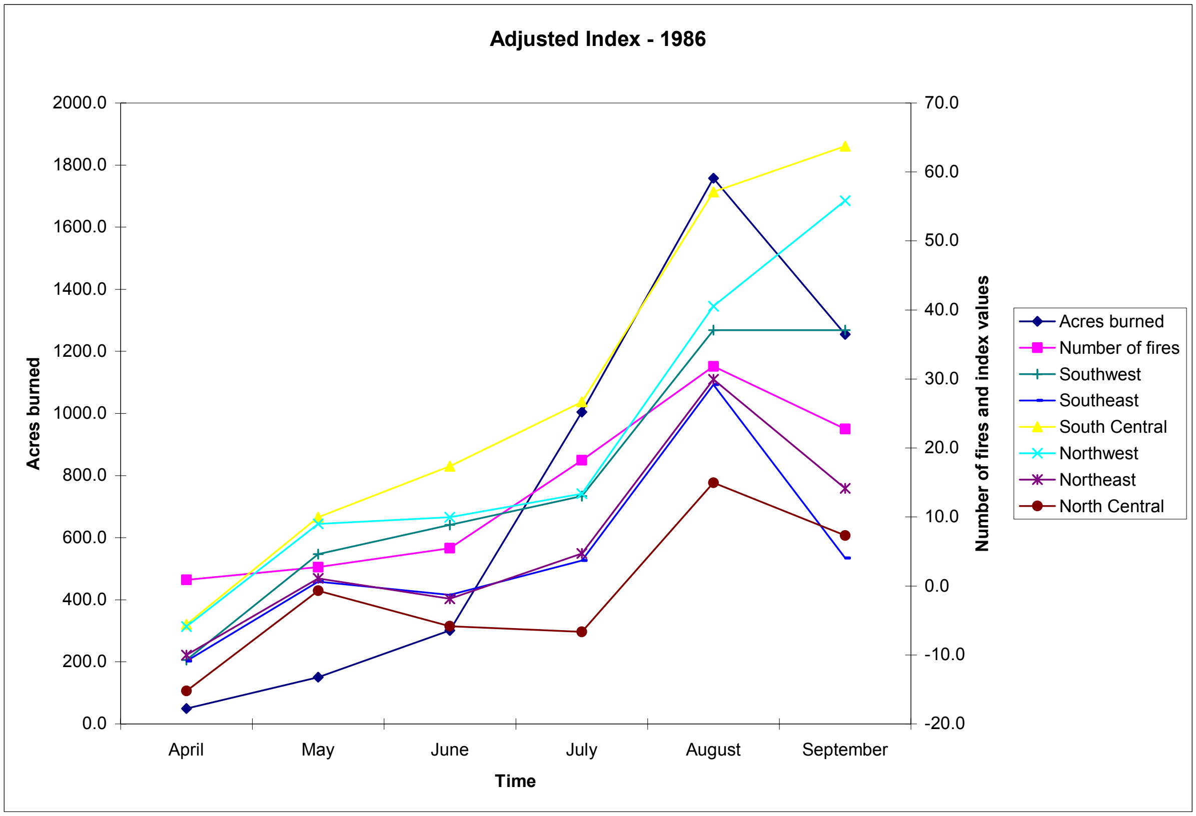

Figure 3. 1986 Adjusted Index Values

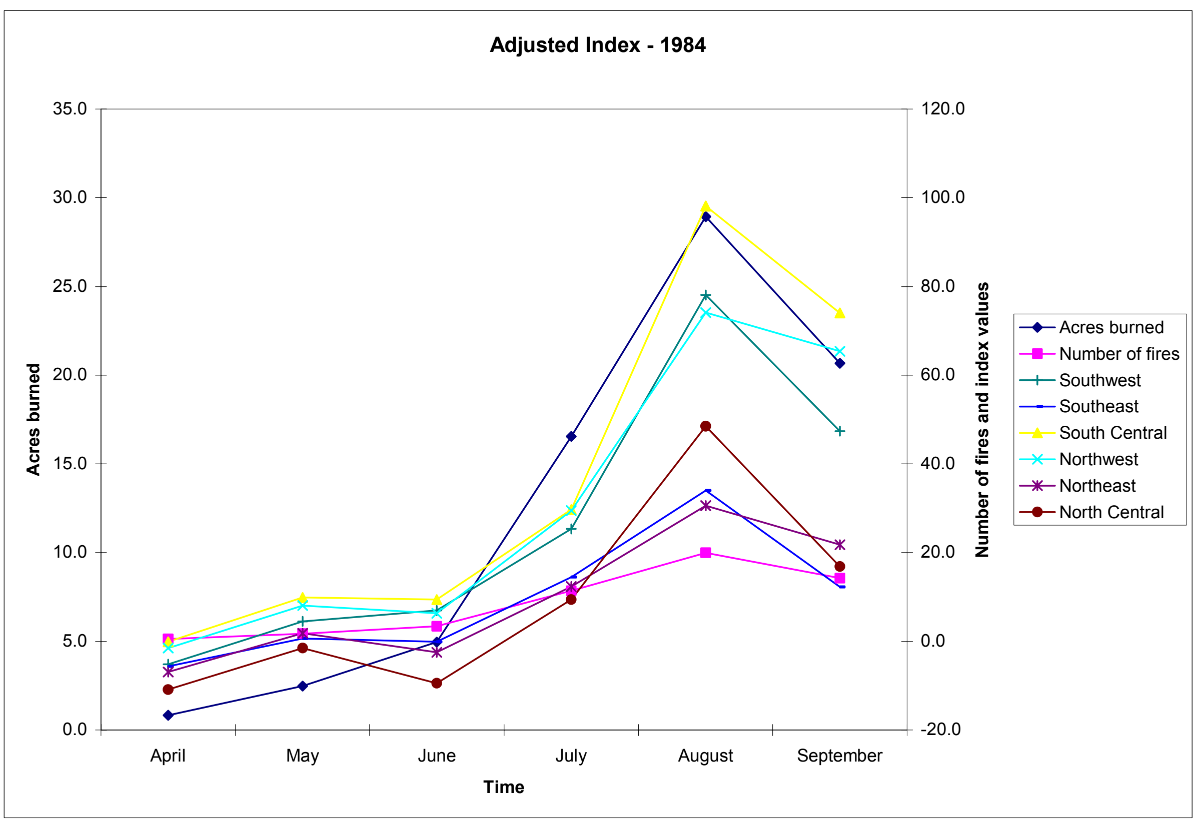

Figure 4. 1984 Adjusted Index Values

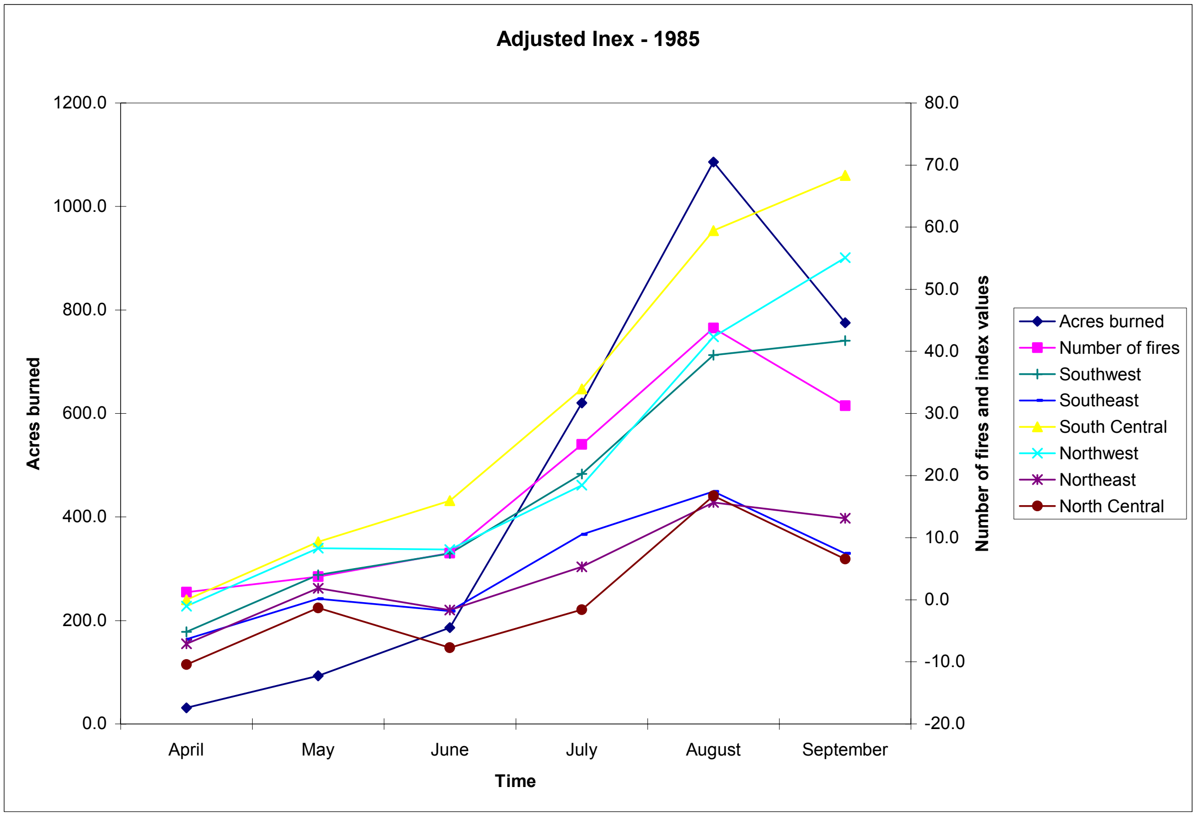

Figure 5. 1985 Adjusted Index Values

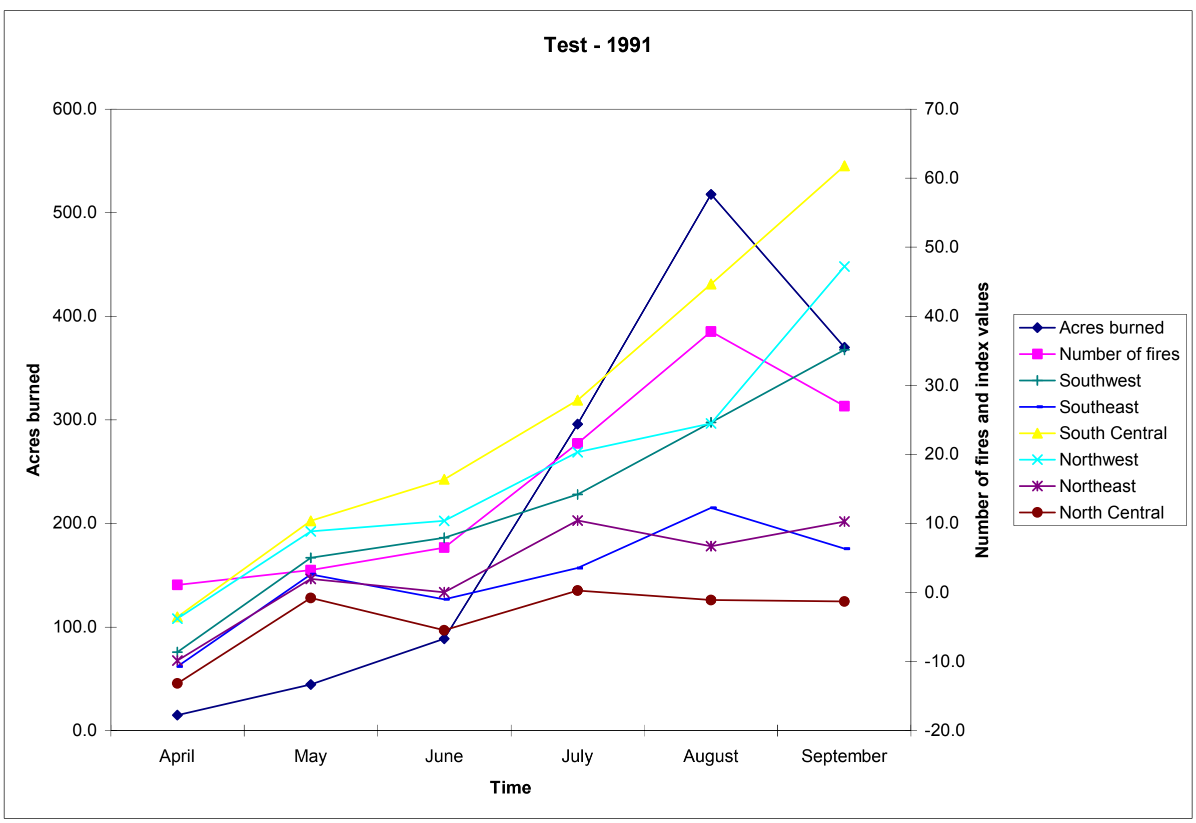

Figure 6. 1991 Tested Index Values

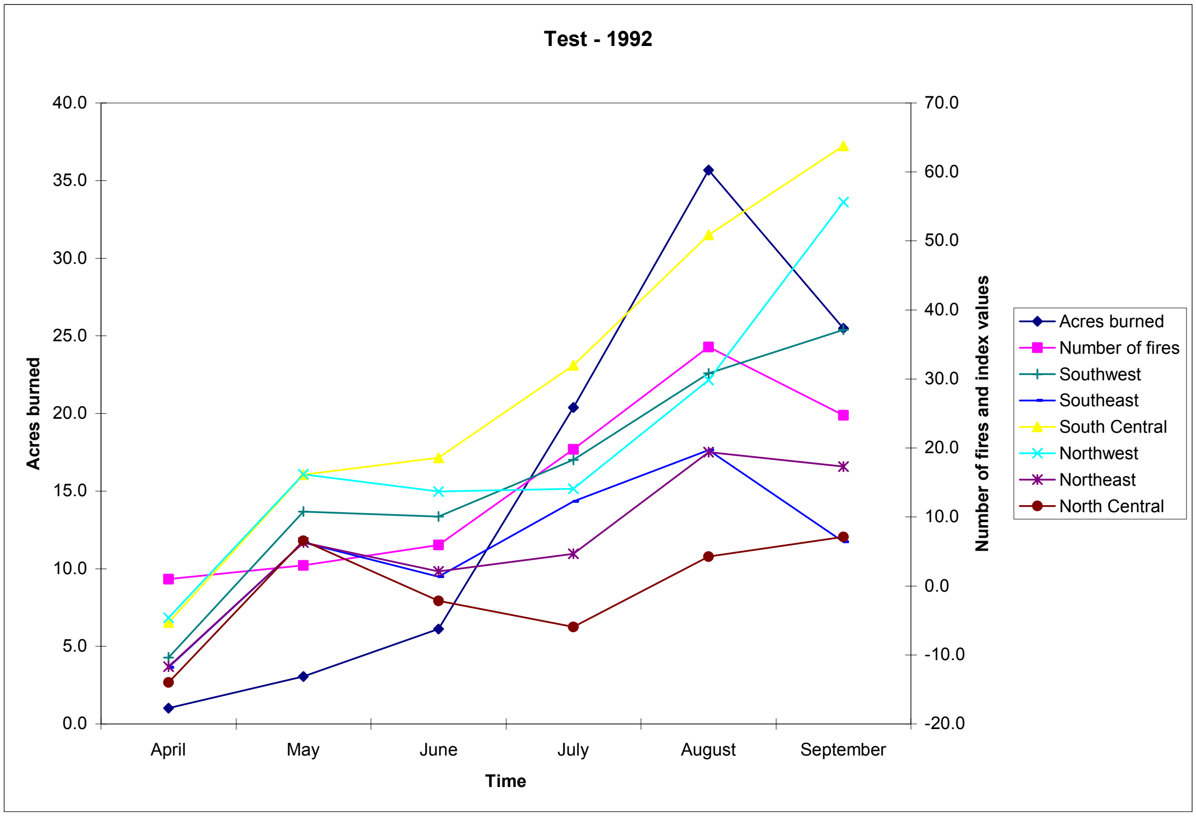

Figure 7. 1992 Tested Index Values

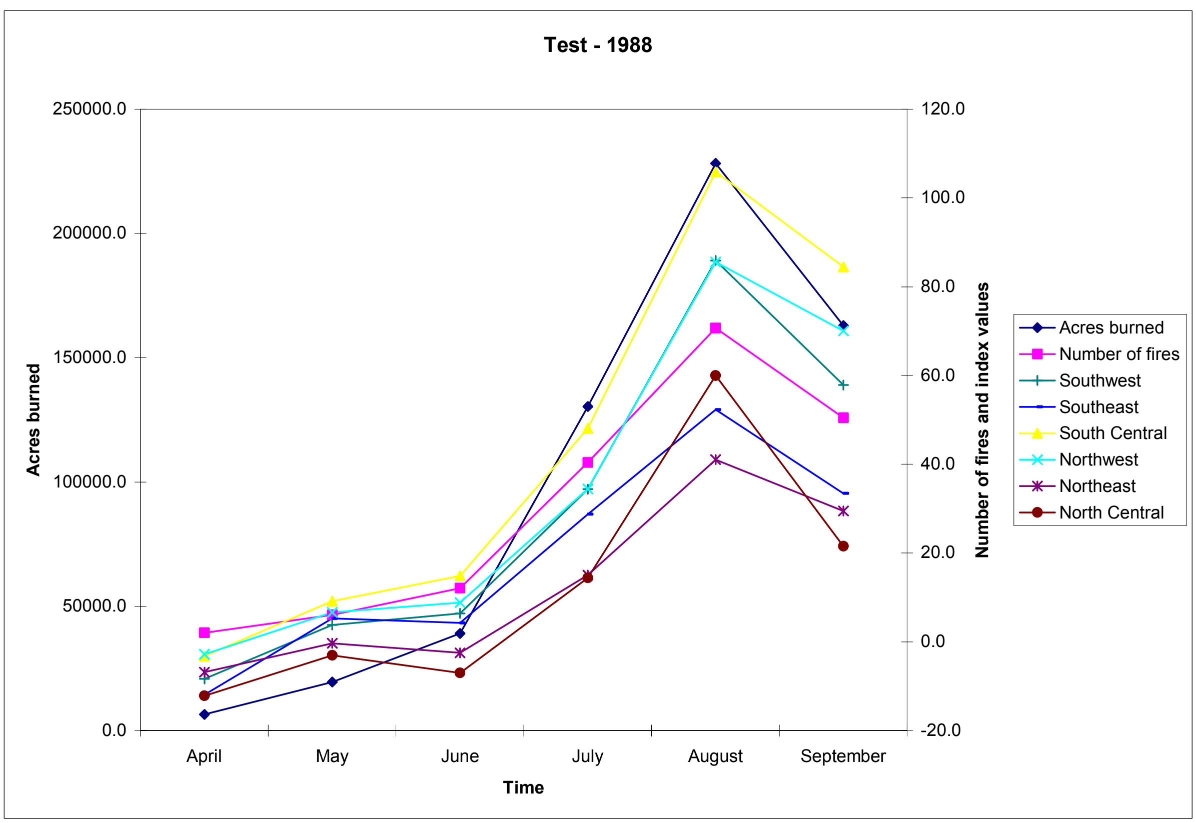

Figure 8. 1988 Tested Index Values

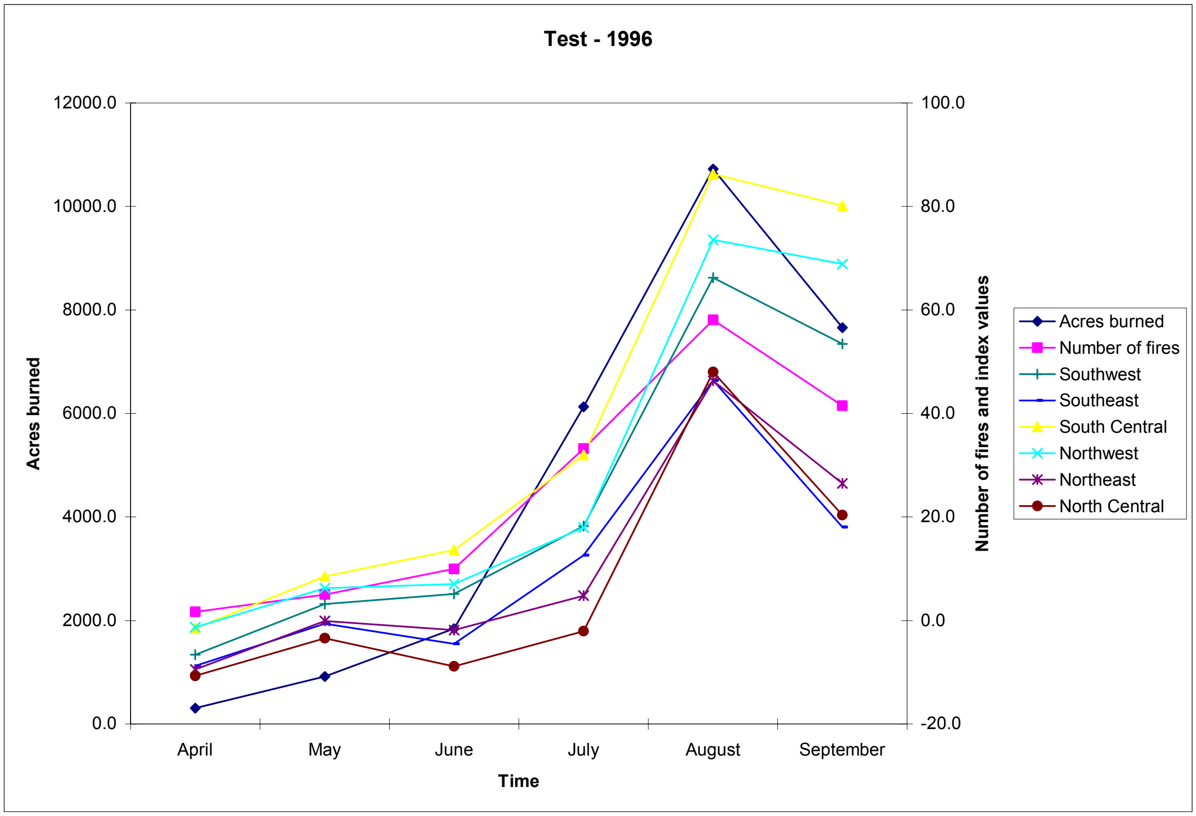

Figure 9. 1996 Tested Index Values

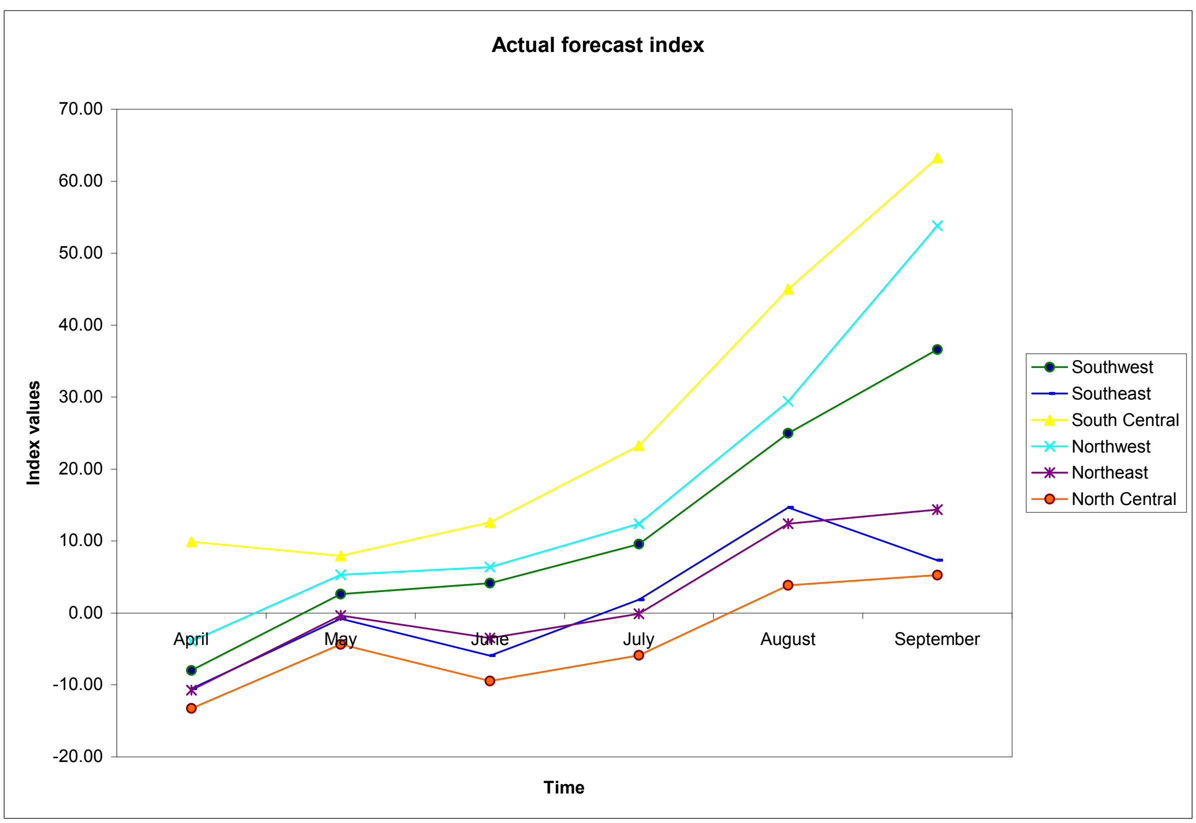

Figure 10. 2002 Forecasted Index