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# An Exploratory Study of Crop-Hail Insurance Data for Evidence of Seeding Effects in North Dakota

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# AN EXPLORATORY STUDY OF CROP-HAIL INSURANCE DATA FOR EVIDENCE OF SEEDING EFFECTS IN NORTH DAKOTA

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# 1. INTRODUCTION

Cloud seeding for hail suppression has been carried out in many parts of the world using a variety of techniques. Dennis (1980) discusses hypotheses as to how seeding could reduce damaging hailfall. Some randomized experiments based on such hypotheses have yielded significant evidence of seeding effects (e.g., Miller et al., 1975; Flueck et al., 1986) while others have not (e.g., Crow et al., 1979; Federer et al., 1986). In spite of these conflicting experimental results, operational hail suppression seeding programs continue and there are indications that at least some of them produce reductions in hail damage (e.g., Hsu, 1985; Dessens, 1986).

Studies of the climatology of hail damage to crops (Changnon, 1977) show that North Dakota experiences the highest dollar loss of any state in the United States, while southwestern North Dakota has the highest ratio of damage claims paid to insured crop liability. Operational seeding has been going on in western North Dakota since the 1950's, with regular hail suppression operations in some areas since 1961 (Rose and Jameson, 1986). The North Dakota program claims to be the longest continuing program in the world employing seeding from aircraft. Since 1976, the operations have been organized as the North Dakota Cloud Modification Project (NDCMP) and supervised by the North Dakota Weather Modification Board, an agency of the State of North Dakota. This sustained support is based on a perception that the seeding has been effective in reducing hail damage to crops. It seems reasonable to examine the available data for any indications that may support this perception.

Rose and Jameson (1986) and Miller and Fuhs (1986, 1987) conducted preliminary analyses of crop-hail insurance data from western North Dakota and neighboring regions. They found some indications of reduced hail damage in the seeded areas. The purpose of the present paper is to present the results of a further exploratory analysis of essentially the same data, using presumably more powerful statistical methods. We follow the philosophy advocated in Mielke et al. (1982) in this analysis.

## 2. CROP-HAIL INSURANCE DATA

Crop-hail insurance data are available for western North Dakota and adjacent regions from 1924 onward (CHIAA, 1978). These data indicate the yearly insured liability and damage claims paid, on a township by township or county by county basis. The use of such data for evaluating seeding effects has limitations, as discussed by Changnon (1969, 1985). Among them are the facts that only part of the crops in any given area are insured; crop sensitivity to hail damage varies over the season; and farming techniques, cropping patterns, crop yields, and crop values vary with time. However, the insurance data also have important advantages: they cover much larger areas than would be practical with any known hail measurement instrument; they cover a long historical period; and they are based on a relevant economic measure of the losses due to hail. We choose to base this exploratory analysis on these data because of these advantages, while at the same time recognizing their limitations.

Crop-hail insurance data are commonly expressed in terms of the ratio of damage claims paid (in dollars) to insured liabilities; this ratio is known as the loss ratio (LR). The use of these ratios, and of annual values, helps to mitigate some of the limitations of the hail insurance data.

Figure 1 shows a county map of the region of interest in western North Dakota, eastern Montana, and northwestern South Dakota. Seeding has been conducted from time to time in many of the counties of western North Dakota, but the six counties shown shaded have been regularly seeded using essentially the same techniques over the whole period of the NDCMP. The southwestern counties (Bowman, Hettinger, and Slope) are in NDCMP District I, while the northern counties (McKenzie, Mountrail, and Ward) are in District II. These six counties comprise the target area for these exploratory analyses; Appendices A and B summarize the history of seeding activity in those counties. The 1[illegible] easternmost counties of Montana provide an upwind control area. The control area is larger than the target area, but the insured liabilities for the two areas are similar over the years (Miller and Fuhs, 1987). The dollar liabilities, however, vary by a factor of about $10^3$ over the period of record.

A change in the general quality of crop-hail insurance data beginning in the late 1940's has been suggested. However, data from the control area employed here were tested (using tests similar to those discussed below) and significant differences related to a division around that time were not found. Consequently, these exploratory analyses make use of the whole historical record (although other periods could readily be tested).

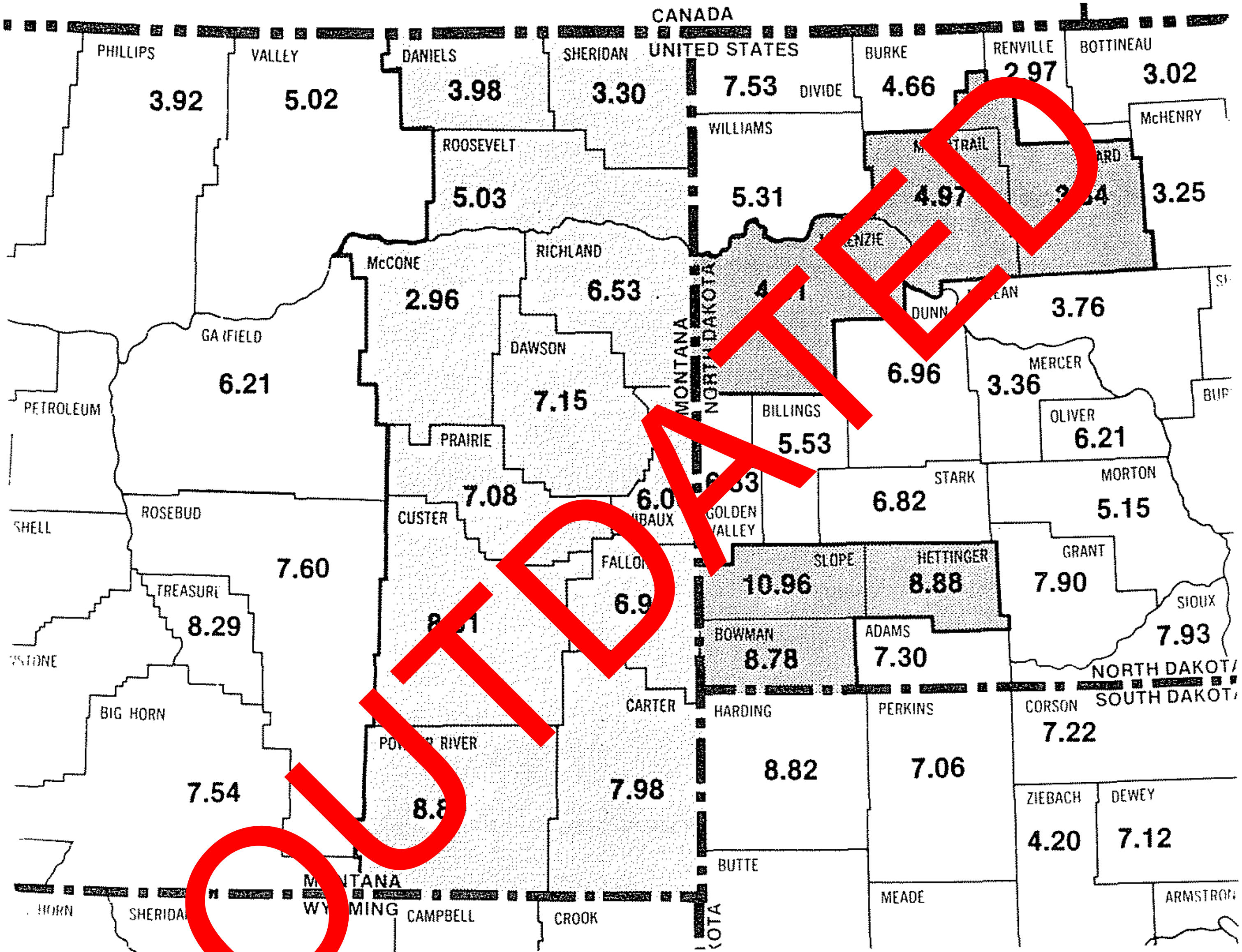


Fig. 1: Map showing the 1924-84 average county loss ratio values (percentages) for the region of interest. The NDCMP "combined target area" comprises the six shaded counties in western North Dakota. The twelve easternmost counties in Montana make up the "west control area."

## 3. HISTORICAL ANALYSIS FOR TARGET AREA

Figure 2 shows the historical record of the annual loss ratios for the six-county NDCMP target area. The data are tabulated in Appendix C. The values range from a low of 0.99% in 1973 and 1980 to a high of 19.63% in 1963. The median for the 61-year period (1934 omitted because the liability was extremely small) is 5.12%. Some visual indication appears of a downward trend after extensive hail suppression seeding began in the 1960's. Indeed, Rose and Jameson (1986) found indications of reduced hail damage in District I over this period. However, auxiliary tests summarized in Appendix D, based on data from the combined target area, have not provided much indication of this effect (perhaps because District I involves only [illegible]5% of the combined target area). Therefore, we concentrate here on the last 10 years, when the NDCMP was in operation. Nine of the 10 loss ratio values for those years are below the overall median value, and the tenth value is only slightly higher.

To explore whether the hail loss experience over this 10-year period differed significantly from that for the earlier period, a permutation analysis was run using the multi-response permutation procedures (MRPP; Mielke _et al._, 1981a,b; Mielke, 1985) in a univariate mode. The analysis proceeds by drawing samples of 10 years (without replacement) at random from the data population of 61 years. Then a measure of the separation between the two groups (the 10 years and the remaining years) in relation to the scatter in each group is calculated for each sample. These test statistics are then ranked and compared to the corresponding test statistic for the actual division into NDCMP and remaining years to determine a P-value. Details of the MRPP test procedures are discussed in Mielke _et al._ (1981a,b); MRPP tests have been used to evaluate randomized weather modification experiments (Mielke _et al._, 1984).

The results of the MRPP test indicate that the probability of finding loss ratio values as small as, or smaller than, those observed during the NDCMP years in a random sample of 10 from the population of 61 values is 0.0041. Hence it is unlikely that the ten NDCMP values are just a random sample from the population. However, this P-value cannot be interpreted in quite the same way as one from a randomized experiment, because the actual NDCMP years were not chosen at random (Gabriel and Petrondas, 1983). They were, however, chosen _a priori_ and, with a P-value this small, the indication of a reduction in hail loss experience in the target area during the NDCMP years has some substance.

Whether the difference was due to the NDCMP seeding cannot be determined from the target area data alone. A climatological shift toward lower hail losses might have occurred during the NDCMP operational period. Changnon's (1984) hail climatology study gives little indication of such a shift, but a more specific examination of the possibility can be made using the control area data.

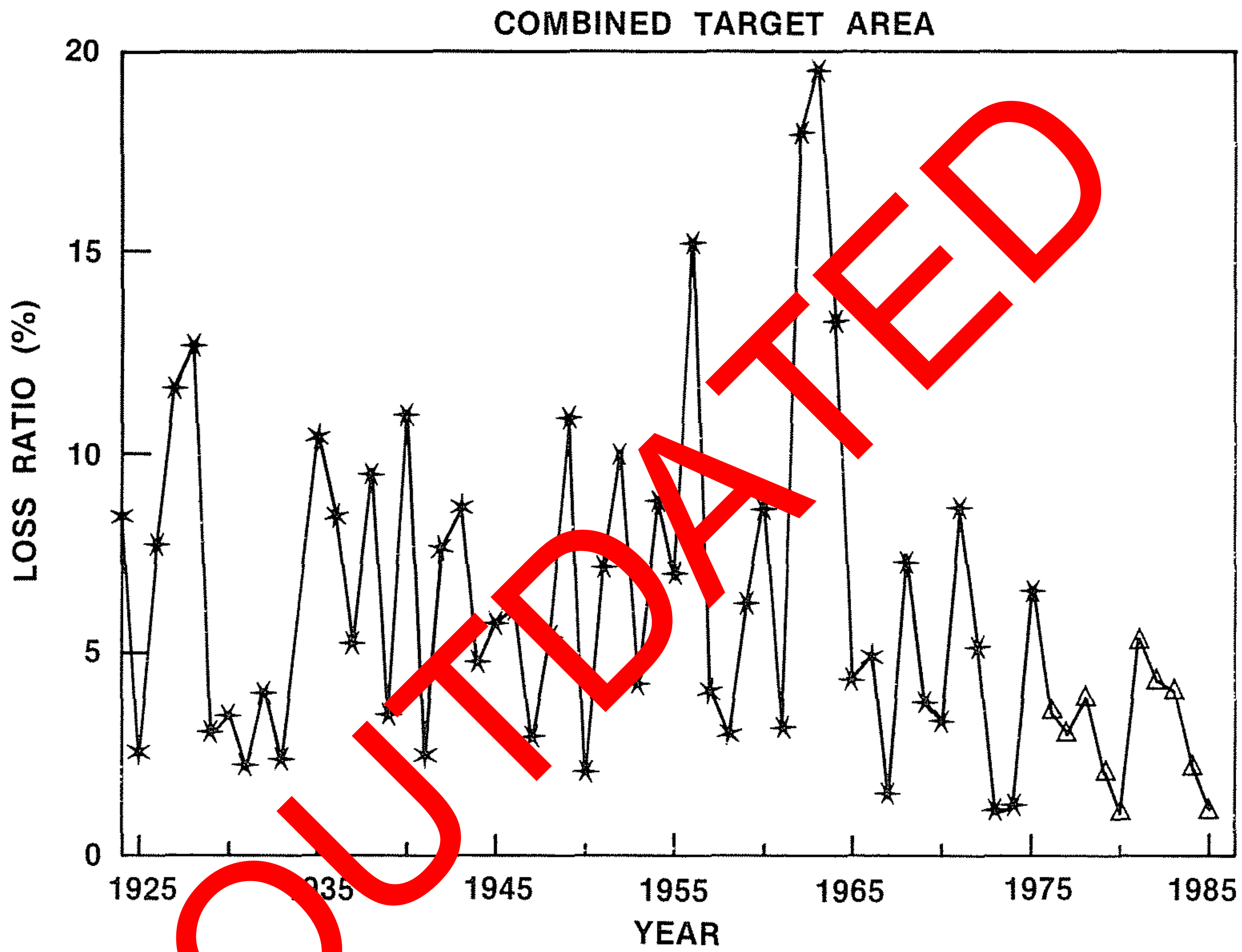


Fig. 2: Historical plot of annual loss ratio values for the combined target area. Asterisks indicate years prior to the NDCMP operations, while triangles indicate the NDCMP operational years.

## 4. HISTORICAL ANALYSIS FOR CONTROL AREA

Figure 3 shows the historical record of loss ratio values for the 12-county control area in eastern Montana. The values range from a low of 0.49% in 1985 to a high of 14.17% in 1940; the median for the 62-year period is 5.38%. There is not much visual indication of a historical trend; losses recorded during the period 1945-1961 were consistently low, but 7 of those 17 values were above the median. During the NDCMP years, 6 of the 10 values were below the median.

The same univariate MRPP test was applied to the control area data using 10-year random samples from the population. The results indicate the probability of obtaining values as extreme as, or more extreme than, those found during the 10 NDCMP years to be 0.973. In other words, the 10-year NDCMP operational period cannot be distinguished from a random sample from the population. This suggests no general climatological shift in hail damage occurrences associated with the NDCMP operational period.

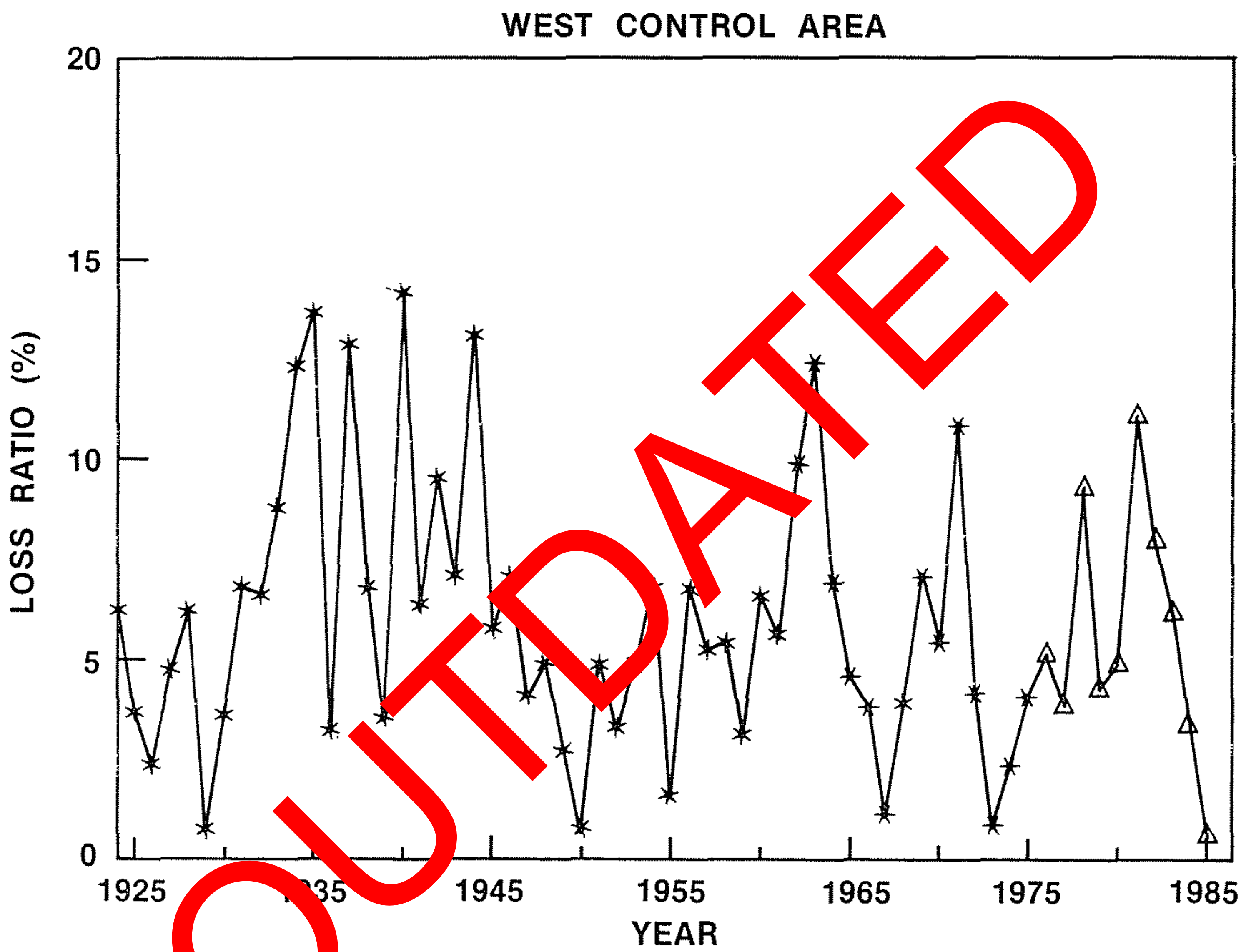




Fig. 3: Historical plot of annual loss ratio values for the west control area. Asterisks indicate years prior to the NDCMP operations, while triangles indicate the years when NDCMP operations were in progress.

## 5. TARGET-CONTROL REGRESSION ANALYSIS

Figure 4 shows a target-control scatter plot, comparing the yearly target and control area loss ratio values. A regression line was forced through the origin, with its slope determined by a least absolute deviation calculation (Bloomfield and Steiger, 1980). The least absolute deviation (LAD) regression has the advantage of not giving undue weight to individual outlying points. The target control LAD regression equation was found to be

loss ratio (target) = 0.789 x loss ratio (control)

The linear correlation between control and target values is not strong, but this relationship provides a rough prediction of the target area loss ratio from the control area value.

All but one of the points for the 10 NDCMP operational years lie on or below the LAD regression line. The (signed) residual displacement from this line was calculated for every point; the residuals ranged from +10.26% to -5.66%, with a median value of 0.66%. Then an MRPP test similar to that used on the historical record was carried out on these residuals. The resulting P-value of 0.002 indicates that the residuals for the NDCMP years were significantly more negative than would be expected in a random sample from the population. In other words, the target area loss ratio values during those years were significantly lower than would be predicted from the LAD regression line.

This small P-value justifies computation of separate LAD regression lines for the 10 NDCMP years and the 51 remaining years. The results, also indicated in Fig. 4, are:

NDCMP years: loss ratio (target) = 0.487 x loss ratio (control)

Earlier period: loss ratio (target) = 0.861 x loss ratio (control)

The separate regression equations provide a means for obtaining a point estimate of the difference in tha hail loss ratio in the target area during the NDCMP years. The ratio of the slopes is (0.487/0.861) = 0.565. This indicates that the crop hail damage in the target area during the NDCMP years was about 43.5% lower than would be predicted from the historical-period LAD regression equation.

This estimate may even be conservative, because some hail suppression seeding was carried out in parts of the target area for 10-15 years prior to the beginning of the NDCMP. The "historical-period" hail losses in the target area may have been reduced somewhat by that seeding (although auxiliary MRPP tests have not indicated significant differences). If so, the unseeded historical-period regression slope should be greater and the estimated reduction during the NDCMP years would be correspondingly larger.

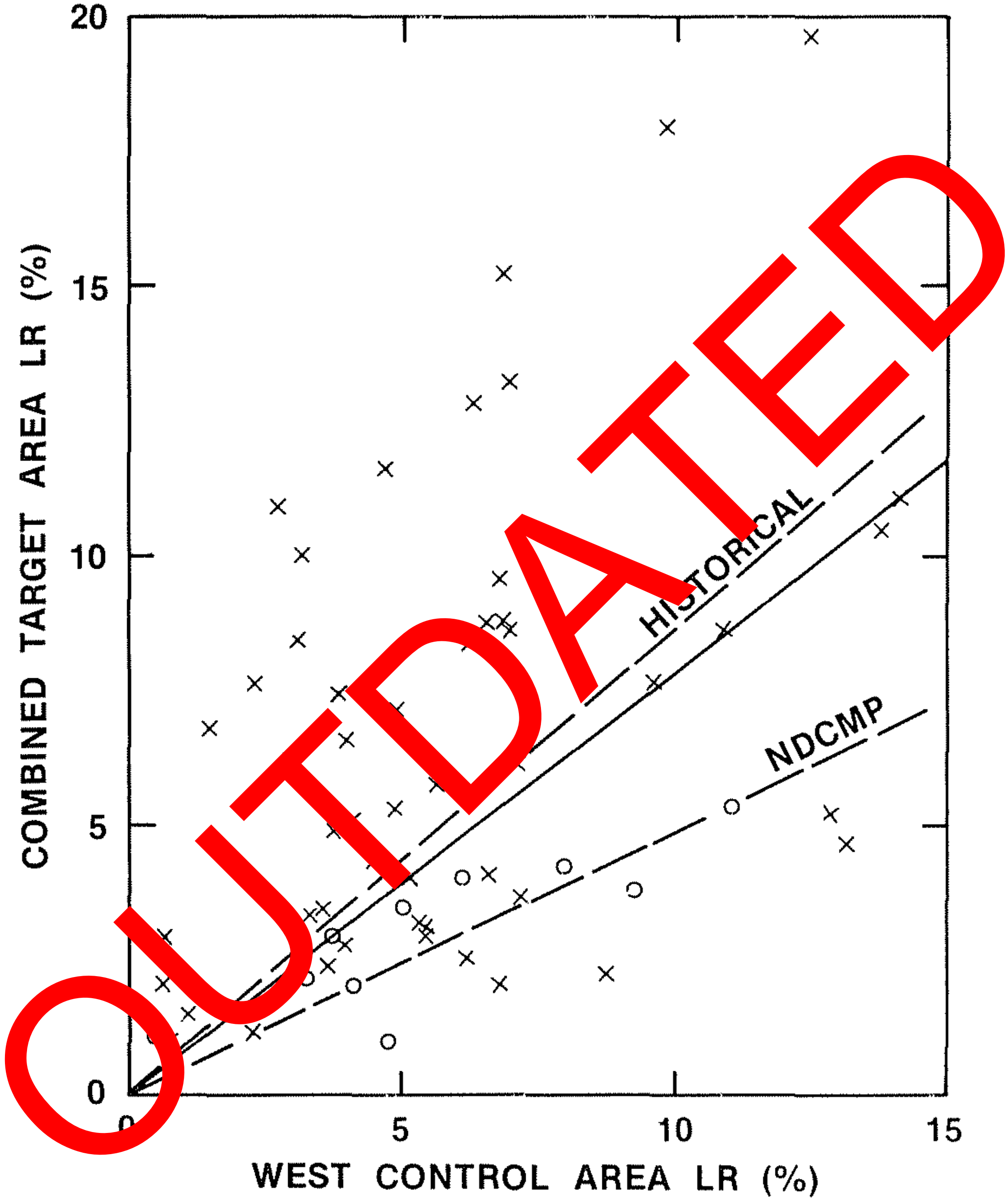


Fig. 4: Scatter plot comparing annual loss ratio (LR) values in the control and target areas. The solid line represents the least-absolute-deviation (LAD) regression equation for the entire 61-year data set. Dashed lines represent separate LAD regressions for the historical (up through 1975, indicated by crosses) and NDCMP operational (1976-85, indicated by circles) periods.