REGRESSION ANALYSIS OF LICHEN DATA FROM THE ATHABASCA OIL SANDS REGION

STATISTICAL REPORT

Prepared for

Shanti Berryman
Woods Buffalo Environmental Association
Moab, Utah

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by

Pacific Analytics
PO Box 219
Albany, OR 97321
(541) 926-0117

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Prepared by:

Pacific Analytics, L.L.C.
Post Office Box 219
Albany, Oregon 97321
Tel. (541) 926-0117
mail@statpros.com
www.statpros.com

Gregory Brenner
Senior Associate / Project Manager

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I. TABLE OF CONTENTS

II. EXECUTIVE SUMMARY

This is a report of regression analysis of Lichen Data from the Athabasca Oil Sands Region. The report answers three general questions of interest for each of 28 elements. The Questions of Interest are:

1. Do the concentrations of elements in lichens change with distance from mine sites?
2. Do the concentrations of elements in lichens change with direction along a transect?
3. Is there an interaction effect between distance and direction?

The report includes an introduction to the analysis, a description of the statistical procedures, and the results of the analyses.

The results are presented in three chapters, one dealing with each species.

III. INTRODUCTION

Lichens are a unique life form, consisting of a relationship between a fungus and a photosynthetic partner, a cyanobacterium or a green alga. The association is said to be symbiotic, such that the fungus provides moisture and shelter for the algal cells allowing them live even in places that otherwise would be unsuitable for them. Due to this symbiotic relationship, lichens are able to live in some of the harshest habitats on earth. Lichens are extremely widespread in nature; they occur from arid desert regions to the Arctic and grow on bare soil, tree trunks, and rocks. Lichens grow very slowly, often less than a millimeter per year.

Lichens lack any outside covering, or cuticle, and consequently are directly exposed to the atmosphere, which they depend upon for their nutrients and water. Moistened lichen tissues act as blotters, soaking up chemicals or materials deposited on their surfaces. This feature has also made them highly susceptible to air pollutants; and lichens are perhaps the plant species most susceptible to sulfur dioxide, heavy metals, and acid rain.

Since lichens are very sensitive to pollutants, they are sometimes used as indicators of air and water pollution. Lichens are investigated at a number of locations surrounding a point or area pollution source, or at a number of locations within an area of interest. Appropriate lichen metrics are recorded at each location and are related to known or inferred pollution levels. The metrics include distribution of individual indicator species, frequency or abundance of individual species, species richness (total number of different species) at each study location, total lichen cover, and element content in lichen samples.

In this study lichens were used as bioindicators of air pollution in the Athabasca Oil Sands region. Concentrations of elements in lichens are used to assess the effects of direction and distance from a point source on element deposition.

Questions of Interest

1. Do the concentrations of elements in lichens change with distance from mine sites?
2. Do the concentrations of elements in lichens change with direction along a transect?
3. Is there an interaction effect between distance and direction?

Species of Interest

Element content was measured from three lichen species:

1 – Clamit = *Cladina mitis*

2 – Evemes = *Evernia mesomorpha*

3 – Hypphy = *Hypogymnia physodes*

Elements

Twenty-nine elements were detected in laboratory analysis:

Percent Nitrogen, Percent Sulfur, parts per million (ppb for Hg) of Al, As, B, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, Hg, K, Li, Mg, Mn, Mo, Na, Ni, P, Pb, Rb, Si, Sr, Ti, V, Zn.

IV. STATISTICAL PROCEDURES

Data Reduction

The sampling units in this study are the sites at which lichen samples were collected. In most cases more than one sample of each species was taken at a site. These field replicate samples are sub-samples of the sampling unit and are not appropriate for analysis without accounting for the structure of the sampling.

For this study, the site mean response of the sub-samples for each element for each species was calculated and used as the response variable for that site.

Twenty-nine elements were detected in laboratory analysis. In each of the species, some of the samples had element concentrations below the detectable limit. Statistical analysis was not conducted for those elements that had greater than about 40% of the samples below detectable limits. These include lithium (Li), beryllium (Be), cobalt (Co), and rubidium (Rb) for all three species. For the same reason, statistical analysis was not performed for arsenic (As) and lead (Pb) in *C. mitis* and *E. mesomorpha*.

Linear Regression

Regression analysis describes statistical relationships between a response variable and several explanatory variables. In the case of lichen data, the response variables are the measurements of element concentration in lichen samples taken at several sites. The explanatory variables are cardinal directions and distance from mine sites.

Knowledge about the statistical relationship between variables enables one to determine certain characteristics of the response variable from the measured explanatory variables. In mathematical terms the relationship looks like

$$\mu = \beta_0 + \beta_1 X_1 + \beta_2 X_2$$

where μ = the mean of the response distribution, β_0 is the intercept coefficient, β_1 is the coefficient for the first explanatory variable, X_1, and β_2 is the coefficient for the next explanatory variable, X_2.

The regression coefficients are calculated using Least Squares Estimation. These parameters are estimated and each has its own associated standard error. An estimate for the value of the response variable can be calculated by inserting the values of the explanatory variables into the equation. The difference between the estimated value and the observed measured value is called the residual. The Least Squares Estimation procedure minimizes the squared residuals while estimating the regression coefficients.

There are several conditions under which Least Squares Estimation is most efficient. The first is that the response distributions for each set of explanatory values have approximately the same standard deviations. The next is that the distributions of the response variables are approximately Normal (Gaussian). The third is that each response is drawn independently of all the other responses.

Least Squares Regression is useful for modeling the fit of a response variable to several continuous explanatory variables. In this study, the distance from mine sites is one such continuous variable. Least Squares Regression can also be used to distinguish between two or more groups or categories. Indicator (or Dummy) variables are set up for each of the groups (or levels of a factor) but one. The indicator variables take on values of “1” or “0”, indicating the attribute is present or absent. This method was used in this study for the analysis of the effect of direction on the concentration of elements in lichens.

When the explanatory variables are categorical, statistical analysis may be accomplished by regression or analysis of variance. The choice between the two methods is straightforward: if the simple linear regression model fits then it is preferred. The regression approach has the advantage of allowing interpolation, it provides more degrees of freedom for error estimation, and it yields smaller standard errors for the estimates of the mean responses.

The fit of the model to the assumptions can be assessed by residual plots. These are the graph of the residuals on the Y axis and the fitted values on the X axis. Inequalities of standard error are easily detected from these graphs. Usually transformations (e.g., log or square root transformations) will correct for departures from equality. In other cases, different distributions may more accurately model the data. One distribution used in this study was the Poisson Distribution.

Poisson Regression

The Poisson probability distribution is useful for describing the population distribution of counts of occurrences of some event over time or space, but has been used in a wide variety of situations. It can be useful for modeling distributions that do not fit the Normal distribution used in linear regression. The distribution is based on the number of successes over a given measurement period.

The probability of obtaining Y successes is given by the formula

$$\text{Probability}\{Y\} = \exp(-\mu)*\mu Y/Y!, \text{ for any } Y = 0,1,2, \ldots$$

The features of the Poisson distribution allow regression models to account for increasing variance with increasing means response. In the Poisson distribution, the variance is equal to the mean.

Poisson log-linear regression models specify that the logarithms of means of Poisson responses are linear in regression coefficients. Coefficients of the Poisson regression model can be estimated using a generalized linear model. The generalized linear model (glm) with a Poisson response is

$$\log(\mu) = \beta 0 + \beta 1\ X1 + \beta 2\ X2$$

where μ = the mean of the Poisson distribution, $\beta 0$ is the intercept coefficient, $\beta 1$ is the coefficient for the first explanatory variable, X1, and $\beta 2$ is the coefficient for the next explanatory variable, X2.

Many times analysis of Poisson distributed data is conducted with transformed data. The logarithm of the response often straightens out the relationship between the response and the explanatory variables. The variance remains non-constant and normal regression analysis often fails to arrive at a parsimonious model. The transformation that stabilizes the variance is the square root of the response, but interpretation is not satisfactory. The Poisson log-linear approach does not require a transformation.

The maximum likelihood method is used to estimate the coefficients in Poisson log-linear regression. The parameters for the model are those that yield the highest probability of observing precisely what was observed. The method is calculation intensive and is used in most modern statistical software packages. A thorough discussion of Generalized Linear Regression and Maximum Likelihood Estimation of model parameters is contained in Generalized Linear Models 2nd Edition (McCullagh and Nelder 1991).

Software used for Poisson log-linear regression was S-Plus version 4.5 (MathSoft 1988-1998).

V. *CLADINA MITIS*

N%

Linear Regression

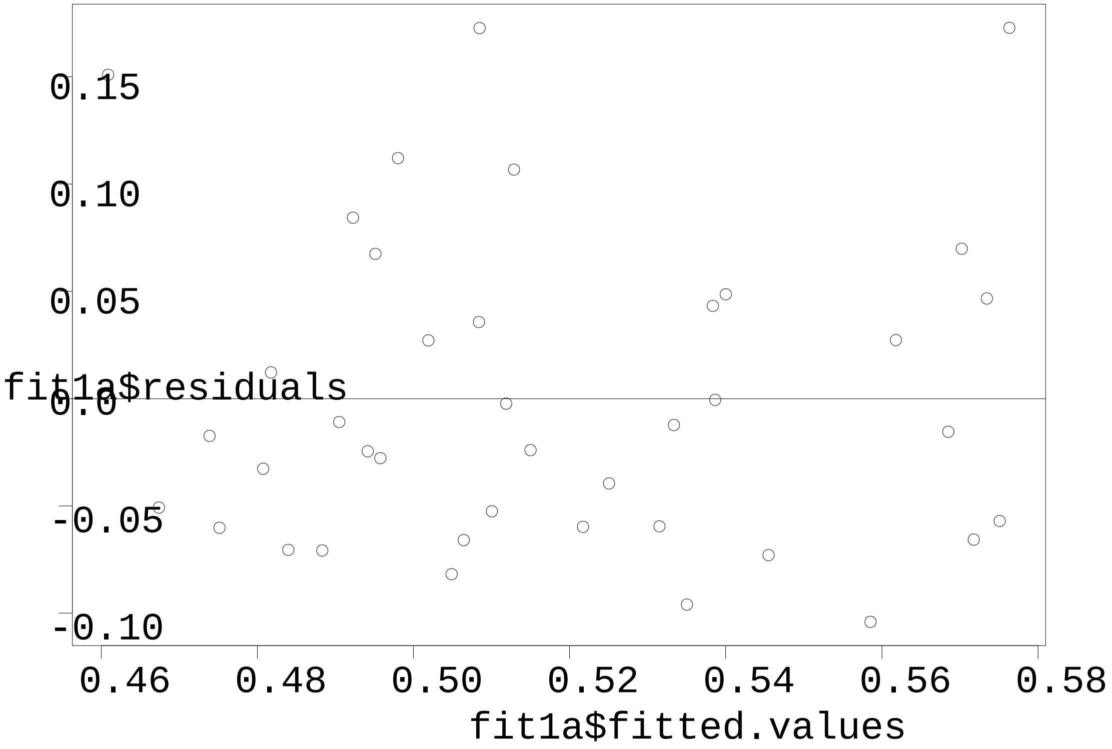
N% Regression Table:

```
Coefficients   Value  Std. Error  t value  P-value
  Intercept   0.5784   0.0283    20.4412   0.0000
      dirNE  -0.0777   0.0356    -2.1834   0.0358
      dirNS  -0.0368   0.0345    -1.0654   0.2940
      dirNW  -0.0635   0.0337    -1.8871   0.0675
  Cdistance  -0.0003   0.0003    -1.0005   0.3240

Residual standard error: 0.077 on 35 degrees of freedom
Multiple R-Squared: 0.1715
F-statistic: 1.811 on 4 and 35 degrees of freedom, the P-
value is 0.1487
```

N% Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the percent of N in *Cladina mitis* lichen samples. There is no evidence that the percent of N in *Cladina mitis* lichen samples decreases as the distance from mine sites increases (p-value = 0.3240). There is evidence that the percent of N in *Cladina mitis* lichen samples is smaller in the East direction than in the North direction (p-value = 0.0358). There is suggestive evidence that the percent of N in *Cladina mitis* lichen samples is smaller in the West direction than in the North direction (p-value = 0.0675).

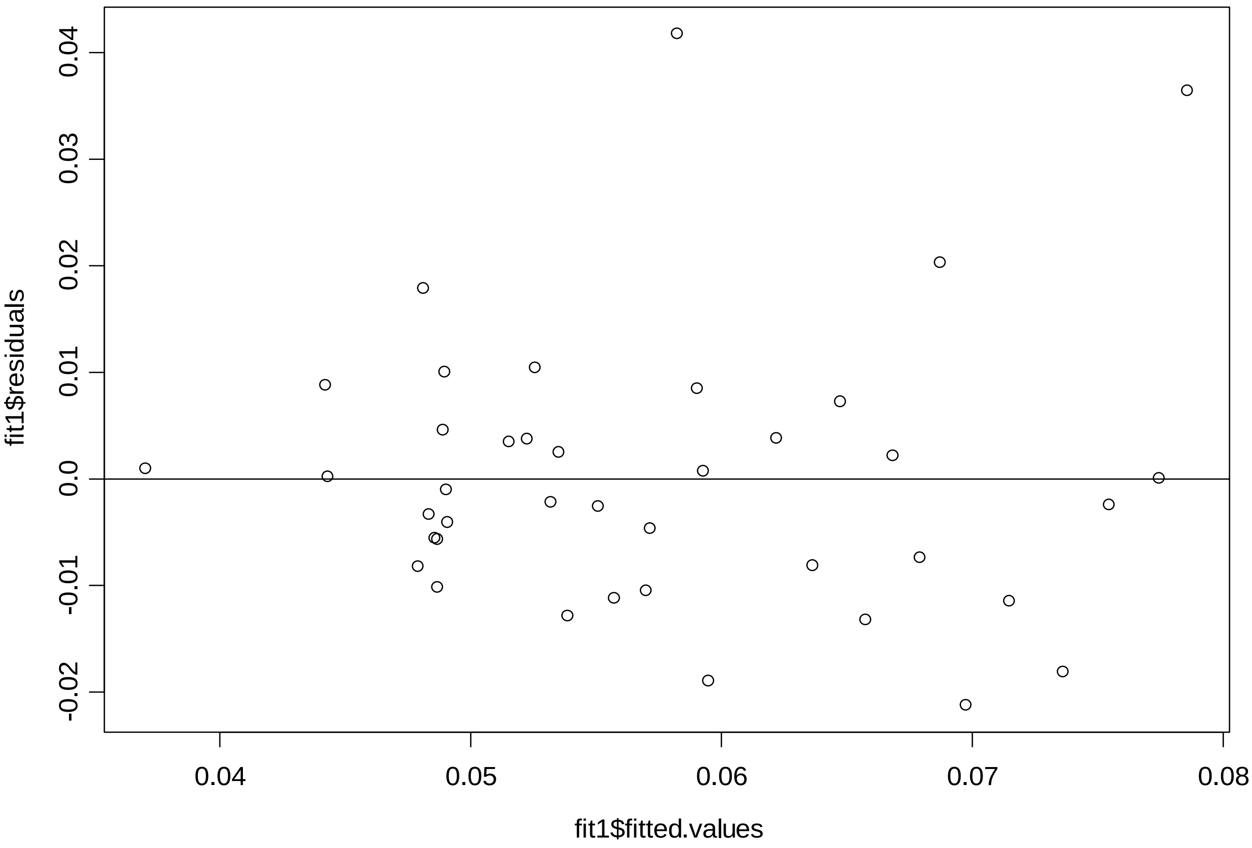
N% Linear Regression Residual Plot:



S%

S% Linear Regression:

S% Linear Regression Residual Plot:



S% Log Transformed Analysis:

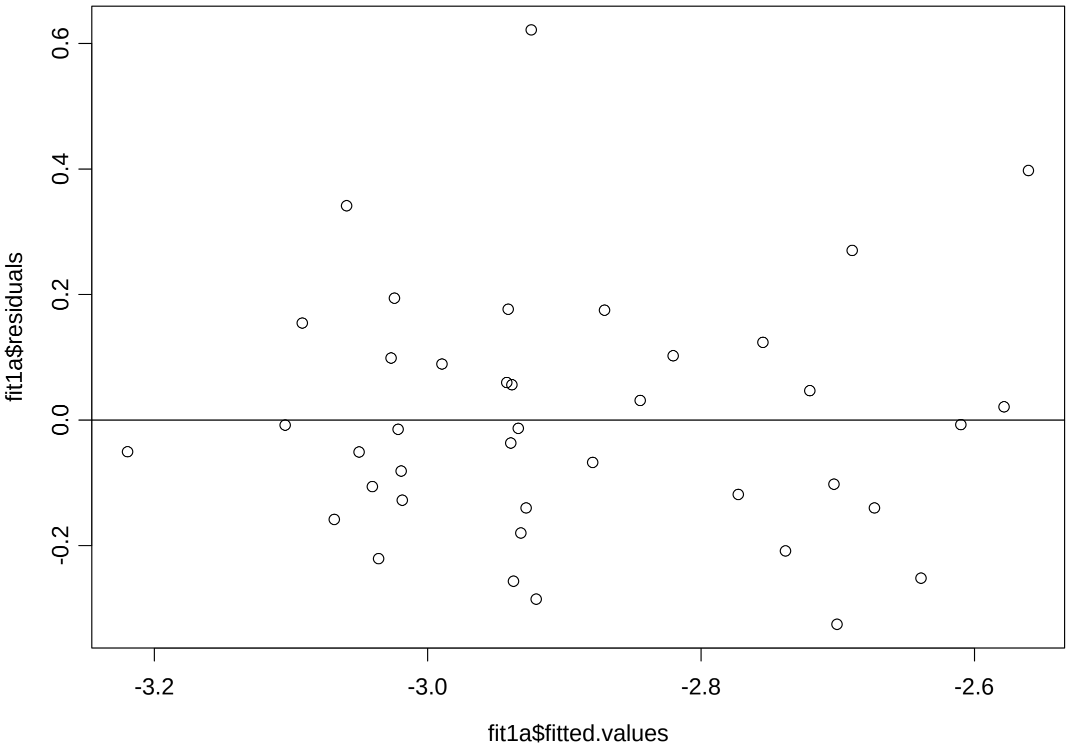
S% Regression Table:

```
Coefficients      Value  Std. Error  t value   P-value
     Intercept  -2.5253   0.1050   -24.0503   0.0000
         dirWE  -0.4871   0.1702    -2.8611   0.0074
         dirWN  -0.1418   0.1487    -0.9534   0.3475
         dirWS  -0.4176   0.1551    -2.6930   0.0112
         dirNE  -0.3453   0.1704    -2.0261   0.0512
         dirNS  -0.2758   0.1553    -1.7764   0.0852
     Cdistance  -0.0058   0.0018    -3.2930   0.0024
dirWECdistance   0.0053   0.0027     1.9840   0.0559
dirWNCdistance   0.0023   0.0025     0.8837   0.3835
dirWSCdistance   0.0060   0.0025     2.3584   0.0246

Residual standard error: 0.2157 on 32 degrees of freedom
Multiple R-Squared: 0.4111
F-statistic: 3.191 on 7 and 32 degrees of freedom, the P-
value is 0.01119
```

S% Statistical Inference:

There is evidence of an interaction effect between distance from mine sites and direction on the percent of S in *Cladina mitis* lichen samples. The percent S decreases more slowly in the South and East direction than in the West direction (*p-values* = 0.0246 and 0.0559 respectively). There is strong evidence that the percent of S in *Cladina mitis* lichen samples decreases as the distance from mine sites increases (p-value = 0.0024).

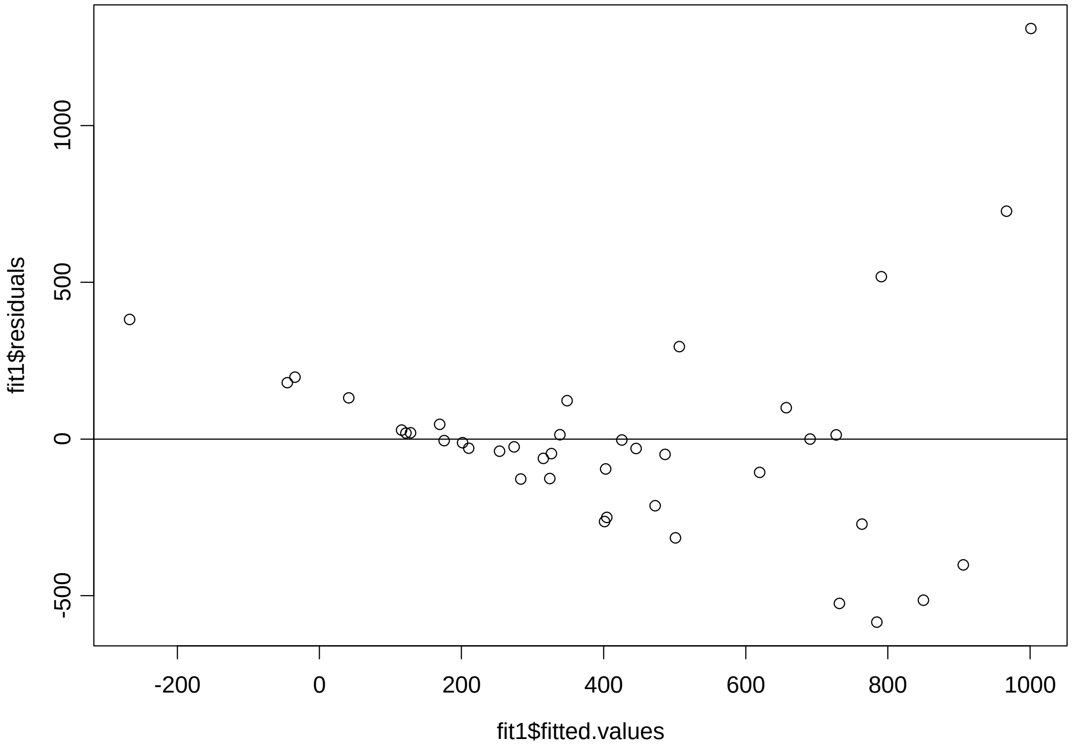
S% Log Transformed Regression Residual Plot:



Al ppm

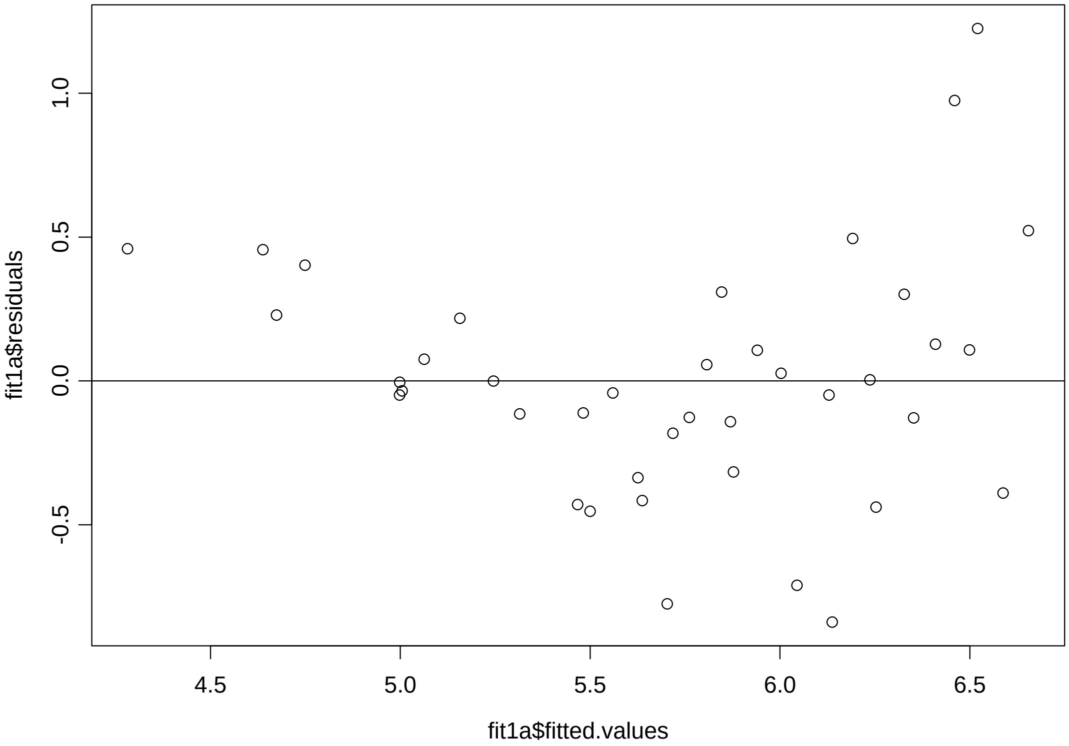
Al ppm Linear Regression

Al ppm Linear Regression Residual Plot:



Al ppm Log Transformation:

Al ppm Log Transformed Residual Plot:



Al ppm Rank Transformation

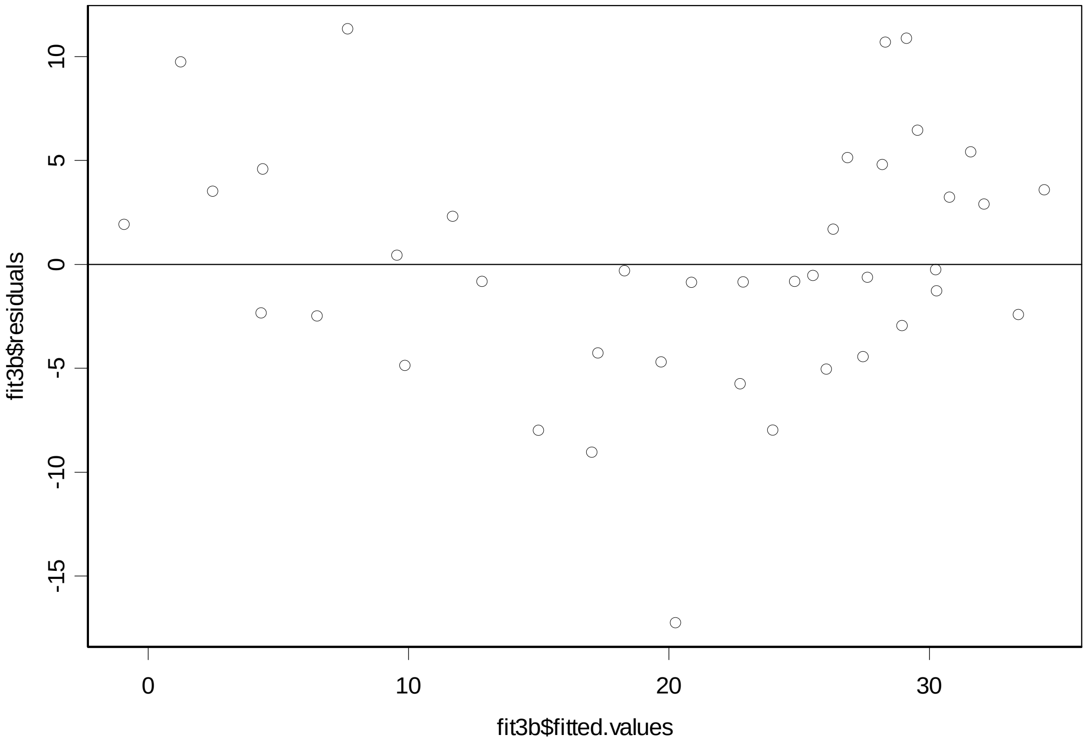
Al ppm Regression Table:

```
Coefficients  Value  Std. Error   t value  P-value
  Intercept  32.9284   2.3637    13.9310   0.0000
      dirSE   1.2360   2.8411     0.4350   0.6662
      dirSN   3.1553   2.7671     1.1403   0.2619
      dirSW  -2.1938   2.6994    -0.8127   0.4219
      dirNW  -5.3492   2.6995    -1.9816   0.0554
  Cdistance  -0.2640   0.0266    -9.9314   0.0000

Residual standard error: 6.175 on 35 degrees of freedom
Multiple R-Squared: 0.7496
F-statistic: 26.2 on 4 and 35 degrees of freedom, the P-
value is 4.218e-010
```

Al ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the Al ppm in *Cladina mitis* lichen samples. There is strong evidence that the Al ppm in *Cladina mitis* lichen samples declines as the distance from mine sites increases (p-value < 0.0001). There is evidence that the Al ppm in *Cladina mitis* lichen samples is smaller in the West direction than in the North direction (p-value = 0.0554).

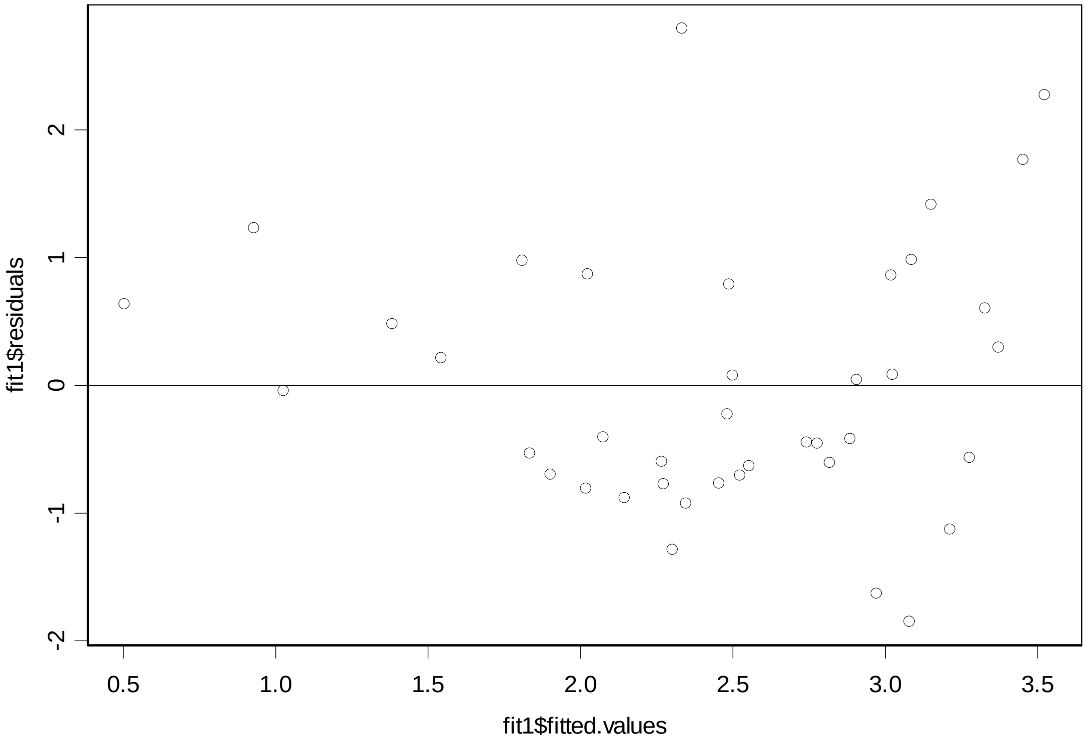
Al ppm Rank Transformed Residual Plot:



B ppm

B ppm Linear Regression

B ppm Linear Regression Residual Plot



B ppm Log Transformation

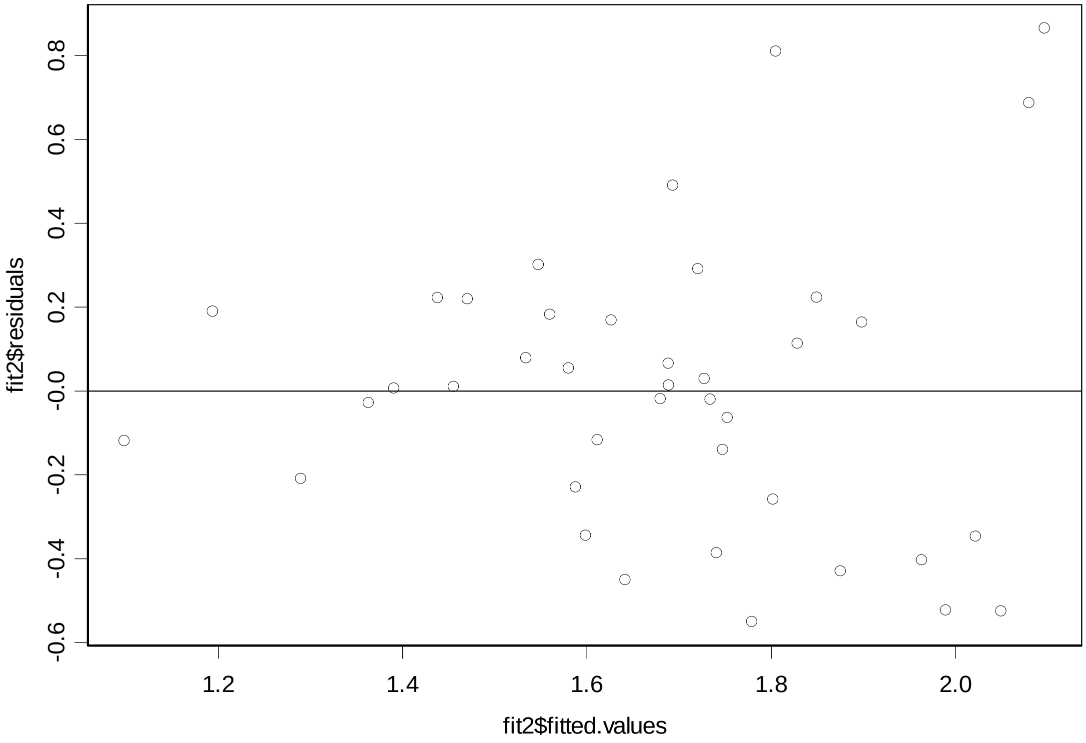
B ppm Regression Table:

```
Coefficients  Value Std. Error  t value P-value
  Intercept  1.2124  0.1617     7.4976  0.0000
      dirSE -0.0941  0.1944    -0.4843  0.6312
      dirSN -0.1333  0.1893    -0.7041  0.4860
      dirSW -0.0937  0.1847    -0.5074  0.6151
  Cdistance -0.0071  0.0018    -3.9211  0.0004

Residual standard error: 0.4224 on 35 degrees of freedom
Multiple R-Squared: 0.312
F-statistic: 3.968 on 4 and 35 degrees of freedom, the P-
value is 0.009288
```

B ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the B ppm in *Cladina mitis* lichen samples. There is strong evidence that the B ppm in *Cladina mitis* lichen samples decreases as the distance from mine sites increases (p-value = 0.0004). There is no evidence that the B ppm in *Cladina mitis* lichen samples is smaller any direction.

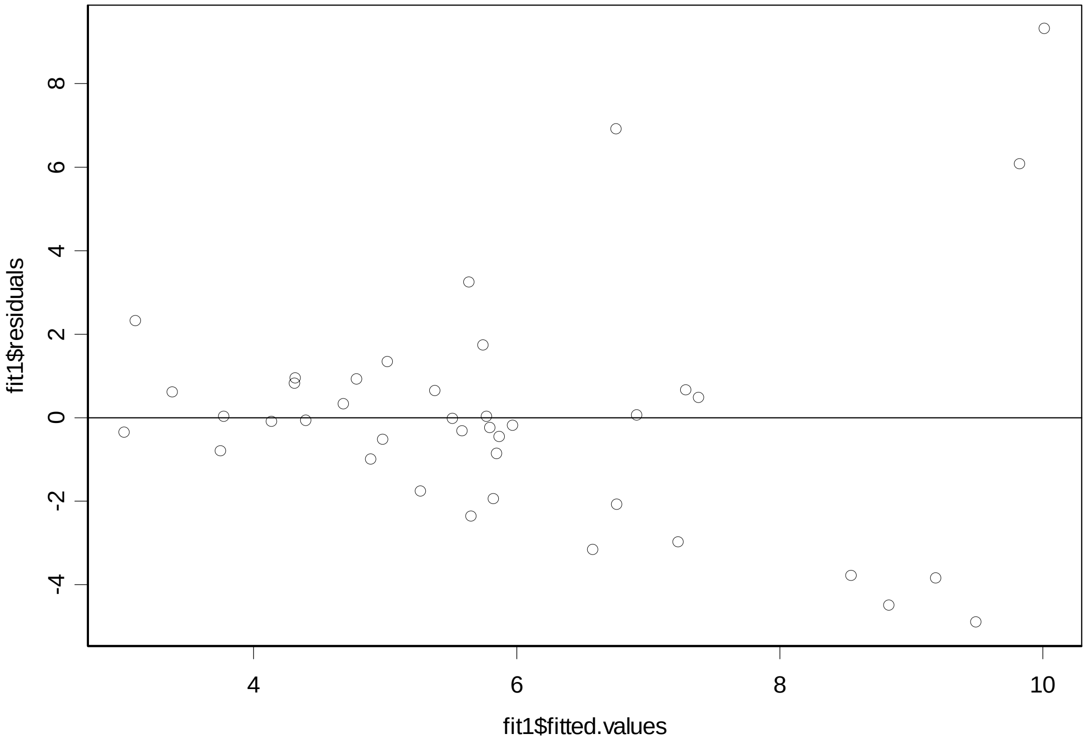
B ppm Log Transformed Residual Plot



Ba ppm

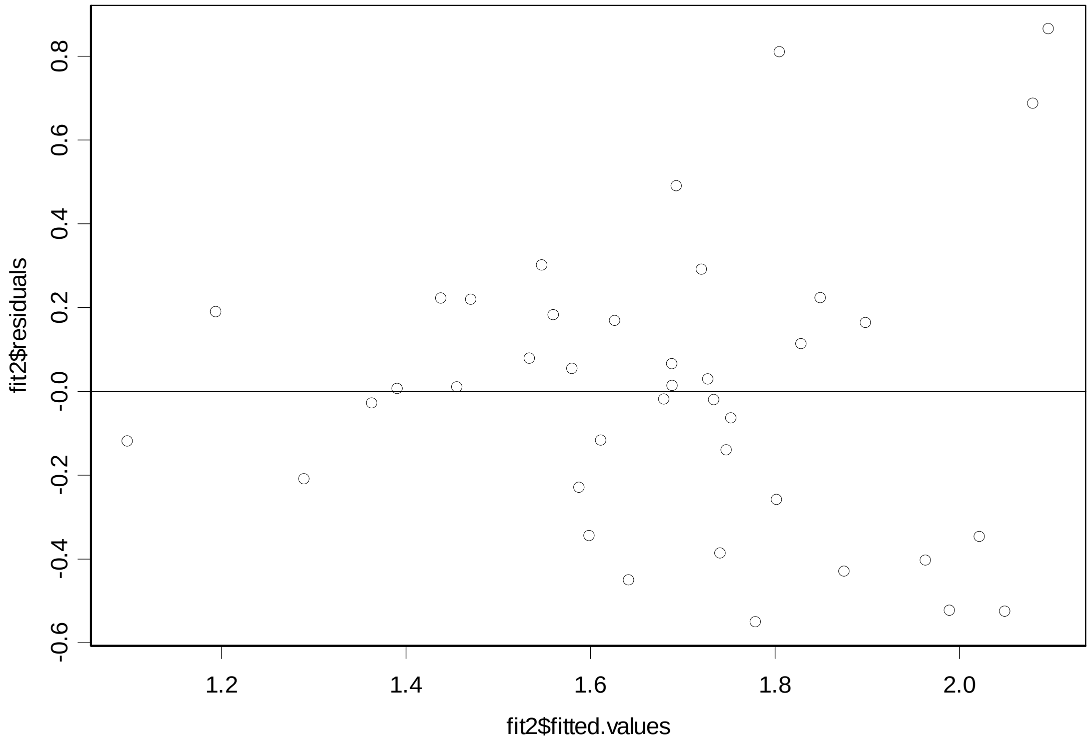
Ba ppm Linear Regression

Ba ppm Linear Regression Residual Plot:



Ba ppm Log Transformation

Ba ppm Log Transformed Residual Plot:



Ba ppm Generalized Linear Models:

Ba ppm Poisson Regression Table:

```
Coefficients       Value   Std. Error     t value    P-value
  Intercept  2.041510016 0.153337009  13.3138766       NA
      dirSE -0.314379361 0.207950959  -1.5117957       NA
      dirSN -0.086010111 0.185786359  -0.4629517       NA
      dirSW  0.215732466 0.169853727   1.2701073       NA
  Cdistance -0.005489355 0.001915124  -2.8663179    0.0031

Null Deviance: 56.07085 on 39 degrees of freedom
Residual Deviance: 37.88166 on 35 degrees of freedom
```

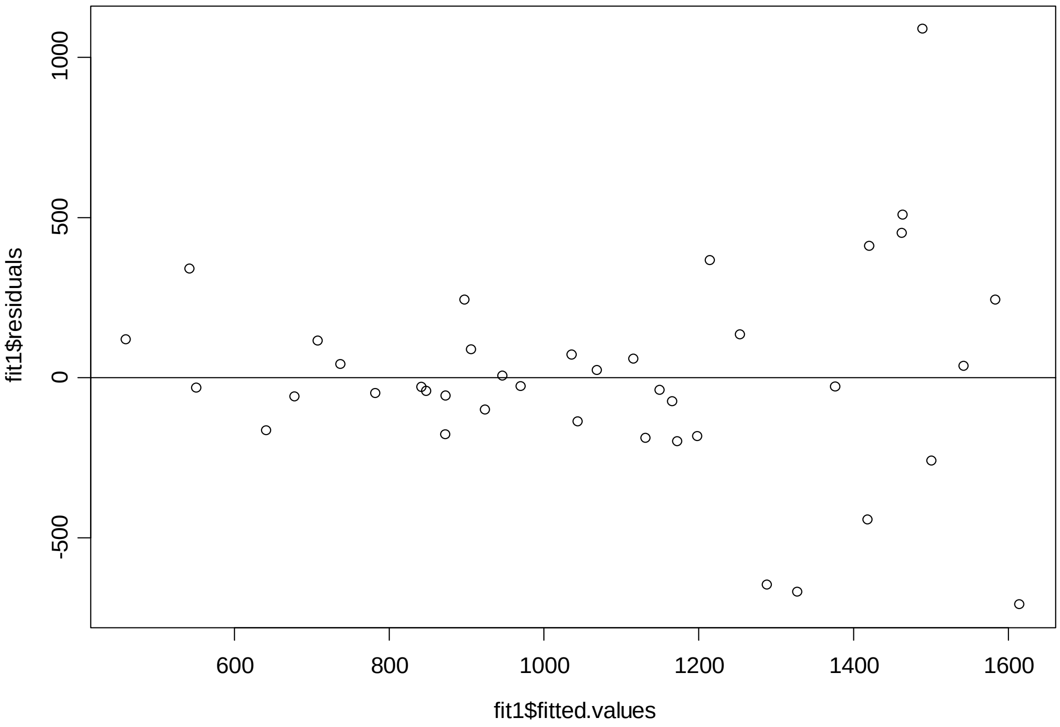
Ba ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the Ba ppm in *Cladina mitis* lichen samples. There is strong evidence that the Ba ppm in *Cladina mitis* lichen samples decreases as the distance from mine sites increases (p-value = 0.0031). There is evidence that the Ba ppm in *Cladina mitis* lichen samples is different on different directional transects (p-value = 0.0435). This p-value is derived from the drop-in-deviance test of the directional explanatory factor.

Ca ppm

Ca ppm Linear Regression

Ca ppm Linear Regression Residual Plot:



Ca ppm Log Transformation

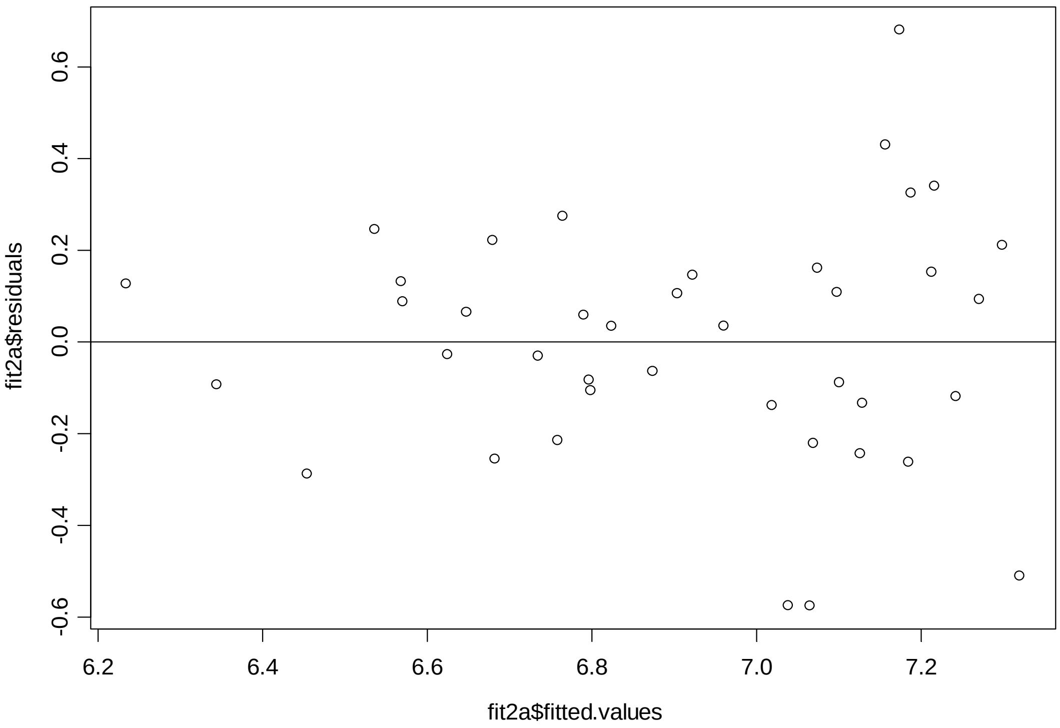
Ca ppm Regression Table:

```
Coefficients   Value  Std. Error  t value  P-value
   Intercept  6.9068   0.1128    61.2482   0.0000
       dirEN  0.4481   0.1270     3.5290   0.0012
       dirES  0.3340   0.1263     2.6440   0.0122
       dirEW  0.3011   0.1238     2.4313   0.0203
   Cdistance -0.0056   0.0012    -4.7438   0.0000

Residual standard error: 0.2745 on 35 degrees of freedom
Multiple R-Squared: 0.5351
F-statistic: 10.07 on 4 and 35 degrees of freedom, the P-
value is 0.00001565
```

Ca ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the Ca ppm in *Cladina mitis* lichen samples. There is strong evidence that the Ca ppm in *Cladina mitis* lichen samples decreases with increasing distance from mine sites (p-value < 0.0001). There is evidence that the Ca ppm in *Cladina mitis* lichen samples is smaller in the East direction than in the North, South and West directions (p-values = 0.0012, 0.0122. 0.0203 respectively).

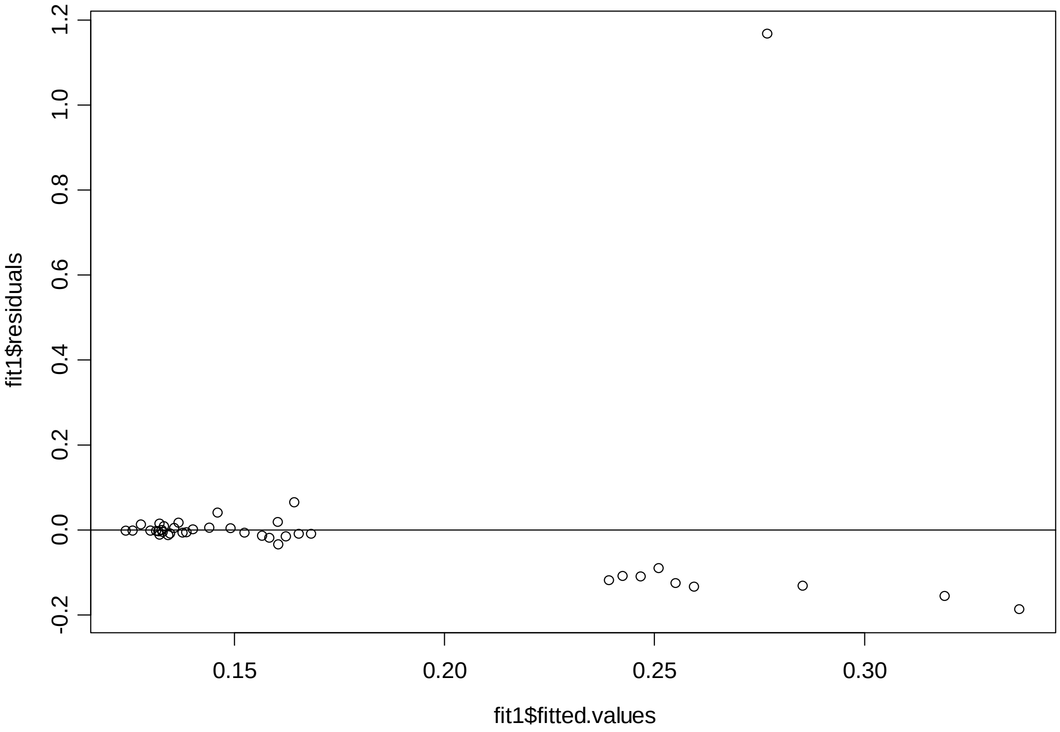
Ca ppm Log Transformed Residual Plot:



Cd ppm

Cd ppm Linear Regression

Cd ppm Linear Regression Residual Plot:



Cd ppm Log Transformation

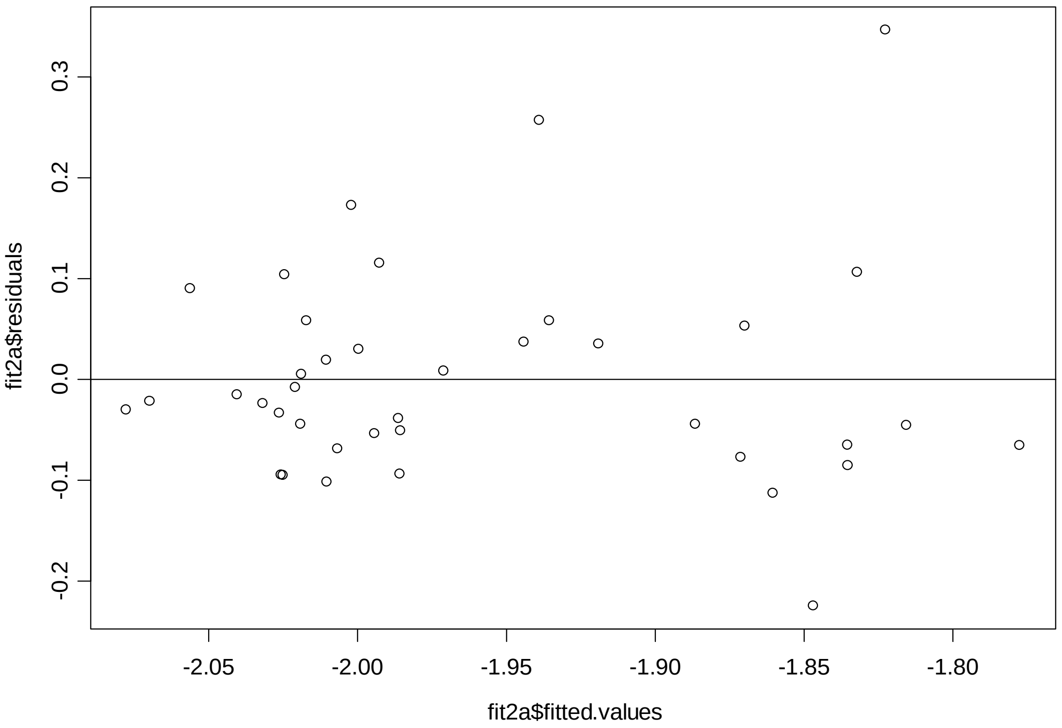
Cd ppm Regression Table:

```
Coefficients       Value Std. Error  t value   P-value
     Intercept  -1.8017   0.0564   -31.9482   0.0000
         dirWE  -0.3092   0.0914    -3.3821   0.0020
         dirWN  -0.2338   0.0805    -2.9063   0.0067
         dirWS  -0.2263   0.0833    -2.7171   0.0107
     Cdistance  -0.0023   0.0009    -2.4377   0.0207
dirWECdistance   0.0051   0.0014     3.5248   0.0013
dirWNCdistance   0.0040   0.0014     2.8988   0.0068
dirWSCdistance   0.0027   0.0014     1.9511   0.0601

Residual standard error: 0.1158 on 31 degrees of freedom
Multiple R-Squared: 0.3848
F-statistic: 2.77 on 7 and 31 degrees of freedom, the P-
value is 0.02335
```

Cd ppm Statistical Inference:

There is strong evidence of an interaction effect between distance from mine sites and direction on the Cd ppm in *Cladina mitis* lichen samples. The Cd ppm decreases more rapidly in the West direction than in the East, North, and South directions (p-value = 0.0013, 0.0068, and 0.0601 respectively). There is strong evidence that the Cd ppm in *Cladina mitis* lichen samples decreases as the distance from mine sites increases (p-value = 0.0207).

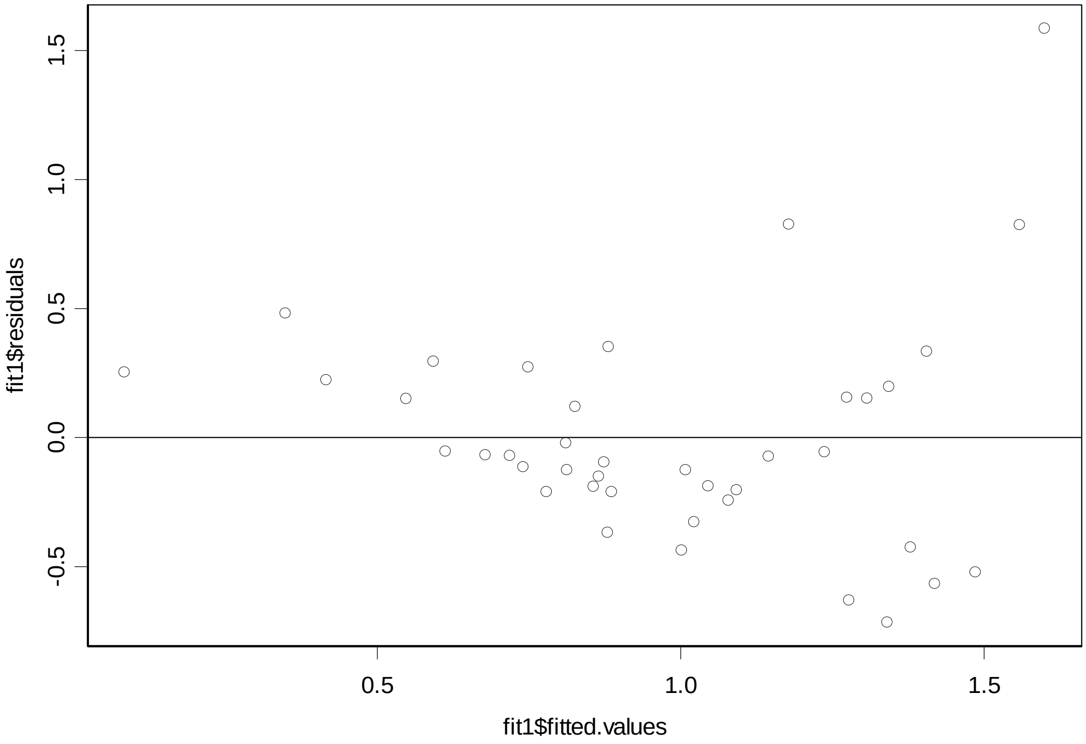
Cd ppm Log Transformed Residual Plot:



Cr ppm

Cr ppm Linear Regression

Cr ppm Linear Regression Residual Plot:



Cr ppm Log Transformation

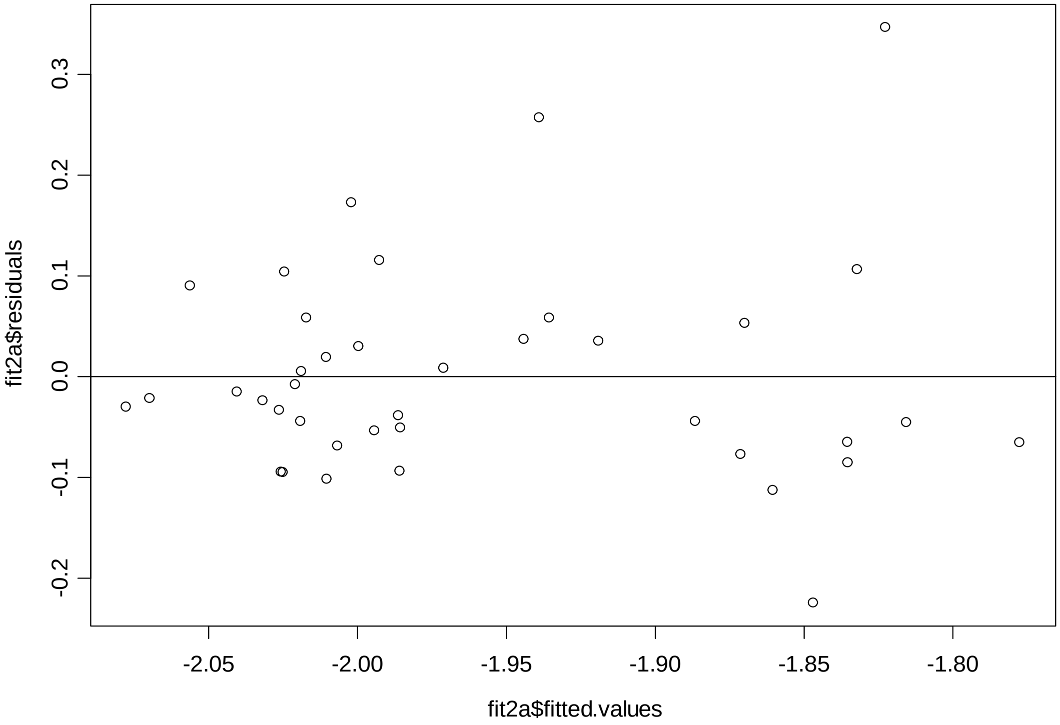
Cr ppm Regression Table:

```
Coefficients      Value Std. Error  t value P-value
     Intercept -0.1257  0.2176    -0.5777  0.5675
         dirEN  0.4924  0.2767     1.7792  0.0847
         dirES  0.2454  0.2858     0.8587  0.3969
         dirEW  0.4932  0.2764     1.7841  0.0839
     Cdistance -0.0018  0.0033    -0.5601  0.5793
dirENCdistance -0.0048  0.0045    -1.0828  0.2870
dirESCdistance -0.0046  0.0044    -1.0455  0.3036
dirEWCdistance -0.0097  0.0044    -2.2233  0.0334

Residual standard error: 0.3502 on 32 degrees of freedom
Multiple R-Squared: 0.4934
F-statistic: 4.452 on 7 and 32 degrees of freedom, the P-
value is 0.001494
```

Cr ppm Statistical Inference:

There is evidence of an interaction effect between distance from mine sites and direction on the Cr ppm in *Cladina mitis* lichen samples. The Cr ppm decreases more rapidly in the West direction than in the East direction (p-value = 0.0334). There is no evidence that the Cr ppm in *Cladina mitis* lichen samples decreases as the distance from mine sites increases (p-value = 0.5793).

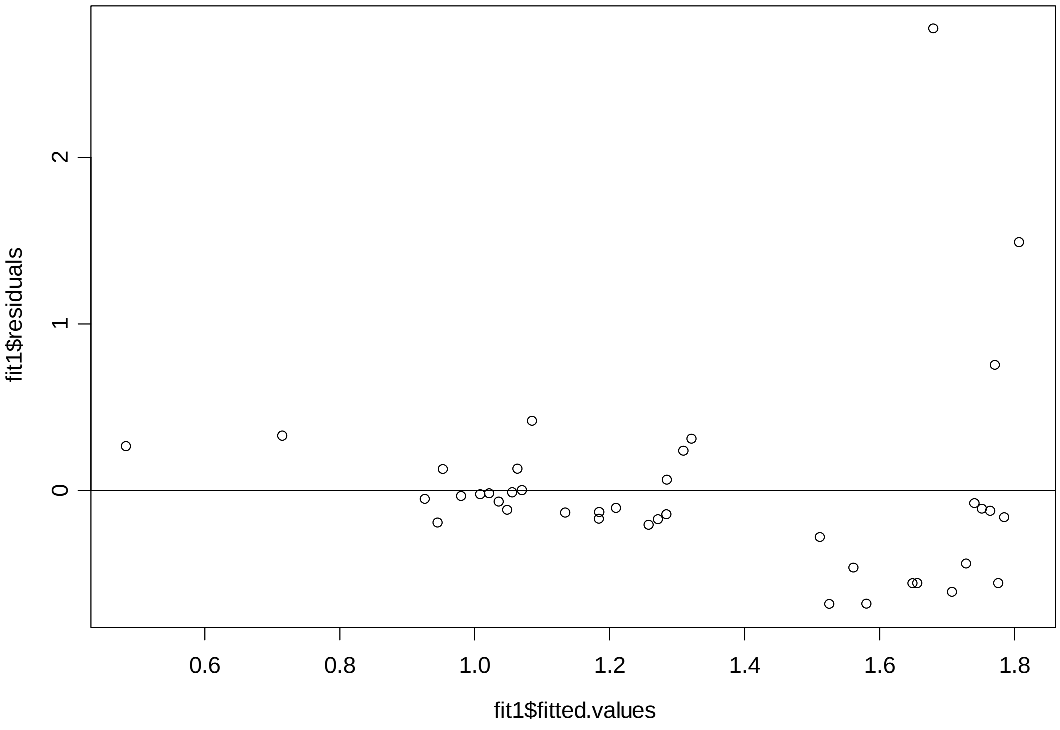
Cr ppm Log Transformed Residual Plot:



Cu ppm

Cu ppm Linear Regression

Cu ppm Linear Regression Residual Plot:



Cu ppm Log Transformation

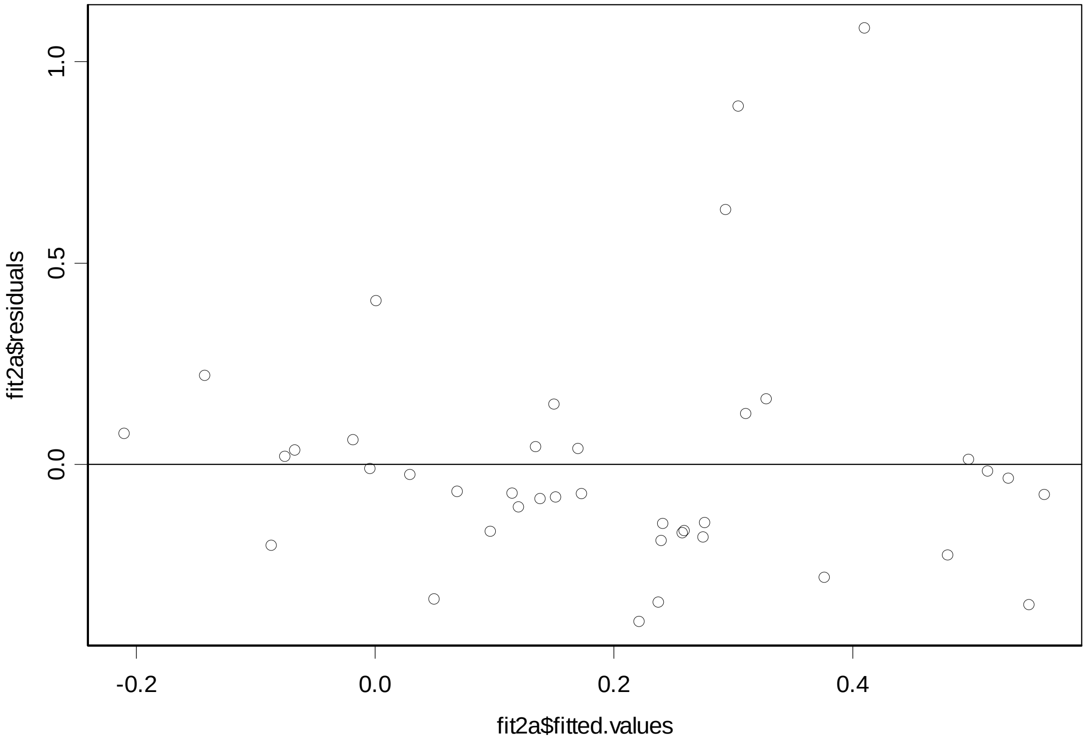
Cu ppm Regression Table:

```
Coefficients  Value Std. Error  t value P-value
  Intercept  0.2023  0.1312     1.5418  0.1321
      dirEN  0.3800  0.1477     2.5721  0.0145
      dirES  0.1428  0.1470     0.9717  0.3379
      dirEW  0.1229  0.1441     0.8526  0.3997
  Cdistance -0.0034  0.0014    -2.4990  0.0173

Residual standard error: 0.3194 on 35 degrees of freedom
Multiple R-Squared: 0.299
F-statistic: 3.732 on 4 and 35 degrees of freedom, the P-
value is 0.01244
```

Cu ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the Cu ppm in *Cladina mitis* lichen samples. There is strong evidence that the Cu ppm in *Cladina mitis* lichen samples decreases as the distance from mine sites increases (p-value = 0.0173). There is evidence that the Cu ppm in *Cladina mitis* lichen samples is smaller in the East direction than in the North direction (p-value = 0.0145).

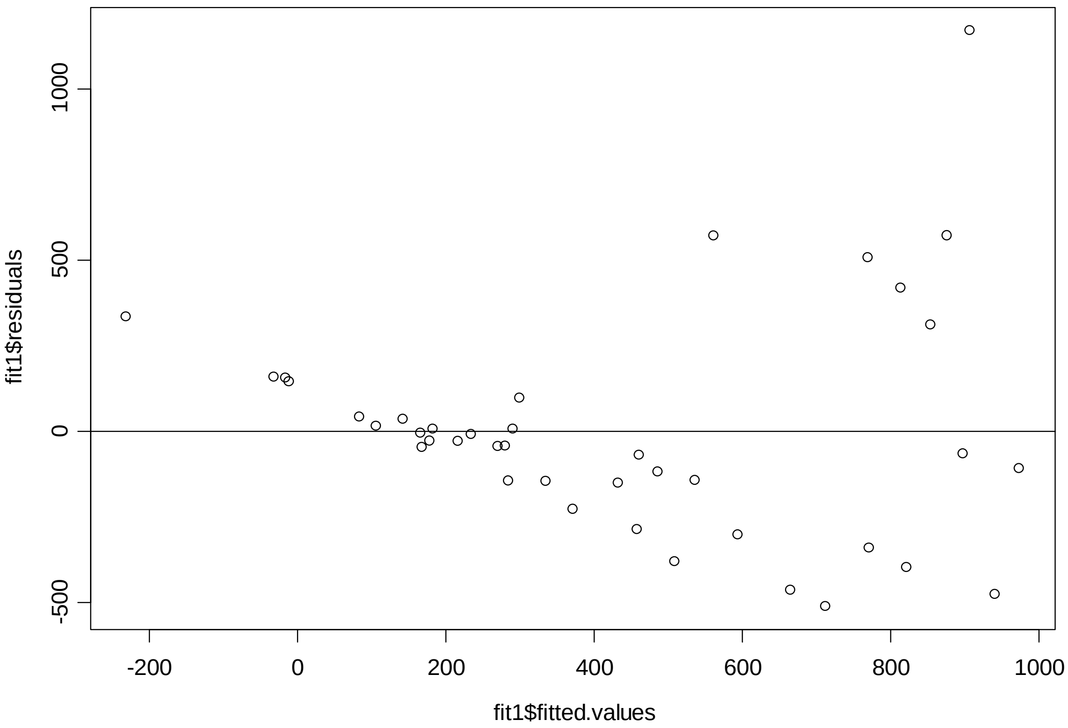
Cu ppm Log Transformed Residual Plot:



Fe ppm

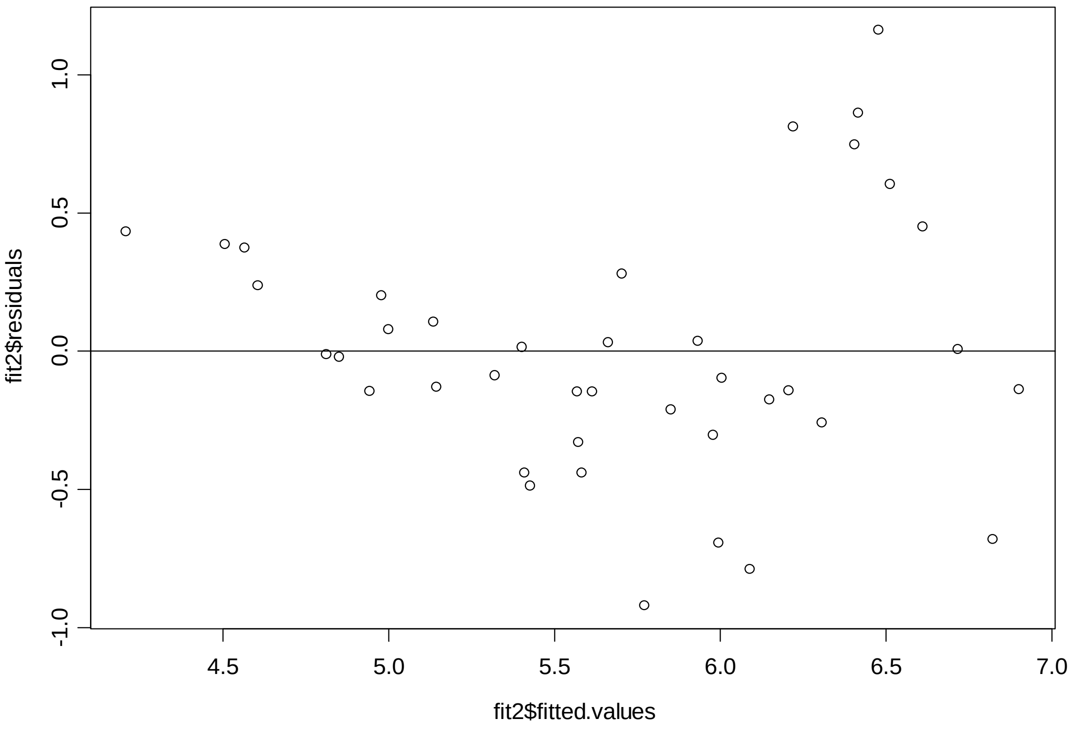
Fe ppm Linear Regression

Fe ppm Linear Regression Residual Plot:



Fe ppm Log Transformation

Fe ppm Log Transformed Residual Plot:



Fe ppm Rank Transformation

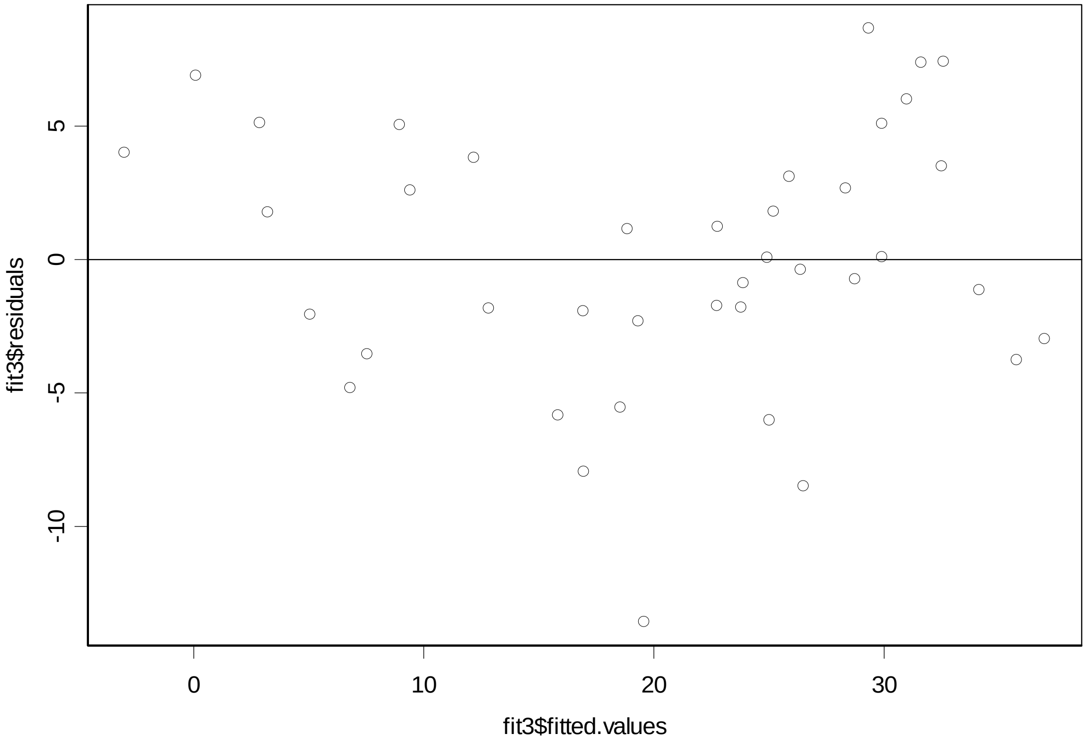
Fe ppm Regression Table:

```
Coefficients    Value Std. Error  t value   P-value
  Intercept  32.5453   2.0056     16.2273   0.0000
      dirWE   0.3762   2.4939      0.1509   0.8809
      dirWN   4.1691   2.4169      1.7250   0.0934
      dirWS   0.3640   2.4168      0.1506   0.8811
  Cdistance  -0.2716   0.0238    -11.4118   0.0000

Residual standard error: 5.529 on 35 degrees of freedom
Multiple R-Squared: 0.7993
F-statistic: 34.85 on 4 and 35 degrees of freedom, the P-
value is 9.344e-012
```

Fe ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the Fe ppm in *Cladina mitis* lichen samples. There is strong evidence that the Fe ppm in *Cladina mitis* lichen samples decreases as the distance from mine sites increases (p-value < 0.0001). There is no evidence that the Fe ppm in *Cladina mitis* lichen samples is different in any direction.

Fe ppm Rank Transformed Residual Plot:



Hg ppb

Hg ppb Linear Regression:

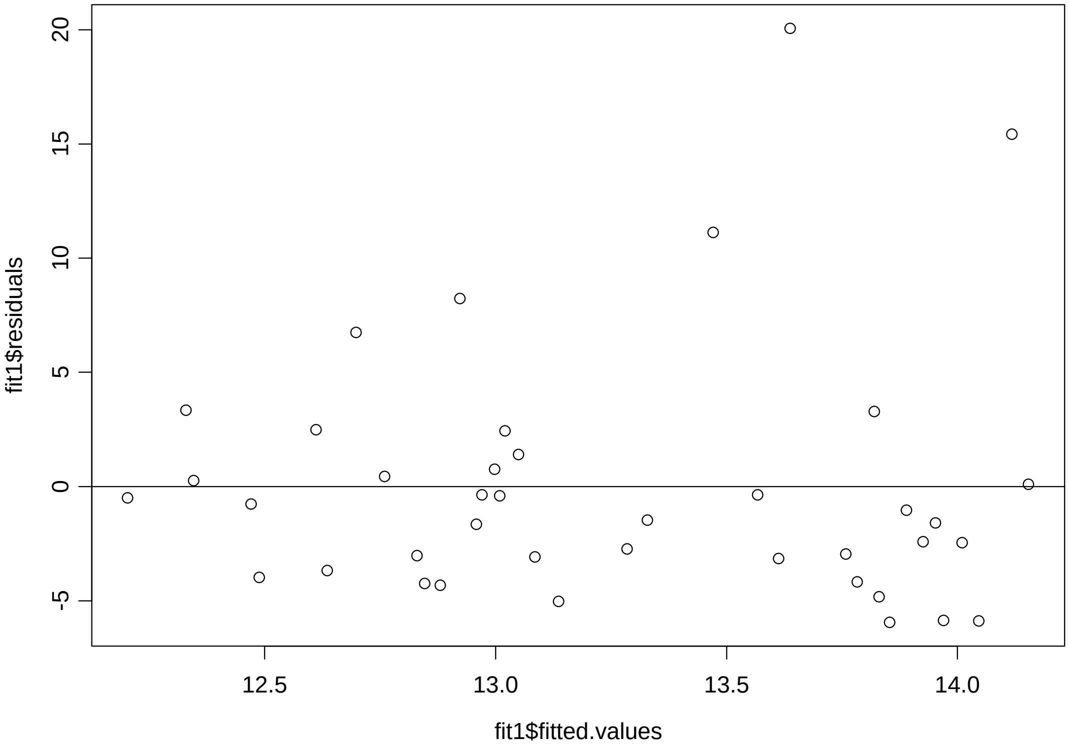
Hg ppb Regression Table:

```
Coefficients      Value  Std. Error  t value   P-value
Intercept       13.0637   2.1404      6.1033   0.0000
      dirWE      0.1273   2.6615      0.0478   0.9621
      dirWN      0.9336   2.5794      0.3619   0.7196
      dirWS      1.1260   2.5793      0.4366   0.6651
  Cdistance     -0.0072   0.0254     -0.2827   0.7791

Residual standard error: 5.9 on 35 degrees of freedom
Multiple R-Squared: 0.01051
F-statistic: 0.09292 on 4 and 35 degrees of freedom, the p-
value is 0.9841
```

Statistical Inference:

There is no evidence of an interaction effect between distance from the mine and direction on the Hg ppb in *Cladina mitis* lichen samples. There is no evidence that the Hg ppb in *Cladina mitis* lichen samples is different in any direction. There is no evidence that the Hg ppb in *Cladina mitis* lichen samples changes with the distance from the mine.

Hg ppb Linear Regression Residual Plot:



K ppm

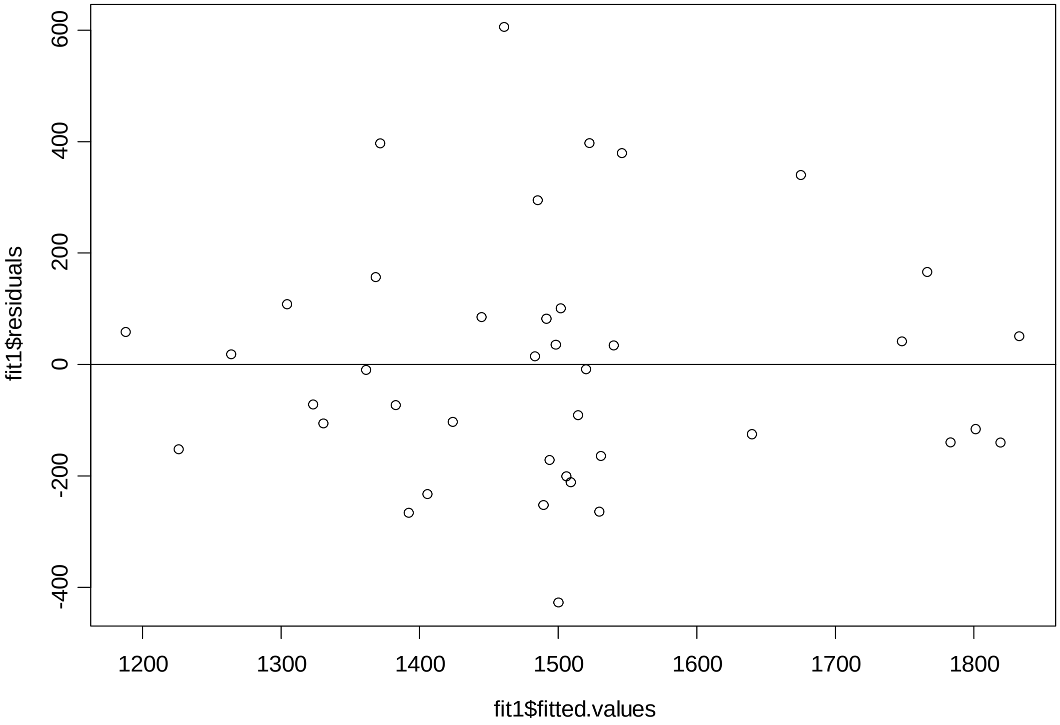
K ppm Regression Table:

```
Coefficients      Value Std. Error    t value     P-value
   Intercept  1409.9485    97.0731    14.5246      0.0000
       dirEN   364.8190   109.2972     3.3379      0.0020
       dirES   179.3849   108.7354     1.6497      0.1079
       dirEW   140.5810   106.6048     1.3187      0.1958
   Cdistance    -1.7379     1.0173    -1.7084      0.0964

Residual standard error: 236.3 on 35 degrees of freedom
Multiple R-Squared: 0.3116
F-statistic: 3.961 on 4 and 35 degrees of freedom, the P-
value is 0.009374
```

K ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the K ppm in *Cladina mitis* lichen samples. There is suggestive evidence that the K ppm in *Cladina mitis* lichen samples decreases as the distance from mine sites increases (p-value = 0.0964). There is evidence that the K ppm in *Cladina mitis* lichen samples is smaller in the East direction than in the North direction (p-value = 0.0020).

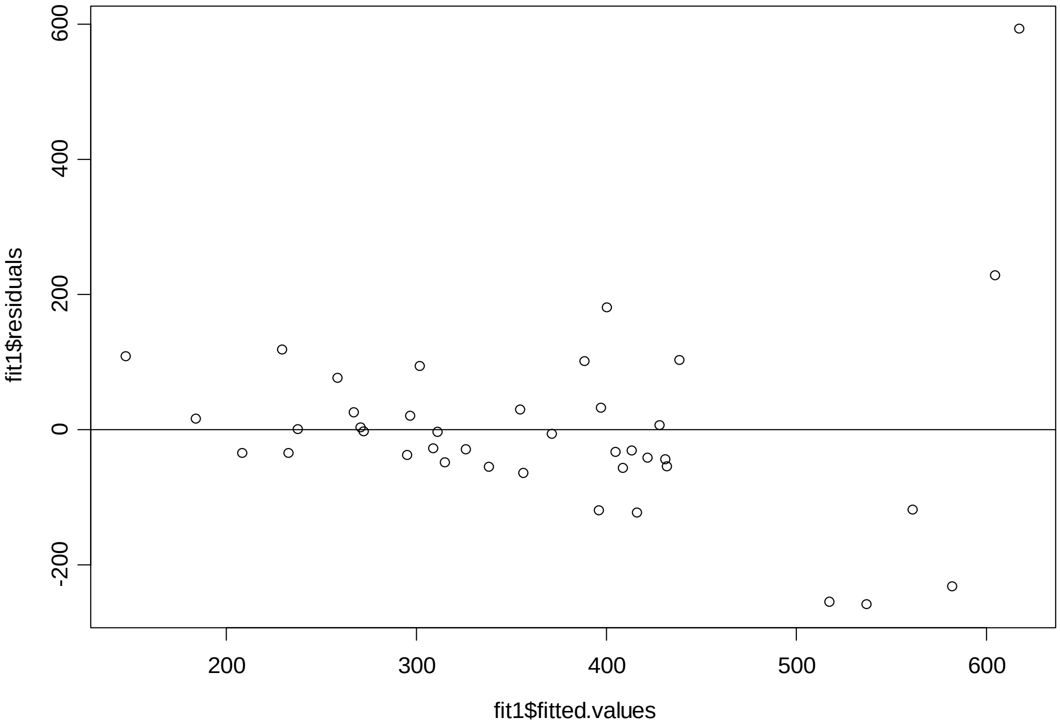
K ppm Linear Regression Residual Plot:



Mg ppm

Mg ppm Linear Regression

Mg ppm Linear Regression Residual Plot:



Mg ppm Log Transformation

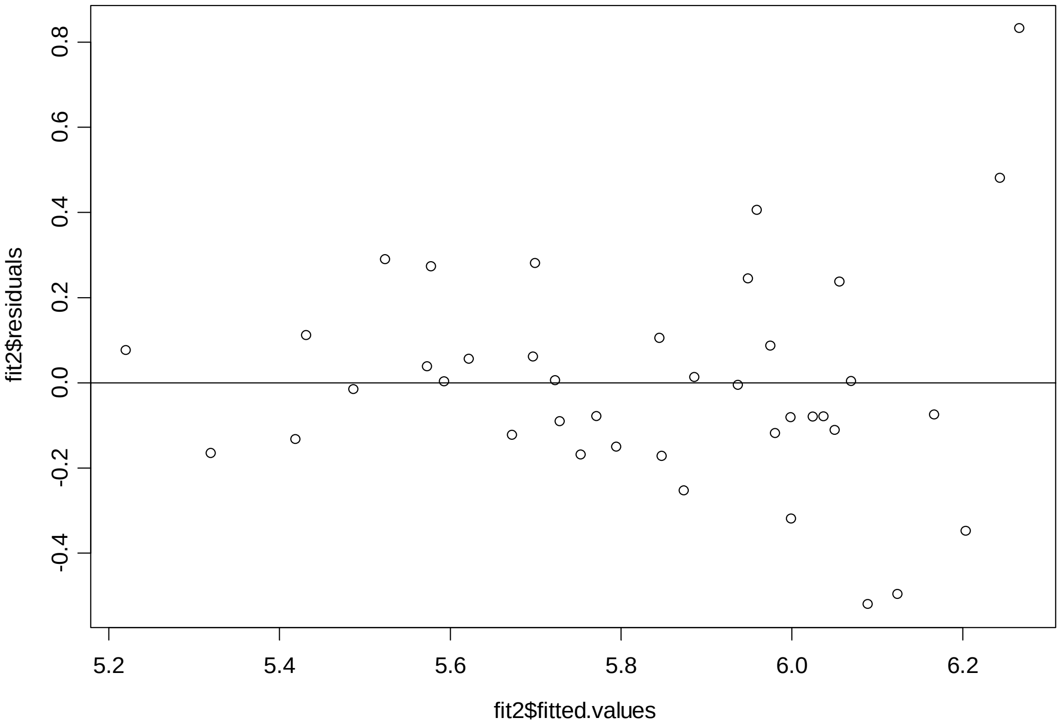
Mg ppm Regression Table:

```
Coefficients    Value Std. Error  t value   P-value
  Intercept   5.8458   0.1118    52.2928   0.0000
      dirEN   0.2673   0.1259     2.1239   0.0408
      dirES   0.3099   0.1252     2.4747   0.0183
      dirEW   0.3737   0.1228     3.0443   0.0044
  Cdistance  -0.0054   0.0012    -4.5933   0.0001

Residual standard error: 0.2722 on 35 degrees of freedom
Multiple R-Squared: 0.4962
F-statistic: 8.617 on 4 and 35 degrees of freedom, the P-
value is 0.0000597
```

Mg ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the Mg ppm in *Cladina mitis* lichen samples. There is strong evidence that the Mg ppm in *Cladina mitis* lichen samples decreases as the distance from mine sites increases (p-value = 0.0001). There is evidence that the Mg ppm in *Cladina mitis* lichen samples is smaller in the East direction than in the North, South, and West directions (p-value = 0.0408, 0.0183, and 0.0044 respectively).

Mg ppm Log transformed Residual Plot:



Mn ppm

Mn ppm Linear Regression

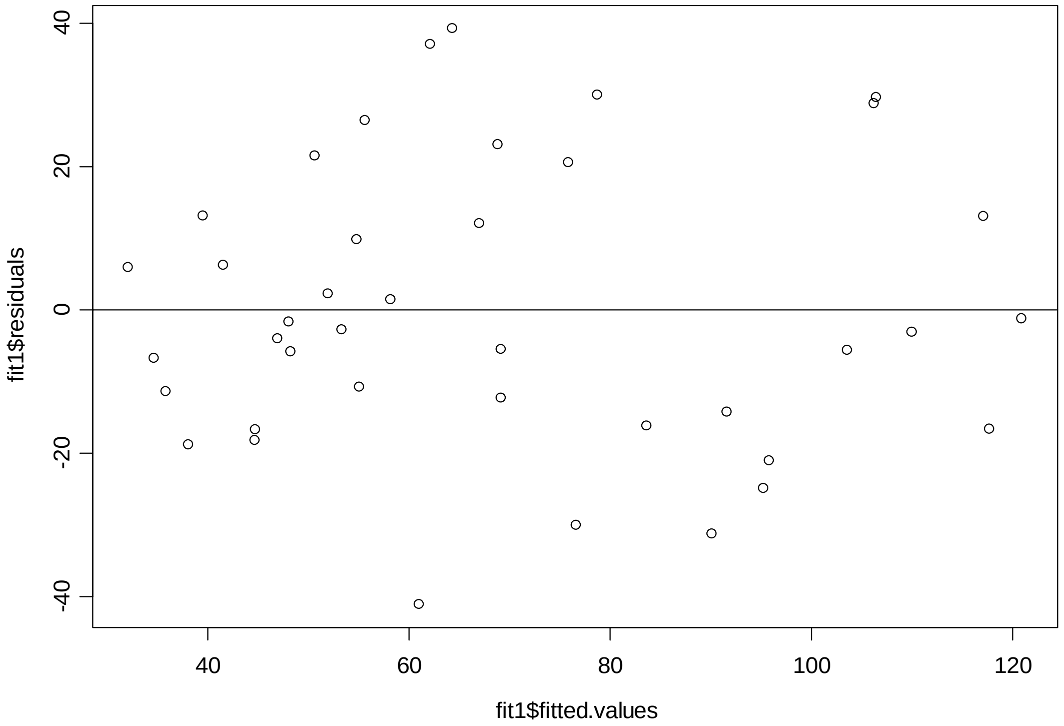
Mn ppm Regression Table:

```
Coefficients  Value Std. Error t value  P-value
  Intercept 28.6202  7.7215     3.7066  0.0007
      dirNE  7.1165  9.7169     0.7324  0.4688
      dirNS  7.2062  9.4149     0.7654  0.4492
      dirNW 16.5683  9.1850     1.8038  0.0799
  Cdistance  0.6669  0.0904     7.3737  0.0000

Residual standard error: 21.01 on 35 degrees of freedom
Multiple R-Squared: 0.6276
F-statistic: 14.75 on 4 and 35 degrees of freedom, the P-
value is 3.721e-007
```

Mn ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the Mn ppm in *Cladina mitis* lichen samples. There is strong evidence that the Mn ppm in *Cladina mitis* lichen samples increases as the distance from mine sites increases (p-value < 0.0001). There is suggestive evidence that the Mn ppm in *Cladina mitis* lichen samples is greater in the West direction than in the North direction (p-value = 0.0799).

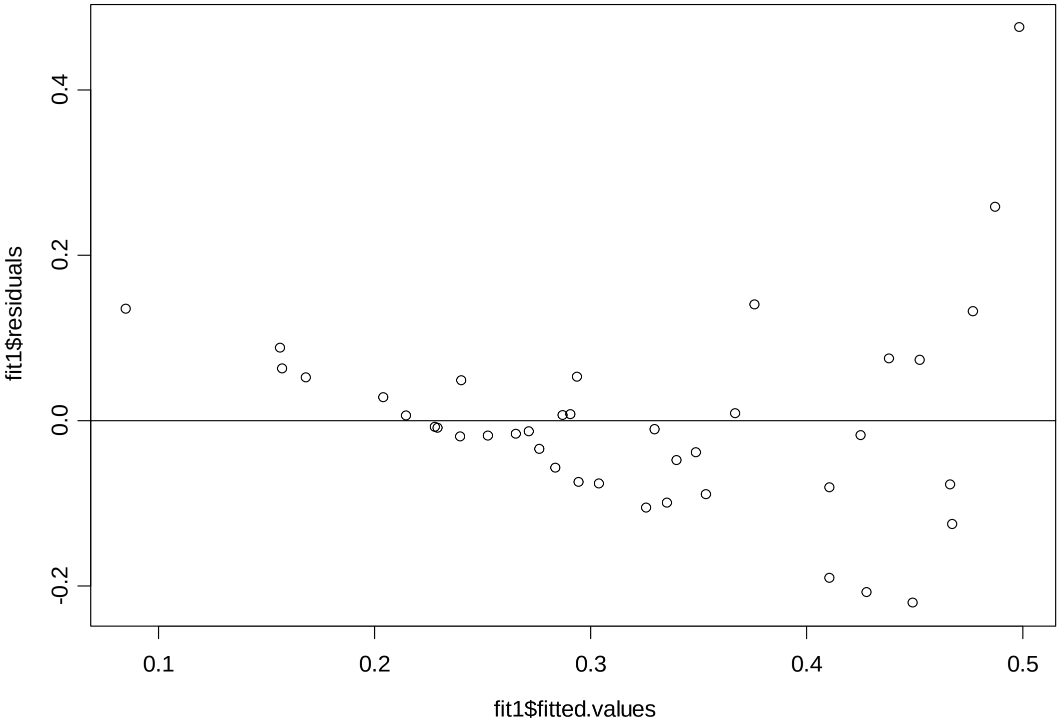
Mn ppm Linear Regression Residual Plot:



Mo ppm

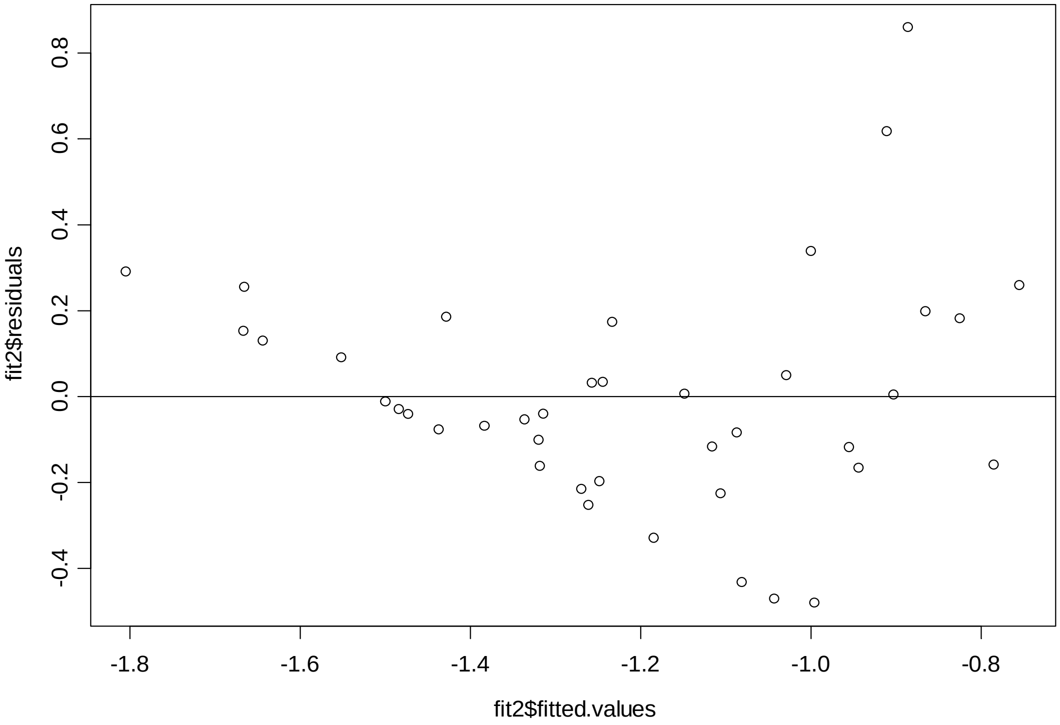
Mo ppm Linear Regression

Mo ppm Linear Regression Residual Plot:



Mo ppm Log Transformation

Mo ppm Log Transformed Residual Plot:



Mo ppm Rank Transformation

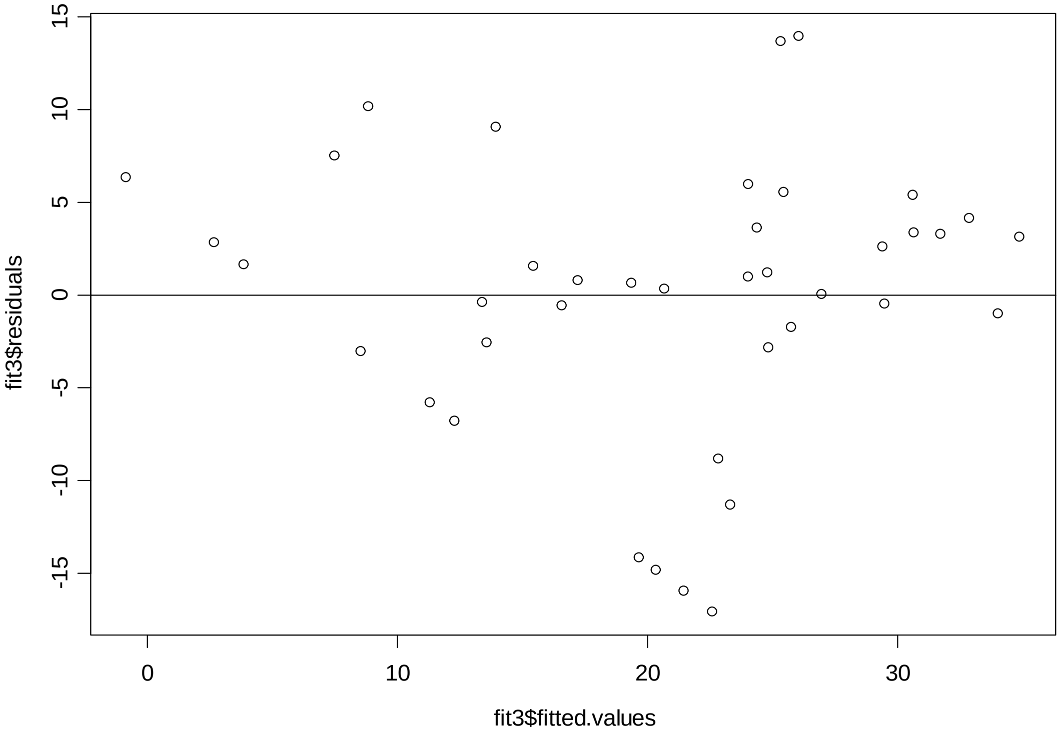
Mo ppm Regression Table:

```
Coefficients       Value Std. Error  t value   P-value
     Intercept  36.3107   3.9797      9.1240   0.0000
         dirNE  -8.8673   6.4406     -1.3768   0.1781
         dirNS  -4.4820   5.8687     -0.7637   0.4506
         dirNW  -8.8251   5.6201     -1.5703   0.1262
     Cdistance  -0.2290   0.0697     -3.2850   0.0025

Residual standard error: 8.151 on 32 degrees of freedom
Multiple R-Squared: 0.5949
F-statistic: 6.712 on 4 and 35 degrees of freedom, the P-
value is 0.00006342
```

Mo ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the Mo ppm in *Cladina mitis* lichen samples. There is strong evidence that the Mo ppm in *Cladina mitis* lichen samples decreases as the distance from mine sites increases (p-value = 0.0025). There is no evidence that the Mo ppm in *Cladina mitis* lichen samples is different in any direction.

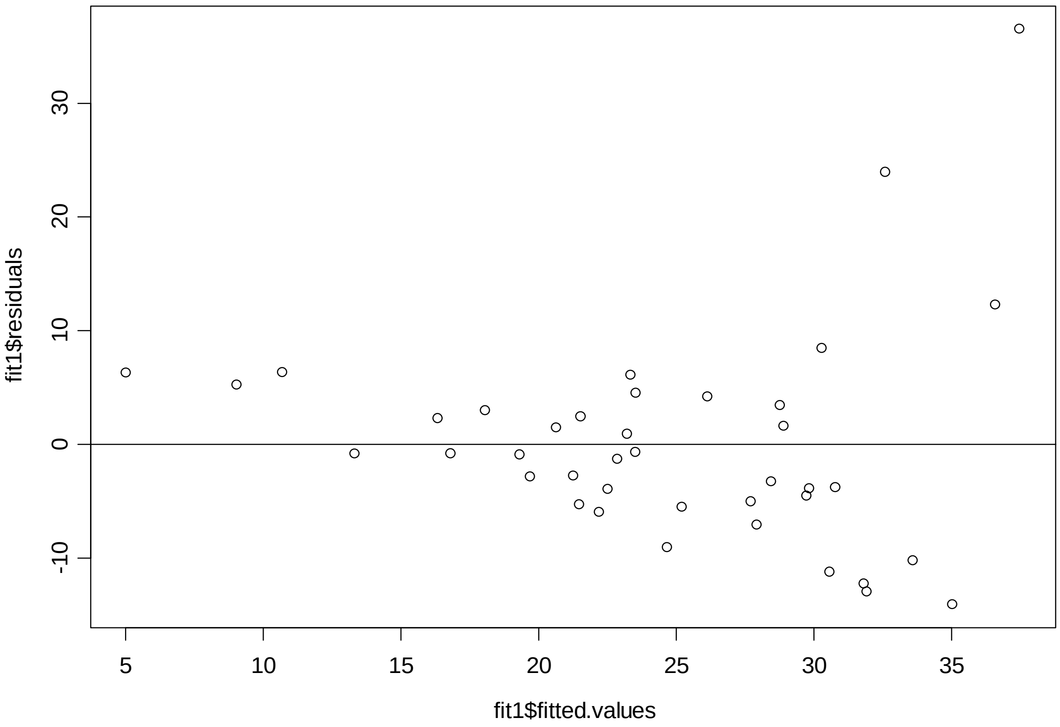
Mo ppm Rank Transformed Residual Plot:



Na ppm

Na ppm Linear Regression

Na ppm Linear Regression Residual Plot:



Na ppm Rank Transformation

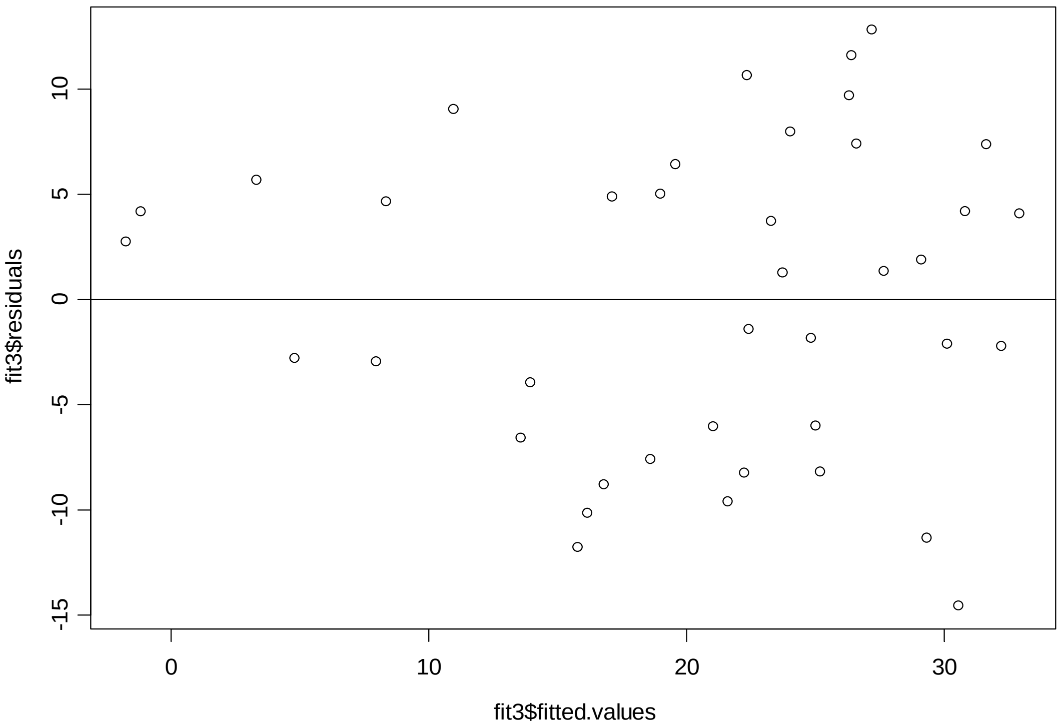
Na ppm Regression Table:

```
Coefficients    Value Std. Error  t value   P-value
   Intercept  26.7649   2.9467      9.0831   0.0000
       dirWE   2.8483   3.6641      0.7774   0.4422
       dirWN   3.3685   3.5510      0.9486   0.3493
       dirWS  10.4713   3.5509      2.9489   0.0056
       dirNS   7.1028   3.6399      1.9514   0.0591
   Cdistance  -0.2123   0.0350     -6.0704   0.0000

Residual standard error: 8.123 on 35 degrees of freedom
Multiple R-Squared: 0.5667
F-statistic: 11.45 on 4 and 35 degrees of freedom, the P-
value is 4.798e-006
```

Na ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the Na ppm in *Cladina mitis* lichen samples. There is strong evidence that the Na ppm in *Cladina mitis* lichen samples decreases as the distance from mine sites increases (p-value < 0.0001). There is evidence that the Na ppm in *Cladina mitis* lichen samples is smaller in the West direction than in the South direction (p-value = 0.0056). There is evidence that the Na ppm in *Cladina mitis* lichen samples is smaller in the North direction than in the South direction (p-value = 0.0591).

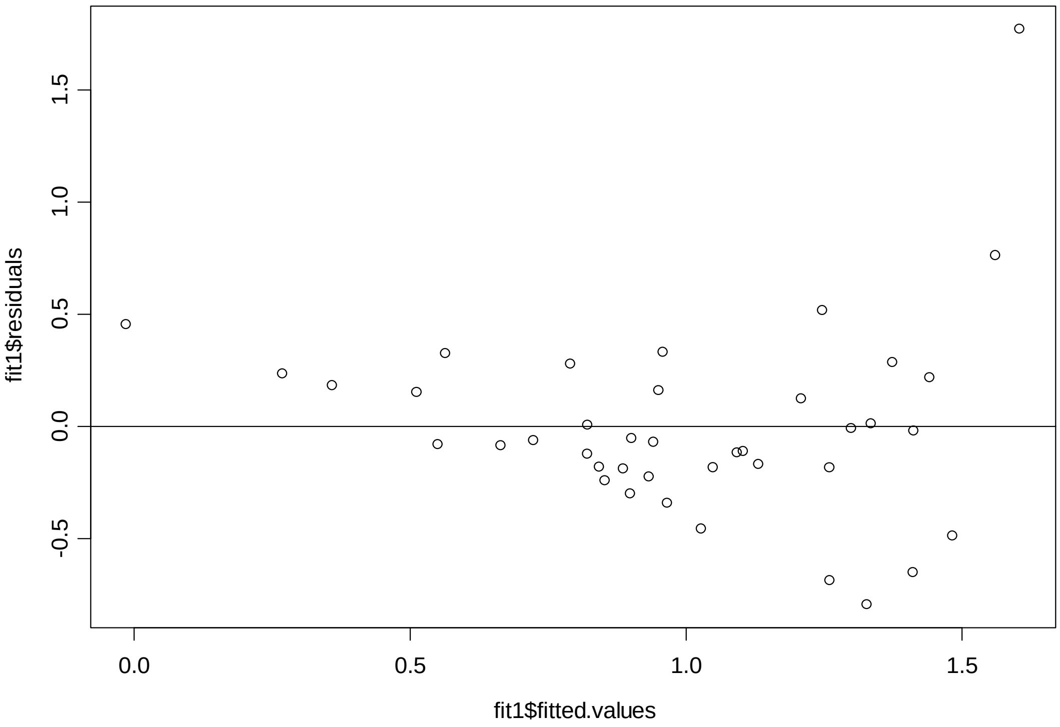
Na ppm Rank Transformed Residual Plot:



Ni ppm

Ni ppm Linear Regression

Ni ppm Linear Regression Residual Plot:



Ni ppm Log Transformation

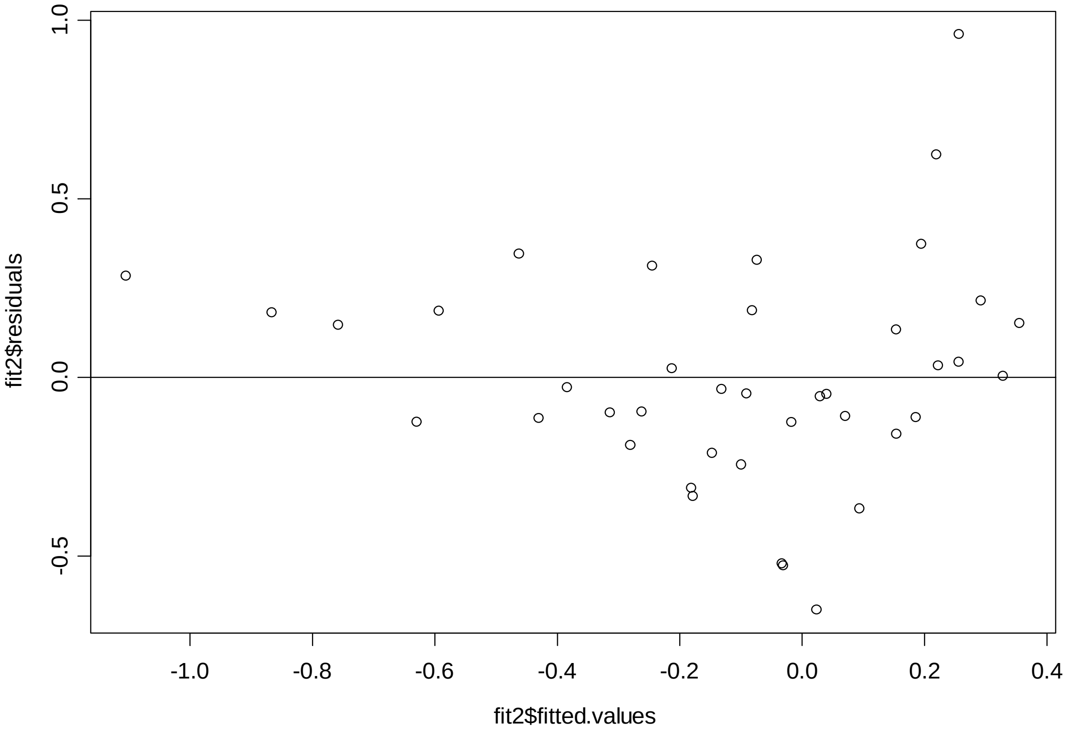
Ni ppm Regression Table:

```
Coefficients     Value Std. Error t value  P-value
     Intercept -0.0490  0.2097    -0.2335  0.8168
         dirEN  0.4496  0.2668     1.6856  0.1016
         dirES  0.2858  0.2755     1.0376  0.3073
         dirEW  0.3781  0.2665     1.4188  0.1656
     Cdistance -0.0016  0.0032    -0.5129  0.6115
dirENCdistance -0.0056  0.0043    -1.2968  0.2040
dirESCdistance -0.0067  0.0043    -1.5600  0.1286
dirEWCdistance -0.0103  0.0042    -2.4587  0.0195

Residual standard error: 0.3376 on 32 degrees of freedom
Multiple R-Squared: 0.5497
F-statistic: 5.581 on 7 and 32 degrees of freedom, the P-
value is 0.0002881
```

Ni ppm Statistical Inference:

There is evidence of an interaction effect between distance from mine sites and direction on the Ni ppm in *Cladina mitis* lichen samples. The Ni ppm decreases more rapidly in the West direction than in the East direction (p-value = 0.0195). There is no evidence that the Ni ppm in *Cladina mitis* lichen samples decreases as the distance from mine sites increases (p-value = 0.6115).

Ni ppm Log Transformed Residual Plot:



P ppm

P ppm Linear Regression

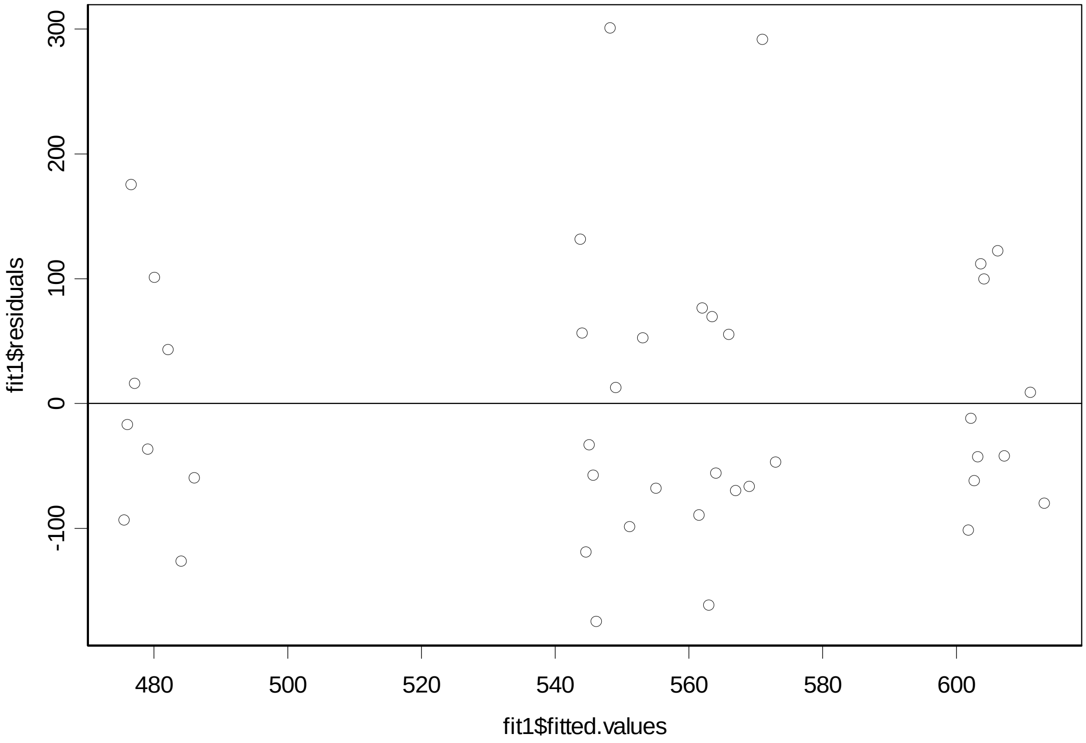
P ppm Regression Table:

```
Coefficients     Value Std. Error   t value    P-value
  Intercept  601.2394   42.1146    14.2763    0.0000
      dirNE -127.1198   52.9981    -2.3986    0.0219
      dirNS  -40.1849   51.3513    -0.7825    0.4392
      dirNW  -58.0430   50.0969    -1.1586    0.2545
  Cdistance    0.0998    0.4933     0.2023    0.8409

Residual standard error: 114.6 on 35 degrees of freedom
Multiple R-Squared: 0.1458
F-statistic: 1.494 on 4 and 35 degrees of freedom, the P-
value is 0.2252
```

P ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the P ppm in *Cladina mitis* lichen samples. There is no evidence that the P ppm in *Cladina mitis* lichen samples decreases as the distance from mine sites increases (p-value = 0.8409). There is evidence that the P ppm in *Cladina mitis* lichen samples is smaller in the East direction than in the North direction (p-value = 0.0219).

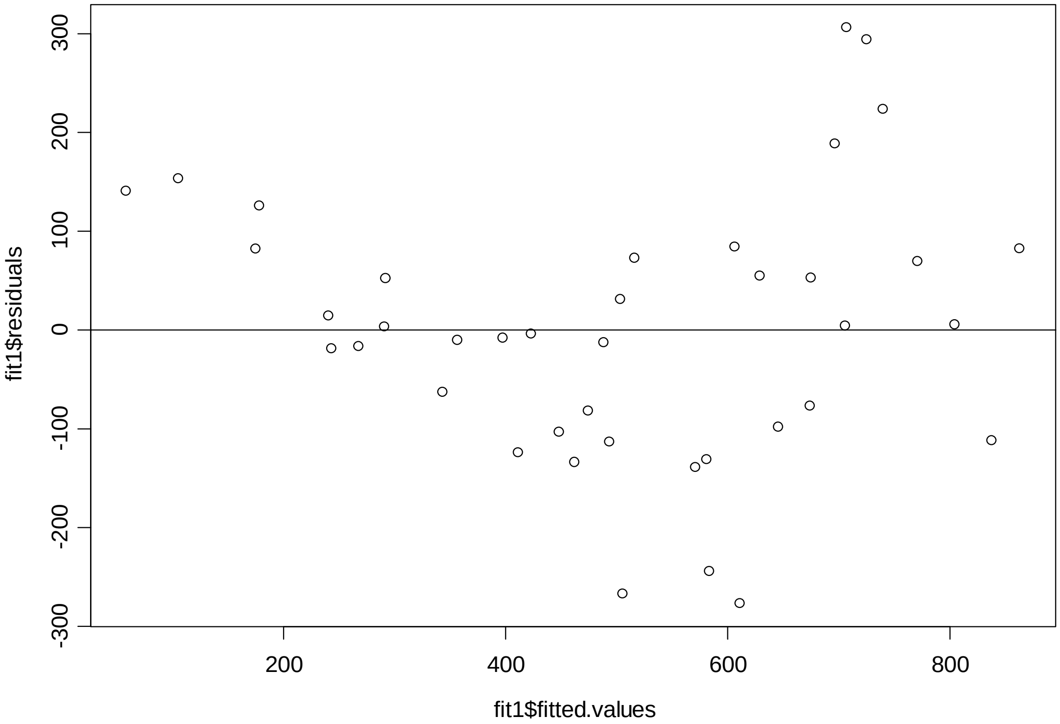
P ppm Linear Regression Residual Plot:



Si ppm

Si ppm Linear Regression

Si ppm Linear Regression Residual Plot:



Si ppm Log Transformation

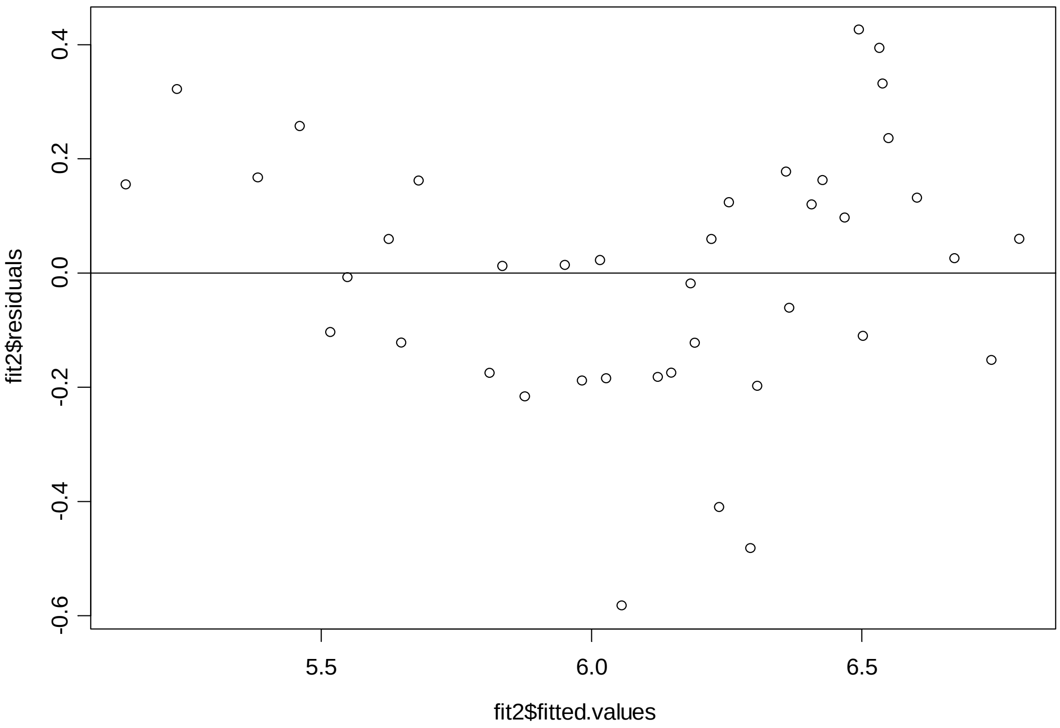
Si ppm Regression Table:

```
Coefficients       Value Std. Error  t value   P-value
     Intercept   6.3545   0.1532    41.4697   0.0000
         dirEN   0.5234   0.1949     2.6856   0.0114
         dirES   0.2431   0.2013     1.2080   0.2359
         dirEW   0.2526   0.1947     1.2973   0.2038
     Cdistance  -0.0067   0.0023    -2.8951   0.0068
dirENCdistance  -0.0070   0.0031    -2.2307   0.0328
dirESCdistance  -0.0028   0.0031    -0.8859   0.3823
dirEWCdistance  -0.0055   0.0031    -1.8026   0.0809

Residual standard error: 0.2466 on 32 degrees of freedom
Multiple R-Squared: 0.7848
F-statistic: 16.67 on 7 and 32 degrees of freedom, the P-
value is 4.794e-009
```

Si ppm Statistical Inference:

There is evidence of an interaction effect between distance from mine sites and direction on the Si ppm in *Cladina mitis* lichen samples. The Si ppm decreases more rapidly in the North direction than in the East direction (p-value = 0.0328). There is evidence that the Si ppm in *Cladina mitis* lichen samples decreases as the distance from mine sites increases (p-value = 0.0068).

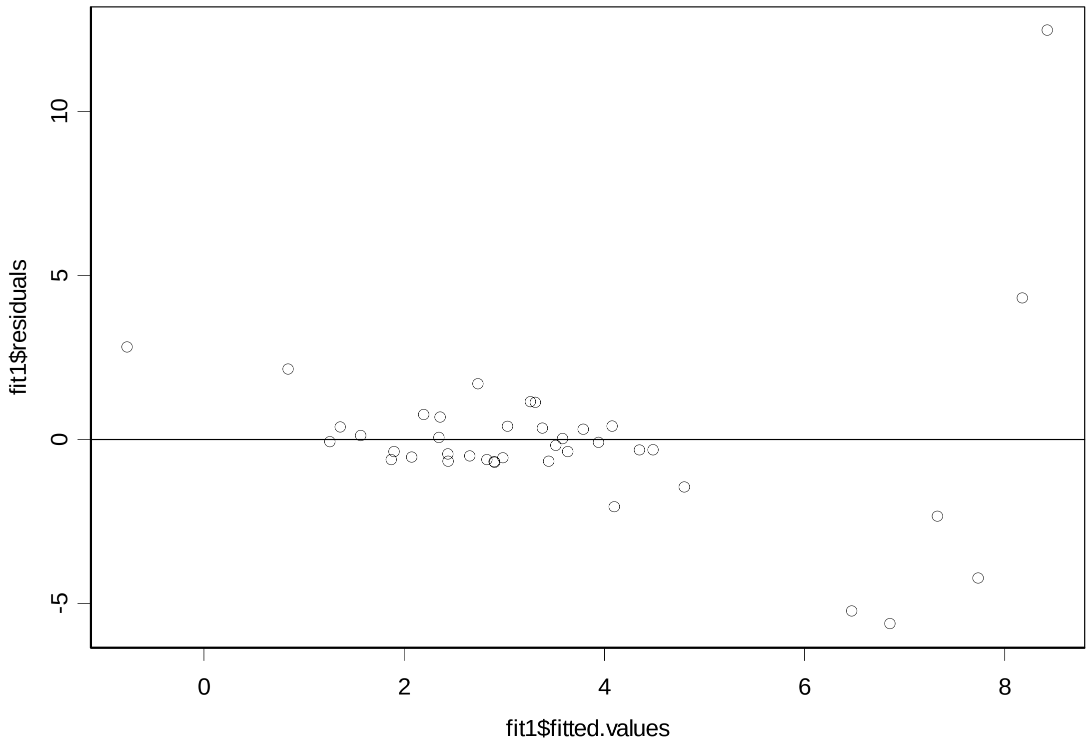
Si ppm Log Transformed Residual Plot:



Sr ppm

Sr ppm Linear Regression

Sr ppm Linear Regression Residual Plot:



Sr ppm Log Transformation

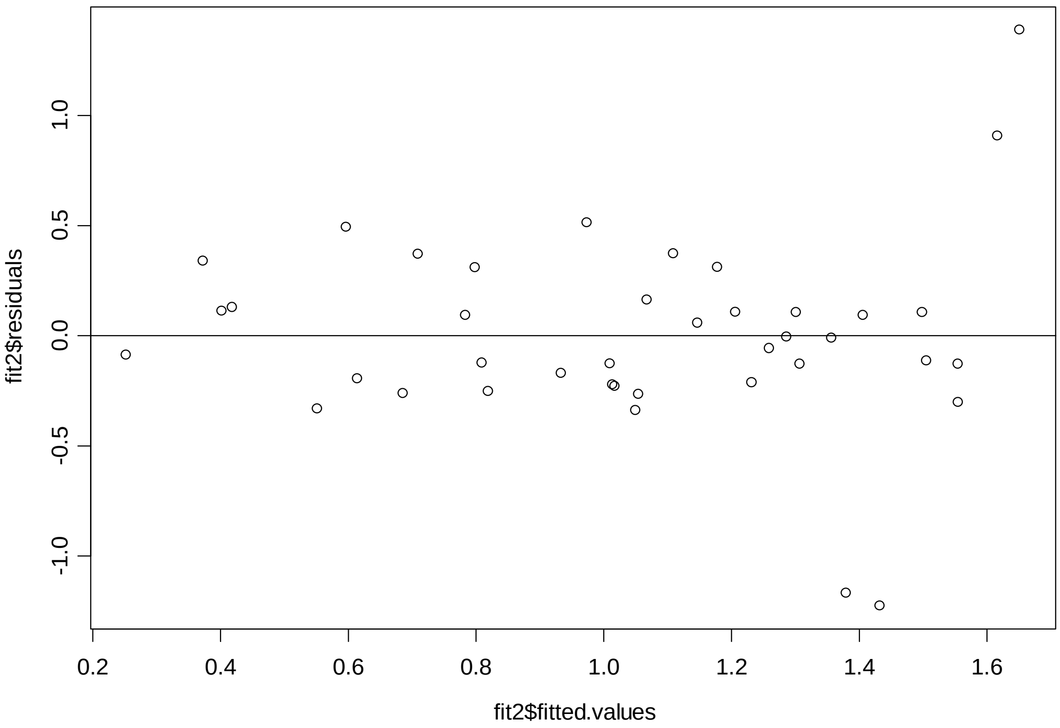
Sr ppm Regression Table:

```
Coefficients  Value Std. Error t value  P-value
  Intercept  1.2254  0.1953     6.2745  0.0000
      dirEN  0.2552  0.2199     1.1606  0.2537
      dirES  0.3176  0.2188     1.4516  0.1555
      dirEW  0.3735  0.2145     1.7414  0.0904
  Cdistance -0.0087  0.0020    -4.2349  0.0002

Residual standard error: 0.4755 on 35 degrees of freedom
Multiple R-Squared: 0.3963
F-statistic: 5.744 on 4 and 35 degrees of freedom, the P-
value is 0.001158
```

Sr ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the Sr ppm in *Cladina mitis* lichen samples. There is strong evidence that the Sr ppm in *Cladina mitis* lichen samples decreases as the distance from mine sites increases (p-value = 0.0002). There is no evidence that the Sr ppm in *Cladina mitis* lichen samples is different in any direction.

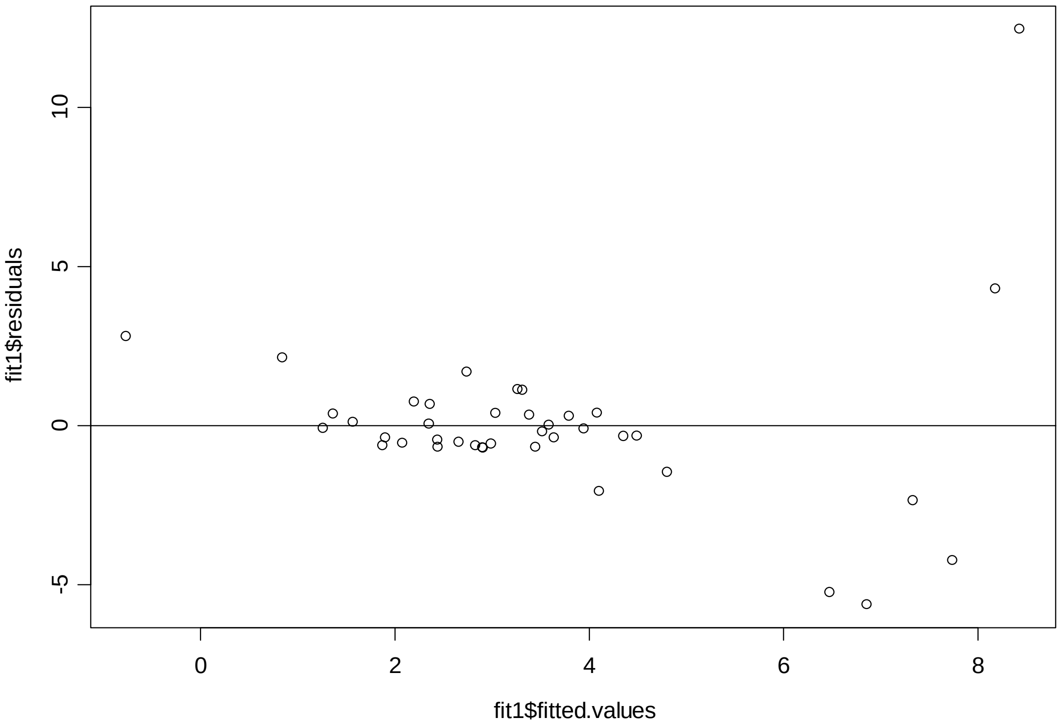
Sr ppm Log Transformed Residual Plot:



Ti ppm

Ti ppm Linear Regression

Ti ppm Linear Regression Residual Plot:



Ti ppm Log Transformation

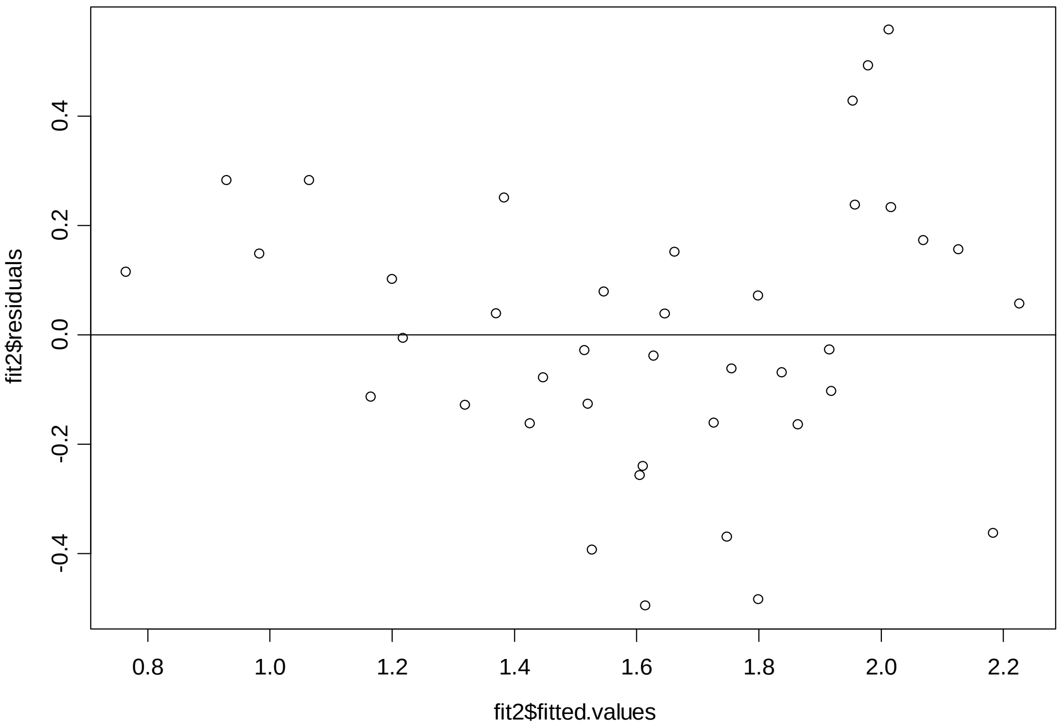
Ti ppm Regression Table:

```
Coefficients      Value Std. Error  t value   P-value
     Intercept   2.2983   0.1334    17.2221   0.0000
         dirNE  -0.5875   0.2160    -2.7201   0.0105
         dirNS  -0.3053   0.1968    -1.5516   0.1306
         dirNW  -0.2188   0.1885    -1.1613   0.2541
     Cdistance  -0.0114   0.0023    -4.8817   0.0000
dirNECdistance   0.0082   0.0035     2.3463   0.0253
dirNSCdistance   0.0037   0.0033     1.1156   0.2729
dirNWCdistance   0.0004   0.0032     0.1366   0.8922
dirEWCdistance  -0.0077   0.0034    -2.2660   0.0303

Residual standard error: 0.2733 on 32 degrees of freedom
Multiple R-Squared: 0.6758
F-statistic: 9.53 on 7 and 32 degrees of freedom, the P-
value is 2.392e-006
```

Ti ppm Statistical Inference:

There is evidence of an interaction effect between distance from mine sites and direction on the Ti ppm in *Cladina mitis* lichen samples. The Ti ppm decreases more rapidly in the North and West directions than in the East direction (p-values = 0.0253 and 0.0303 respectively). There is evidence that the Ti ppm in *Cladina mitis* lichen samples decreases as the distance from mine sites increases (p-value < 0.0001).

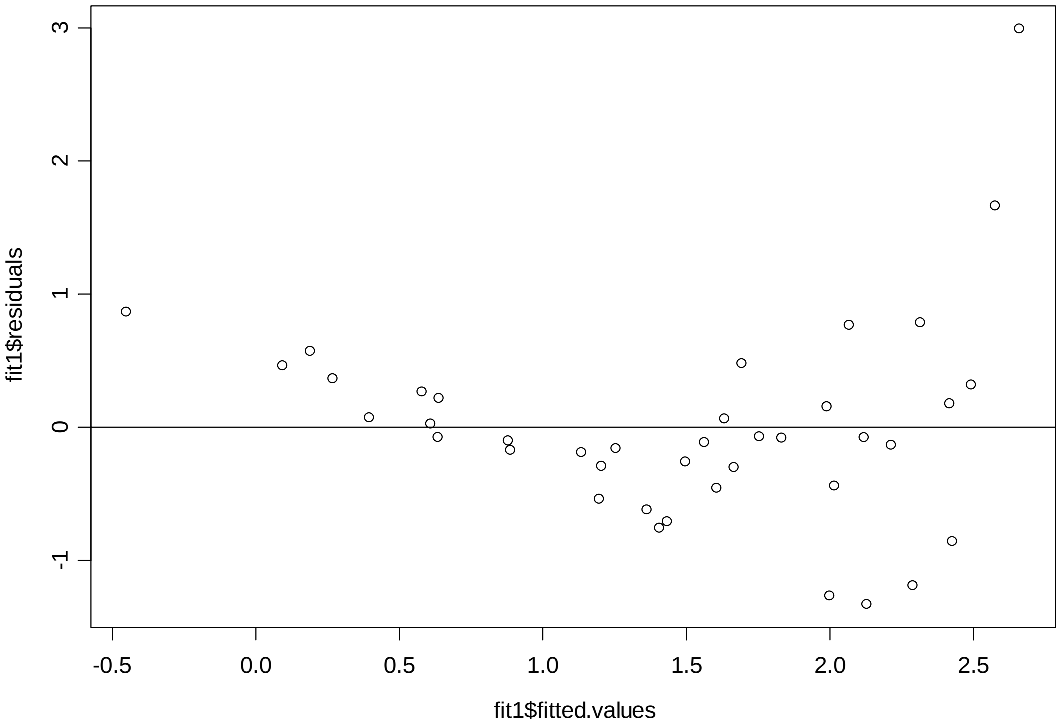
Ti ppm Log Transformed Residual Plot:



V ppm

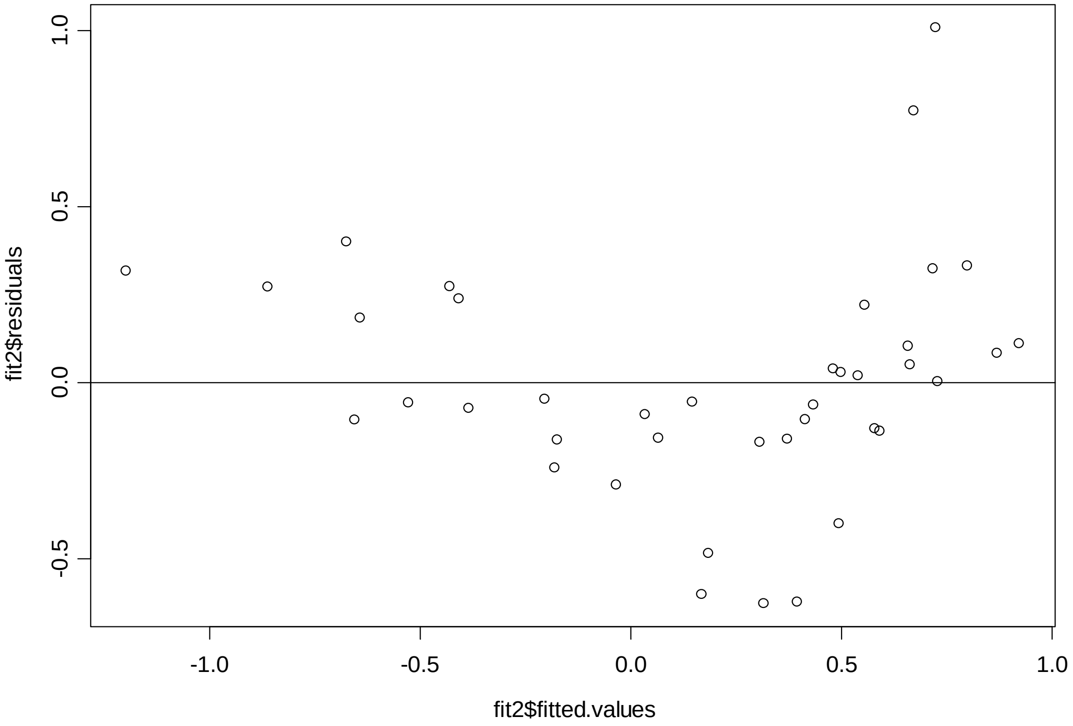
V ppm Linear Regression

V ppm Linear Regression Residual Plot:



V ppm Log Transformation

V ppm Log Transformed Residual Plot:



V ppm Rank Transformation

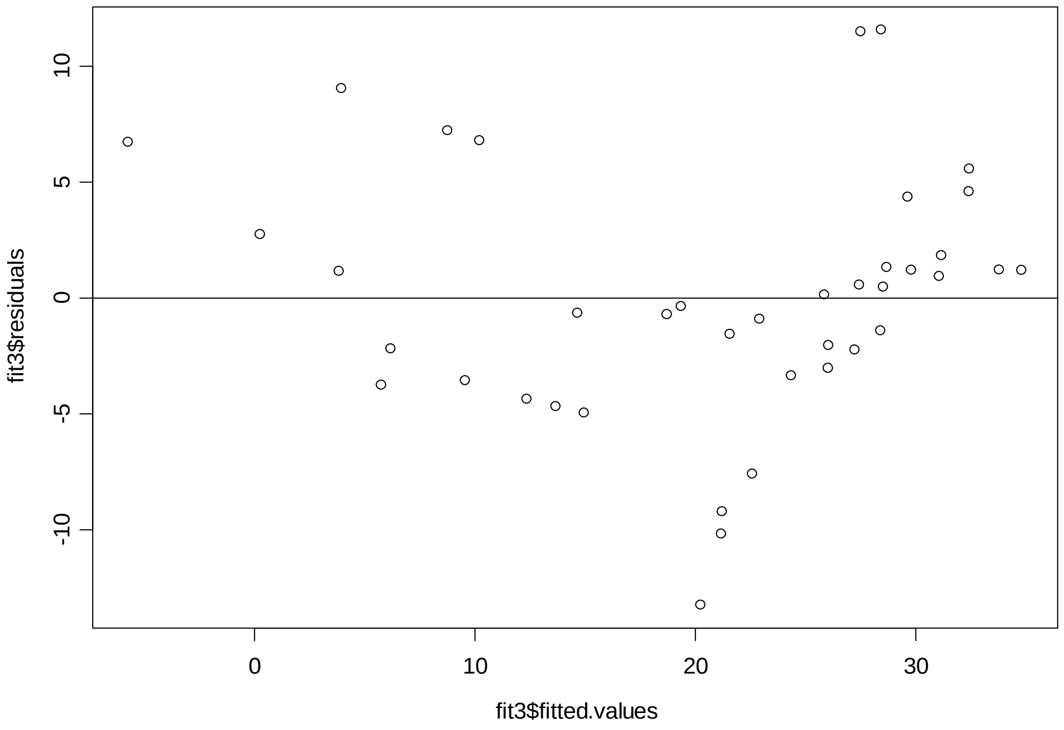
V ppm Regression Table:

```
Coefficients   Value Std. Error  t value   P-value
  Intercept  28.5640   2.1026    13.5852   0.0000
      dirWE   6.5027   2.6145     2.4871   0.0178
      dirWN   7.6302   2.5338     3.0114   0.0048
      dirWS   5.8764   2.5337     2.3193   0.0263
  Cdistance  -0.2642   0.0249   -10.5904   0.0000

Residual standard error: 5.796 on 35 degrees of freedom
Multiple R-Squared: 0.7794
F-statistic: 30.92 on 4 and 35 degrees of freedom, the P-
value is 4.767e-011
```

V ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the V ppm in *Cladina mitis* lichen samples. There is strong evidence that the V ppm in *Cladina mitis* lichen samples decreases as the distance from mine sites increases (p-value < 0.0001). There is evidence that the V ppm in *Cladina mitis* lichen samples is smaller in the West direction than in the North, South, and East directions (p-value = 0.0048, 0.0263, and 0.0178 respectively).

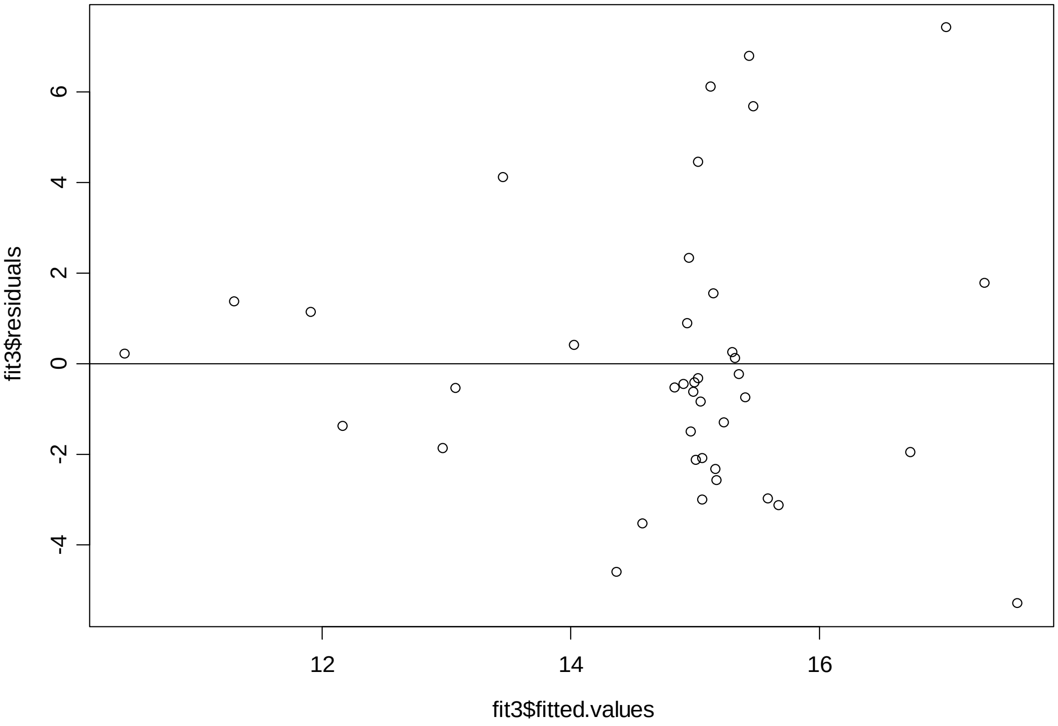
V ppm Rank Transformed Residual Plot:



Zn ppm

Zn ppm Linear Regression

Zn ppm Linear Regression Residual Plot:



Zn ppm Log Transformation

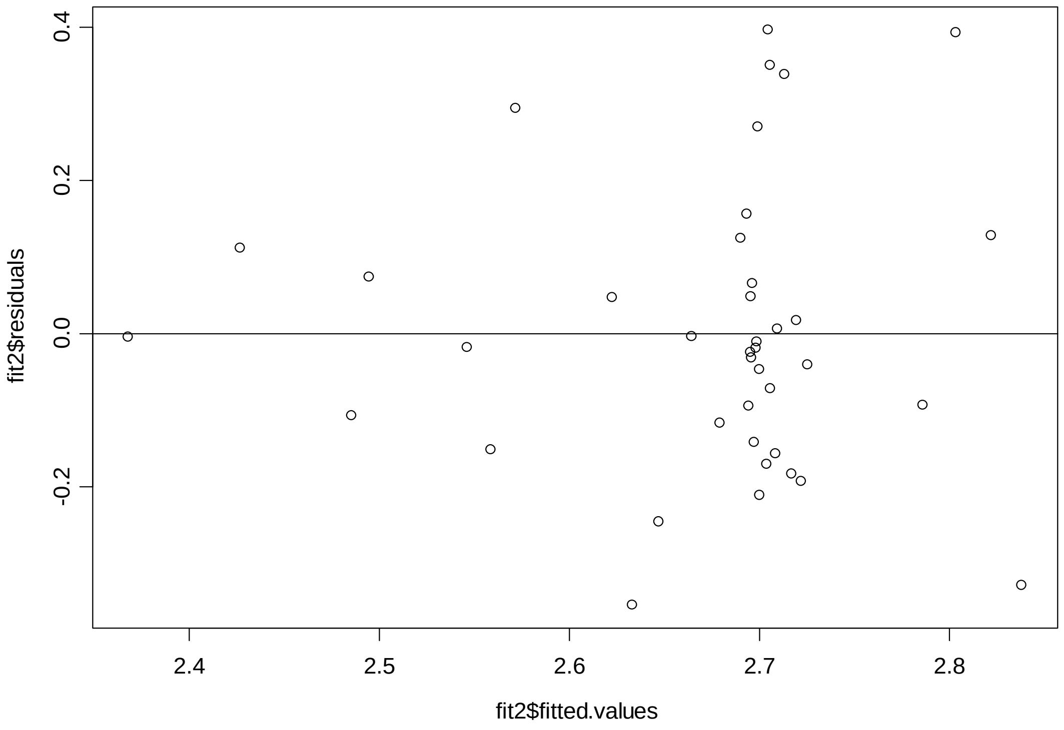
Zn ppm Regression Table:

```
Coefficients   Value Std. Error  t value   P-value
  Intercept   2.6489   0.0751    35.2629   0.0000
      dirWE   0.1327   0.0934     1.4205   0.1643
      dirWN   0.1153   0.0905     1.2742   0.2110
      dirWS   0.1245   0.0905     1.3757   0.1777
  Cdistance  -0.0014   0.0009    -1.5579   0.1282

Residual standard error: 0.2071 on 35 degrees of freedom
Multiple R-Squared: 0.1274
F-statistic: 1.278 on 4 and 35 degrees of freedom, the P-
value is 0.2974
```

Zn ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the Zn ppm in *Cladina mitis* lichen samples. There is no evidence that the Zn ppm in *Cladina mitis* lichen samples decreases as the distance from mine sites increases (p-value = 0.1282). There is no evidence that the Zn ppm in *Cladina mitis* lichen samples is different in any direction.

Zn ppm Log Transformed Residual Plot:



VI. *Evernia mesomorpha*

N%

N% Linear Regression

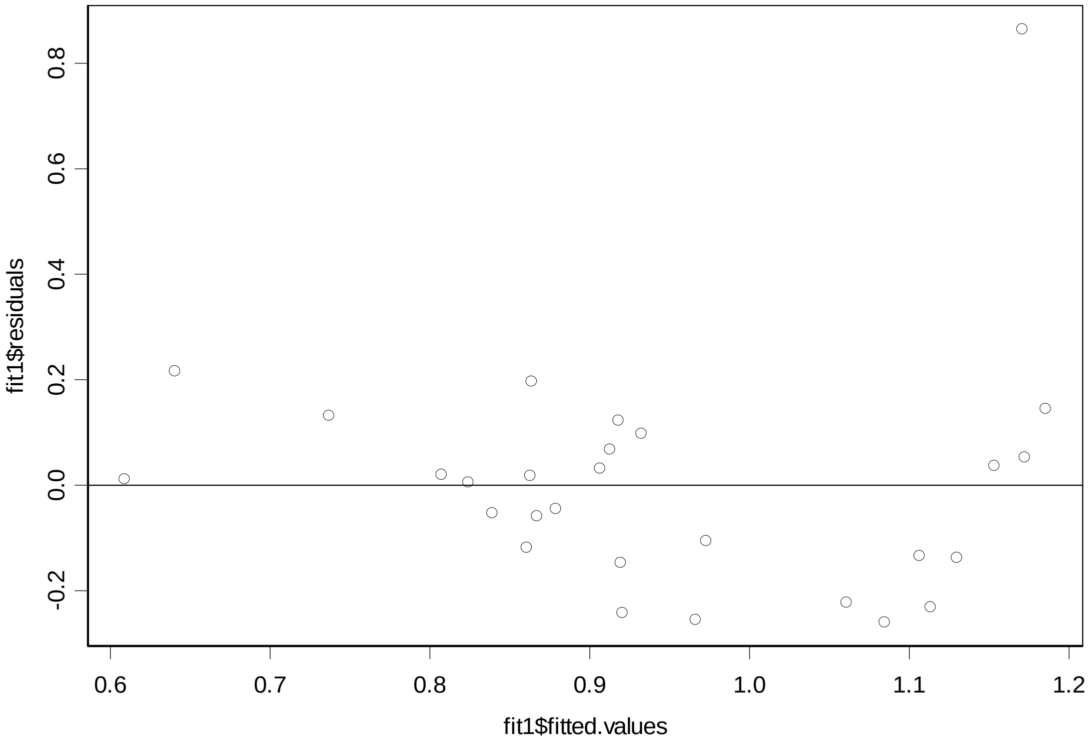
N% Regression Table:

```
Coefficients  Value Std. Error t value  P-value
  Intercept  0.8874  0.1205     7.3622  0.0000
      dirWE  0.3008  0.1588     1.8937  0.0709
      dirWN  0.2162  0.1396     1.5491  0.1350
      dirWS  0.1543  0.1588     0.9722  0.3411
  Cdistance -0.0026  0.0013    -2.0391  0.0531

Residual standard error: 0.2556 on 23 degrees of freedom
Multiple R-Squared: 0.2291
F-statistic: 1.708 on 4 and 23 degrees of freedom, the P-
value is 0.1825
```

N% Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the percent of N in *Evernia mesomorpha* lichen samples. There is evidence that the percent of N in *Evernia mesomorpha* lichen samples decreases as the distance from mine sites increases (p-value = 0.0531). There is no evidence that the percent of N in *Evernia mesomorpha* lichen samples is different in any direction

N% Linear Regression Residual Plot:



S%

S% Linear Regression:

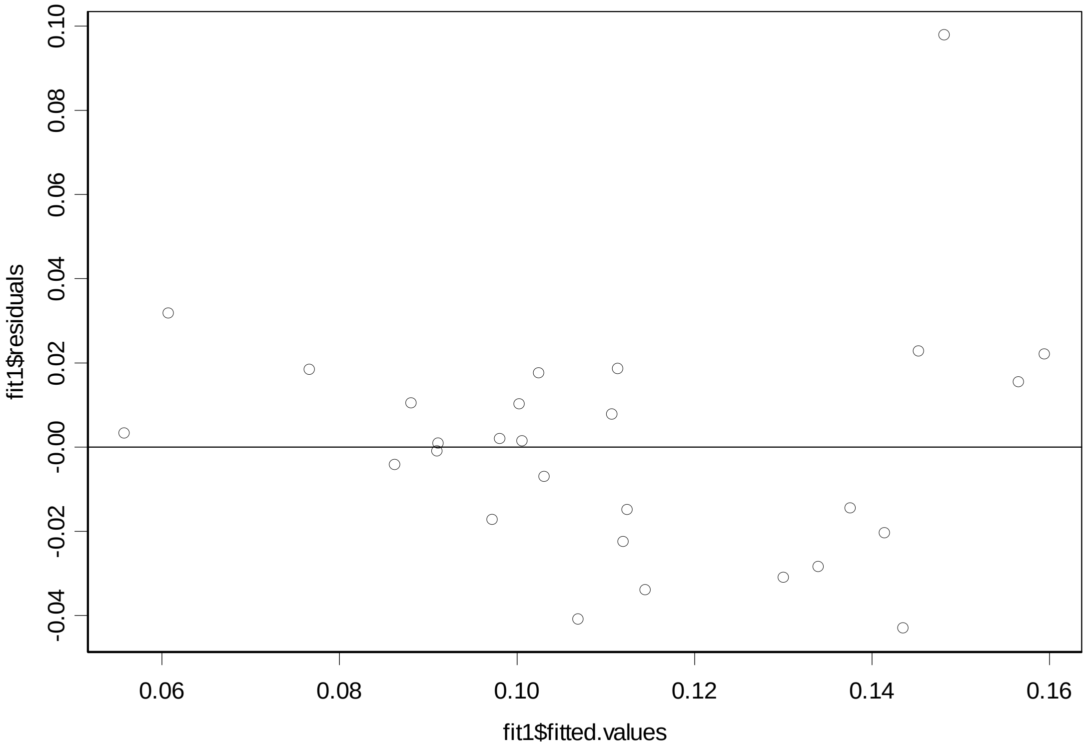
S% Regression Table:

```
Coefficients  Value Std. Error t value  P-value
  Intercept  0.1029  0.0154     6.6895  0.0000
      dirWE  0.0553  0.0203     2.7294  0.0120
      dirWN  0.0396  0.0178     2.2234  0.0363
      dirWS  0.0344  0.0203     1.7000  0.1026
  Cdistance -0.0005  0.0002    -3.3339  0.0029

Residual standard error: 0.03261 on 23 degrees of freedom
Multiple R-Squared: 0.4075
F-statistic: 3.955 on 4 and 23 degrees of freedom, the P-
value is 0.01382
```

S% Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the percent of S in *Evernia mesomorpha* lichen samples. There is strong evidence that the percent of S in *Evernia mesomorpha* lichen samples decreases as the distance from mine sites increases (p-value = 0.0029). There is evidence that the percent of S in *Evernia mesomorpha* lichen samples is greater in the East and North directions than in the West direction (p-value = 0.0120 and 0.0363 respectively).

S% Linear Regression Residual Plot:



Al ppm

Al ppm Linear Regression

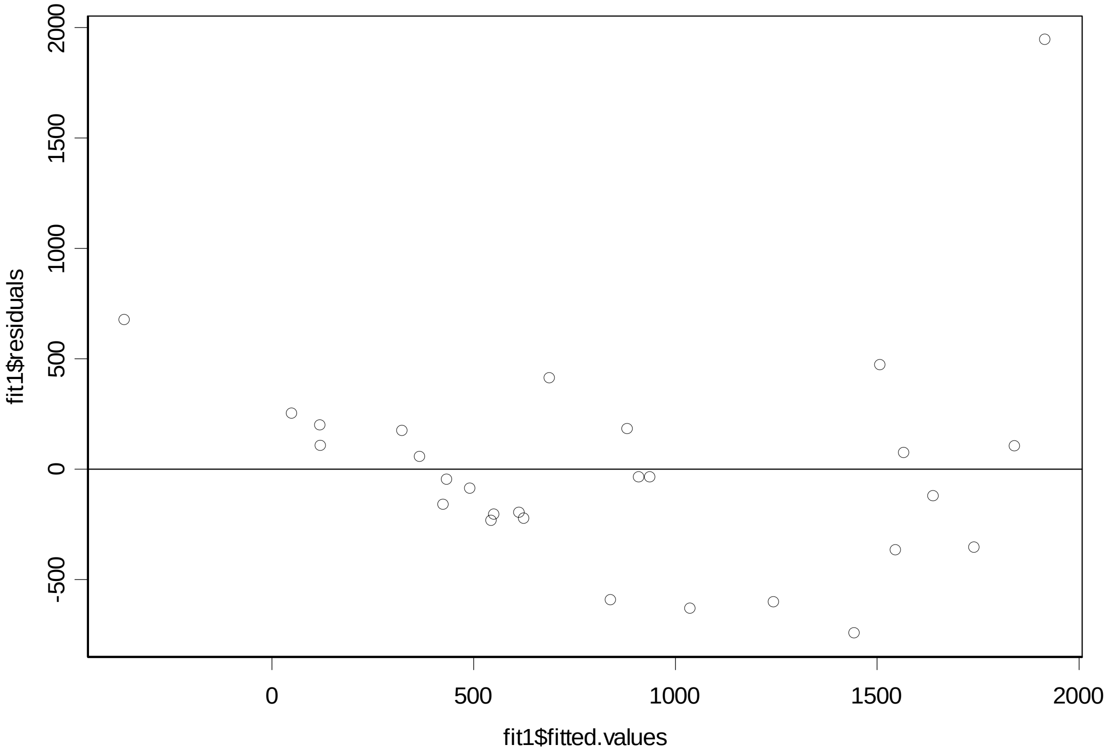
Al ppm Regression Table:

```
Coefficients     Value Std. Error   t value    P-value
  Intercept  894.1478  284.6893      3.1408     0.0046
      dirWE  778.8757  375.0951      2.0765     0.0492
      dirWN  832.1107  329.6017      2.5246     0.0189
      dirWS  544.4184  374.9431      1.4520     0.1600
  Cdistance  -13.3286    3.0219     -4.4107     0.0002

Residual standard error: 603.7 on 23 degrees of freedom
Multiple R-Squared: 0.507
F-statistic: 5.913 on 4 and 23 degrees of freedom, the P-
value is 0.002006
```

Al ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the Al ppm in *Evernia mesomorpha* lichen samples. There is strong evidence that the Al ppm in *Evernia mesomorpha* lichen samples declines as the distance from mine sites increases (p-value = 0.0002). There is evidence that the Al ppm in *Evernia mesomorpha* lichen samples is smaller in the West direction than in the North and East directions (p-value = 0.0189 and 0.0492 respectively).

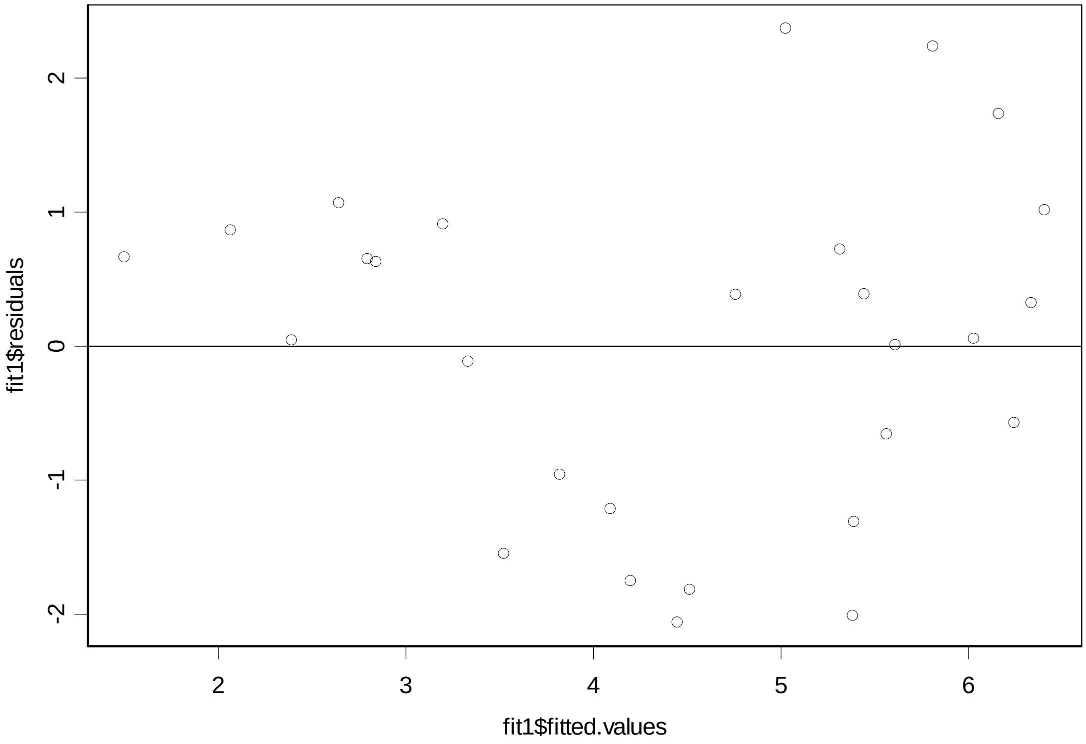
Al ppm Linear Regression Residual Plot:



B ppm

B ppm Linear Regression

B ppm Linear Regression Residual Plot



B ppm Log Transformation

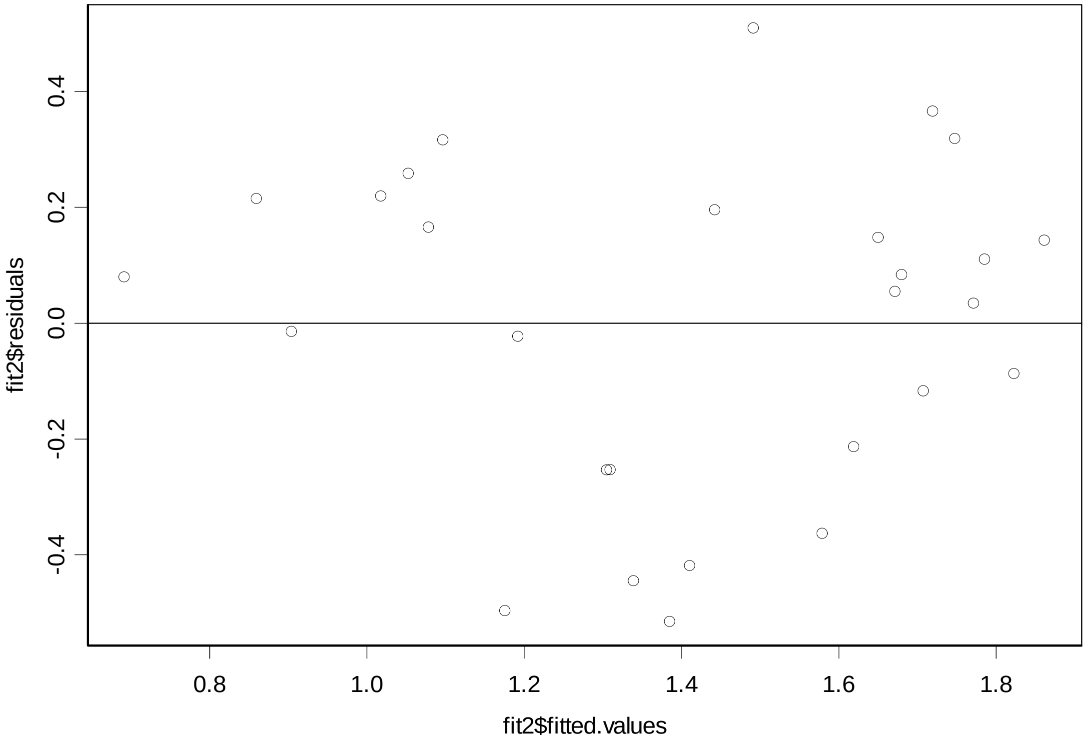
B ppm Regression Table:

```
Coefficients   Value Std. Error  t value   P-value
  Intercept   1.8382   0.1564    11.7569   0.0000
      dirEN  -0.0073   0.1595    -0.0455   0.9641
      dirES   0.0728   0.1805     0.4036   0.6903
      dirEW  -0.2487   0.1942    -1.2807   0.2131
  Cdistance  -0.0083   0.0016    -5.2790   0.0000

Residual standard error: 0.3126 on 23 degrees of freedom
Multiple R-Squared: 0.5526
F-statistic: 7.103 on 4 and 23 degrees of freedom, the P-
value is 0.0007065
```

B ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the B ppm in *Evernia mesomorpha* lichen samples. There is strong evidence that the B ppm in *Evernia mesomorpha* lichen samples decreases as the distance from mine sites increases (p-value < 0.0001). There is no evidence that the B ppm in *Evernia mesomorpha* lichen samples is different in any direction.

B ppm Log Transformed Residual Plot



Ba ppm

Ba ppm Linear Regression

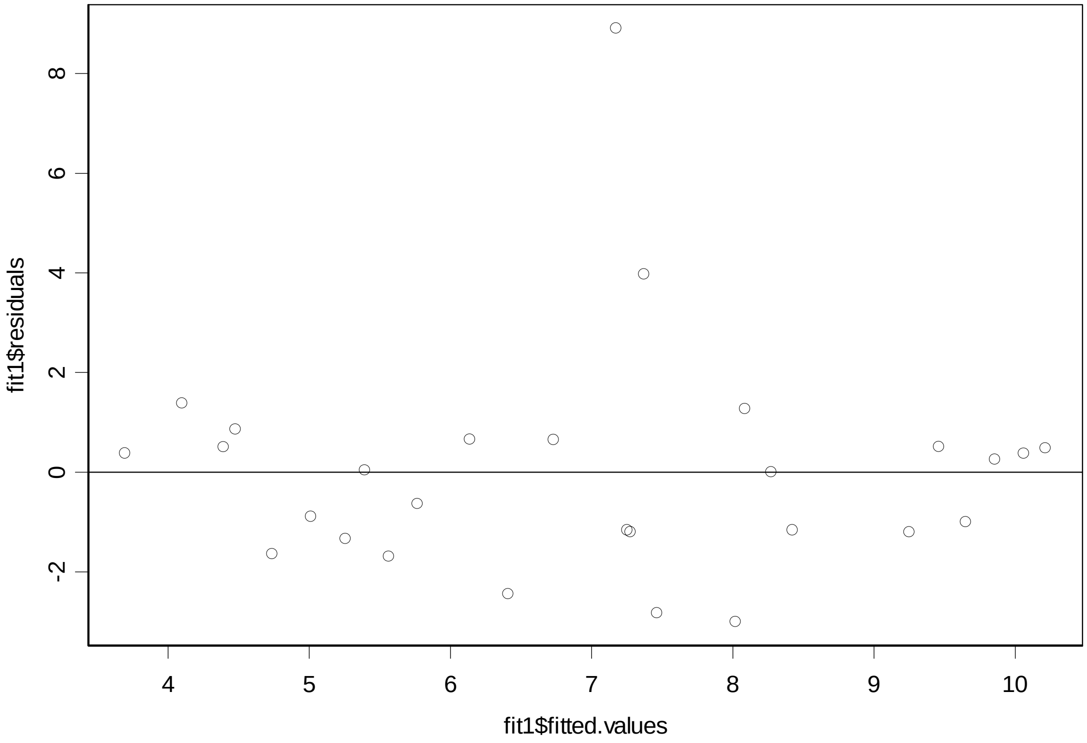
Ba ppm Regression Table:

```
Coefficients  Value Std. Error t value  P-value
  Intercept  5.9229  1.2185     4.8607  0.0001
      dirWE  2.0422  1.6055     1.2720  0.2161
      dirWN  4.0842  1.4108     2.8950  0.0082
      dirWS  2.4298  1.6048     1.5141  0.1436
  Cdistance -0.0310  0.0129    -2.3979  0.0250

Residual standard error: 2.584 on 23 degrees of freedom
Multiple R-Squared: 0.3701
F-statistic: 3.379 on 4 and 23 degrees of freedom, the P-
value is 0.02583
```

Ba ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the Ba ppm in *Evernia mesomorpha* lichen samples. There is strong evidence that the Ba ppm in *Evernia mesomorpha* lichen samples decreases as the distance from mine sites increases (p-value = 0.0250). There is evidence that the Ba ppm in *Evernia mesomorpha* lichen samples is greater in the North direction than in the West direction (p-value = 0.0082).

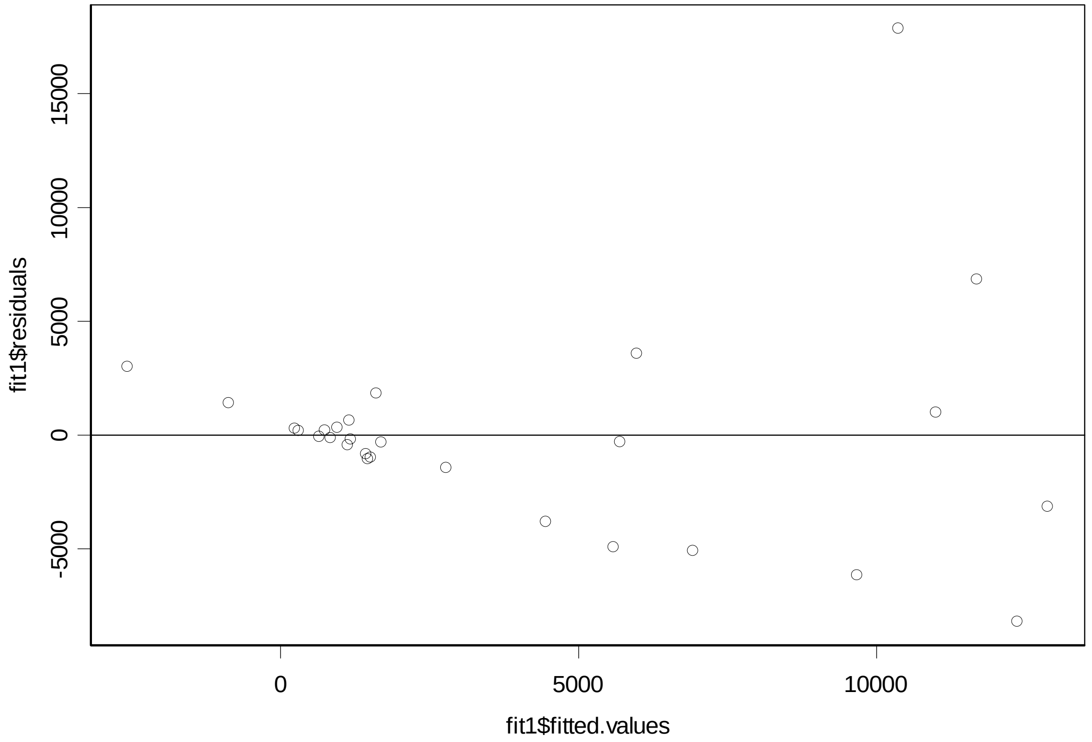
Ba ppm Linear Regression Residual Plot:



Ca ppm

Ca ppm Linear Regression

Ca ppm Linear Regression Residual Plot:



Ca ppm Log Transformation

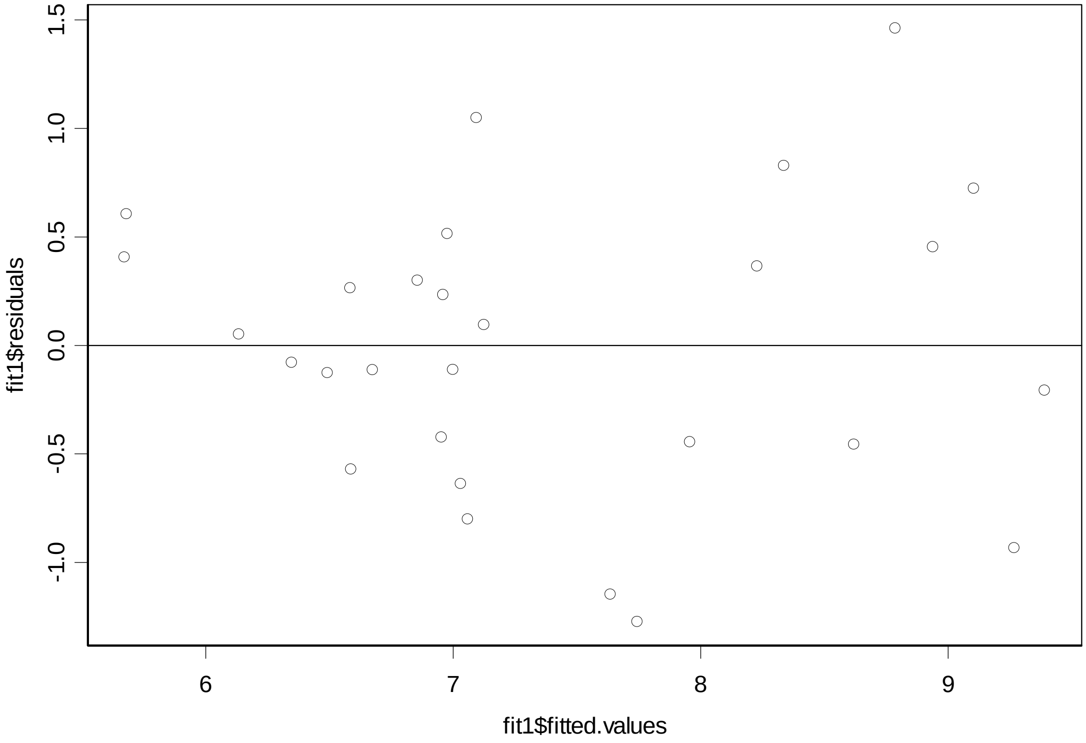
Ca ppm Regression Table:

```
Coefficients   Value Std. Error  t value   P-value
  Intercept   7.6537   0.4077    18.7715   0.0000
      dirWE   0.6627   0.5372     1.2336   0.2298
      dirWN   1.3800   0.4721     2.9233   0.0076
      dirWS   0.3196   0.5370     0.5953   0.5575
  Cdistance  -0.0207   0.0043    -4.7897   0.0001

Residual standard error: 0.8646 on 23 degrees of freedom
Multiple R-Squared: 0.5965
F-statistic: 8.5 on 4 and 23 degrees of freedom, the P-
value is 0.0002306
```

Ca ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the Ca ppm in *Evernia mesomorpha* lichen samples. There is strong evidence that the Ca ppm in *Evernia mesomorpha* lichen samples decreases with increasing distance from mine sites (p-value = 0.0001). There is evidence that the Ca ppm in *Evernia mesomorpha* lichen samples is smaller in the West direction than in the North direction (p-value = 0.0076).

Ca ppm Log Transformed Residual Plot:



Cd ppm

Cd ppm Linear Regression

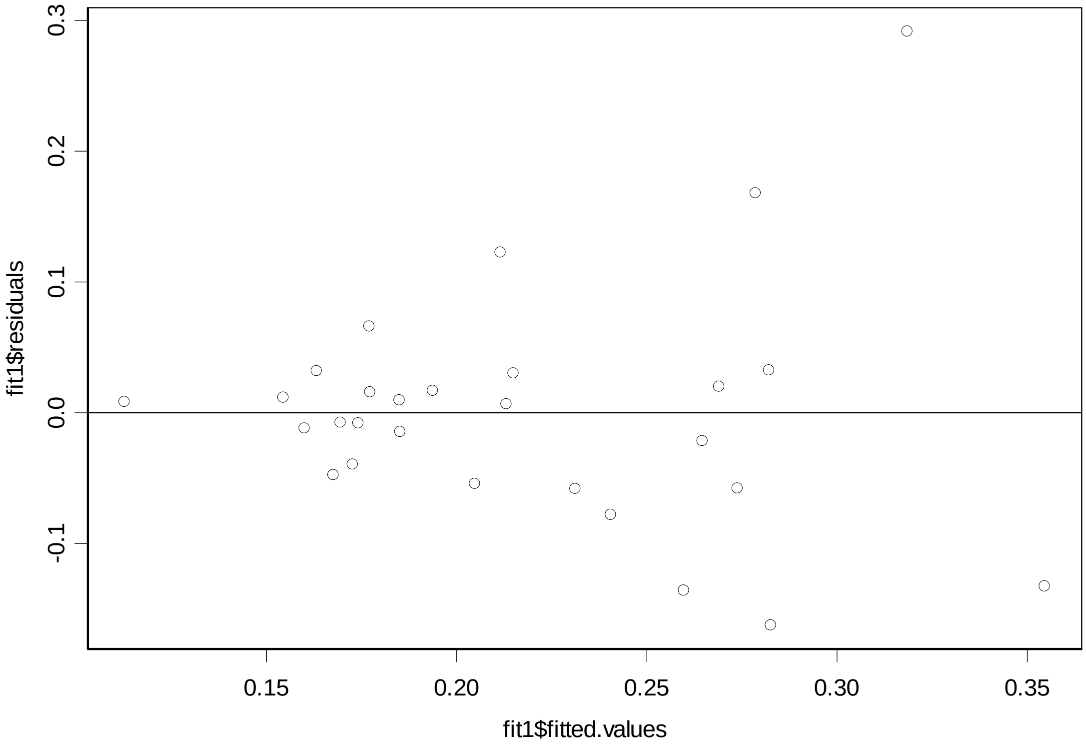
Cd ppm Regression Table:

```
Coefficients Value Std. Error t value P-value
  Intercept 0.1602 0.0518     3.0943  0.0051
      dirWE 0.0333 0.0682     0.4882  0.6300
      dirWN 0.0829 0.0599     1.3826  0.1801
      dirWS 0.0802 0.0682     1.1765  0.2514
  Cdistance 0.0000 0.0005     0.0185  0.9854

Residual standard error: 0.1098 on 23 degrees of freedom
Multiple R-Squared: 0.09859
F-statistic: 0.6289 on 4 and 23 degrees of freedom, the P-
value is 0.6468
```

Cd ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the Cd ppm in *Evernia mesomorpha* lichen samples. There is no evidence that the Cd ppm in *Evernia mesomorpha* lichen samples decreases as the distance from mine sites increases (p-value = 0.9854). There is no evidence that the Cd ppm in *Evernia mesomorpha* lichen samples is different in any direction.

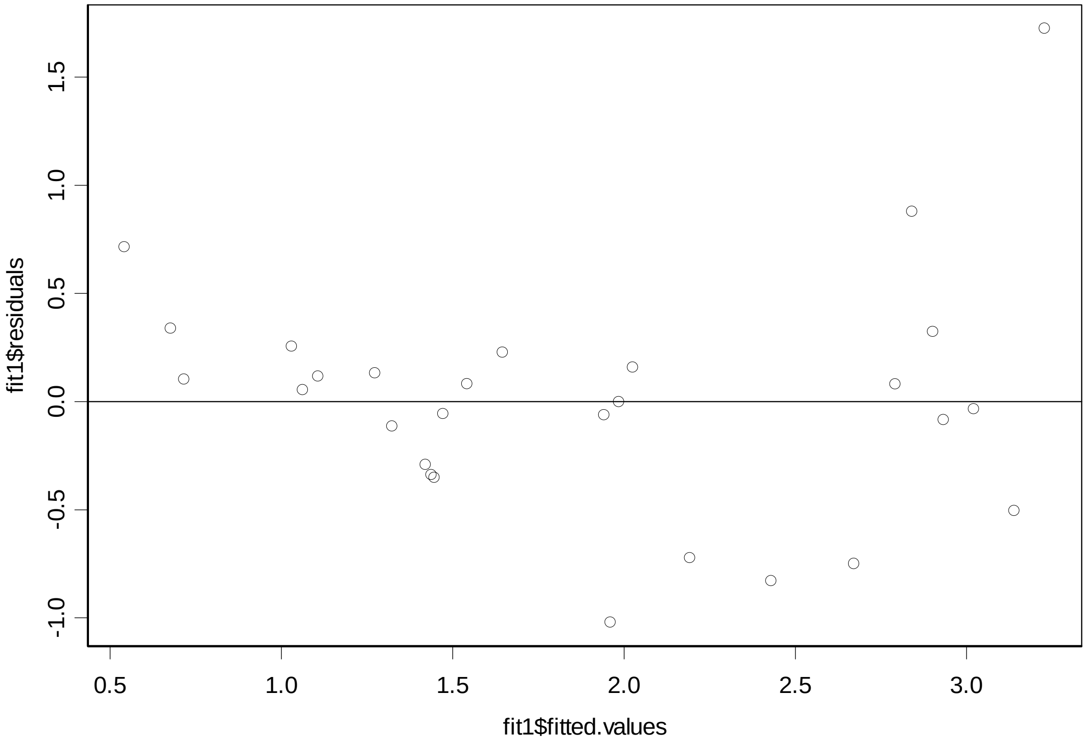
Cd ppm Linear Regression Residual Plot:



Cr ppm

Cr ppm Linear Regression

Cr ppm Linear Regression Residual Plot:



Cr ppm Log Transformation

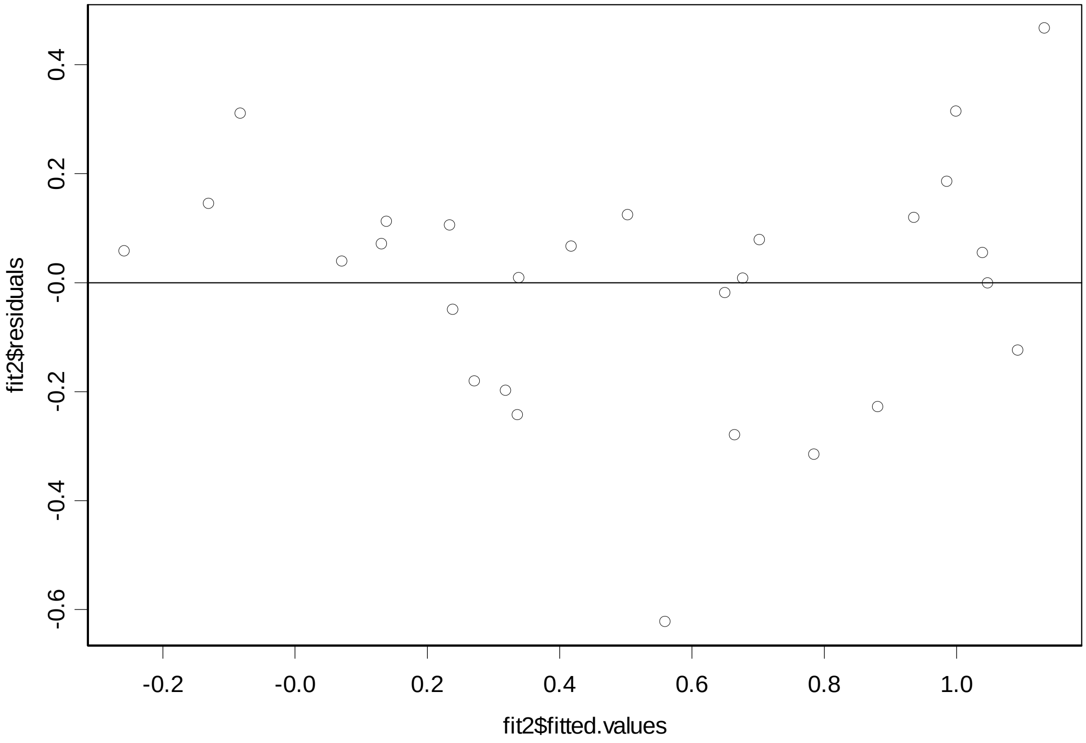
Cr ppm Regression Table:

```
Coefficients  Value Std. Error  t value P-value
  Intercept  0.5176  0.1252     4.1355  0.0004
      dirWE  0.5176  0.1649     3.1393  0.0046
      dirWN  0.6098  0.1449     4.2087  0.0003
      dirWS  0.4636  0.1648     2.8124  0.0099
  Cdistance -0.0091  0.0013    -6.8794  0.0000

Residual standard error: 0.2654 on 23 degrees of freedom
Multiple R-Squared: 0.7164

F-statistic: 14.52 on 4 and 23 degrees of freedom, the P-
value is 4.702e-006
```

Cr ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the Cr ppm in *Evernia mesomorpha* lichen samples. There is strong evidence that the Cr ppm in *Evernia mesomorpha* lichen samples decreases as the distance from mine sites increases (p-value < 0.0001). There is evidence that the Cr ppm in *Evernia mesomorpha* lichen samples is greater in the East, North, and South directions than in the West direction (p-values = 0.0046, 0003, and 0099 respectively).

Cr ppm Log Transformed Residual Plot:



Cu ppm

Cu ppm Linear Regression

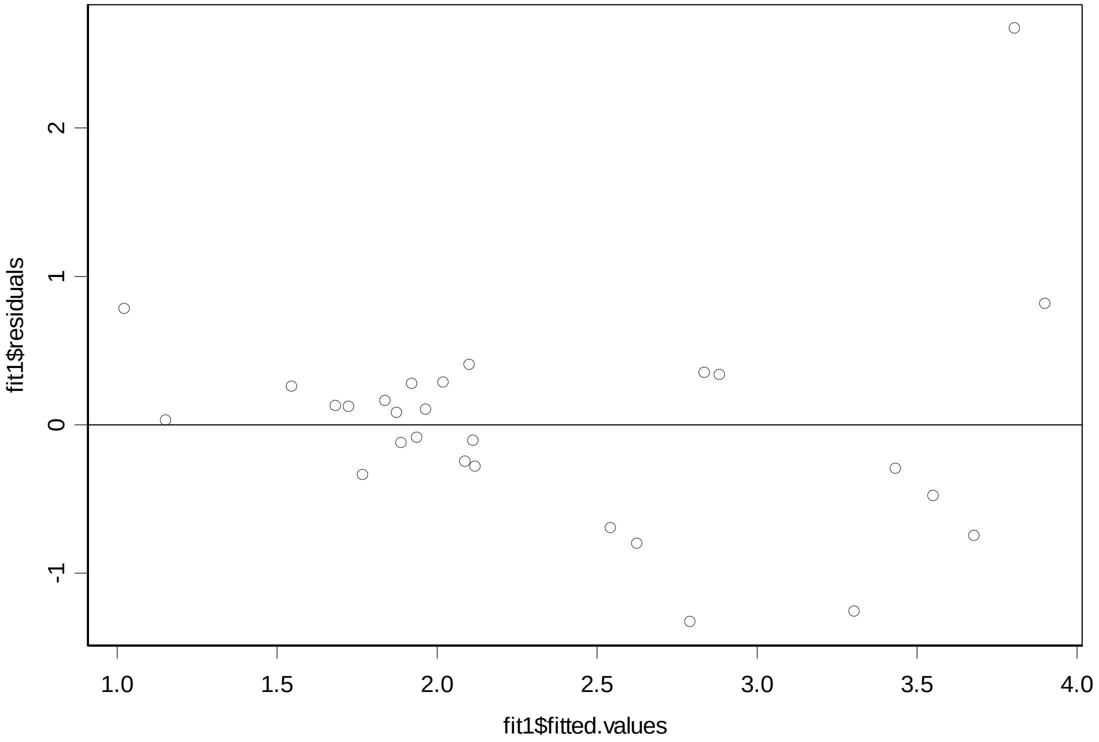
Cu ppm Regression Table:

```
Coefficients  Value Std. Error t value  P-value
   Intercept  2.1018  0.4219     4.9813  0.0000
       dirWE  1.0473  0.5559     1.8838  0.0723
       dirWN  1.4178  0.4885     2.9023  0.0080
       dirWS  0.6867  0.5557     1.2357  0.2290
   Cdistance -0.0138  0.0045    -3.0814  0.0053

Residual standard error: 0.8947 on 23 degrees of freedom
Multiple R-Squared: 0.4239
F-statistic: 4.23 on 4 and 23 degrees of freedom, the P-
value is 0.01035
```

Cu ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the Cu ppm in *Evernia mesomorpha* lichen samples. There is strong evidence that the Cu ppm in *Evernia mesomorpha* lichen samples decreases as the distance from mine sites increases (p-value = 0.0053). There is evidence that the Cu ppm in *Evernia mesomorpha* lichen samples is smaller in the West direction than in the North direction (p-value = 0.0080).

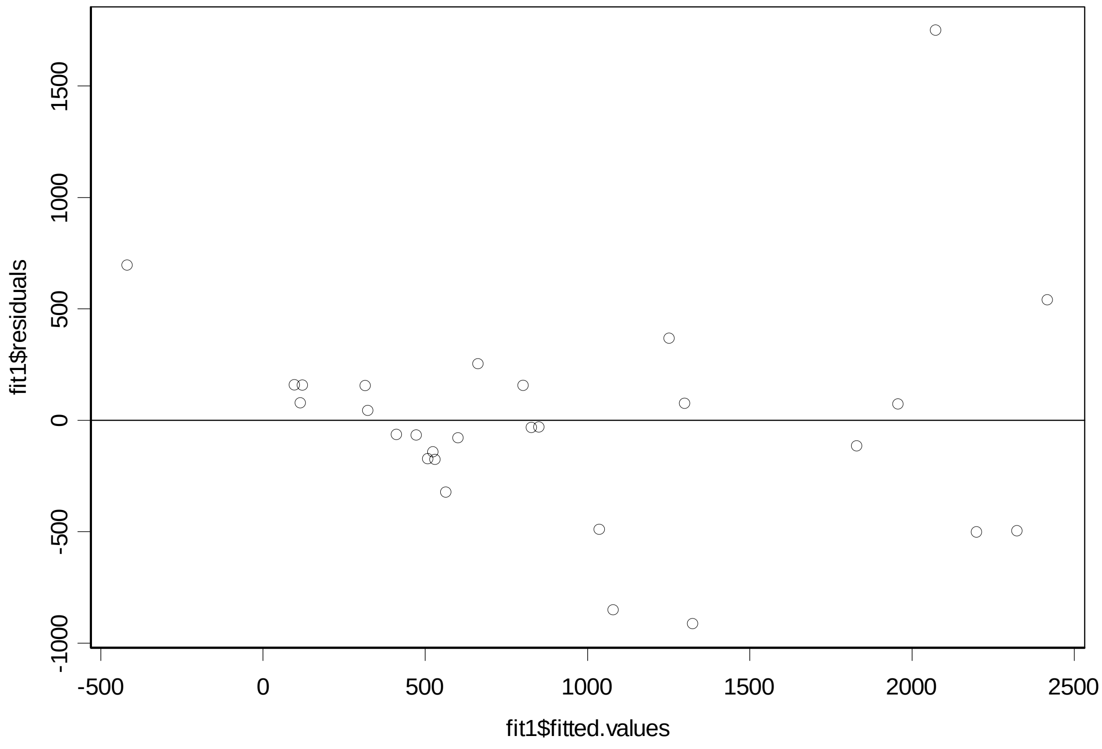
Cu ppm Linear Regression Residual Plot:



Fe ppm

Fe ppm Linear Regression

Fe ppm Linear Regression Residual Plot:



Fe ppm Log Transformation

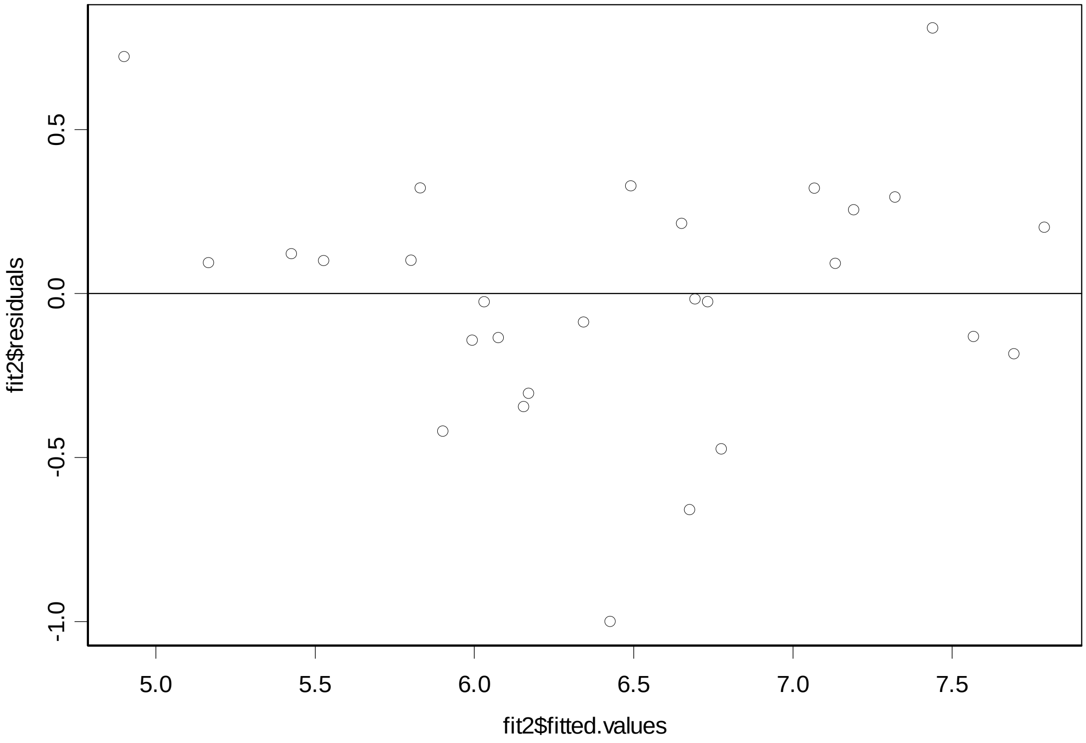
Fe ppm Regression Table:

```
Coefficients        Value Std. Error  t value   P-value
     Intercept   7.9498   0.2162    36.7760   0.0000
         dirNE  -0.7442   0.3659    -2.0338   0.0555
         dirNS  -1.1338   0.3672    -3.0875   0.0058
         dirNW  -1.0263   0.4770    -2.1516   0.0438
     Cdistance  -0.0254   0.0036    -7.0085   0.0000
dirNECdistance   0.0114   0.0054     2.1054   0.0481
dirNSCdistance   0.0172   0.0055     3.1469   0.0051
dirNWCdistance  -0.0041   0.0131    -0.3112   0.7589

Residual standard error: 0.443 on 20 degrees of freedom
Multiple R-Squared: 0.8012
F-statistic: 11.51 on 7 and 20 degrees of freedom, the P-
value is 8.319e-006
```

Fe ppm Statistical Inference:

There is evidence of an interaction effect between distance from mine sites and direction on the Fe ppm in *Evernia mesomorpha* lichen samples. The Fe ppm decreases more rapidly in the East and South directions then in the North direction (p-values = 0.0481 and 0.0051 respectively). There is strong evidence that the Fe ppm in *Evernia mesomorpha* lichen samples decreases as the distance from mine sites increases (p-value < 0.0001).

Fe ppm Log Transformed Residual Plot:



Hg ppb

Hg ppb Linear Regression

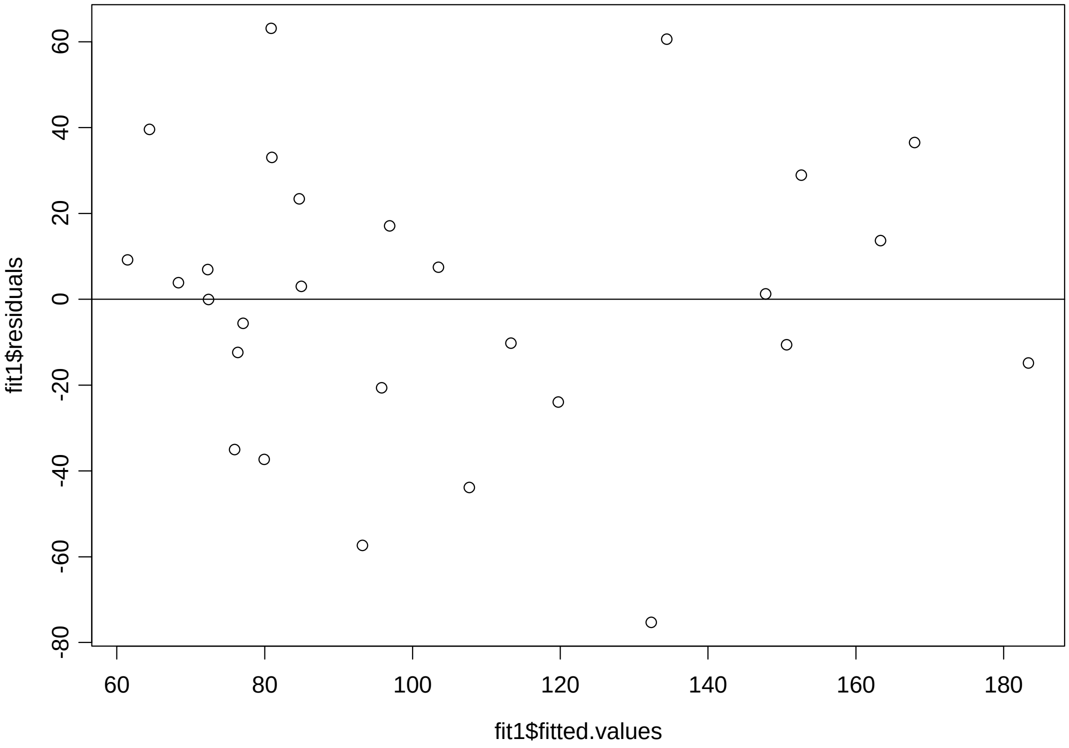
Hg ppb Linear Regression Table:

```
Coefficients        Value Std. Error  t value   P-value
  Intercept       56.5501 13.5343      4.1783   0.0004
      dirNE       32.7218 18.0821      1.8096   0.0834
      dirNS       12.7233 18.0779      0.7038   0.4886
      dirNW        4.4209 19.3422      0.2286   0.8212
  Cdistance        0.7844  0.1773      4.4234   0.0002

Residual standard error: 35.42 on 23 degrees of freedom
Multiple R-Squared: 0.5405
F-statistic: 6.763 on 4 and 23 degrees of freedom, the p-
value is 0.0009434
```

Hg ppb Statistical Inference:

There is no evidence of an interaction effect between distance from the mine and direction on the Hg ppb in *Evernia mesomorpha* lichen samples. There is evidence that the Hg ppb in *Evernia mesomorpha* lichen samples increases the further the distance from the mine (p-value = 0.0002). There is no evidence that the Hg ppb in *Evernia mesomorpha* lichen samples is different in any direction.

Hg ppb Linear Regression Residual Plot:



K ppm

K ppm Linear Regression

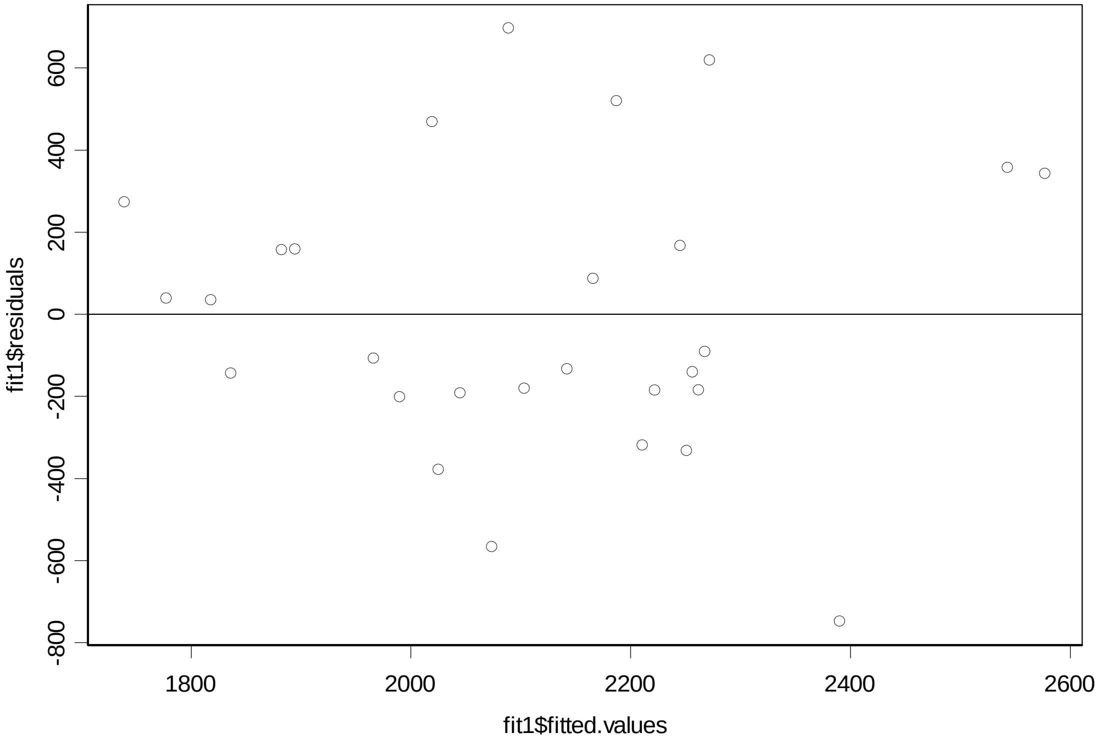
K ppm Regression Table:

```
Coefficients     Value Std. Error    t value     P-value
  Intercept  2403.8538   195.6864    12.2842     0.0000
      dirEN    -6.9854   199.6698    -0.0350     0.9724
      dirES  -231.2712   225.8464    -1.0240     0.3165
      dirEW  -326.8191   243.0651    -1.3446     0.1919
  Cdistance    -3.6499     1.9582    -1.8639     0.0751

Residual standard error: 391.2 on 23 degrees of freedom
Multiple R-Squared: 0.2127
F-statistic: 1.553 on 4 and 23 degrees of freedom, the P-
value is 0.2203
```

K ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the K ppm in *Evernia mesomorpha* lichen samples. There is suggestive evidence that the K ppm in *Evernia mesomorpha* lichen samples decreases as the distance from mine sites increases (p-value = 0.0751). There is no evidence that the K ppm in *Evernia mesomorpha* lichen samples is different in any direction.

K ppm Linear Regression Residual Plot:



Mg ppm

Mg ppm Linear Regression

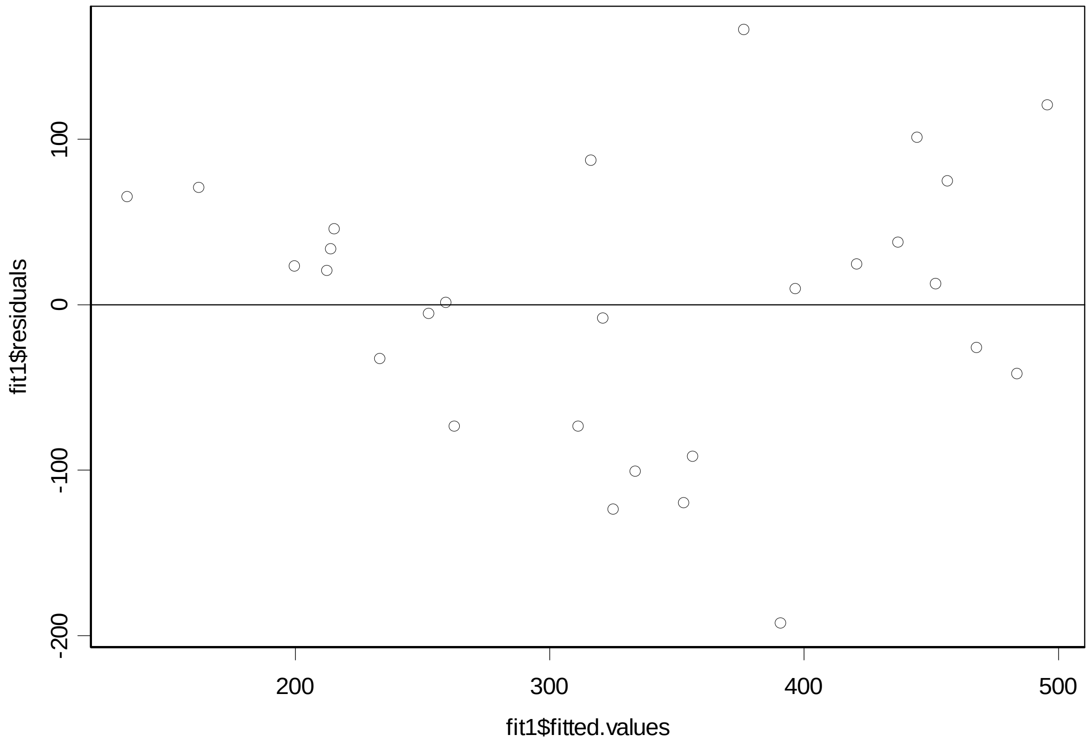
Mg ppm Regression Table:

```
Coefficients    Value Std. Error   t value    P-value
  Intercept  406.0160   45.8622     8.8530    0.0000
      dirWE   52.6010   60.4261     0.8705    0.3930
      dirWN   71.7662   53.0974     1.3516    0.1896
      dirWS    5.3013   60.4017     0.0878    0.9308
  Cdistance   -2.3728    0.4868    -4.8741    0.0001

Residual standard error: 97.25 on 23 degrees of freedom
Multiple R-Squared: 0.5427
F-statistic: 6.824 on 4 and 23 degrees of freedom, the P-
value is 0.0008957
```

Mg ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the Mg ppm in *Evernia mesomorpha* lichen samples. There is strong evidence that the Mg ppm in *Evernia mesomorpha* lichen samples decreases as the distance from mine sites increases (p-value = 0.0001). There is no evidence that the Mg ppm in *Evernia mesomorpha* lichen samples is different in any direction.

Mg ppm Linear Regression Residual Plot:



Mn ppm

Mn ppm Linear Regression

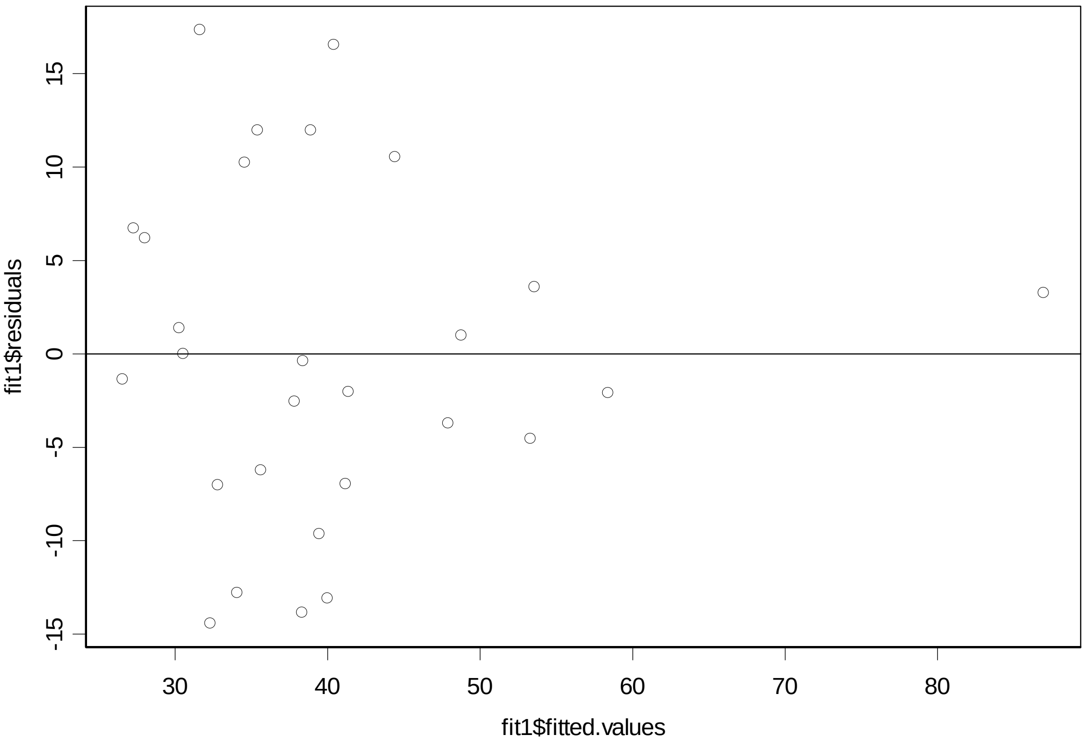
Mn ppm Regression Table:

```
Coefficients       Value Std. Error  t value   P-value
     Intercept  41.0852   5.1203      8.0240   0.0000
         dirNE -15.3167   8.6671     -1.7672   0.0924
         dirNS -11.8887   8.6982     -1.3668   0.1869
         dirNW -22.4058  11.2985     -1.9831   0.0613
     Cdistance  -0.1089   0.0859     -1.2677   0.2195
dirNECdistance   0.2644   0.1286      2.0560   0.0531
dirNSCdistance   0.3525   0.1295      2.7217   0.0131
dirNWCdistance   1.2550   0.3101      4.0467   0.0006
dirEWCdistance   0.9906   0.3130      3.1650   0.0049

Residual standard error: 10.49 on 20 degrees of freedom
Multiple R-Squared: 0.6468
F-statistic: 5.233 on 7 and 20 degrees of freedom, the P-
value is 0.001632
```

Mn ppm Statistical Inference:

There is evidence of an interaction effect between distance from mine sites and direction on the Mn ppm in *Evernia mesomorpha* lichen samples. The Mn ppm decreases more rapidly in the North direction than in the East, West, and South directions (p-values = 0.0531, 0.0006, and 0.0131 respectively). The Mn ppm decreases more rapidly in the East direction than in the West direction (p-value = 0.0049). There is no evidence that the Mn ppm in *Evernia mesomorpha* lichen samples decreases as the distance from mine sites increases (p-value < 0.2195).

Mn ppm Linear Regression Residual Plot:



Mo ppm

Mo ppm Linear Regression

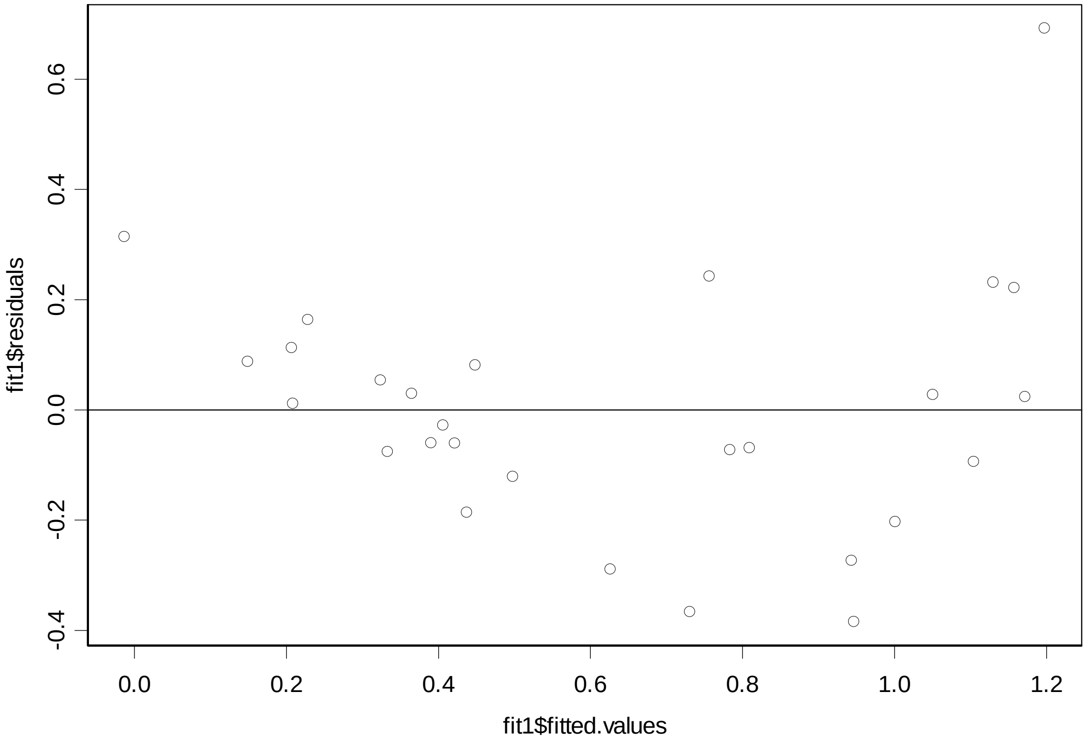
Mo ppm Regression Table:

```
Coefficients  Value Std. Error t value  P-value
  Intercept  0.6176  0.1230     5.0199  0.0000
      dirWE  0.5692  0.1621     3.5113  0.0019
      dirWN  0.5403  0.1424     3.7929  0.0009
      dirWS  0.4227  0.1620     2.6088  0.0157
  Cdistance -0.0084  0.0013    -6.4166  0.0000

Residual standard error: 0.2609 on 23 degrees of freedom
Multiple R-Squared: 0.6854
F-statistic: 12.53 on 4 and 23 degrees of freedom, the P-
value is 0.00001488
```

Mo ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the Mo ppm in *Evernia mesomorpha* lichen samples. There is strong evidence that the Mo ppm in *Evernia mesomorpha* lichen samples decreases as the distance from mine sites increases (p-value < 0.0001). There is evidence that the Mo ppm in *Evernia mesomorpha* lichen samples is greater in the East, North, and South directions than in the West direction (p-values = 0.0019, 0.0009, and 0.0157 respectively).

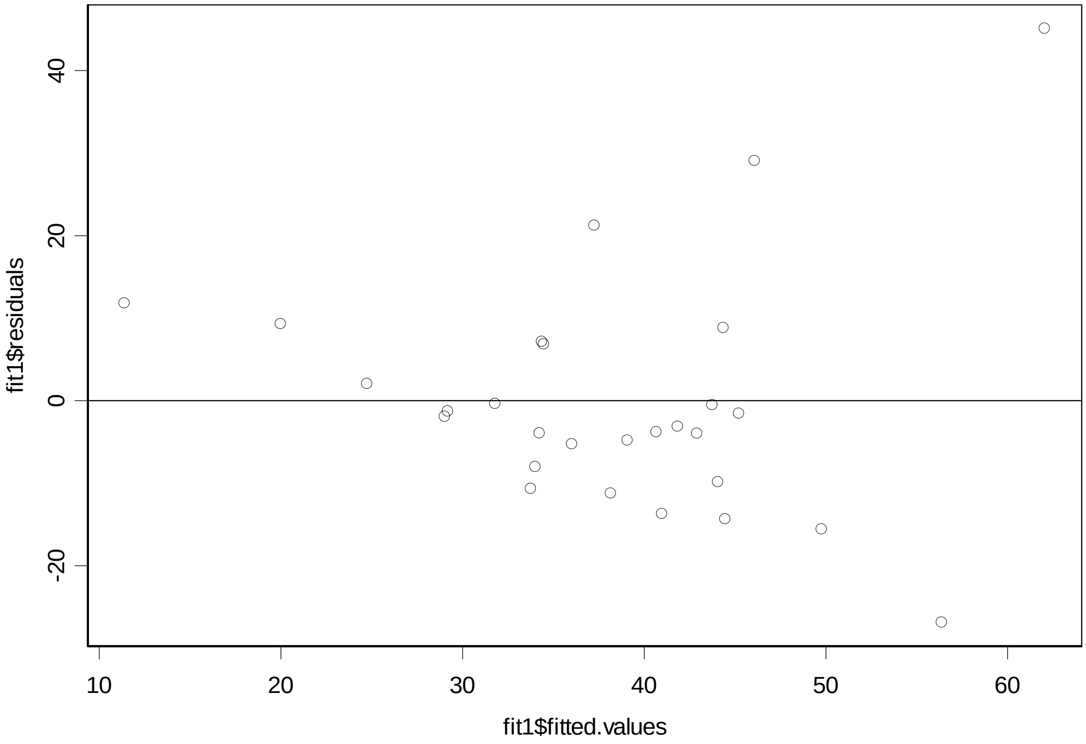
Mo ppm Linear Regression Residual Plot:



Na ppm

Na ppm Linear Regression

Na ppm Linear Regression Residual Plot:



Na ppm Rank Transformation

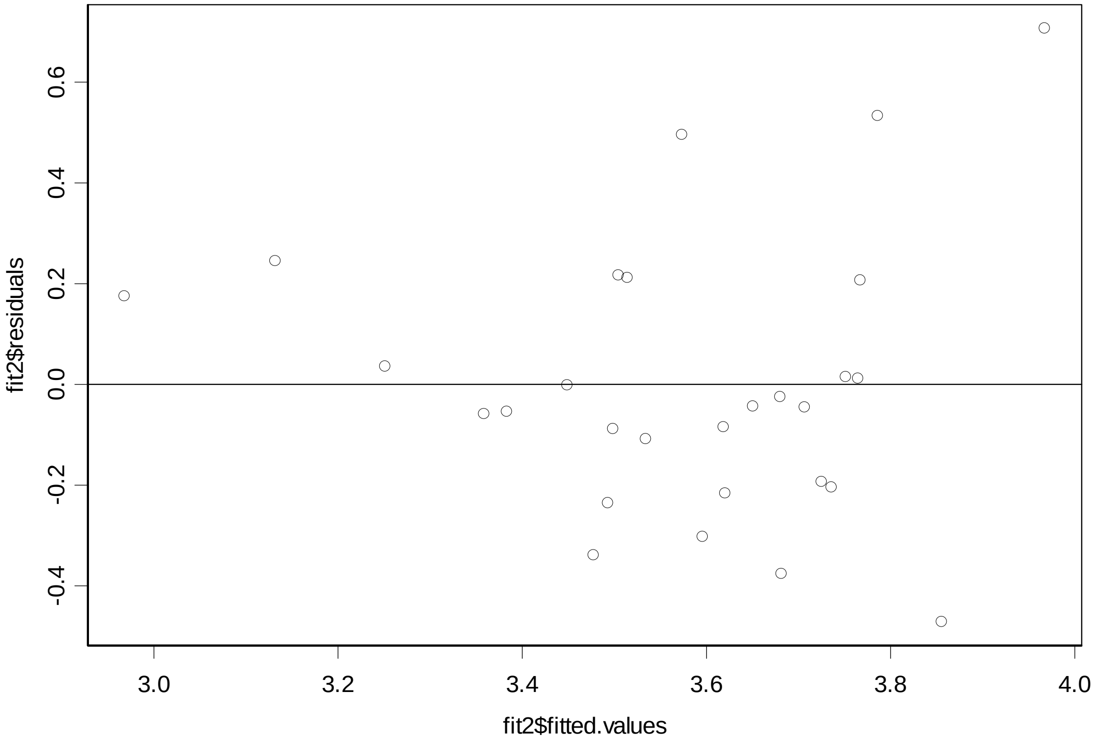
Na ppm Regression Table:

```
Coefficients         Value Std. Error  t value   P-value
     Intercept   4.2917   0.3069    13.9850   0.0000
         dirWE  -0.5076   0.3736    -1.3587   0.1894
         dirWN  -0.4695   0.3443    -1.3637   0.1878
         dirWS  -0.8099   0.3743    -2.1639   0.0427
     Cdistance  -0.0222   0.0091    -2.4466   0.0238
dirWECdistance   0.0189   0.0095     1.9791   0.0617
dirWNCdistance   0.0165   0.0094     1.7420   0.0969
dirWSCdistance   0.0234   0.0095     2.4461   0.0238

Residual standard error: 0.3197 on 20 degrees of freedom
Multiple R-Squared: 0.3852
F-statistic: 1.79 on 7 and 20 degrees of freedom, the P-
value is 0.1451
```

Na ppm Statistical Inference:

There is evidence of an interaction effect between distance from mine sites and direction on the Na ppm in *Evernia mesomorpha* lichen samples. The Na ppm decreases more rapidly in the West direction than in the South direction (p-value = 0.0238). There is strong evidence that the Na ppm in *Evernia mesomorpha* lichen samples decreases as the distance from mine sites increases (p-value = 0.0238).

Na ppm Rank Transformed Residual Plot:



Ni ppm

Ni ppm Linear Regression

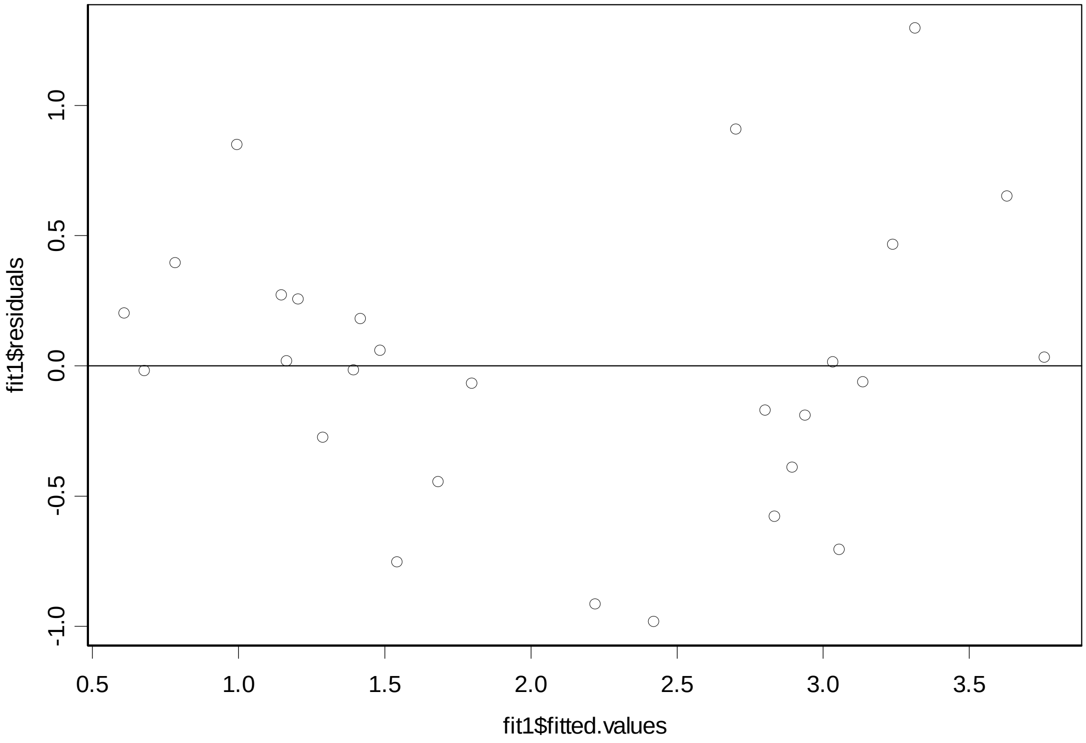
Ni ppm Regression Table:

```
Coefficients  Value Std. Error t value  P-value
  Intercept  1.8711  0.2857     6.5484  0.0000
      dirWE  1.7184  0.3765     4.5644  0.0001
      dirWN  1.6506  0.3308     4.9895  0.0000
      dirWS  1.3814  0.3763     3.6706  0.0013
  Cdistance -0.0221  0.0030    -7.2800  0.0000

Residual standard error: 0.6059 on 23 degrees of freedom
Multiple R-Squared: 0.7506
F-statistic: 17.3 on 4 and 23 degrees of freedom, the P-
value is 1.118e-006
```

Ni ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the Ni ppm in *Evernia mesomorpha* lichen samples. There is strong evidence that the Ni ppm in *Evernia mesomorpha* lichen samples decreases as the distance from mine sites increases (p-value < 0.0001). There is evidence that the Ni ppm in *Evernia mesomorpha* lichen samples is greater in the East, North, and South directions than in the West direction (p-values = 0.0001, 0.0001, and 0.0013 respectively).

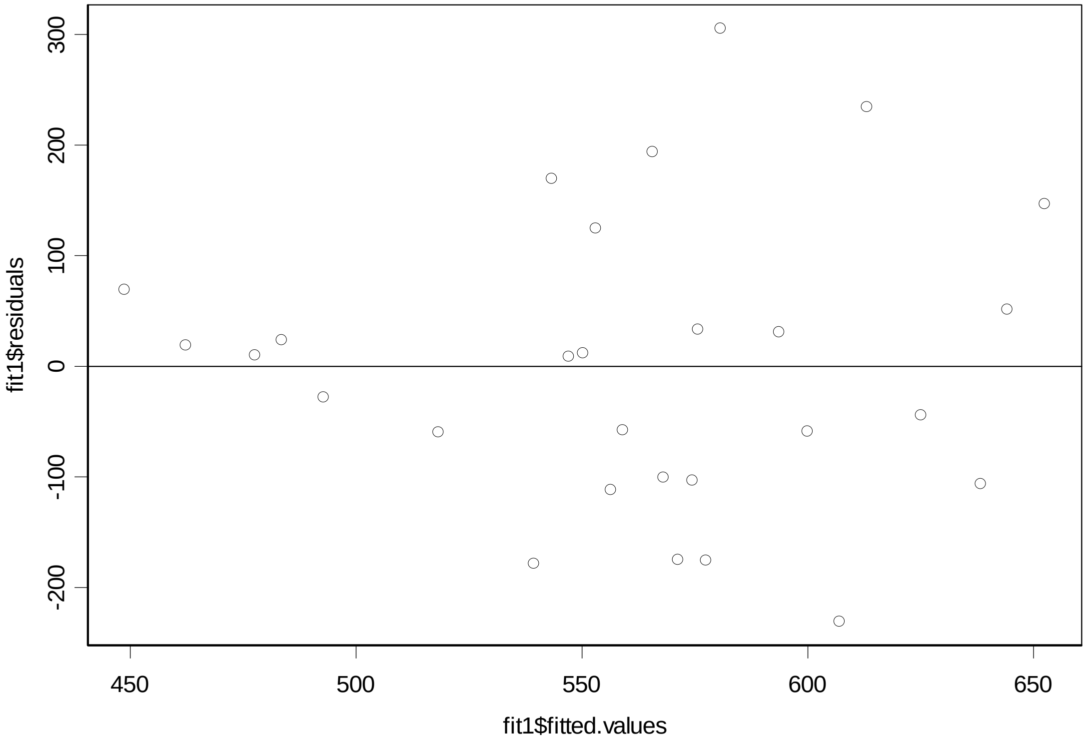
Ni ppm Linear Regression Residual Plot:



P ppm

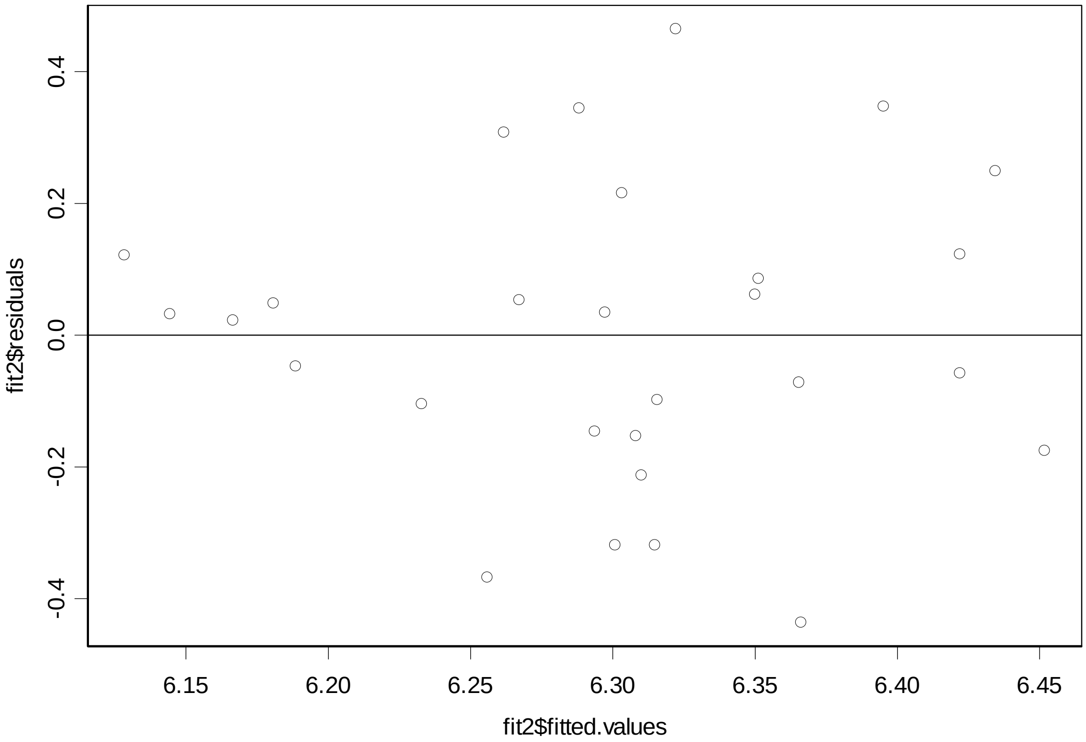
P ppm Linear Regression

P ppm Linear Regression Residual Plot:



P ppm Log Transformation

P ppm Log Transformed Residual Plot:



P ppm Rank Transformation

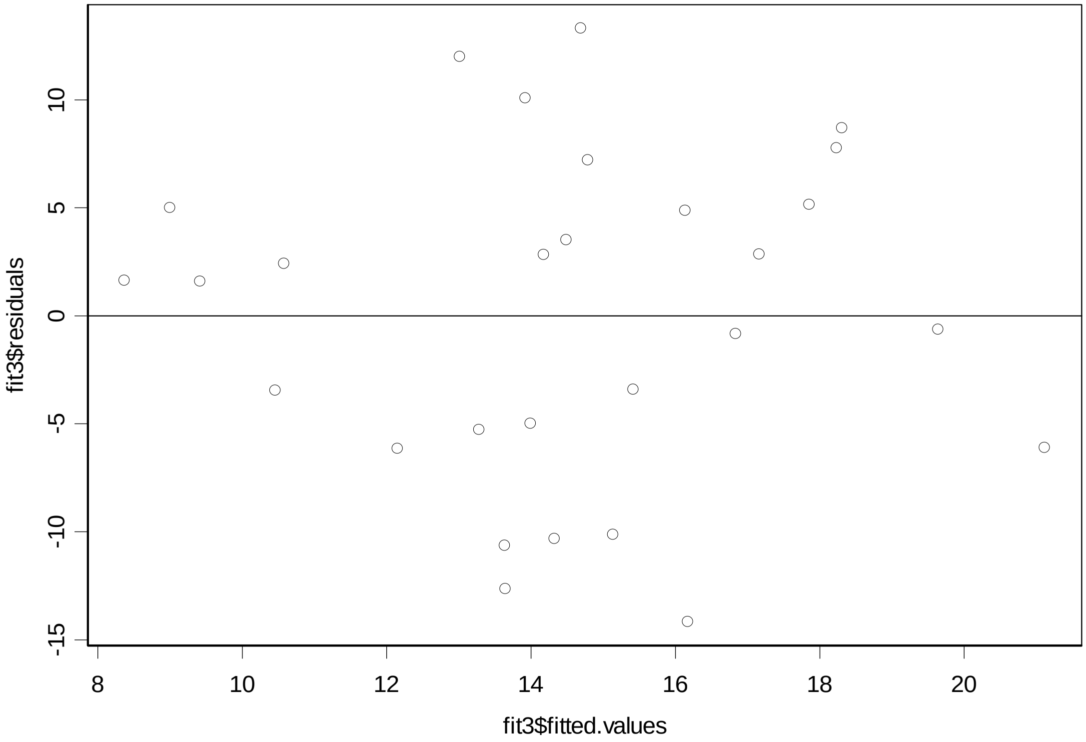
P ppm Regression Table:

```
Coefficients       Value Std. Error  t value   P-value
     Intercept  18.6412   5.8876     3.1662   0.0049
         dirEN  -6.0726   7.2971    -0.8322   0.4151
         dirES  -3.9356   8.3493    -0.4714   0.6425
         dirEW  -5.0173  10.3232    -0.4860   0.6322
     Cdistance  -0.0804   0.0806    -0.9973   0.3305

Residual standard error: 8.834 on 20 degrees of freedom
Multiple R-Squared: 0.1456
F-statistic: 0.487 on 4 and 23 degrees of freedom, the P-
value is 0.8328
```

Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the P ppm in *Evernia mesomorpha* lichen samples. There is no evidence that the P ppm in *Evernia mesomorpha* lichen samples decreases as the distance from mine sites increases (p-value = 0.3305). There is no evidence that the P ppm in *Evernia mesomorpha* lichen samples is different in any direction.

P ppm Rank Transformed Residual Plot:



Si ppm

Si ppm Linear Regression

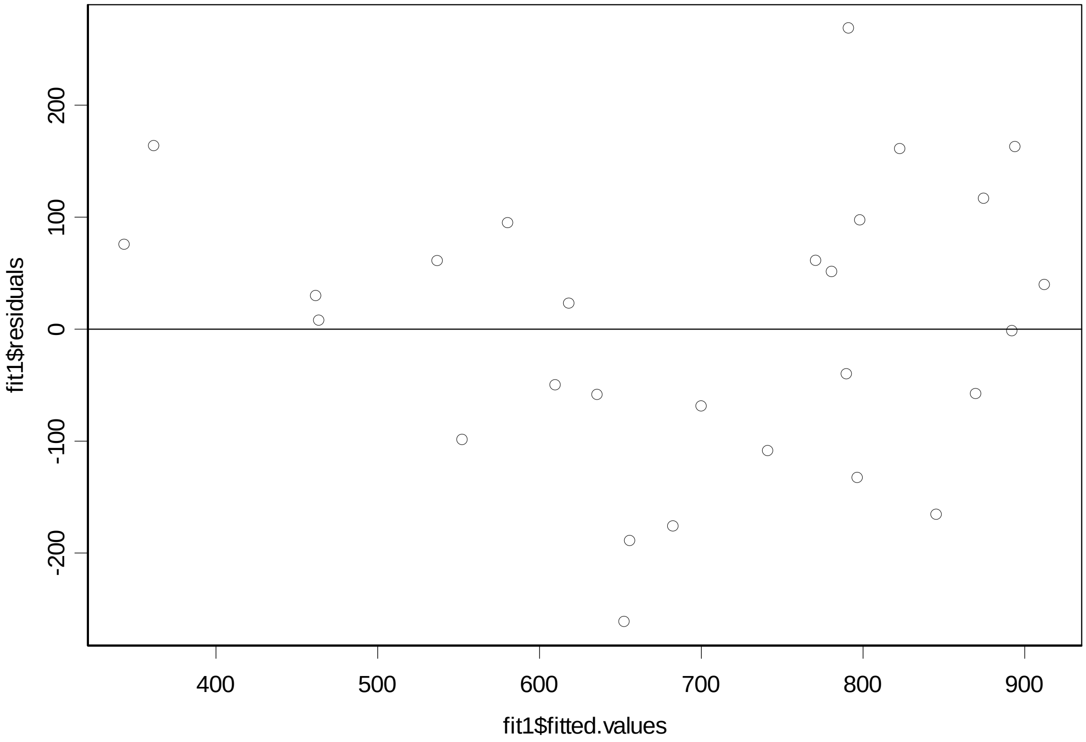
Si ppm Regression Table:

```
Coefficients    Value Std. Error   t value    P-value
  Intercept  915.4686   75.5950    12.1102    0.0000
      dirEN  -21.5161   77.1338    -0.2789    0.7828
      dirES    2.8126   87.2460     0.0322    0.9746
      dirEW -162.7606   93.8977    -1.7334    0.0964
  Cdistance   -3.8031    0.7565    -5.0275    0.0000

Residual standard error: 151.1 on 23 degrees of freedom
Multiple R-Squared: 0.5323
F-statistic: 6.543 on 4 and 23 degrees of freedom, the P-
value is 0.001141
```

Si ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the Si ppm in *Evernia mesomorpha* lichen samples. There is strong evidence that the Si ppm in *Evernia mesomorpha* lichen samples decreases as the distance from mine sites increases (p-value < 0.0001). There is no evidence that the Si ppm in *Evernia mesomorpha* lichen samples is different in any direction.

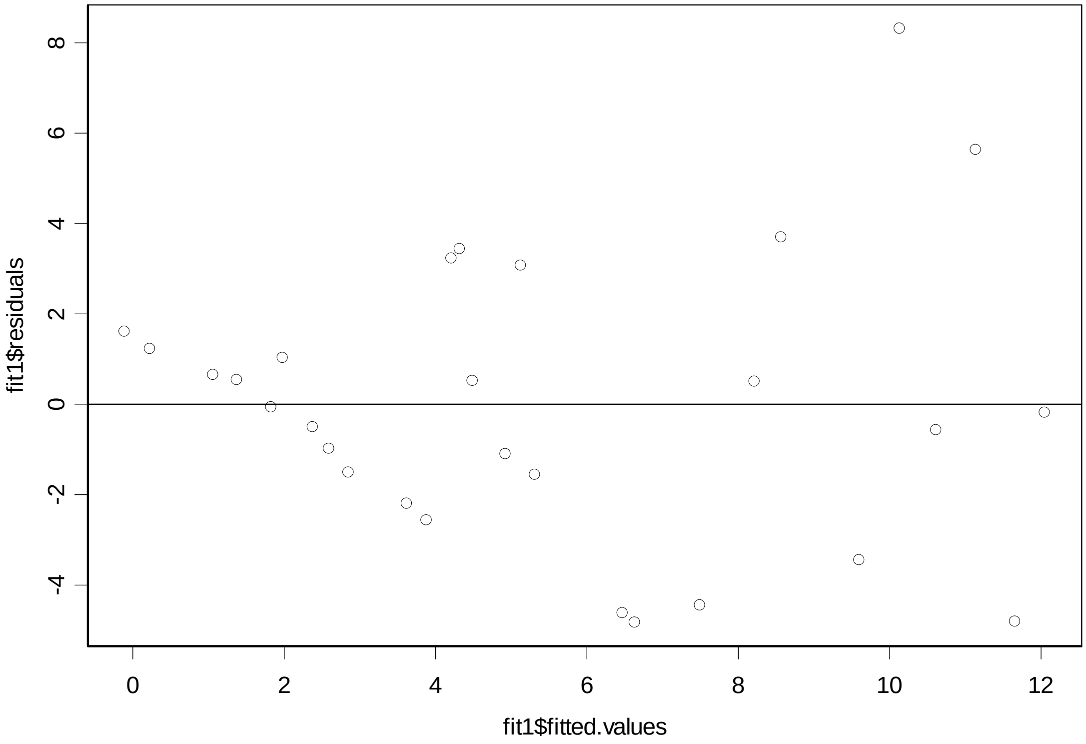
Si ppm Linear Regression Residual Plot:



Sr ppm

Sr ppm Linear Regression

Sr ppm Linear Regression Residual Plot:



Sr ppm Log Transformation

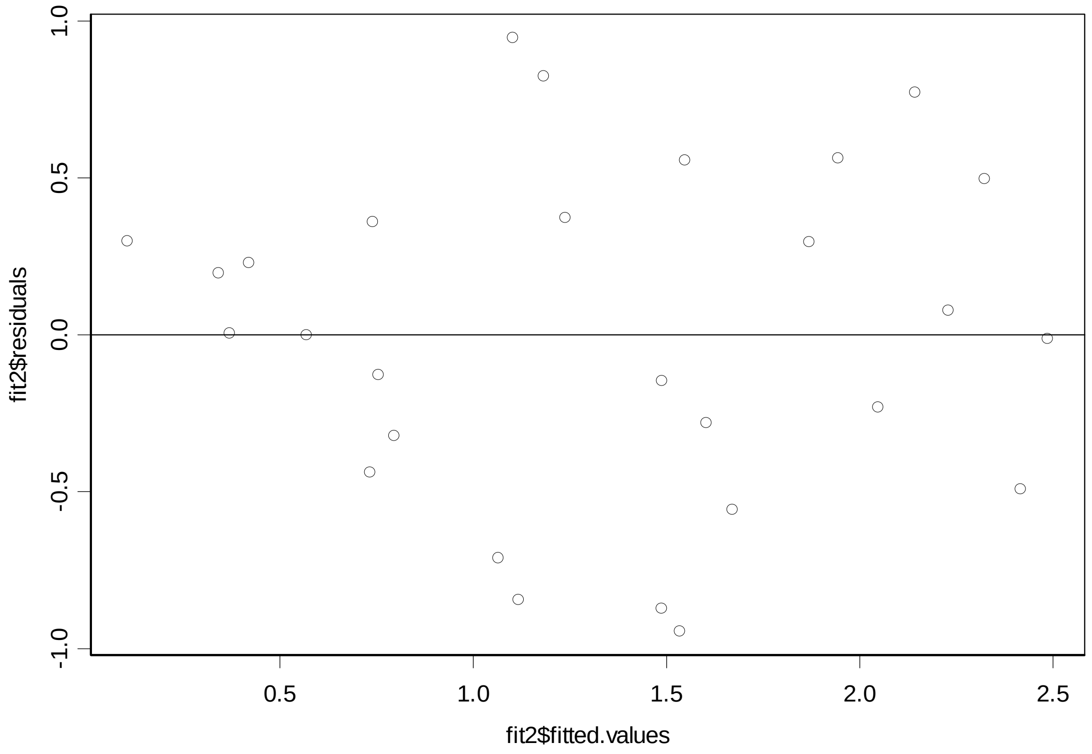
Sr ppm Regression Table:

```
Coefficients   Value Std. Error  t value   P-value
  Intercept   2.4567   0.2231    11.0138   0.0000
      dirNE  -0.4602   0.2980    -1.5443   0.1362
      dirNS  -0.5074   0.2979    -1.7032   0.1020
      dirNW  -0.9242   0.3188    -2.8993   0.0081
  Cdistance  -0.0155   0.0029    -5.3029   0.0000

Residual standard error: 0.5838 on 23 degrees of freedom
Multiple R-Squared: 0.6135
F-statistic: 9.129 on 4 and 23 degrees of freedom, the P-
value is 0.0001438
```

Sr ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the Sr ppm in *Evernia mesomorpha* lichen samples. There is strong evidence that the Sr ppm in *Evernia mesomorpha* lichen samples decreases as the distance from mine sites increases (p-value < 0.0001). There is evidence that the Sr ppm in *Evernia mesomorpha* lichen samples is smaller in the West direction than in the North direction (p-value = 0.0081).

Sr ppm Log Transformed Residual Plot:



Ti ppm

Ti ppm Linear Regression

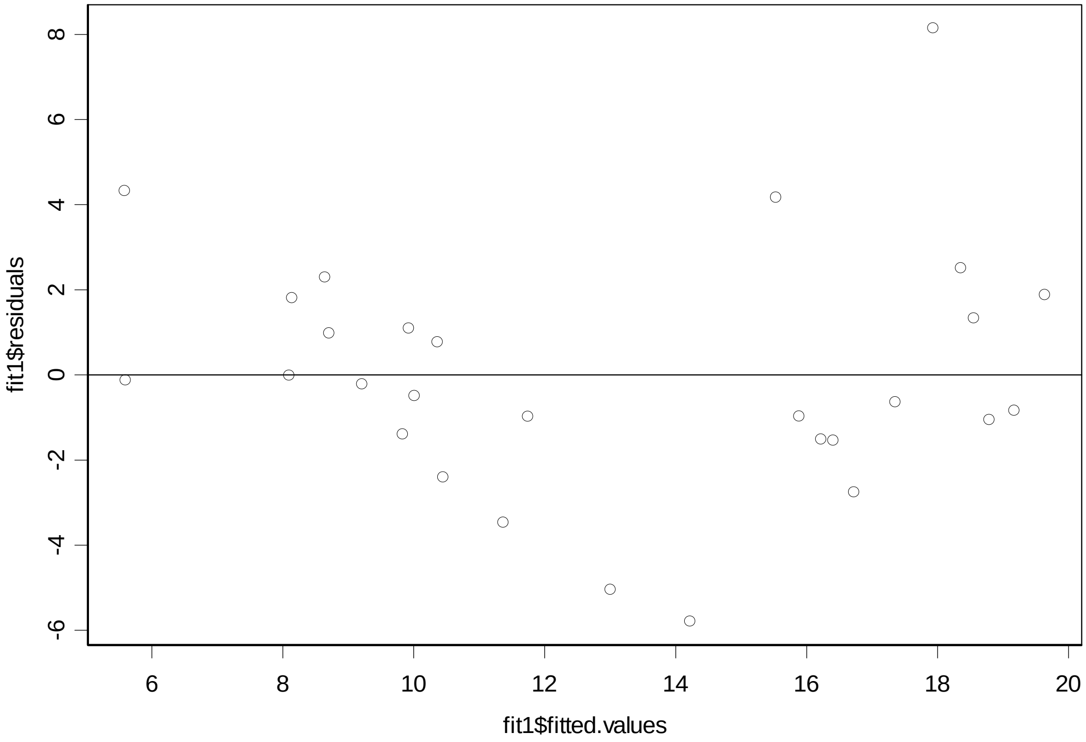
Ti ppm Regression Table:

```
Coefficients   Value Std. Error  t value   P-value
  Intercept  11.6701   1.5263     7.6458   0.0000
      dirWE   7.8680   2.0110     3.9124   0.0007
      dirWN   7.5330   1.7671     4.2628   0.0003
      dirWS   6.9031   2.0102     3.4340   0.0023
  Cdistance  -0.0978   0.0162    -6.0368   0.0000

Residual standard error: 3.236 on 23 degrees of freedom
Multiple R-Squared: 0.6773
F-statistic: 12.07 on 4 and 23 degrees of freedom, the P-
value is 0.0000197
```

Ti ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the Ti ppm in *Evernia mesomorpha* lichen samples. There is strong evidence that the Ti ppm in *Evernia mesomorpha* lichen samples decreases as the distance from mine sites increases (p-value < 0.0001). There is evidence that the Ti ppm in *Evernia mesomorpha* lichen samples is smaller in the West direction than in the East, North, and South directions (p-values = 0.0007, 0.0003, and 0.0023 respectively).

Ti ppm Linear Regression Residual Plot:



V ppm

V ppm Linear Regression

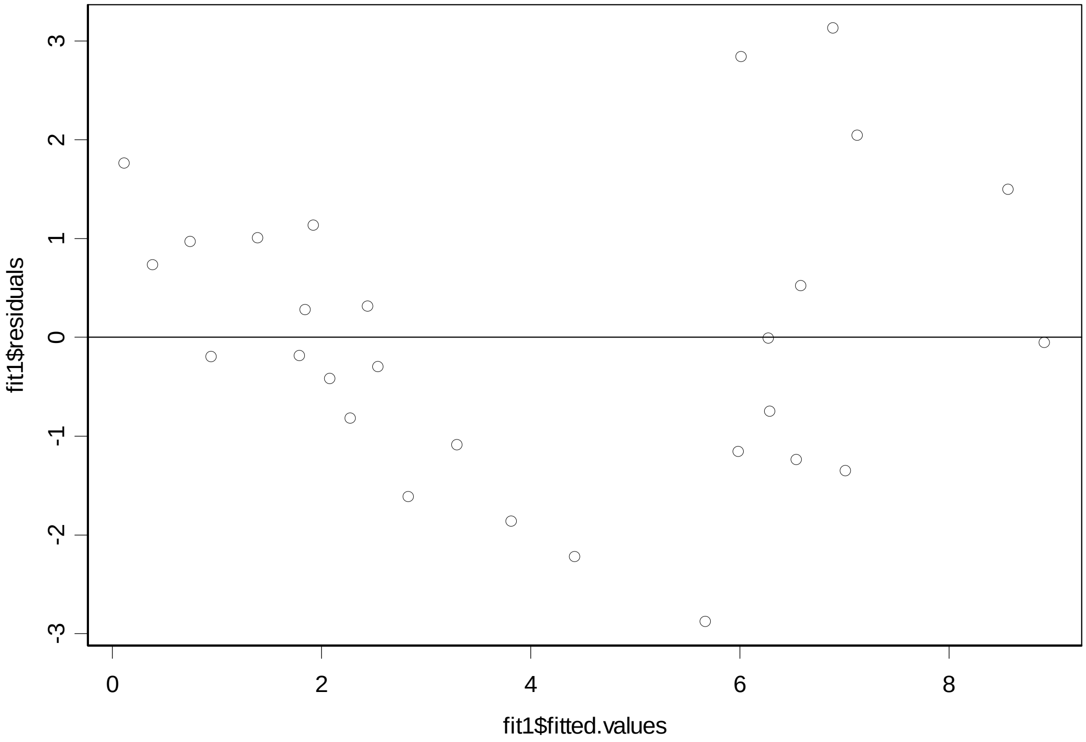
V ppm Regression Table:

```
Coefficients  Value Std. Error t value  P-value
   Intercept  3.7878  0.7754     4.8849  0.0001
       dirWE  4.7945  1.0216     4.6930  0.0001
       dirWN  3.7374  0.8977     4.1631  0.0004
       dirWS  3.8130  1.0212     3.7337  0.0011
   Cdistance -0.0619  0.0082    -7.5255  0.0000

Residual standard error: 1.644 on 23 degrees of freedom
Multiple R-Squared: 0.7479
F-statistic: 17.06 on 4 and 23 degrees of freedom, the P-
value is 1.26e-006
```

V ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the V ppm in *Evernia mesomorpha* lichen samples. There is strong evidence that the V ppm in *Evernia mesomorpha* lichen samples decreases as the distance from mine sites increases (p-value < 0.0001). There is evidence that the V ppm in *Evernia mesomorpha* lichen samples is smaller in the West direction than in the North, South, and East directions (p-value = 0.0004, 0.0011, and 0.0001 respectively).

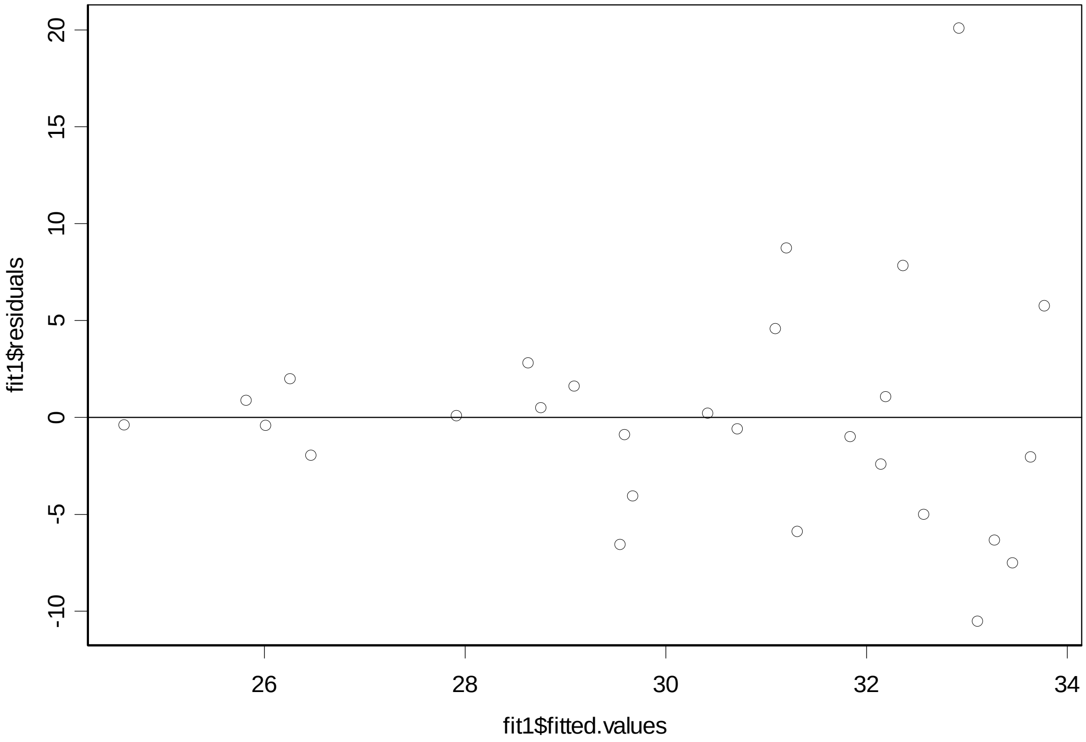
V ppm Linear Regression Residual Plot:



Zn ppm

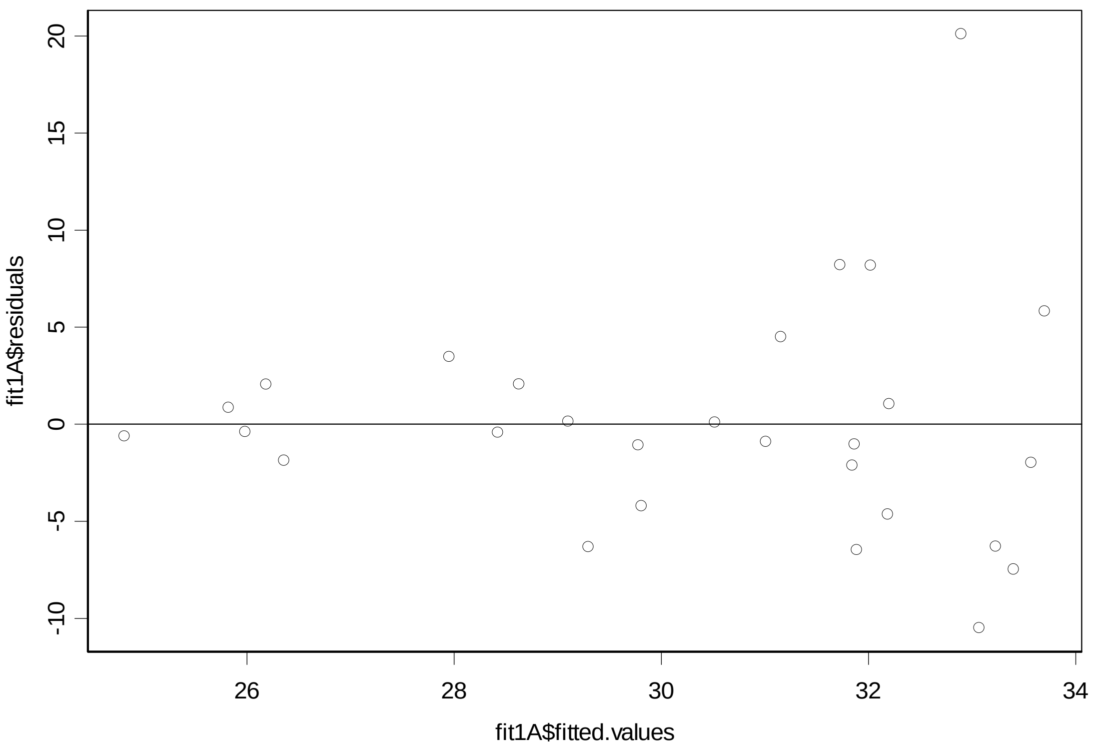
Zn ppm Linear Regression

Zn ppm Linear Regression Residual Plot:



Zn ppm Log Transformation

Zn ppm Log Transformed Residual Plot:



Zn ppm Rank Transformation

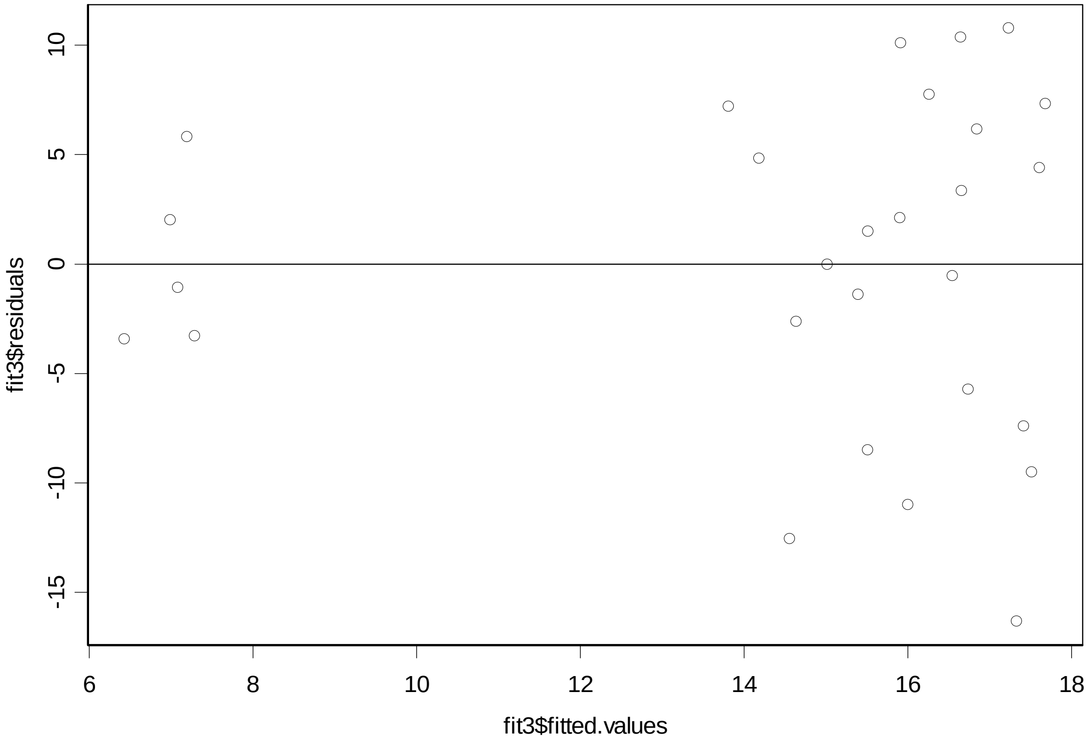
Zn ppm Regression Table:

```
Coefficients       Value Std. Error  t value   P-value
     Intercept  14.0914   5.6181      2.5082   0.0209
         dirEN   3.6078   6.9631      0.5181   0.6100
         dirES   4.5397   7.9671      0.5698   0.5752
         dirEW  -3.9704   9.8507     -0.4031   0.6912
     Cdistance   0.0157   0.0769      0.2046   0.8399

Residual standard error: 8.43 on 20 degrees of freedom
Multiple R-Squared: 0.2221
F-statistic: 0.8155 on 4 and 23 degrees of freedom, the P-
value is 0.5853
```

Zn ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the Zn ppm in *Evernia mesomorpha* lichen samples. There is no evidence that the Zn ppm in *Evernia mesomorpha* lichen samples decreases as the distance from mine sites increases. There is no evidence that the Zn ppm in *Evernia mesomorpha* lichen samples is different in any direction.

Zn ppm Rank Transformed Residual Plot:

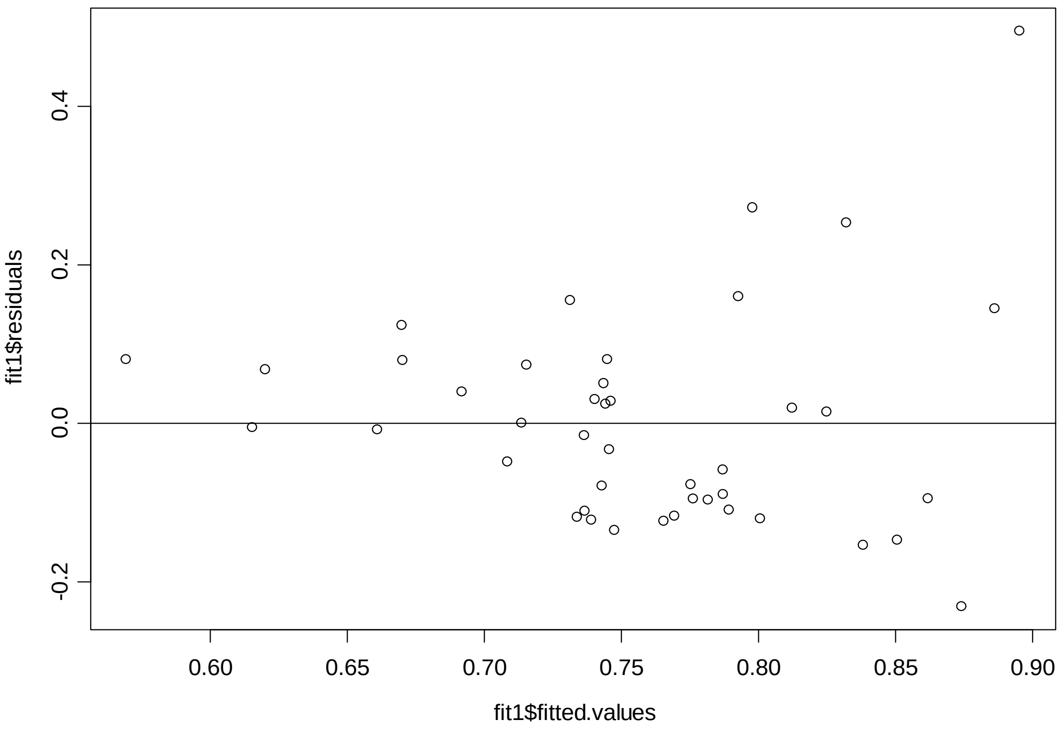


VII. *Hypogymnia physodes*

N%

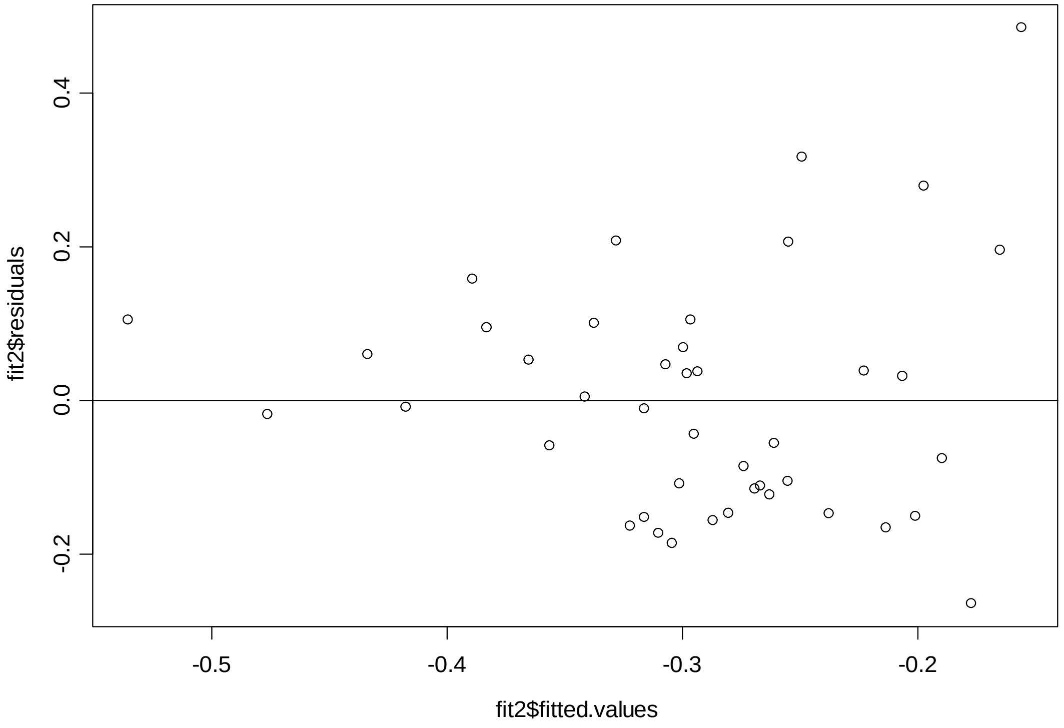
N% Linear Regression

N% Linear Regression Residual Plot:



N% Log Transformation

N% Log Transformed Residual Plot:



N% Rank Transformation

N% Regression Table:

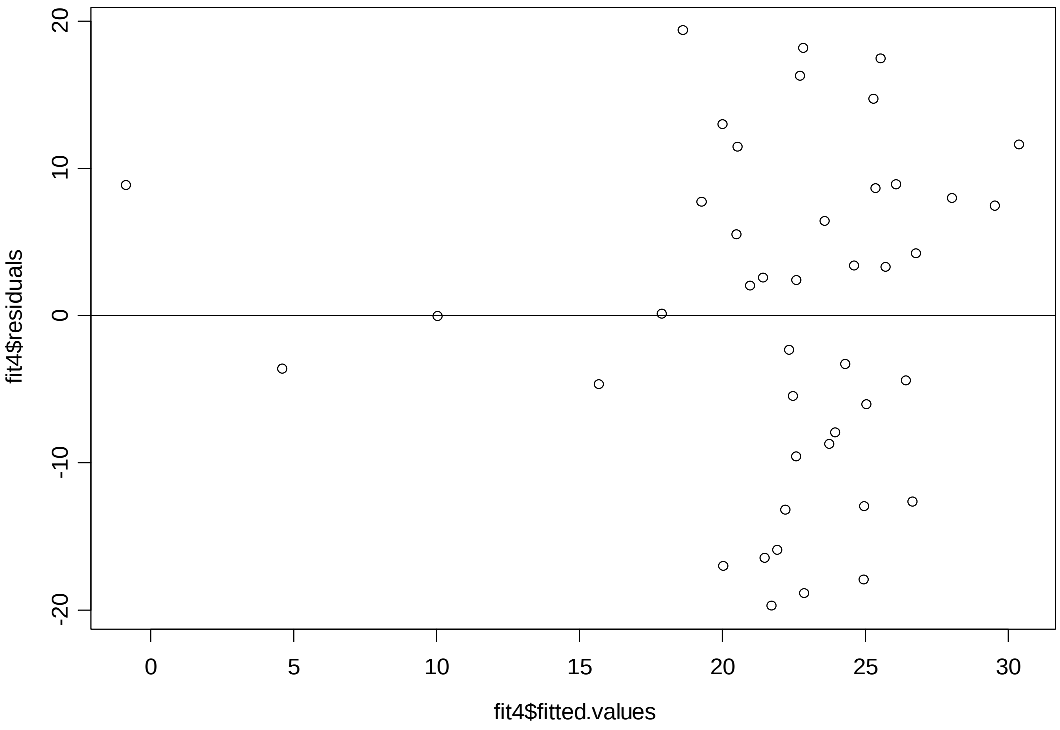
```
Coefficients  Value  Std. Error  t value   P-value
 Intercept   26.9473   4.4080     6.1133   0.0000
     dirEN    0.9894   5.2623     0.1880   0.8519
     dirES    1.9926   5.2623     0.3786   0.7071
     dirEW   -2.5743   5.3923    -0.4774   0.6358
  Cdistance  -0.1092   0.0503    -2.1705   0.0363
```

```
Residual standard error: 12.34 on 38 degrees of freedom
Multiple R-Squared: 0.126
F-statistic: 1.37 on 4 and 38 degrees of freedom, the P-
value is 0.2626
```

N% Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the percent of N in *Hypogymnia physodes* lichen samples. There is evidence that the percent of N in *Hypogymnia physodes lichen* samples decreases as the distance from mine sites increases (p-value = 0.0363). There is no evidence that the percent of N in *Hypogymnia physodes* lichen samples is different in any direction.

N% Rank Transformed Residual Plot:



S%

S% Linear Regression:

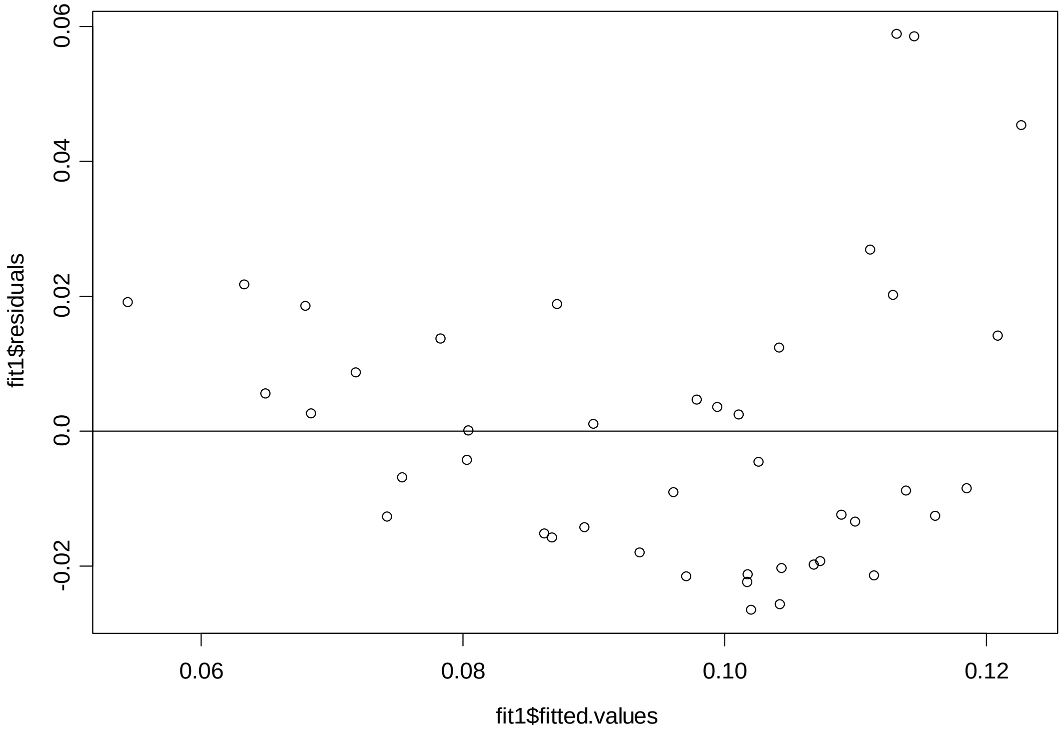
S% Regression Table:

```
Coefficients   Value Std. Error  t value   P-value
Intercept     0.1156   0.0080    14.4426   0.0000
      dirEN   0.0083   0.0096     0.8662   0.3918
      dirES  -0.0040   0.0096    -0.4218   0.6756
      dirEW  -0.0020   0.0098    -0.2086   0.8359
  Cdistance  -0.0004   0.0001    -4.7981   0.0000

Residual standard error: 0.02241 on 38 degrees of freedom
Multiple R-Squared: 0.396
F-statistic: 6.229 on 4 and 38 degrees of freedom, the P-
value is 0.0005893
```

S% Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the percent of S in *Hypogymnia physodes lichen* samples. There is strong evidence that the percent of S in *Hypogymnia physodes lichen* samples decreases as the distance from mine sites increases (p-value < 0.0001). There is no evidence that the percent of S in *Hypogymnia physodes lichen* samples is different in any direction.

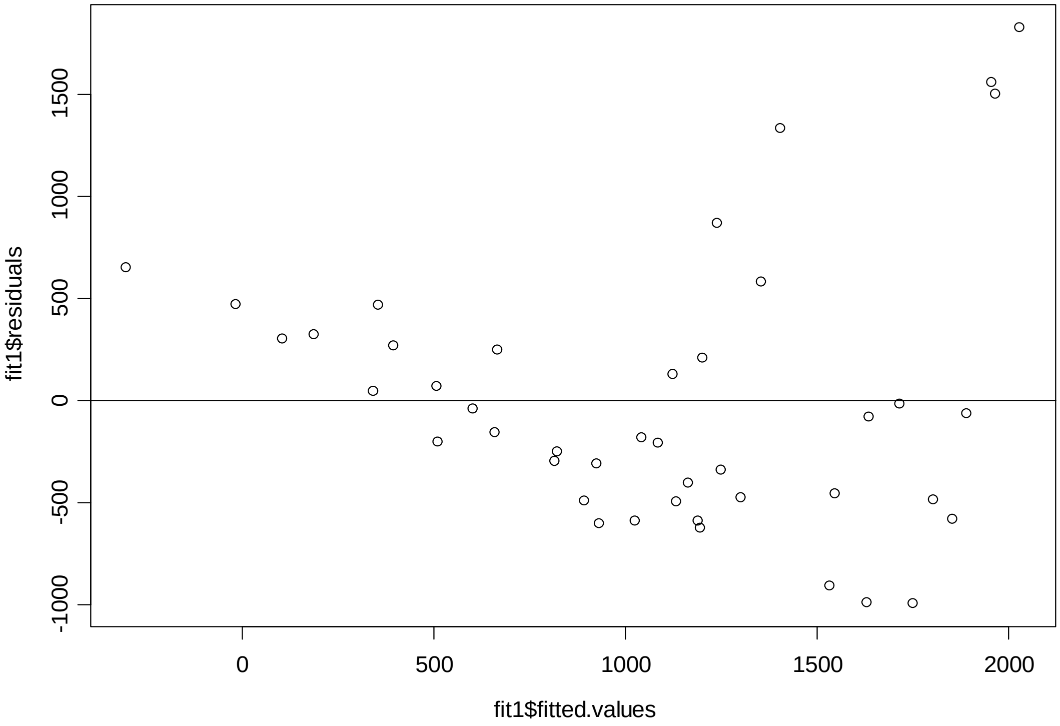
S% Linear Regression Residual Plot:



Al ppm

Al ppm Linear Regression

Al ppm Linear Regression Residual Plot:



Al ppm Log Transformation

Al ppm Regression Table:

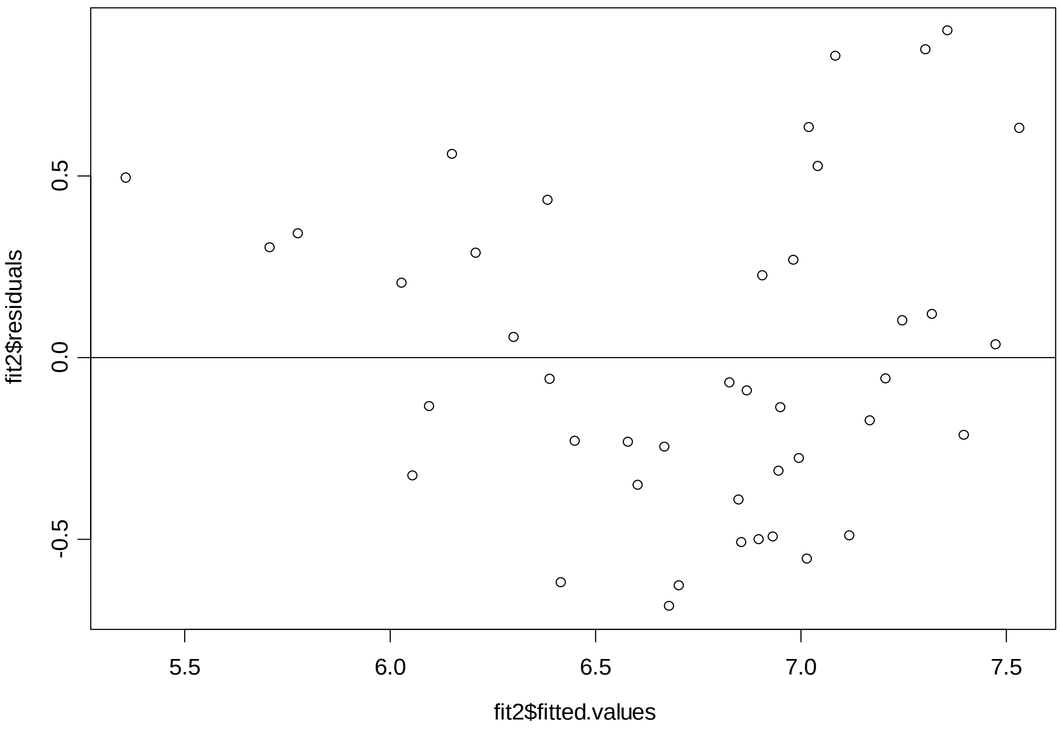
```
Coefficients   Value Std. Error  t value   P-value
Intercept     7.2834   0.1737    41.9348   0.0000
      dirEN   0.2043   0.2073     0.9853   0.3307
      dirES   0.0032   0.2073     0.0153   0.9879
      dirEW  -0.0588   0.2125    -0.2767   0.7835
  Cdistance  -0.0124   0.0020    -6.2679   0.0000
```

```
Residual standard error: 0.4863 on 38 degrees of freedom
Multiple R-Squared: 0.5193
F-statistic: 10.26 on 4 and 38 degrees of freedom, the P-
value is 9.799e-006
```

Al ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the Al ppm in *Hypogymnia physodes lichen* samples. There is strong evidence that the Al ppm in *Hypogymnia physodes lichen* samples declines as the distance from mine sites increases (p-value < 0.0001). There is no evidence that the Al ppm in *Hypogymnia physodes lichen* samples is different in any direction.

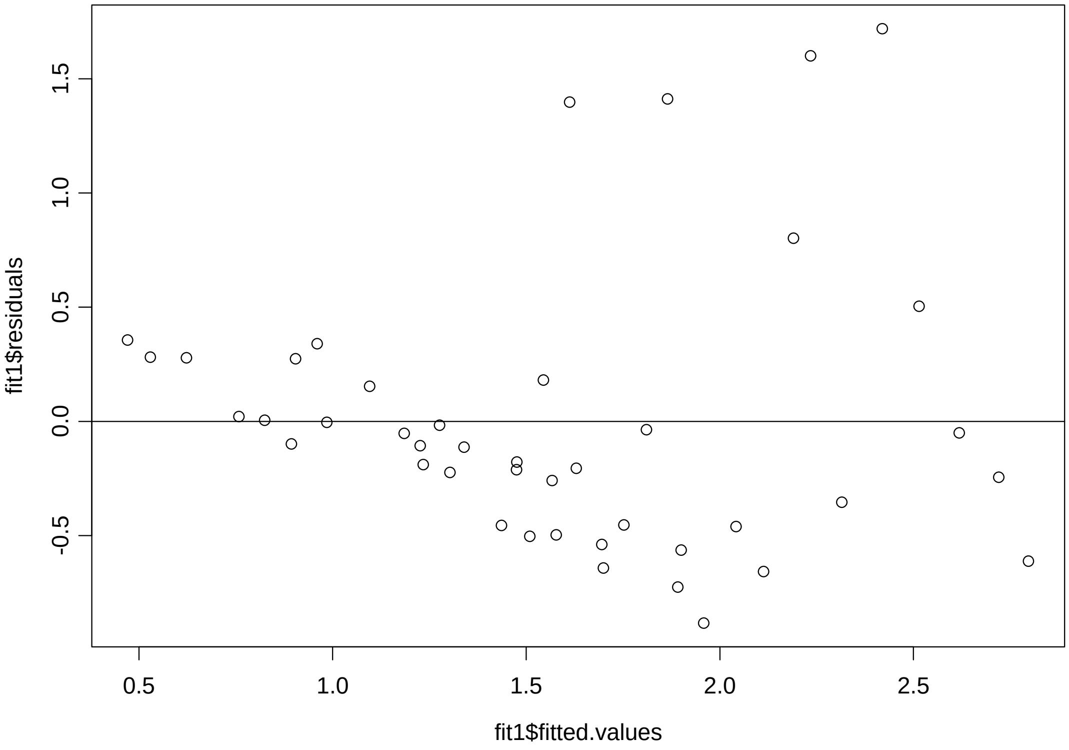
Al ppm Log Transformed Residual Plot:



As ppm

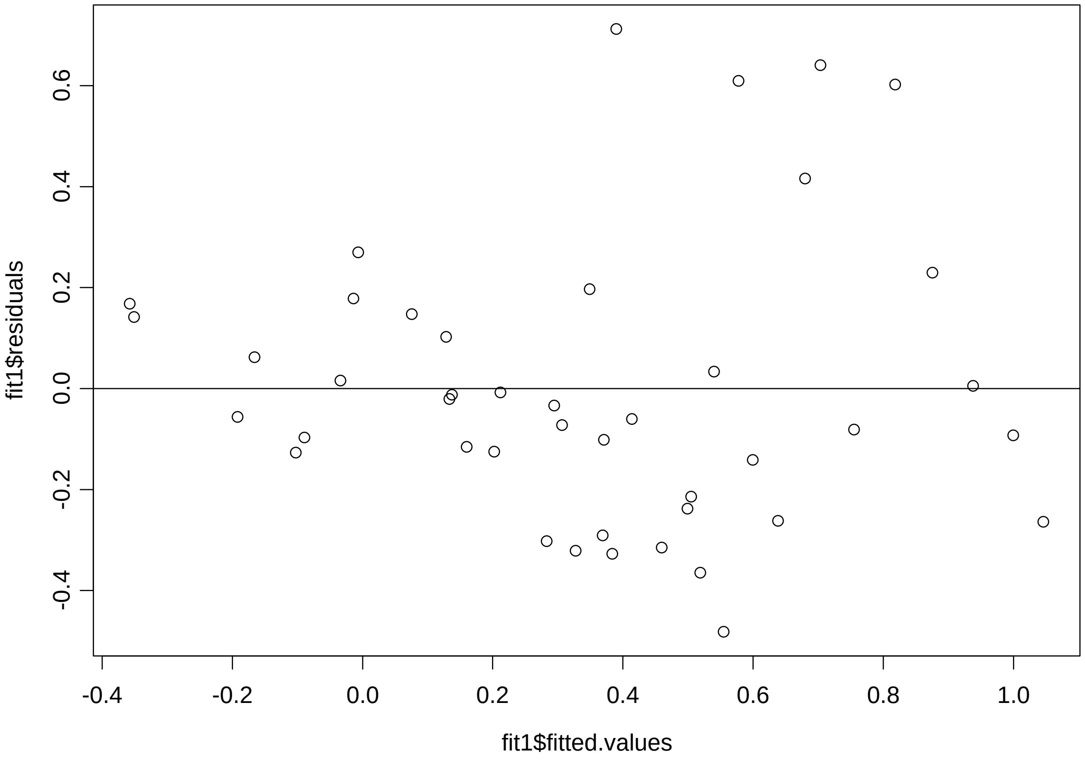
As ppm Linear Regression

As ppm Linear Regression Residual Plot:



As ppm Log Transformation

As ppm Log Transformation Regression Residual Plot:



As ppm Rank Regression:

As ppm Rank Regression Table:

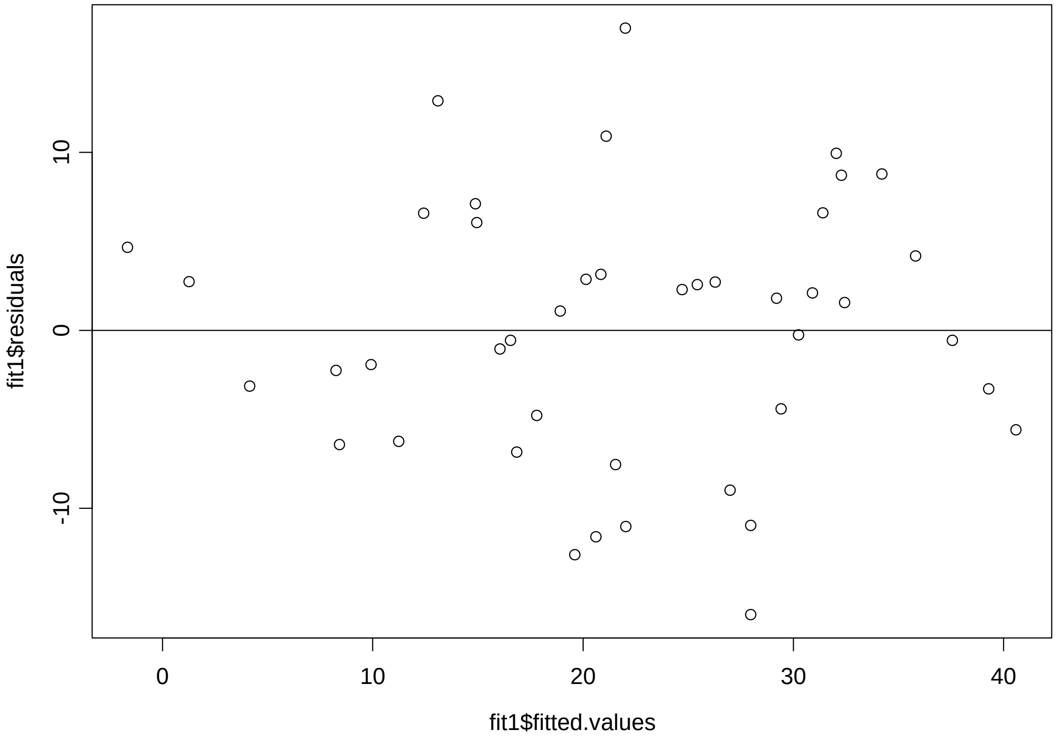
Coefficients	Value	Std. Error	t value	p-value
Intercept	22.4890	3.9069	5.7562	0.0000
dirSE	11.2986	5.5240	2.0454	0.0484
dirSN	20.2686	5.5332	3.6631	0.0008
dirSW	10.8207	5.5660	1.9441	0.0600
Cdistance	-0.0938	0.0654	-1.4343	0.1604
dirSECdistance	-0.2017	0.0924	-2.1839	0.0358
dirSNCdistance	-0.2521	0.0927	-2.7194	0.0101
dirSWCdistance	-0.1152	0.0926	-1.2448	0.2215
dirNECdistance	0.0504	0.0926	0.5442	0.5897
dirNWCdistance	0.1369	0.0928	1.4747	0.1492

```
Residual standard error: 8.029 on 35 degrees of freedom
Multiple R-Squared: 0.6592
F-statistic: 9.673 on 7 and 35 degrees of freedom, the p-
value is 1.215e-006
```

As ppm Statistical Inference:

There is evidence of an interaction effect between distance from the mine and direction on the As ppm in *Hypogymnia physodes* lichen samples. The As ppm falls more rapidly in the East and North directions than in the South direction (p-values = 0.0358 and 0.0101 respectively). There is no evidence that the As ppm in *Hypogymnia physodes* lichen samples decreases as the distance from mine sites increases.

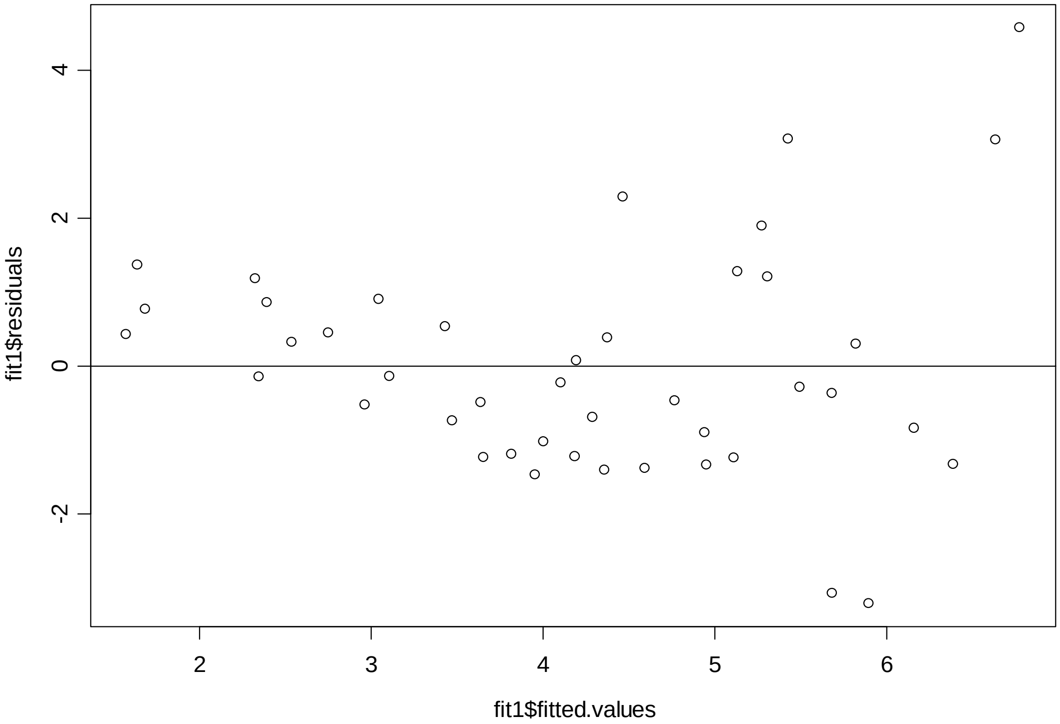
As ppm Rank Regression Residual Plot:



B ppm

B ppm Linear Regression

B ppm Linear Regression Residual Plot



B ppm Log Transformation

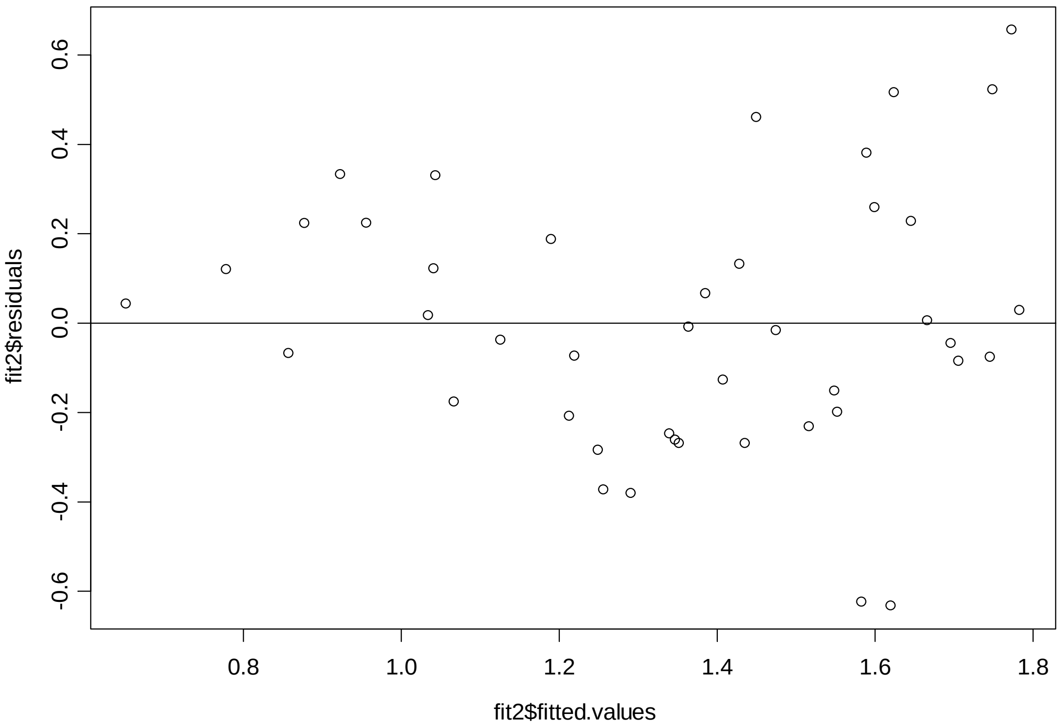
B ppm Regression Table:

```
Coefficients    Value  Std. Error  t value  P-value
Intercept      1.6616   0.1124    14.7862   0.0000
      dirEN    0.0626   0.1342     0.4667   0.6434
      dirES   -0.0463   0.1342    -0.3452   0.7319
      dirEW    0.1358   0.1375     0.9880   0.3294
  Cdistance   -0.0074   0.0013    -5.7415   0.0000

Residual standard error: 0.3146 on 38 degrees of freedom
Multiple R-Squared: 0.4796
F-statistic: 8.755 on 4 and 38 degrees of freedom, the P-
value is 0.00004125
```

B ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the B ppm in *Hypogymnia physodes lichen* samples. There is strong evidence that the B ppm in *Hypogymnia physodes lichen* samples decreases as the distance from mine sites increases (p-value < 0.0001). There is no evidence that the B ppm in *Hypogymnia physodes lichen* samples is different in any direction.

B ppm Log Transformed Residual Plot



Ba ppm

Ba ppm Linear Regression

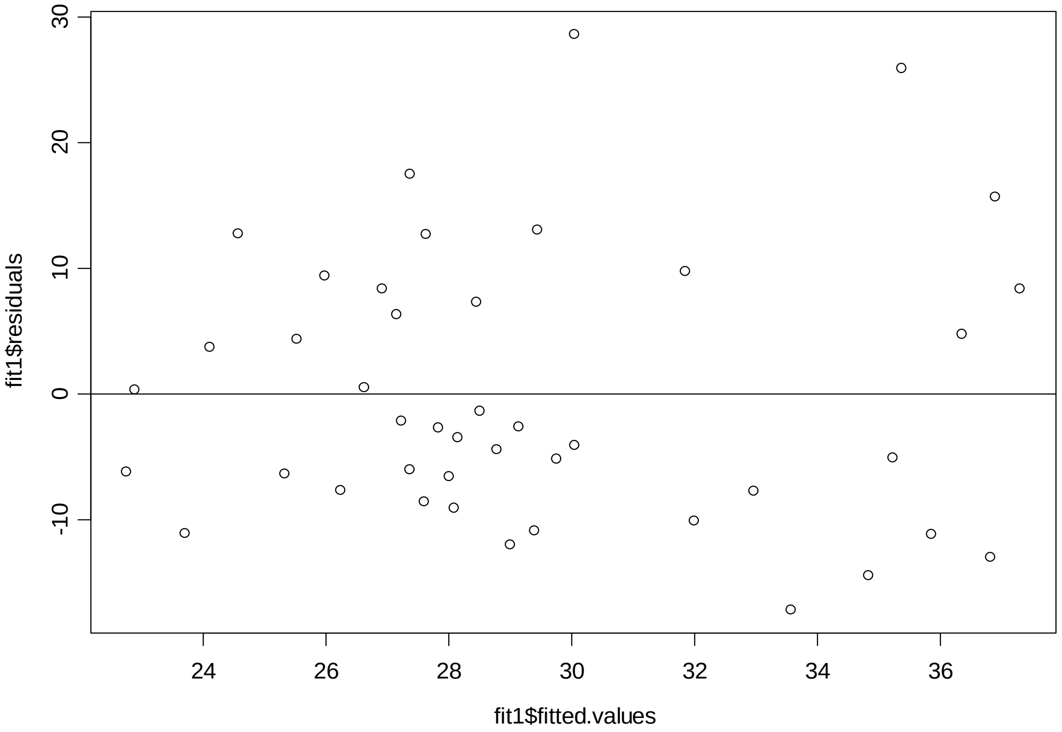
Ba ppm Regression Table:

```
Coefficients   Value Std. Error  t value   P-value
Intercept    28.8641   4.1499     6.9554   0.0000
      dirEN  -1.3111   4.9541    -0.2647   0.7927
      dirES   5.8265   4.9541     1.1761   0.2469
      dirEW   3.3017   5.0765     0.6504   0.5194
  Cdistance  -0.0304   0.0474    -0.6415   0.5251

Residual standard error: 11.62 on 38 degrees of freedom
Multiple R-Squared: 0.07205
F-statistic: 0.7377 on 4 and 38 degrees of freedom, the P-
value is 0.5721
```

Ba ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the Ba ppm in *Hypogymnia physodes lichen* samples. There is no evidence that the Ba ppm in *Hypogymnia physodes lichen* samples decreases as the distance from mine sites increases (p-value = 0.5251). There is no evidence that the Ba ppm in *Hypogymnia physodes lichen* samples is different in any direction.

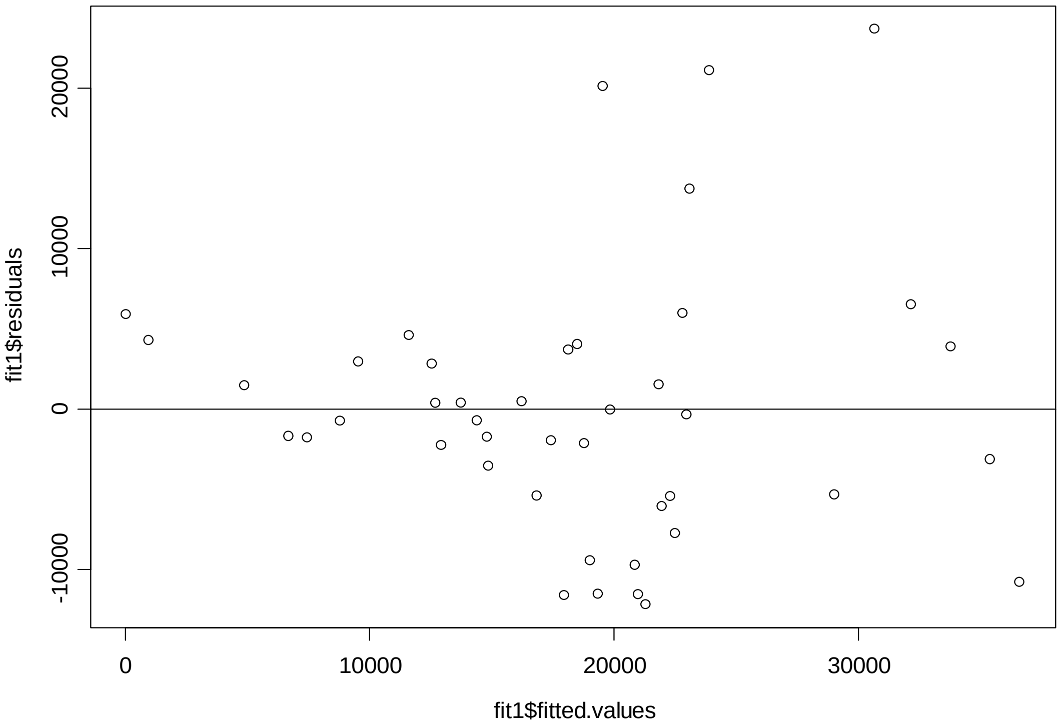
Ba ppm Linear Regression Residual Plot:



Ca ppm

Ca ppm Linear Regression

Ca ppm Linear Regression Residual Plot:



Ca ppm Log Transformation

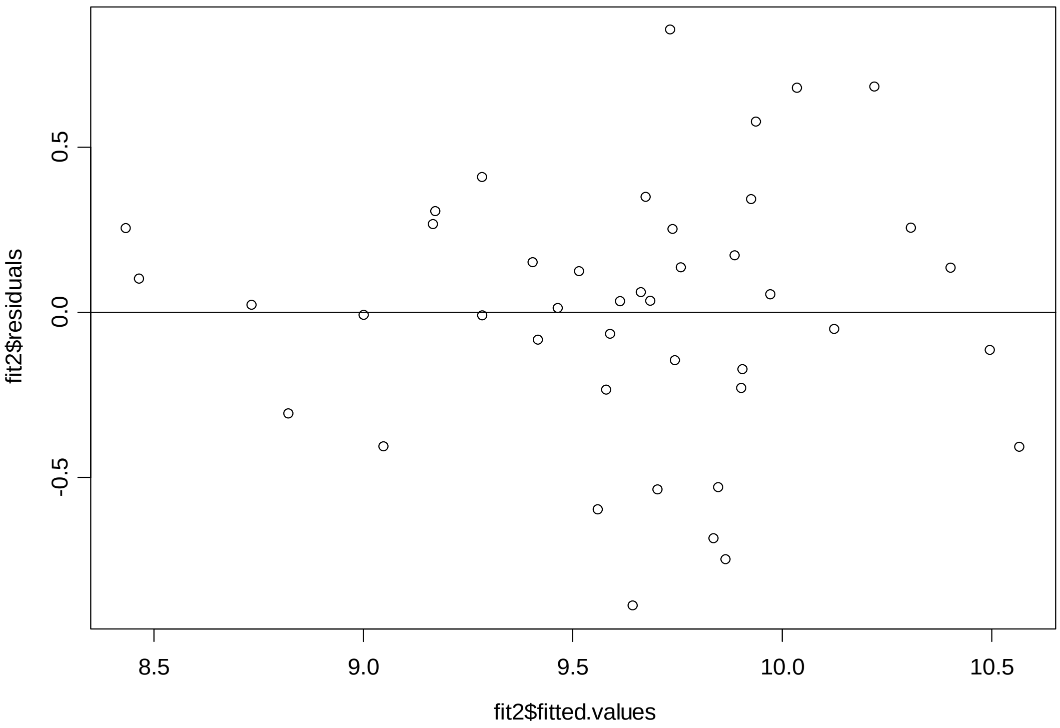
Ca ppm Regression Table:

```
Coefficients       Value Std. Error  t value   P-value
     Intercept   9.9607   0.2084    47.7973   0.0000
         dirWE   0.1453   0.2925     0.4966   0.6225
         dirWN   0.7241   0.2930     2.4714   0.0185
         dirWS  -0.1974   0.2926    -0.6747   0.5043
     Cdistance  -0.0037   0.0034    -1.0762   0.2892
dirWECdistance  -0.0100   0.0049    -2.0502   0.0479
dirWNCdistance  -0.0151   0.0049    -3.0863   0.0039
dirWSCdistance  -0.0022   0.0049    -0.4615   0.6473

Residual standard error: 0.4221 on 35 degrees of freedom
Multiple R-Squared: 0.6149
F-statistic: 7.983 on 7 and 35 degrees of freedom, the P-
value is 8.821e-006
```

Ca ppm Statistical Inference:

There is evidence of an interaction effect between distance from mine sites and direction on the Ca ppm in *Hypogymnia physodes lichen* samples. The Ca ppm decreases more rapidly in the East and North directions than in the West direction (p-values = 0.0479 and 0.0039 respectively). There is no evidence that the Ca ppm in *Hypogymnia physodes lichen* samples decreases with increasing distance from mine sites (p-value = 0.2892).

Ca ppm Log Transformed Residual Plot:



Cd ppm

Cd ppm Linear Regression

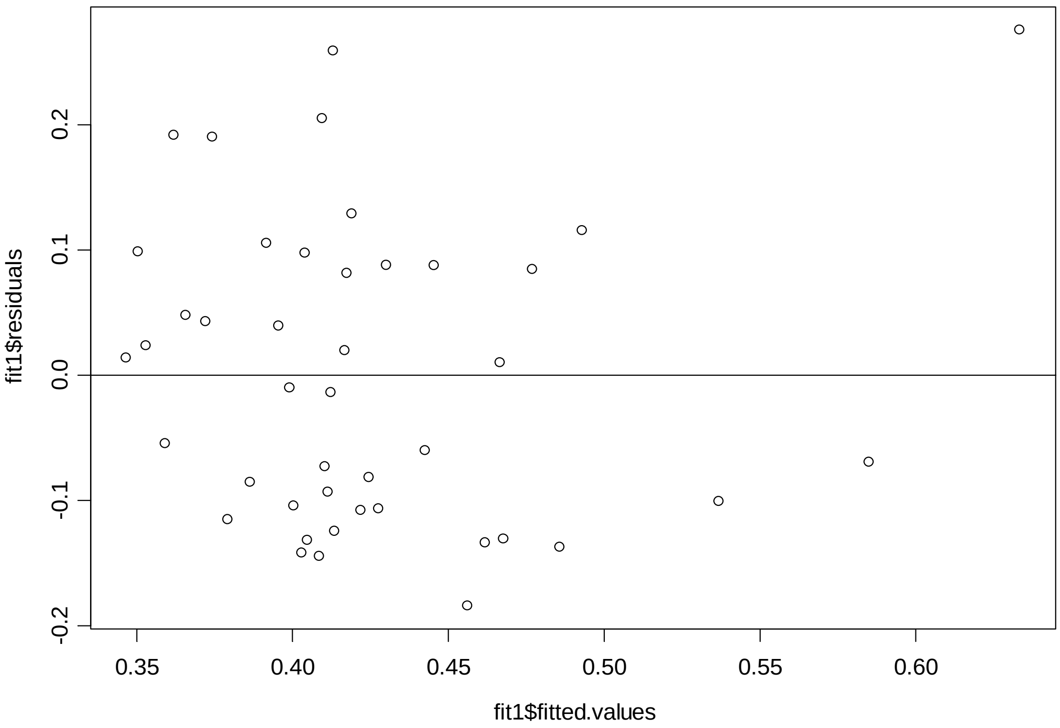
Cd ppm Linear Regression Table:

```
Coefficients       Value Std. Error  t value   P-value
Intercept         0.4056   0.0475     8.5450   0.0000
      dirEN      -0.0481   0.0567    -0.8494   0.4010
      dirES      -0.0536   0.0567    -0.9453   0.3505
      dirEW      -0.0145   0.0581    -0.2499   0.8040
  Cdistance       0.0010   0.0005     1.8884   0.0666

Residual standard error: 0.1329 on 38 degrees of freedom
Multiple R-Squared: 0.1123
F-statistic: 1.202 on 4 and 38 degrees of freedom, the p-
value is 0.3258
```

Cd ppm Statistical Inference:

There is no evidence of an interaction effect between distance from the mine and direction on the Cd ppm in *Hypogymnia physodes* lichen samples. There is suggestive evidence that the Cd ppm in *Hypogymnia physodes* lichen samples falls the further the distance from the mine (p-value = 0.0666). There is no evidence that the Cd ppm in *Hypogymnia physodes* lichen samples is different in any direction.

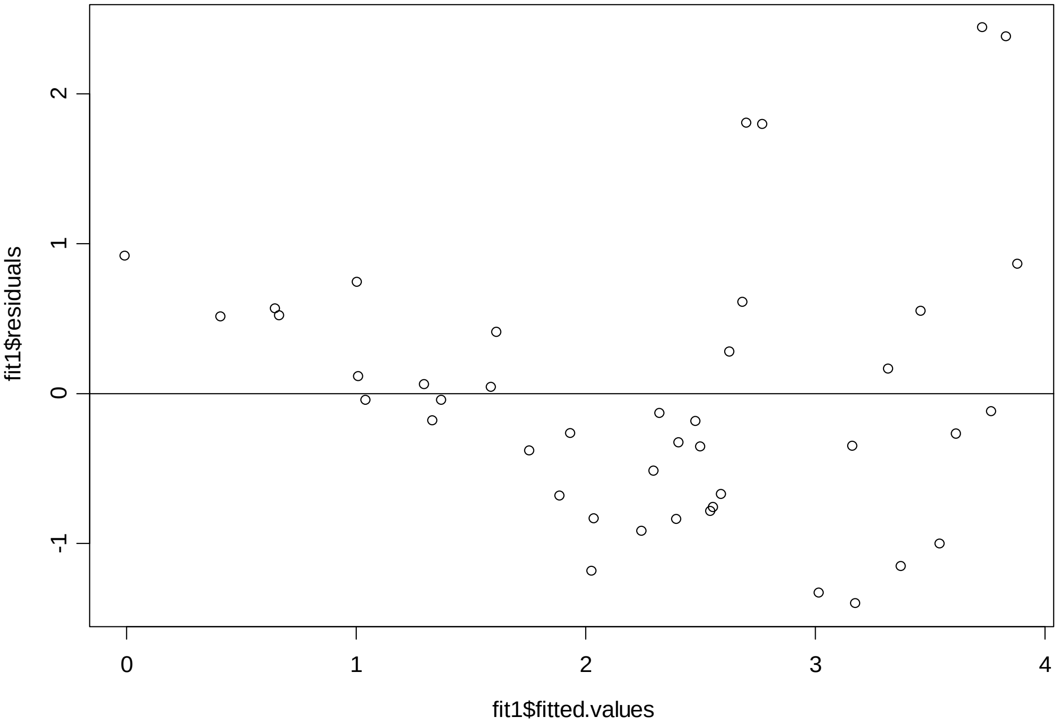
Cd ppm Linear Regression Residual Plot:



Cr ppm

Cr ppm Linear Regression

Cr ppm Linear Regression Residual Plot:



Cr ppm Log Transformation

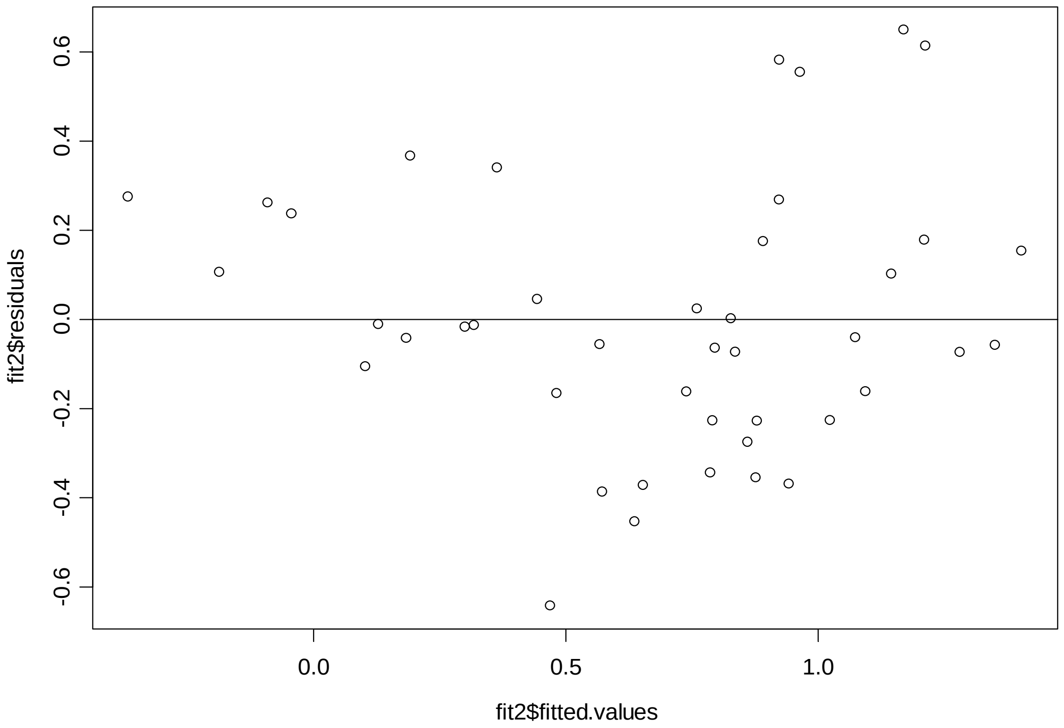
Cr ppm Regression Table:

```
Coefficients  Value Std. Error t value  P-value
Intercept    1.1013  0.1210     9.0992  0.0000
      dirEN  0.2378  0.1445     1.6457  0.1081
      dirES  0.0592  0.1445     0.4096  0.6844
      dirEW  0.0494  0.1481     0.3333  0.7407
  Cdistance -0.0107  0.0014    -7.7744  0.0000

Residual standard error: 0.3389 on 38 degrees of freedom
Multiple R-Squared: 0.6257
F-statistic: 15.88 on 4 and 38 degrees of freedom, the P-
value is 1.001e-007
```

Cr ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the Cr ppm in *Hypogymnia physodes lichen* samples. There is strong evidence that the Cr ppm in *Hypogymnia physodes lichen* samples decreases as the distance from mine sites increases (p-value < 0.0001). There is no evidence that the Cr ppm in *Hypogymnia physodes lichen* samples is different in any direction.

Cr ppm Log Transformed Residual Plot:



Cu ppm

Cu ppm Linear Regression

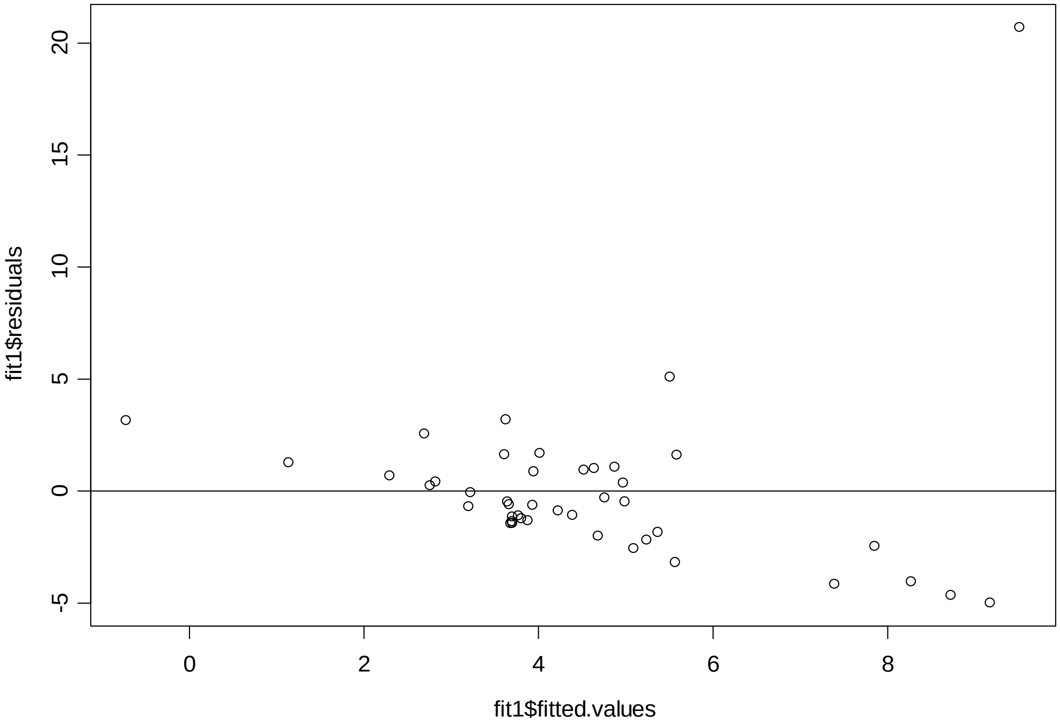
Cu ppm Regression Table:

```
Coefficients  Value Std. Error t value  P-value
Intercept    5.3415  1.5294     3.4927  0.0012
      dirEN  2.0945  1.8258     1.1472  0.2585
      dirES  0.2464  1.8258     0.1350  0.8933
      dirEW  0.7835  1.8709     0.4188  0.6777
  Cdistance -0.0337  0.0175    -1.9291  0.0612

Residual standard error: 4.282 on 38 degrees of freedom
Multiple R-Squared: 0.1224
F-statistic: 1.324 on 4 and 38 degrees of freedom, the P-
value is 0.2785
```

Cu ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the Cu ppm in *Hypogymnia physodes lichen* samples. There is suggestive evidence that the Cu ppm in *Hypogymnia physodes lichen* samples decreases as the distance from mine sites increases (p-value = 0.0612). There is no evidence that the Cu ppm in *Hypogymnia physodes lichen* samples is different in any direction.

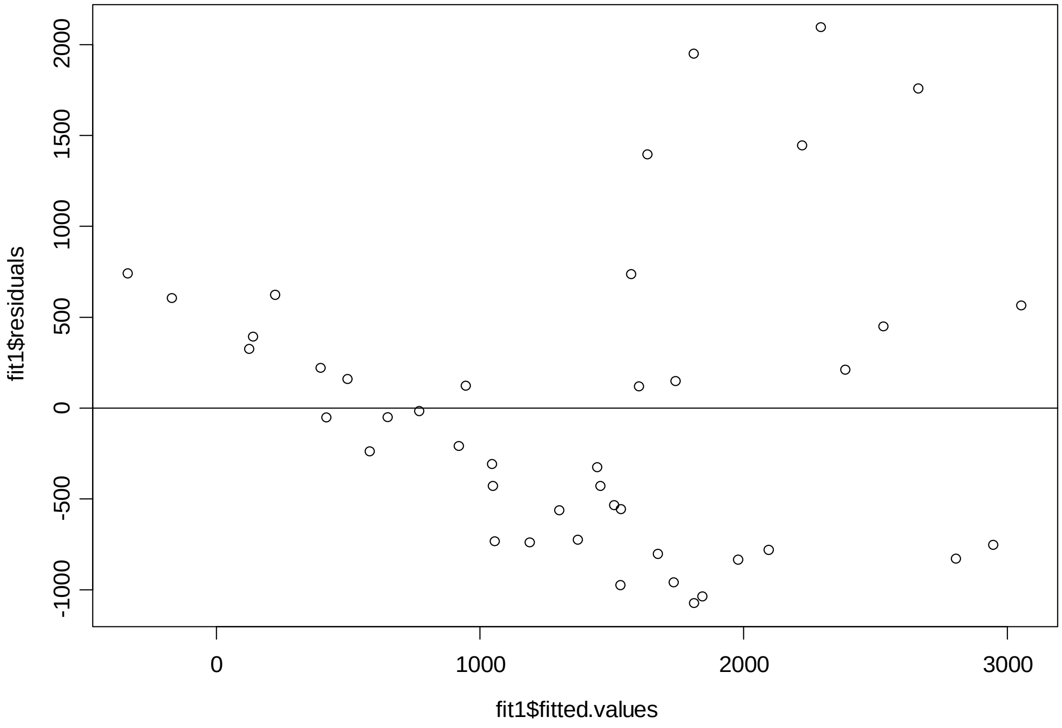
Cu ppm Linear Regression Residual Plot:



Fe ppm

Fe ppm Linear Regression

Fe ppm Linear Regression Residual Plot:



Fe ppm Log Transformation

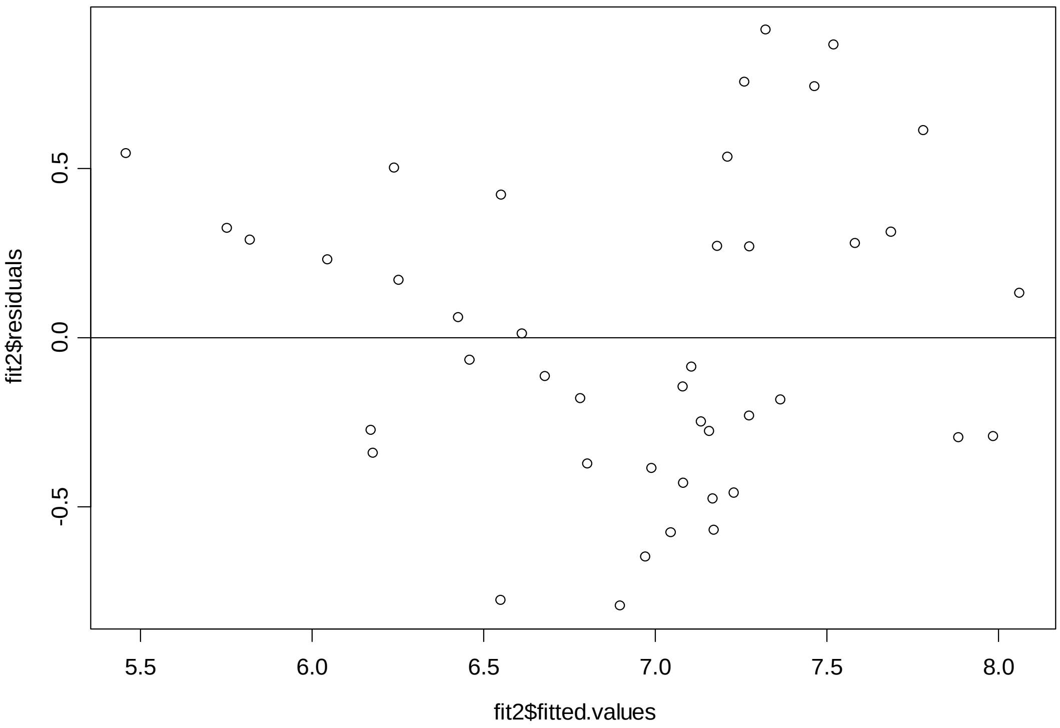
Fe ppm Regression Table:

```
Coefficients   Value Std. Error  t value   P-value
Intercept     7.9202   0.1823    43.4398   0.0000
      dirNE  -0.4178   0.2178    -1.9183   0.0626
      dirNS  -0.3086   0.2178    -1.4170   0.1646
      dirNW  -0.4545   0.2232    -2.0367   0.0487
  Cdistance  -0.0146   0.0021    -7.0044   0.0000

Residual standard error: 0.5108 on 38 degrees of freedom
Multiple R-Squared: 0.5883
F-statistic: 13.57 on 4 and 38 degrees of freedom, the P-
value is 5.801e-007
```

Fe ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the Fe ppm in *Hypogymnia physodes lichen* samples. There is strong evidence that the Fe ppm in *Hypogymnia physodes lichen* samples decreases as the distance from mine sites increases (p-value < 0.0001). There is evidence that the Fe ppm in *Hypogymnia physodes lichen* samples is greater in the North than in the East and West (p-values = 0.0626 and 0.0487 respectively).

Fe ppm Log Transformed Residual Plot:



Hg ppb

Hg ppb Linear Regression

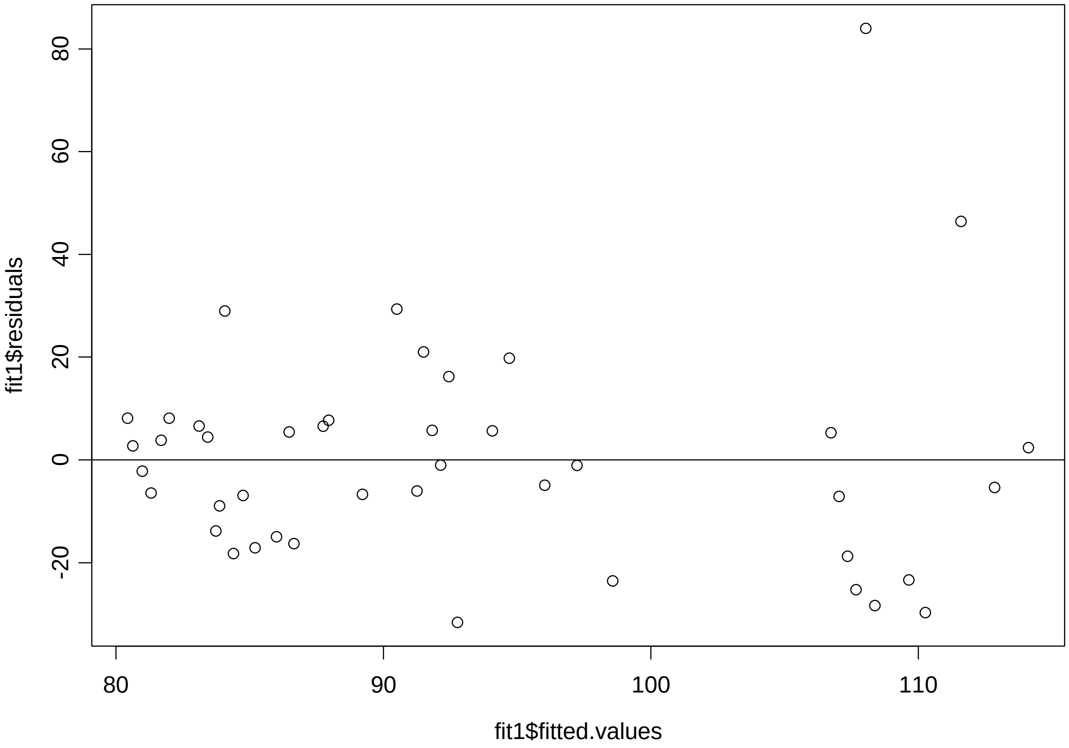
Hg ppb Linear Regression Table:

```
Coefficients  Value     Std. Error  t value   p-value
Intercept    106.4114    7.9644    13.3608    0.0000
      dirEN  -15.5528    9.5080    -1.6358    0.1101
      dirES  -23.6229    9.5080    -2.4845    0.0175
      dirEW  -26.3638    9.7429    -2.7060    0.0101
  Cdistance    0.0643    0.0909     0.7074    0.4836

Residual standard error: 22.3 on 38 degrees of freedom
Multiple R-Squared: 0.2021
F-statistic: 2.407 on 4 and 38 degrees of freedom, the p-
value is 0.06631
```

Hg ppb Statistical Inference:

There is no evidence of an interaction effect between distance from the mine and direction on the Hg ppb in *Hypogymnia physodes* lichen samples. There is no evidence that the Hg ppb in *Hypogymnia physodes lichen* samples changes the further the distance from the mine (p-value = 0.4836). There is evidence that the Hg ppb in *Hypogymnia physodes* lichen samples is greater in the East direction than in the South and West directions (p-values = 0.0175 and 0.0101 respectively).

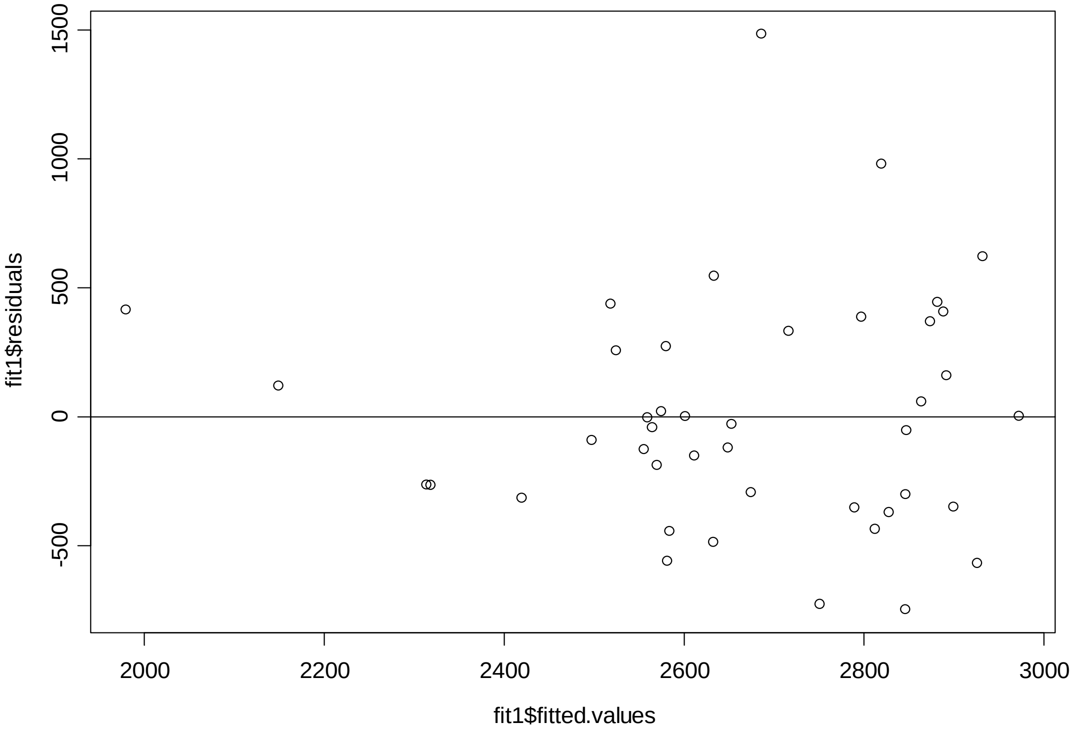
Hg ppb Linear Regression Residual Plot:



K ppm

K ppm Linear Regression

K ppm Linear Regression Residual Plot:



K ppm Log Transformation

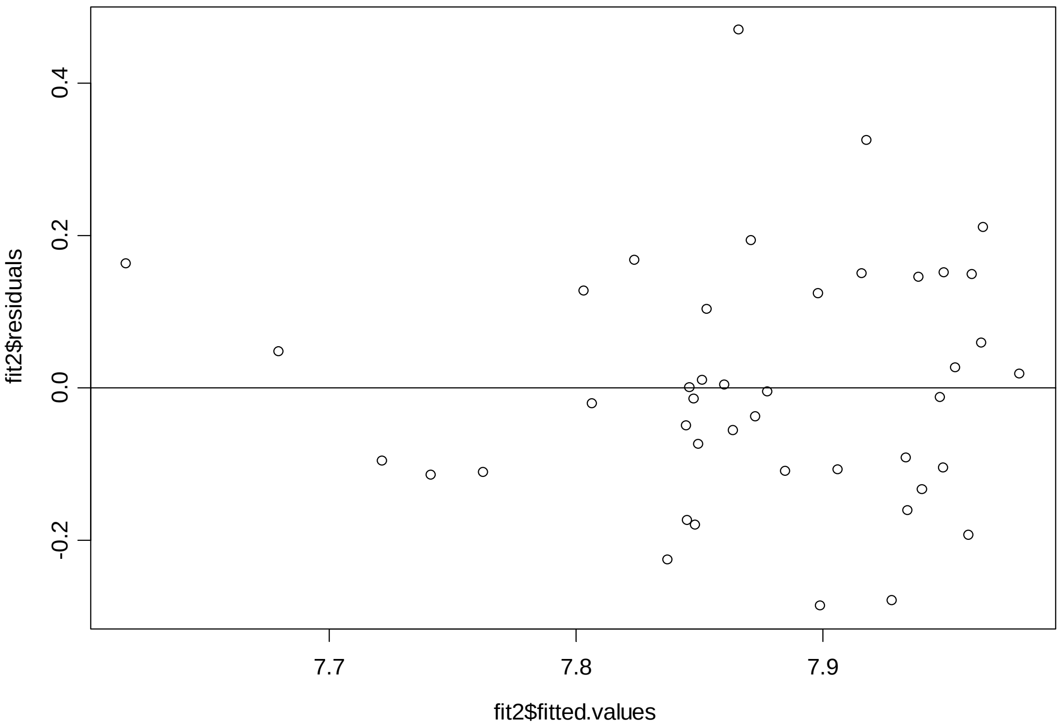
K ppm Regression Table:

```
Coefficients    Value Std. Error   t value    P-value
Intercept      7.9197     0.0620  127.8312     0.0000
      dirEN    0.0112     0.0740    0.1517     0.8803
      dirES    0.0246     0.0740    0.3331     0.7409
      dirEW    0.0659     0.0758    0.8693     0.3901
  Cdistance   -0.0015     0.0007   -2.1668     0.0366

Residual standard error: 0.1735 on 38 degrees of freedom
Multiple R-Squared: 0.1278
F-statistic: 1.392 on 4 and 38 degrees of freedom, the P-
value is 0.2551
```

K ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the K ppm in *Hypogymnia physodes lichen* samples. There is evidence that the K ppm in *Hypogymnia physodes lichen* samples decreases as the distance from mine sites increases (p-value = 0.0366). There is no evidence that the K ppm in *Hypogymnia physodes lichen* samples is different in any direction.

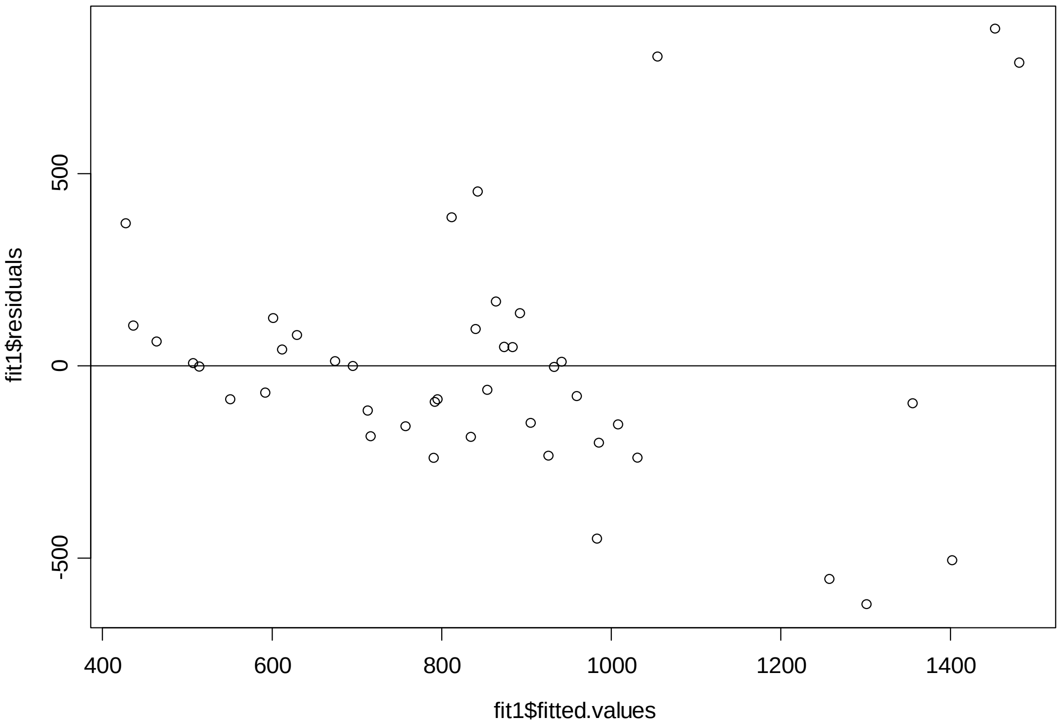
K ppm Log Transformed Residual Plot:



Mg ppm

Mg ppm Linear Regression

Mg ppm Linear Regression Residual Plot:



Mg ppm Log Transformation

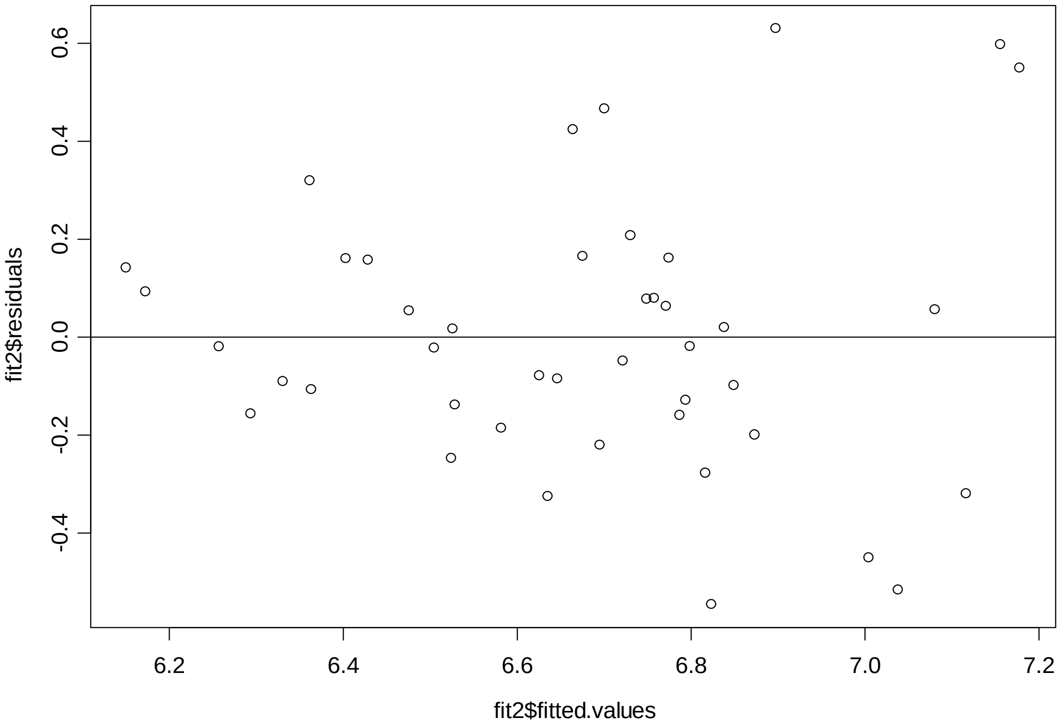
Mg ppm Regression Table:

```
Coefficients   Value Std. Error  t value   P-value
Intercept      7.1596   0.1063    67.3224   0.0000
      dirWE  -0.3381   0.1261    -2.6823   0.0108
      dirWN  -0.2850   0.1261    -2.2607   0.0296
      dirWS  -0.1944   0.1261    -1.5424   0.1313
  Cdistance  -0.0058   0.0012    -4.9695   0.0000

Residual standard error: 0.2885 on 38 degrees of freedom
Multiple R-Squared: 0.4654
F-statistic: 8.27 on 4 and 38 degrees of freedom, the P-
value is 0.00006695
```

Mg ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the Mg ppm in *Hypogymnia physodes lichen* samples. There is strong evidence that the Mg ppm in *Hypogymnia physodes lichen* samples decreases as the distance from mine sites increases (p-value < 0.0001). There is evidence that the Mg ppm in *Hypogymnia physodes lichen* samples is smaller in the East and North directions than in the West direction (p-values = 0.0108 and 0.0296 respectively).

Mg ppm Log Transformed Residual Plot:



Mn ppm

Mn ppm Linear Regression

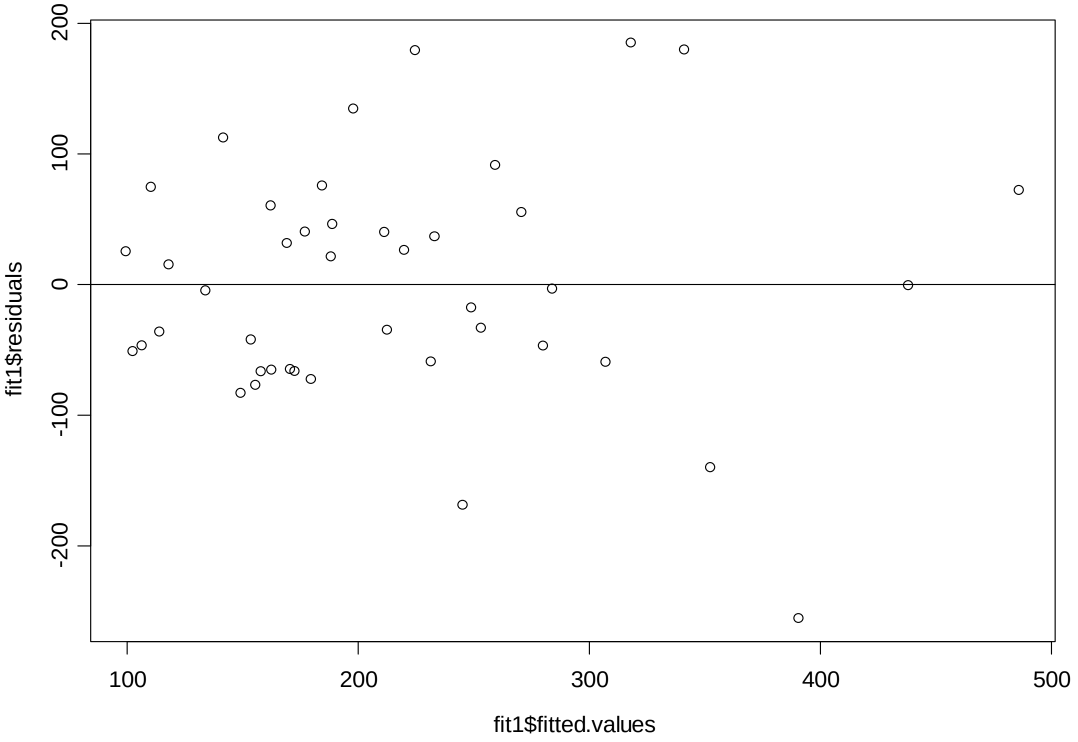
Mn ppm Regression Table:

```
Coefficients    Value Std. Error   t value    P-value
Intercept    236.6152   35.8677     6.5969    0.0000
      dirWE -103.7161   42.5169    -2.4394    0.0195
      dirWN -178.8894   42.5168    -4.2075    0.0002
      dirWS  -84.2673   42.5168    -1.9820    0.0547
      dirNS   94.6221   41.4918     2.2805    0.0283
  Cdistance    1.5743    0.3967     3.9685    0.0003

Residual standard error: 97.31 on 38 degrees of freedom
Multiple R-Squared: 0.4688
F-statistic: 8.385 on 4 and 38 degrees of freedom, the P-
value is 0.00005963
```

Mn ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the Mn ppm in *Hypogymnia physodes lichen* samples. There is strong evidence that the Mn ppm in *Hypogymnia physodes* lichen samples increases as the distance from mine sites increases (p-value < 0.0003). There is evidence that the Mn ppm in *Hypogymnia physodes* lichen samples is greater in the West direction than in the East, North, and South directions (p-values = 0.0195, 0.0002, ,and 0.0547 respectively). There is evidence that the Mn ppm in *Hypogymnia physodes* lichen samples is greater in the South direction than in the North direction (p-value = 0.0.0283).

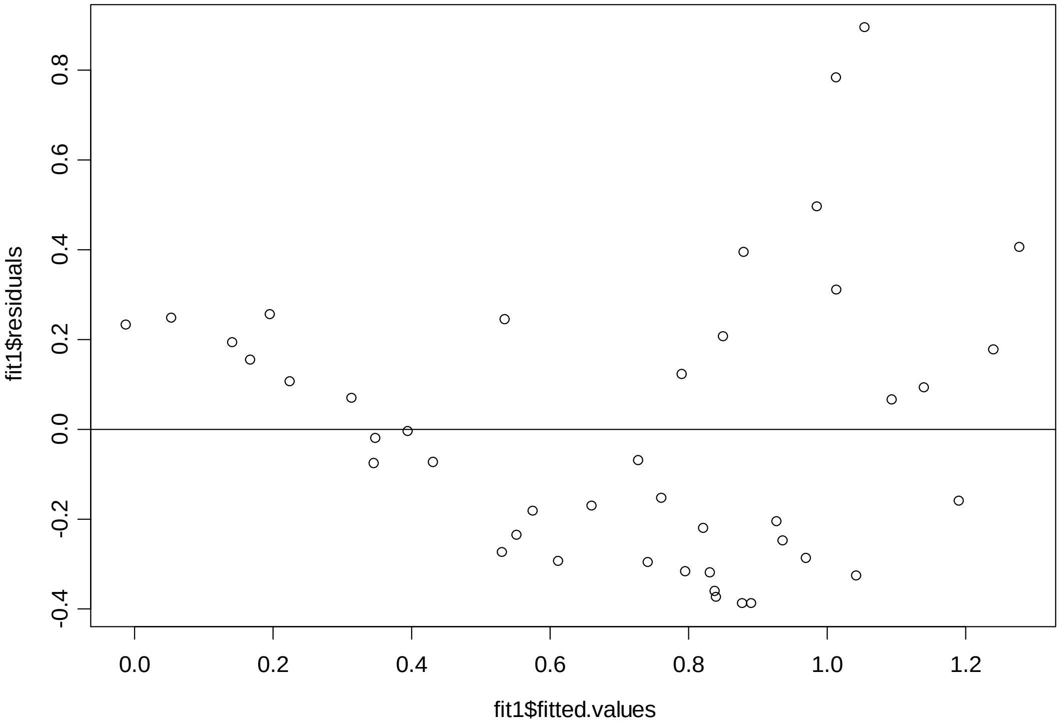
Mn ppm Linear Regression Residual Plot:



Mo ppm

Mo ppm Linear Regression

Mo ppm Linear Regression Residual Plot:



Mo ppm Log Transformation

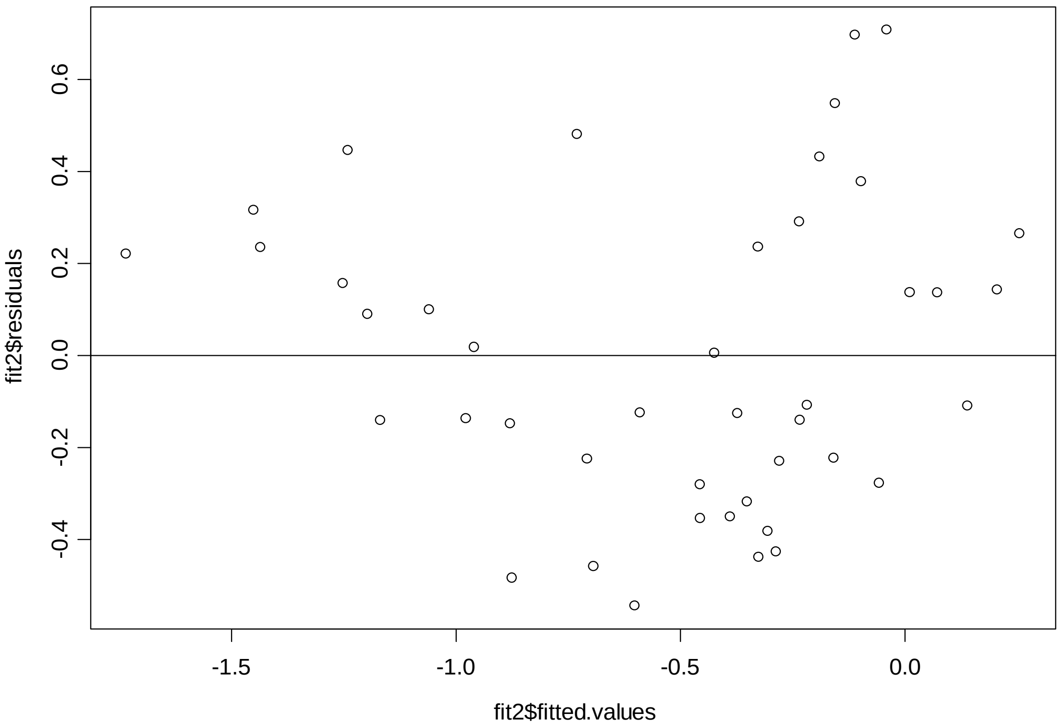
Mo ppm Regression Table:

```
Coefficients  Value Std. Error t value  P-value
Intercept    0.2892  0.1273     2.2711  0.0289
      dirNE -0.2650  0.1521    -1.7426  0.0895
      dirNS -0.2896  0.1521    -1.9041  0.0645
      dirNW -0.4100  0.1559    -2.6303  0.0123
  Cdistance -0.0122  0.0015    -8.3901  0.0000

Residual standard error: 0.3567 on 38 degrees of freedom
Multiple R-Squared: 0.6718
F-statistic: 19.45 on 4 and 38 degrees of freedom, the P-
value is 8.822e-009
```

Mo ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the Mo ppm in *Hypogymnia physodes lichen* samples. There is strong evidence that the Mo ppm in *Hypogymnia physodes lichen* samples decreases as the distance from mine sites increases (p-value < 0.0001). There is evidence that the Mo ppm in *Hypogymnia physodes lichen* samples is greater in the North than in the West direction (p-value = 0.0123). There is suggestive evidence that the Mo ppm in *Hypogymnia physodes lichen* samples is greater in the North than in the East and South directions (p-value = 0.0895 and 0.0645 respectively).

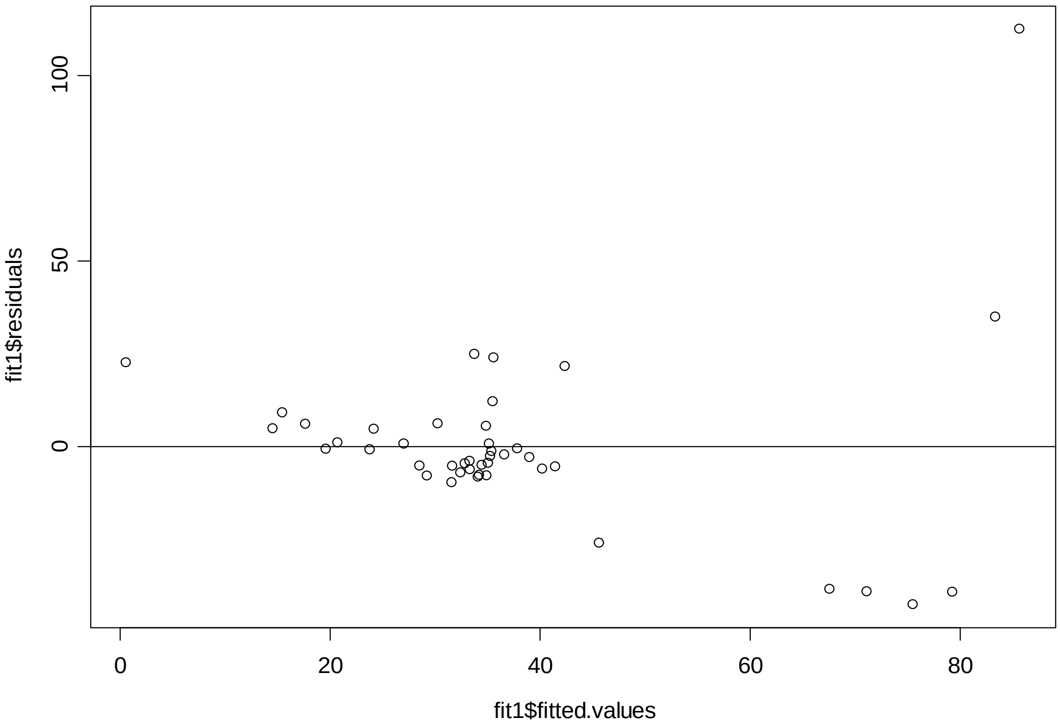
Mo ppm Log Transformed Residual Plot:



Na ppm

Na ppm Linear Regression

Na ppm Linear Regression Residual Plot:



Na ppm Log Transformation

Na ppm Regression Table:

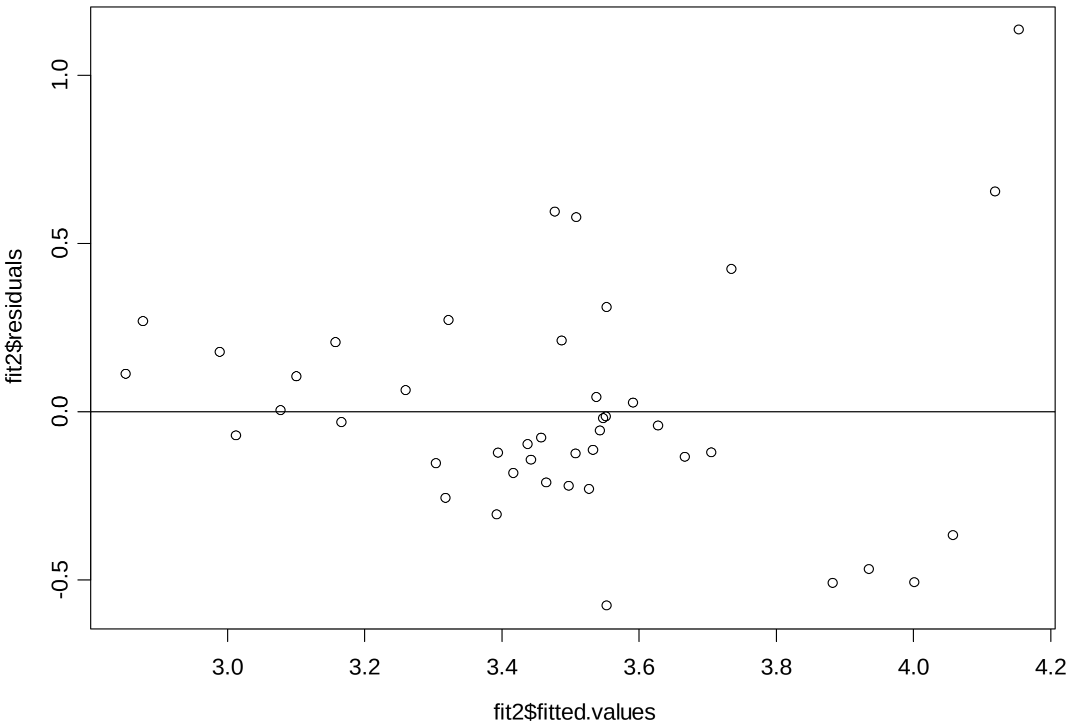
```
Coefficients   Value Std. Error  t value   P-value
Intercept      3.9849   0.1406    28.3431   0.0000
      dirWE  -0.3780   0.1667    -2.2684   0.0291
      dirWN  -0.2784   0.1667    -1.6704   0.1031
      dirWS  -0.1866   0.1667    -1.1199   0.2698
  Cdistance  -0.0061   0.0016    -3.9332   0.0003
```

```
Residual standard error: 0.3814 on 38 degrees of freedom
Multiple R-Squared: 0.3571
F-statistic: 5.278 on 4 and 38 degrees of freedom, the P-
value is 0.00176
```

Na ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the Na ppm in *Hypogymnia physodes lichen* samples. There is strong evidence that the Na ppm in *Hypogymnia physodes lichen* samples decreases as the distance from mine sites increases (p-value = 0.0003). There is evidence that the Na ppm in *Hypogymnia physodes lichen* samples is greater in the West direction than in the East direction (p-value = 0.0291).

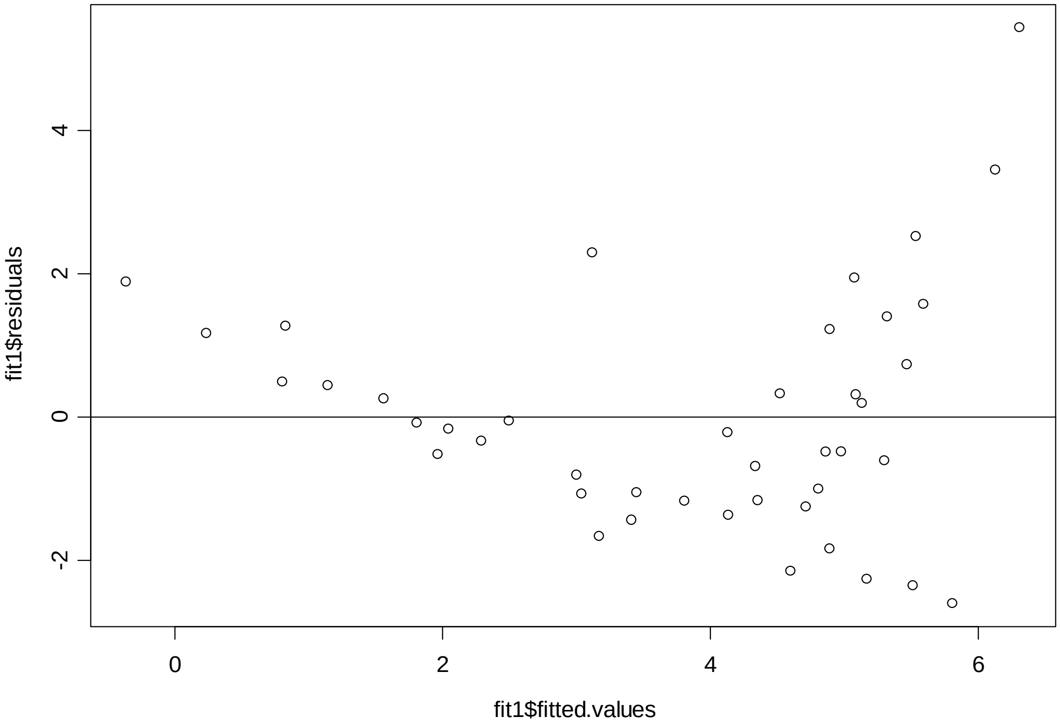
Na ppm Log Transformed Residual Plot:



Ni ppm

Ni ppm Linear Regression

Ni ppm Linear Regression Residual Plot:



Ni ppm Log Transformation

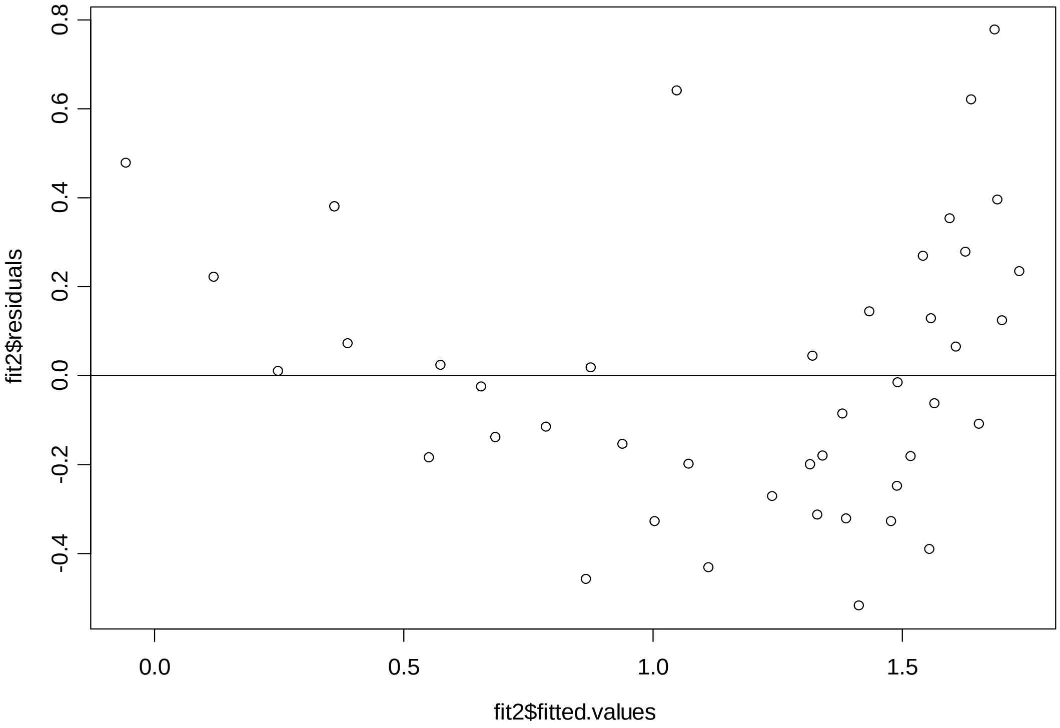
Ni ppm Regression Table:

```
Coefficients   Value Std. Error  t value   P-value
Intercept     1.9346   0.1207    16.0336   0.0000
      dirNE  -0.2409   0.1441    -1.6712   0.1029
      dirNS  -0.2141   0.1441    -1.4854   0.1457
      dirNW  -0.2981   0.1477    -2.0181   0.0507
  Cdistance  -0.0123   0.0014    -8.8928   0.0000

Residual standard error: 0.338 on 38 degrees of freedom
Multiple R-Squared: 0.688
F-statistic: 20.95 on 4 and 38 degrees of freedom, the P-
value is 3.447e-009
```

Ni ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the Ni ppm in *Hypogymnia physodes lichen* samples. There is strong evidence that the Ni ppm in *Hypogymnia physodes lichen* samples decreases as the distance from mine sites increases (p-value < 0.0001). There is evidence that the Ni ppm in *Hypogymnia physodes* lichen samples is greater in the North direction than in the West direction (p-value = 0.0507).

Ni ppm Log Transformed Residual Plot:



P ppm

P ppm Linear Regression

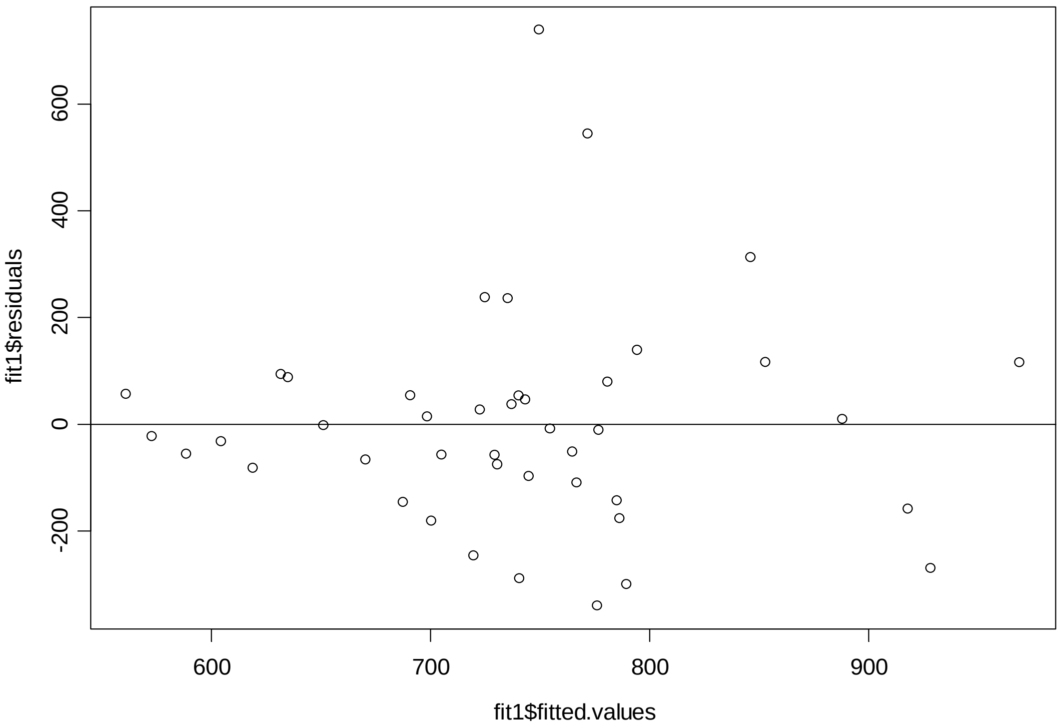
P ppm Regression Table:

```
Coefficients     Value Std. Error   t value    P-value
Intercept    665.3911   80.6206     8.2534    0.0000
      dirEN  -15.0515   96.2454    -0.1564    0.8766
      dirES   48.7134   96.2454     0.5061    0.6157
      dirEW  116.1946   98.6233     1.1782    0.2461
  Cdistance    0.8163    0.9202     0.8871    0.3806

Residual standard error: 225.7 on 38 degrees of freedom
Multiple R-Squared: 0.07124
F-statistic: 0.7287 on 4 and 38 degrees of freedom, the P-
value is 0.5779
```

P ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the P ppm in *Hypogymnia physodes lichen* samples. There is no evidence that the P ppm in *Hypogymnia physodes lichen* samples decreases as the distance from mine sites increases (p-value = 0.3806). There is no evidence that the P ppm in *Hypogymnia physodes lichen* samples is different in any direction.

P ppm Linear Regression Residual Plot:



Pb ppm

Pb ppm Linear Regression

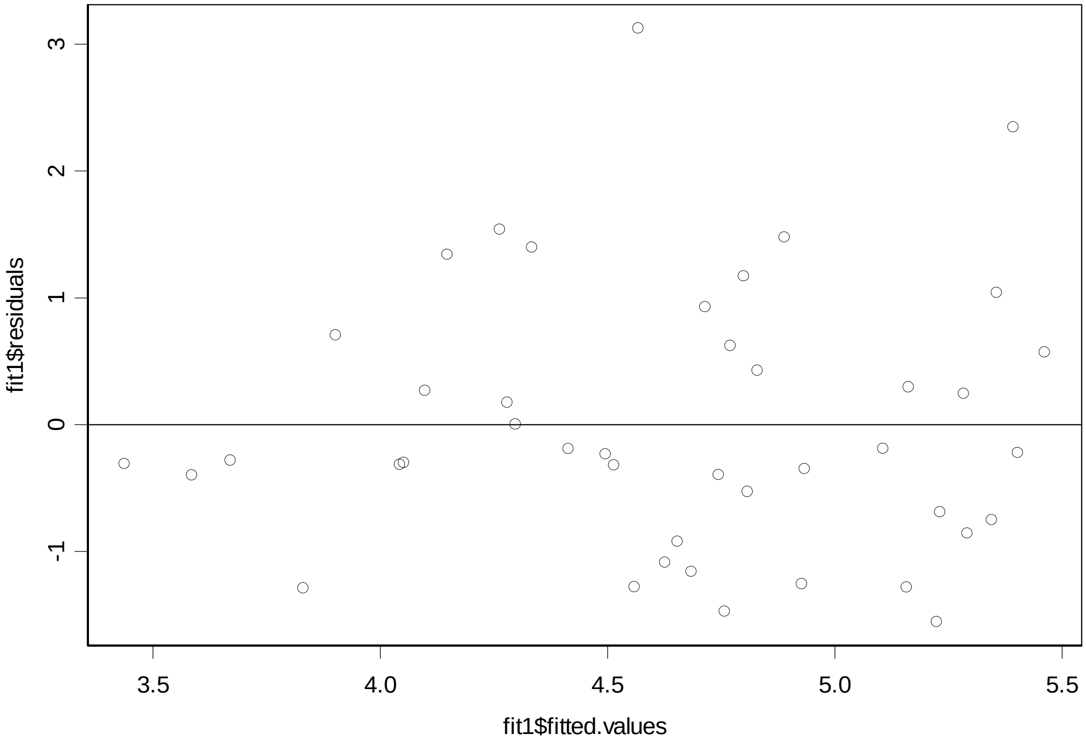
Pb ppm Regression Table:

```
Coefficients   Value Std. Error  t value   P-value
(Intercept)   4.8599   0.3936    12.3466   0.0000
      dirEN   0.1480   0.4699     0.3149   0.7545
      dirES   0.6611   0.4699     1.4069   0.1676
      dirEW   0.6047   0.4815     1.2558   0.2169
  Cdistance  -0.0119   0.0045    -2.6396   0.0120

Residual standard error: 1.102 on 38 degrees of freedom
Multiple R-Squared: 0.2064
F-statistic: 2.471 on 4 and 38 degrees of freedom, the p-
value is 0.06088
```

Pb ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the Pb ppm in *Hypogymnia physodes lichen* samples. There is evidence that the Pb ppm in *Hypogymnia physodes lichen* samples decreases as the distance from mine sites increases (p-value = 0.0120). There is no evidence that the Pb ppm in *Hypogymnia physodes lichen* samples is different in any direction.

Pb ppm Linear Regression Residual Plot:



Si ppm

Si ppm Linear Regression

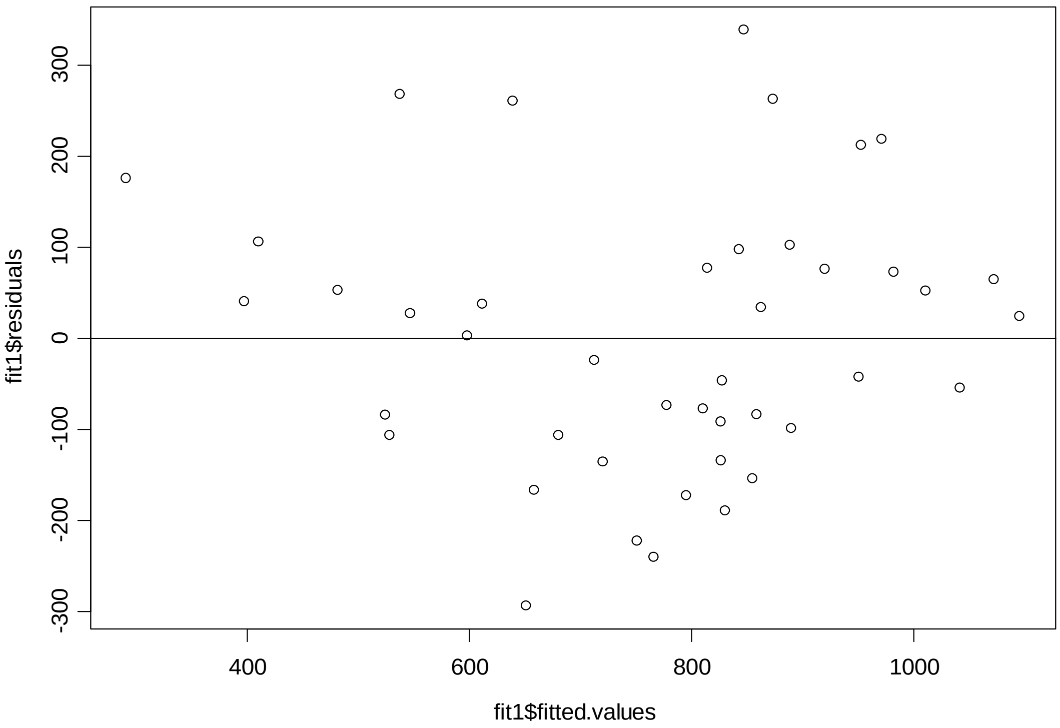
Si ppm Regression Table:

```
Coefficients     Value Std. Error   t value    P-value
Intercept    940.3978   59.5608    15.7889    0.0000
      dirEN  121.8090   71.1040     1.7131    0.0948
      dirES   36.6327   71.1040     0.5152    0.6094
      dirEW    3.5742   72.8607     0.0491    0.9611
  Cdistance   -4.6130    0.6798    -6.7856    0.0000

Residual standard error: 166.8 on 38 degrees of freedom
Multiple R-Squared: 0.567
F-statistic: 12.44 on 4 and 38 degrees of freedom, the P-
value is 1.457e-006
```

Si ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the Si ppm in *Hypogymnia physodes lichen* samples. There is strong evidence that the Si ppm in *Hypogymnia physodes lichen* samples decreases as the distance from mine sites increases (p-value < 0.0001). There is no evidence that the Si ppm in *Hypogymnia physodes lichen* samples is different in any direction.

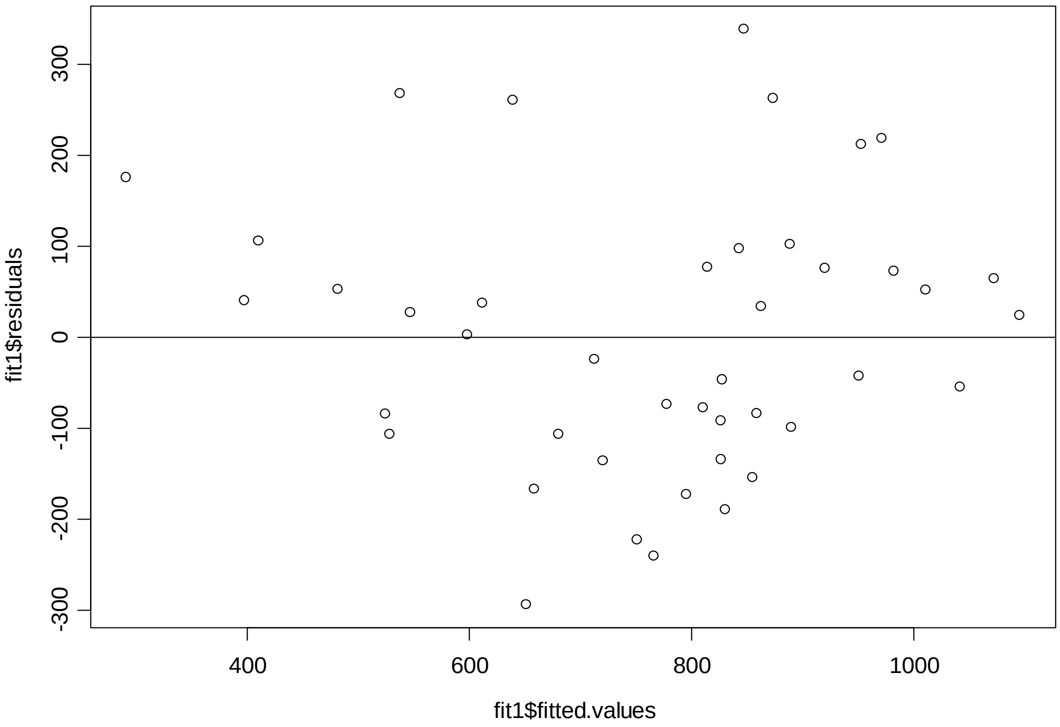
Si ppm Linear Regression Residual Plot:



Sr ppm

Sr ppm Linear Regression

Sr ppm Linear Regression Residual Plot:



Sr ppm Log Transformation

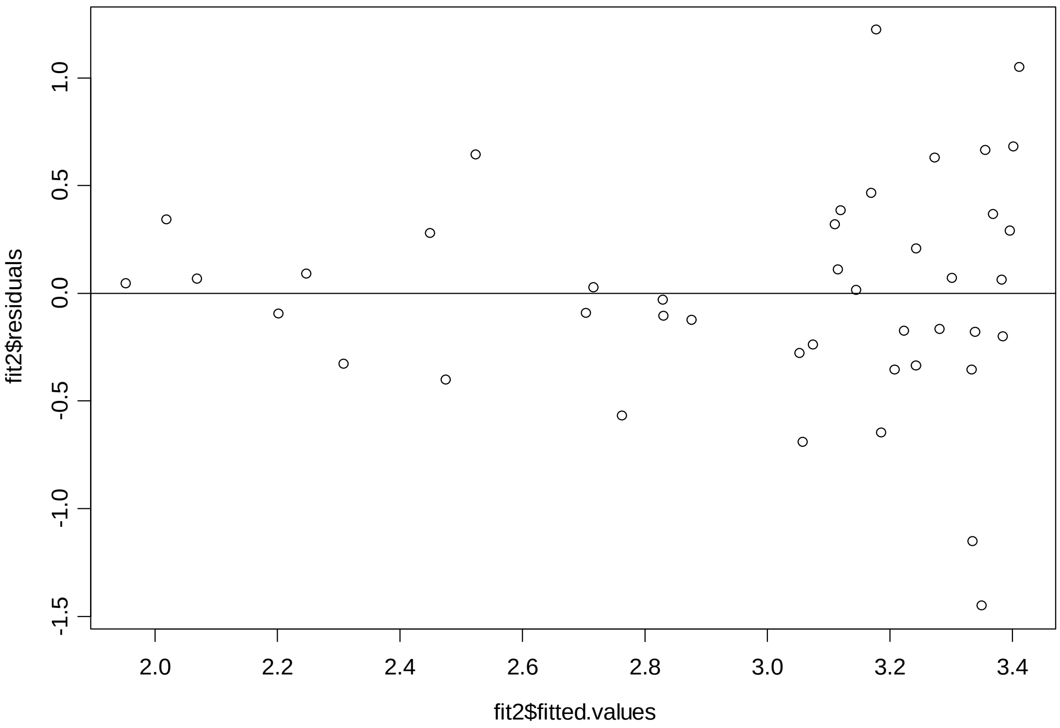
Sr ppm Regression Table:

```
Coefficients   Value Std. Error  t value   P-value
Intercept      3.3259   0.1986    16.7468   0.0000
      dirEN    0.0441   0.2371     0.1860   0.8534
      dirES    0.0010   0.2371     0.0041   0.9967
      dirEW    0.4107   0.2429     1.6905   0.0991
  Cdistance   -0.0097   0.0023    -4.2931   0.0001

Residual standard error: 0.556 on 38 degrees of freedom
Multiple R-Squared: 0.3714
F-statistic: 5.613 on 4 and 38 degrees of freedom, the P-
value is 0.001189
```

Sr ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the Sr ppm in *Hypogymnia physodes lichen* samples. There is strong evidence that the Sr ppm in *Hypogymnia physodes lichen* samples decreases as the distance from mine sites increases (p-value = 0.0001). There is no evidence that the Sr ppm in *Hypogymnia physodes lichen* samples is different in any direction.

Sr ppm Log Transformed Residual Plot:



Ti ppm

Ti ppm Linear Regression

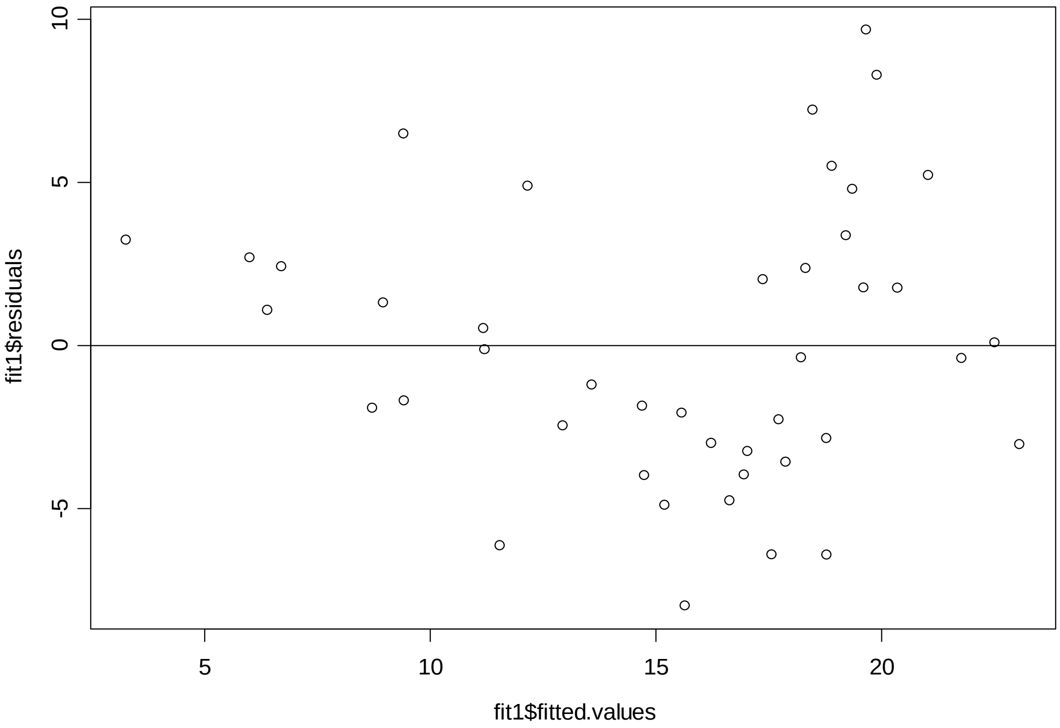
Ti ppm Regression Table:

```
Coefficients   Value Std. Error  t value   P-value
Intercept    19.0126   1.6727    11.3665   0.0000
      dirWE   1.8007   1.9828     0.9082   0.3695
      dirWN   3.8080   1.9828     1.9205   0.0623
      dirWS   2.6307   1.9828     1.3268   0.1925
  Cdistance  -0.1219   0.0185    -6.5891   0.0000

Residual standard error: 4.538 on 38 degrees of freedom
Multiple R-Squared: 0.5541
F-statistic: 11.8 on 4 and 38 degrees of freedom, the P-
value is 2.5e-006
```

Ti ppm Statistical Inference:

There is no evidence of an interaction effect between distance from mine sites and direction on the Ti ppm in *Hypogymnia physodes lichen* samples. There is strong evidence that the Ti ppm in *Hypogymnia physodes lichen* samples decreases as the distance from mine sites increases (p-value < 0.0001). There is suggestive evidence that the Ti ppm in *Hypogymnia physodes lichen* samples is smaller in the West direction than in the North direction (p-value = 0.0623).

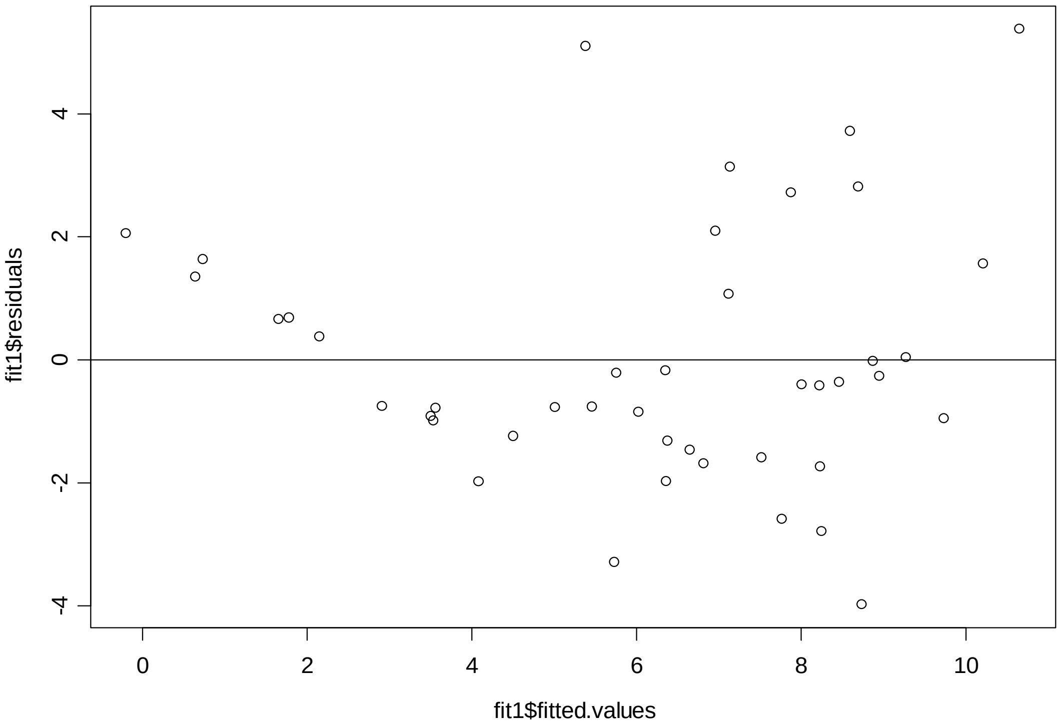
Ti ppm Linear Regression Residual Plot:



V ppm

V ppm Linear Regression

V ppm Linear Regression Residual Plot:



V ppm Log Transformation

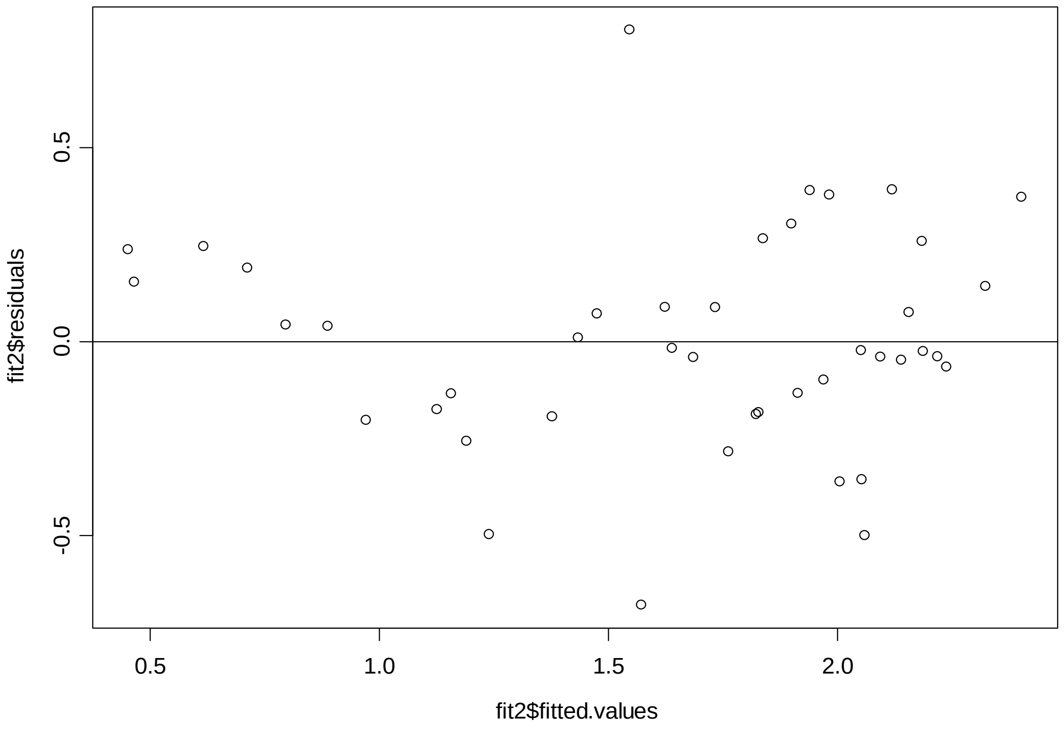
V ppm Regression Table:

```
Coefficients       Value Std. Error  t value   P-value
     Intercept   2.4877   0.1490    16.6928   0.0000
         dirEN  -0.2121   0.2111    -1.0048   0.3219
         dirES  -0.2317   0.2108    -1.0993   0.2791
         dirEW  -0.4683   0.2124    -2.2053   0.0341
     Cdistance  -0.0169   0.0025    -6.7726   0.0000
dirENCdistance   0.0078   0.0035     2.2113   0.0336
dirESCdistance   0.0032   0.0035     0.9058   0.3712
dirEWCdistance   0.0038   0.0035     1.0716   0.2912

Residual standard error: 0.3064 on 35 degrees of freedom
Multiple R-Squared: 0.7845
F-statistic: 18.2 on 7 and 35 degrees of freedom, the P-
value is 5.969e-010
```

V ppm Statistical Inference:

There is evidence of an interaction effect between distance from mine sites and direction on the V ppm in *Hypogymnia physodes lichen* samples. The V ppm in *Hypogymnia physodes* lichen samples decreases more rapidly in the East than in the North direction (p-value = 0.0336). There is strong evidence that the V ppm in *Hypogymnia physodes lichen* samples decreases as the distance from mine sites increases (p-value < 0.0001).

V ppm Log Transformed Residual Plot:



Zn ppm

Zn ppm Linear Regression

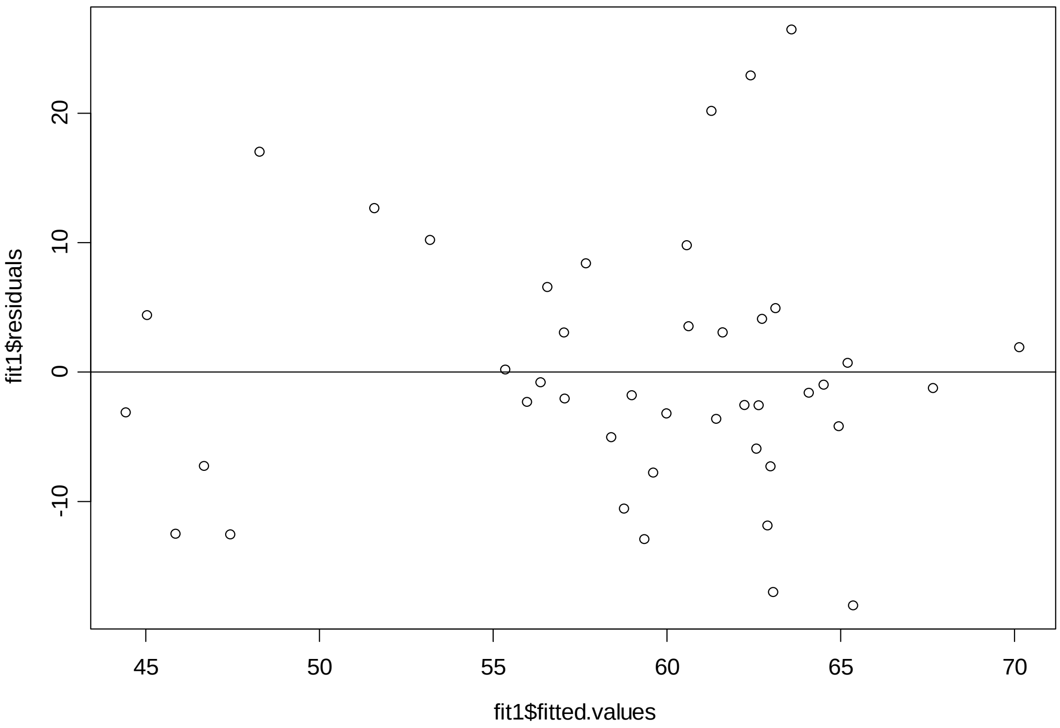
Zn ppm Regression Table:

```
Coefficients        Value Std. Error  t value   P-value
     Intercept  65.8116   5.2939    12.4317   0.0000
         dirEN -22.3889   7.4991    -2.9856   0.0051
         dirES  -2.5798   7.4883    -0.3445   0.7325
         dirEW -10.5738   7.5436    -1.4017   0.1698
     Cdistance  -0.0871   0.0884    -0.9849   0.3314
dirENCdistance   0.2503   0.1255     1.9938   0.0540
dirESCdistance   0.0548   0.1252     0.4379   0.6641
dirEWCdistance   0.2116   0.1254     1.6879   0.1003

Residual standard error: 10.88 on 35 degrees of freedom
Multiple R-Squared: 0.2852
F-statistic: 1.995 on 7 and 35 degrees of freedom, the P-
value is 0.08386
```

Zn ppm Statistical Inference:

There is evidence of an interaction effect between distance from mine sites and direction on the Zn ppm in *Hypogymnia physodes lichen* samples. The Zn ppm in *Hypogymnia physodes lichen* samples decreases more rapidly in the East direction than in the North direction (p-value = 0.0540). There is no evidence that the Zn ppm in *Hypogymnia physodes lichen* samples decreases as the distance from mine sites increases (p-value = 0.3314).

Zn ppm Linear Regression Residual Plot:



VIII. Literature Cited

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