JACK PINE FITNESS UNDER CURRENT AND FUTURE CLIMATE

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Faculty of Natural Resource Management

Lakehead University

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Partial Fulfillment of the Requirements for the
Degree of Honours Bachelor of Science in Forestry

Faculty of Natural Resources Management

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ABSTRACT

Keywords: Provenance, seed source, fitness, climate change, jack pine, Allegan, Baskatong Lake, Caramat, Clova, Espanola, Fraserdale, Kakabeka, Michigan, Ontario, Quebec, Red Lake, Swastika

Climate change has the potential to drastically alter the functioning of Canada's forests and the species that live there. The importance of understanding patterns of adaptive variation in relation to climate is imperative to predict how populations will react to climate change. Site transfer functions were used to identify optimal seed sources for northern, central and southern planting locations under current climate while population response functions were used to identify optimal climate conditions for individual provenances e used to determine which climatic factors most strongly affect Optimal climate values were compared to current and predicted future climate conditions to predict potential changes to volume growth under climate change. Minimum winter temperatures were the strongest predictors of volume growth when multiple seed sources were compared for a given test locality (transfer functions) while average summer precipitation was the strongest predictor of volume growth for individual provenances planted at multiple test locations (response functions). Understanding how jack pine performance is related to climatic factors is important when predicting future outcomes for the species under changing climatic conditions. Research such as this can be further used to build more accurate prediction models of how the growth of jack pine will be affected in the future.

ACKNOWLEDGEMENTS

First and foremost, I would like to thank my thesis supervisor, Dr. Ashley Thomson, for her help during my thesis writing process. With her help I was able to use new software and analysis techniques as well as complete my thesis project. I would like to extend further thanks to Jennifer Manion for her continued help and support to the entire Natural Resources Department. Finally, I would like to thank my parents Bill Whelan and Wendy Atkins, and my sister Rhiannon Whelan for providing me with support and encouragement throughout my education, without them I could not have made it this far.

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INTRODUCTION

Provenance tests allow conclusions to be drawn about genetic differences between trees from various geographic locations. Observations can be made for differences in performance, phenology, cold hardiness, and drought resistance as well as other factors (Lu et al. 2016). Provenance tests can also be used to determine how a seed source will react to the conditions of the test site (Pukkala, 2017). Response functions can be used in order to predict how a seed source will react to the conditions of a variety of test sites. Transfer functions show how a variety of seed sources respond to the conditions of a test site (Kapeller et al. 2012).

Several studies in the past have drawn conclusions regarding *Pinus banksiana* (Lamb.) (jack pine) performance and climate (Brooks, 1998; Despland and Houle, 1997; Dietrich et al. 2016; Huang et al. 2013; Parker et al., 2006; Savva, 2007; Subedi and Sharma, 2013; Thomson, 2005; Thomson and Parker, 2008). Jack pine growth and performance cannot be strongly predicted by precipitation levels during the growing season (Despland and Houle, 1997; Dietrich, 2016). However, some studies have found the performance of jack pine at northern latitudes to be more greatly affected by precipitation (Brooks, 1998). Other studies have shown that increased precipitation levels can negatively impact the growth of jack pine (Subedi and Sharma, 2016). Temperature seems to be a strong predictor for jack pine growth, as some studies have found growing season temperature to correlate with performance (Dietrich et al. 2016). However, other studies have found the mean annual temperature to be a better predictor of growth (Pokharel and Froese, 2009).

In 2007, the Intergovernmental Panel on Climate Change (IPCC, 2007) released a report stating that global temperatures are increasing and that climate change is being caused primarily due to human influence on the planet. Climate change may affect local mean temperatures and precipitation, which could affect fire and drought frequency (Price et al. 2013; Stocks et al. 1998). As we move into the future, climate change will continue to progress and affect how our forests grow and develop. Jack pine at the southern expanse of their natural range are the most threatened for extirpation (McKenny et al. 2007). The southern border of species ranges is the most threatened because these areas are likely to have increases in temperature that push jack pine beyond their optimal growth temperatures. As temperatures gradually increase there will be a decrease in fitness, a decrease in the competitive ability of individuals, and eventually local extirpations. Predicting how tree species will react to changing temperatures and moisture regimes is crucial to protecting the future forests of Canada.

The objective of this study is to identify optimal seed sources for reforestation under current climates and to predict how jack pine volume growth will be affected under changing environmental conditions. I predict that local sources will outperform other sources under current conditions and that southern sources will out-compete local sources under future climatic conditions.

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LITERATURE REVIEW

CHARACTERISTICS OF JACK PINE

The jack pine is an economically important tree in North America. Jack pine has a variety of uses in the forest products industry, such as pulp, and lumber (Moore and Wilson, 2006). Jack pine has a wide range across Canada and the northern United States. In Ontario, it is found mostly found in the northern part of Ontario in the boreal on poor sites with sandy well-drained soil (Rudolph and Laidly, 1990; Farrar, 2017). Jack pine prefers climates with short mild summers and long cold winters. Across its range the average annual max temperature is between 29 °C and 38 °C, the average annual minimum temperature is between -21 °C and -46 °C, and the average annual precipitation is 250 mm to 1400 mm (Rudolph and Laidly, 1990; Rudolph and Yeatman, 1982). The boreal forest currently has a climate that is sub-optimal for jack pine as higher latitudes have lower rates of tree growth (Hyun, 1979).

CLIMATE CHANGE AND GROWTH

Tree growth is affected greatly by the local climate. Temperature and moisture have the greatest influence on tree growth in the boreal forest (Subedi and Sharma, 2012). Pokharel and Froese (2009) found the mean annual temperature to have the greatest impact on annual basal area growth for jack pine. As the climate changes in the boreal forest, there will also be changes to the growth patterns of tree species such as jack pine.

Thomson and Parker (2008) stated that northern populations of jack pine would benefit from increases in temperature, but southern and central populations would be negatively affected. So northern populations within the boreal will benefit more from climate change than southern populations (Huang et al. 2013). McKenney et al. (2006) did an extensive report on climate data from 1901-2000. They showed that there has been a trend of mean annual temperature increase in Canada. There was also found to be no significant increase in precipitation. In a later study by McKenney (2010) it was predicted that there would be both temperature and precipitation increases in Ontario due to climate change. Wang et al (2014) predict that precipitation in central and northern Canada will increase, and that few areas in Canada will experience drought conditions. An alternate study by Wotton (2005) suggests that the increases in precipitation will not meet the increase in rates of evapotranspiration. In a study modeling growth increases of Scots pine with global warming there was found to be an increase in the net primary productivity by 24-37% in a scenario with 4°C or more of warming (Bergh et al, 2003). In the model water was not a limiting factor.

CHOICE OF SEED SOURCE FOR REFORESTATION

King (1965) suggests that southern sites should be planted with local sources but planting on northern sites should occur with a mix of local and southern seed sources Yeatman (1976) found that local jack pine seed outperformed other seed sources when comparing tree heights at ten years. The exception to this was found on the Caramat site in Ontario, where seed sources from Quebec grew 18% taller than local sources. In a study of jack pine plantations in the Lake States (Jeffers and Jensen, 1978) local seed sources (within 100 miles of the planting site) were found to outcompete other seed sources in most tests. The exception for this was found at the Superior National forest site where seed from lower Michigan and northeastern Minnesota performed the best.

REFORESTATION UNDER CLIMATE CHANGE

Under current climatic conditions, local jack pine seed sources generally outcompete non-local sources (King, 1965; Yeatman, 1976; Jeffers and Jensen, 1978). However, southern sources have been shown to perform better than local sources at northern test sites (Thomson et al. 2008). In the future, under different climates, non-local sources may be best. In order to determine what sources will perform best, predictors for the growth of transferred seeds must be determined. In a study by Savva et al. (2007) the best predictors for growth were the difference between the planting site and site of origin for the mean annual maximum daily temperature and annual precipitation. They found that seeds sourced from warmer and drier areas like ones from the southern extent of the range performed better when moved northward. Parker et al. (2006) found that northern jack pine trees were growing in non-ideal conditions and that they would benefit from increased temperatures. They also found that central and southern sources will suffer from increasing temperatures and would benefit from being transferred north. This was further mentioned in the study by Thomson and Parker (2008) and they suggested that the optimal zone for growth would shift north by 2° latitude by 2070.

METHODS

PHENOTYPIC DATA COLLECTION

Jack pine growth data used for this study was collected as part of a previous study examining intraspecific variation in height growth in relation to climate (Thomson and Parker 2008). Tree survival, height, and diameter volumes were collected for 97 provenances at 13 different sites located in Ontario, Quebec, and Michigan (Figure 1). For this study, I examined a subset of nine locations (Figure 2).

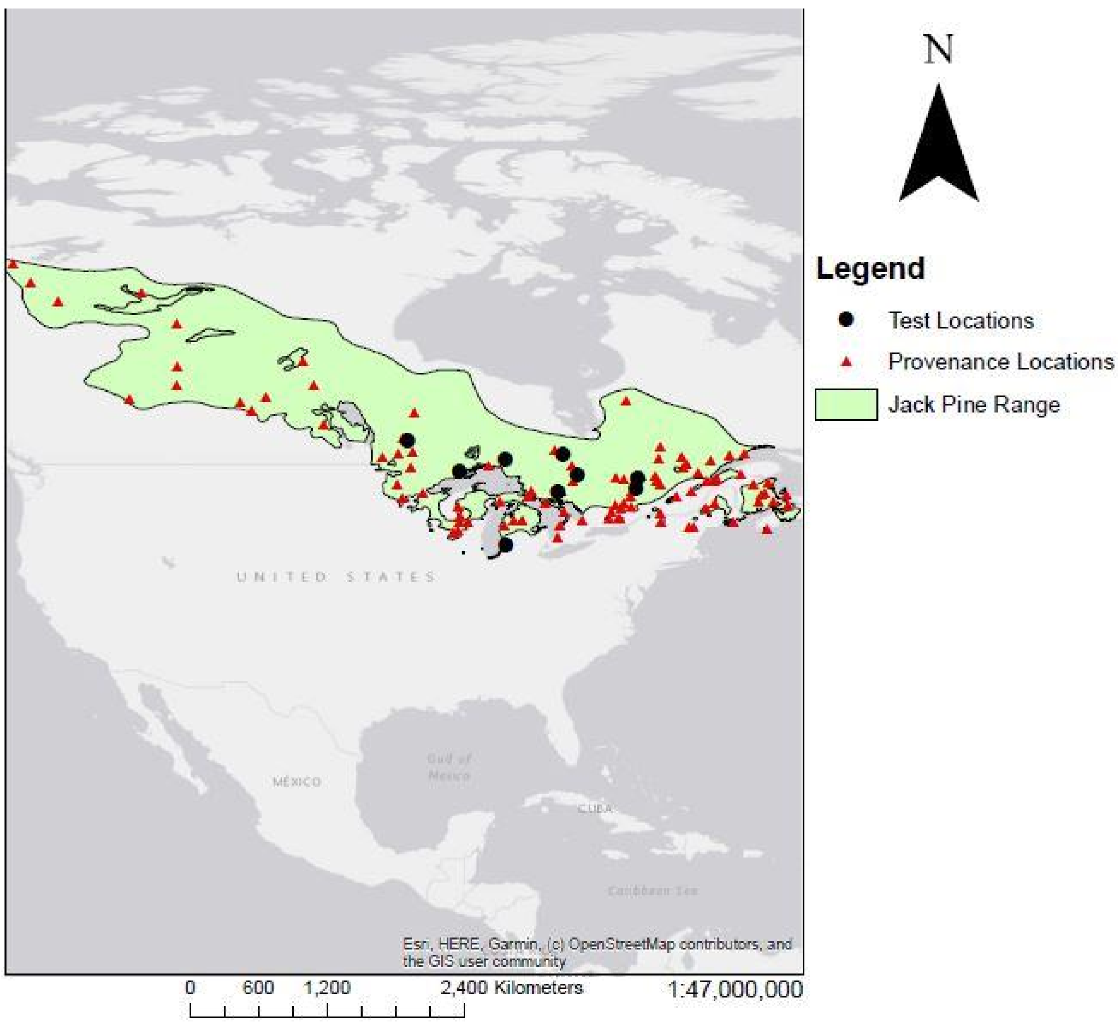

Figure 1.0 Map of Canada and the United States showing the range of jack pine, the provenance locations and the nine testing locations.

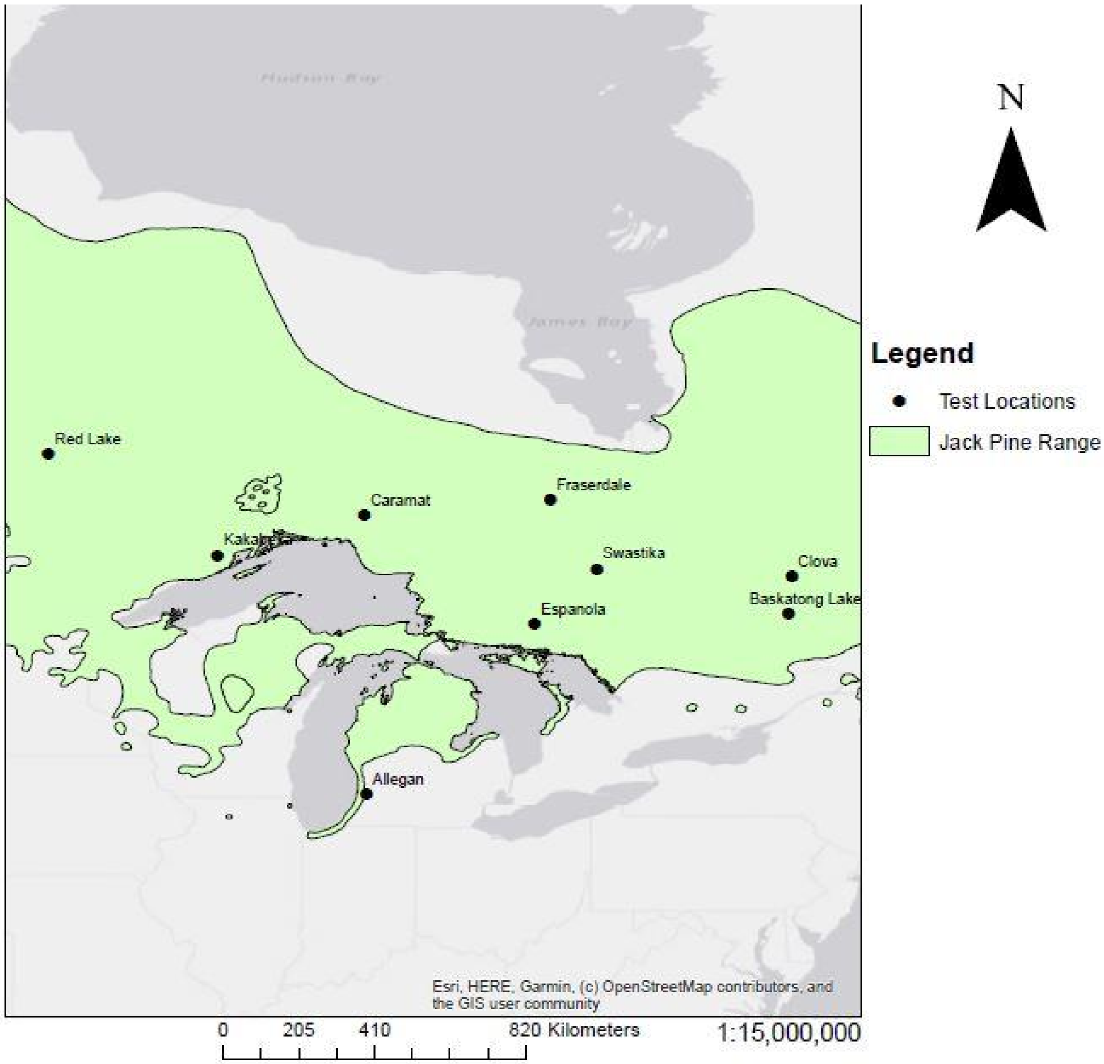

Figure 2. Map displaying the locations of each of the nine test sites examined in this study.

CLIMATE DATA

Climate data was compiled for this report using ClimateNA software (Wang et al. 2016). The climate data used in the construction of the site transfer functions were obtained based on the geographic location of each provenance. The data used for the transfer functions ranged from 1931-2000, in thirty-year periods. There were five periods in total ranging from; 1931-1960, 1941-1970, 1951-1980, and 1971-2000. The climate data used for the response functions ranged from 1961 and 1990.

DATA ANALYSIS

Tree height and diameter data collected from each of the nine test sites were used to find average tree volumes using the Honer's volume equations (Honer, 1967). The following equation was used to calculate volume in dm^3:

$$Total\ Volume\ (dm^3) = \left[\frac{DBH^2}{\left(A + \left(\frac{B}{Ht}\right)\right)}\right] \times 1000$$

Where DBH= Diameter at breast height, Ht= Height of the tree, A= 204.37,
B= 24203.5.

The volumes for individual trees were used to find the average volume for each provenance in each block at each site. These averages were used to find the average volume of each provenance across all sites. After determining the average volumes for each provenance, the data was compiled into Microsoft Excel along with the five climatic variables being tested for each seed source. The provenances being tested were located at the Espanola, Fraserdale, and Swastika sites. The climate data for the transfer functions was for the location of each seed source and not for the test site location. Five graphs were produced for each test site during each time period, for a total of 75 graphs. Each graph had the average volume as the y-axis and the climatic variable being tested along the x-axis. Once the data was plotted, the trendline function was used to produce a second-order polynomial. Each graph displayed the R^2 value that was calculated in Excel.

The R^2 values of each second-order polynomial regression were recorded and average R^2 values were calculated for each climatic variable across all test sites.

Average R^2 values were used to determine which climatic variable could explain the most variance in volume growth. Since minimum winter temperature had the highest R^2 value, this climatic variable was used to produce Cauchy function graphs. SigmaPlot software was used to produce the Cauchy function graphs for this report. The volume data for each provenance of each test site was once again plotted against the seed source climate data for each time period. However, only the minimum winter temperature climate data was used since it had the highest R^2 value. Using the "regression wizard" tool in SigmaPlot Cauchy function graphs were produced using the Lorentzian 3-parameter curve. A total of fifteen Cauchy function graphs were produced for the site transfer models. Optimal minimum winter temperature and the corresponding estimate average volume were found for each time period by determining the value at the peak of each polynomial regression produced in Excel. An average for the optimal minimum winter temperature of each seed source was found for each site.

Population response functions were constructed by regressing the volume of an individual provenance at each test site against the climate at each test site. Five graphs were produced for each provenance during the time period of 1961-1990, for a total of 485 graphs. Each graph had the average volume as the y-axis and the climatic variable being tested along the x-axis. Once the data was plotted the Excel trendline function was used to produce a second-order polynomial. Each graph displayed the R^2 value that was calculated by excel. The R^2 values were recorded and average R^2 values were calculated for each climatic variable across all provenances. The average R^2 values were used to determine which climatic variable could explain the most variance in the data. Since average summer precipitation had the highest average R^2 value, this climatic variable was used to produce Cauchy function graphs. SigmaPlot software was used to produce the Cauchy function graphs for this report. The volume data for each provenance at each site was once again plotted against the local climate data for each time period. However, only the average summer precipitation data was used since it had the highest R^2 value. Using the "regression wizard" tool in SigmaPlot Cauchy function graphs were produced using the Lorentzian 3-parameter curve. A total of ninety-two graphs were produced for the response functions in this way. Some provenances could not produce graphs using the SigmaPlot software since they ware not present at enough test sites to build a Cauchy function. Using the vertex of each graph, the optimal average summer precipitation and the corresponding estimate average volume was found for each provenance. An average for optimal average summer precipitation of each site was found.

RESULTS

The site found to have the highest mean volume (dm^3) was the Fraserdale site, with an average volume of 189.77 dm^3. The lowest average volume was found to be 61.63 dm^3 at the Red Lake test site. The Red Lake test site had the least amount of variation of volume from the average of the nine test sites. The standard deviation for the Red Lake test site is 16.22. The Allegan test site had the highest variation of volume from the average with a standard deviation of 58.62. A summary of the descriptive statistics can be seen in Table 1.0.

Table 1. Average jack pine volume (dm^3) at each test site.

Site	Mean Volume (dm^3)	Standard Deviation
Espanola	102.38	19.51
Fraserdale	189.77	46.93
Swastika	170.66	40.96
Red Lake	61.63	16.22
Kakabeka	183.14	53.20
Allegan	108.63	58.62
Baskatong Lake	93.28	30.27
Caramat	134.83	37.54
Clova	79.87	33.30

TRANSFER FUNCTIONS

The R^2 values for maximum summer temperature ranged from 0.12 to 0.29. Minimum winter temperature had R^2 value ranges from 0.38 to 0.45. Minimum spring temperature R^2 values ranged from 0.08 to 0.43. The average winter precipitation and average summer precipitation had R^2 ranges of 0.07 to 0.51 and 0.00 to 0.14 respectively. For the transfer functions the minimum winter temperature (MinWtT) was found to have the highest correlation to the data. The average minimum winter temperature R^2 value across all sites was 0.4, this shows that the minimum winter temperature variable can explain 40% of the variation found in the performance of the jack pine at their source. A summary of the R^2 values for each climatic variable at each test site can be seen in Table 2.0.

Table 2. R^2 values of site transfer functions for three test sites based on climatic normals for individual provenances for five periods.

			Espanola		
Date Range	MaxSmT	MinWtT	MinSpT	AvWtPP	AvSmPP
1931-1960	0.2901	0.3920	0.1442	0.4600	0.0017
1941-1970	0.2625	0.4324	0.1537	0.4732	0.0022
1951-1980	0.2516	0.4490	0.1423	0.4800	0.0039
1961-1990	0.2282	0.4336	0.1027	0.4983	0.0016
1971-2000	0.2494	0.3961	0.0769	0.5049	0.0013
			Fraserdale		
Date Range	MaxSmT	MinWtT	MinSpT	AvWtPP	AvSmPP
1931-1960	0.2244	0.4228	0.4239	0.0720	0.1260
1941-1970	0.2166	0.3879	0.4335	0.0798	0.1429
1951-1980	0.2001	0.3796	0.4184	0.0777	0.1221
1961-1990	0.1688	0.3912	0.3795	0.0839	0.1206
1971-2000	0.1788	0.4122	0.3423	0.0759	0.0962
			Swastika		
Date Range	MaxSmT	MinWtT	MinSpT	AvWtPP	AvSmPP
1931-1960	0.1442	0.4127	0.2767	0.2125	0.0977
1941-1970	0.1291	0.4117	0.2773	0.2257	0.1091
1951-1980	0.1307	0.4106	0.2746	0.2264	0.0973
1961-1990	0.1176	0.4027	0.2424	0.2514	0.1067
1971-2000	0.1296	0.3978	0.2104	0.2496	0.0999
			All Sites		
Average	0.1948	0.4088	0.2599	0.2648	0.0753

Examples of Cauchy transfer functions relating minimum winter temperature to seed source performance for the Espanola, Fraserdale, and Swastika test sites are presented in Figures 3 to 5, while Cauchy functions for the remaining tests are presented in appendix II.

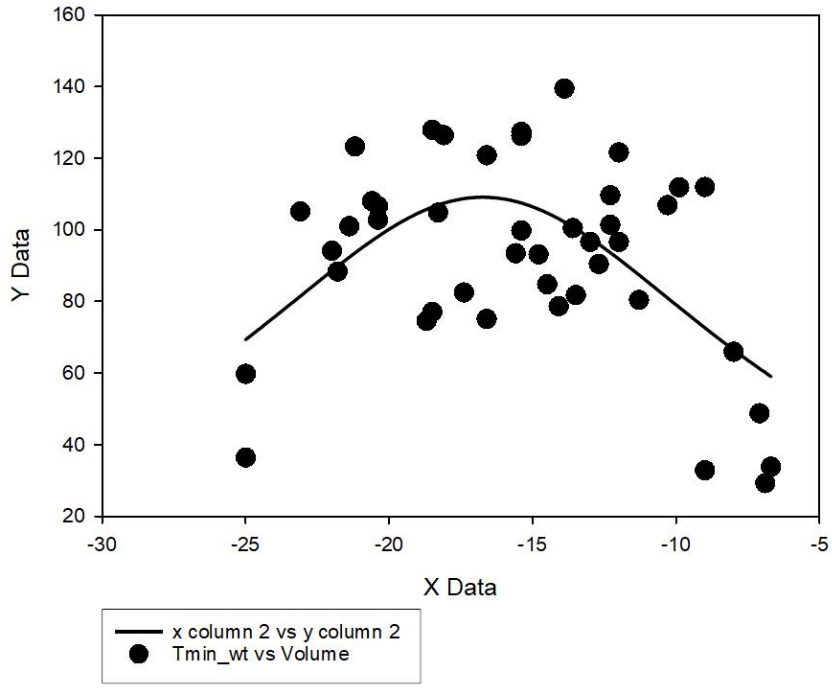

Figure 3. Transfer function graph of Espanola for minimum winter temperature (°C) from 1951-1980 and the average provenance volume per block (dm^3).

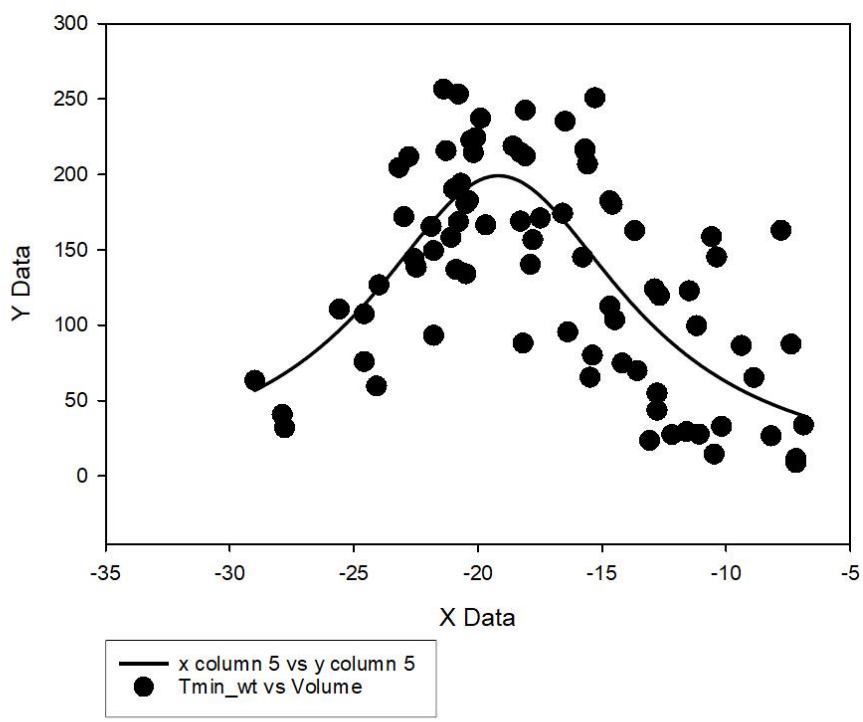

Figure 4. Transfer function graph of Fraserdale for minimum winter temperature (°C) from 1931-1960 and the average provenance volume per block (dm^3).

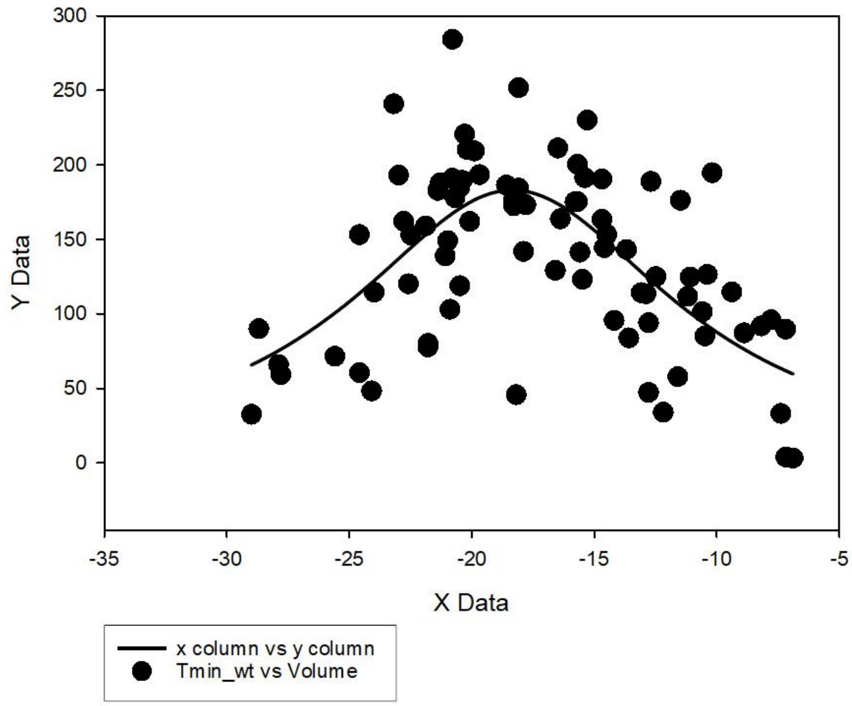

Figure 5. Transfer function graph of Swastika for minimum winter temperature (°C) from 1931-1960 and the average provenance volume per block (dm^3).

The optimal winter temperatures ranged from a -19.88 to -16.30 °C with an average volume of 163.47 dm^3. Fraserdale was found to have the lowest optimal minimum winter temperature and the highest estimated average volume for that temperature across all three sites. These values were -19.45°C and 198.62dm^3 respectively. Swastika had the next lowest minimum winter temperature and the next highest average volume. The values were -18.86°C and 182.41dm^3 respectively. The highest optimal minimum winter temperature was found at the Espanola site. Espanola was also found to have the lowest estimated average volume across the three test sites. These values were -16.60 °C and 109.38dm^3 respectively. The remaining optimal winter minimum temperatures and resulting estimated volumes are summarized in Table 3.0.

Table 3. Optimal temperature range for minimum winter temperature factor of each time period and the corresponding estimated volume of each test site.

	Espanola		Fraserdale		Swastika	
Period	Temp (°C)	Vol (dm^3)	Temp (°C)	Vol (dm^3)	Temp (°C)	Vol (dm^3)
1931-60	-16.30	108.91	-19.42	200.19	-18.64	184.23
1941-70	-16.70	109.24	-19.56	198.39	-18.68	183.53
1951-80	-16.71	109.78	-19.61	198.17	-19.88	179.10
1961-90	-16.95	109.52	-19.63	197.78	-18.87	182.34
1971-2000	-16.34	109.43	-19.01	198.56	-18.21	182.83
Average	-16.60	109.38	-19.45	198.62	-18.86	182.41

The current minimum winter temperatures at Espanola, Fraserdale, and Swastika are all above the optimal minimum winter temperature for the sites. The greatest difference in temperature is for the Swastika site. The current temperature is 2.32°C warmer than the optimal temperature. The smallest difference between current and optimal temperature is at the Espanola site, with a difference of 1.37°C. A summary of the current and optimal temperatures for the three test sites can be seen in table 4.

Table 4. Current and optimal average temperature (°C) for each of the three transfer function test sites.

Site	Current Temperature	Optimal Temperature
Espanola	-15.23	-16.60
Fraserdale	-17.12	-19.45
Swastika	-17.20	-18.86

RESPONSE FUNCTIONS

The R^2 values for all climatic variables ranged from ±1.0. Minimum winter temperature (MinWtT) had the lowest average R^2 value of 0.38. The highest average R^2 value was found for the average summer precipitation (AvSmPP) with a value of 0.50. The average summer precipitation can explain 50% of the variation found in the performance of jack pine for each provenance. The variation in R^2 values were the lowest for maximum summer temperature (MaxSmT) and average winter precipitation (AvWtPP), with standard deviation values 0f 0.30. The highest variation between R^2 values was found for both minimum winter temperature (MinWtT) and minimum spring temperature (MinSpT) with a standard deviation of 0.34. A summary of the R^2 values for each climatic variable at each test site can be seen in appendix I. The average R^2 values and standard deviations for each climatic variable can be seen in table 5.

Table 5. Average R^2 values for each climatic variable of the response functions.

	Average	Standard Deviation
MaxSmT	0.40	0.30
MinWtT	0.38	0.34
MinSpT	0.38	0.34
AvWtPP	0.50	0.30
AvSmPP	0.50	0.32

The climate data used was for average summer precipitation as it had the strongest correlation (highest R^2 value) for the response functions. The best-fitting graphs for each seed source will be presented below (Figures 6 to15). The remaining graphs will be displayed within appendix II.

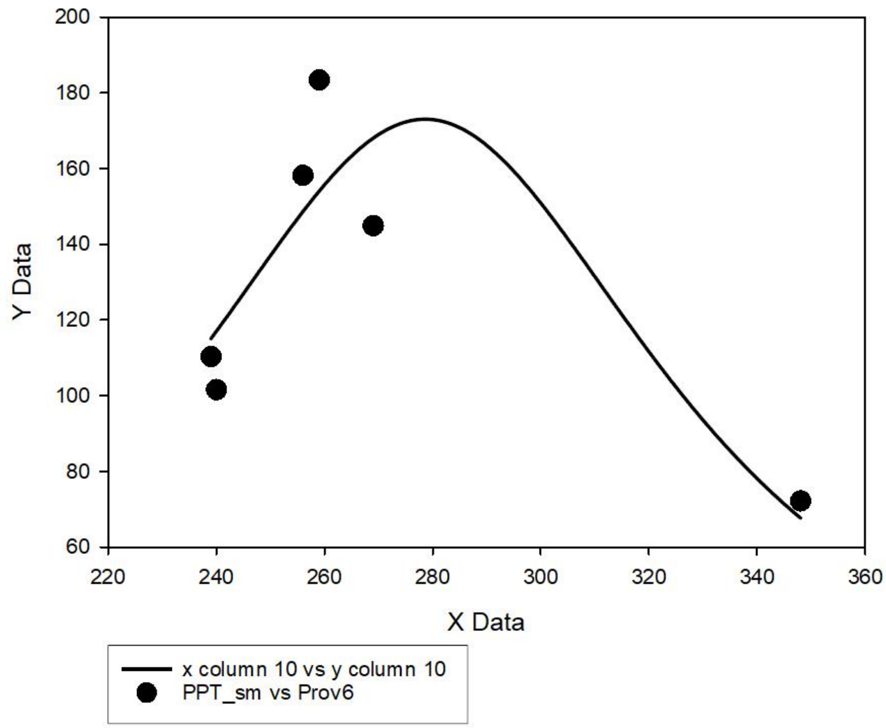

Figure 6 Response function graph of average summer precipitation (mm) and the average volume (dm^3) of provenance 6 for each test site.

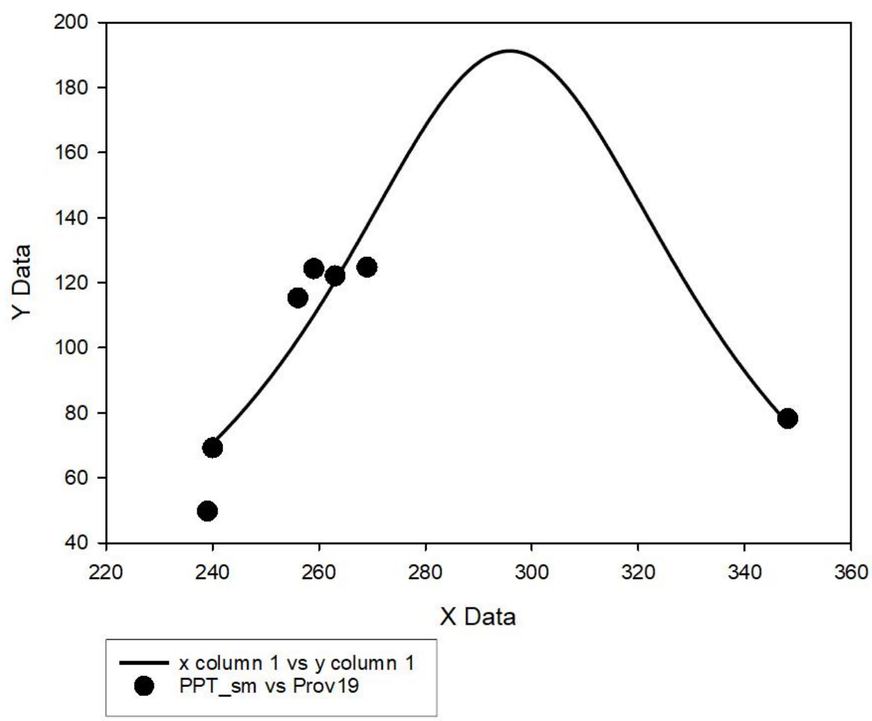

Figure 7 Response function graph of average summer precipitation (mm) and the average volume (dm^3) of provenance 19 for each test site.

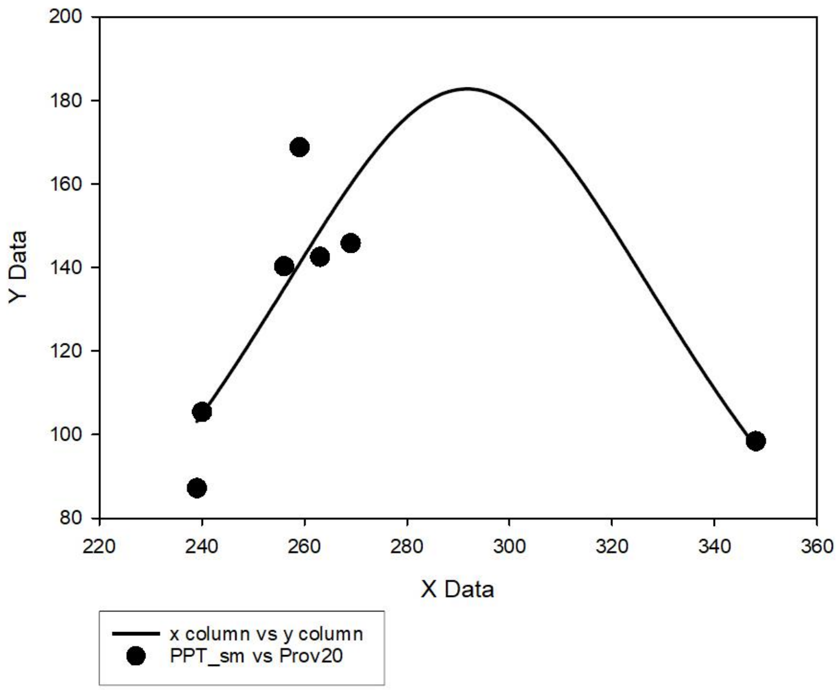

Figure 8 Response function graph of average summer precipitation (mm) and the average volume (dm^3) of provenance 20 for each test site.

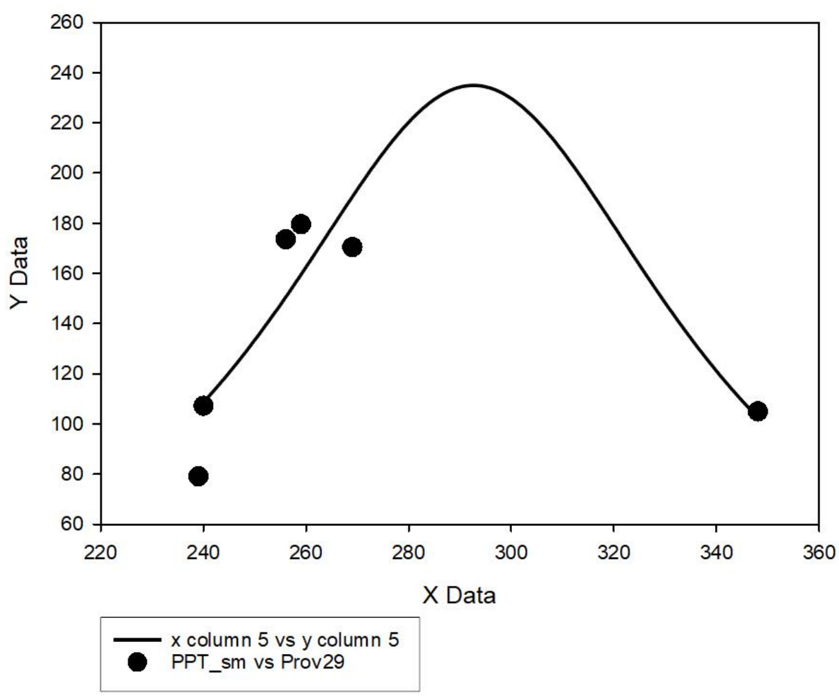

Figure 9 Response function graph of average summer precipitation (mm) and the average volume (dm^3) of provenance 29 for each test site.

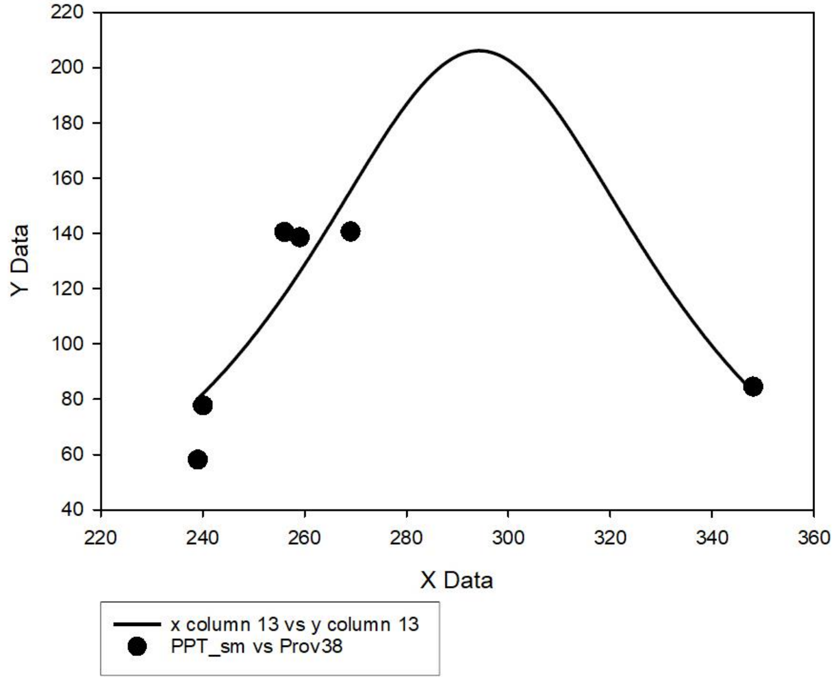

Figure 10 Response function graph of average summer precipitation (mm) and the average volume (dm^3) of provenance 38 for each test site.

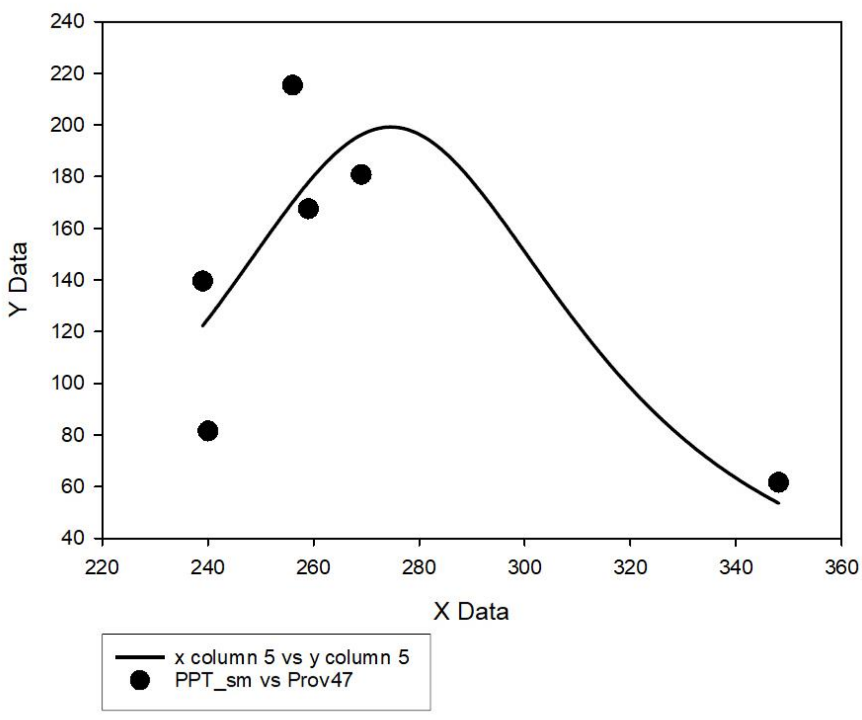

Figure 11 Response function graph of average summer precipitation (mm) and the average volume (dm^3) of provenance 47 for each test site.

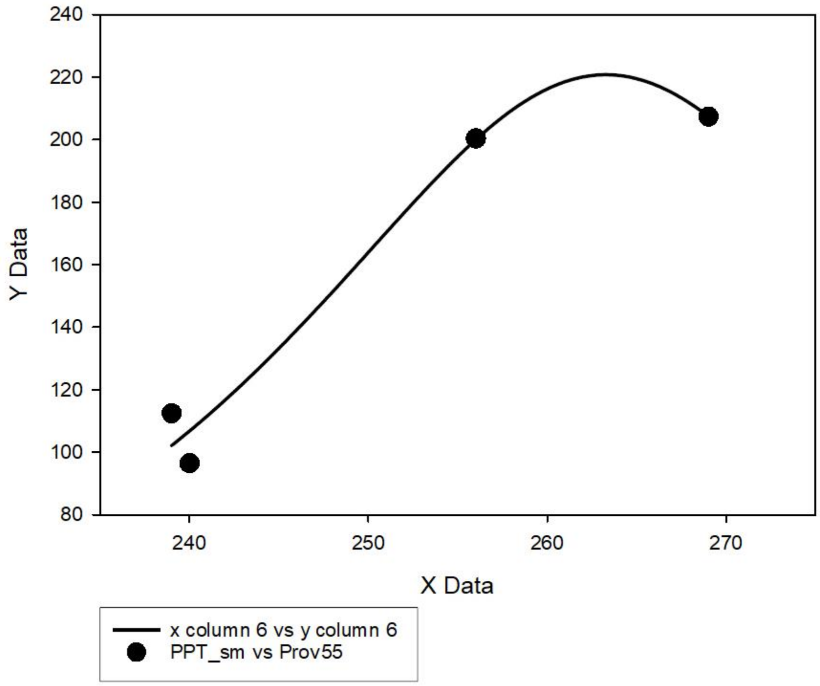

Figure 12 Response function graph of average summer precipitation (mm) and the average volume (dm^3) of provenance 55 for each test site.

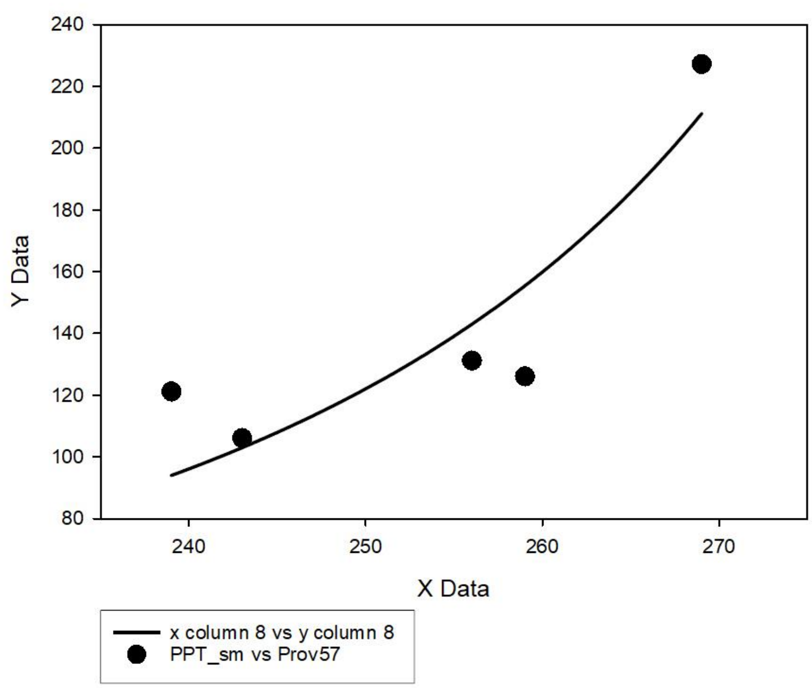

Figure 13 Response function graph of average summer precipitation (mm) and the average volume (dm^3) of provenance 57 for each test site.

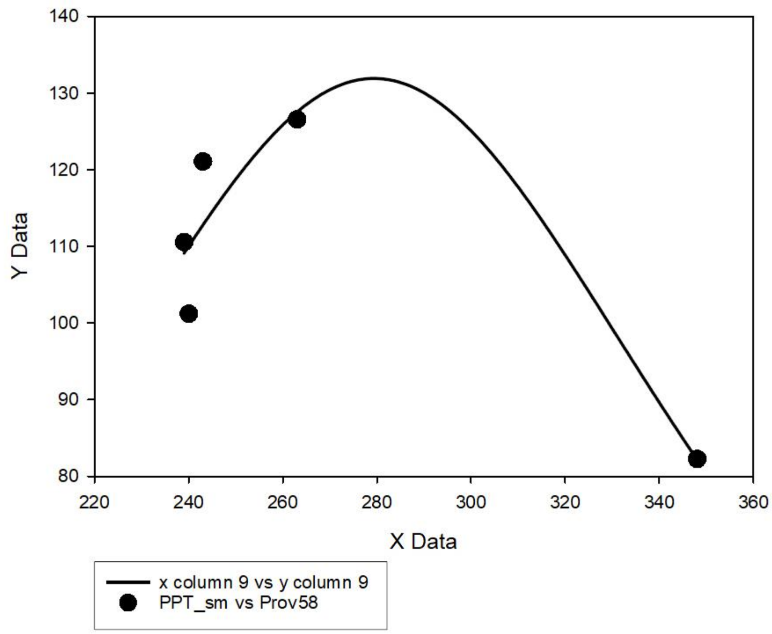

Figure 14 Response function graph of average summer precipitation (mm) and the average volume (dm^3) of provenance 58 for each test site.

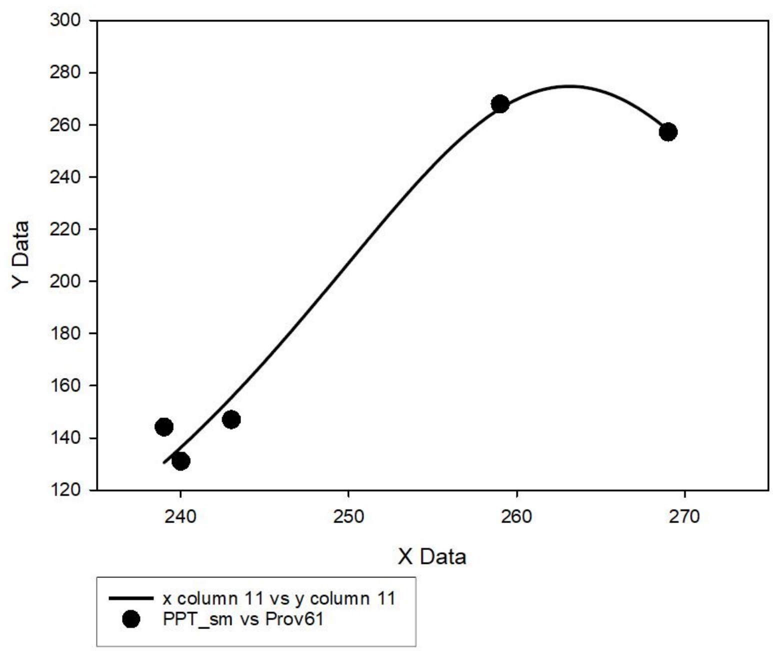

Figure 15 Response function graph of average summer precipitation (mm) and the average volume (dm^3) of provenance 61 for each test site.

Table 6. Optimal average summer precipitation (mm) for each seed source and the corresponding estimated average volume (dm^3) response.

Prov	AvgSmPP (mm)	Vol (dm^3)	Prov	AvgSmPP (mm)	Vol (dm^3)
3	262.35	181.77	56	278.17	164.56
4	259.86	207.19	57	268.53	208.50
5	279.87	61.32	58	278.17	132.09
6	278.17	173.52	60	263.96	258.99
7	292.22	197.07	61	262.67	275.26
9	276.04	136.94	62	263.84	224.57
11	283.71	189.94	63	262.44	262.17
12	293.50	194.26	64	257.87	245.01
13	290.52	307.89	65	252.71	378.27
14	293.50	189.34	66	239.00	248.59
15	296.91	189.23	68	268.53	180.30
19	295.20	191.69	69	267.95	156.52
20	290.09	183.02	70	274.34	207.94
23	267.10	147.65	71	264.12	169.50
25	288.81	174.90	72	249.65	153.54
26	290.52	259.59	73	266.68	157.17
27	288.82	210.69	74	267.95	175.89
28	294.78	218.01	75	273.06	169.28
29	292.22	235.61	76	288.39	233.91
30	298.18	217.60	77	288.39	235.06
31	295.63	299.80	78	291.80	195.74
34	293.50	237.44	79	280.72	216.21
35	293.93	251.97	80	276.04	201.94
36	298.18	277.80	81	268.18	245.59
37	295.20	239.31	82	264.16	201.56
38	293.50	206.65	83	289.24	226.29
39	279.02	150.41	84	284.13	208.70
41	262.84	1241.16	85	295.20	610.23
42	273.49	198.16	86	267.59	170.81
43	254.33	139.38	87	293.93	223.84
44	271.78	155.01	88	292.22	232.69
45	261.99	226.10	89	293.50	255.07
46	55.49	281.16	90	289.24	168.73
47	273.49	199.85	91	290.95	216.26
48	285.41	203.54	93	262.79	174.33

Prov	AvgSmPP (mm)	Vol (dm^3)	Prov	AvgSmPP (mm)	Vol (dm^3)
49	295.63	305.41	94	263.02	254.79
50	293.93	268.75	95	261.50	254.19
51	293.07	293.84	96	260.33	130.06
53	259.04	256.35	98	268.65	126.61
54	253.65	157.44	99	262.20	352.62
55	262.79	221.21	Avg	274.69	229.40

For the provenances with the highest R^2 values, the lowest estimated average volume in response to the optimal average summer precipitation was for provenance 58. Provenance 58 had an estimate average volume of 132.09 dm^3, and an optimal average summer precipitation of 278 mm. Of the provenances with the highest R^2 values, the highest estimated average volume in response to the optimal average summer precipitation was for provenance 61. Provenance 61 had an estimate average volume of 275.26 dm^3, and an optimal average summer precipitation of 263 mm. The average across all provenances for optimal summer precipitation was found to be 275 mm and the corresponding optimal estimated average volume was 229.40 dm^3.

Some provenances are currently receiving precipitation that is above the optimal level, while others are receiving sub-optimal levels of precipitation. Provenance 98 is currently receiving an average of 146 mm of precipitation. This is 123mm less than the optimal precipitation level of 169 mm for that provenance. Provenance 46 appears to be receiving an excess of 188 mm of precipitation. The current precipitation level for provenance 46 is 243 mm and the optimal level of precipitation is 55 mm. However, provenance 46 may be an outlier, provenance 25 has the second-highest difference between current and optimal precipitation levels and only receives an excess of 81 mm of precipitation. A summary of all provenances and their current and optimal precipitation levels can be seen in Table 7.

Table 7. Current and optimal average summer precipitation (mm) for each applicable provenance.

Prov	Current Precipitation (mm)	Optimal Precipitation (mm)	Prov	Current Precipitation (mm)	Optimal Precipitation (mm)
3	310	262	56	221	278
4	287	260	57	212	269
5	283	280	58	218	278
6	266	278	60	244	264
7	251	292	61	243	263
9	268	276	62	252	264
11	279	284	63	269	262
12	271	294	64	259	258
13	303	291	65	302	253
14	294	294	66	293	239
15	303	297	68	295	269
19	324	295	69	306	268
20	266	290	70	292	274
23	284	267	71	239	264
25	370	289	72	224	250
26	303	291	73	247	267
27	296	289	74	246	268
28	349	295	75	242	273
29	289	292	76	256	288
30	326	298	77	263	288
31	279	296	78	286	292
34	332	294	79	292	281
35	343	294	80	270	276
36	327	298	81	287	268
37	308	295	82	258	264
38	308	294	83	240	289
39	218	279	84	278	284
41	219	263	85	246	295
42	230	273	86	256	268
43	237	254	87	188	294
44	240	272	88	205	292
45	239	262	89	222	294
46	243	55	90	206	289
47	277	273	91	213	291
48	295	285	93	284	263
49	326	296	94	238	263

Prov	Current Precipitation (mm)	Optimal Precipitation (mm)	Prov	Current Precipitation (mm)	Optimal Precipitation (mm)
50	314	294	95	218	262
51	348	293	96	141	260
53	239	259	98	146	269
54	234	254	99	149	262
55	224	263			

DISCUSSION

RELATIONSHIP BETWEEN JACK PINE VOLUME GROWTH AND CLIMATE

The temperature related climatic variables generally had higher R^2 values than the precipitation climatic variables for the transfer functions. For the transfer functions up to 40% of the variation in performance could be attributed to minimum winter temperature. The precipitation climatic variables seemed to be more strongly correlated with performance in the response functions when compared to the temperature related variables. Other studies have found temperature related climatic variables to be weaker predictors of performance in transfer functions of jack pine when compared to precipitation variables (Thomson and Parker, 2008). The average summer precipitation was found to have the highest R^2 value for the response functions. Up to 50% of the variation for volume could be attributed to average summer precipitation.

For the transfer functions, the stronger correlation with the temperature variables may be due to the nature of the data itself. The temperature data that was used was for either high or low extremes with maximum summer temperature and minimum winter temperature respectively. Whereas the data used for precipitation was an average, so the high end and low- end extremes for precipitation were included but not used directly.

Transfer functions test how a specific seed source is adapted to the local climate. Seeds planted within the locality of their source could be adapted to local precipitation levels. This could be why we see less effect from variables like average precipitation rates in the transfer functions. When we look at the response functions, we see a higher R^2 value for average summer precipitation. Seed sources appear to be more greatly affected by precipitation levels than temperature when transferred to a new site. Monthly precipitation for the spring and summer was found to be strongly correlated with tree ring widths in other studies for jack pine performance (Savva et al. 2007). Jack pine grow on sandy well-drained sites (Rudolph and Laidly, 1990), these sites would be more prone to drought conditions and would have water availability be a limiting factor, especially during times of high evapotranspiration rates. Since jack pine grow on these site conditions the correlation we see between performance and average summer precipitation for the transfer functions is valid.

It stands to reason that local seed sources are also adapted to withstand their local temperatures and may be more greatly affected by higher than normal temperatures, or lower than normal temperatures locally. However, when seed sources are at the test sites, maximum and minimum temperatures vary rather little from their source, and we see precipitation levels vary by hundreds of millimeters in some cases. We saw this in the best performing provenance 31, where it performed best at a site with similar conditions to that of its source and performed rather poorly at a site with warmer winter temperatures and much lower precipitation levels. This could be why we saw a higher explanation of variance from the maximum summer temperatures and minimum winter temperatures locally but not at the test sites. Larsen and Macdonald (1995) also found a negative correlation with response functions of jack pine performance for May and June temperatures.

TRANSFER FUNCTIONS

The Fraserdale site was found to have the lowest optimal minimum winter temperature and the highest resulting estimated average volume. Swastika had the second lowest optimal minimum winter temperature and the second highest resulting estimated average volume. The Espanola site had the highest optimal minimum winter temperature and the lowest resulting estimated volume. Jack pine prefer climates with short mild summers, and long cold winters (Rudolph and Laidly, 1990; Rudolph and Yeatman, 1982). The preference for longer and colder winters could be why the sites with the lower minimum winter temperatures had higher estimated average volumes.

RESPONSE FUNCTIONS

On average provenance 31 was the top performing seed source. It performed best at the Fraserdale site and had the worst performance at the Allegan site. Having an average volume of 266.21dm^3 and 87.12dm^3 at the sites respectively. The Fraserdale site was further north and west than the seed source. Whereas the Allegan site was more southern and much further west from the seed source. The minimum winter temperature for the Allegan site was 11.12°C warmer than that of the seed source and received 40mm less rainfall during the summer. The Fraserdale site had climatic conditions more similar to that of the seed source location for provenance 31. The minimum winter temperature at

Fraserdale was 1.6°C cooler than the seed source location and received only 20mm less of average summer rainfall.

The poorest performing provenance on average was provenance 5. It performed the best at the Kakabeka site and the worst at the Red Lake site., having an average volume of 67.54dm^3 and 17.63dm^3 at the sites respectively. Both sites were further north and west than the seed source location. However, the Red Lake site was the more drastic change in latitude and longitude. Jeffers and Jensen (1978) state that longitude has a great effect on performance for transferred seed. The poor performance of provenance 5 could be due to the drastic change in longitude that resulted in the seed source being exposed to temperatures much colder than it was locally adapted to. The minimum winter temperature at the Kakabeka site was 11.6°C cooler than the seed source, and the Red Lake site was 16.4°C cooler than the seed source on average. The average summer precipitation was 11mm less than the seed source for both the Red Lake and Kakabeka sites.

Provenance 31 resulted in higher volumes when moved northward and had lower volumes when moved towards the south. Thompson and Parker (2008) determined that southern populations would benefit from moving northward and that northern populations would benefit from moving south or from temperatures increasing. Provenance 31 was a more centrally located source that benefitted from a northward shift. However, we see very poor performance when it was moved south. This could have been a result of minimum winter temperatures being to high. As seen in the results section cooler winter temperatures had a correlation with increased performance.

FUTURE CLIMATIC CHANGES AND PREDICTED EFFECTS ON PERFORMANCE

Climate greatly affects local plant communities and the rate at which they grow. Growth rates of any species will vary from area to area depending on the local climate. Temperature and moisture levels have been found to have the greatest impact on the growth rates of trees within the boreal forest (Subedi and Sharma, 2012). Other studies have concluded that mean annual temperature is the climatic factor that most greatly affects growth performance of jack pine (Pokharel and Froese, 2009). There are various prediction models that predict future climate under various climate change scenarios. Each with different conclusions of the location and magnitude of effects on climatic variables such as precipitation and temperature. Changes in precipitation and temperature will shift current ecoregions northward across Ontario (McKenny, 2010). With these northward shifts, the optimal growing regions for jack pine will also shift northwards. Thomson and Parker (2008) predicted that by 2070, the optimal growing zone will shift northward by 2° latitude, moving the optimal zone from 46°-47° to 48°-49°.

Some future climatic models estimate increases in mean summer temperatures in Ontario to increase by 1 to 1.5°C by 2040 and by 4-5°C by 2090 (Wotton, 2005). Other studies predict similar results and expect there to be an increase in average summer temperatures by 5.1°C by 2100 (McKenny, 2010). These temperature increases could benefit northern populations of jack pine that are currently growing in sub-optimal conditions. However, negative effects may arise along the southern edge of the jack pine range as temperatures exceed the ranges that jack pine prefer. In the performed transfer functions the sites with lower minimum winter temperatures performed better when compared to sites with higher minimum winter temperatures. By increasing winter temperatures there may be negative effects on performance.

The response functions showed that tree performance was strongly linked to the average summer precipitation levels. Studies by McKenney (2010) predicted that there will be increases in the amount of precipitation across Ontario by 2100 by 5.2 to 6.8%. Wotton (2005) states that predicted increases in precipitation levels will not be enough to counter the increases in rates of evapotranspiration. If the increases in precipitation are insufficient to meet evapotranspiration rates, we could see an increase in forest fire frequency with the changing climate (Podur, and Wotton, 2010). An increase in the frequency of fire could be beneficial for the proliferation of jack pine as they are a serotinous species and are shade intolerant. However, if fire intensities and frequency increase dramatically there could be negative effects on the population (de Groot, et al. 2004).

RECOMMENDATIONS

The findings of this study provide a background and preliminary results of the climatic factors that affect the performance of jack pine growth. Further studies should be done in order to have a better understanding of the correlation between climate and the volume of jack pine. I recommend that further studies compare the results of two separate transfer function and response function tests. The first test should compare temperature and precipitation extremes to provenance volumes. The climatic factors that should be analyzed are; maximum summer temperature; minimum winter temperature; minimum spring temperature; maximum winter precipitation; and maximum summer precipitation. The second test should compare temperature and precipitation averages to provenance volumes. The climatic factors that should analysed are; average summer temperature; average winter temperature; average spring temperature; average winter precipitation; and average summer precipitation. Analysis of variance (ANOVA) tests should also be performed on these data to determine if there is a statistically significant interaction between the volumes and climatic variables. By comparing these two tests that examine the effects of climate extreme variables and climatic averages, better results can be drawn for how these variables affect performance. If these tests find similar results to the ones discussed in this report than it is more likely that the findings of this report are accurate. By performing further studies with the data used there can be a better understanding of how climate affects jack pine performance and better prediction models can be built.

CONCLUSION

The results of this study demonstrate that both temperature and precipitation have a significant effect on jack pine volume growth. Minimum winter precipitation has the strongest correlation to the performance of seed sources and average summer precipitation has the strongest effect to growth at new sites. The best performing seed sources that were moved northward were found to have performed better than when moved further south. However, there is an optimal threshold for both northern and southern transfers. This was demonstrated by the worst performing seed sources that were moved northward by too much and there was a decrease in performance. As suggested in the recommendations section there is still further research that must be performed in order to better understand the correlation between the climatic variables and volume. This research should be used alongside additional analysis of jack pine interactions with climate in order to produce stronger prediction models for jack pine populations under future climatic conditions.

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APPENDICES

APPENDIX I: TABLES

Appendix 1.1. Average provenance volumes (dm^3) per block for transfer functions

Prov #	Espanola	Fraserdale	Swastika	Prov #	Espanola	Fraserdale	Swastika
1	33.59	66.89	88.83	55		164.43	97.58
3	30.01	13.38	5.67	56		34.66	196.05
4	49.47	89.05	34.86	57	112.41	88.12	116.27
5	34.58	35.59	5.17	58	110.21		
6		146.75	128.01	59	139.92		
7	107.45	160.18	103.05	60		252.03	231.38
9	91.04	125.66	115.15	61	128.43	243.87	252.97
11		181.61	146.00	62		254.37	285.34
12		164.18	144.66	63		205.94	242.24
13	75.74	97.07	165.17	64		257.75	184.18
14		175.63	130.66	65		31.23	59.51
15	83.14	172.46		66		29.26	35.67
19		94.85	81.75	68	101.08	121.24	190.26
20		135.62	120.46	69		76.44	97.23
23	82.40	25.32	115.77	70		146.68	176.67
25	79.24	71.55	85.43	71	112.50	28.35	93.45
26	121.32	236.48	212.58	72	81.06	16.35	86.76
27	127.86	218.15	201.69	73	122.15	29.51	126.25
28	100.39	208.15	142.97	74	97.18	101.20	113.33
29		217.32	176.75	75	101.98	124.36	177.65
30	126.95	215.73	178.41	76	77.66	170.41	173.94
31		215.70	211.50	77	105.70	213.15	163.53
34		182.15	186.24	78	105.37	158.21	174.58
35		191.75	150.61	79		213.59	185.82
36		139.98	154.34	80		238.50	210.69
37	94.75	167.01	160.48	81		223.93	221.89
38		128.35	116.14	82	107.17	167.95	194.73
39	97.22	45.39	95.55	83	101.58	170.11	192.37
40			126.60	84	108.56	225.58	163.47
41		56.61	48.94	86		173.42	194.43
42	85.41	105.30	154.79	87		159.80	140.39
43	93.74	114.21	164.92	88		145.80	121.78
44	94.07	67.11	124.67	89	60.41	109.11	154.67
45		183.86	191.84	90	88.96	138.46	104.70
46	126.75	81.71	192.77	91	37.15	77.50	62.17
47		141.87	143.44	92		42.49	67.65
48		220.15	187.75	93	75.20	89.66	47.36
49	103.37	184.00	190.95	94		151.00	79.37
50	123.77	217.04	189.32	95		61.33	49.95
51		195.46	179.40	96		33.72	60.88
53		112.31	73.12	98			91.57
54	66.59	10.65	91.30	99		65.08	34.25

Appendix 1.2. Climatic variables for each provenance at Espanola from 1931-1960

Prov	Tmax_sm	Tmin_wt	Tmin_sp	PPT_wt	PPT_sm	Prov	Tmax_sm	Tmin_wt	Tmin_sp	PPT_wt	PPT_sm
1	23.3	-8.9	0.5	403	268	54	25.9	-7.2	1.2	180	200
3	20.7	-7.2	-0.9	381	271	57	22.4	-9.4	-1.4	206	187
4	19.8	-7.4	-2.1	342	252	58	23.3	-11.6	-2	159	200
5	19.6	-6.9	-1.9	335	249	59	23.5	-13.3	-3	147	227
7	22.1	-10.6	-1.3	275	220	61	22.9	-18.1	-5.5	160	221
9	23.8	-12.9	-1.5	286	246	68	27.4	-12.7	-0.3	98	285
13	23.6	-16.4	-4.3	208	288	71	26.4	-8.2	0.1	155	228
15	21.1	-17.5	-5.2	234	284	72	26.4	-10.5	-1.7	140	215
23	25.4	-13.1	-1.4	191	259	73	26.3	-11.1	-2.1	113	235
25	22.3	-13.6	-2.7	308	363	74	26.3	-11.2	-2.1	114	233
26	23	-16.5	-4.6	225	287	75	24.1	-11.5	-2.5	140	250
27	24.5	-15.7	-2	249	284	76	19.6	-18.3	-5.5	162	262
28	23.2	-15.6	-2.7	275	338	77	22.2	-22.8	-8.8	149	249
30	22.2	-18.3	-4.6	204	333	78	25.6	-17.8	-2.8	54	286
37	21.1	-21.9	-6.7	161	309	82	23.8	-19.7	-4.2	83	235
39	24.7	-12.8	-1.3	195	199	83	23.7	-20.8	-4.8	68	223
42	25.7	-14.5	-1.8	180	203	84	22.9	-20.1	-4.3	92	252
43	25.4	-14.7	-1.2	198	213	89	20.8	-24.6	-7.7	73	202
44	25.6	-15.5	-2.1	184	212	90	23.1	-20.9	-5.1	57	211
46	25.5	-15.4	-2.4	168	215	91	21.2	-24.6	-8.3	67	201
49	21.3	-20.4	-6.2	204	285	93	21.4	-18.2	-4.5	83	272
50	21.7	-21.3	-6.5	193	275						

Appendix 1.3. Climatic variables for each provenance at Espanola from 1941-1970

Prov	Tmax_sm	Tmin_wt	Tmin_sp	PPT_wt	PPT_sm	Prov	Tmax_sm	Tmin_wt	Tmin_sp	PPT_wt	PPT_sm
1	23.1	-9	0.4	405	260	54	25.6	-7.7	1.2	182	212
3	20.5	-6.9	-1	391	284	57	22	-9.7	-1.3	212	198
4	19.6	-7	-2.1	356	263	58	22.9	-11.9	-1.9	157	208
5	19.4	-6.5	-1.9	348	259	59	23.1	-13.6	-2.8	143	233
7	22	-10.3	-1.4	283	225	61	22.5	-18.3	-5.4	158	234
9	23.6	-12.7	-1.5	294	247	68	26.9	-13.2	-0.3	91	283
13	23.4	-16.5	-4.4	205	285	71	26.1	-8.7	0.2	156	229
15	20.9	-17.2	-5.3	241	283	72	26.2	-11	-1.6	139	217
23	25.2	-13.4	-1.4	177	258	73	26.1	-11.6	-1.9	110	239
25	22.2	-14	-2.8	300	350	74	26.1	-11.6	-2	111	238
26	22.8	-16.6	-4.6	220	283	75	23.9	-11.9	-2.3	133	249
27	24.4	-15.5	-1.9	241	275	76	19.3	-18.3	-5.2	156	260
28	23.2	-15.4	-2.6	270	329	77	21.9	-22.9	-8.6	146	254
30	22	-18	-4.5	205	329	78	25.5	-18	-2.7	56	297
37	21	-21.7	-6.6	166	305	82	23.5	-20.2	-4.2	83	252
39	24.4	-13	-1.2	193	209	83	23.4	-21.2	-4.9	66	240
42	25.4	-14.5	-1.7	181	212	84	22.5	-20.4	-4.2	93	269
43	25.1	-14.8	-1.1	195	217	89	20.9	-24.9	-8.1	74	210
44	25.3	-15.6	-2	186	219	90	22.9	-21.5	-5.5	62	213
46	25.2	-15.5	-2.4	171	224	91	21.2	-24.9	-8.7	69	208
49	21.1	-20.4	-6.1	203	301	93	21.3	-18.6	-4.6	86	269
50	21.4	-21.3	-6.5	190	290						

Appendix 1.4. Climatic variables for each provenance at Espanola from 1951-1980

Prov	Tmax_sm	Tmin_wt	Tmin_sp	PPT_wt	PPT_sm	Prov	Tmax_sm	Tmin_wt	Tmin_sp	PPT_wt	PPT_sm
1	23.1	-9	0.6	429	273	54	25.4	-8	1.2	189	216
3	20.5	-6.9	-1	424	292	57	21.8	-9.9	-1.2	222	207
4	19.6	-7.1	-2	384	271	58	22.7	-12.3	-1.8	166	221
5	19.4	-6.7	-1.8	376	267	59	22.9	-13.9	-2.7	152	247
7	22	-10.3	-1.3	308	235	61	22.2	-18.5	-5.3	165	242
9	23.6	-12.7	-1.3	319	256	68	26.9	-13.6	-0.2	95	287
13	23.1	-16.6	-4.3	218	300	71	25.9	-9	0.4	159	239
15	20.9	-17.4	-5.1	257	300	72	26	-11.3	-1.5	143	228
23	25.1	-13.5	-1.4	184	268	73	25.8	-12	-1.8	114	252
25	22.1	-14.1	-2.8	319	353	74	25.9	-12	-1.8	114	250
26	22.6	-16.6	-4.4	229	299	75	23.8	-12.3	-2.2	140	254
27	24.2	-15.4	-1.5	249	290	76	19.2	-18.5	-5.1	154	261
28	23.1	-15.4	-2.3	281	349	77	21.9	-23.1	-8.4	141	258
30	22.1	-18.1	-4.3	212	338	78	25.7	-18.3	-2.5	57	299
37	21	-22	-6.3	176	317	82	23.5	-20.4	-4	77	249
39	24.1	-13	-1.1	194	215	83	23.5	-21.4	-4.6	62	234
42	25.2	-14.5	-1.6	185	224	84	22.5	-20.6	-4.1	87	270
43	24.8	-14.8	-1	196	230	89	20.7	-25	-7.8	72	214
44	25.1	-15.6	-1.9	190	232	90	23	-21.8	-5.4	62	208
46	25	-15.4	-2.3	176	237	91	21.2	-25	-8.4	67	208
49	21	-20.4	-5.9	205	318	93	20.9	-18.7	-4.4	88	285
50	21.3	-21.2	-6.2	192	305						

Appendix 1.5. Climatic variables for each provenance at Espanola from 1961-1990

Prov	Tmax_sm	Tmin_wt	Tmin_sp	PPT_wt	PPT_sm	Prov	Tmax_sm	Tmin_wt	Tmin_sp	PPT_wt	PPT_sm
1	23.2	-9.2	0.6	398	281	54	25.3	-8.1	1.3	192	234
3	20.5	-7.4	-1	420	310	57	21.8	-9.9	-1	229	212
4	19.7	-7.7	-2.1	390	287	58	22.8	-12.4	-1.8	174	218
5	19.5	-7.2	-1.9	382	283	59	22.9	-14.1	-2.6	163	240
7	22	-10.8	-1.3	297	251	61	22.3	-18.5	-5.1	168	243
9	23.6	-13	-1.3	295	268	68	27.1	-13.5	0.2	96	295
13	23.2	-16.8	-4.2	202	303	71	25.8	-9.1	0.5	162	239
15	21	-17.6	-5	242	303	72	25.8	-11.4	-1.4	147	224
23	24.9	-13.6	-1.4	176	284	73	25.7	-12.1	-1.8	118	247
25	22.2	-14.2	-2.6	305	370	74	25.7	-12.1	-1.8	118	246
26	22.6	-16.7	-4.3	213	303	75	23.8	-12.4	-2.1	145	242
27	24.2	-15.3	-1.4	235	296	76	19.3	-18.5	-4.9	153	256
28	23.1	-15.4	-2.1	267	349	77	21.8	-23.2	-8.2	140	263
30	22.2	-18.2	-4.1	204	326	78	26	-18.2	-2	55	286
37	21.2	-22.1	-6.1	172	308	82	23.7	-20.2	-3.4	73	258
39	24	-13	-1	194	218	83	23.7	-21.1	-4	61	240
42	25.1	-14.4	-1.4	181	230	84	22.6	-20.3	-3.5	83	278
43	24.7	-14.7	-0.9	187	237	89	21	-24.6	-7	68	222
44	25.1	-15.5	-1.8	182	240	90	23.2	-21.4	-4.7	57	206
46	24.9	-15.3	-2.1	173	243	91	21.5	-24.9	-7.9	65	213
49	21	-20.4	-5.8	196	326	93	21.1	-18.1	-3.8	82	284
50	21.3	-21.2	-6	186	314						

Appendix 1.6. Climatic variables for each provenance at Espanola from 1971-2000

Prov	Tmax_sm	Tmin_wt	Tmin_sp	PPT_wt	PPT_sm	Prov	Tmax_sm	Tmin_wt	Tmin_sp	PPT_wt	PPT_sm
1	23.5	-8.7	0.9	403	283	54	25.3	-7.5	1.6	200	237
3	20.7	-7.4	-0.8	418	309	57	21.9	-9.5	-0.7	235	212
4	19.9	-7.9	-2	391	288	58	22.9	-11.9	-1.6	178	219
5	19.7	-7.4	-1.8	384	284	59	23	-13.6	-2.5	164	243
7	22.2	-10.7	-1	298	253	61	22.6	-18.1	-4.9	169	237
9	23.8	-12.7	-1	306	273	68	27	-12.7	0.5	95	314
13	23.4	-16.5	-3.9	210	305	71	25.6	-8.4	0.5	164	256
15	21.1	-17.6	-4.7	254	310	72	25.7	-10.9	-1.4	151	235
23	25.1	-13	-1.2	186	291	73	25.6	-11.5	-1.7	124	258
25	22.3	-13.5	-2.3	312	381	74	25.6	-11.6	-1.8	124	256
26	22.8	-16.3	-4	217	307	75	23.7	-12.1	-2	144	248
27	24.4	-14.9	-1.1	239	302	76	19.4	-18.2	-4.7	152	263
28	23.2	-15.1	-1.9	272	352	77	22	-22.8	-8	135	262
30	22.4	-18.1	-3.9	210	323	78	25.9	-17.4	-1.6	52	304
37	21.4	-22	-6	174	307	82	23.7	-19.2	-2.8	70	266
39	24.1	-12.5	-0.8	198	222	83	23.7	-20.1	-3.4	60	250
42	25.3	-13.8	-1.1	186	234	84	22.6	-19.4	-2.9	78	281
43	24.8	-14.2	-0.6	197	241	89	20.8	-23.6	-6.2	64	228
44	25.2	-15	-1.5	187	245	90	22.9	-20.4	-4	54	217
46	25	-14.8	-1.8	177	247	91	21.5	-24	-7.1	61	216
49	21.2	-20.1	-5.5	197	327	93	20.9	-17.4	-3.3	75	301
50	21.6	-20.9	-5.7	185	312						

Appendix 1.7. Climatic variables for each provenance at Fraserdale from 1931-1960

Prov	Tmax_sm	Tmin_wt	Tmin_sp	PPT_wt	PPT_sm	Prov	Tmax_sm	Tmin_wt	Tmin_sp	PPT_wt	PPT_sm
1	23.3	-8.9	0.5	403	268	54	25.9	-7.2	1.2	180	200
3	20.7	-7.2	-0.9	381	271	55	24.2	-7.8	0.1	228	197
4	19.8	-7.4	-2.1	342	252	56	25.2	-10.2	-1	221	196
5	19.6	-6.9	-1.9	335	249	57	22.4	-9.4	-1.4	206	187
6	22.7	-10.4	-1.3	299	232	60	22.6	-15.3	-4.3	174	233
7	22.1	-10.6	-1.3	275	220	61	22.9	-18.1	-5.5	160	221
9	23.8	-12.9	-1.5	286	246	62	22.8	-20.8	-6.8	155	229
11	23.7	-14.6	-2.9	283	251	63	22.4	-23.2	-7.9	166	243
12	22.6	-13.7	-2.8	264	239	64	22.4	-21.4	-6.7	177	237
13	23.6	-16.4	-4.3	208	288	65	27.9	-11.6	0.4	95	304
14	22.4	-16.6	-4.7	253	273	66	27.8	-12.2	-0.1	91	287
15	21.1	-17.5	-5.2	234	284	68	27.4	-12.7	-0.3	98	285
19	21	-21.8	-7.5	195	322	69	26	-14.2	-1.4	85	310
20	20.2	-20.5	-6.7	214	261	70	25	-15.8	-3.1	82	307
23	25.4	-13.1	-1.4	191	259	71	26.4	-8.2	0.1	155	228
25	22.3	-13.6	-2.7	308	363	72	26.4	-10.5	-1.7	140	215
26	23	-16.5	-4.6	225	287	73	26.3	-11.1	-2.1	113	235
27	24.5	-15.7	-2	249	284	74	26.3	-11.2	-2.1	114	233
28	23.2	-15.6	-2.7	275	338	75	24.1	-11.5	-2.5	140	250
29	22.4	-15.7	-3.4	224	298	76	19.6	-18.3	-5.5	162	262
30	22.2	-18.3	-4.6	204	333	77	22.2	-22.8	-8.8	149	249
31	21.7	-20.2	-4.9	165	279	78	25.6	-17.8	-2.8	54	286
34	21.1	-20.5	-6.8	230	318	79	24.8	-18.1	-4.6	73	291
35	20.5	-21	-7.2	214	331	80	24.9	-19.9	-4.3	51	267
36	20.4	-22.5	-7.8	175	321	81	24.2	-20.3	-4.2	76	266
37	21.1	-21.9	-6.7	161	309	82	23.8	-19.7	-4.2	83	235
38	19.5	-24	-9.3	181	302	83	23.7	-20.8	-4.8	68	223
39	24.7	-12.8	-1.3	195	199	84	22.9	-20.1	-4.3	92	252
41	24.6	-12.8	-1.1	213	198	86	22.6	-23	-6.6	88	232
42	25.7	-14.5	-1.8	180	203	87	23.6	-21.1	-5.1	58	171
43	25.4	-14.7	-1.2	198	213	88	22.5	-22.6	-6.3	60	187
44	25.6	-15.5	-2.1	184	212	89	20.8	-24.6	-7.7	73	202
45	24.3	-14.7	-2.5	182	213	90	23.1	-20.9	-5.1	57	211
46	25.5	-15.4	-2.4	168	215	91	21.2	-24.6	-8.3	67	201
47	24	-17.9	-3.5	200	249	92	19.3	-27.9	-11.1	68	188
48	23.2	-18.6	-4.2	208	265	93	21.4	-18.2	-4.5	83	272
49	21.3	-20.4	-6.2	204	285	94	21.2	-21.8	-6.3	62	225
50	21.7	-21.3	-6.5	193	275	95	22.6	-24.1	-6.9	65	198
51	21.3	-20.7	-6.7	220	324	96	20.8	-27.8	-9.9	58	112
53	15.9	-25.6	-11.5	119	255	99	20.6	-29	-9.7	48	141

Appendix 1.8. Climatic variables for each provenance at Fraserdale from 1941-1970

Prov	Tmax_sm	Tmin_wt	Tmin_sp	PPT_wt	PPT_sm	Prov	Tmax_sm	Tmin_wt	Tmin_sp	PPT_wt	PPT_sm
1	23.1	-9	0.4	405	260	54	25.6	-7.7	1.2	182	212
3	20.5	-6.9	-1	391	284	55	23.9	-8.2	0.2	237	210
4	19.6	-7	-2.1	356	263	56	24.9	-10.5	-0.9	226	206
5	19.4	-6.5	-1.9	348	259	57	22	-9.7	-1.3	212	198
6	22.6	-10	-1.4	314	239	60	22.2	-15.6	-4.1	170	238
7	22	-10.3	-1.4	283	225	61	22.5	-18.3	-5.4	158	234
9	23.6	-12.7	-1.5	294	247	62	22.4	-21	-6.7	154	242
11	23.5	-14.3	-2.9	291	251	63	22.1	-23.3	-7.8	163	257
12	22.4	-13.2	-2.8	274	240	64	22.2	-21.4	-6.7	173	250
13	23.4	-16.5	-4.4	205	285	65	27.4	-12.3	0.4	90	304
14	22.2	-16.3	-4.8	259	270	66	27.3	-12.9	-0.1	84	286
15	20.9	-17.2	-5.3	241	283	68	26.9	-13.2	-0.3	91	283
19	20.9	-21.4	-7.4	199	323	69	25.6	-14.7	-1.4	80	309
20	20	-20	-6.7	225	262	70	24.7	-16.3	-3.1	77	305
23	25.2	-13.4	-1.4	177	258	71	26.1	-8.7	0.2	156	229
25	22.2	-14	-2.8	300	350	72	26.2	-11	-1.6	139	217
26	22.8	-16.6	-4.6	220	283	73	26.1	-11.6	-1.9	110	239
27	24.4	-15.5	-1.9	241	275	74	26.1	-11.6	-2	111	238
28	23.2	-15.4	-2.6	270	329	75	23.9	-11.9	-2.3	133	249
29	22.3	-15.4	-3.3	226	291	76	19.3	-18.3	-5.2	156	260
30	22	-18	-4.5	205	329	77	21.9	-22.9	-8.6	146	254
31	21.6	-20	-4.8	167	276	78	25.5	-18	-2.7	56	297
34	21.1	-20.4	-6.9	235	314	79	24.7	-18.4	-4.4	77	300
35	20.5	-20.9	-7.2	218	328	80	24.7	-20.1	-4.1	53	281
36	20.3	-22.5	-7.7	179	322	81	24	-20.7	-4.1	77	284
37	21	-21.7	-6.6	166	305	82	23.5	-20.2	-4.2	83	252
38	19.4	-23.9	-9.1	184	302	83	23.4	-21.2	-4.9	66	240
39	24.4	-13	-1.2	193	209	84	22.5	-20.4	-4.2	93	269
41	24.3	-12.9	-1	211	208	86	22.4	-23.4	-6.6	89	246
42	25.4	-14.5	-1.7	181	212	87	23.6	-21.4	-5.4	58	179
43	25.1	-14.8	-1.1	195	217	88	22.4	-22.7	-6.5	61	198
44	25.3	-15.6	-2	186	219	89	20.9	-24.9	-8.1	74	210
45	23.9	-14.8	-2.4	183	223	90	22.9	-21.5	-5.5	62	213
46	25.2	-15.5	-2.4	171	224	91	21.2	-24.9	-8.7	69	208
47	23.7	-18	-3.5	202	256	92	19.3	-28.1	-11.4	70	194
48	23	-18.7	-4.2	209	273	93	21.3	-18.6	-4.6	86	269
49	21.1	-20.4	-6.1	203	301	94	21.1	-21.9	-6.4	64	229
50	21.4	-21.3	-6.5	190	290	95	22.5	-24.2	-6.9	65	202
51	21.2	-20.6	-6.7	221	329	96	20.8	-27.8	-10	59	116
53	15.7	-25.3	-11.4	110	242	99	20.7	-29.1	-9.7	52	146

Appendix 1.9. Climatic variables for each provenance at Fraserdale from 1951-1980

Prov	Tmax_sm	Tmin_wt	Tmin_sp	PPT_wt	PPT_sm	Prov	Tmax_sm	Tmin_wt	Tmin_sp	PPT_wt	PPT_sm
1	23.1	-9	0.6	429	273	54	25.4	-8	1.2	189	216
3	20.5	-6.9	-1	424	292	55	23.7	-8.4	0.3	247	215
4	19.6	-7.1	-2	384	271	56	24.7	-10.5	-0.7	230	214
5	19.4	-6.7	-1.8	376	267	57	21.8	-9.9	-1.2	222	207
6	22.5	-9.9	-1.3	341	249	60	22	-15.9	-4	182	251
7	22	-10.3	-1.3	308	235	61	22.2	-18.5	-5.3	165	242
9	23.6	-12.7	-1.3	319	256	62	22.3	-20.9	-6.4	156	245
11	23.4	-14.3	-2.7	315	263	63	22.1	-23.3	-7.6	159	256
12	22.3	-13.2	-2.6	290	255	64	22.3	-21.6	-6.5	162	249
13	23.1	-16.6	-4.3	218	300	65	27.4	-12.8	0.4	88	309
14	22.1	-16.4	-4.6	278	284	66	27.3	-13.3	0	84	294
15	20.9	-17.4	-5.1	257	300	68	26.9	-13.6	-0.2	95	287
19	20.9	-21.4	-7.1	209	333	69	25.6	-15	-1.3	84	312
20	20.1	-20.1	-6.4	230	271	70	24.7	-16.7	-3	80	308
23	25.1	-13.5	-1.4	184	268	71	25.9	-9	0.4	159	239
25	22.1	-14.1	-2.8	319	353	72	26	-11.3	-1.5	143	228
26	22.6	-16.6	-4.4	229	299	73	25.8	-12	-1.8	114	252
27	24.2	-15.4	-1.5	249	290	74	25.9	-12	-1.8	114	250
28	23.1	-15.4	-2.3	281	349	75	23.8	-12.3	-2.2	140	254
29	22.2	-15.5	-3.1	236	298	76	19.2	-18.5	-5.1	154	261
30	22.1	-18.1	-4.3	212	338	77	21.9	-23.1	-8.4	141	258
31	21.6	-20.3	-4.6	177	286	78	25.7	-18.3	-2.5	57	299
34	21	-20.3	-6.5	246	330	79	24.8	-18.6	-4.1	79	305
35	20.4	-20.9	-6.9	231	343	80	24.9	-20.2	-4	55	273
36	20.3	-22.6	-7.3	191	334	81	24	-20.8	-3.8	76	279
37	21	-22	-6.3	176	317	82	23.5	-20.4	-4	77	249
38	19.5	-24	-8.8	194	315	83	23.5	-21.4	-4.6	62	234
39	24.1	-13	-1.1	194	215	84	22.5	-20.6	-4.1	87	270
41	24.1	-12.8	-0.9	213	216	86	22.3	-23.6	-6.3	80	246
42	25.2	-14.5	-1.6	185	224	87	23.3	-21.4	-5.2	57	182
43	24.8	-14.8	-1	196	230	88	22.2	-22.8	-6.3	61	201
44	25.1	-15.6	-1.9	190	232	89	20.7	-25	-7.8	72	214
45	23.7	-14.7	-2.3	187	234	90	23	-21.8	-5.4	62	208
46	25	-15.4	-2.3	176	237	91	21.2	-25	-8.4	67	208
47	23.5	-17.9	-3.4	204	270	92	19.2	-28.1	-11	70	198
48	22.8	-18.7	-4.1	211	288	93	20.9	-18.7	-4.4	88	285
49	21	-20.4	-5.9	205	318	94	20.7	-21.9	-6.2	67	244
50	21.3	-21.2	-6.2	192	305	95	22.1	-24.3	-6.7	70	220
51	21.1	-20.6	-6.4	228	346	96	20.8	-28	-9.8	59	132
53	15.9	-25.5	-11.3	104	252	99	20.8	-29.5	-9.8	52	148

Appendix 1.10. Climatic variables for each provenance at Fraserdale from 1961-1990

Prov	Tmax_sm	Tmin_wt	Tmin_sp	PPT_wt	PPT_sm	Prov	Tmax_sm	Tmin_wt	Tmin_sp	PPT_wt	PPT_sm
1	23.2	-9.2	0.6	398	281	54	25.3	-8.1	1.3	192	234
3	20.5	-7.4	-1	420	310	55	23.7	-8.4	0.5	253	224
4	19.7	-7.7	-2.1	390	287	56	24.6	-10.5	-0.6	235	221
5	19.5	-7.2	-1.9	382	283	57	21.8	-9.9	-1	229	212
6	22.5	-10.4	-1.3	331	266	60	22	-16.1	-3.9	194	244
7	22	-10.8	-1.3	297	251	61	22.3	-18.5	-5.1	168	243
9	23.6	-13	-1.3	295	268	62	22.4	-21	-6.2	156	252
11	23.5	-14.7	-2.7	293	279	63	22.2	-23.5	-7.5	157	269
12	22.4	-13.7	-2.6	275	271	64	22.3	-21.8	-6.4	157	259
13	23.2	-16.8	-4.2	202	303	65	27.5	-12.9	0.8	90	302
14	22.1	-16.7	-4.5	258	294	66	27.3	-13.3	0.4	86	293
15	21	-17.6	-5	242	303	68	27.1	-13.5	0.2	96	295
19	21	-21.5	-6.9	201	324	69	25.8	-15	-0.9	87	306
20	20.2	-20.3	-6.3	217	266	70	24.9	-16.7	-2.5	84	292
23	24.9	-13.6	-1.4	176	284	71	25.8	-9.1	0.5	162	239
25	22.2	-14.2	-2.6	305	370	72	25.8	-11.4	-1.4	147	224
26	22.6	-16.7	-4.3	213	303	73	25.7	-12.1	-1.8	118	247
27	24.2	-15.3	-1.4	235	296	74	25.7	-12.1	-1.8	118	246
28	23.1	-15.4	-2.1	267	349	75	23.8	-12.4	-2.1	145	242
29	22.3	-15.6	-2.9	224	289	76	19.3	-18.5	-4.9	153	256
30	22.2	-18.2	-4.1	204	326	77	21.8	-23.2	-8.2	140	263
31	21.8	-20.4	-4.4	173	279	78	26	-18.2	-2	55	286
34	21	-20.3	-6.2	231	332	79	25.2	-18.4	-3.6	80	292
35	20.4	-20.9	-6.6	219	343	80	25.1	-19.9	-3.3	53	270
36	20.5	-22.7	-7.1	186	327	81	24.1	-20.5	-3.1	74	287
37	21.2	-22.1	-6.1	172	308	82	23.7	-20.2	-3.4	73	258
38	19.6	-24.1	-8.6	190	308	83	23.7	-21.1	-4	61	240
39	24	-13	-1	194	218	84	22.6	-20.3	-3.5	83	278
41	24	-12.9	-0.8	211	219	86	22.6	-23.3	-5.8	75	256
42	25.1	-14.4	-1.4	181	230	87	23.5	-20.9	-4.3	53	188
43	24.7	-14.7	-0.9	187	237	88	22.4	-22.4	-5.4	57	205
44	25.1	-15.5	-1.8	182	240	89	21	-24.6	-7	68	222
45	23.6	-14.6	-2.1	188	239	90	23.2	-21.4	-4.7	57	206
46	24.9	-15.3	-2.1	173	243	91	21.5	-24.9	-7.9	65	213
47	23.5	-17.9	-3.3	193	277	92	19.4	-28.1	-10.6	67	202
48	22.9	-18.6	-4	198	295	93	21.1	-18.1	-3.8	82	284
49	21	-20.4	-5.8	196	326	94	20.9	-21.4	-5.5	62	238
50	21.3	-21.2	-6	186	314	95	22.3	-23.8	-6.1	64	218
51	21.2	-20.6	-6.2	216	348	96	21	-27.7	-9.5	55	141
53	16	-26	-11.6	96	239	99	21	-29	-9.6	52	149

Appendix 1.11. Climatic variables for each provenance at Fraserdale from 1971-2000

Prov	Tmax_sm	Tmin_wt	Tmin_sp	PPT_wt	PPT_sm	Prov	Tmax_sm	Tmin_wt	Tmin_sp	PPT_wt	PPT_sm
1	23.5	-8.7	0.9	403	283	54	25.3	-7.5	1.6	200	237
3	20.7	-7.4	-0.8	418	309	55	23.7	-7.9	0.7	260	225
4	19.9	-7.9	-2	391	288	56	24.6	-10	-0.3	238	222
5	19.7	-7.4	-1.8	384	284	57	21.9	-9.5	-0.7	235	212
6	22.6	-10.2	-0.8	332	267	60	22.1	-15.5	-3.7	194	246
7	22.2	-10.7	-1	298	253	61	22.6	-18.1	-4.9	169	237
9	23.8	-12.7	-1	306	273	62	22.7	-20.6	-6	153	242
11	23.6	-14.5	-2.4	304	284	63	22.5	-23.1	-7.3	150	254
12	22.5	-13.8	-2.4	284	276	64	22.6	-21.4	-6.1	148	247
13	23.4	-16.5	-3.9	210	305	65	27.3	-12.1	1.1	91	329
14	22.3	-16.7	-4.2	271	300	66	27.2	-12.4	0.7	87	319
15	21.1	-17.6	-4.7	254	310	68	27	-12.7	0.5	95	314
19	21.2	-21.6	-6.7	207	323	69	25.7	-14.2	-0.6	85	322
20	20.3	-20.4	-6	220	269	70	24.8	-15.9	-2.3	83	303
23	25.1	-13	-1.2	186	291	71	25.6	-8.4	0.5	164	256
25	22.3	-13.5	-2.3	312	381	72	25.7	-10.9	-1.4	151	235
26	22.8	-16.3	-4	217	307	73	25.6	-11.5	-1.7	124	258
27	24.4	-14.9	-1.1	239	302	74	25.6	-11.6	-1.8	124	256
28	23.2	-15.1	-1.9	272	352	75	23.7	-12.1	-2	144	248
29	22.5	-15.5	-2.7	233	288	76	19.4	-18.2	-4.7	152	263
30	22.4	-18.1	-3.9	210	323	77	22	-22.8	-8	135	262
31	22	-20.2	-4.3	177	277	78	25.9	-17.4	-1.6	52	304
34	21.1	-20	-6	233	335	79	25	-17.5	-3.2	75	319
35	20.6	-20.6	-6.4	221	345	80	25	-19.1	-2.9	51	292
36	20.8	-22.4	-6.9	189	322	81	24.1	-19.5	-2.7	71	291
37	21.4	-22	-6	174	307	82	23.7	-19.2	-2.8	70	266
38	20	-23.8	-8.3	192	302	83	23.7	-20.1	-3.4	60	250
39	24.1	-12.5	-0.8	198	222	84	22.6	-19.4	-2.9	78	281
41	24.1	-12.3	-0.5	218	222	86	22.6	-22.4	-5.2	72	263
42	25.3	-13.8	-1.1	186	234	87	23.2	-20	-3.6	50	194
43	24.8	-14.2	-0.6	197	241	88	22.2	-21.5	-4.8	53	209
44	25.2	-15	-1.5	187	245	89	20.8	-23.6	-6.2	64	228
45	23.6	-14.1	-1.9	193	243	90	22.9	-20.4	-4	54	217
46	25	-14.8	-1.8	177	247	91	21.5	-24	-7.1	61	216
47	23.7	-17.5	-3	199	281	92	19.6	-27.4	-9.8	63	205
48	23.1	-18.2	-3.7	203	299	93	20.9	-17.4	-3.3	75	301
49	21.2	-20.1	-5.5	197	327	94	20.9	-20.6	-4.9	57	245
50	21.6	-20.9	-5.7	185	312	95	22.3	-22.9	-5.4	59	228
51	21.5	-20.3	-6	218	350	96	21.1	-26.6	-8.6	51	148
53	16.5	-25.8	-11.3	100	246	99	21.2	-28.2	-8.9	50	149

Appendix 1.12 Climatic variables for each provenance at Swastika from 1931-1960

Prov	Tmax_sm	Tmin_wt	Tmin_sp	PPT_wt	PPT_sm	Prov	Tmax_sm	Tmin_wt	Tmin_sp	PPT_wt	PPT_sm
1	23.3	-8.9	0.5	403	268	55	24.2	-7.8	0.1	228	197
3	20.7	-7.2	-0.9	381	271	56	25.2	-10.2	-1	221	196
4	19.8	-7.4	-2.1	342	252	57	22.4	-9.4	-1.4	206	187
5	19.6	-6.9	-1.9	335	249	60	22.6	-15.3	-4.3	174	233
6	22.7	-10.4	-1.3	299	232	61	22.9	-18.1	-5.5	160	221
7	22.1	-10.6	-1.3	275	220	62	22.8	-20.8	-6.8	155	229
9	23.8	-12.9	-1.5	286	246	63	22.4	-23.2	-7.9	166	243
11	23.7	-14.6	-2.9	283	251	64	22.4	-21.4	-6.7	177	237
12	22.6	-13.7	-2.8	264	239	65	27.9	-11.6	0.4	95	304
13	23.6	-16.4	-4.3	208	288	66	27.8	-12.2	-0.1	91	287
14	22.4	-16.6	-4.7	253	273	68	27.4	-12.7	-0.3	98	285
19	21	-21.8	-7.5	195	322	69	26	-14.2	-1.4	85	310
20	20.2	-20.5	-6.7	214	261	70	25	-15.8	-3.1	82	307
23	25.4	-13.1	-1.4	191	259	71	26.4	-8.2	0.1	155	228
25	22.3	-13.6	-2.7	308	363	72	26.4	-10.5	-1.7	140	215
26	23	-16.5	-4.6	225	287	73	26.3	-11.1	-2.1	113	235
27	24.5	-15.7	-2	249	284	74	26.3	-11.2	-2.1	114	233
28	23.2	-15.6	-2.7	275	338	75	24.1	-11.5	-2.5	140	250
29	22.4	-15.7	-3.4	224	298	76	19.6	-18.3	-5.5	162	262
30	22.2	-18.3	-4.6	204	333	77	22.2	-22.8	-8.8	149	249
31	21.7	-20.2	-4.9	165	279	78	25.6	-17.8	-2.8	54	286
34	21.1	-20.5	-6.8	230	318	79	24.8	-18.1	-4.6	73	291
35	20.5	-21	-7.2	214	331	80	24.9	-19.9	-4.3	51	267
36	20.4	-22.5	-7.8	175	321	81	24.2	-20.3	-4.2	76	266
37	21.1	-21.9	-6.7	161	309	82	23.8	-19.7	-4.2	83	235
38	19.5	-24	-9.3	181	302	83	23.7	-20.8	-4.8	68	223
39	24.7	-12.8	-1.3	195	199	84	22.9	-20.1	-4.3	92	252
40	24.8	-12.5	-0.8	215	196	86	22.6	-23	-6.6	88	232
41	24.6	-12.8	-1.1	213	198	87	23.6	-21.1	-5.1	58	171
42	25.7	-14.5	-1.8	180	203	88	22.5	-22.6	-6.3	60	187
43	25.4	-14.7	-1.2	198	213	89	20.8	-24.6	-7.7	73	202
44	25.6	-15.5	-2.1	184	212	90	23.1	-20.9	-5.1	57	211
45	24.3	-14.7	-2.5	182	213	91	21.2	-24.6	-8.3	67	201
46	25.5	-15.4	-2.4	168	215	92	19.3	-27.9	-11.1	68	188
47	24	-17.9	-3.5	200	249	93	21.4	-18.2	-4.5	83	272
48	23.2	-18.6	-4.2	208	265	94	21.2	-21.8	-6.3	62	225
49	21.3	-20.4	-6.2	204	285	95	22.6	-24.1	-6.9	65	198
50	21.7	-21.3	-6.5	193	275	96	20.8	-27.8	-9.9	58	112
51	21.3	-20.7	-6.7	220	324	98	21.5	-28.7	-8.9	50	135
53	15.9	-25.6	-11.5	119	255	99	20.6	-29	-9.7	48	141
54	25.9	-7.2	1.2	180	200						

Appendix 1.13. Climatic variables for each provenance at Swastika from 1941-1970

Prov	Tmax_sm	Tmin_wt	Tmin_sp	PPT_wt	PPT_sm
1	23.1	-9	0.4	405	260
3	20.5	-6.9	-1	391	284
4	19.6	-7	-2.1	356	263
5	19.4	-6.5	-1.9	348	259
6	22.6	-10	-1.4	314	239
7	22	-10.3	-1.4	283	225
9	23.6	-12.7	-1.5	294	247
11	23.5	-14.3	-2.9	291	251
12	22.4	-13.2	-2.8	274	240
13	23.4	-16.5	-4.4	205	285
14	22.2	-16.3	-4.8	259	270
19	20.9	-21.4	-7.4	199	323
20	20	-20	-6.7	225	262
23	25.2	-13.4	-1.4	177	258
25	22.2	-14	-2.8	300	350
26	22.8	-16.6	-4.6	220	283
27	24.4	-15.5	-1.9	241	275
28	23.2	-15.4	-2.6	270	329
29	22.3	-15.4	-3.3	226	291
30	22	-18	-4.5	205	329
31	21.6	-20	-4.8	167	276
34	21.1	-20.4	-6.9	235	314
35	20.5	-20.9	-7.2	218	328
36	20.3	-22.5	-7.7	179	322
37	21	-21.7	-6.6	166	305
38	19.4	-23.9	-9.1	184	302
39	24.4	-13	-1.2	193	209
40	24.4	-12.6	-0.7	213	205
41	24.3	-12.9	-1	211	208
42	25.4	-14.5	-1.7	181	212
43	25.1	-14.8	-1.1	195	217
44	25.3	-15.6	-2	186	219
45	23.9	-14.8	-2.4	183	223
46	25.2	-15.5	-2.4	171	224
47	23.7	-18	-3.5	202	256
48	23	-18.7	-4.2	209	273
49	21.1	-20.4	-6.1	203	301
50	21.4	-21.3	-6.5	190	290
51	21.2	-20.6	-6.7	221	329
53	15.7	-25.3	-11.4	110	242
54	25.6	-7.7	1.2	182	212
55	23.9	-8.2	0.2	237	210
56	24.9	-10.5	-0.9	226	206
57	22	-9.7	-1.3	212	198
60	22.2	-15.6	-4.1	170	238
61	22.5	-18.3	-5.4	158	234
62	22.4	-21	-6.7	154	242
63	22.1	-23.3	-7.8	163	257
64	22.2	-21.4	-6.7	173	250
65	27.4	-12.3	0.4	90	304
66	27.3	-12.9	-0.1	84	286
68	26.9	-13.2	-0.3	91	283
69	25.6	-14.7	-1.4	80	309
70	24.7	-16.3	-3.1	77	305
71	26.1	-8.7	0.2	156	229
72	26.2	-11	-1.6	139	217
73	26.1	-11.6	-1.9	110	239
74	26.1	-11.6	-2	111	238
75	23.9	-11.9	-2.3	133	249
76	19.3	-18.3	-5.2	156	260
77	21.9	-22.9	-8.6	146	254
78	25.5	-18	-2.7	56	297
79	24.7	-18.4	-4.4	77	300
80	24.7	-20.1	-4.1	53	281
81	24	-20.7	-4.1	77	284
82	23.5	-20.2	-4.2	83	252
83	23.4	-21.2	-4.9	66	240
84	22.5	-20.4	-4.2	93	269
86	22.4	-23.4	-6.6	89	246
87	23.6	-21.4	-5.4	58	179
88	22.4	-22.7	-6.5	61	198
89	20.9	-24.9	-8.1	74	210
90	22.9	-21.5	-5.5	62	213
91	21.2	-24.9	-8.7	69	208
92	19.3	-28.1	-11.4	70	194
93	21.3	-18.6	-4.6	86	269
94	21.1	-21.9	-6.4	64	229
95	22.5	-24.2	-6.9	65	202
96	20.8	-27.8	-10	59	116
98	21.5	-28.7	-8.9	53	134
99	20.7	-29.1	-9.7	52	146

Appendix 1.14. Climatic variables for each provenance at Swastika from 1951-1980

Prov	Tmax_sm	Tmin_wt	Tmin_sp	PPT_wt	PPT_sm	Prov	Tmax_sm	Tmin_wt	Tmin_sp	PPT_wt	PPT_sm
1	23.1	-9	0.6	429	273	55	23.7	-8.4	0.3	247	215
3	20.5	-6.9	-1	424	292	56	24.7	-10.5	-0.7	230	214
4	19.6	-7.1	-2	384	271	57	21.8	-9.9	-1.2	222	207
5	19.4	-6.7	-1.8	376	267	60	22	-15.9	-4	182	251
6	22.5	-9.9	-1.3	341	249	61	22.2	-18.5	-5.3	165	242
7	22	-10.3	-1.3	308	235	62	22.3	-20.9	-6.4	156	245
9	23.6	-12.7	-1.3	319	256	63	22.1	-23.3	-7.6	159	256
11	23.4	-14.3	-2.7	315	263	64	22.3	-21.6	-6.5	162	249
12	22.3	-13.2	-2.6	290	255	65	27.4	-12.8	0.4	88	309
13	23.1	-16.6	-4.3	218	300	66	27.3	-13.3	0	84	294
14	22.1	-16.4	-4.6	278	284	68	26.9	-13.6	-0.2	95	287
19	20.9	-21.4	-7.1	209	333	69	25.6	-15	-1.3	84	312
20	20.1	-20.1	-6.4	230	271	70	24.7	-16.7	-3	80	308
23	25.1	-13.5	-1.4	184	268	71	25.9	-9	0.4	159	239
25	22.1	-14.1	-2.8	319	353	72	26	-11.3	-1.5	143	228
26	22.6	-16.6	-4.4	229	299	73	25.8	-12	-1.8	114	252
27	24.2	-15.4	-1.5	249	290	74	25.9	-12	-1.8	114	250
28	23.1	-15.4	-2.3	281	349	75	23.8	-12.3	-2.2	140	254
29	22.2	-15.5	-3.1	236	298	76	19.2	-18.5	-5.1	154	261
30	22.1	-18.1	-4.3	212	338	77	21.9	-23.1	-8.4	141	258
31	21.6	-20.3	-4.6	177	286	78	25.7	-18.3	-2.5	57	299
34	21	-20.3	-6.5	246	330	79	24.8	-18.6	-4.1	79	305
35	20.4	-20.9	-6.9	231	343	80	24.9	-20.2	-4	55	273
36	20.3	-22.6	-7.3	191	334	81	24	-20.8	-3.8	76	279
37	21	-22	-6.3	176	317	82	23.5	-20.4	-4	77	249
38	19.5	-24	-8.8	194	315	83	23.5	-21.4	-4.6	62	234
39	24.1	-13	-1.1	194	215	84	22.5	-20.6	-4.1	87	270
40	24.3	-12.5	-0.6	215	212	86	22.3	-23.6	-6.3	80	246
41	24.1	-12.8	-0.9	213	216	87	23.3	-21.4	-5.2	57	182
42	25.2	-14.5	-1.6	185	224	88	22.2	-22.8	-6.3	61	201
43	24.8	-14.8	-1	196	230	89	20.7	-25	-7.8	72	214
44	25.1	-15.6	-1.9	190	232	90	23	-21.8	-5.4	62	208
45	23.7	-14.7	-2.3	187	234	91	21.2	-25	-8.4	67	208
46	25	-15.4	-2.3	176	237	92	19.2	-28.1	-11	70	198
47	23.5	-17.9	-3.4	204	270	93	20.9	-18.7	-4.4	88	285
48	22.8	-18.7	-4.1	211	288	94	20.7	-21.9	-6.2	67	244
49	21	-20.4	-5.9	205	318	95	22.1	-24.3	-6.7	70	220
50	21.3	-21.2	-6.2	192	305	96	20.8	-28	-9.8	59	132
51	21.1	-20.6	-6.4	228	346	98	21.6	-29	-9	54	138
53	15.9	-25.5	-11.3	104	252	99	20.8	-29.5	-9.8	52	148
54	25.4	-8	1.2	189	216						

Appendix 1.15. Climatic variables for each provenance at Swastika from 1961-1990

Prov	Tmax_sm	Tmin_wt	Tmin_sp	PPT_wt	PPT_sm	Prov	Tmax_sm	Tmin_wt	Tmin_sp	PPT_wt	PPT_sm
1	23.2	-9.2	0.6	398	281	55	23.7	-8.4	0.5	253	224
3	20.5	-7.4	-1	420	310	56	24.6	-10.5	-0.6	235	221
4	19.7	-7.7	-2.1	390	287	57	21.8	-9.9	-1	229	212
5	19.5	-7.2	-1.9	382	283	60	22	-16.1	-3.9	194	244
6	22.5	-10.4	-1.3	331	266	61	22.3	-18.5	-5.1	168	243
7	22	-10.8	-1.3	297	251	62	22.4	-21	-6.2	156	252
9	23.6	-13	-1.3	295	268	63	22.2	-23.5	-7.5	157	269
11	23.5	-14.7	-2.7	293	279	64	22.3	-21.8	-6.4	157	259
12	22.4	-13.7	-2.6	275	271	65	27.5	-12.9	0.8	90	302
13	23.2	-16.8	-4.2	202	303	66	27.3	-13.3	0.4	86	293
14	22.1	-16.7	-4.5	258	294	68	27.1	-13.5	0.2	96	295
19	21	-21.5	-6.9	201	324	69	25.8	-15	-0.9	87	306
20	20.2	-20.3	-6.3	217	266	70	24.9	-16.7	-2.5	84	292
23	24.9	-13.6	-1.4	176	284	71	25.8	-9.1	0.5	162	239
25	22.2	-14.2	-2.6	305	370	72	25.8	-11.4	-1.4	147	224
26	22.6	-16.7	-4.3	213	303	73	25.7	-12.1	-1.8	118	247
27	24.2	-15.3	-1.4	235	296	74	25.7	-12.1	-1.8	118	246
28	23.1	-15.4	-2.1	267	349	75	23.8	-12.4	-2.1	145	242
29	22.3	-15.6	-2.9	224	289	76	19.3	-18.5	-4.9	153	256
30	22.2	-18.2	-4.1	204	326	77	21.8	-23.2	-8.2	140	263
31	21.8	-20.4	-4.4	173	279	78	26	-18.2	-2	55	286
34	21	-20.3	-6.2	231	332	79	25.2	-18.4	-3.6	80	292
35	20.4	-20.9	-6.6	219	343	80	25.1	-19.9	-3.3	53	270
36	20.5	-22.7	-7.1	186	327	81	24.1	-20.5	-3.1	74	287
37	21.2	-22.1	-6.1	172	308	82	23.7	-20.2	-3.4	73	258
38	19.6	-24.1	-8.6	190	308	83	23.7	-21.1	-4	61	240
39	24	-13	-1	194	218	84	22.6	-20.3	-3.5	83	278
40	24.2	-12.6	-0.5	212	216	86	22.6	-23.3	-5.8	75	256
41	24	-12.9	-0.8	211	219	87	23.5	-20.9	-4.3	53	188
42	25.1	-14.4	-1.4	181	230	88	22.4	-22.4	-5.4	57	205
43	24.7	-14.7	-0.9	187	237	89	21	-24.6	-7	68	222
44	25.1	-15.5	-1.8	182	240	90	23.2	-21.4	-4.7	57	206
45	23.6	-14.6	-2.1	188	239	91	21.5	-24.9	-7.9	65	213
46	24.9	-15.3	-2.1	173	243	92	19.4	-28.1	-10.6	67	202
47	23.5	-17.9	-3.3	193	277	93	21.1	-18.1	-3.8	82	284
48	22.9	-18.6	-4	198	295	94	20.9	-21.4	-5.5	62	238
49	21	-20.4	-5.8	196	326	95	22.3	-23.8	-6.1	64	218
50	21.3	-21.2	-6	186	314	96	21	-27.7	-9.5	55	141
51	21.2	-20.6	-6.2	216	348	98	21.8	-28.5	-8.7	57	146
53	16	-26	-11.6	96	239	99	21	-29	-9.6	52	149
54	25.3	-8.1	1.3	192	234						

Appendix 1.16. Climatic variables for each provenance at Swastika from 1971-2000

Prov	Tmax_sm	Tmin_wt	Tmin_sp	PPT_wt	PPT_sm	Prov	Tmax_sm	Tmin_wt	Tmin_sp	PPT_wt	PPT_sm
1	23.5	-8.7	0.9	403	283	55	23.7	-7.9	0.7	260	225
3	20.7	-7.4	-0.8	418	309	56	24.6	-10	-0.3	238	222
4	19.9	-7.9	-2	391	288	57	21.9	-9.5	-0.7	235	212
5	19.7	-7.4	-1.8	384	284	60	22.1	-15.5	-3.7	194	246
6	22.6	-10.2	-0.8	332	267	61	22.6	-18.1	-4.9	169	237
7	22.2	-10.7	-1	298	253	62	22.7	-20.6	-6	153	242
9	23.8	-12.7	-1	306	273	63	22.5	-23.1	-7.3	150	254
11	23.6	-14.5	-2.4	304	284	64	22.6	-21.4	-6.1	148	247
12	22.5	-13.8	-2.4	284	276	65	27.3	-12.1	1.1	91	329
13	23.4	-16.5	-3.9	210	305	66	27.2	-12.4	0.7	87	319
14	22.3	-16.7	-4.2	271	300	68	27	-12.7	0.5	95	314
19	21.2	-21.6	-6.7	207	323	69	25.7	-14.2	-0.6	85	322
20	20.3	-20.4	-6	220	269	70	24.8	-15.9	-2.3	83	303
23	25.1	-13	-1.2	186	291	71	25.6	-8.4	0.5	164	256
25	22.3	-13.5	-2.3	312	381	72	25.7	-10.9	-1.4	151	235
26	22.8	-16.3	-4	217	307	73	25.6	-11.5	-1.7	124	258
27	24.4	-14.9	-1.1	239	302	74	25.6	-11.6	-1.8	124	256
28	23.2	-15.1	-1.9	272	352	75	23.7	-12.1	-2	144	248
29	22.5	-15.5	-2.7	233	288	76	19.4	-18.2	-4.7	152	263
30	22.4	-18.1	-3.9	210	323	77	22	-22.8	-8	135	262
31	22	-20.2	-4.3	177	277	78	25.9	-17.4	-1.6	52	304
34	21.1	-20	-6	233	335	79	25	-17.5	-3.2	75	319
35	20.6	-20.6	-6.4	221	345	80	25	-19.1	-2.9	51	292
36	20.8	-22.4	-6.9	189	322	81	24.1	-19.5	-2.7	71	291
37	21.4	-22	-6	174	307	82	23.7	-19.2	-2.8	70	266
38	20	-23.8	-8.3	192	302	83	23.7	-20.1	-3.4	60	250
39	24.1	-12.5	-0.8	198	222	84	22.6	-19.4	-2.9	78	281
40	24.2	-12	-0.3	220	219	86	22.6	-22.4	-5.2	72	263
41	24.1	-12.3	-0.5	218	222	87	23.2	-20	-3.6	50	194
42	25.3	-13.8	-1.1	186	234	88	22.2	-21.5	-4.8	53	209
43	24.8	-14.2	-0.6	197	241	89	20.8	-23.6	-6.2	64	228
44	25.2	-15	-1.5	187	245	90	22.9	-20.4	-4	54	217
45	23.6	-14.1	-1.9	193	243	91	21.5	-24	-7.1	61	216
46	25	-14.8	-1.8	177	247	92	19.6	-27.4	-9.8	63	205
47	23.7	-17.5	-3	199	281	93	20.9	-17.4	-3.3	75	301
48	23.1	-18.2	-3.7	203	299	94	20.9	-20.6	-4.9	57	245
49	21.2	-20.1	-5.5	197	327	95	22.3	-22.9	-5.4	59	228
50	21.6	-20.9	-5.7	185	312	96	21.1	-26.6	-8.6	51	148
51	21.5	-20.3	-6	218	350	98	22	-27.7	-7.9	52	158
53	16.5	-25.8	-11.3	100	246	99	21.2	-28.2	-8.9	50	149
54	25.3	-7.5	1.6	200	237						

Appendix 1.17. Average provenance volume for response functions for each site

	Western			Central		Eastern			
Prov #	Red Lake	Kakabeka	Baskatong Lake	Allegan	Caramat	Espanola	Fraserdale	Swastika	Clova
1	21.78	80.09	39.93		42.28	78.79	222.97	296.12	19.65
2								56.67	
3		68.27	20.11		194.86	91.51	133.81	120.32	18.99
4	27.99	77.91	50.19	48.86	92.35	65.96	177.50		23.31
5	17.63	67.54	40.17	22.74	65.85	62.45	62.31	51.66	26.48
6		158.74	102.25	110.96			183.88	145.52	72.92
7	66.46	170.72	118.42	102.14	143.58	115.04	191.25	171.98	102.53
8			122.18	126.22					
9	70.82	168.76	102.46	102.63	118.35	119.67	166.76	128.43	69.89
10				107.30					
11		191.62		89.34			172.47	151.78	90.36
12	67.03	143.07	121.53	85.28	150.60		186.19	156.53	99.93
13	67.79	195.40	65.13	79.74	104.17	85.02	163.52	210.85	63.90
14		135.96	116.23	62.26			182.81	133.52	105.21
15	78.49	121.41	106.75	65.33	134.00	82.59	165.52	133.78	98.58
16				64.78					
17				181.39					
18				80.43	207.40				
19		116.11	70.05	50.68	122.80		125.01	125.46	79.01

	Western			Central		Eastern			
Prov #	Red Lake	Kakabeka	Baskatong Lake	Allegan	Caramat	Espanola	Fraserdale	Swastika	Clova
20		140.83	106.02	87.88	143.07		169.25	146.32	99.08
21				44.68					
22				45.19					
23	39.30	227.14	65.72	178.14	68.71	93.40	253.24	151.39	48.39
24				85.56					
25	36.21	99.08	69.17	81.36	77.72	73.37	145.52	153.69	47.61
26	71.13	212.04	136.48	102.89	186.45	119.28	229.99	201.96	108.27
27	67.48	198.16	105.80	104.75	146.81	118.89	204.97	177.76	96.52
28	71.51	172.44	103.57	91.28	147.45	100.03	234.99	152.73	109.08
29		174.40	108.22	80.12			180.40	171.37	105.99
30	76.33	161.30	138.38	99.08	149.90	117.16	219.59	175.82	132.31
31		212.34	169.14	87.12			266.21	202.42	169.24
32				60.93					
33				90.28					137.60
34		170.99	127.21	84.15			205.24	169.68	126.72
35		171.78	123.30	58.05			215.00	164.77	120.13
36	69.25	167.10	109.19	47.47	155.03		177.88	160.92	115.85
37	84.25	147.53	132.21	66.91	164.83	99.24	166.05	174.99	100.01
38		141.31	78.66	59.12			139.39	141.43	85.45
39	55.59	161.12	48.45	138.35		97.84	162.53	140.26	51.03
40				109.30				160.66	
41	51.78	142.76	63.18	100.25			283.06	136.33	27.66
42		210.43	104.82	167.51		92.71	175.51	183.76	58.41

	Western			Central		Eastern			
Prov #	Red Lake	Kakabeka	Baskatong Lake	Allegan	Caramat	Espanola	Fraserdale	Swastika	Clova
43	91.52	203.97	93.41	199.62	105.85	92.40	147.08	147.69	30.87
44	55.49	235.43	91.91	183.99	133.05	109.16	154.25	174.79	60.46
45		265.70					215.51	197.11	
46	71.27	286.45	135.87	163.08	138.94	132.21	141.53	209.22	56.22
47		216.07	82.55	140.50			168.36	181.62	62.73
48	60.66	246.77	180.74	124.33			205.50	198.99	118.89
49	70.20	223.65	117.24	73.61	189.30	116.40	252.39	192.09	121.25
50	86.19	188.43	118.71	91.80	179.66	118.22	218.33	192.86	112.68
51		235.59	98.70	80.47			259.70	177.79	134.65
53				113.08			256.34	197.62	
54	81.95	210.23		183.50		105.87	202.60	127.21	
55		201.00	97.34	113.24				207.92	
56			69.01	228.31			129.79	187.54	109.17
57		131.97		121.93		106.96	126.82	227.74	
58			101.49	110.82	126.77	121.30			82.60
59				106.32		132.36			
60				97.69			242.55	243.55	
61			132.06	145.10		147.97	268.53	257.87	
62				117.03	153.51		272.53	240.80	
63				102.31			253.62	233.63	
64				89.61			245.53	165.51	
65				201.00			312.26	161.30	
66				258.31			97.55	180.21	

	Western			Central		Eastern			
Prov #	Red Lake	Kakabeka	Baskatong Lake	Allegan	Caramat	Espanola	Fraserdale	Swastika	Clova
67				220.61	148.56				
68	68.82	272.14		157.43		121.03	149.84	183.51	
69	52.63	269.53	84.39	189.19	147.95		171.00	144.80	88.58
70	56.06	281.66	54.59	193.03			189.47	204.58	51.96
71	84.81	181.41	97.03	269.31	139.84	122.81	211.05	218.06	65.35
72		217.78	66.56	253.19	29.54	88.63	163.50	151.23	10.85
73		257.98	78.42	220.65	133.98	120.03	98.37	161.50	98.51
74		211.54	84.80	261.33	122.68	88.41	222.97	172.75	81.53
75	61.30	201.63	68.40	175.09	170.90	106.74	155.67	175.36	40.06
76	49.60	125.46	69.19	48.12	113.92	84.87	172.87	164.03	49.93
77	64.29	159.40	81.48	76.95	142.69	102.38	206.51	179.32	67.08
78	52.71	217.43	95.28	163.79	158.57	97.27	186.47	174.04	106.93
79	48.36	265.79	77.72	150.61	165.66		212.44	202.48	67.34
80	54.93	264.37	104.83	153.24	149.31		241.18	204.89	63.88
81	59.93	246.09		110.30			218.13	248.83	
82	82.94	264.41		94.23		115.79	202.23	193.18	
83	60.62	184.09	100.92	110.61	152.53	117.33	217.12	186.83	93.45
84	76.15	194.20	110.53	94.01	137.56	115.21	225.46	185.03	75.33
85	57.02	144.58	94.10	71.80	177.12				81.12
86	98.39	145.24		66.25	134.37		189.82	176.81	
87	56.65	149.54	97.62	48.19			159.55	147.49	83.90
88	65.95	159.56	68.58	61.43			164.11	150.06	75.75
89	56.74	142.44	65.87	33.50		69.96	130.63	146.19	60.47

	Western			Central		Eastern			
Prov #	Red Lake	Kakabeka	Baskatong Lake	Allegan	Caramat	Espanola	Fraserdale	Swastika	Clova
90	61.47	133.68	70.83	57.02	107.44	94.62	148.65	135.51	63.75
91	63.31	165.14	91.91	29.65	156.91	72.29	107.21	138.45	63.17
92	44.60		68.05	11.69	106.84		212.43	248.93	63.51
93	58.19	271.10		38.72		89.30	139.35	162.00	
94	63.64	138.44		39.02			173.49	136.27	
95	46.32	181.50		63.65			204.43	92.99	
96	62.31	152.55	55.16	24.20	97.26		167.44	106.70	
97				94.88					
98	43.26			61.62				136.26	
99	57.13	152.41		71.76			216.93	114.18	

Appendix 1.18. Climatic variables from 1961-1990 for each of the nine test sites

Site	Tmax_sm	Tmin_wt	Tmin_sp	PPT_wt	PPT_sm
Espanola	22.3	-18.5	-5.1	168	243
Fraserdale	22.3	-21.8	-6.4	157	259
Swastika	22.2	-23.5	-7.5	157	269
Red Lake	22.6	-23.3	-5.8	75	256
Kakabeka	19.3	-18.5	-4.9	153	256
Allegan	25.8	-9.1	0.5	162	239
Baskatong Lake	22.9	-14.1	-2.6	163	240
Caramat	21.8	-23.2	-8.2	140	263
Clova	21.2	-20.6	-6.2	216	348

Appendix 1.19. R^2 value for each climatic variable at each provenance for the response functions

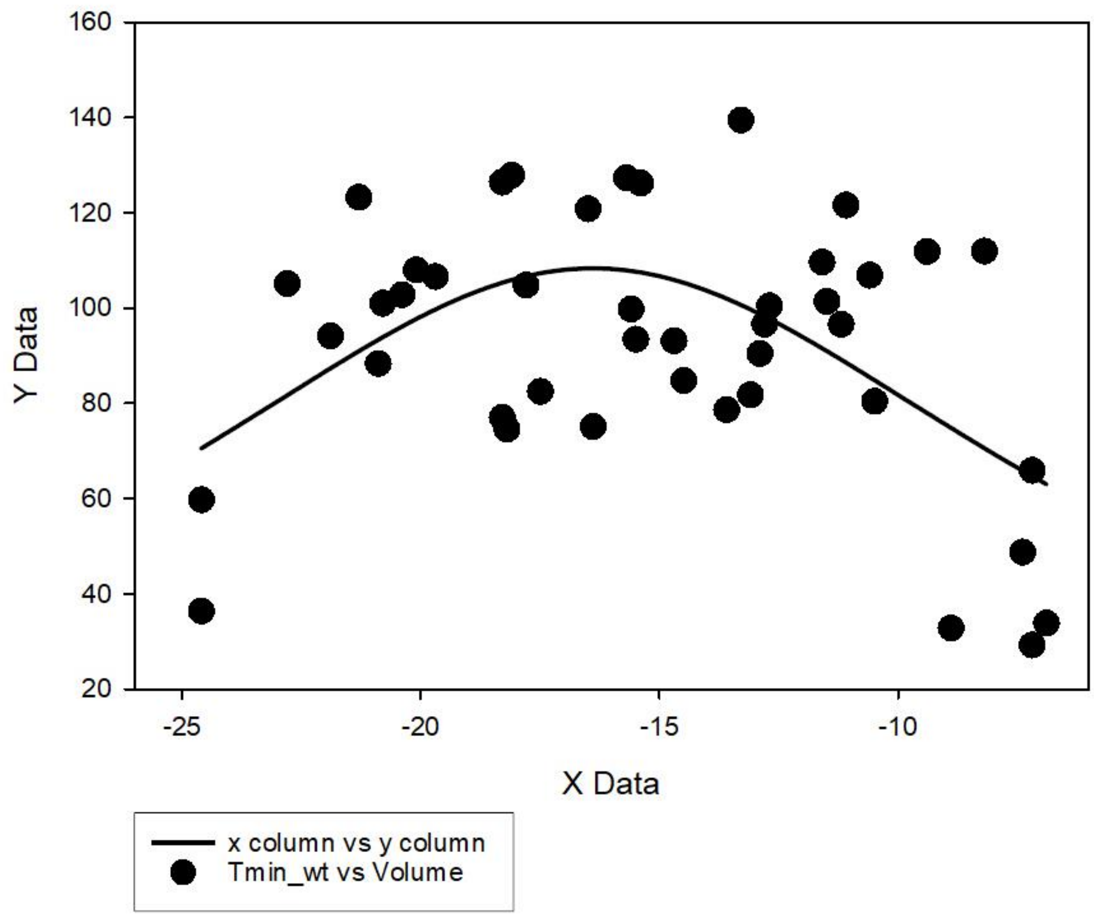
Provenance	MaxSmT	MinWtT	MinSpT	AvWtPP	AvSmPP
Prov1	0.0215	0.1315	0.1393	0.2398	0.3577
Prov2	0.0000	0.0000	0.0000	0.0000	0.0000
Prov3	0.1350	0.5763	0.6457	0.6588	0.6607
Prov4	0.0335	0.0699	0.1230	0.3492	0.3604
Prov5	0.2938	0.2640	0.2156	0.4973	0.2783
Prov6	0.0630	0.1731	0.1251	0.7949	0.8133
Prov7	0.1714	0.0934	0.1497	0.4929	0.3358
Prov8	1.0000	1.0000	1.0000	1.0000	1.0000
Prov9	0.2139	0.0676	0.0281	0.5760	0.3396
Prov10	0.0000	0.0000	0.0000	0.0000	0.0000
Prov11	0.3933	0.3330	0.3706	0.9331	0.7187
Prov12	0.1894	0.1877	0.2487	0.4850	0.3416
Prov13	0.2426	0.1244	0.1515	0.2665	0.5270
Prov14	0.5318	0.6191	0.6136	0.3559	0.5411
Prov15	0.2903	0.3069	0.3942	0.1737	0.4864
Prov16	0.0000	0.0000	0.0000	0.0000	0.0000
Prov17	0.0000	0.0000	0.0000	0.0000	0.0000
Prov18	1.0000	1.0000	1.0000	1.0000	1.0000
Prov19	0.4962	0.7686	0.7356	0.3803	0.9386
Prov20	0.3359	0.5579	0.5117	0.3340	0.8136
Prov21	0.0000	0.0000	0.0000	0.0000	0.0000
Prov22	0.0000	0.0000	0.0000	0.0000	0.0000
Prov23	0.2672	0.0282	0.0279	0.3551	0.1550
Prov24	0.0000	0.0000	0.0000	0.0000	0.0000
Prov25	0.0056	0.0525	0.1130	0.4425	0.3435
Prov26	0.2221	0.1267	0.2045	0.4471	0.4200
Prov27	0.2403	0.0942	0.1328	0.4426	0.3756
Prov28	0.1692	0.1401	0.1807	0.2581	0.3361
Prov29	0.4422	0.6003	0.5695	0.7545	0.8809
Prov30	0.1701	0.1526	0.1925	0.3413	0.2670
Prov31	0.6289	0.7324	0.7267	0.4197	0.5813
Prov32	0.0000	0.0000	0.0000	0.0000	0.0000
Prov33	1.0000	1.0000	1.0000	1.0000	1.0000
Prov34	0.5127	0.6751	0.6513	0.5353	0.7272
Prov35	0.5689	0.6954	0.6821	0.4931	0.6601
Prov36	0.5341	0.4986	0.4955	0.2311	0.4917

Provenance	MaxSmT	MinWtT	MinSpT	AvWtPP	AvSmPP
Prov37	0.3280	0.3034	0.4254	0.2777	0.5451
Prov38	0.4722	0.6453	0.6142	0.7810	0.9134
Prov39	0.2426	0.0387	0.1743	0.4890	0.3395
Prov40	1.0000	1.0000	1.0000	1.0000	1.0000
Prov41	0.0082	0.0399	0.0958	0.3941	0.3660
Prov42	0.2627	0.1649	0.1155	0.9155	0.6860
Prov43	0.5345	0.2160	0.2227	0.4943	0.3819
Prov44	0.4955	0.0632	0.1006	0.5420	0.2324
Prov45	0.9174	0.9938	1.0000	0.9328	0.7152
Prov46	0.4595	0.0362	0.0091	0.5219	0.2822
Prov47	0.2585	0.1115	0.0806	0.9264	0.7522
Prov48	0.2939	0.2520	0.0437	0.6805	0.1550
Prov49	0.3441	0.2511	0.3000	0.2743	0.4464
Prov50	0.2530	0.2334	0.3386	0.3226	0.5383
Prov51	0.4410	0.5238	0.4945	0.7480	0.6509
Prov53	0.8153	1.0000	1.0000	0.8338	1.0000
Prov54	0.4510	0.2261	0.0938	0.6950	0.0125
Prov55	0.4937	0.7442	0.7388	0.9907	0.9700
Prov56	0.5000	0.9908	0.9958	0.1323	0.1065
Prov57	0.0990	0.7370	0.7946	0.2738	0.9755
Prov58	0.2148	0.1315	0.1906	0.7853	0.8815
Prov59	1.0000	1.0000	1.0000	1.0000	1.0000
Prov60	0.9997	1.0000	1.0000	1.0000	1.0000
Prov61	0.5571	0.8833	0.8245	0.9966	0.9542
Prov62	0.9957	0.6725	0.9545	0.9683	0.4868
Prov63	0.9788	1.0000	1.0000	0.9852	1.0000
Prov64	0.7149	1.0000	1.0000	0.7367	1.0000
Prov65	0.0578	1.0000	1.0000	0.0697	1.0000
Prov66	0.7139	1.0000	1.0000	0.7357	1.0000
Prov67	1.0000	1.0000	1.0000	1.0000	1.0000
Prov68	0.7341	0.1979	0.0022	0.7843	0.0498
Prov69	0.6516	0.0721	0.0439	0.4561	0.1117
Prov70	0.4465	0.0098	0.0891	0.5108	0.3026
Prov71	0.4068	0.3589	0.4025	0.4424	0.2256
Prov72	0.5828	0.2830	0.2888	0.3877	0.2742
Prov73	0.8103	0.1358	0.1465	0.1153	0.0973
Prov74	0.4886	0.3345	0.2666	0.2097	0.1951
Prov75	0.2792	0.0881	0.2398	0.6139	0.4052

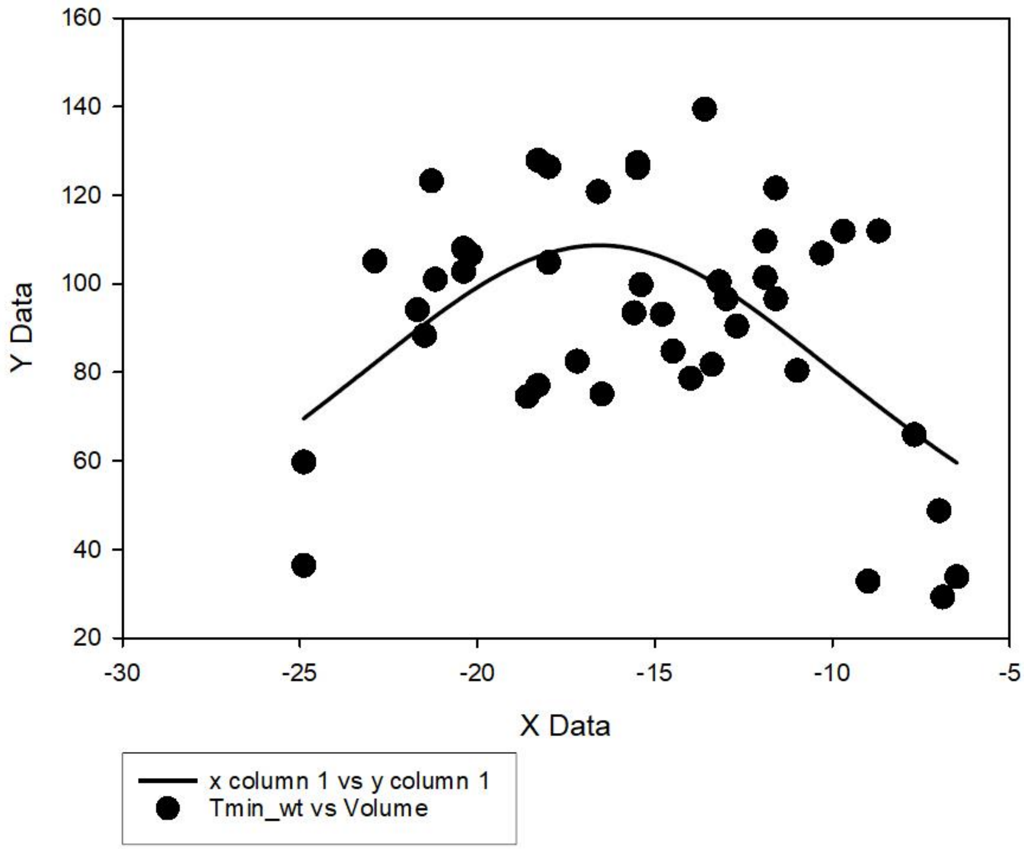
Provenance	MaxSmT	MinWtT	MinSpT	AvWtPP	AvSmPP
Prov76	0.1627	0.2333	0.3080	0.3476	0.5879
Prov77	0.1382	0.1829	0.2661	0.3810	0.5647
Prov78	0.3682	0.0078	0.1193	0.4773	0.1798
Prov79	0.3267	0.0097	0.0551	0.5486	0.3301
Prov80	0.2496	0.0172	0.0153	0.5904	0.3231
Prov81	0.3706	0.3513	0.2345	0.9210	0.3645
Prov82	0.6544	0.2799	0.1837	0.8002	0.3543
Prov83	0.1328	0.0747	0.1617	0.4680	0.3865
Prov84	0.1618	0.1078	0.1295	0.4188	0.4582
Prov85	0.2917	0.1359	0.3578	0.3826	0.3909
Prov86	0.5457	0.5522	0.5516	0.2021	0.6347
Prov87	0.3882	0.3581	0.3428	0.3205	0.4545
Prov88	0.3242	0.2635	0.3304	0.2831	0.5977
Prov89	0.3958	0.3178	0.3990	0.2111	0.6734
Prov90	0.2617	0.2504	0.2940	0.3343	0.5519
Prov91	0.4997	0.3040	0.3837	0.2470	0.5557
Prov92	0.2725	0.3335	0.3904	0.1889	0.5717
Prov93	0.8561	0.3783	0.2374	0.6354	0.3496
Prov94	0.5535	0.6063	0.5181	0.6865	0.5601
Prov95	0.3796	0.6662	0.2351	0.6802	0.2644
Prov96	0.5852	0.5653	0.4907	0.2558	0.5610
Prov97	0.0000	0.0000	0.0000	0.0000	0.0000
Prov98	1.0000	1.0000	1.0000	0.3758	1.0000
Prov99	0.2456	0.4391	0.1948	0.5565	0.2364

APPENDIX II: FIGURES

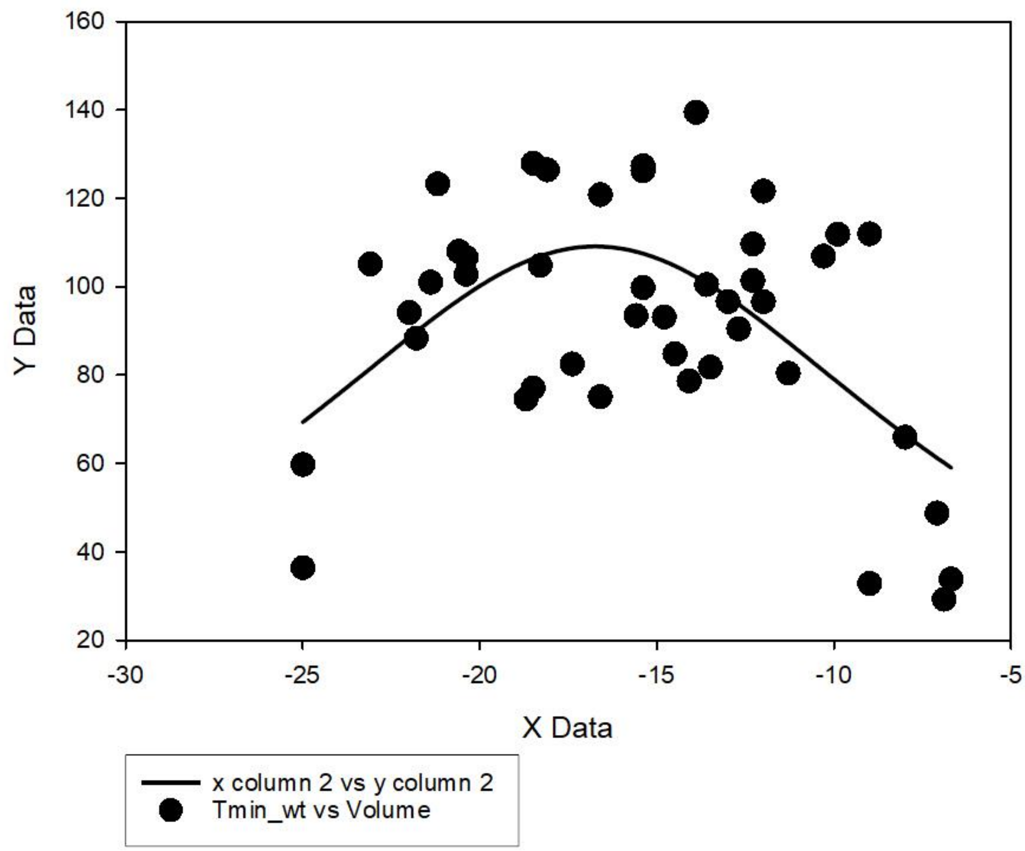
Appendix 2.1. Transfer function graph for Espanola between 1931 and 1960, comparing average provenance volumes (dm^3) per block and minimum winter temperature



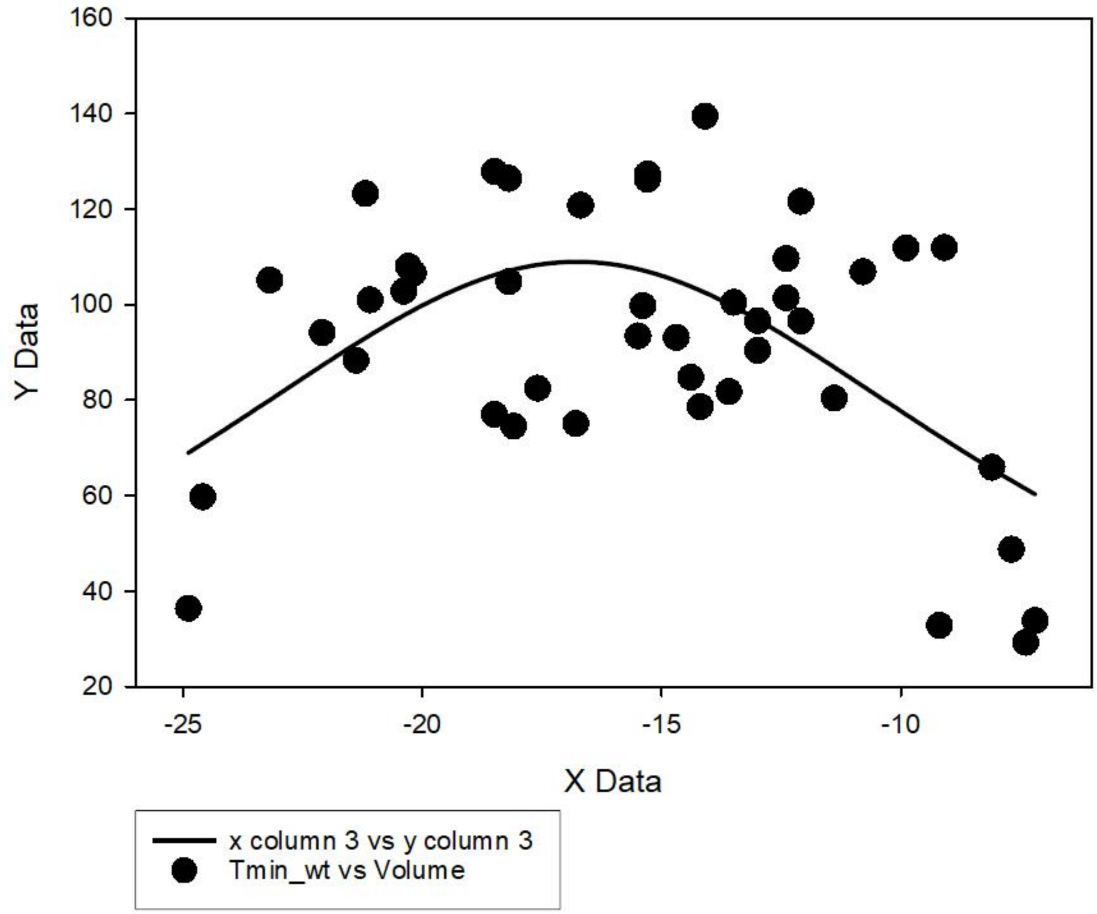
Appendix 2.2. Transfer function graph for Espanola between 1941 and 1970, comparing average provenance volumes (dm^3) per block and minimum winter temperature



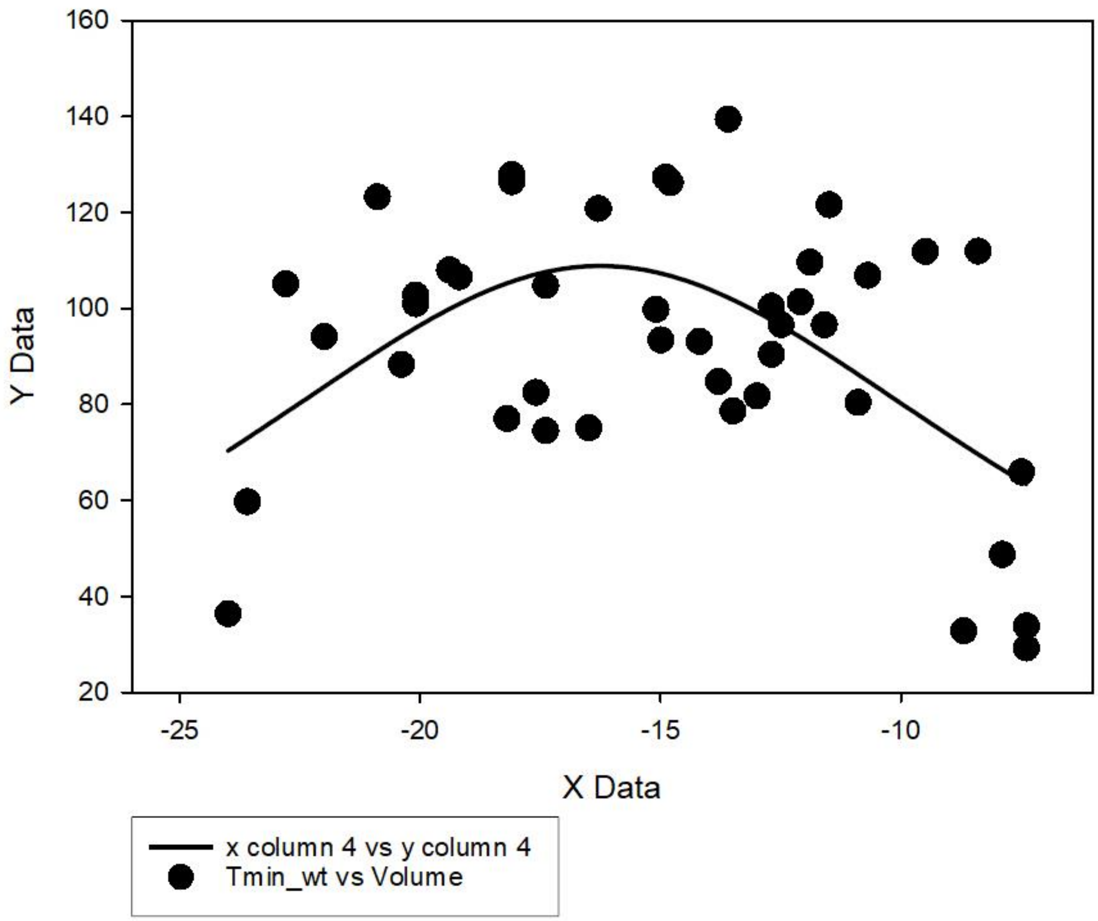
Appendix 2.3. Transfer function graph for Espanola between 1951 and 1980, comparing average provenance volumes (dm^3) per block and minimum winter temperature



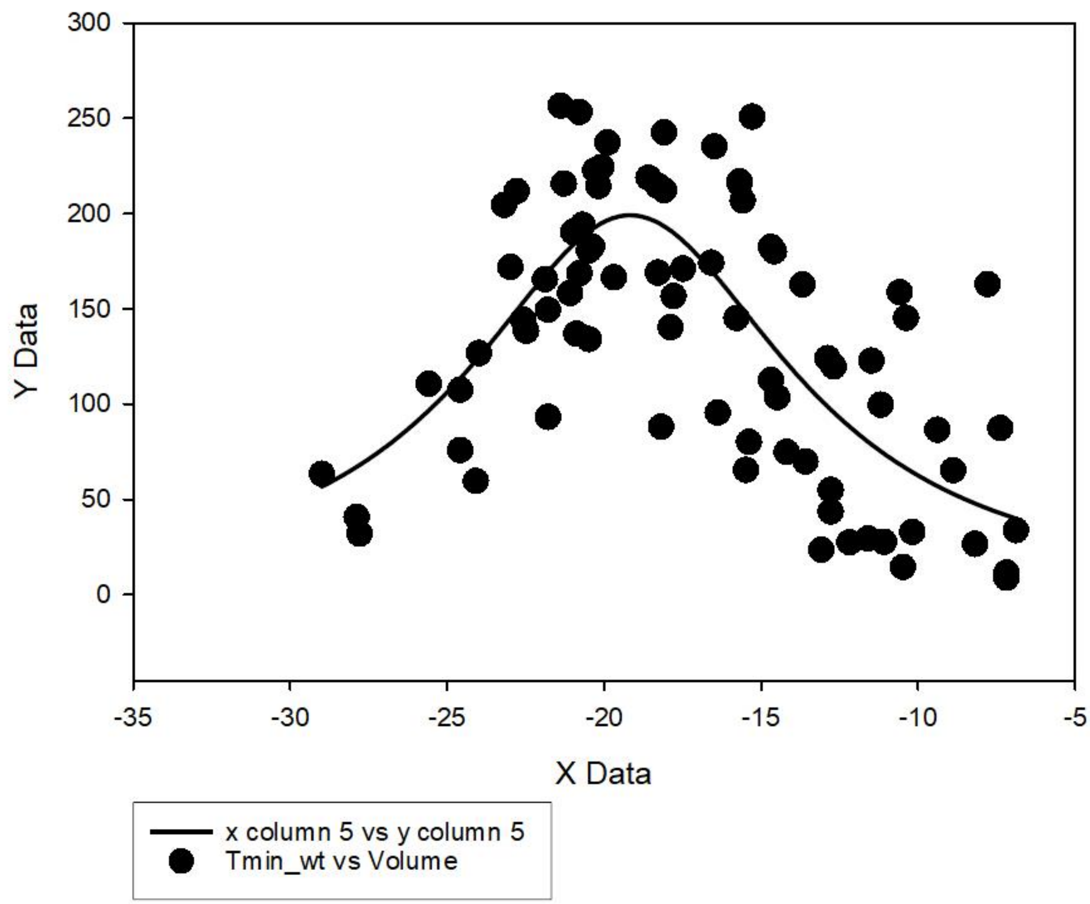
Appendix 2.4. Transfer function graph for Espanola between 1961 and 1990, comparing average provenance volumes (dm^3) per block and minimum winter temperature



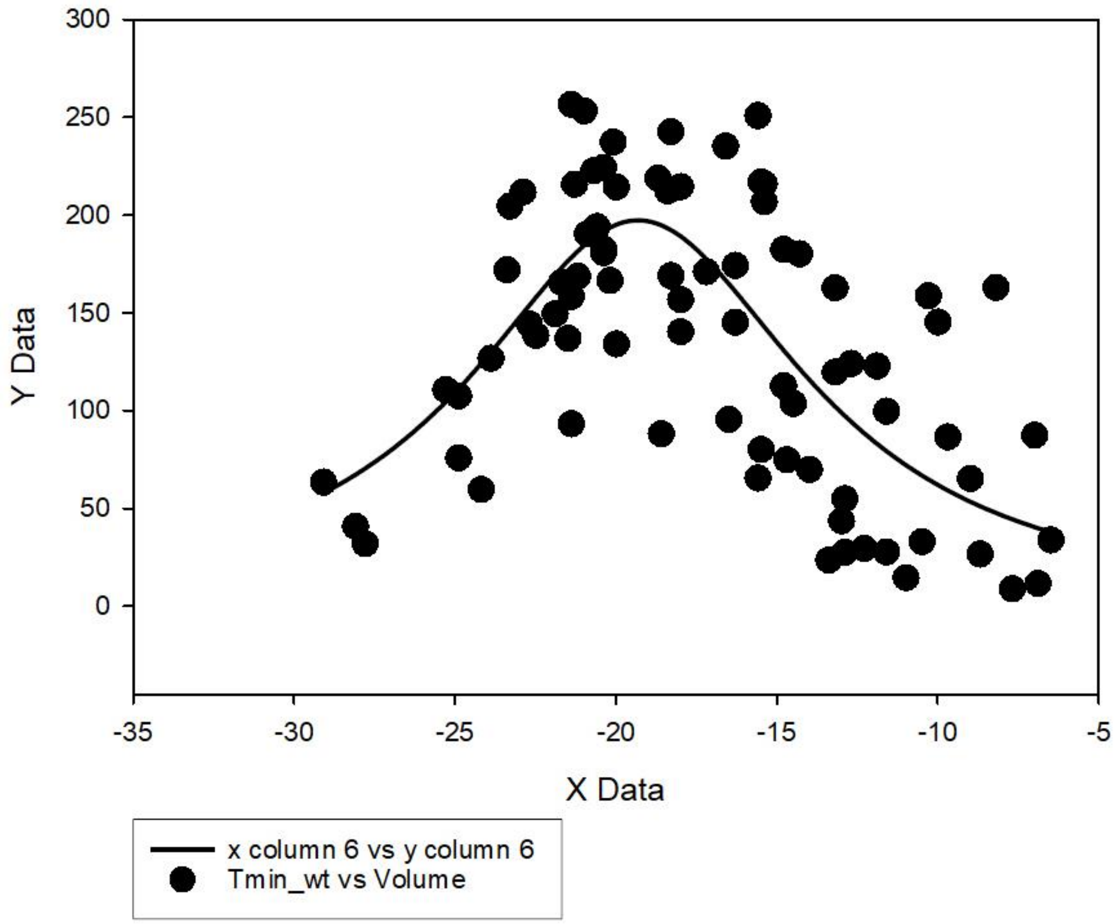
Appendix 2.5. Transfer function graph for Espanola between 1971 and 2000, comparing average provenance volumes (dm^3) per block and minimum winter temperature



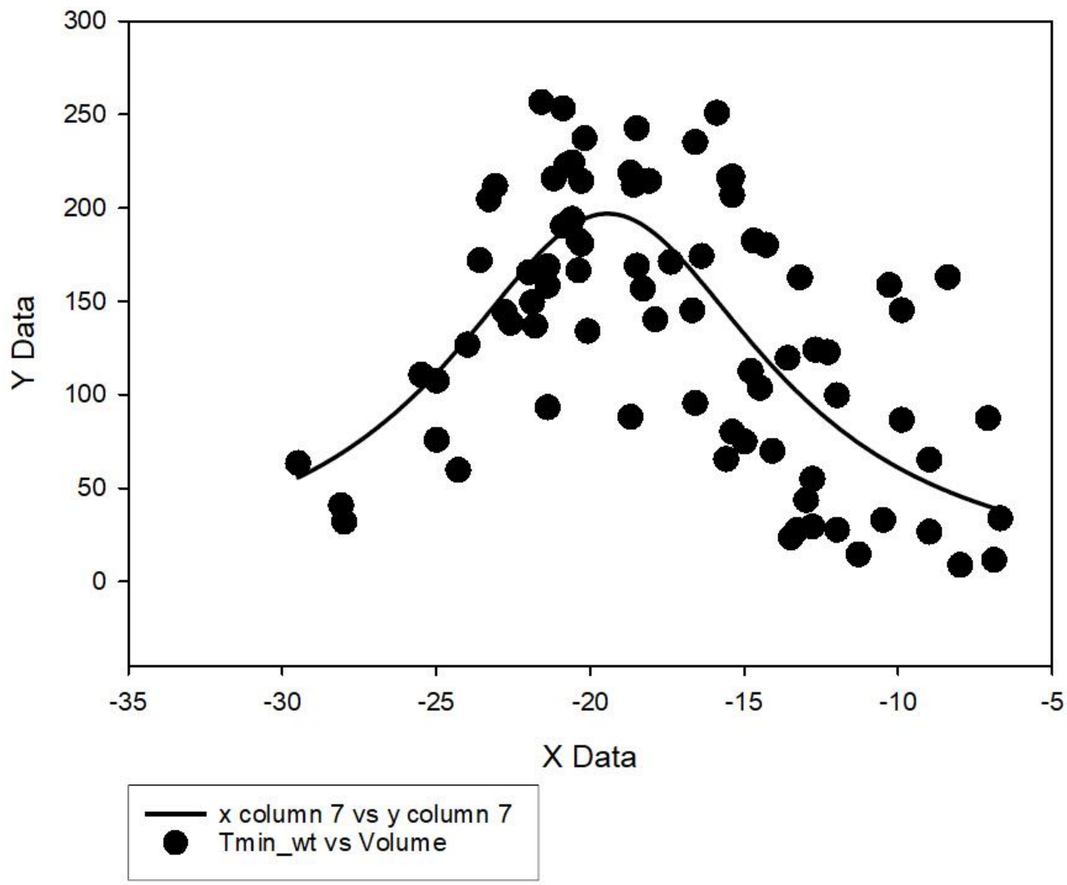
Appendix 2.6. Transfer function graph for Fraserdale between 1931 and 1960, comparing average provenance volumes (dm^3) per block and minimum winter temperature



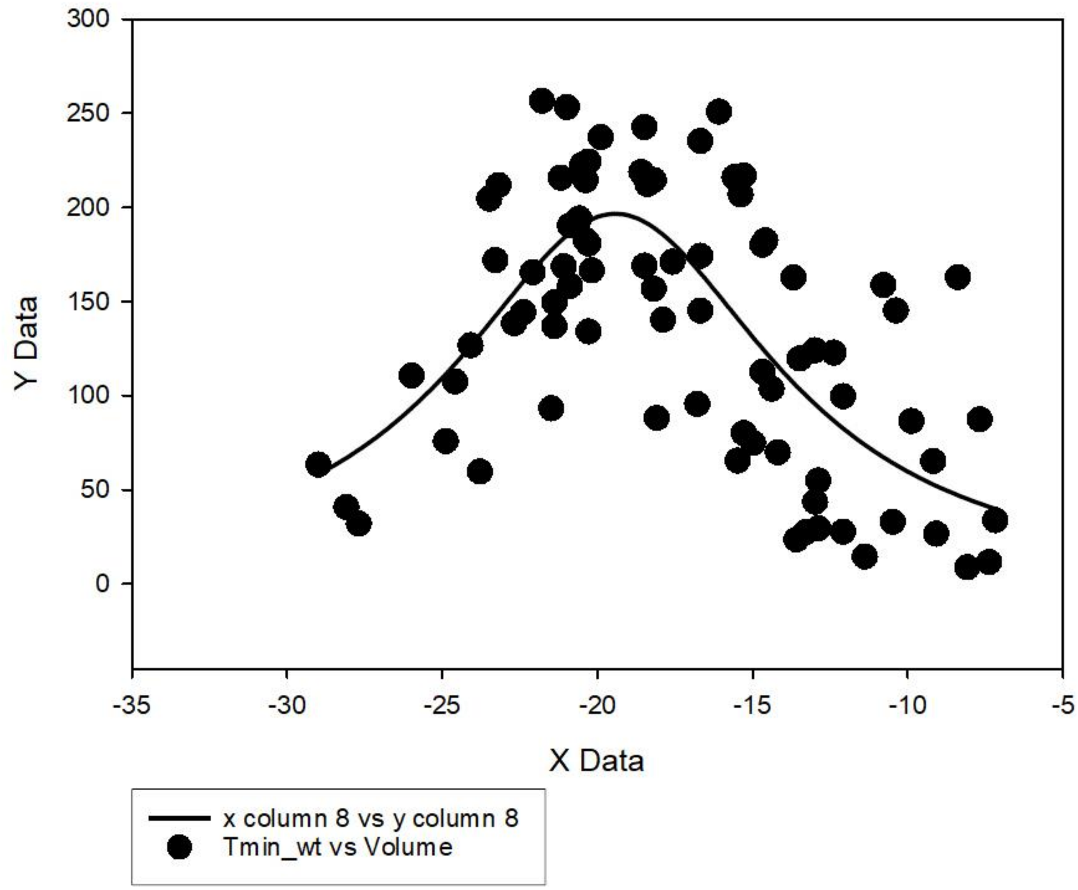
Appendix 2.7. Transfer function graph for Fraserdale between 1941 and 1970, comparing average provenance volumes (dm^3) per block and minimum winter temperature



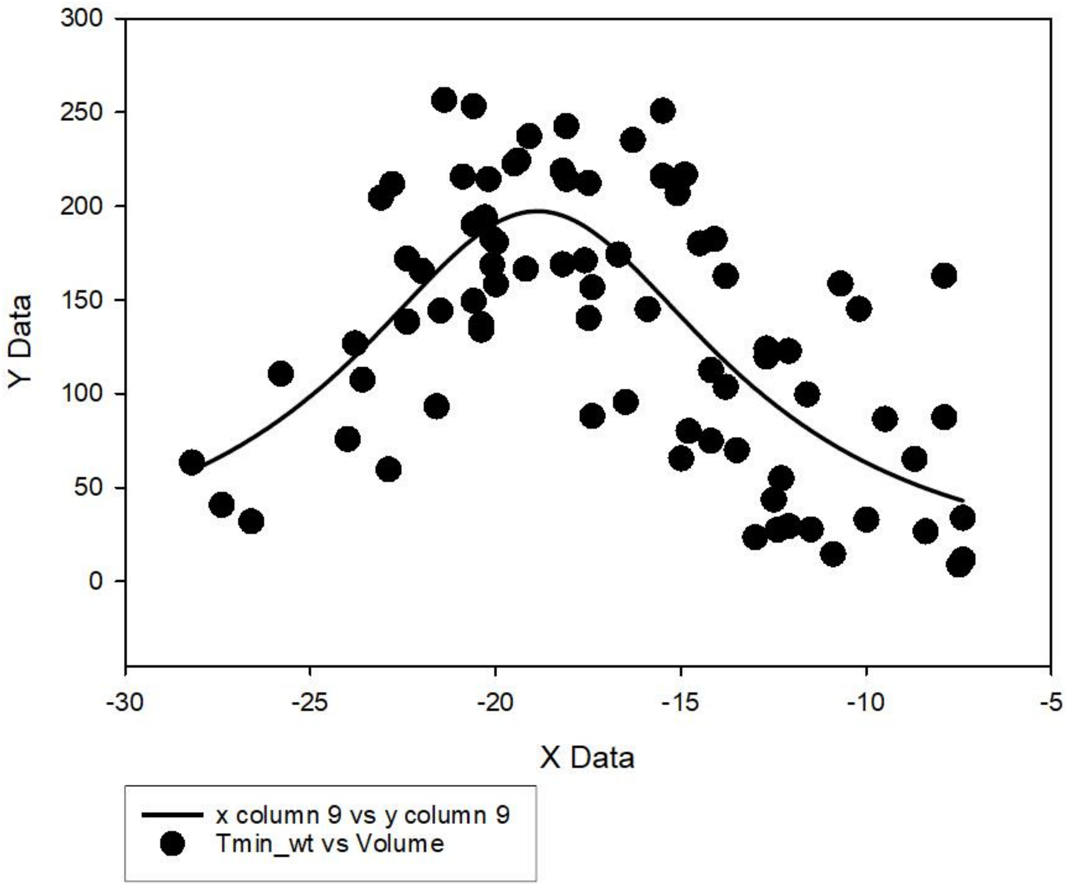
Appendix 2.8. Transfer function graph for Fraserdale between 1951 and 1980, comparing average provenance volumes (dm^3) per block and minimum winter temperature



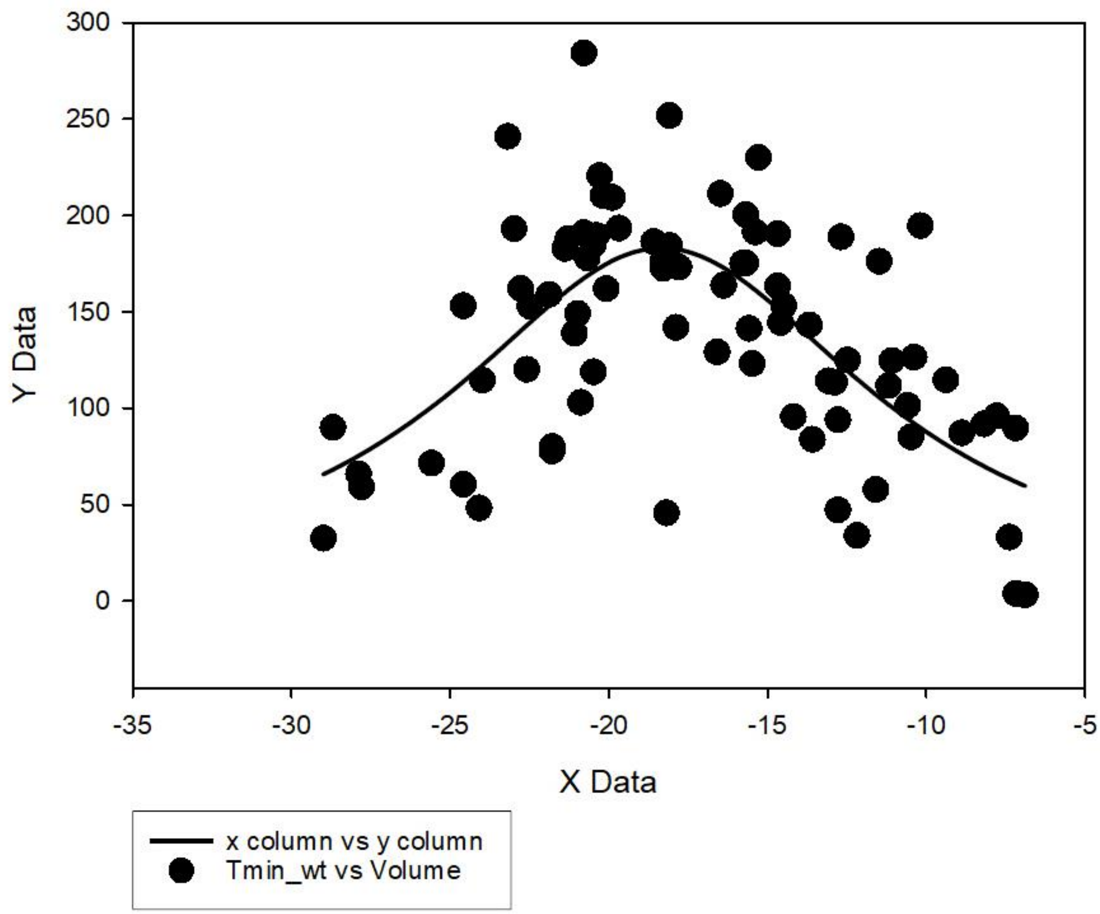
Appendix 2.9. Transfer function graph for Fraserdale between 1961 and 1990, comparing average provenance volumes (dm^3) per block and minimum winter temperature



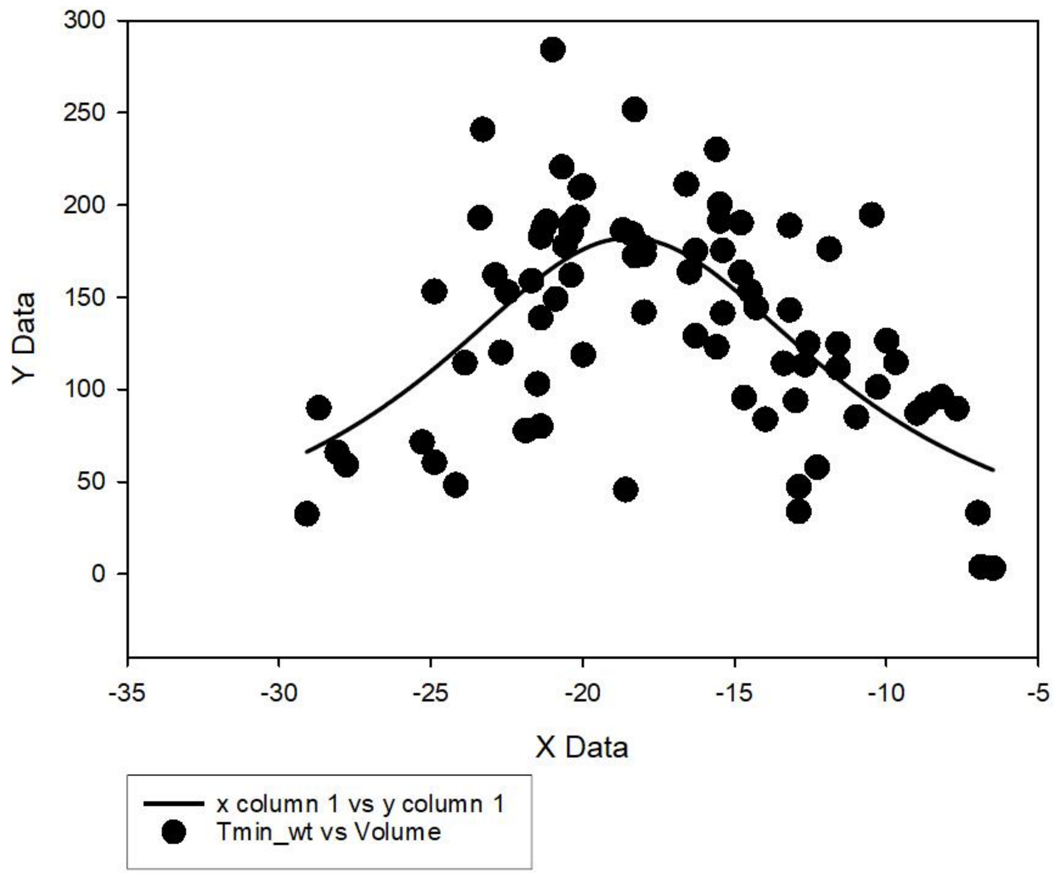
Appendix 2.10. Transfer function graph for Fraserdale between 1971 and 2000, comparing average provenance volumes (dm3) per block and minimum winter temperature



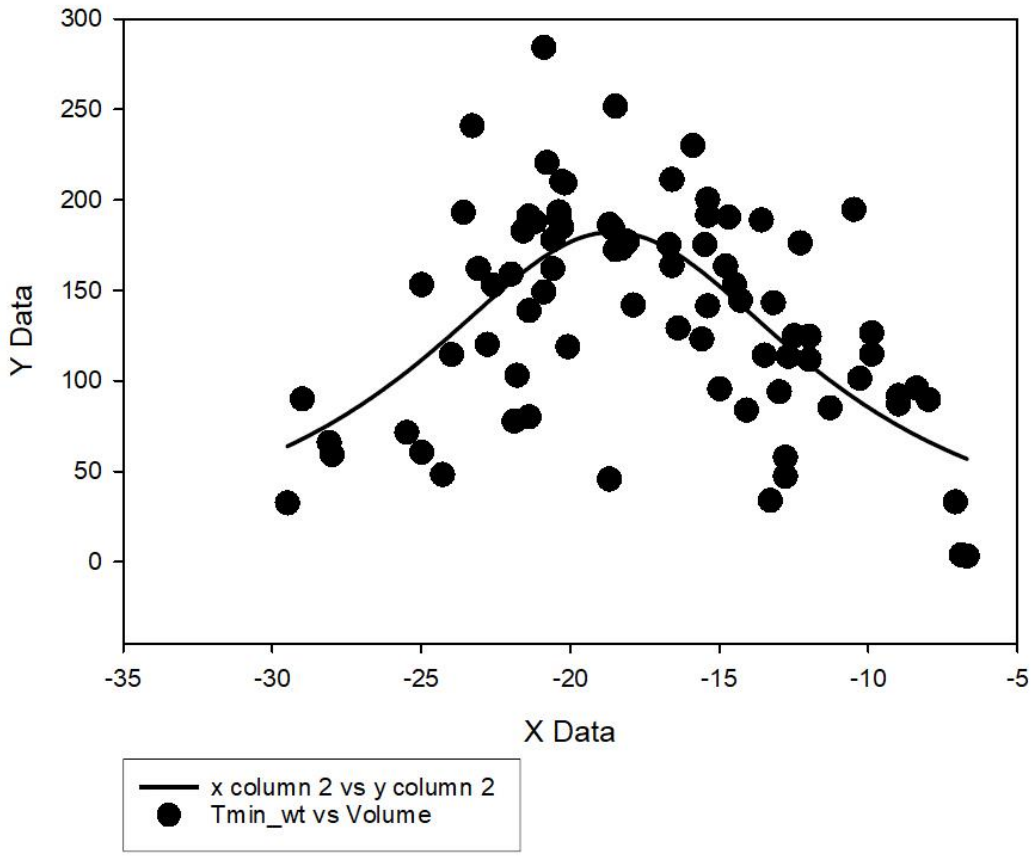
Appendix 2.11. Transfer function graph for Swastika between 1931 and 1960, comparing average provenance volumes (dm^3) per block and minimum winter temperature



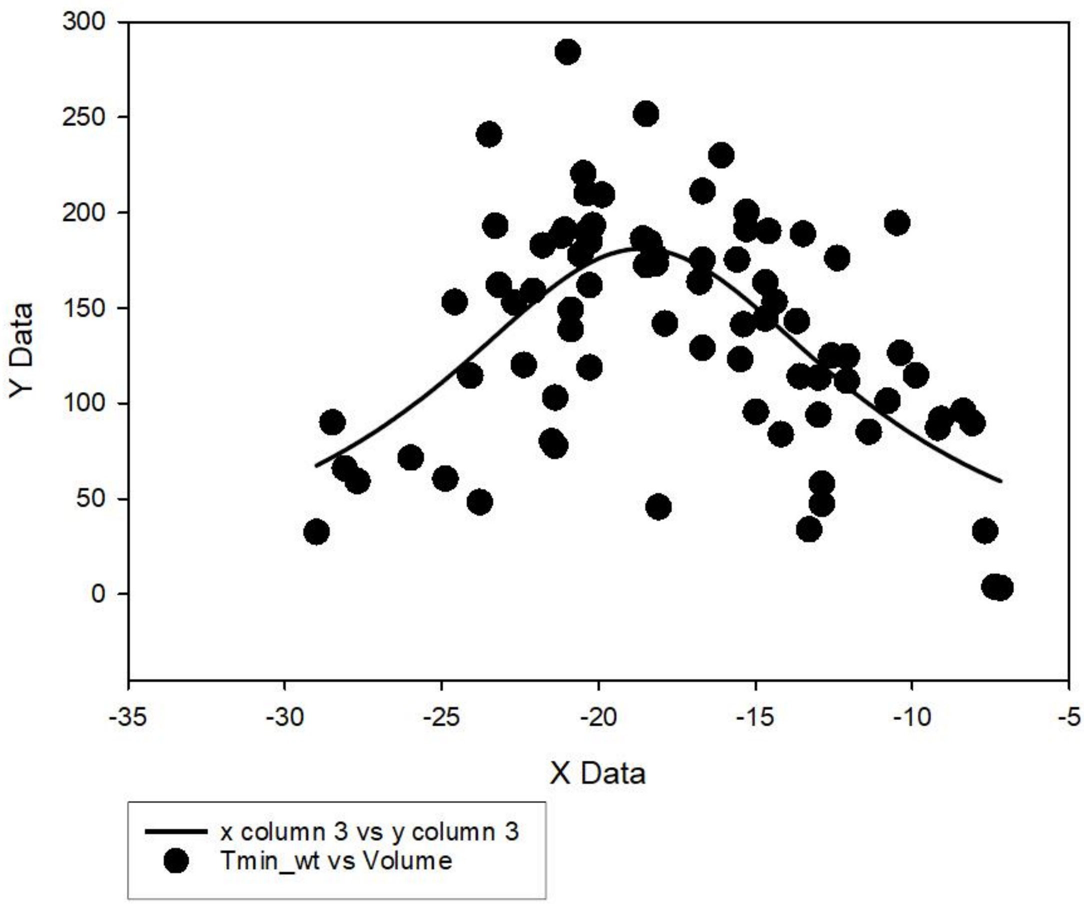
Appendix 2.12. Transfer function graph for Swastika between 1941 and 1970, comparing average provenance volumes (dm^3) per block and minimum winter temperature



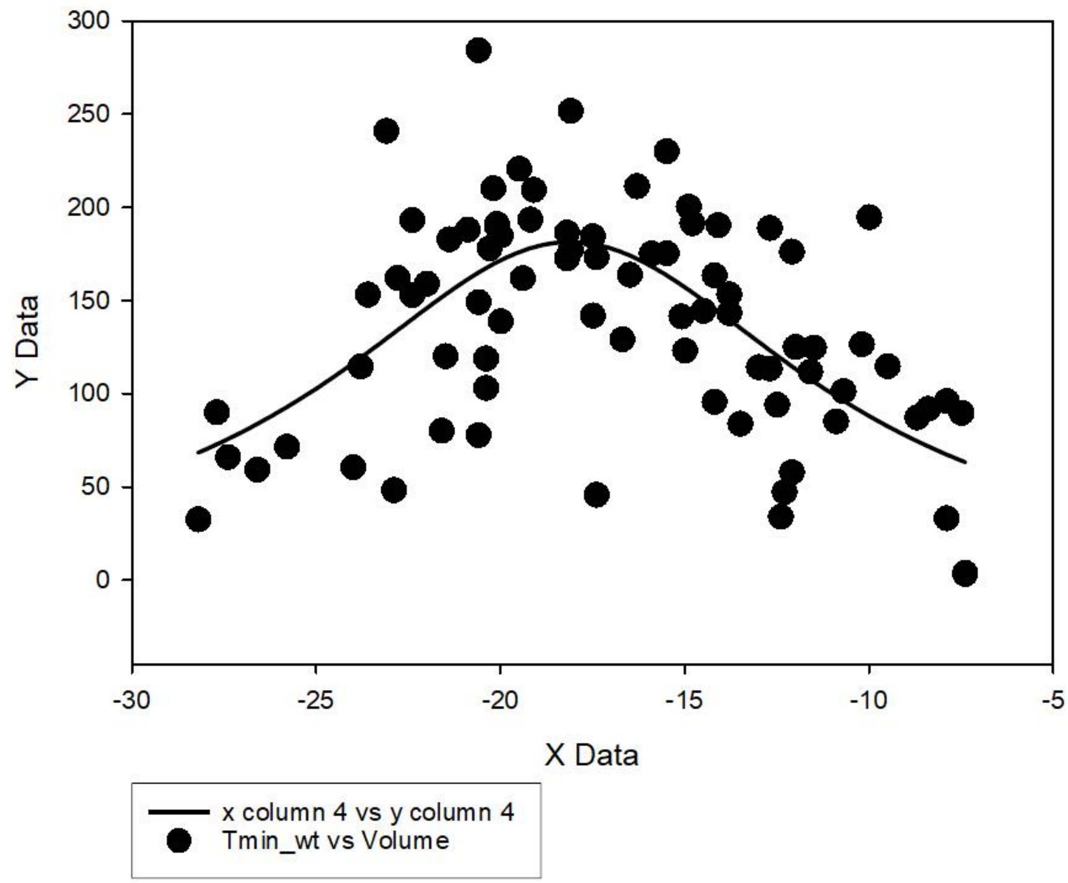
Appendix 2.13. Transfer function graph for Swastika between 1951 and 1980, comparing average provenance volumes (dm^3) per block and minimum winter temperature



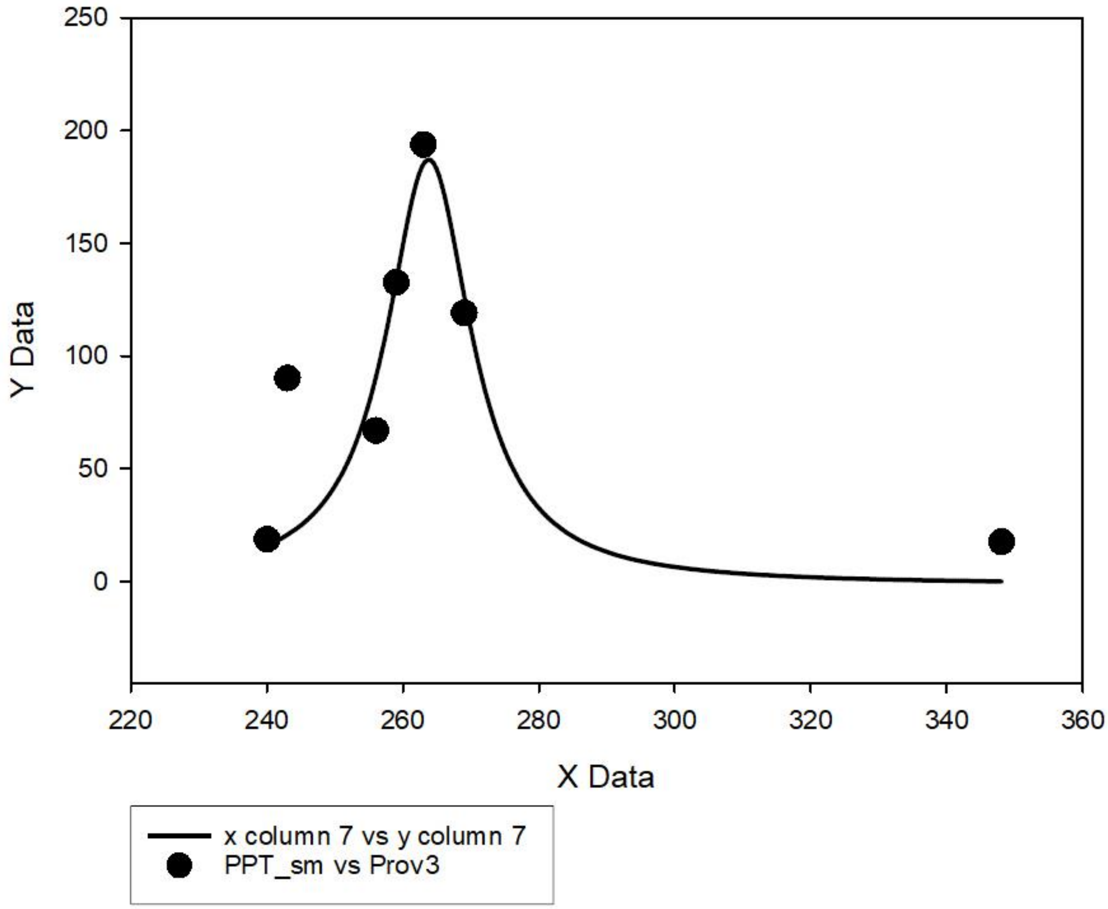
Appendix 2.14. Transfer function graph for Swastika between 1961 and 1990, comparing average provenance volumes (dm^3) per block and minimum winter temperature



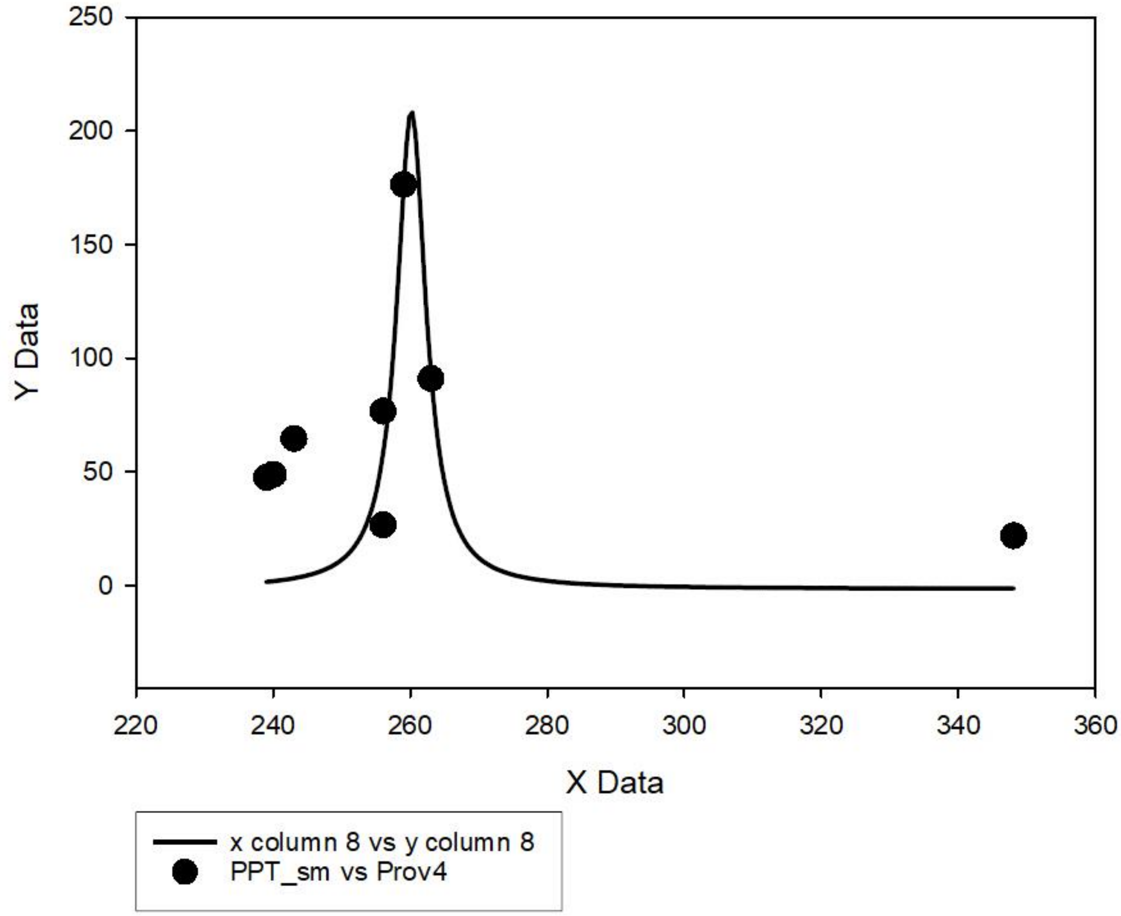
Appendix 2.15. Transfer function graph for Swastika between 1971 and 2000, comparing average provenance volumes (dm^3) per block and minimum winter temperature



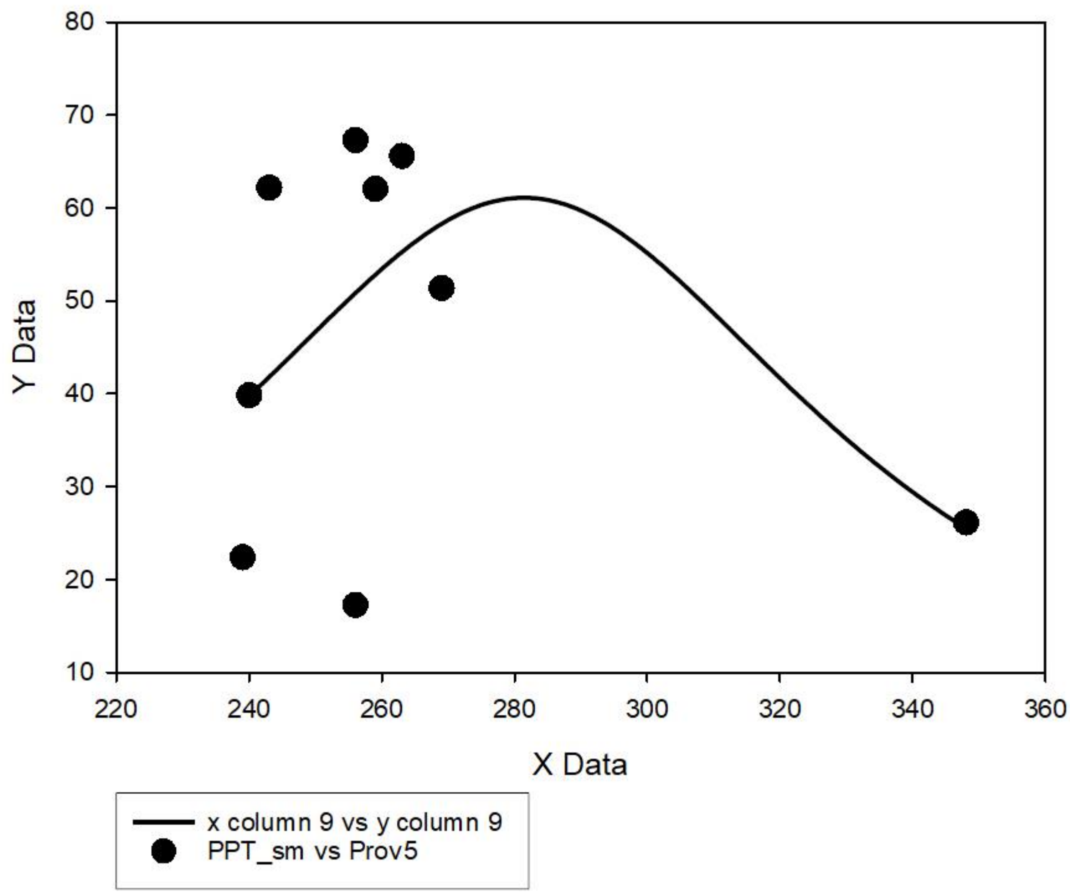
Appendix 2.16. Response function graph for provenance 3 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



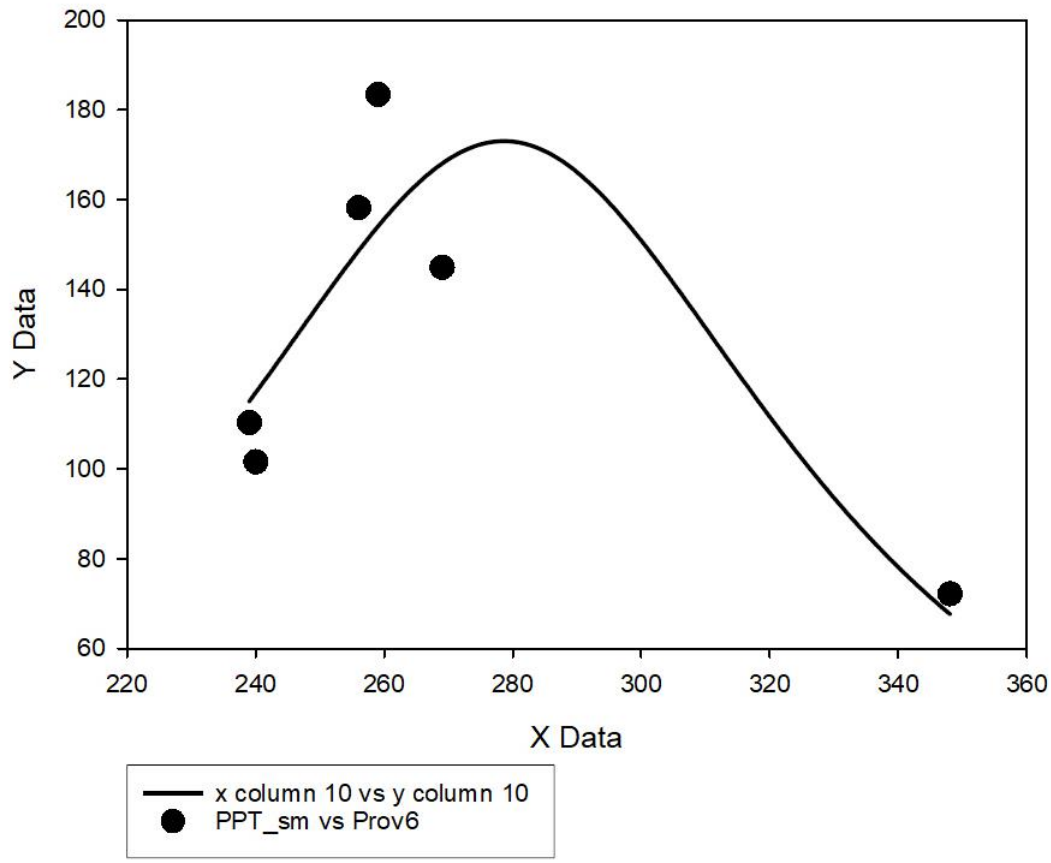
Appendix 2.17. Response function graph for provenance 4 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



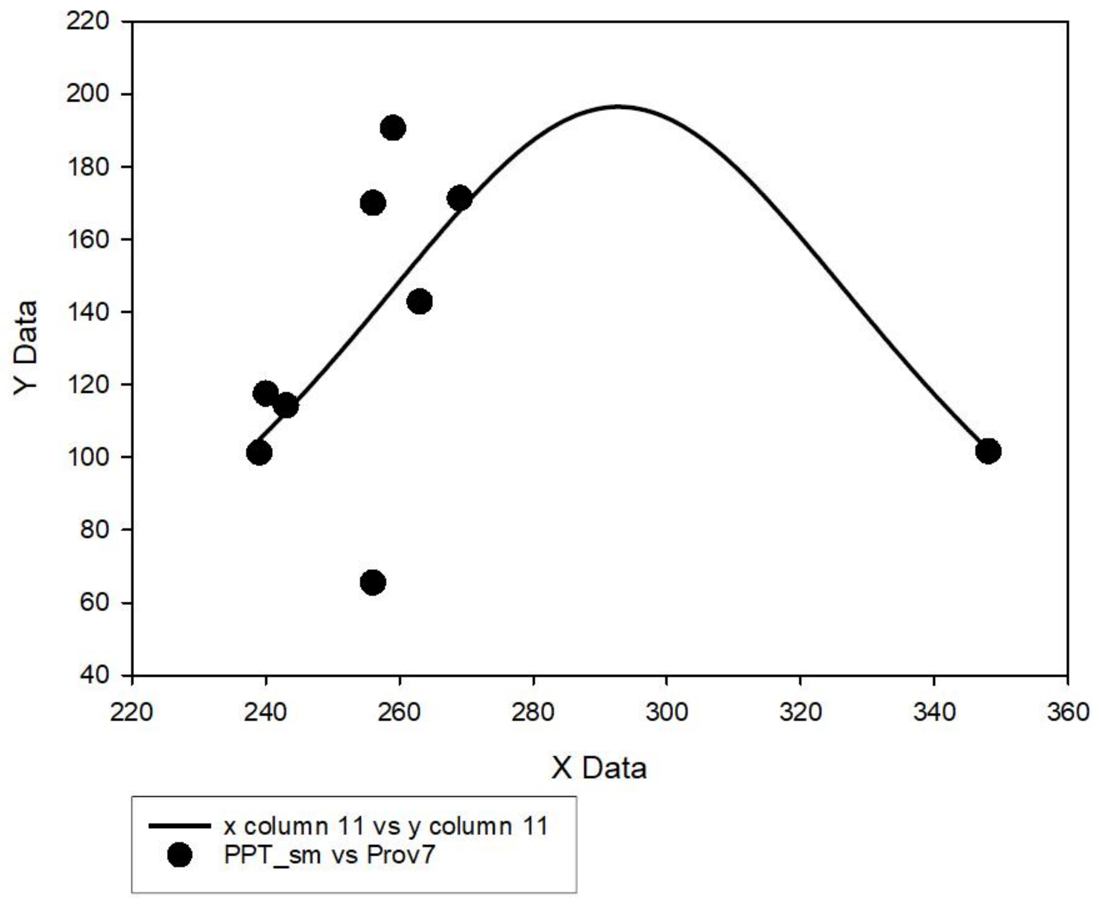
Appendix 2.18. Response function graph for provenance 5 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



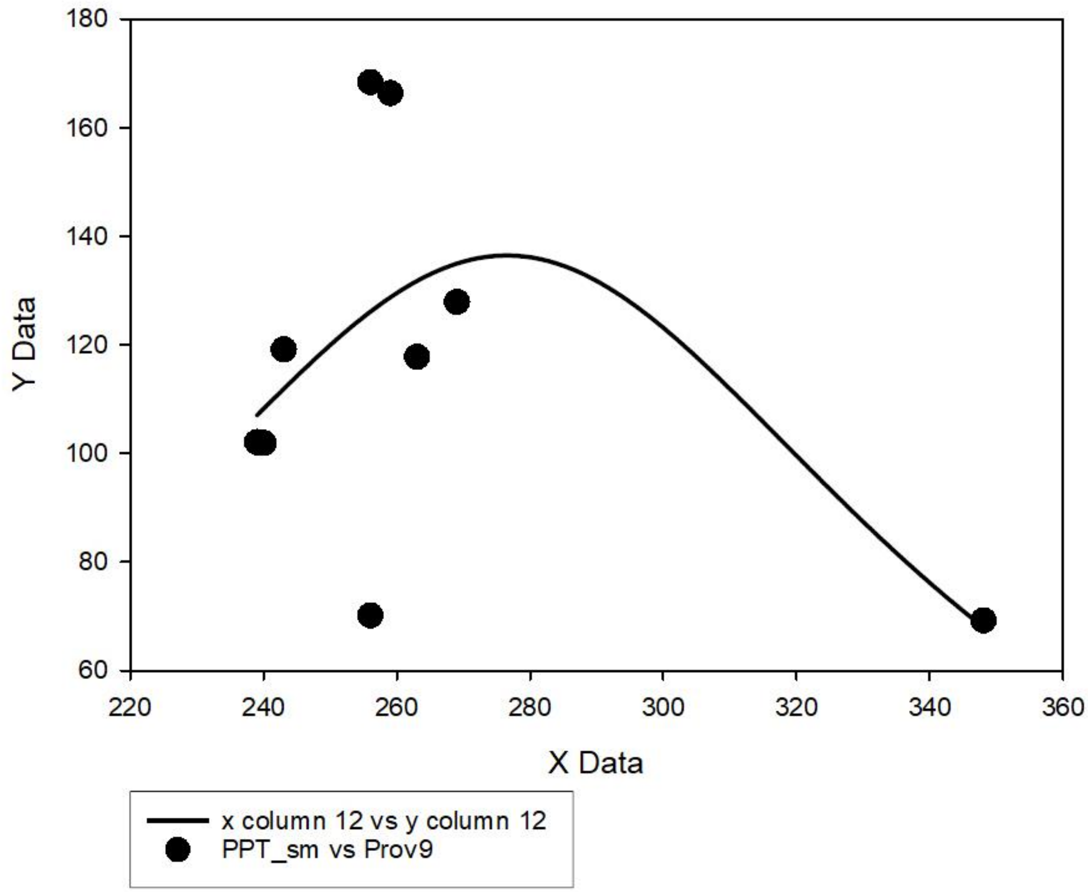
Appendix 2.19. Response function graph for provenance 6 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



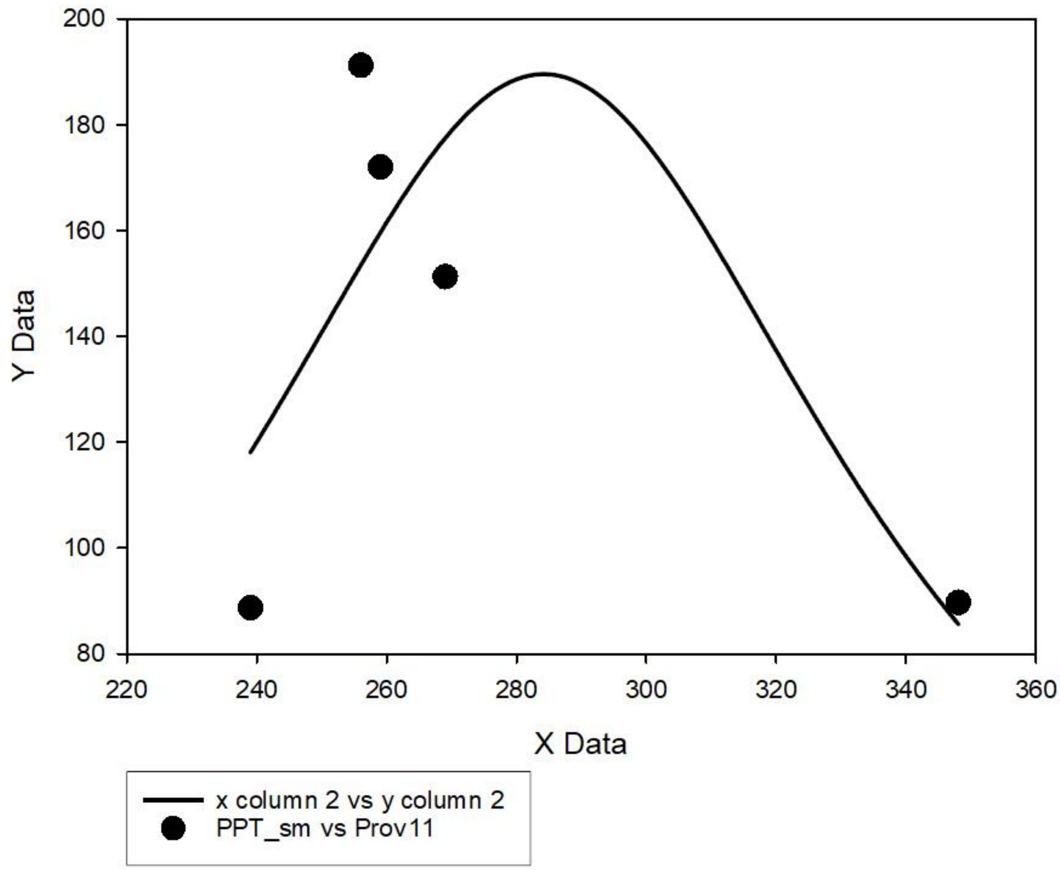
Appendix 2.20. Response function graph for provenance 7 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



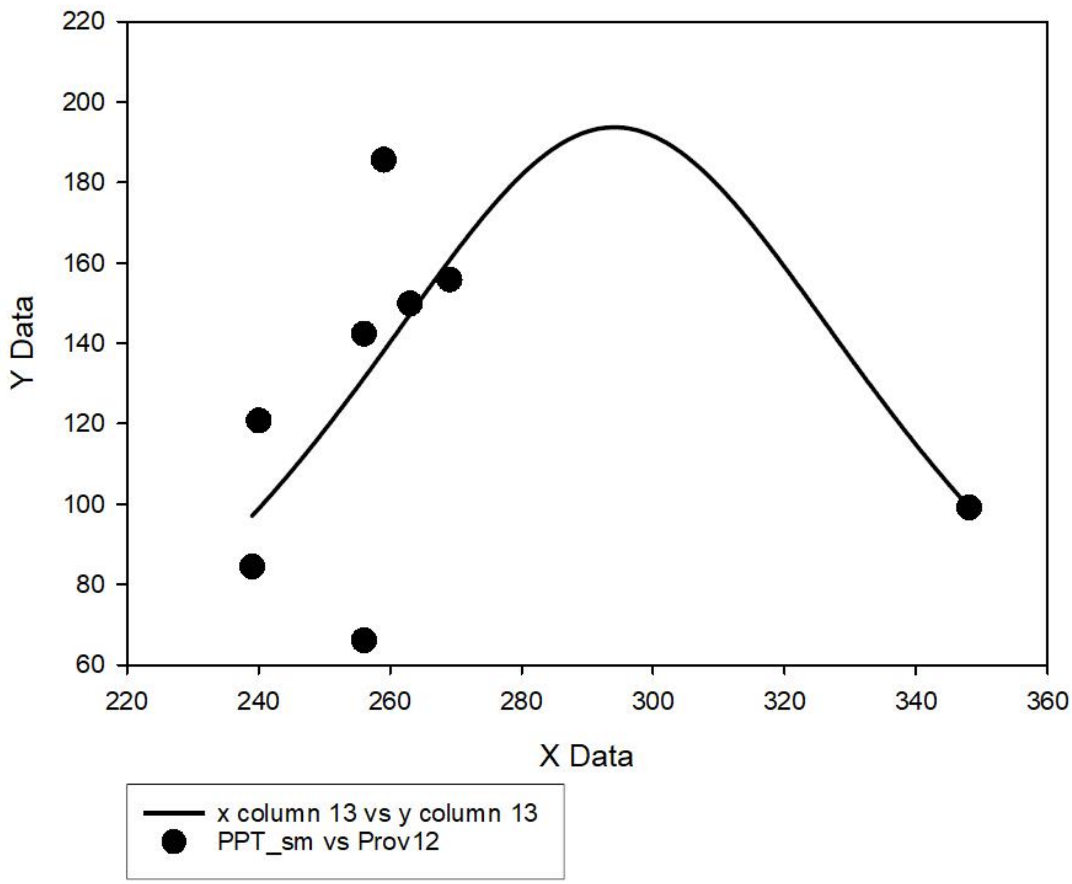
Appendix 2.21. Response function graph for provenance 9 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



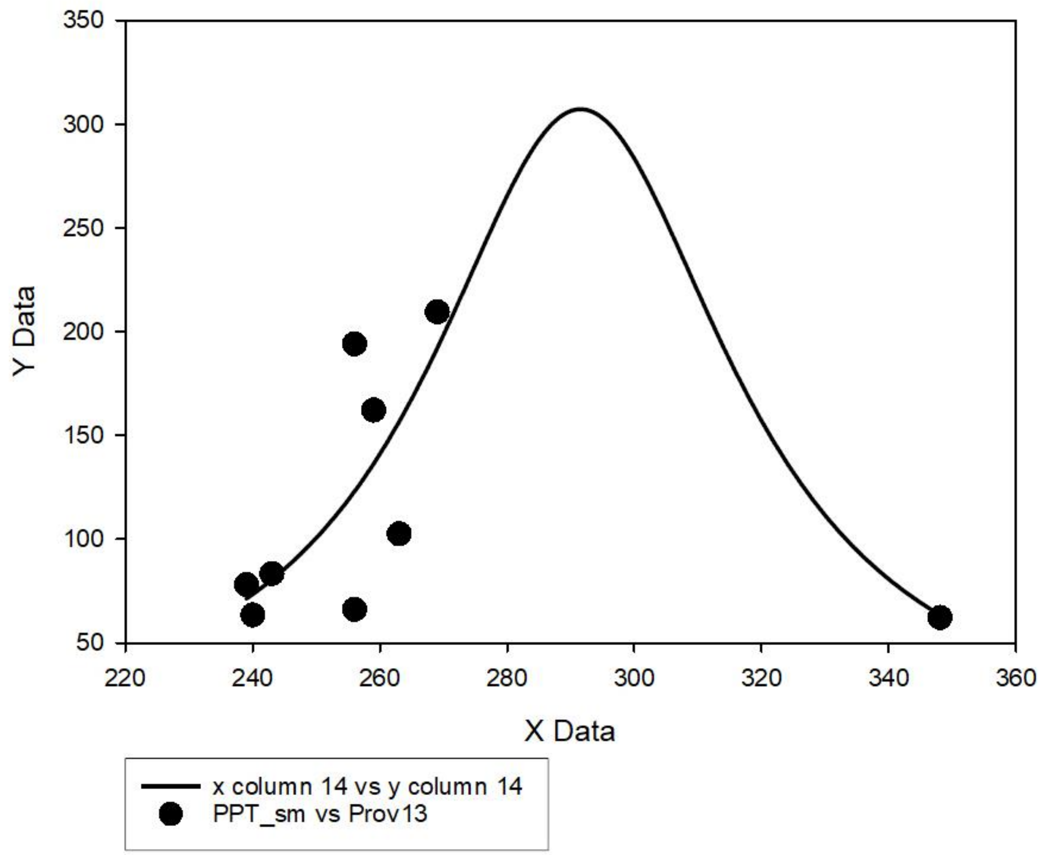
Appendix 2.22. Response function graph for provenance 11 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



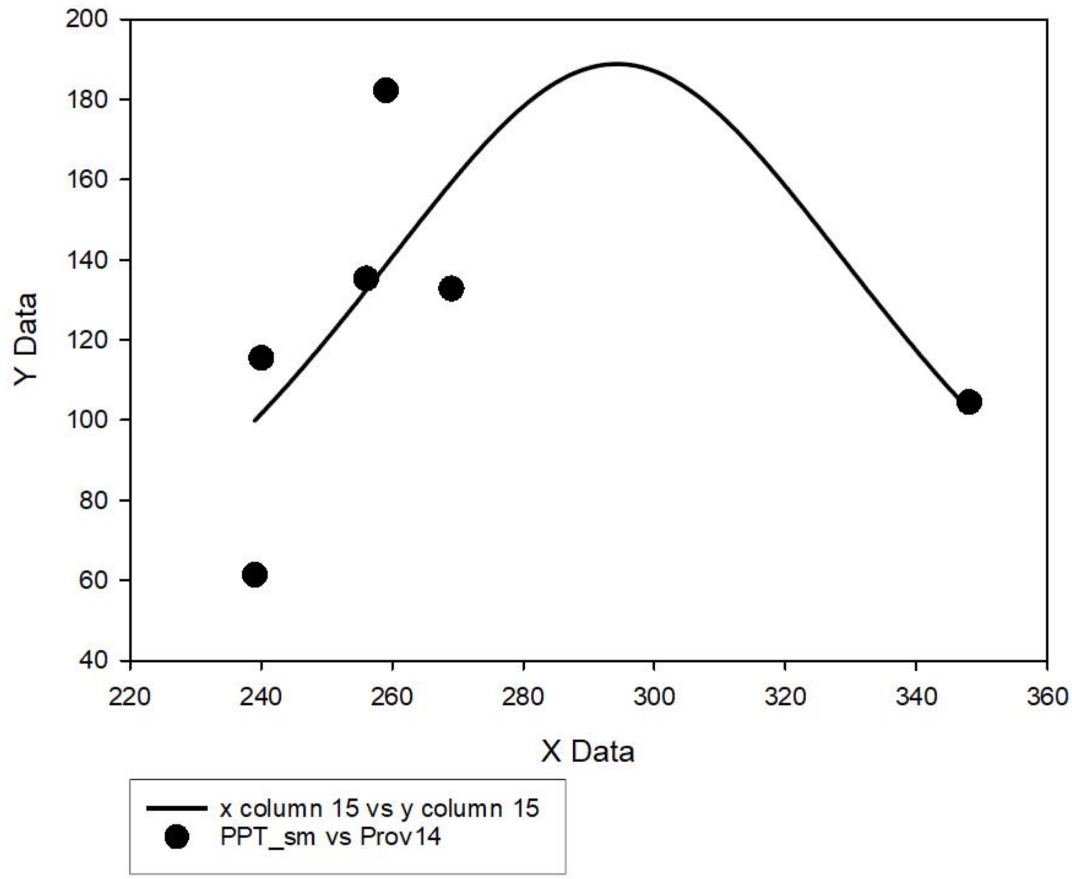
Appendix 2.23. Response function graph for provenance 12 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



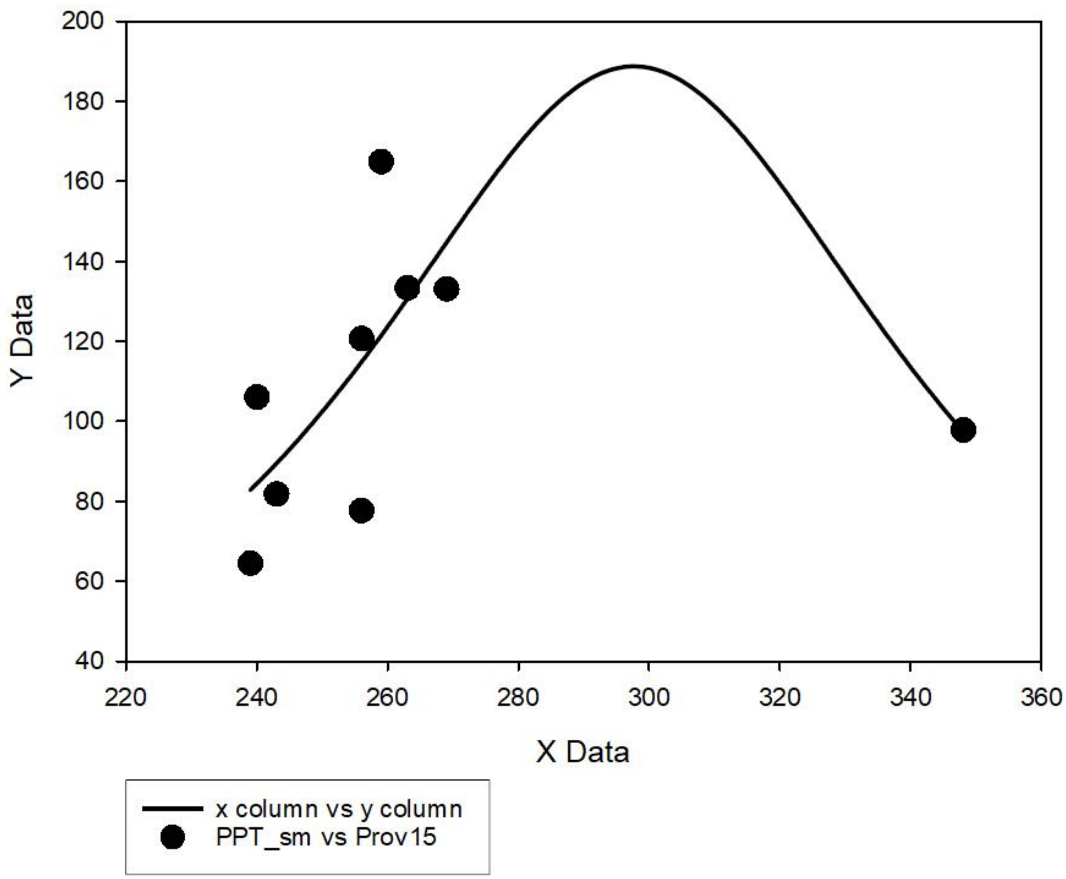
Appendix 2.24. Response function graph for provenance 13 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



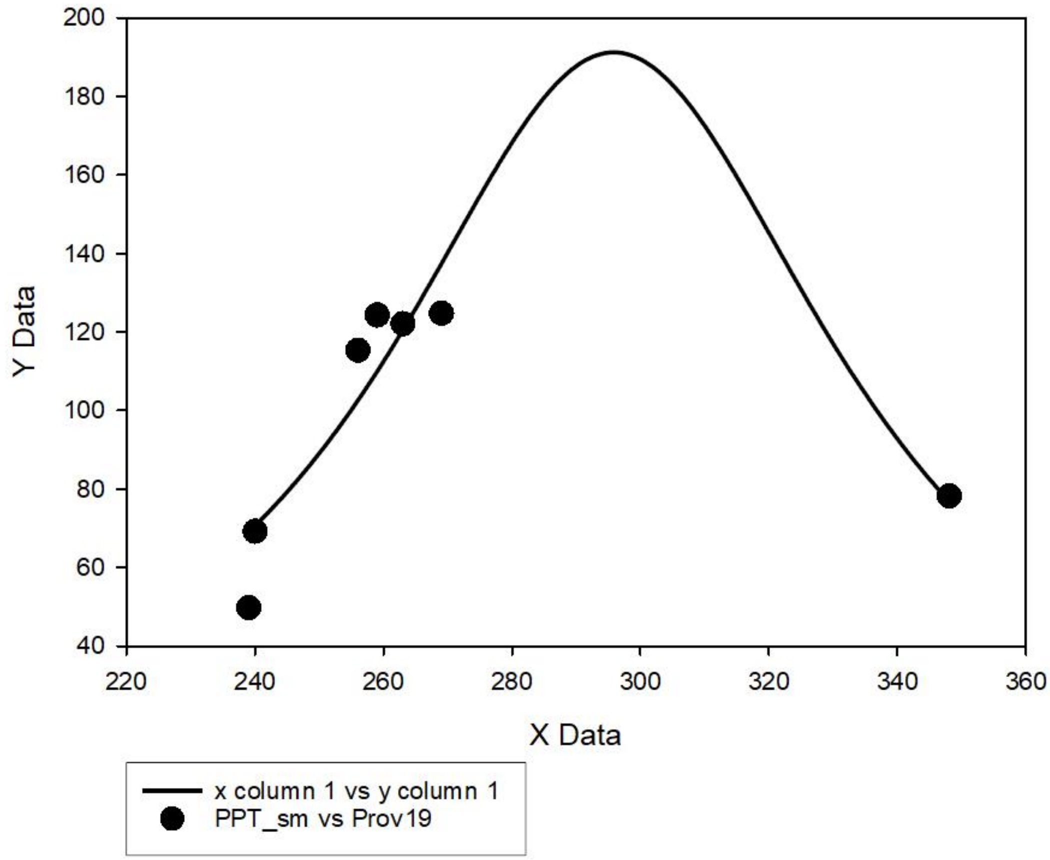
Appendix 2.25. Response function graph for provenance 14 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



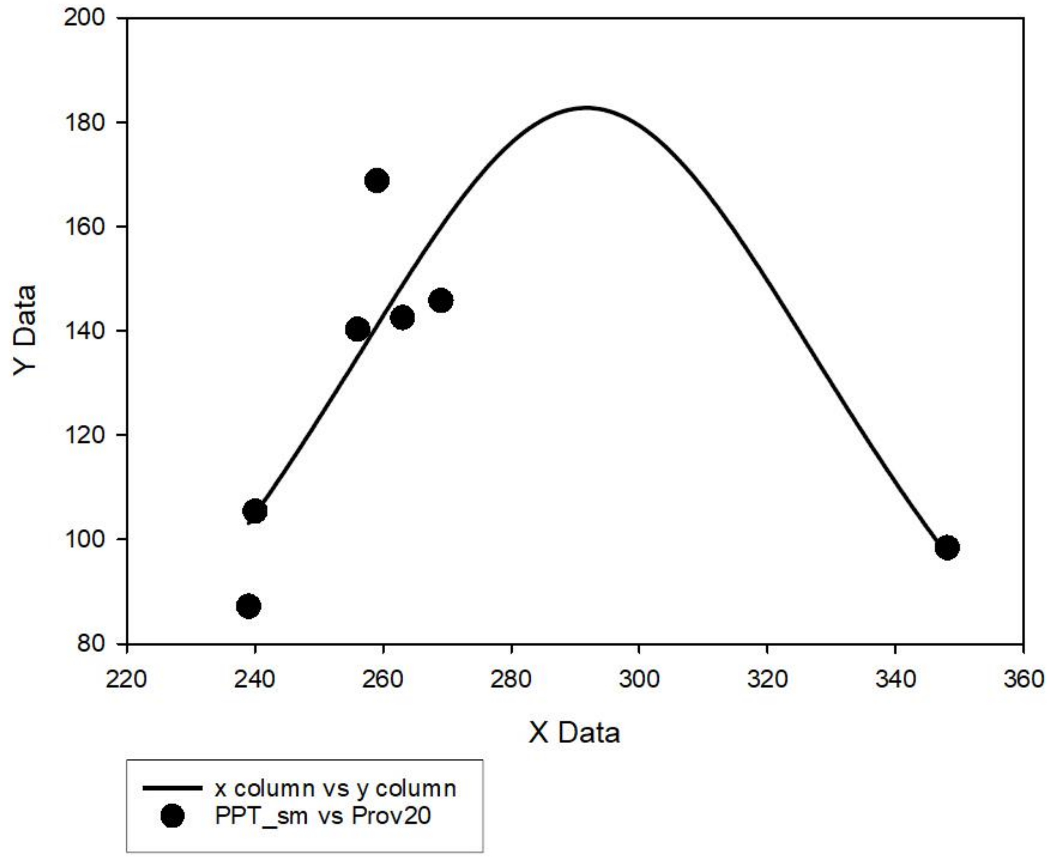
Appendix 2.26. Response function graph for provenance 15 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



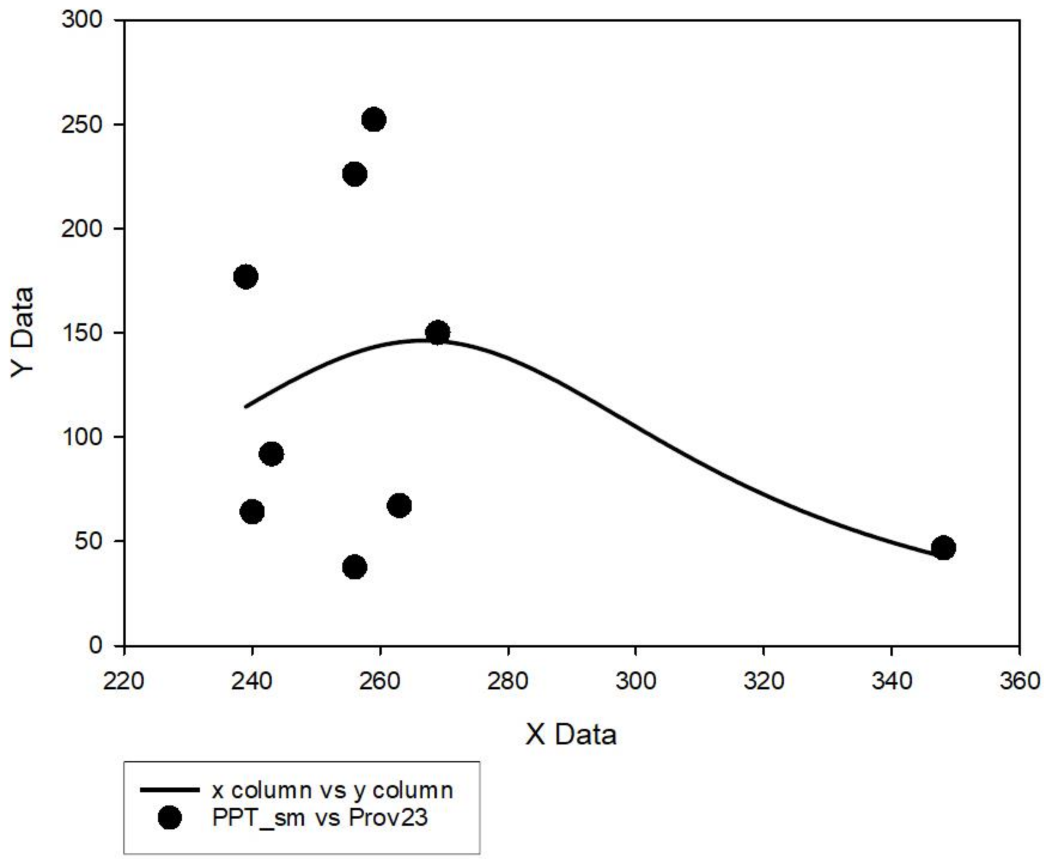
Appendix 2.27. Response function graph for provenance 19 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



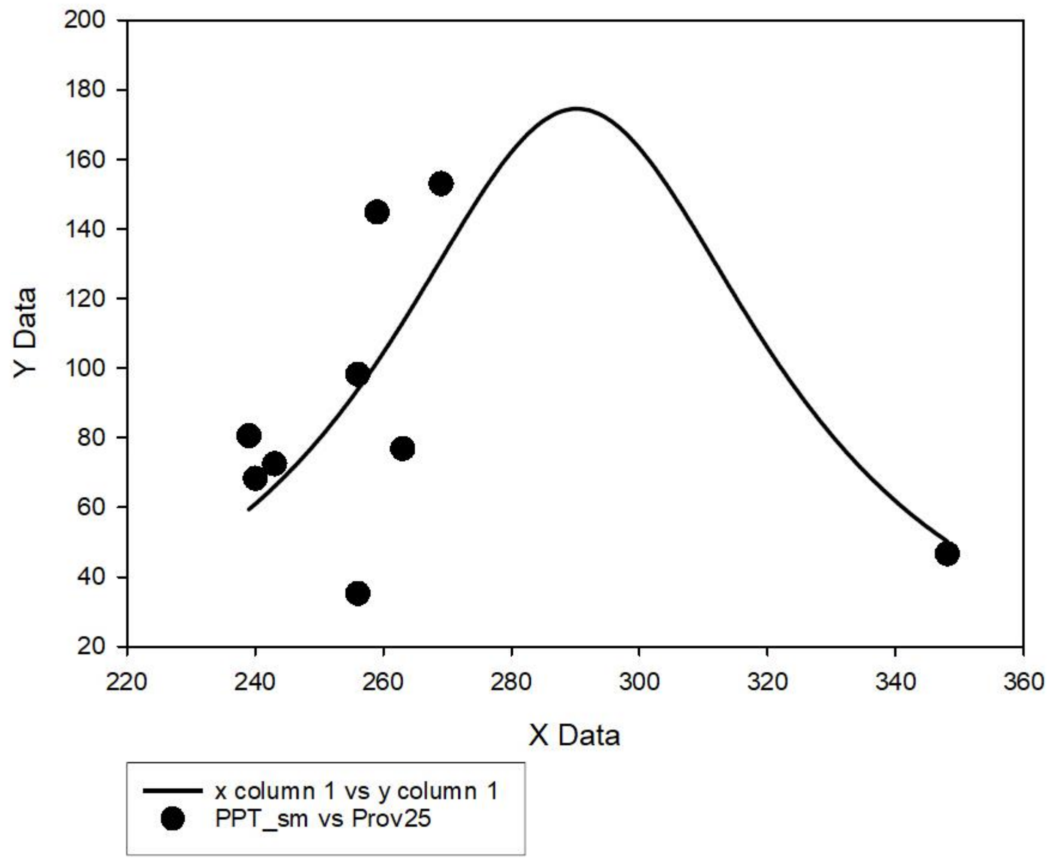
Appendix 2.28. Response function graph for provenance 20 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



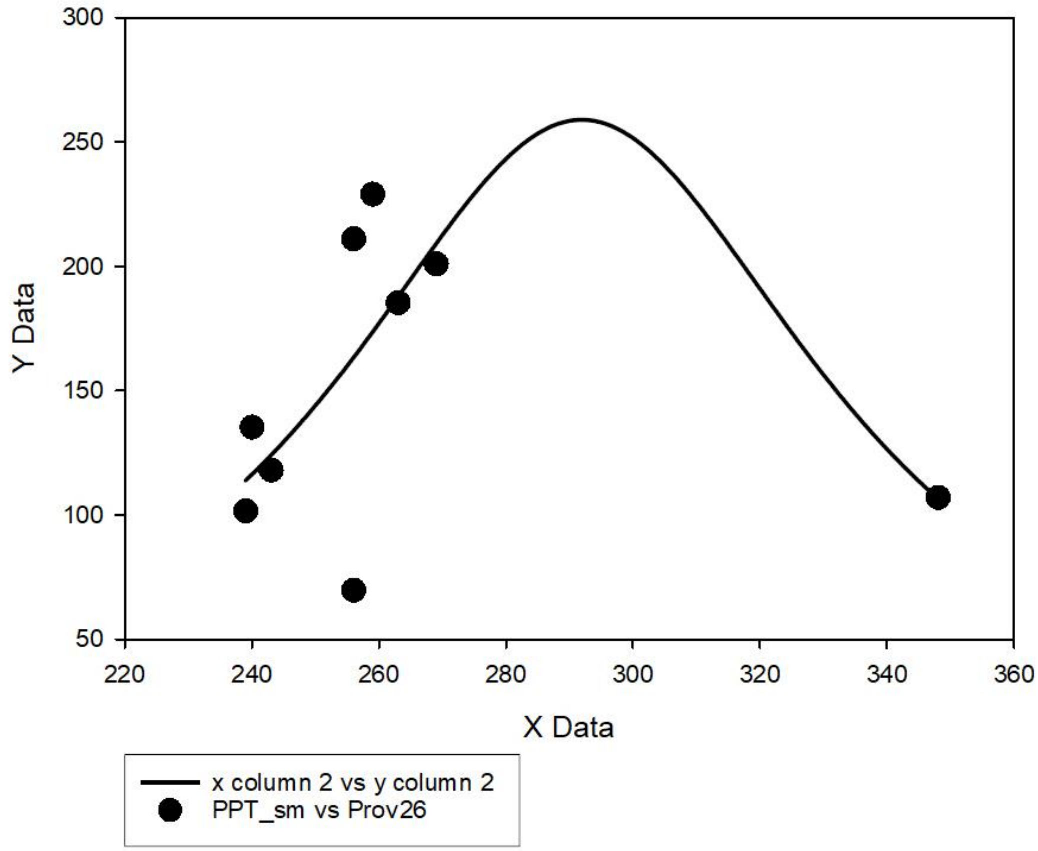
Appendix 2.29. Response function graph for provenance 23 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



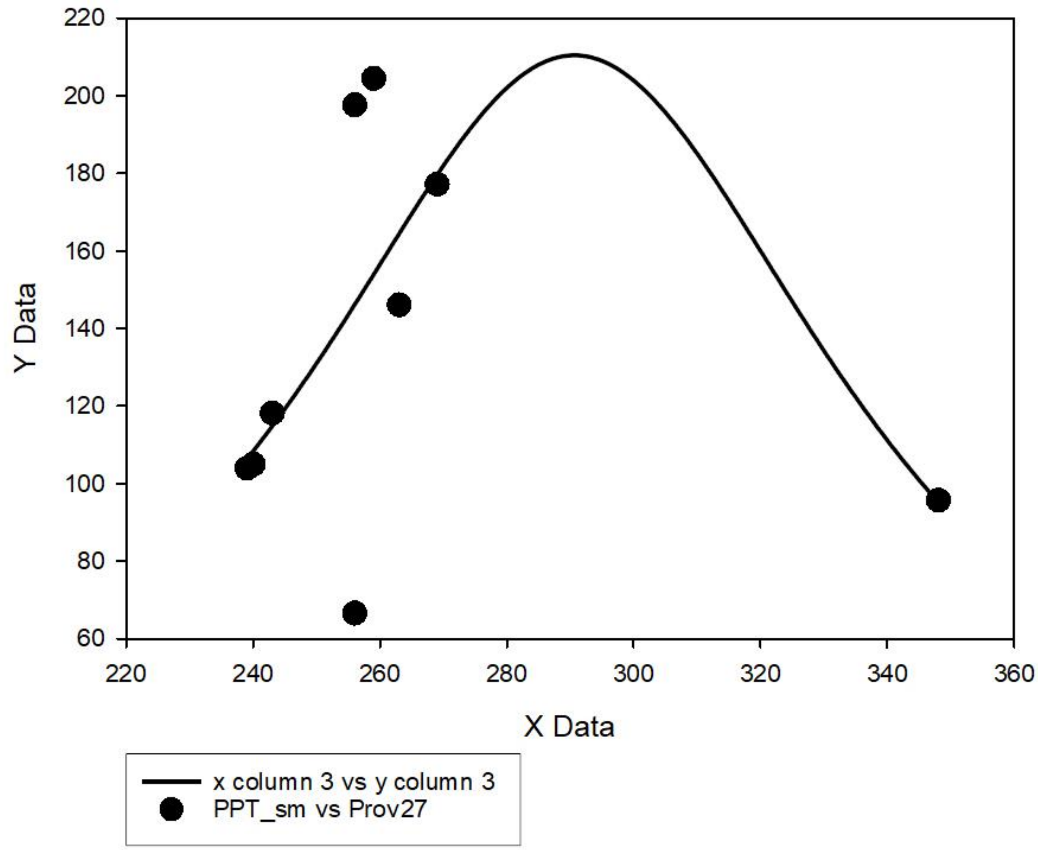
Appendix 2.30. Response function graph for provenance 25 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



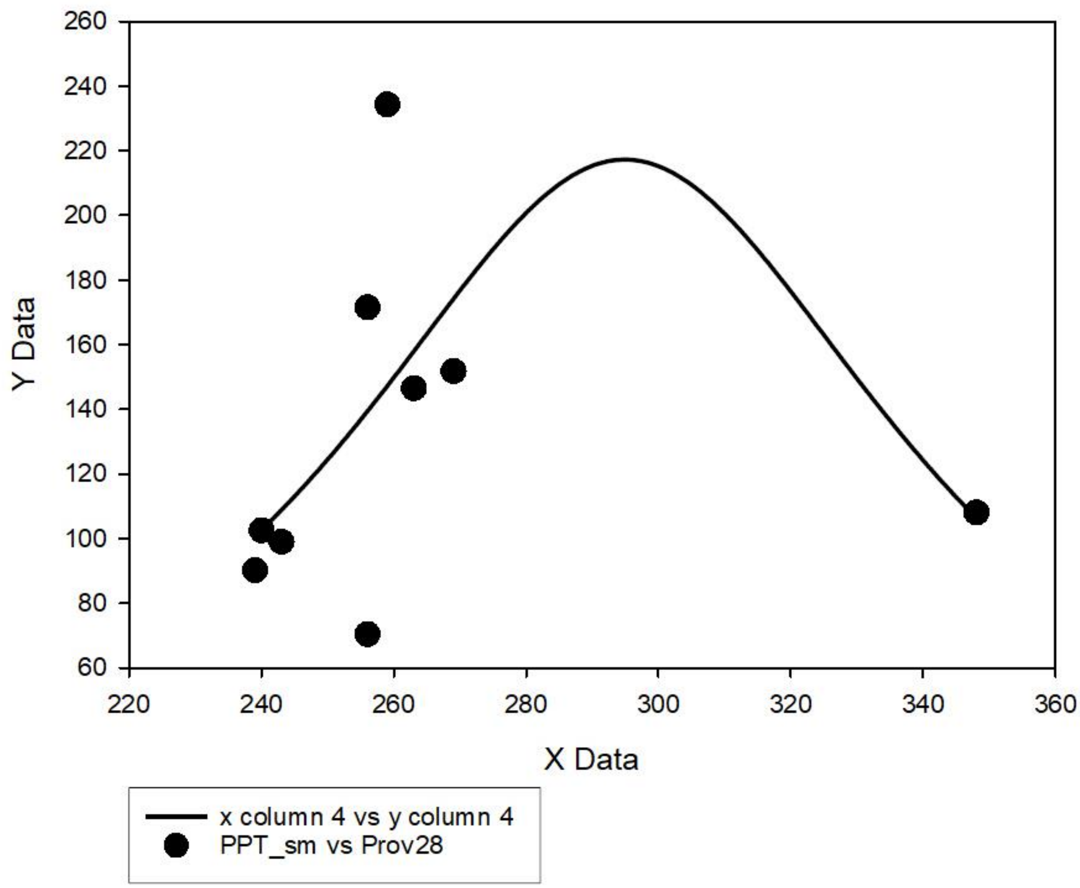
Appendix 2.31. Response function graph for provenance 26 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



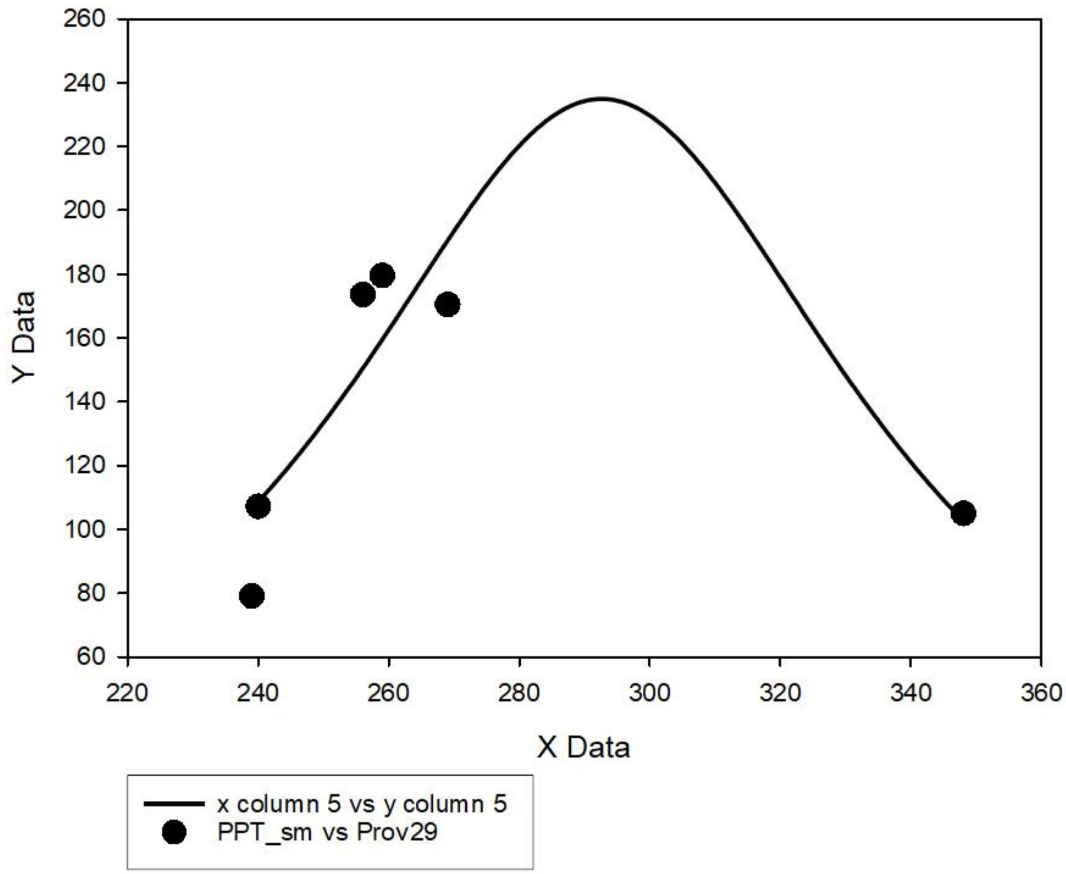
Appendix 2.32. Response function graph for provenance 27 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



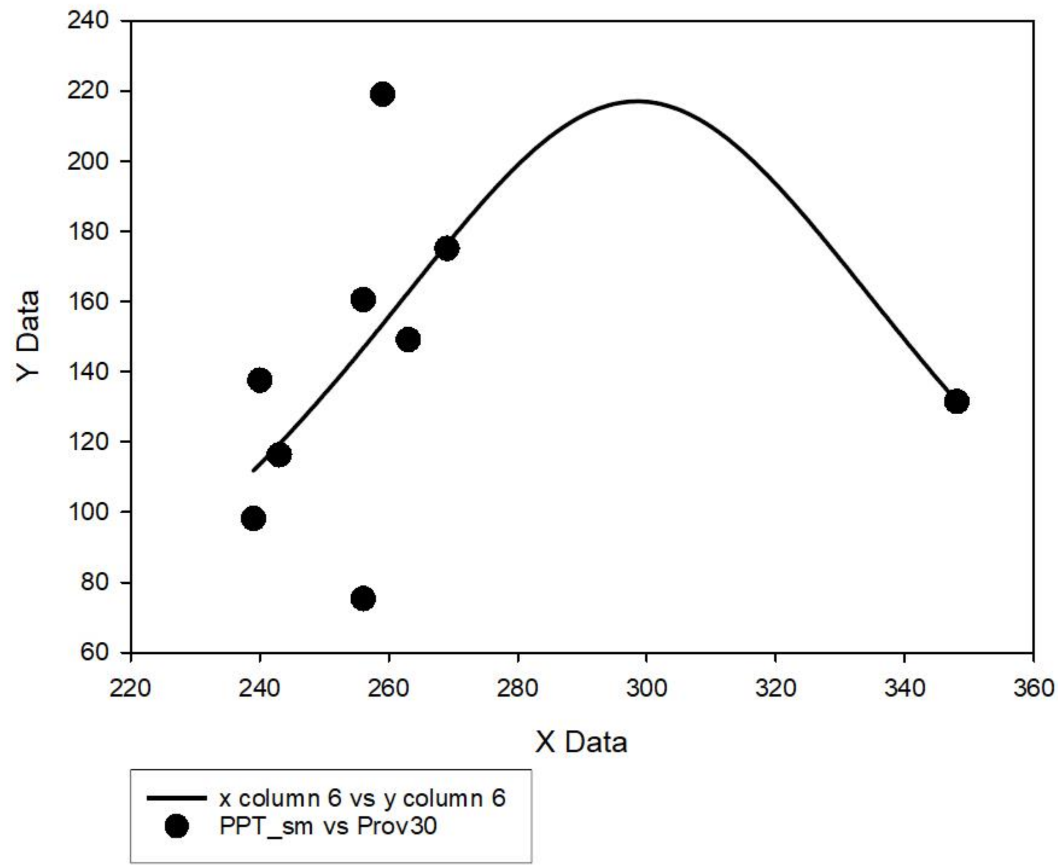
Appendix 2.33. Response function graph for provenance 28 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



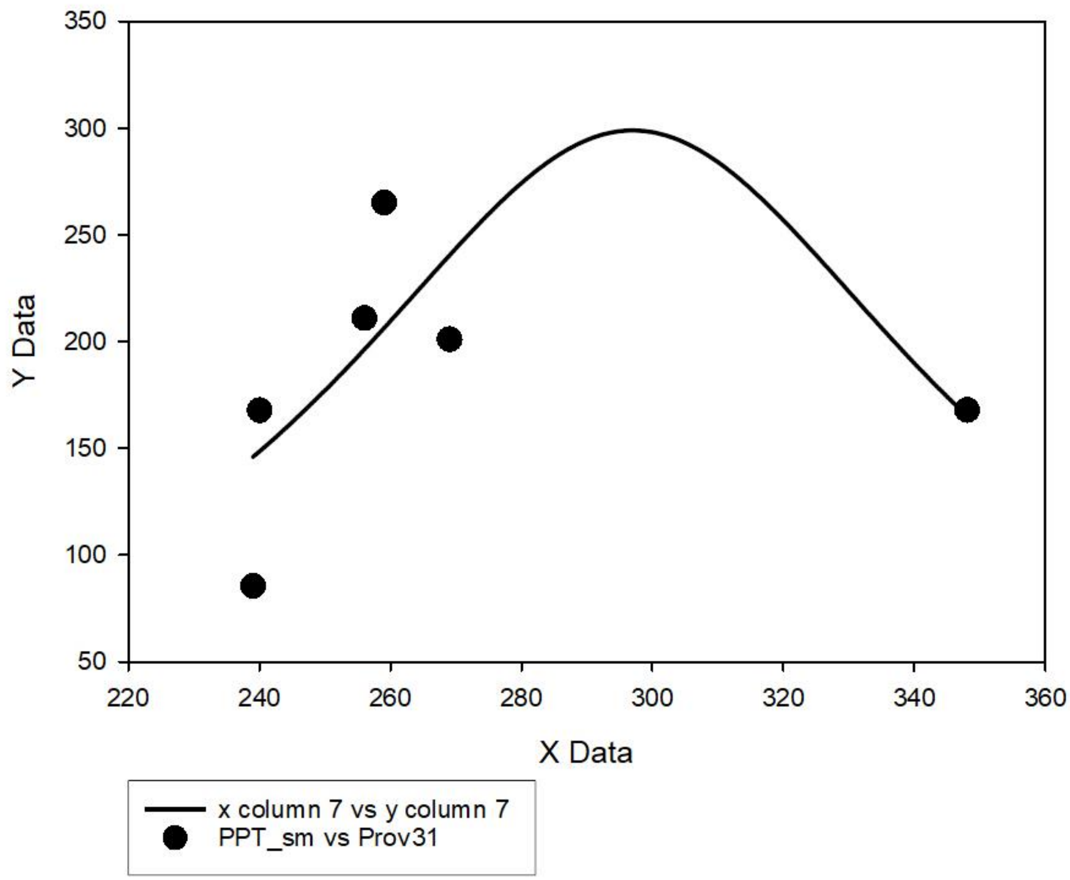
Appendix 2.34. Response function graph for provenance 29 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



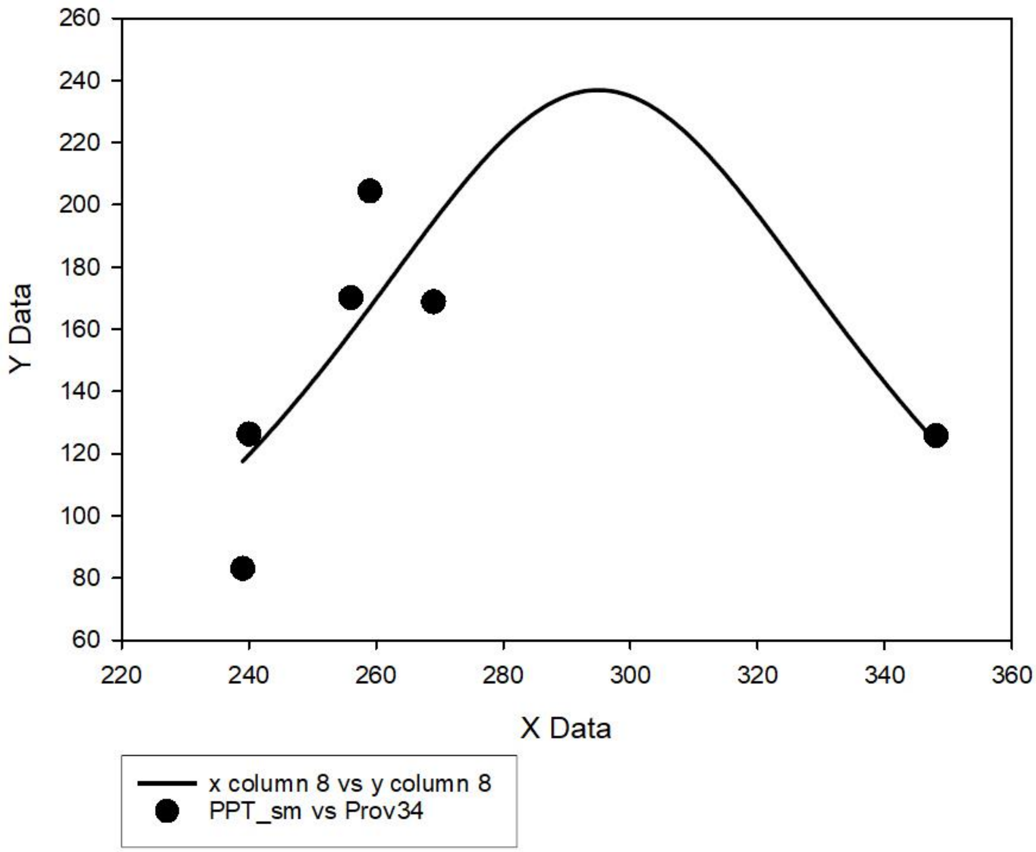
Appendix 2.35. Response function graph for provenance 30 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



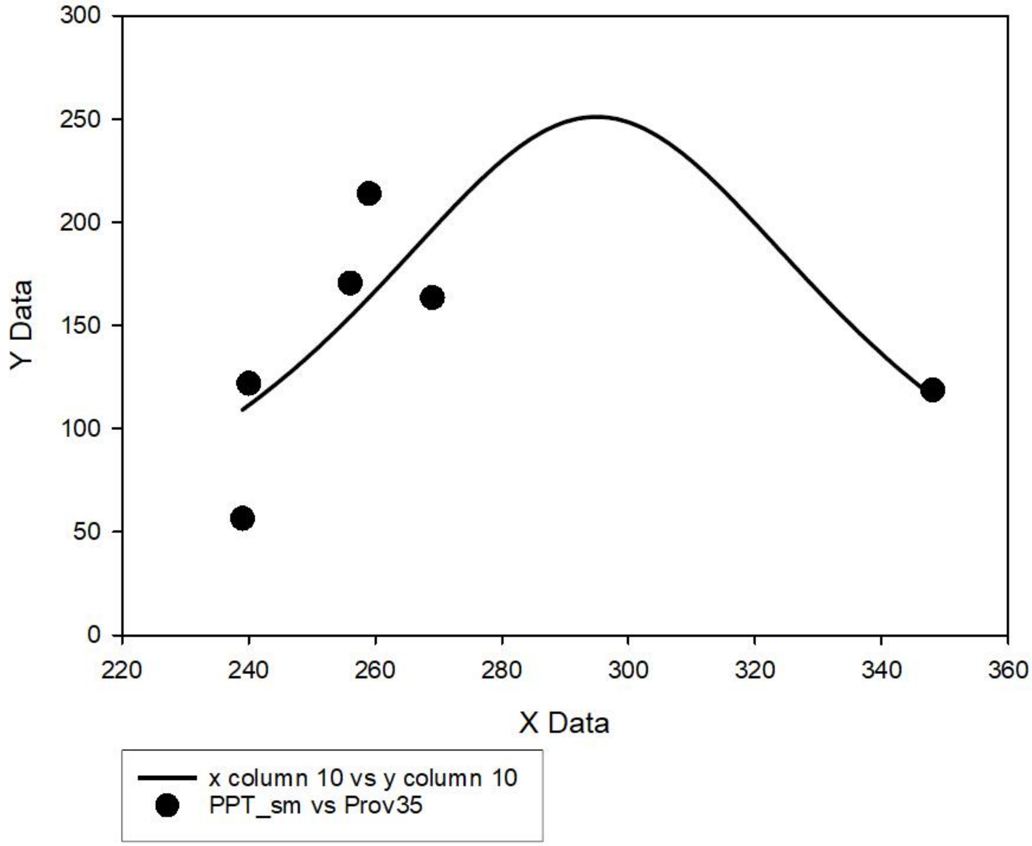
Appendix 2.36. Response function graph for provenance 31 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



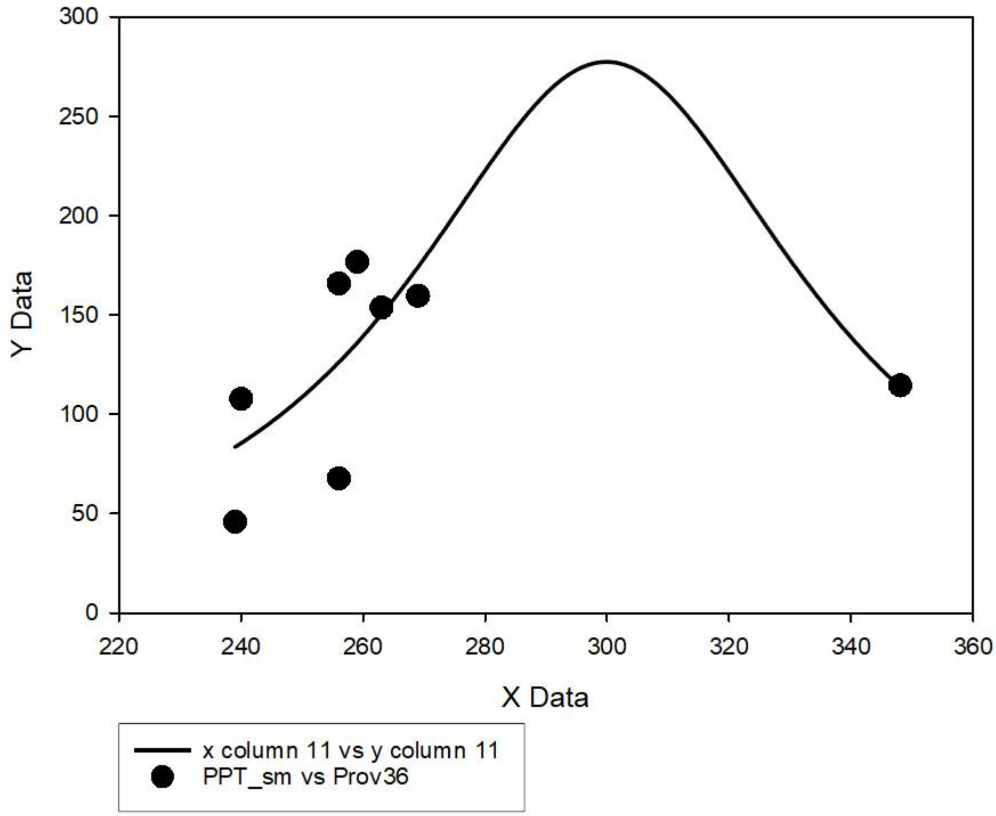
Appendix 2.37. Response function graph for provenance 34 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



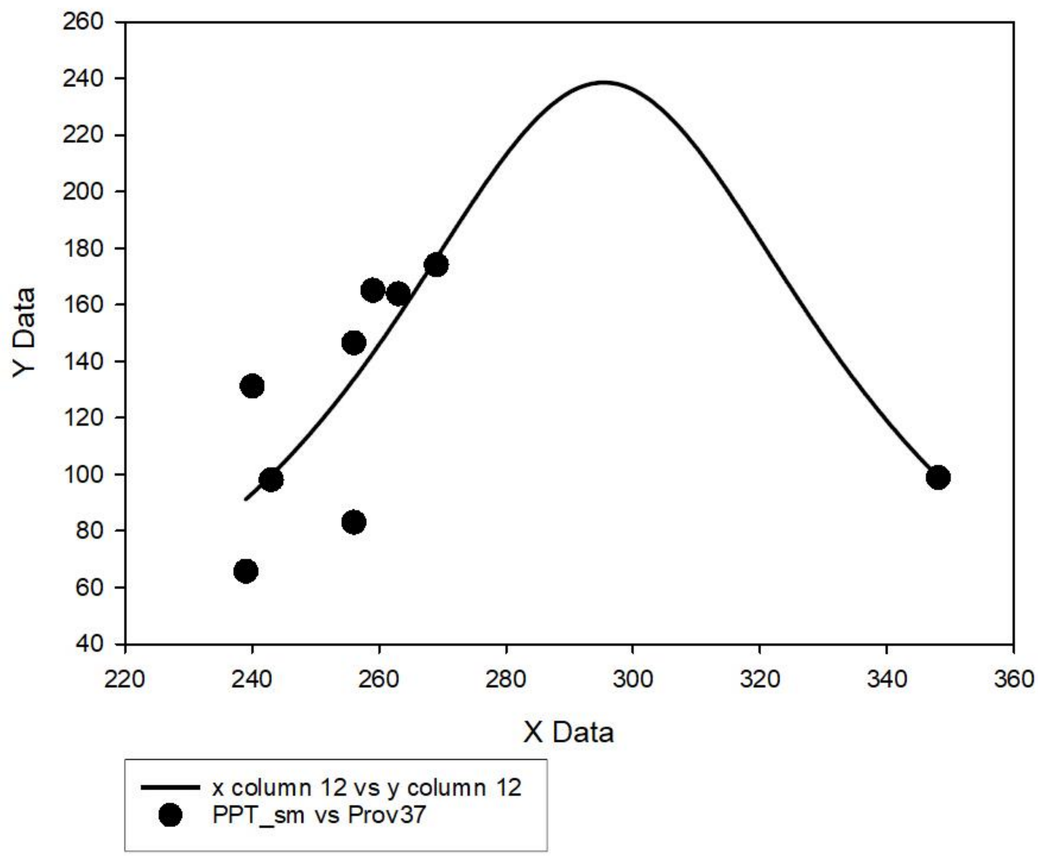
Appendix 2.38. Response function graph for provenance 35 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



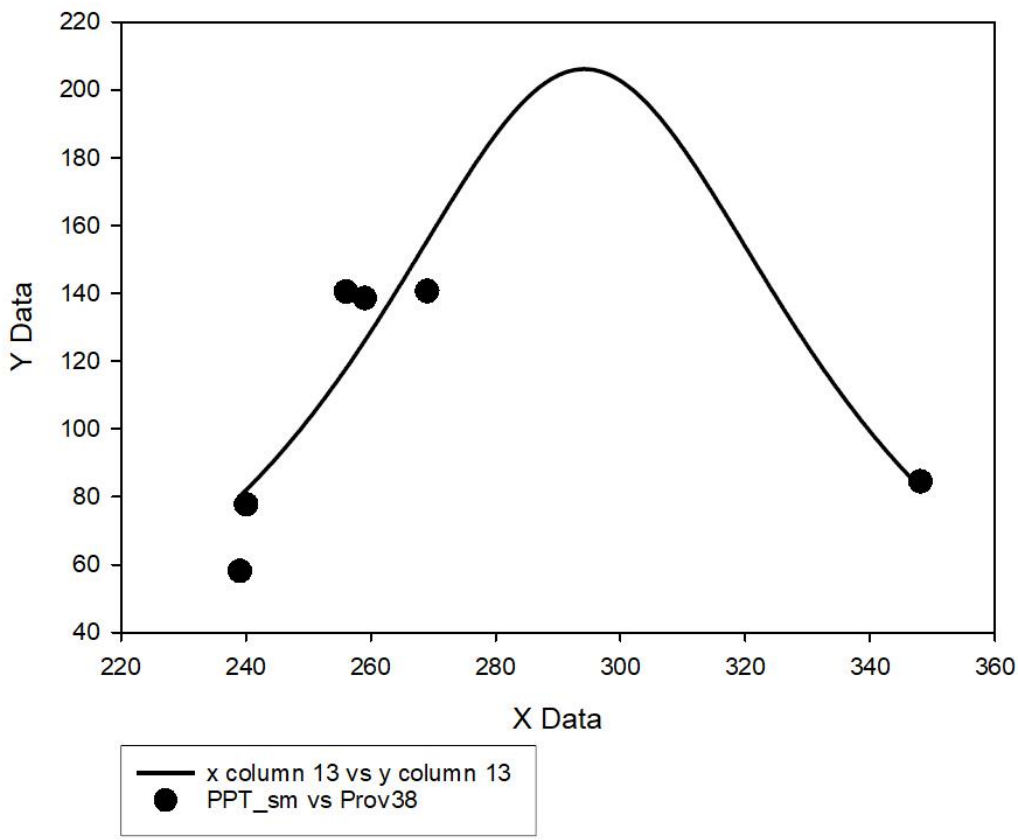
Appendix 2.39. Response function graph for provenance 36 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



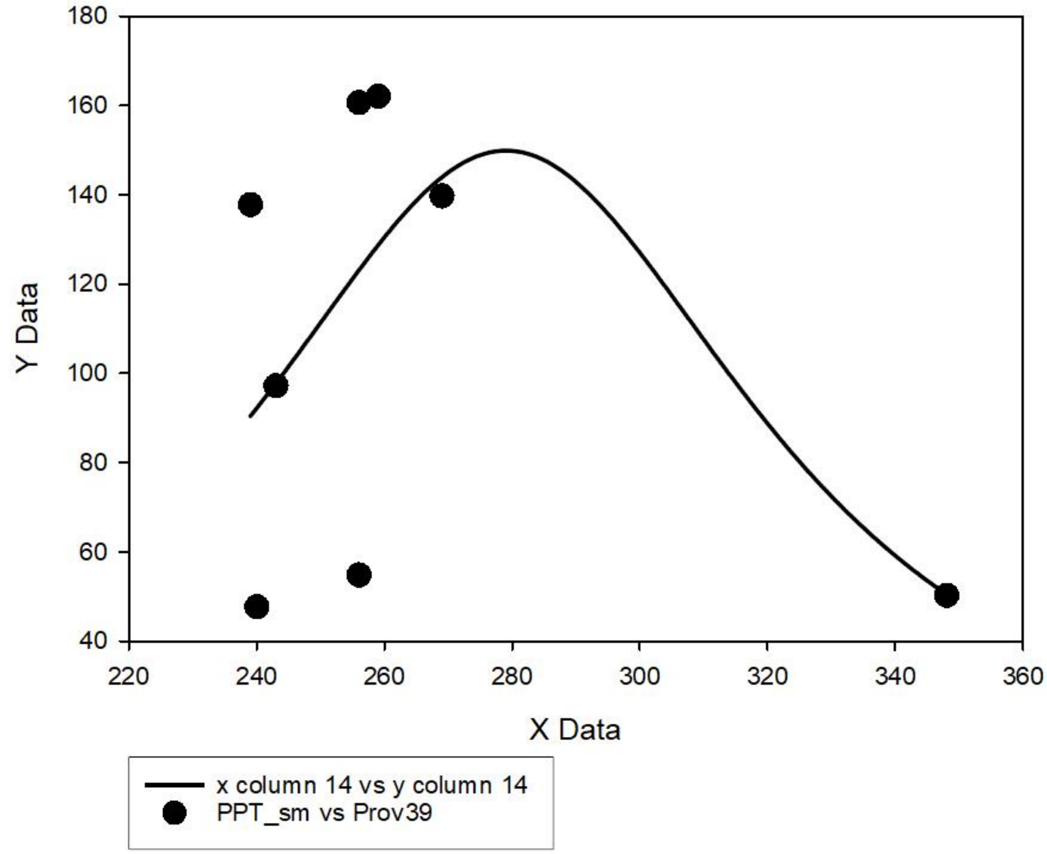
Appendix 2.40. Response function graph for provenance 37 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



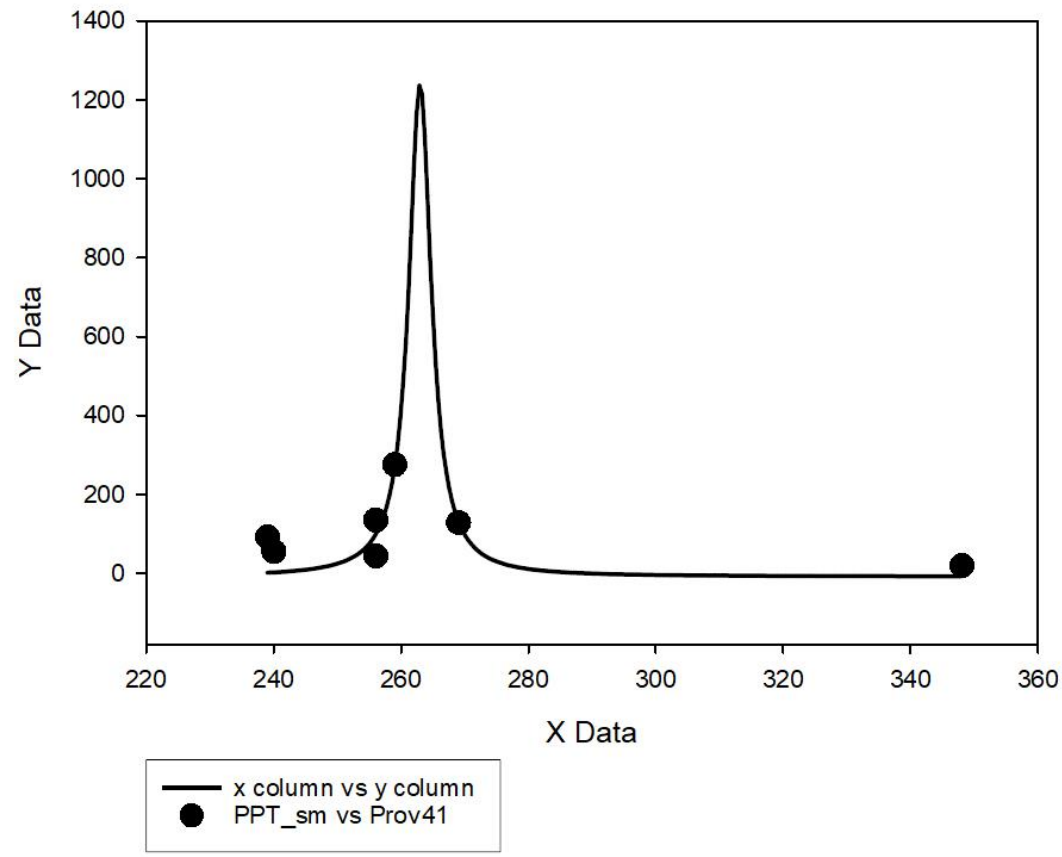
Appendix 2.41. Response function graph for provenance 38 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



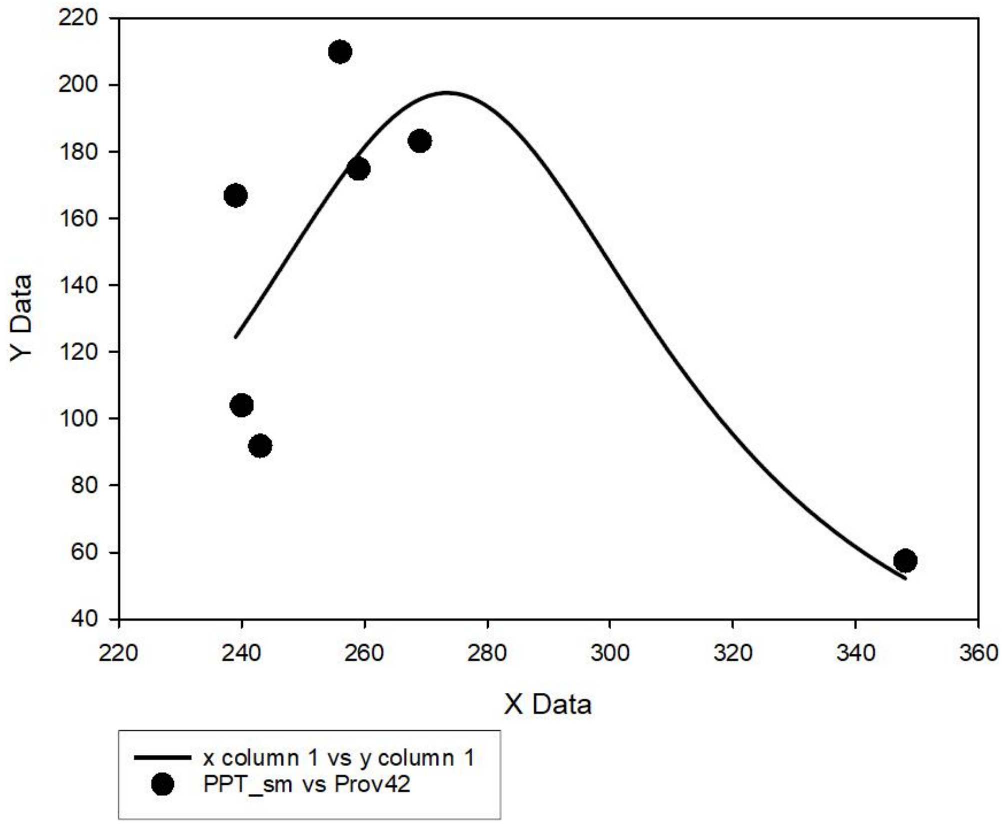
Appendix 2.42. Response function graph for provenance 39 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



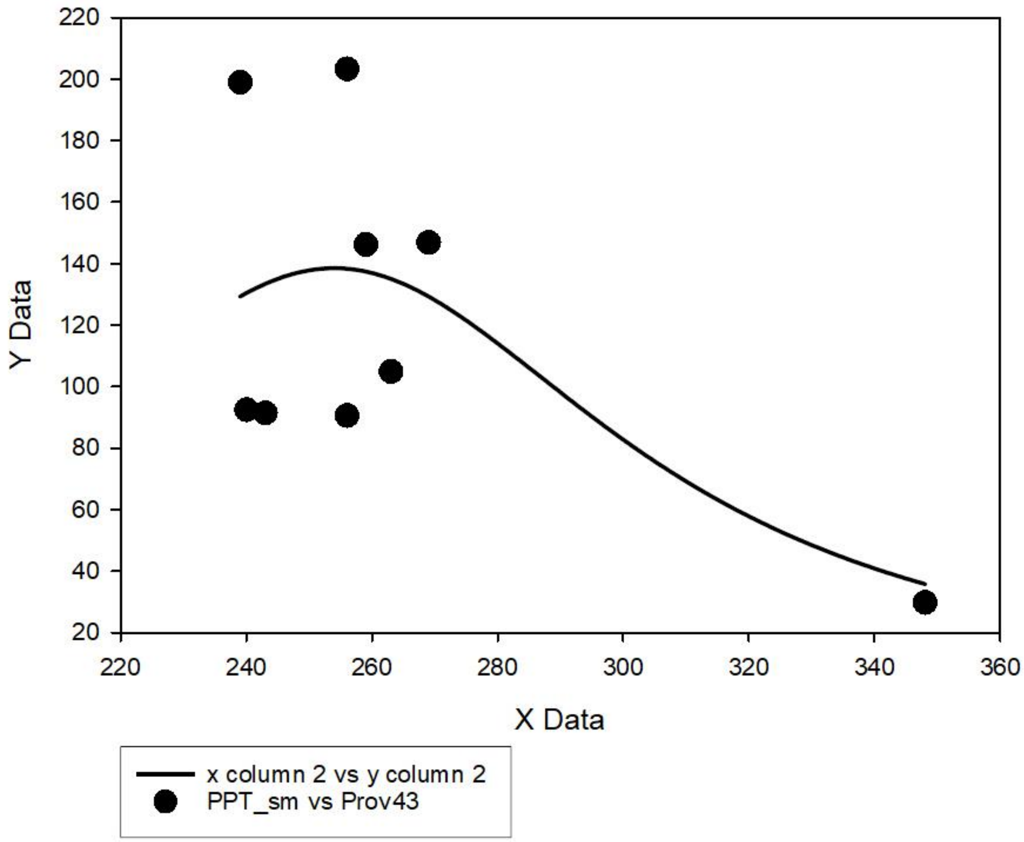
Appendix 2.43. Response function graph for provenance 41 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



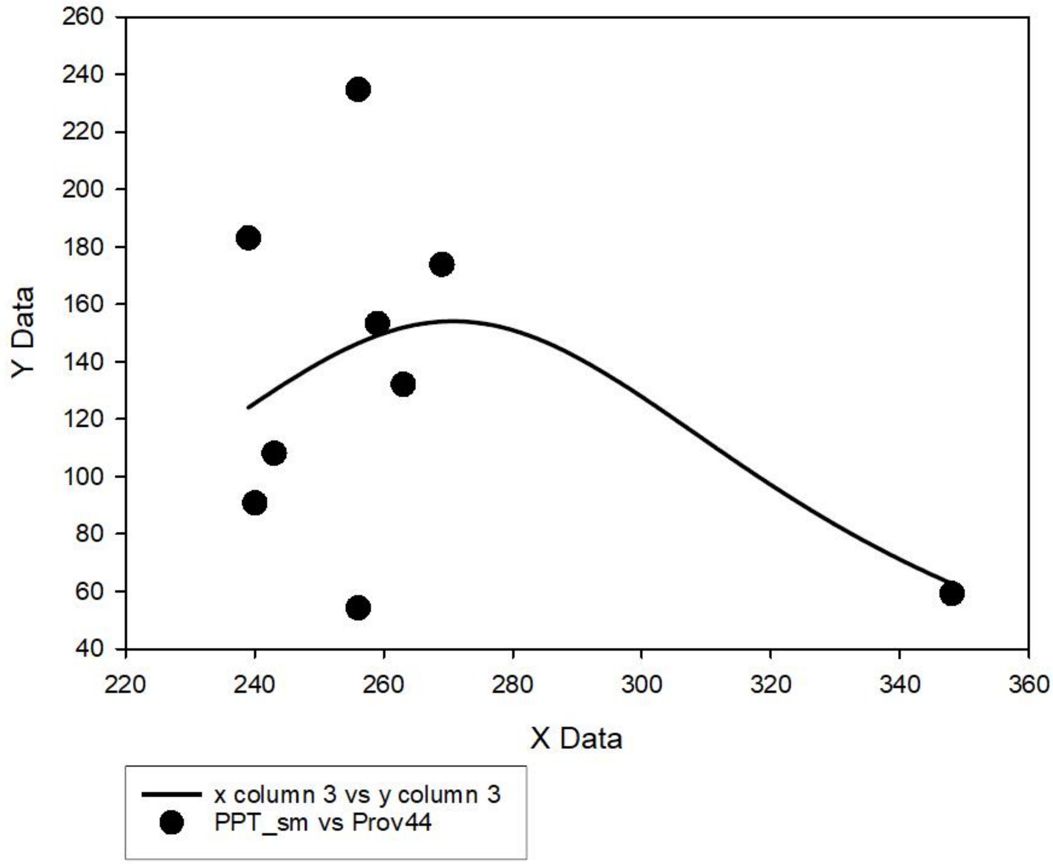
Appendix 2.44. Response function graph for provenance 42 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



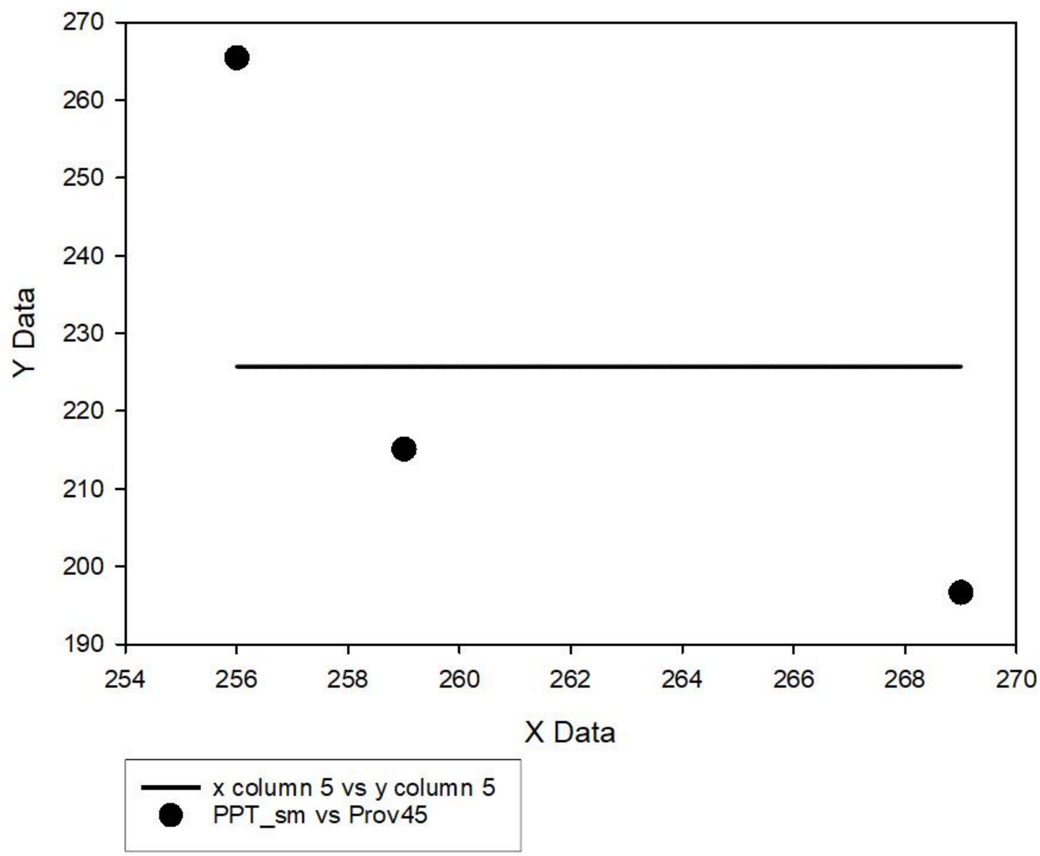
Appendix 2.45. Response function graph for provenance 43 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



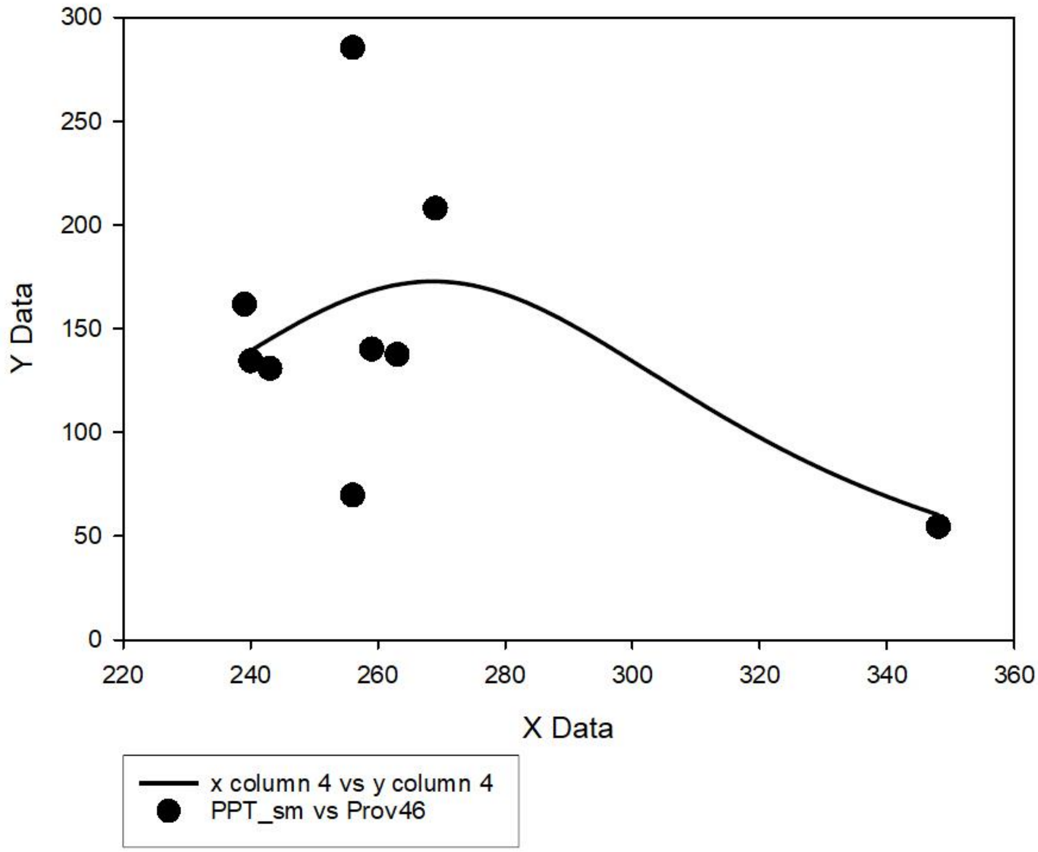
Appendix 2.46. Response function graph for provenance 44 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



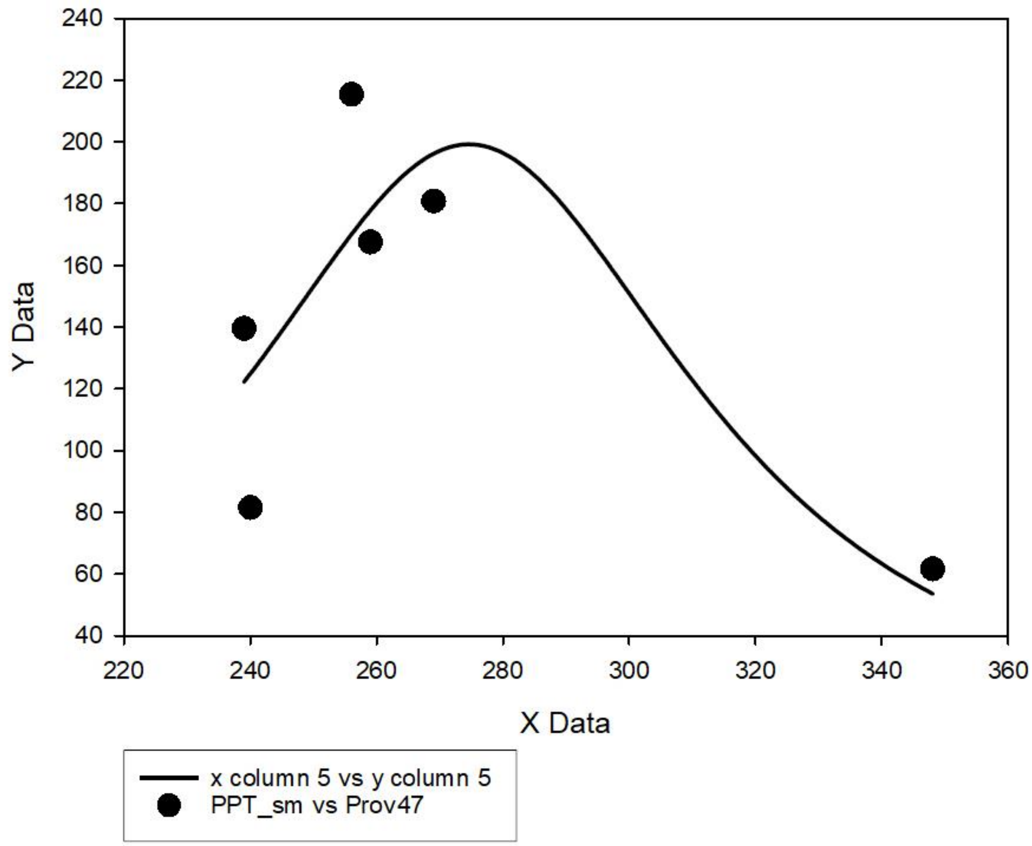
Appendix 2.47. Response function graph for provenance 45 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



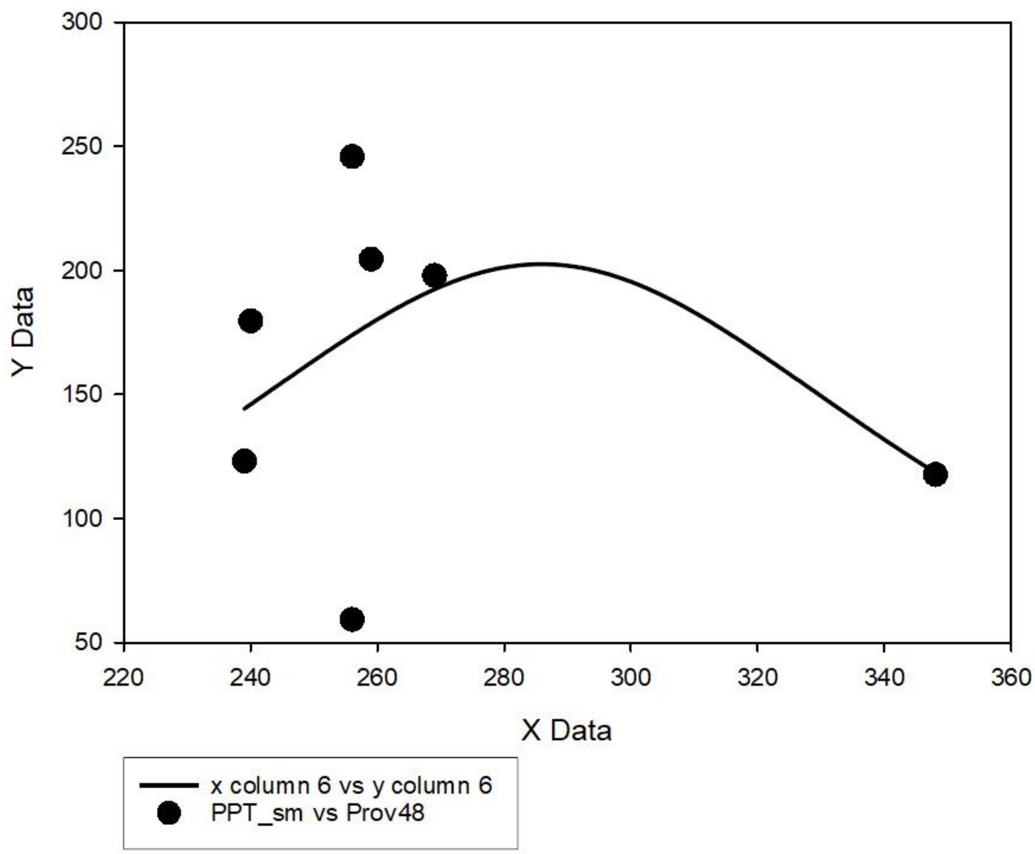
Appendix 2.48. Response function graph for provenance 46 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



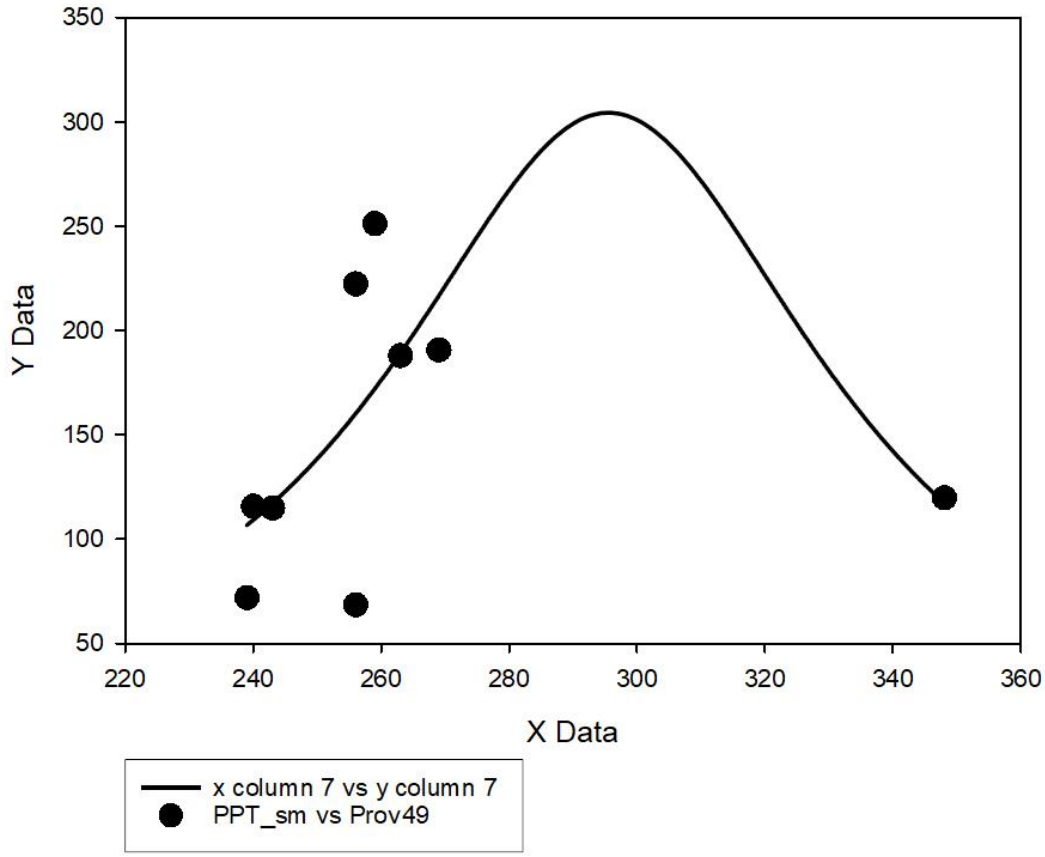
Appendix 2.49. Response function graph for provenance 47 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



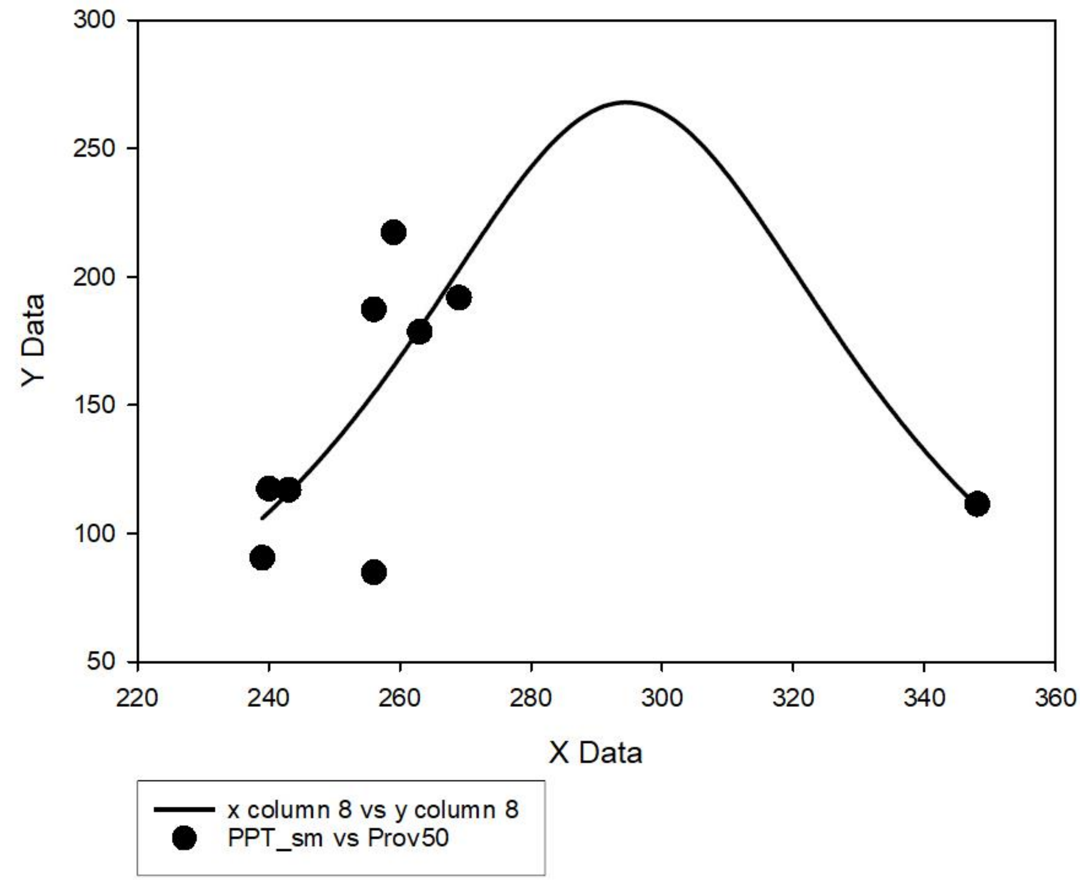
Appendix 2.50. Response function graph for provenance 48 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



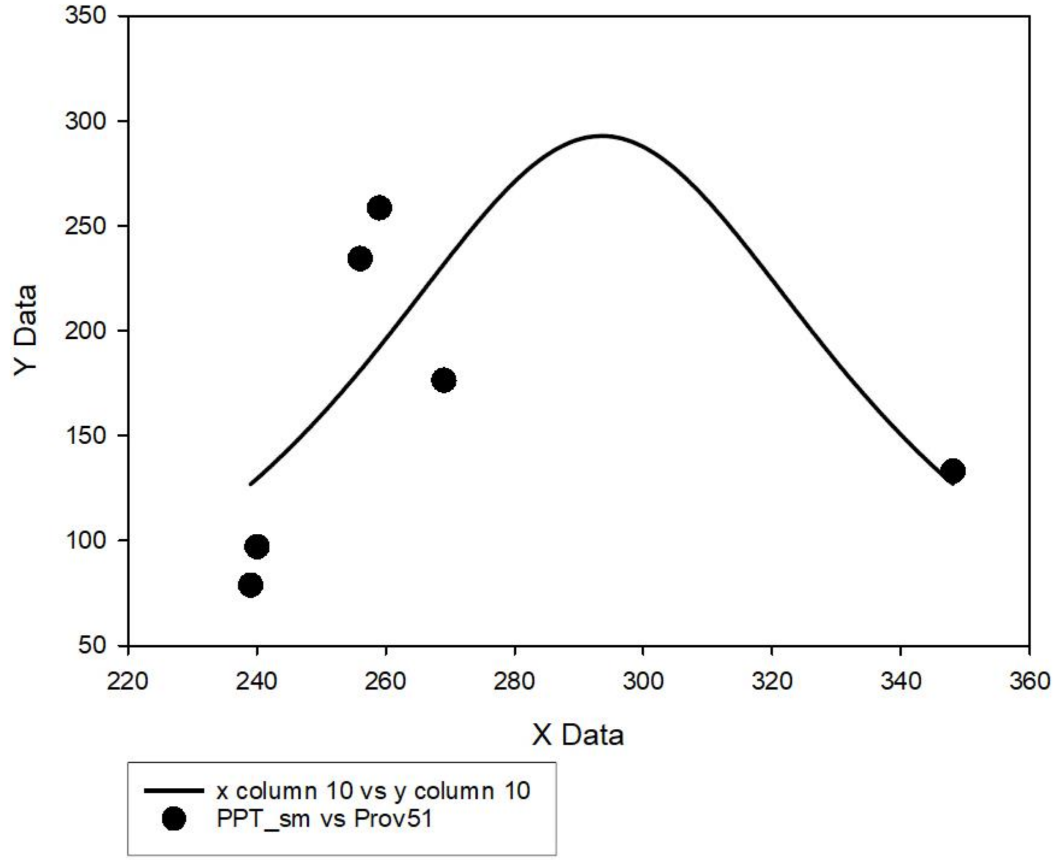
Appendix 2.51. Response function graph for provenance 49 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



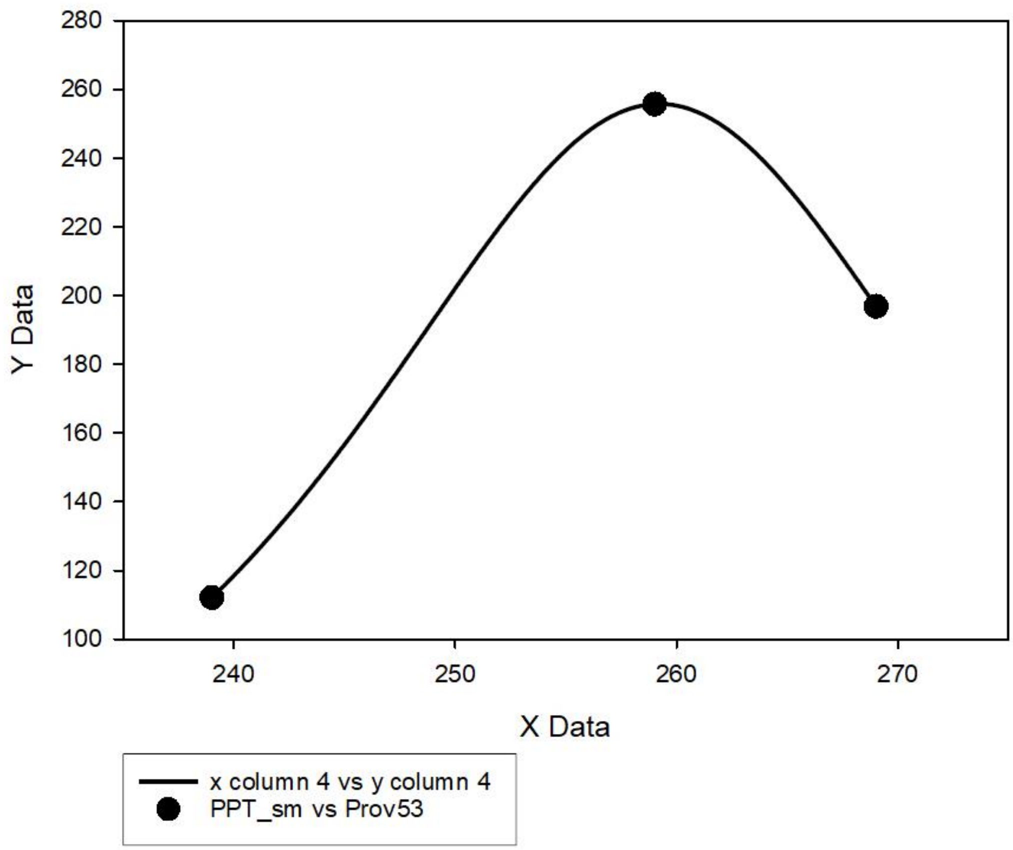
Appendix 2.52. Response function graph for provenance 50 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



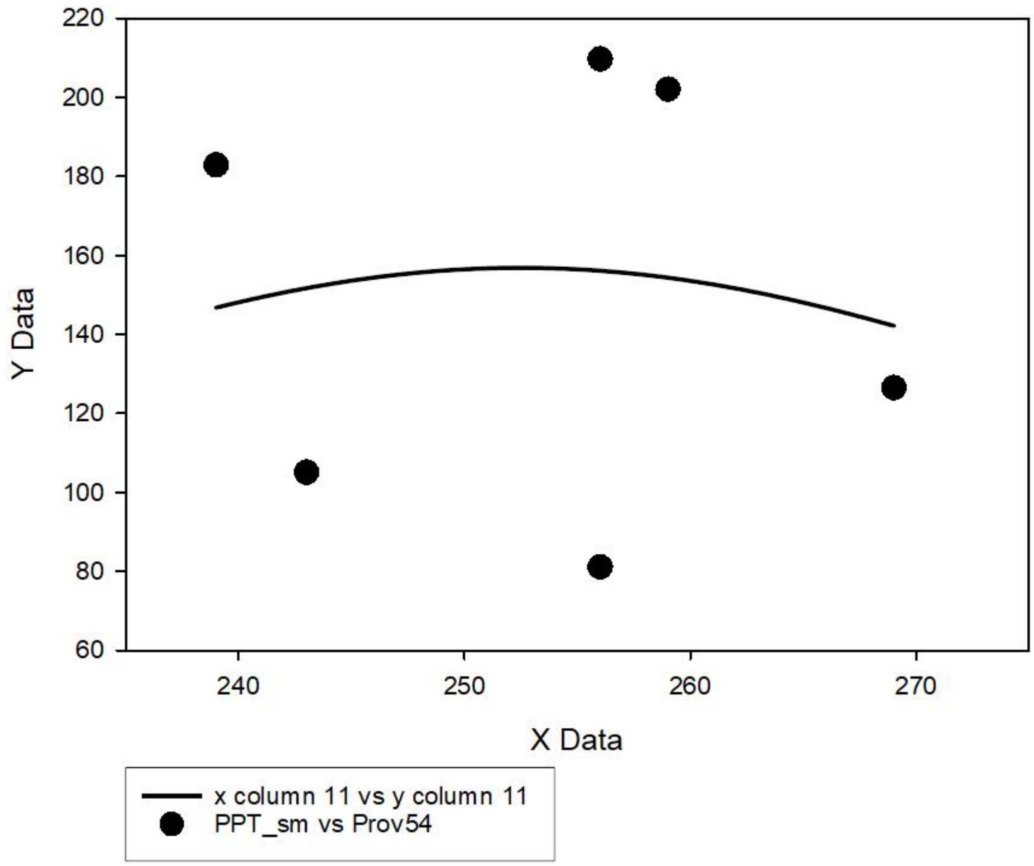
Appendix 2.53. Response function graph for provenance 51 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



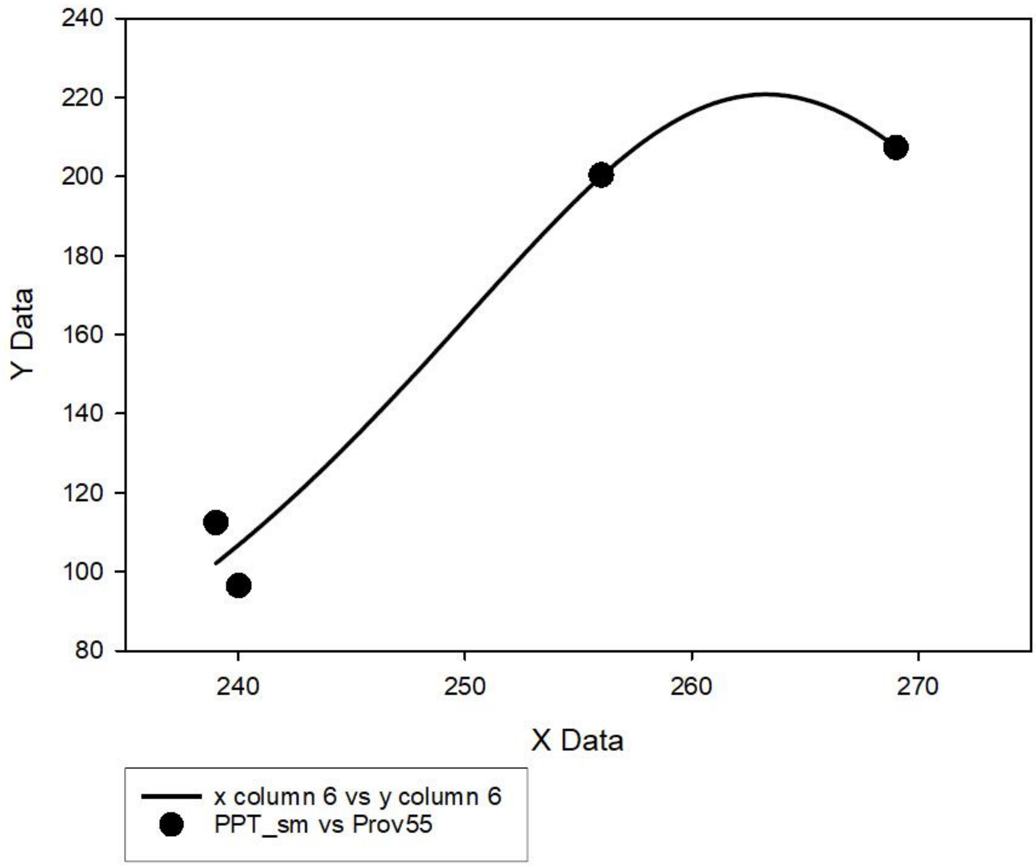
Appendix 2.54. Response function graph for provenance 53 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



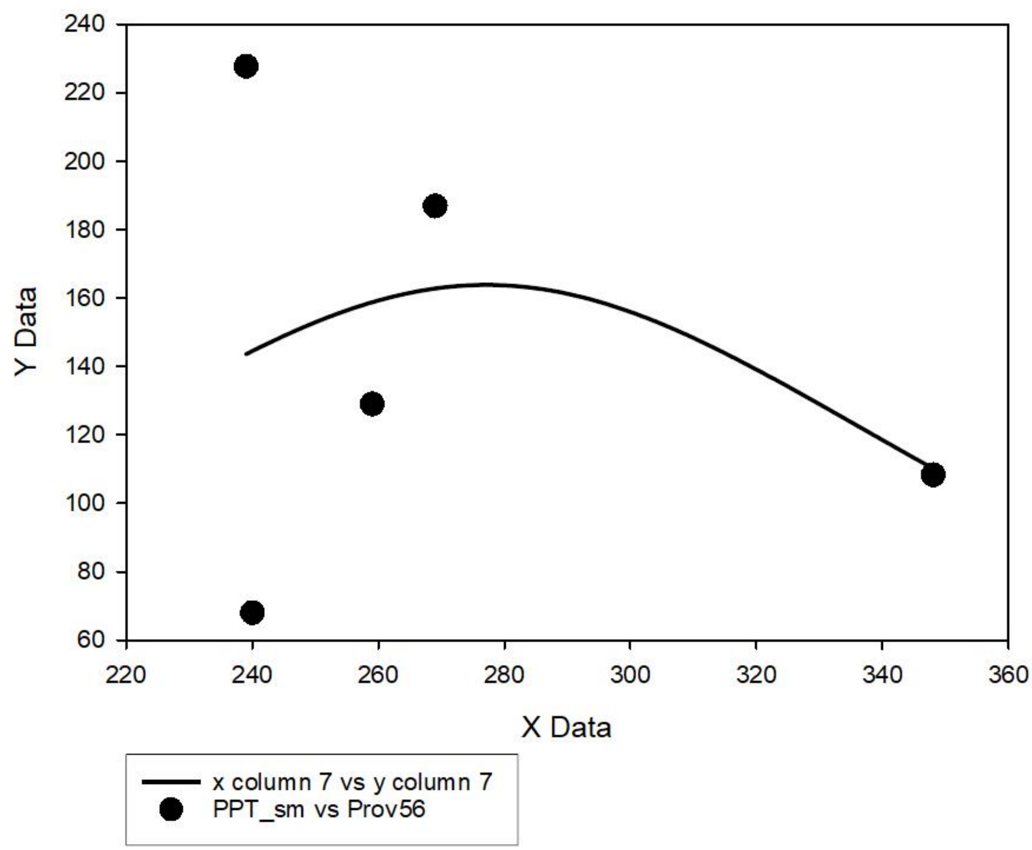
Appendix 2.55. Response function graph for provenance 54 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



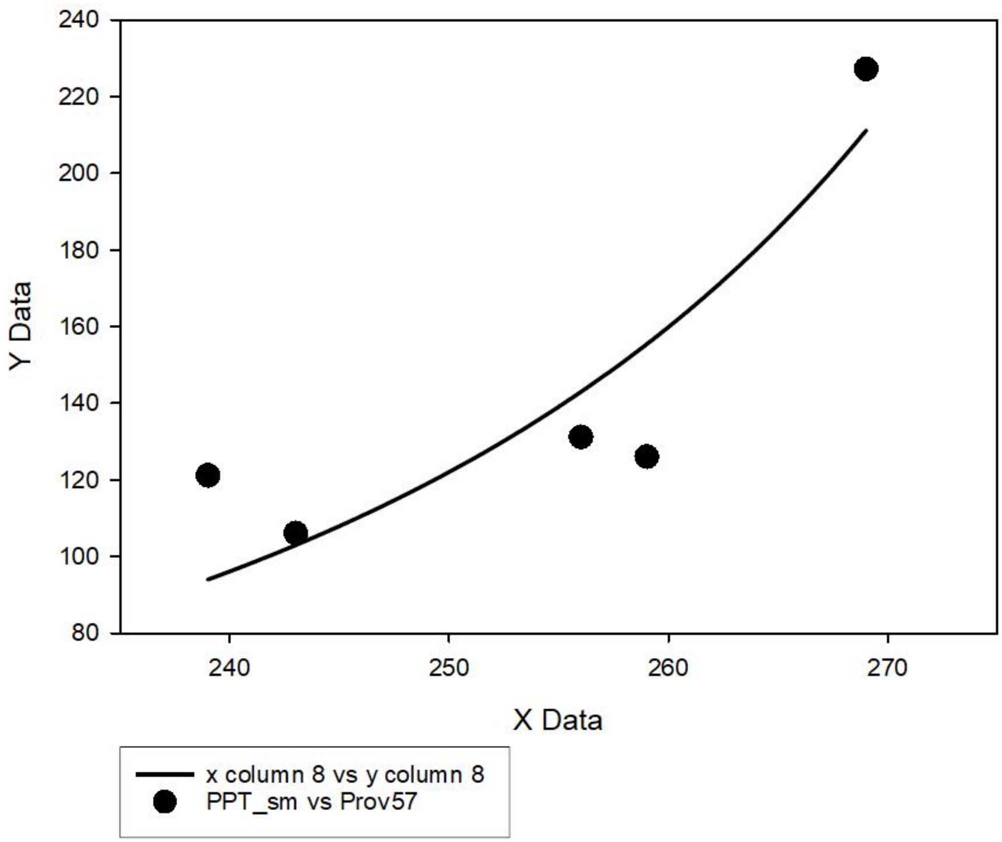
Appendix 2.56. Response function graph for provenance 55 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



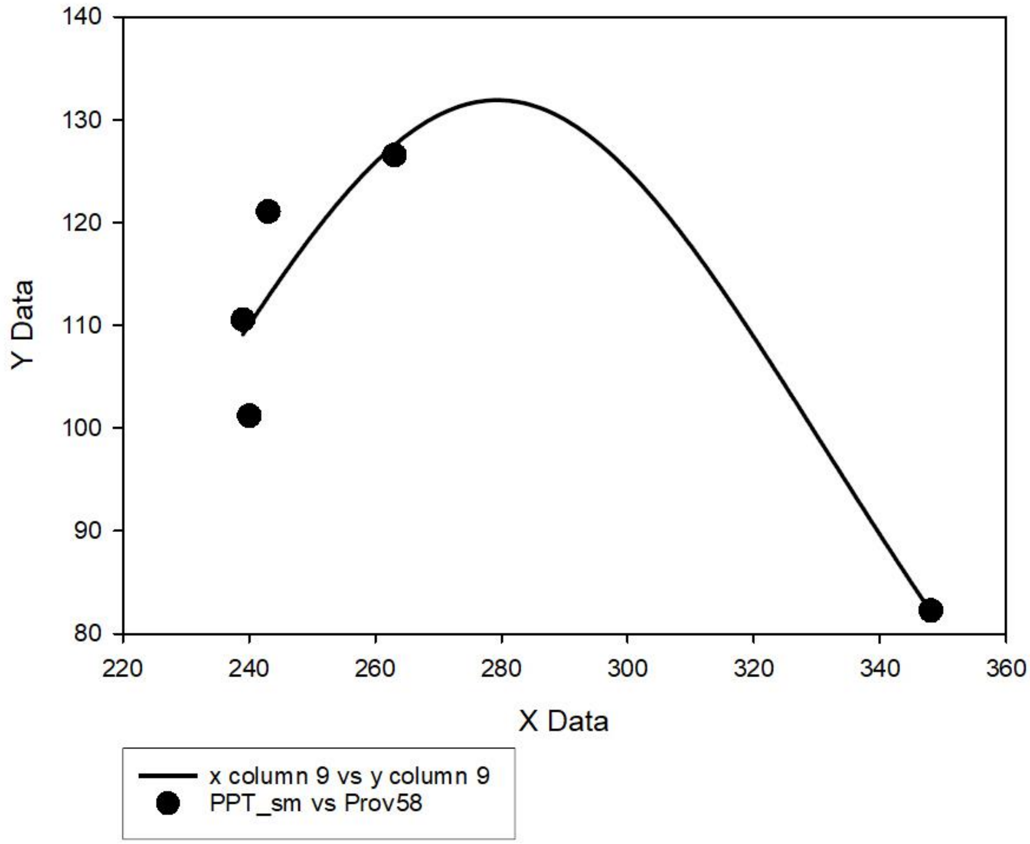
Appendix 2.57. Response function graph for provenance 56 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



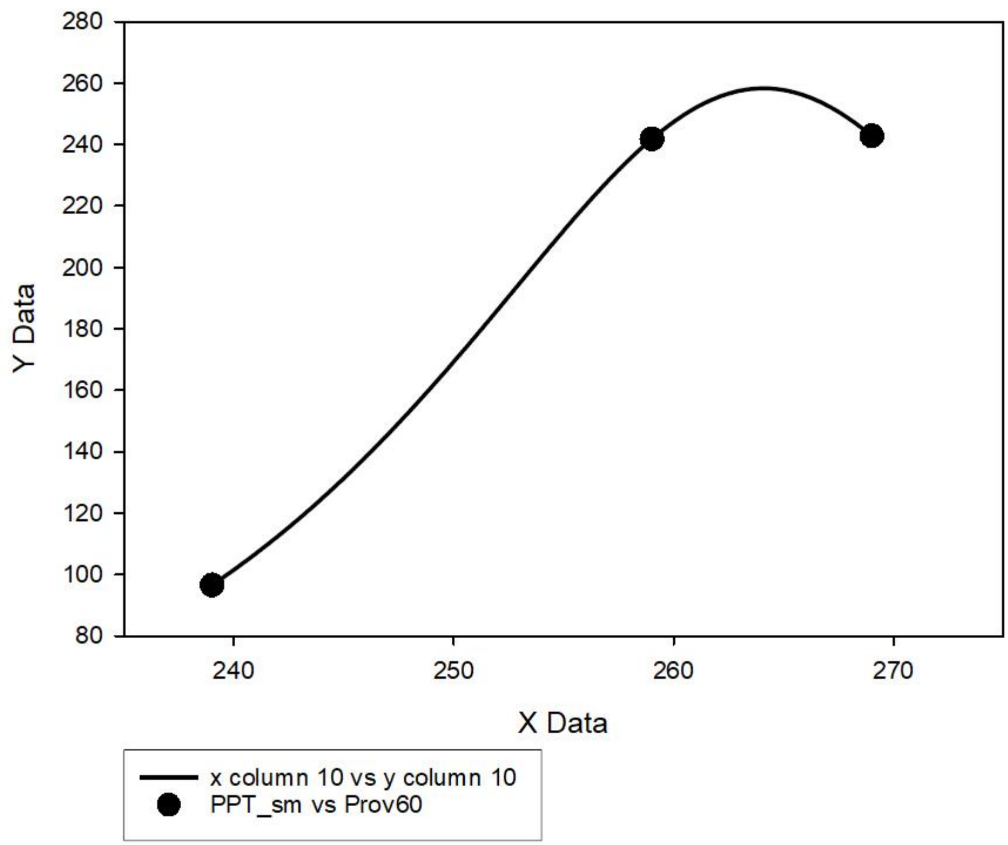
Appendix 2.58. Response function graph for provenance 57 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



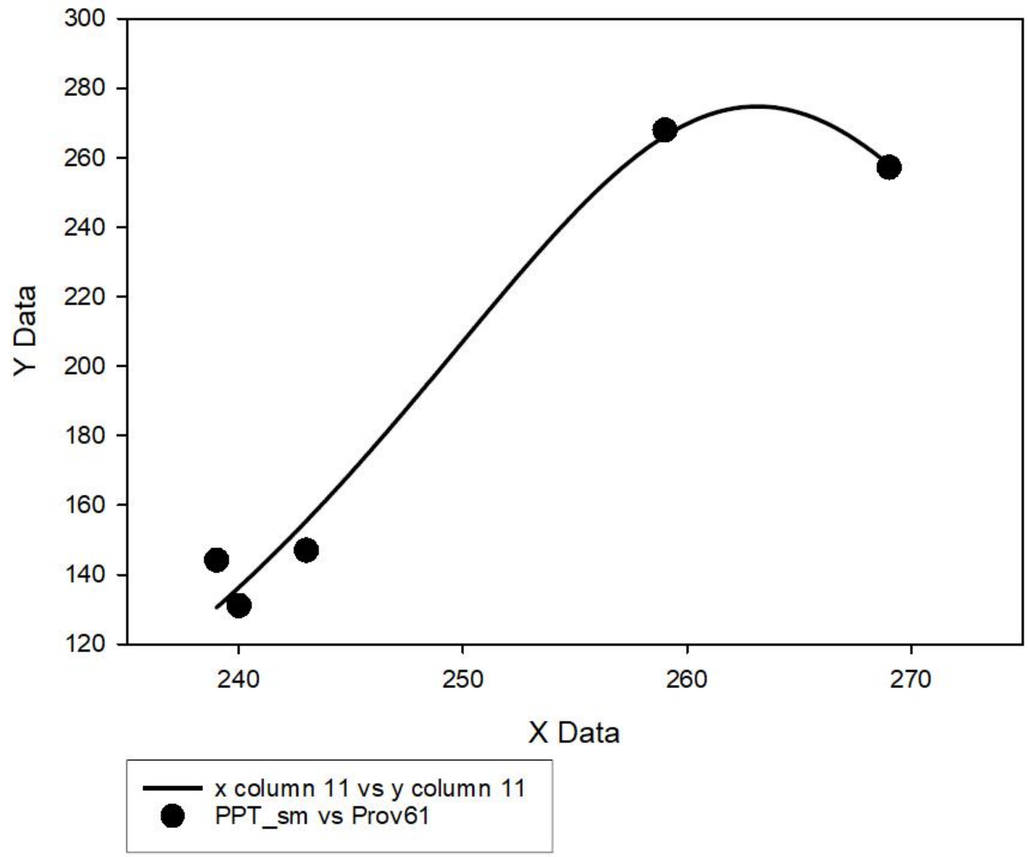
Appendix 2.59. Response function graph for provenance 58 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



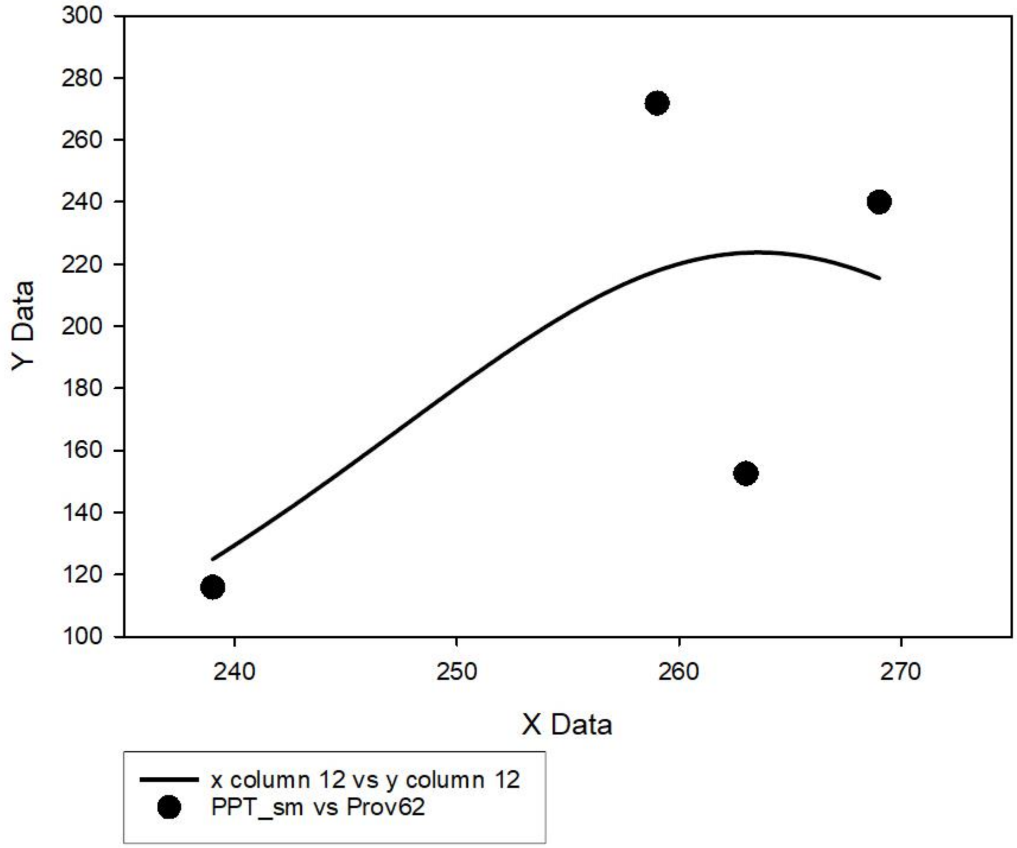
Appendix 2.60. Response function graph for provenance 60 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



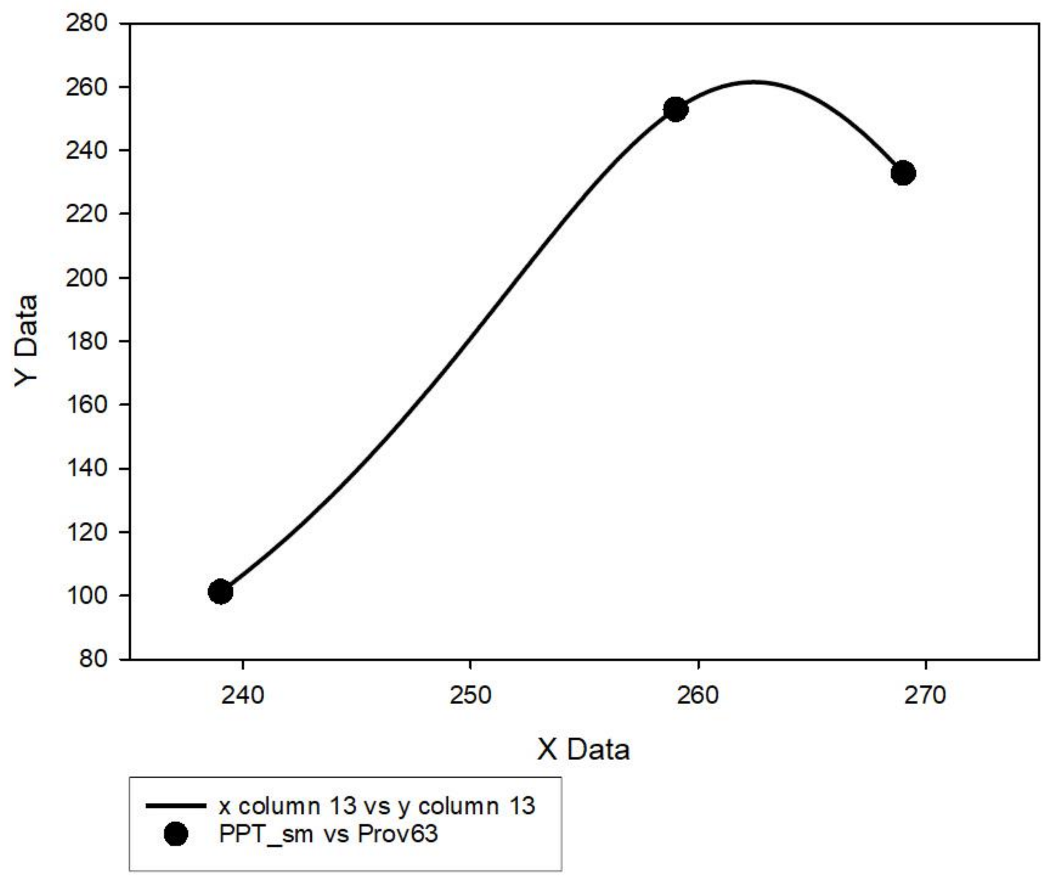
Appendix 2.61. Response function graph for provenance 61 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



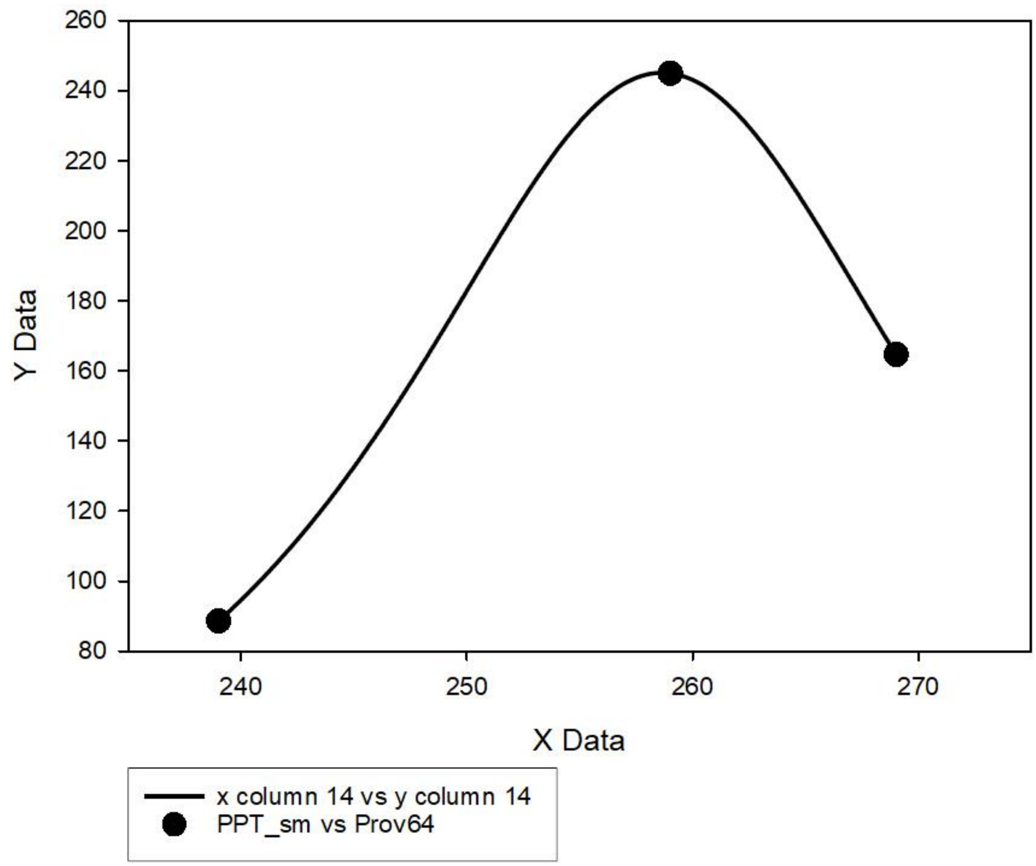
Appendix 2.62. Response function graph for provenance 62 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



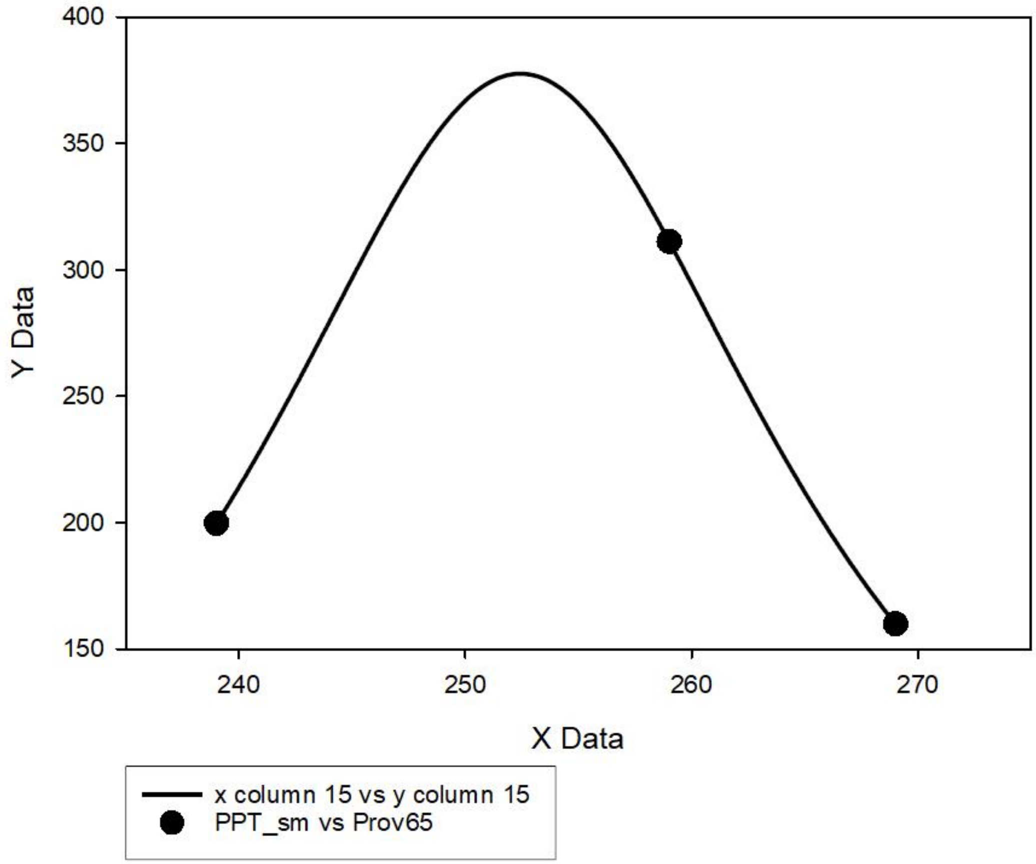
Appendix 2.63. Response function graph for provenance 63 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



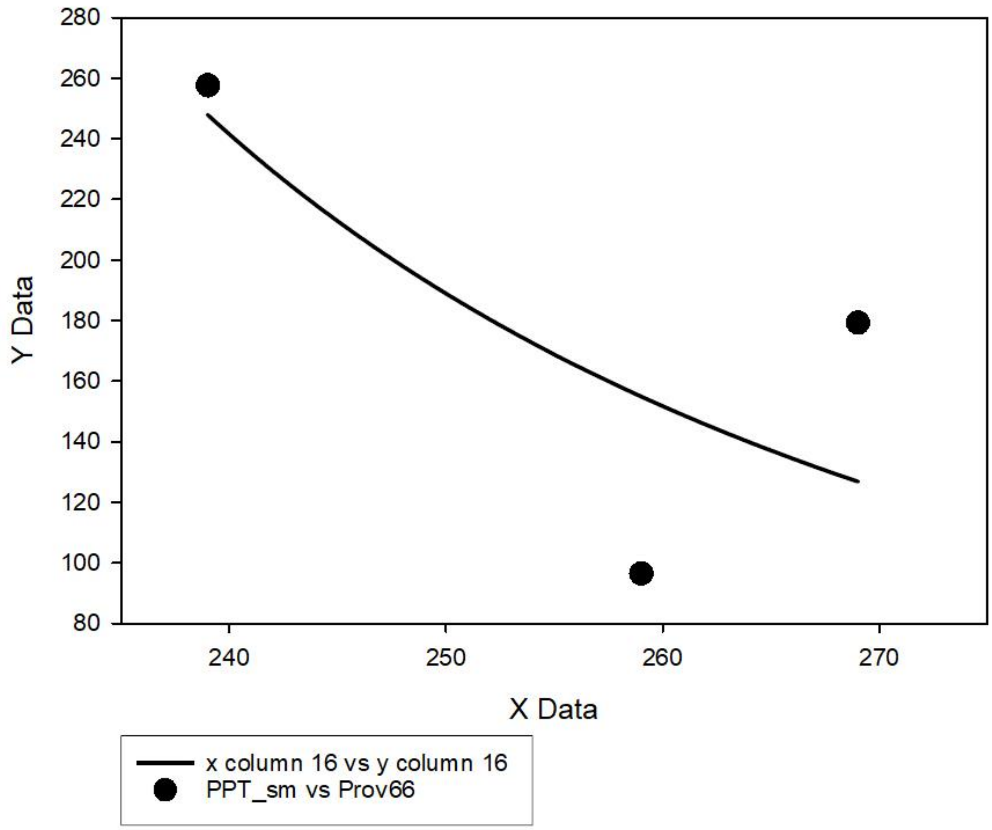
Appendix 2.64. Response function graph for provenance 64 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



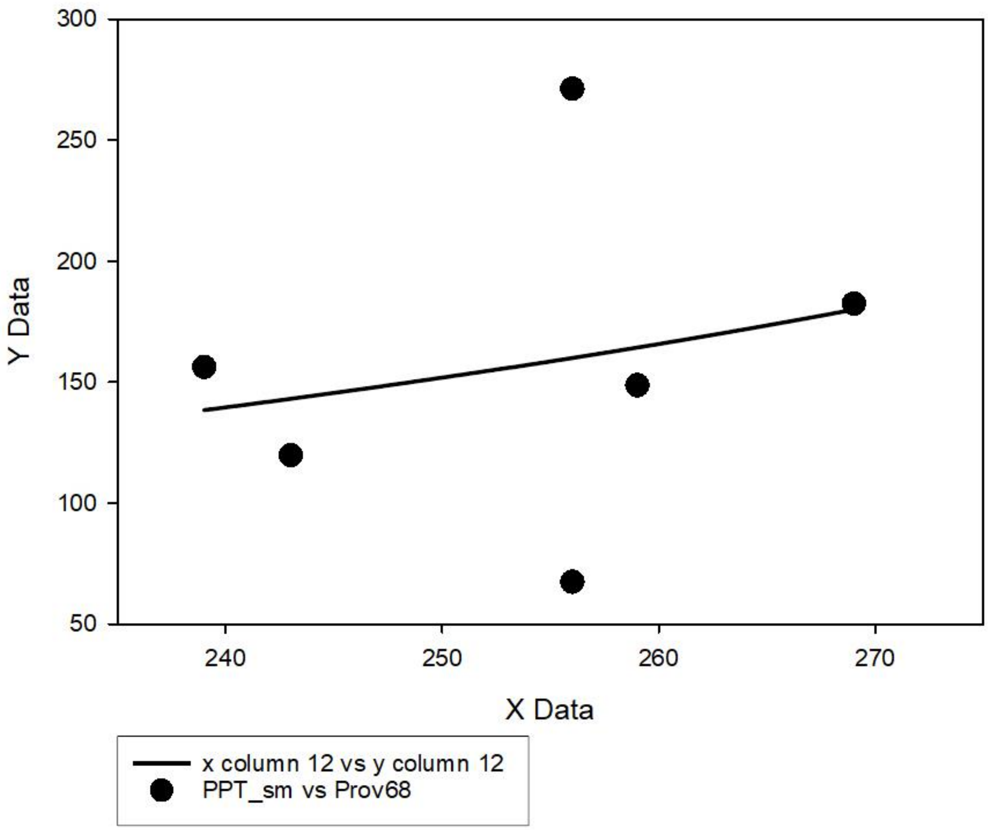
Appendix 2.65. Response function graph for provenance 65 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



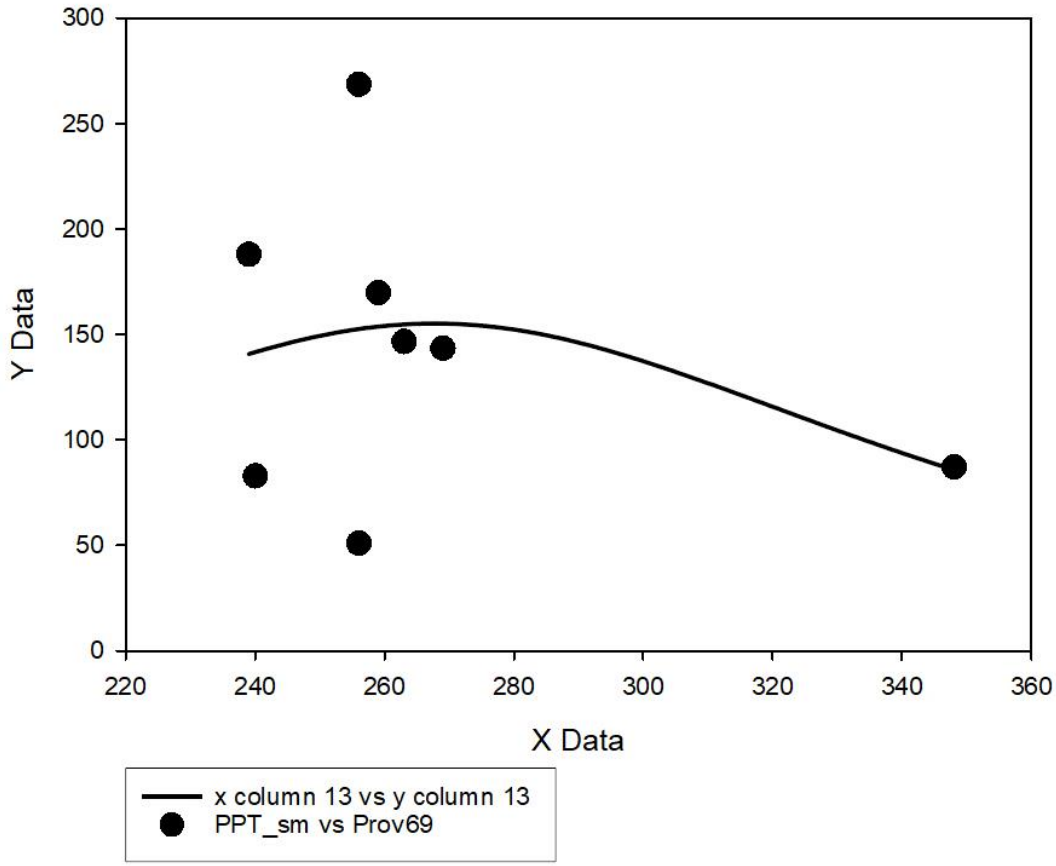
Appendix 2.66. Response function graph for provenance 66 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



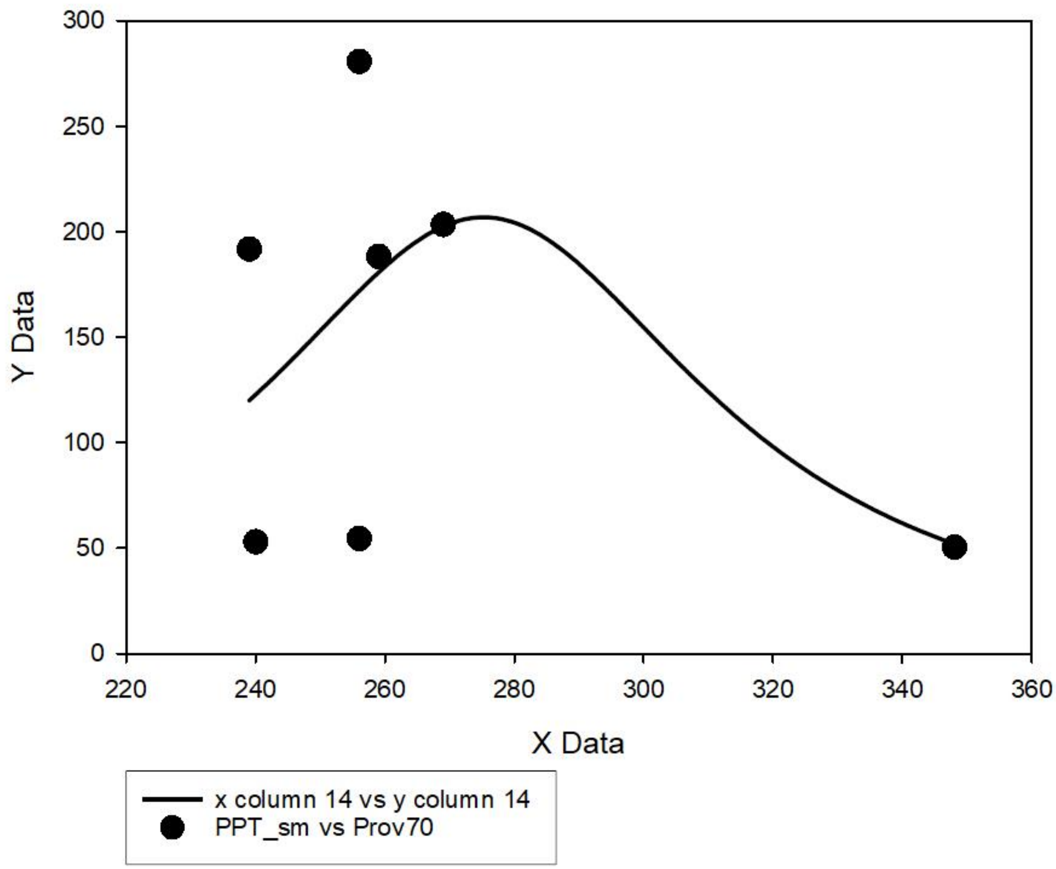
Appendix 2.67. Response function graph for provenance 68 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



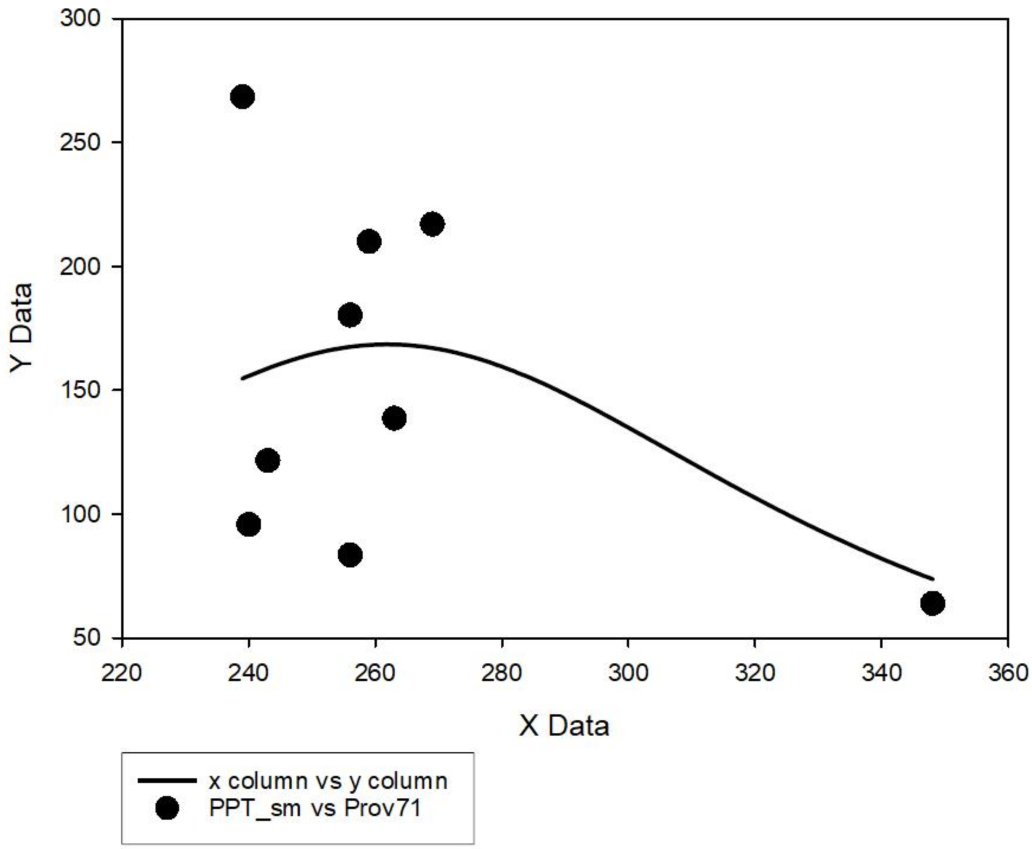
Appendix 2.68. Response function graph for provenance 69 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



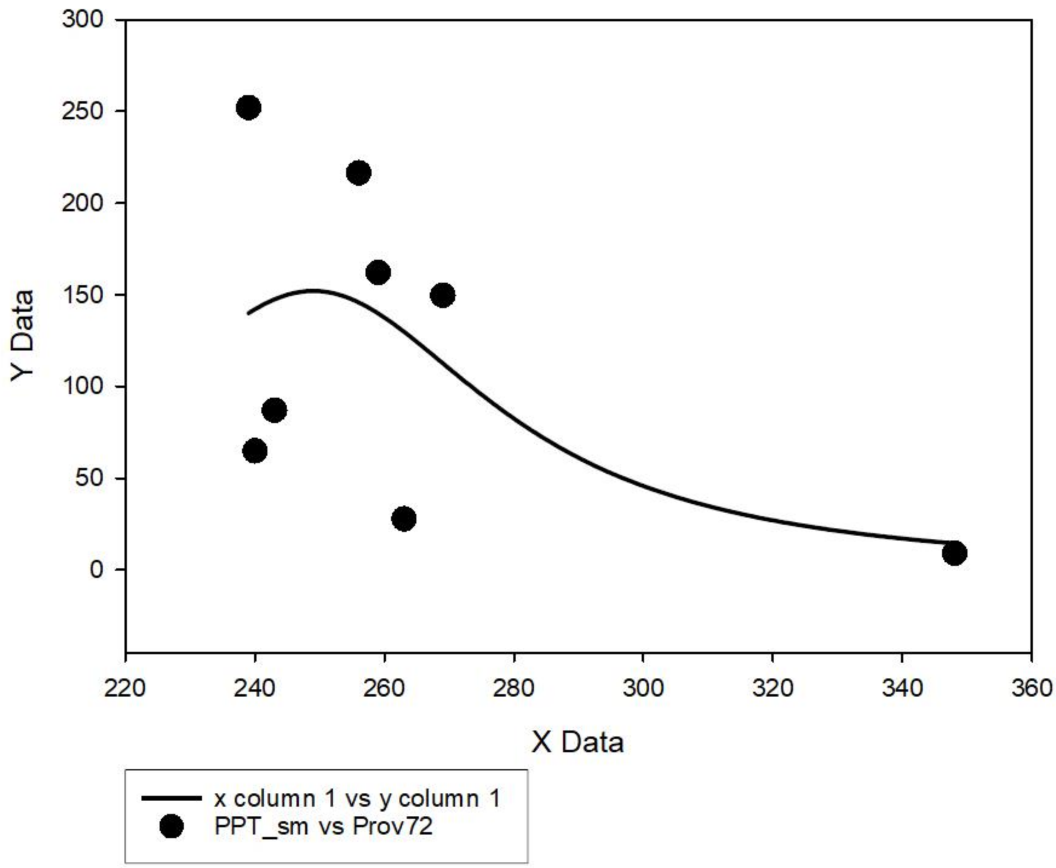
Appendix 2.69. Response function graph for provenance 70 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



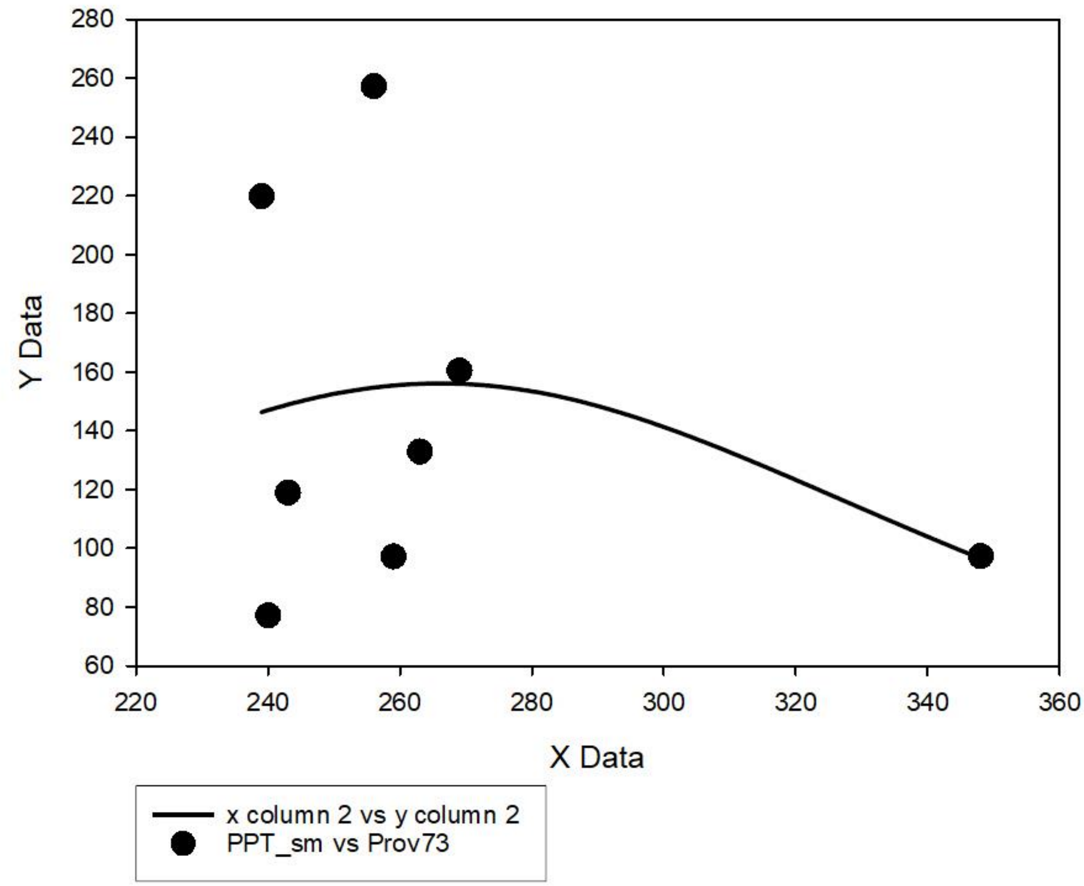
Appendix 2.70. Response function graph for provenance 71 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



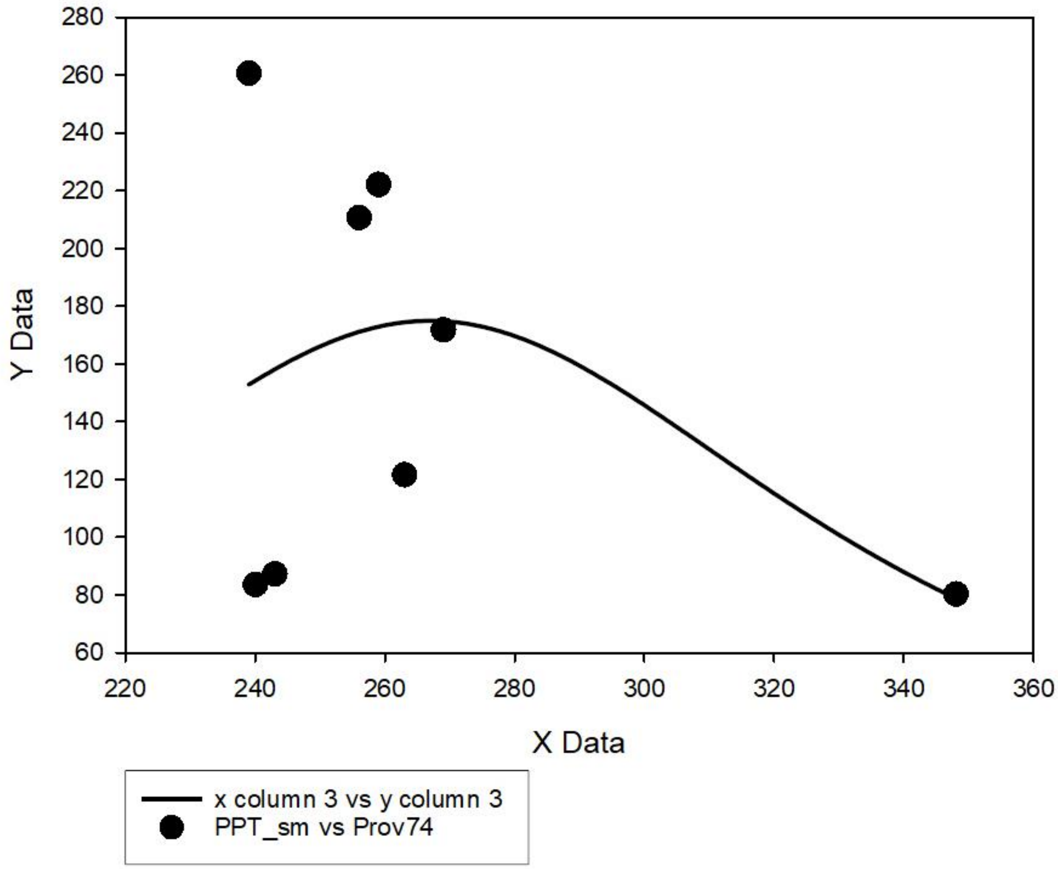
Appendix 2.80. Response function graph for provenance 72 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



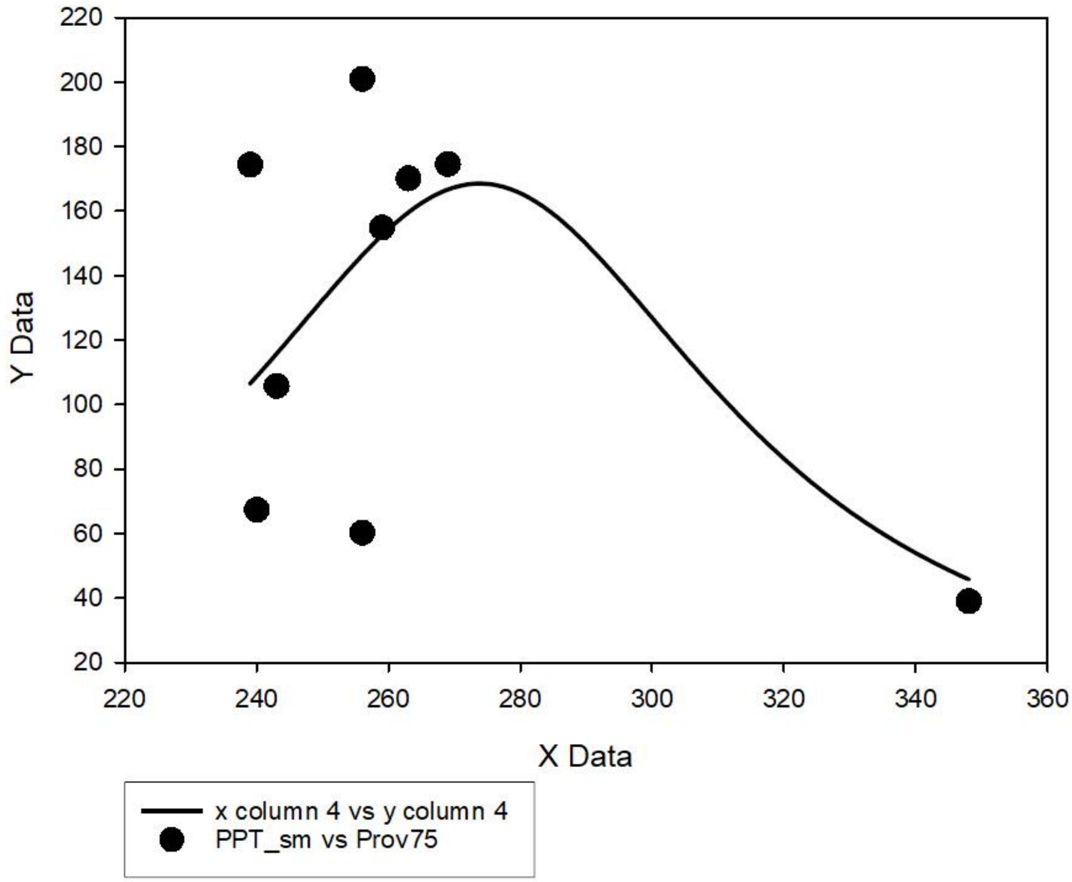
Appendix 2.81. Response function graph for provenance 73 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



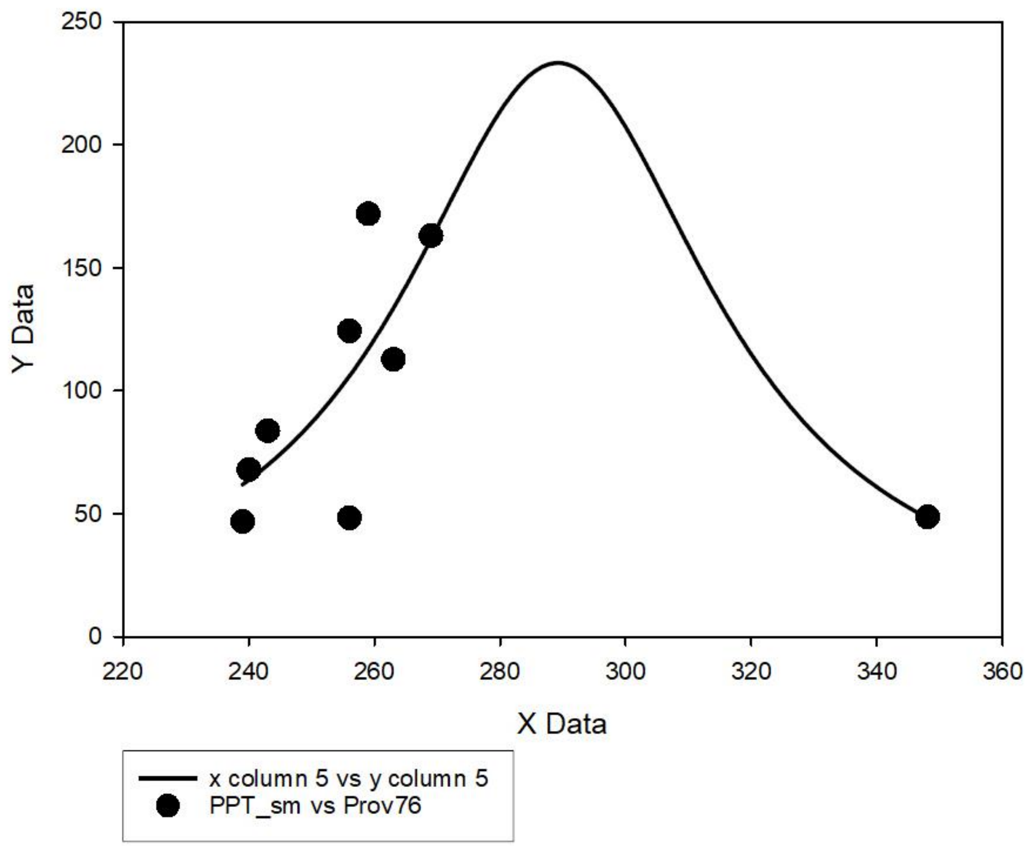
Appendix 2.82. Response function graph for provenance 74 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



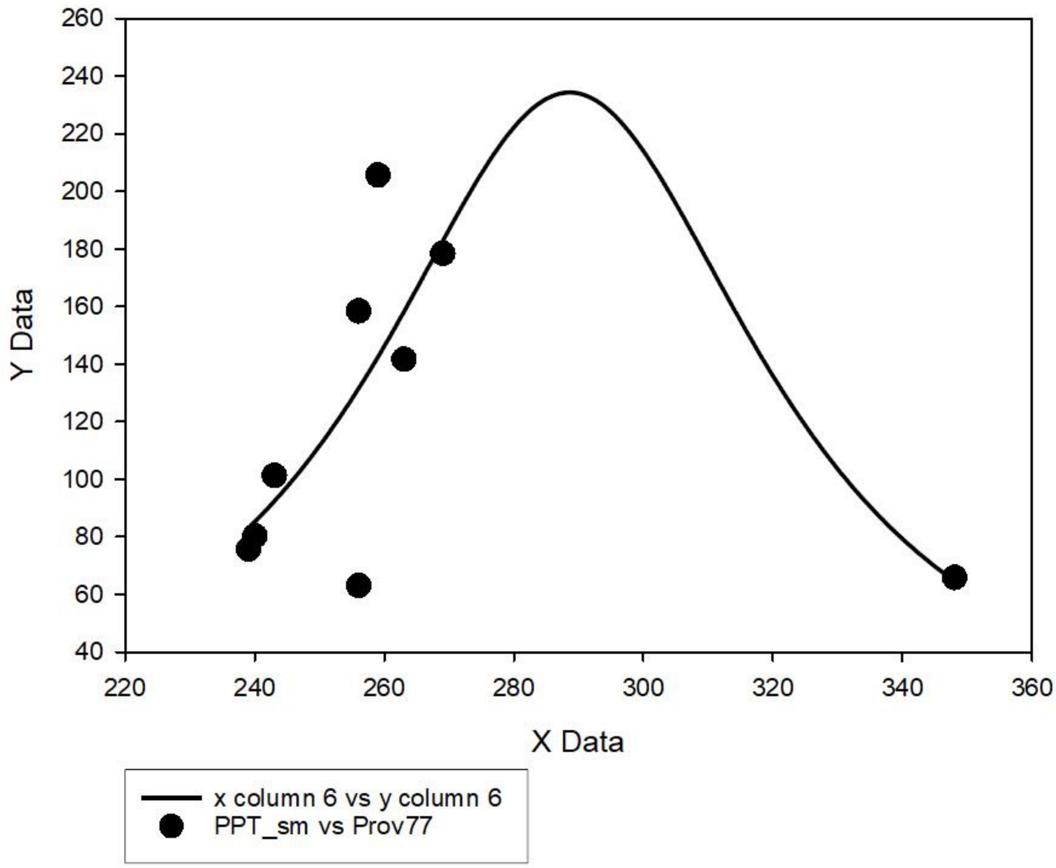
Appendix 2.83. Response function graph for provenance 75 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



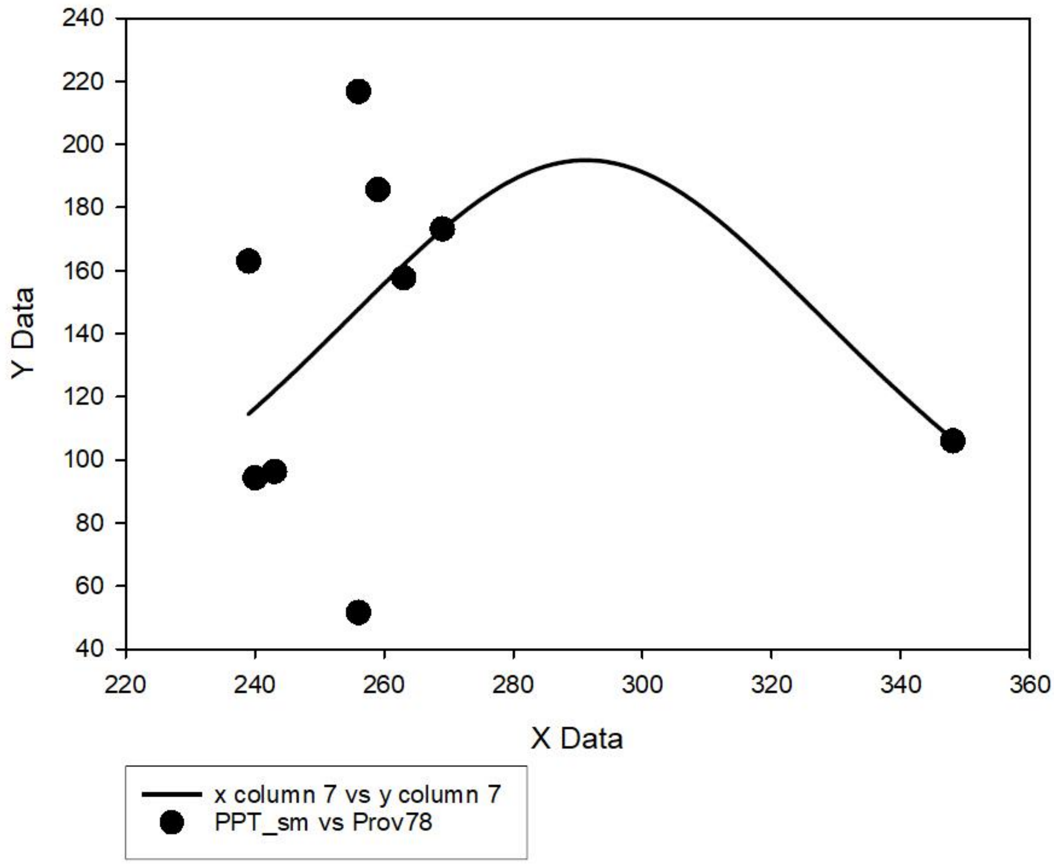
Appendix 2.84. Response function graph for provenance 76 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



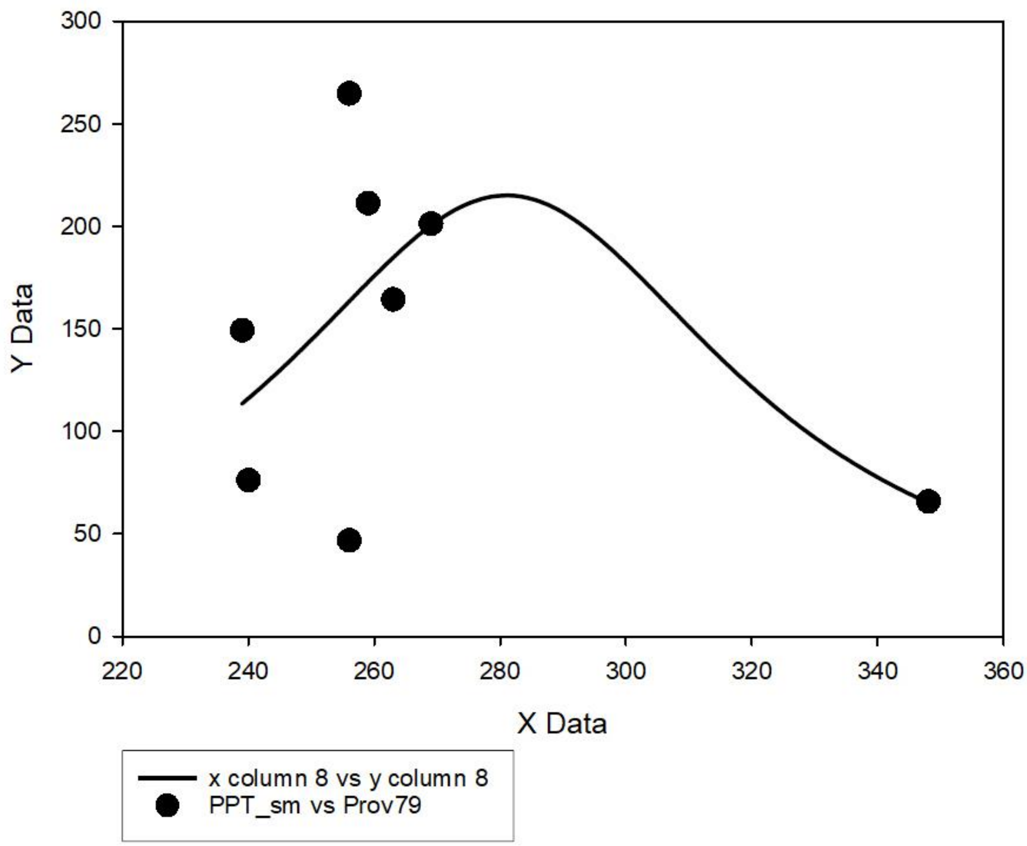
Appendix 2.85. Response function graph for provenance 77 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



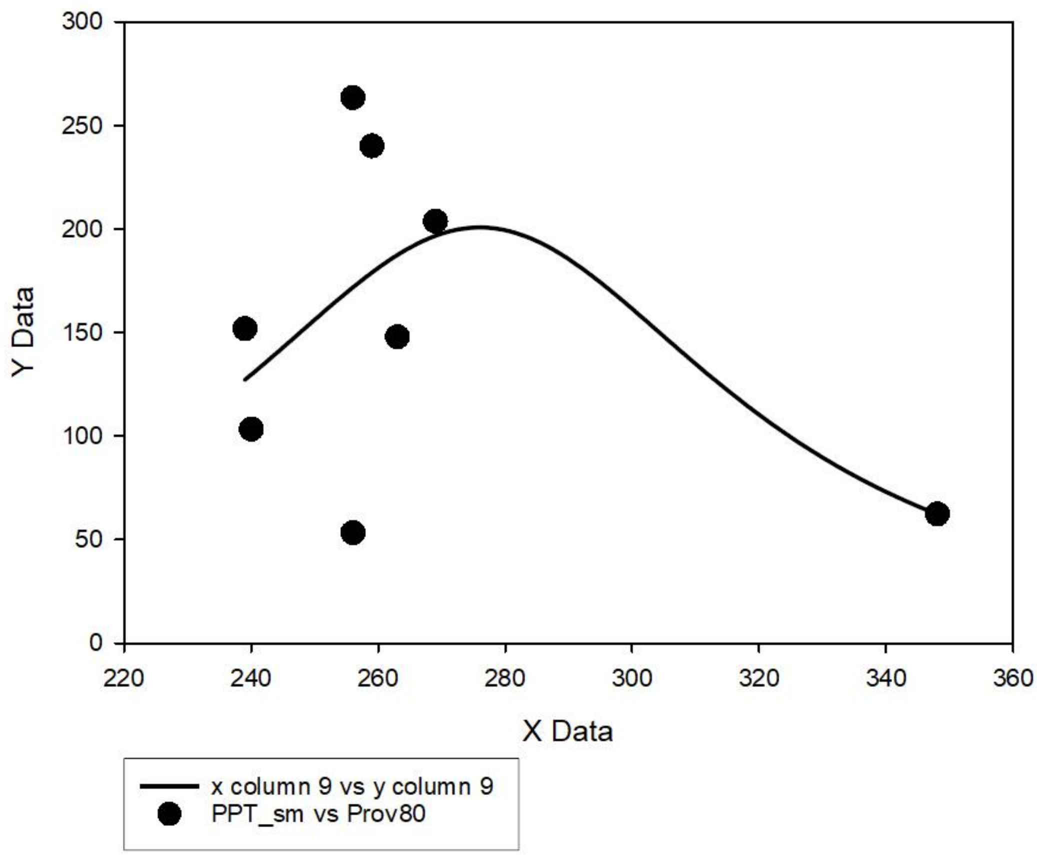
Appendix 2.86. Response function graph for provenance 78 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



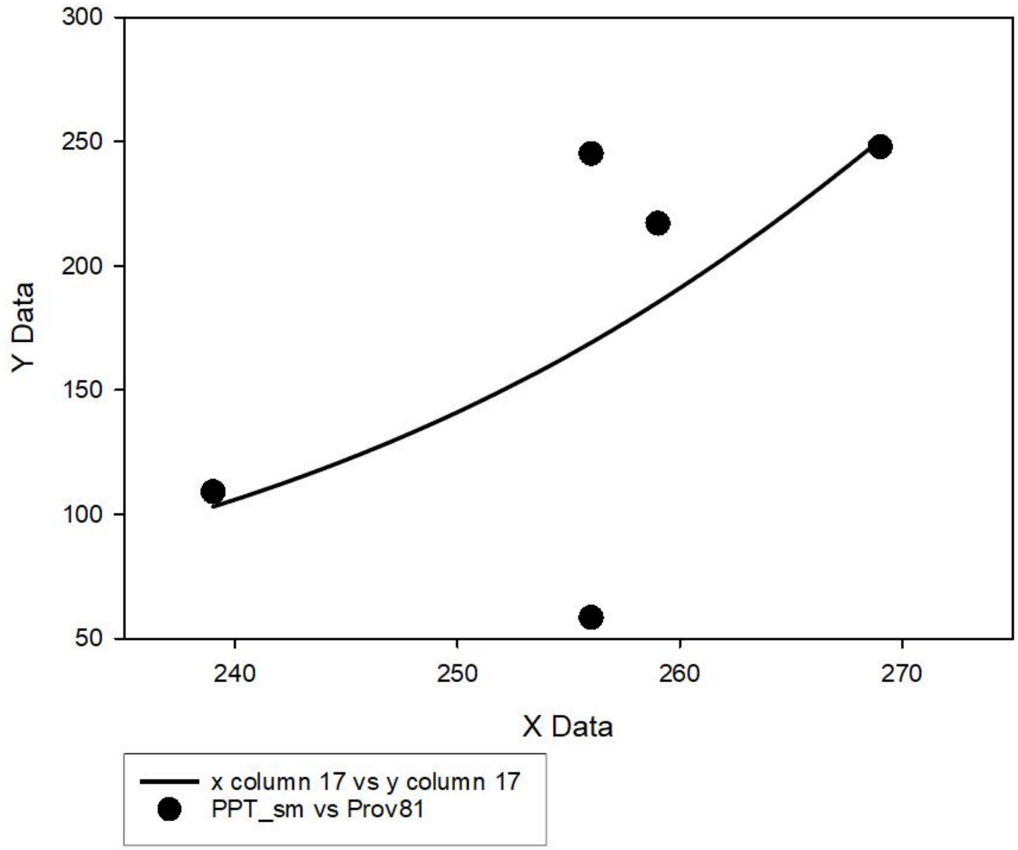
Appendix 2.87. Response function graph for provenance 79 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



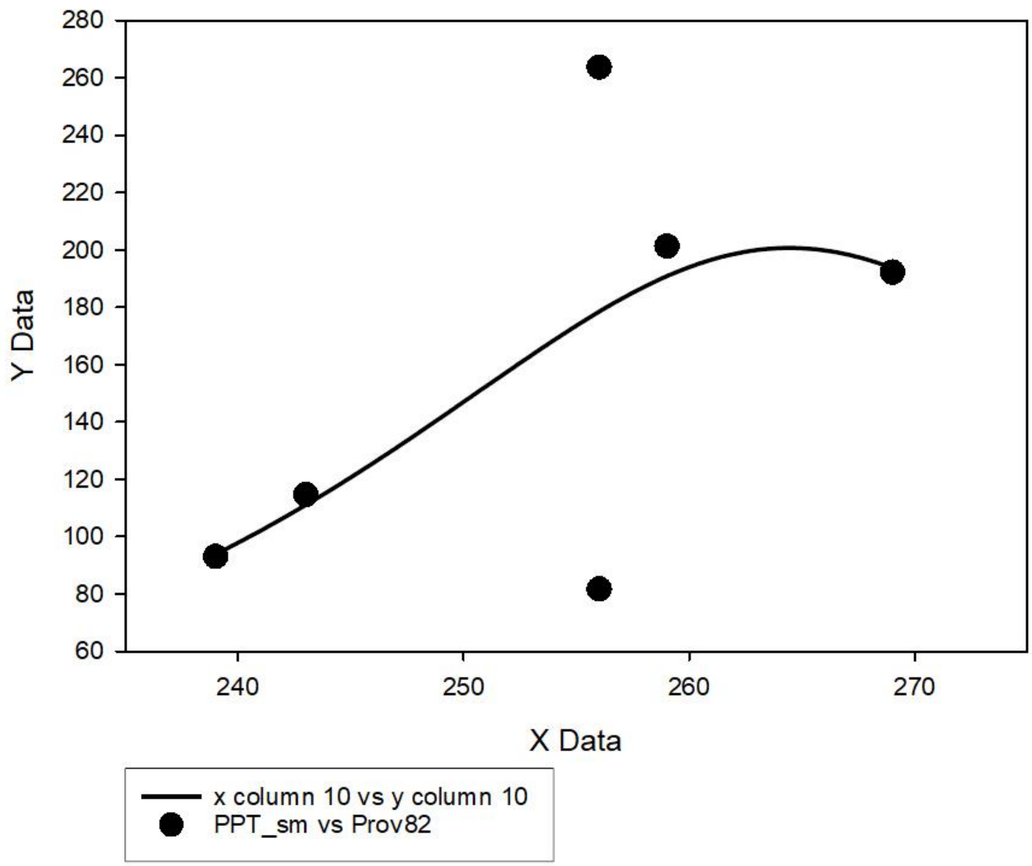
Appendix 2.88. Response function graph for provenance 80 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



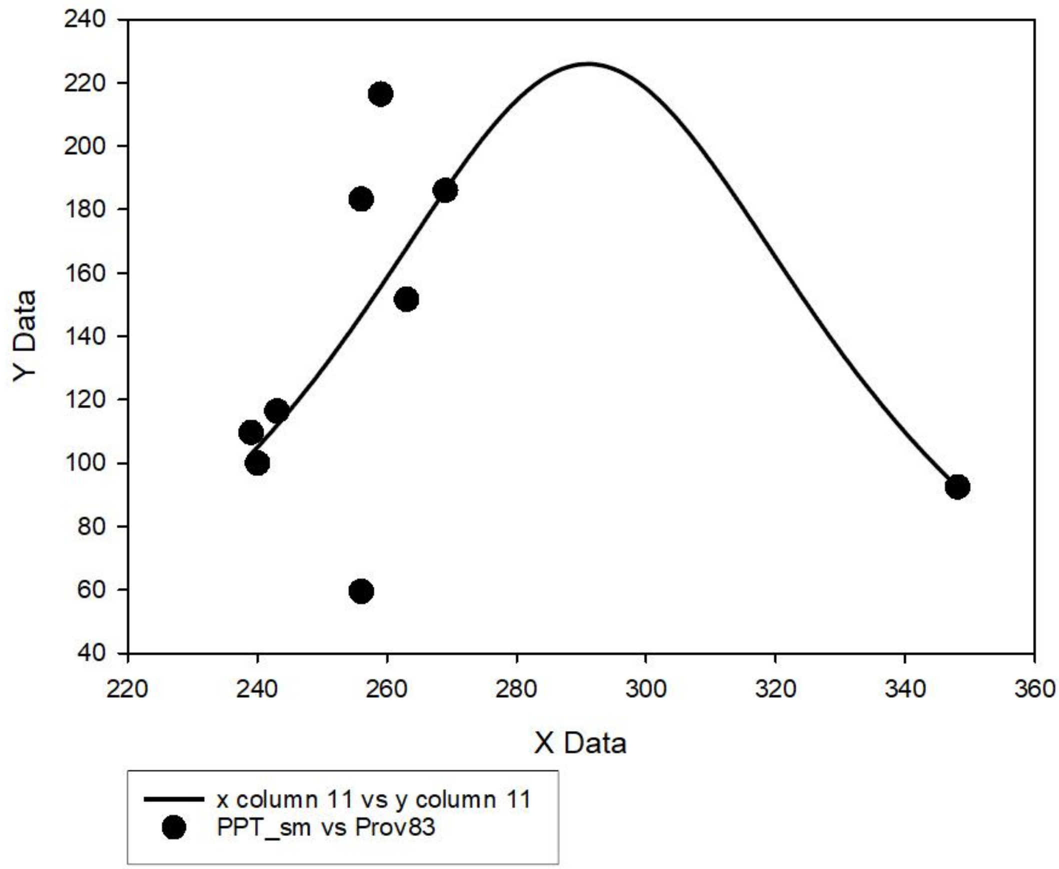
Appendix 2.89. Response function graph for provenance 81 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



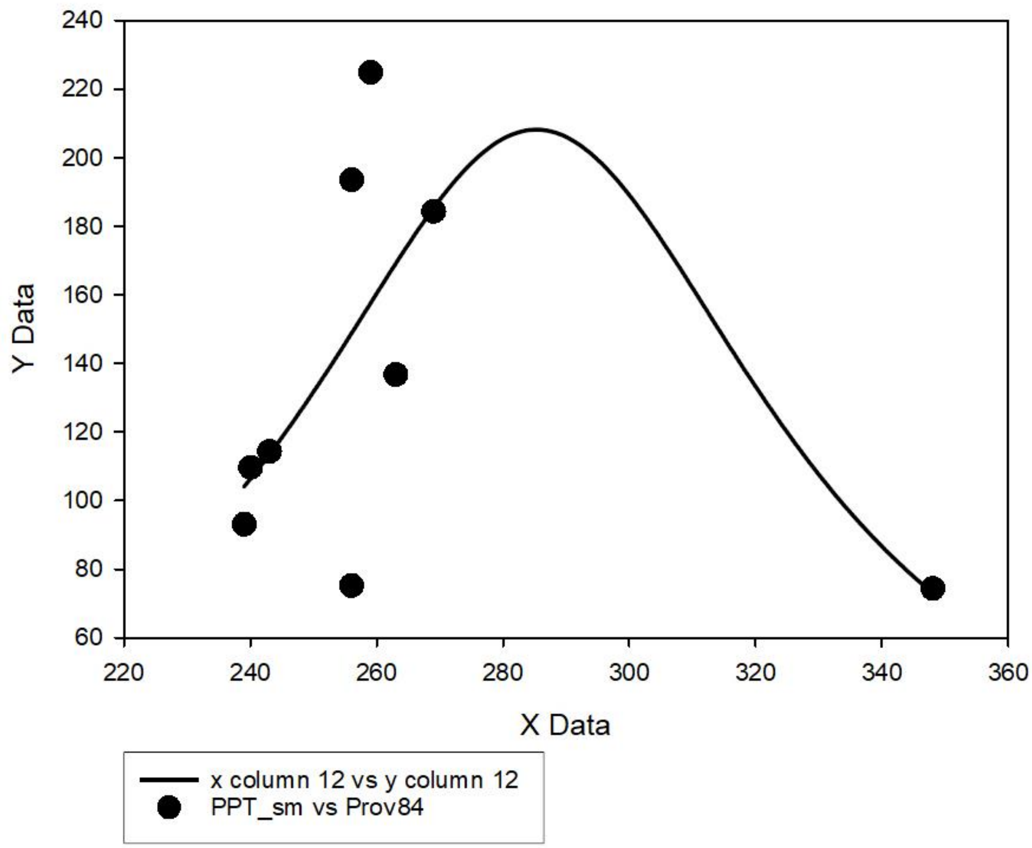
Appendix 2.90. Response function graph for provenance 82 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



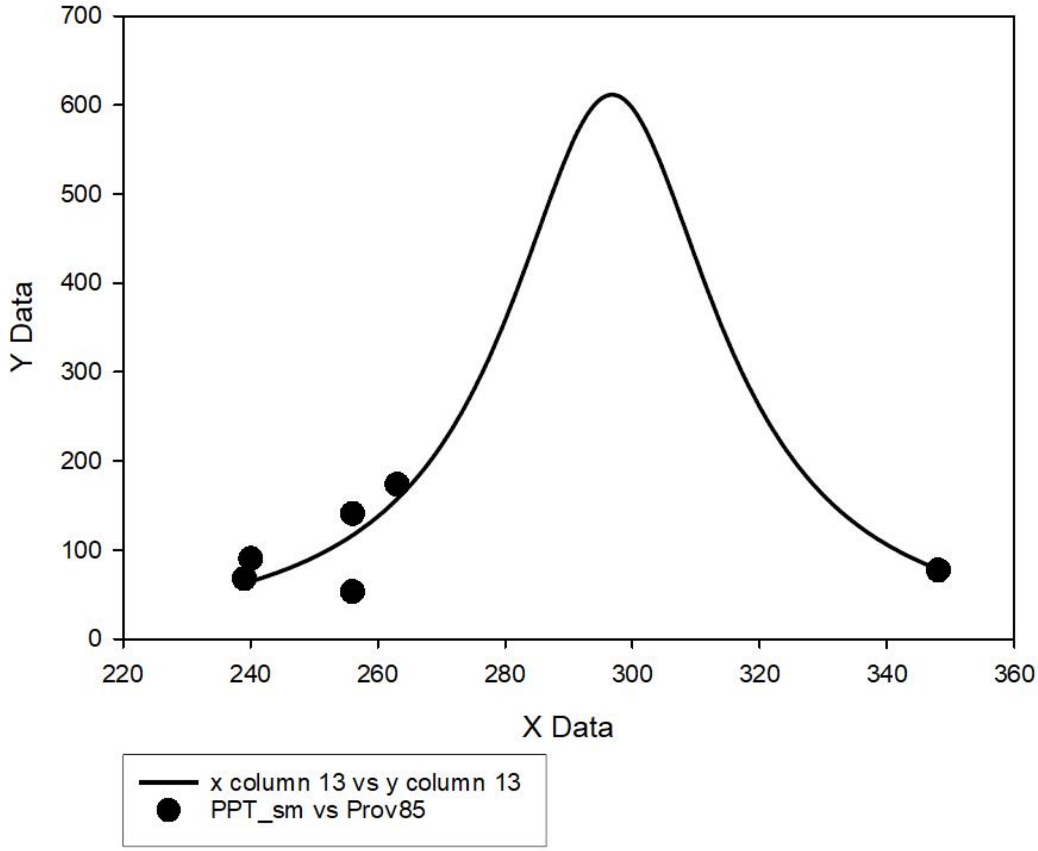
Appendix 2.91. Response function graph for provenance 83 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



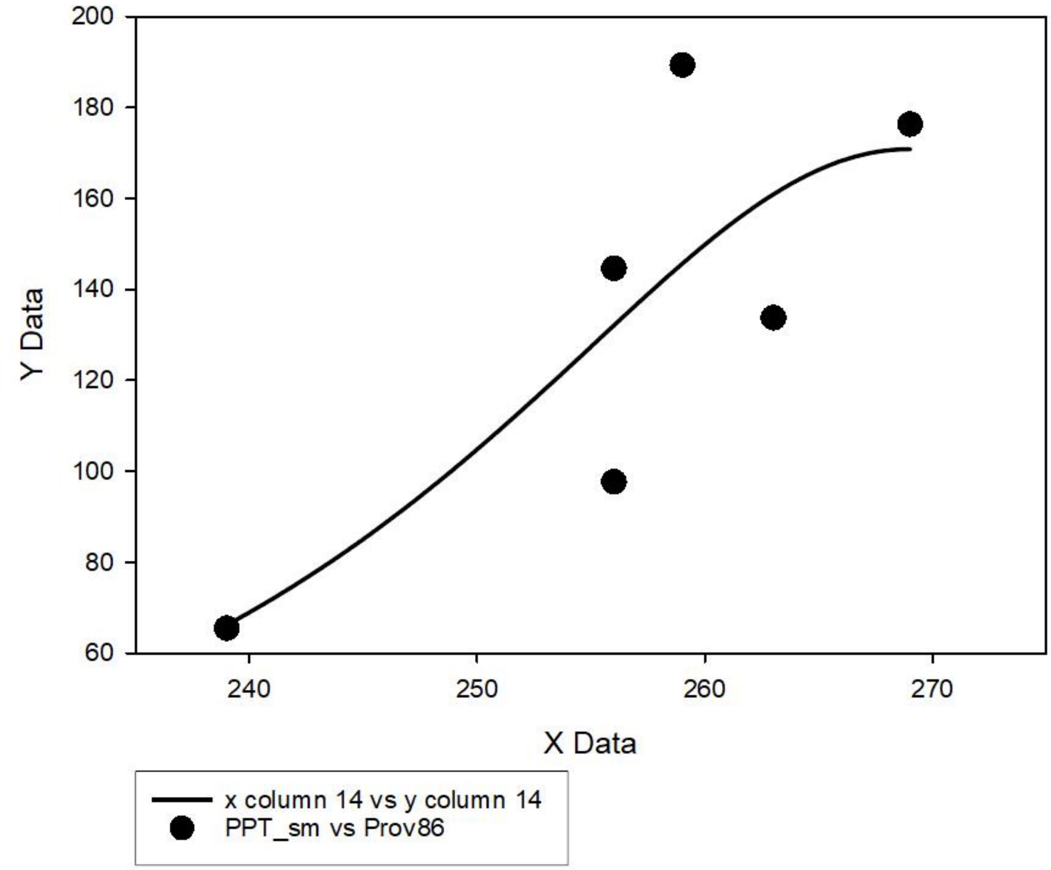
Appendix 2.92. Response function graph for provenance 84 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



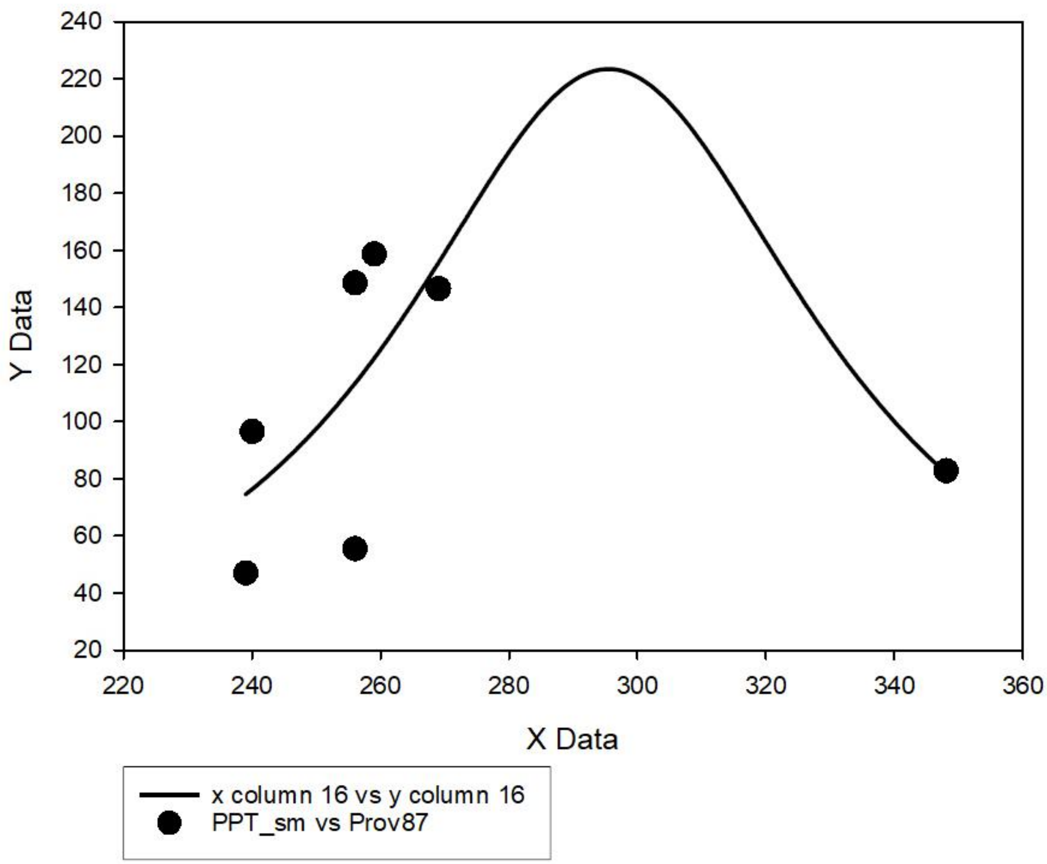
Appendix 2.93. Response function graph for provenance 85 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



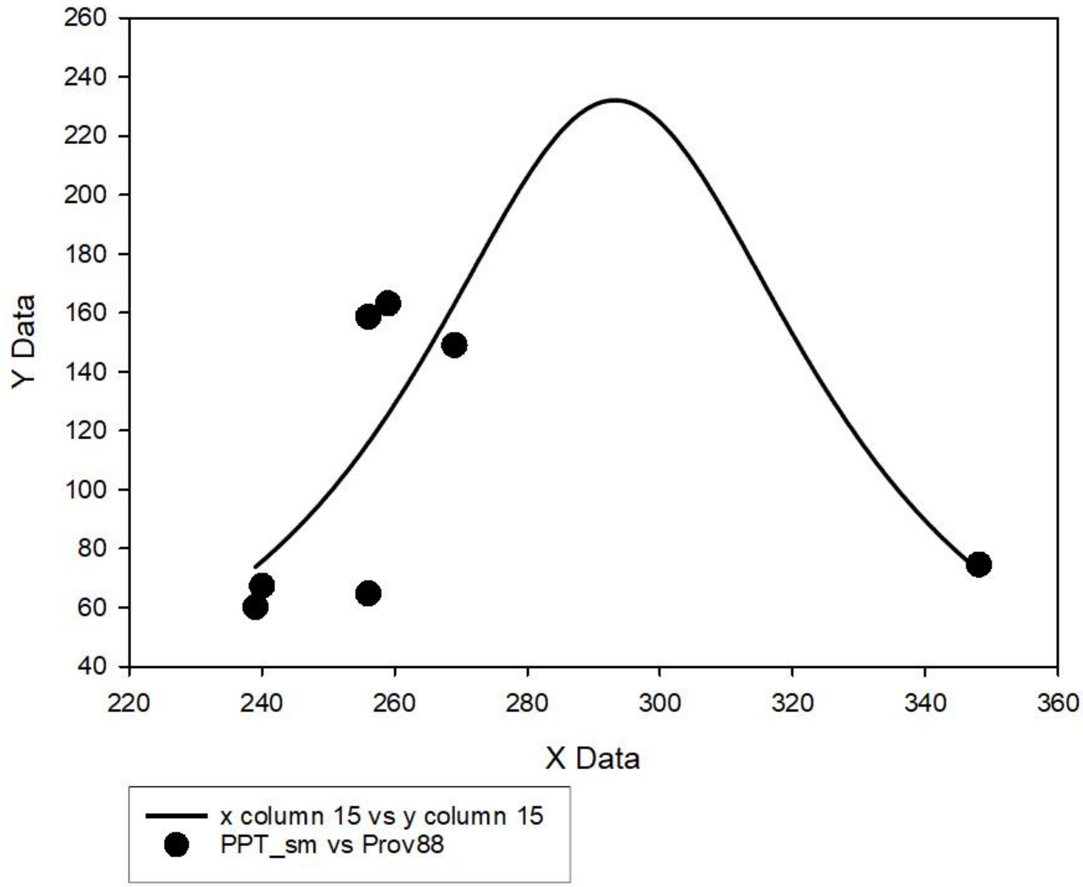
Appendix 2.94. Response function graph for provenance 86 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



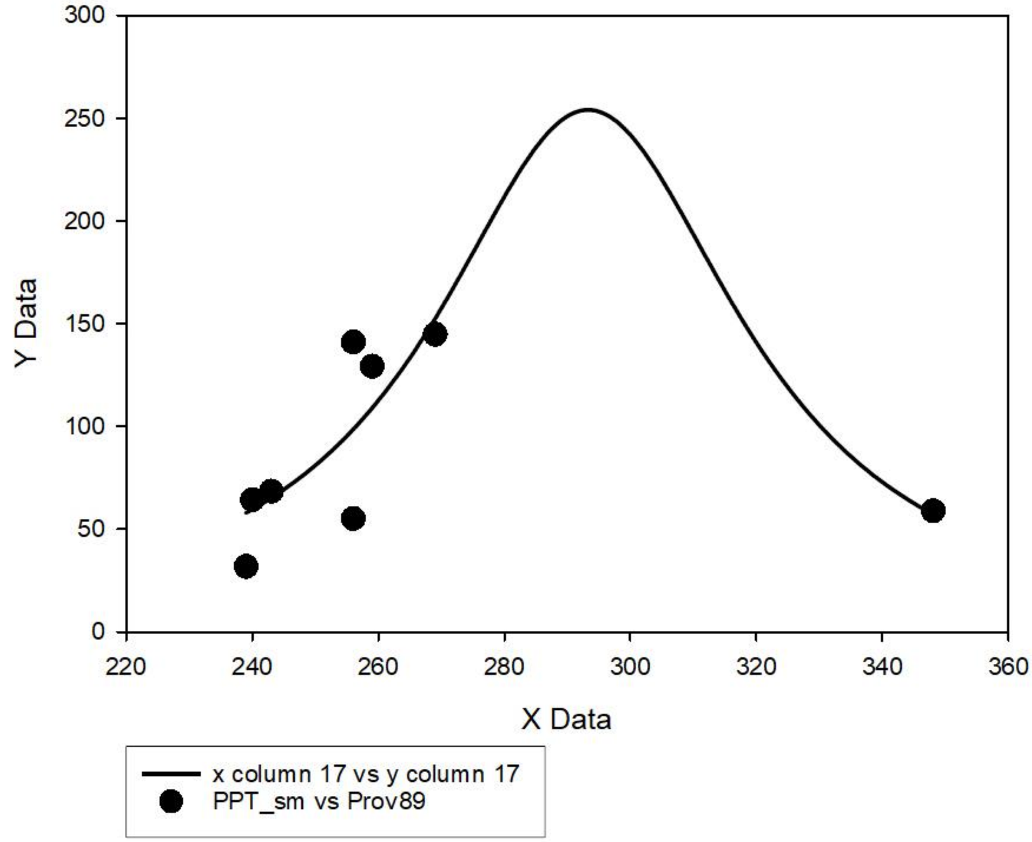
Appendix 2.95. Response function graph for provenance 87 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



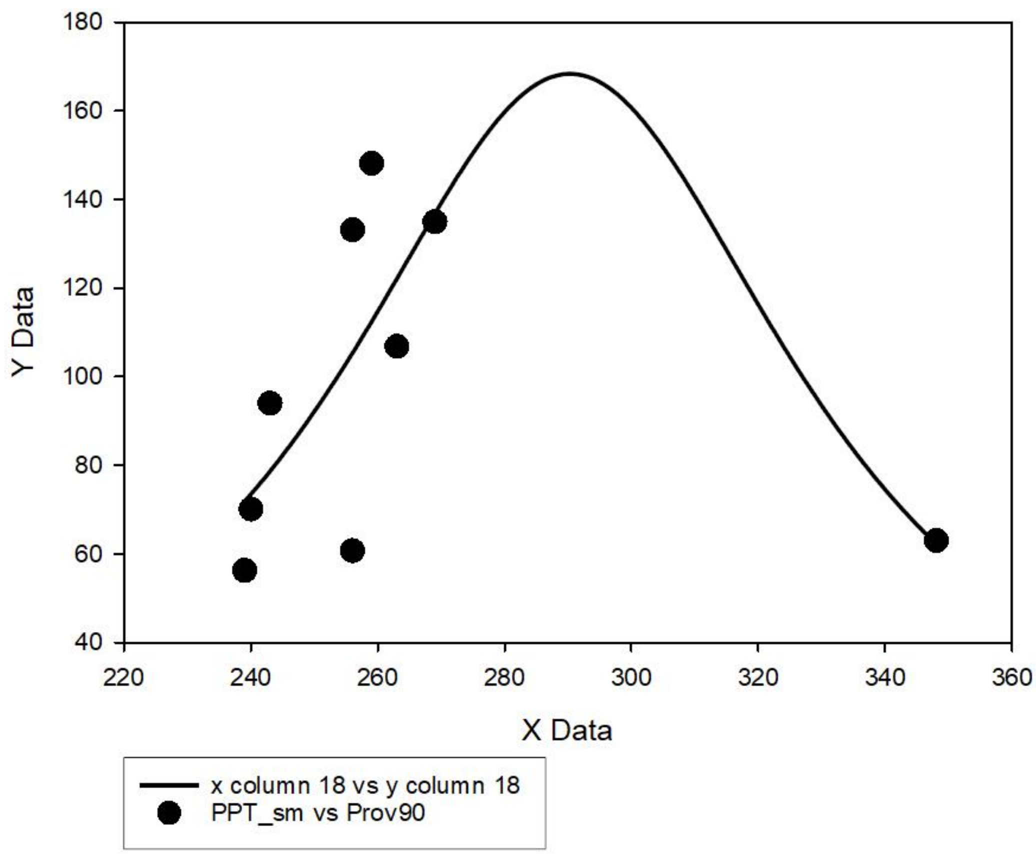
Appendix 2.96. Response function graph for provenance 88 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



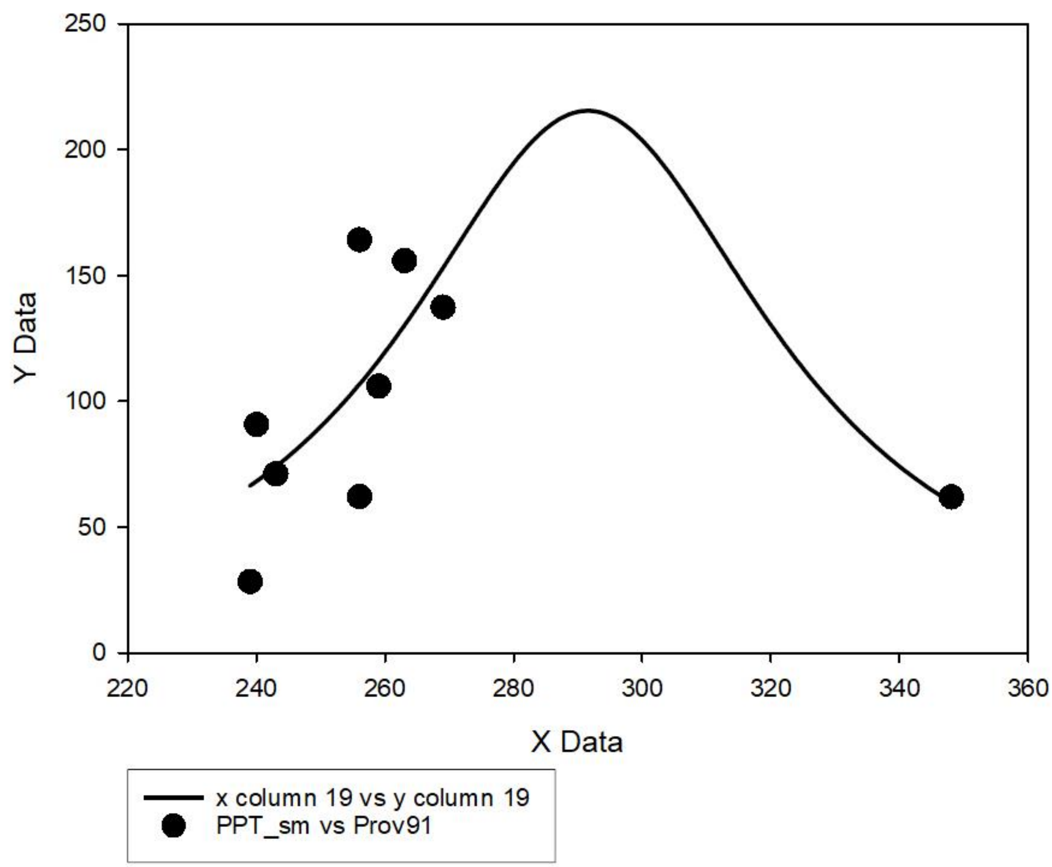
Appendix 2.97. Response function graph for provenance 89 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



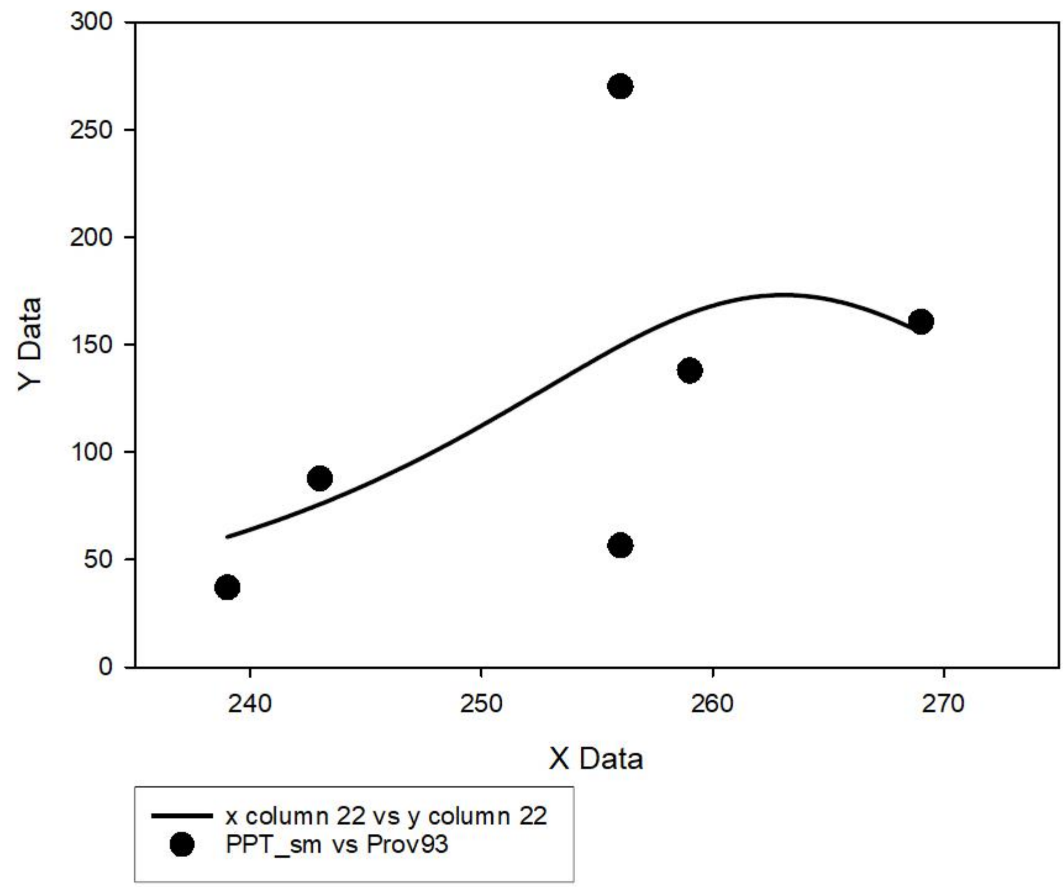
Appendix 2.98. Response function graph for provenance 90 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



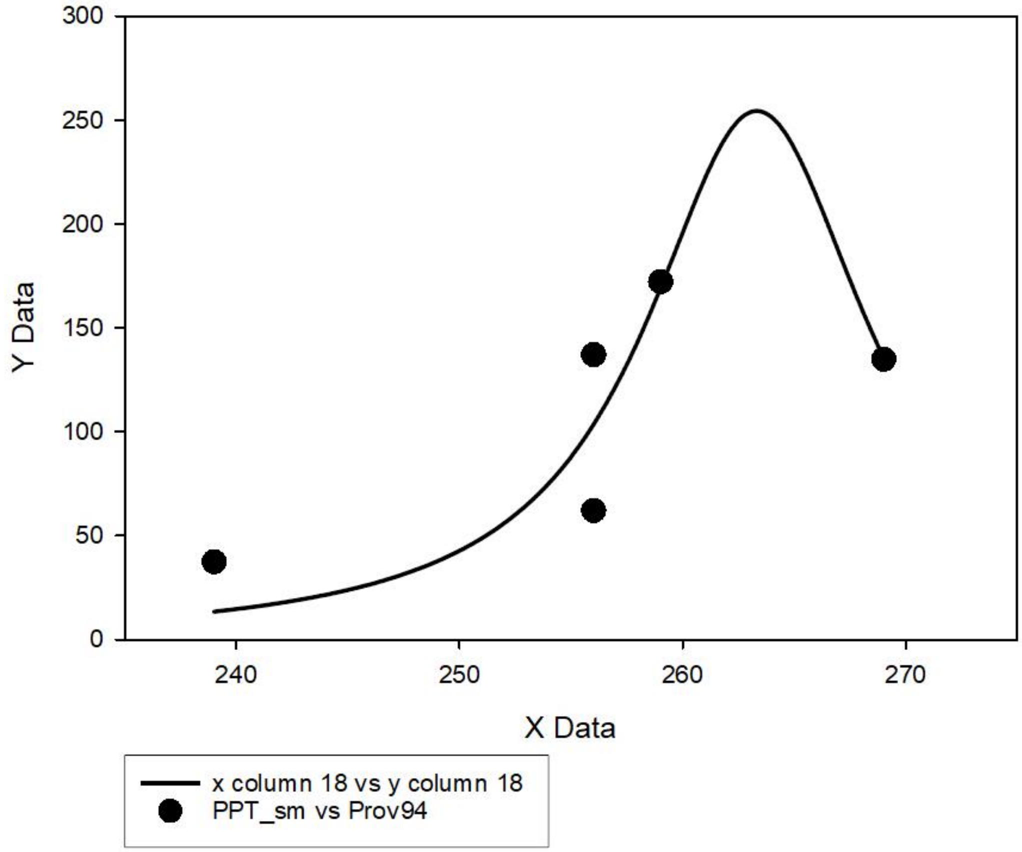
Appendix 2.99. Response function graph for provenance 91 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



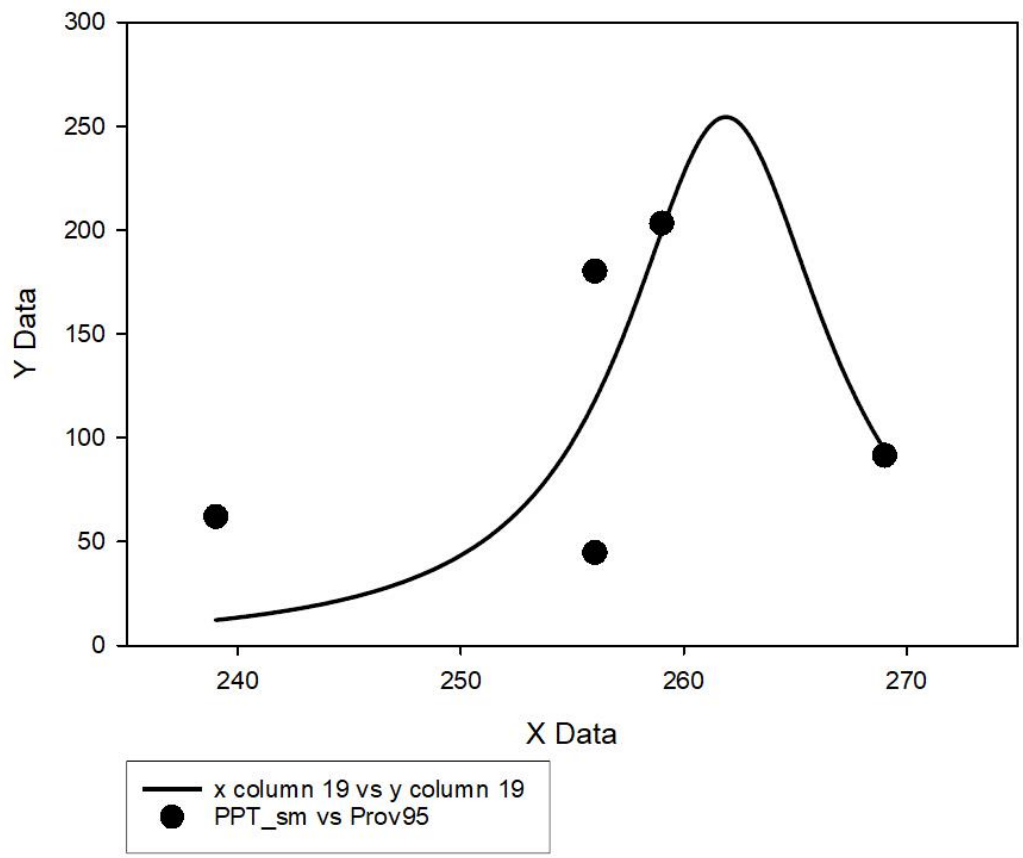
Appendix 2.100. Response function graph for provenance 93 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



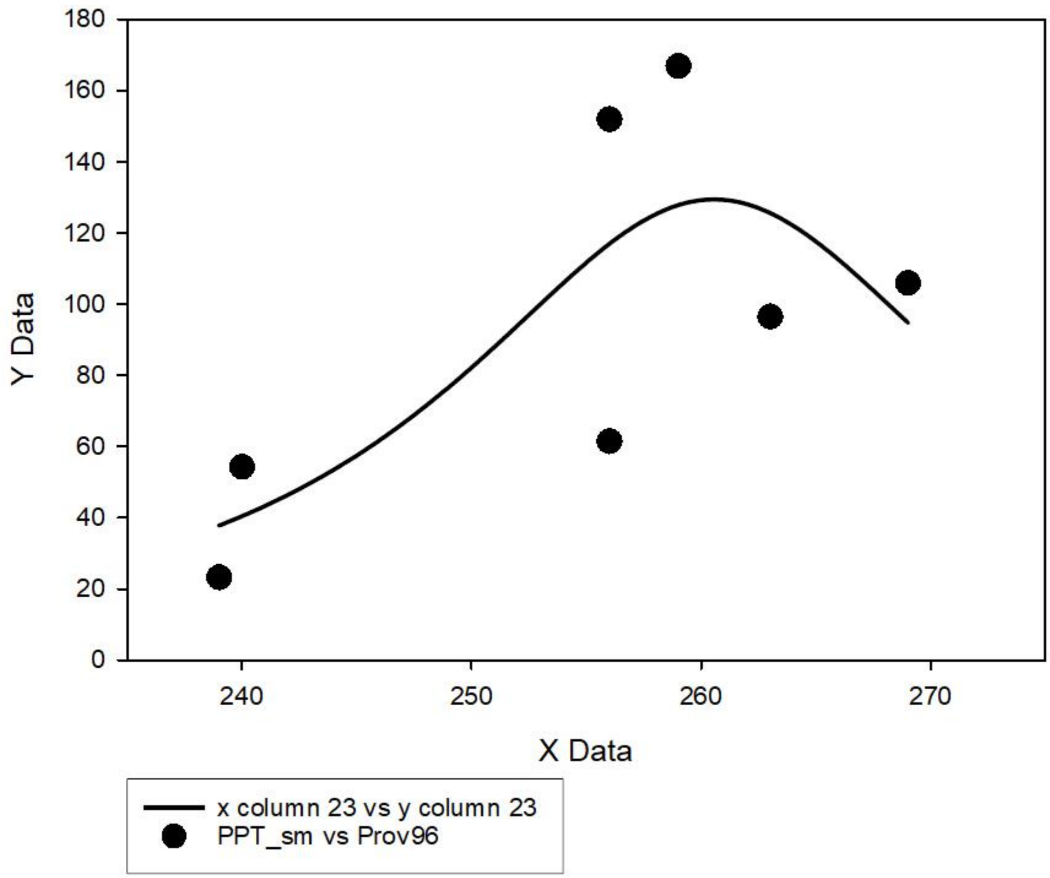
Appendix 2.101. Response function graph for provenance 94 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



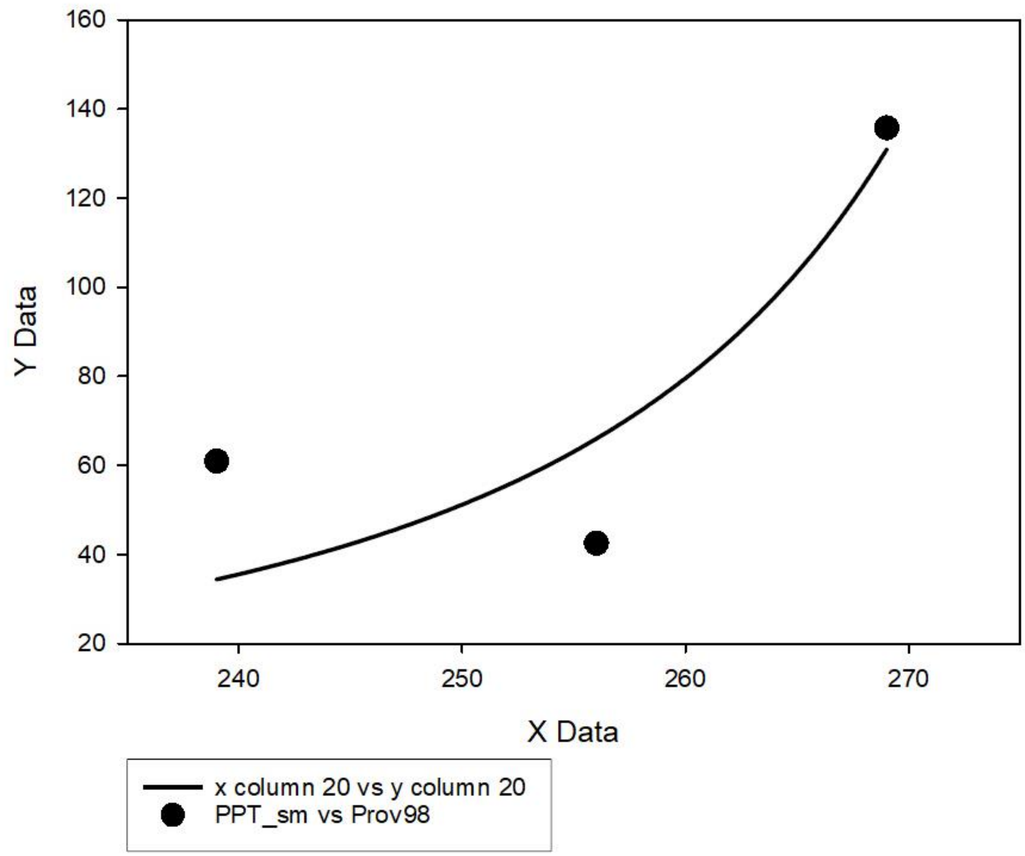
Appendix 2.102. Response function graph for provenance 95 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



Appendix 2.103. Response function graph for provenance 96 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



Appendix 2.104. Response function graph for provenance 98 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990



Appendix 2.105. Response function graph for provenance 99 comparing average provenance volumes (dm^3) and average summer precipitation between 1961 and 1990