

Using Geographic Information Systems (GIS) to Analyze Quality of Quaking Aspen (*Populus tremuloides*) in Southwestern Lake County, Minnesota.

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Abstract

Quaking aspen (*Populus tremuloides*) is one of the most important commercial tree species in northeastern Minnesota. The Lake County Forestry department is interested in assessing the quality of aspen stands on tax forfeit land. Knowing the quality of aspen is important for forest management decisions. Using handheld computers, data from 2,231 plots was collected in stands labeled as aspen in the forest inventory. Five categories of data from this inventory were interpolated into rasters using ArcGIS 9.x Spatial Analyst Extension. Inverse Distance Weight (IDW), Spline, and Natural Neighbor with multiple combinations of parameters were all used to derive interpolations. Each of these interpolated rasters was statistically compared with each other to find the most appropriate method of interpolation. The IDW method using a power of 3 and a 140 m fixed radius was the most accurate. The interpolated rasters for each data category were then reclassified based on an index scale of 1 to 5, with 5 being the most desirable trait for aspen. The reclassified rasters were then added together to find the overall quality index. Based on the results from this study, aspen quality increases with distance from Lake Superior. No values greater than 23 out of 25 and no values less than 5 were generated. GIS can successfully be used to analyze quaking aspen quality. Lake County Forestry department now has an important tool to help decision-making processes.

Introduction

Since its introduction, GIS has been providing tools to enable natural resource managers to make informed decisions. These tools include ways to collect, store, analyze, and visualize data. This project uses all of GIS's tools to study the quality of quaking aspen in southwestern Lake County, Minnesota. GIS has and will continue to be an integral part in natural resource management.

Aspen Background

Quaking aspen (*Populus tremuloides*), hereon referred to as aspen, is the most abundant forest type in Minnesota. Nearly 34% of timberland is classified as aspen (Miles et al., 1995). Until the mid 1980's, aspen was considered a weed species, suitable only for improving the soil. However, with the influx of oriented strand board (OSB) mills, aspen is now preferred for pulpwood production. The level of pulpwood

production has significantly increased, with Minnesota leading in pulpwood production (Cleland et al., 2001). Aspen is a significant Minnesota tree species.

Because of aspen's significance, efficient and ecologically sound management needs to be practiced. The traditional simplistic approach to aspen management was to clear-cut the stand and walk away letting the root suckers retake the site (Cleland et al., 2001). As a result, foresters in Lake County have observed aspen stands with timber productivity much less than desirable. Perhaps land managers did not understand the potential of the land and managed for the wrong species. Whatever the reason, analyzing the quality of aspen is important if managing the land for its greatest productivity is the goal.

Once low quality aspen stands are identified, a decision needs to be made. A common practice with low quality aspen is to harvest the stand and convert the area to conifer species. Conifer species tend to grow well on some land unsuitable for aspen. The introduction of biomass utilization in energy production has created an environment possibly suitable for this practice. Woody biomass is chipped and hauled to facilities that burn the chips to create steam, which in turn is used to generate electricity. Biofuel is being looked at more and more as an alternative fuel source. Typically, low quality stands are undesirable for logging. These stands do not have enough volume to be cut and sold to traditional markets. However, if there is a market for biofuel, these stands become marketable. Low quality aspen and any other woody species now have some value as biomass. Determining which stands to convert to conifer, based

on site quality prior to an increased demand for biofuel is a responsible action in land management.

An essential part of site and species specific decision making is generating accurate predictions of the site quality (Chen et al., 1998). A forester equipped with the knowledge of what will grow best will be most efficient when working with the land. According to Carmean and Li (1998), knowledge of site quality is very important because aspen is capable of high quality yields when grown on suitable land. By contrast, aspen on unsuitable land has low quality, low yields and is vulnerable to damage and disease. The goal of this research project is to use GIS with field-collected data to determine aspen quality. Thus, site quality can be inferred from aspen quality. The results of this project will be significant for forest management decisions.

Methods Background

The data collected for this study is point-based data. Each point has a spatial location and data that represents the specific area of the forest. This type of data is classified as vector data. A more appropriate type of data for this study is raster data. Raster data consists of cells of a certain size arranged in rows and columns, much like the pixels of a digital picture. Each cell in a raster has a value that represents a specific geographic area. Using raster data allows entire areas, rather than specific points, to be studied. Raster data is used to represent data that varies continuously (Wade and Sommer, 2006). Creating raster-based data from point-based data is called interpolation. Interpolation is defined as estimating values of

unsampled locations based on known values of surrounding locations (Figure 1) (Wade and Sommer, 2006). Interpolation is an important step of this analysis.

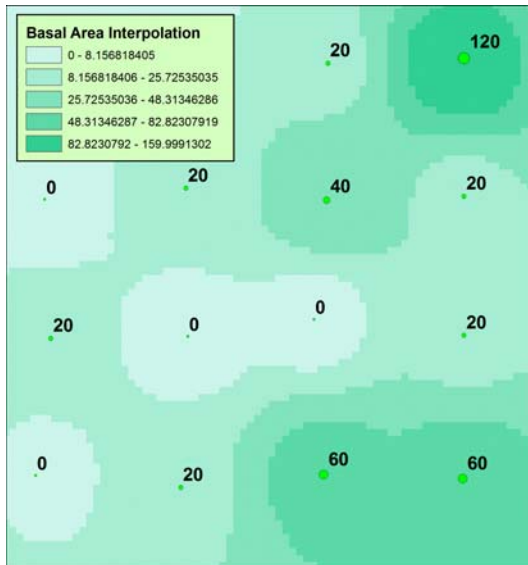


Figure 1. Example of interpolation raster with original point data values shown. Note as the point value increases the raster value increases as well (1:2,600 scale).

ArcGIS Spatial Analyst extension provides many methods and options for interpolation. Two categories of interpolation exist: deterministic and geostatistical. Deterministic interpolation methods create rasters based on point data values. IDW, Spline, and Natural Neighbor are all deterministic methods. Geostatistical interpolation methods are based on statistics of the point data values. Geostatistical methods also provide some measure of certainty or accuracy of predictions (ESRI, 2007).

This study analyzes the effectiveness of three deterministic methods:

- 1) IDW
- 2) Spline
- 3) Natural Neighbor

Each will be compared against one another to find the most appropriate method. The method with the output that is statistically closest to the input data will be used in the analysis.

IDW determines cell values by assuming the value of a cell is influenced proportionally to the distance from a known sample point. An important characteristic of IDW is the minima and maxima values predicted will not be outside the bounds of the input data. The user can determine the significance of input points on the interpolated values by changing the power parameter. A higher power places more emphasis on the nearest points. A lower power places more emphasis on points farther away. The user can also control the search radius parameter of IDW. A variable search travels any distance to find the closest specified number of points. A fixed radius will only travel the specified amount and find any number of points. The method chosen depends on the spatial nature of the point data.

Spline interpolation uses a mathematical function that minimizes the overall surface curvature. Spline has been compared to bending a rubber sheet to pass through all sample points with the minimal amount of curvature (Childs, 2004). Unlike IDW, the minima and maxima values of the output raster are not defined by the bounds of the input data. Two variations, regularized and tension, of spline exist. Regularized spline incorporates the first (slope), second (rate of change in slope), and third (rate of change in the second) derivative. For the regularized spline method, the weight defines the weight of the third derivatives. A higher weight creates a smoother output raster. Tension uses the first and second derivatives and includes more points in

the spline calculation. The user has control over the weight and number of points used in the spline interpolation. For the tension spline method, the weight defines the weight of the tension. A higher weight creates a coarser output raster. The number of points parameter determines the number of points used in the calculation of each interpolated cell.

Natural neighbor interpolation is very similar to IDW. This method finds the closest subset of input points and applies weights to them based on proportionate areas. Natural neighbor is also known as a Sibson or “area-stealing” interpolation (ESRI, 2007). Only values surrounding the cell are used and minima and maxima values are within the bounds of the input data. Because of natural neighbor’s characteristics, there are no user-defined parameters.

The assumption of this study is aspen quality will be evident by looking at data collected during an aspen inventory. Theoretically, all data for a specific point should agree on some level of aspen quality. It is also assumed that levels of quality will be somewhat spatially grouped and therefore easily mapped. Conceptually, the idea of the analysis is to combine the field data to determine overall quality for aspen and display the results graphically for decision makers.

Methods

Study Area and Stands

The study area consists of 219 aspen stands totaling 4,355.96 ha in southwestern Lake County, Minnesota (Figure 2). The study area is bound on the east by the Gooseberry River, on the south by Lake Superior, on the west by

the St. Louis County and on the north by the ecological classification system delineation of the Cloquet Island Lake Plain. Elevation of the study area ranges from 183m to 527m. Data (means for a period of 30 years, 1971-2000) from the closest climatic station in Duluth, MN indicate the mean annual precipitation is 79 cm, mean annual snowfall is 207 cm, mean annual temperature of the warmest month (July) is 18.6°C, and mean temperature of the coldest month (January) is -13.1°C (National Oceanographic and Atmospheric Administration 2006).

This area has a history of cultural disturbances. Logging began in the 1830’s and by the early 1900’s, logging in the area was extensive. Early settlers also cleared the land for firewood and grazing purposes (Lake County Historical Society, 1983).

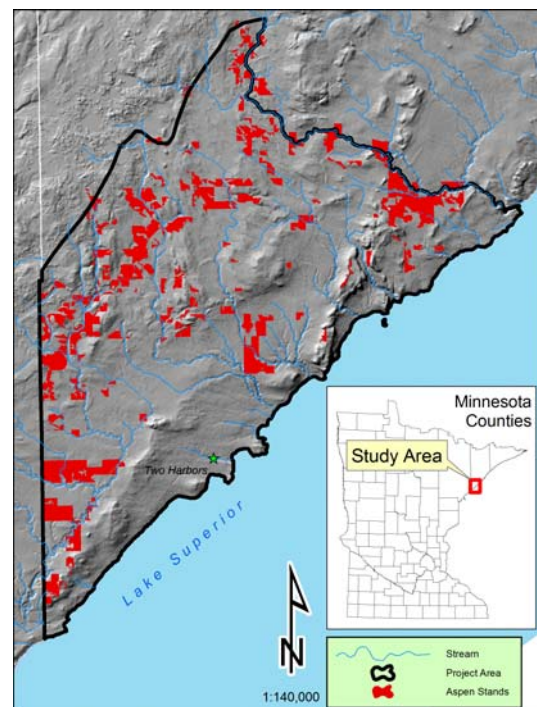


Figure 2. Map showing overview of project area.

Data Collection

Data was collected from July 2006 through April 2007. Plots at 2,231 locations were recorded. A private forester was contracted to complete the data collection. The forester hired another private forester to assist in the data collection.

The data was collected using a Dell Axim X51 and a Juniper System Archer personal digital assistant (PDA). Custom forms, created in ArcPad Studio 7.0, were used in ArcPad 7.0 to record the data. Plot locations were based on a 140 m predetermined grid. This sample design is set up to avoid plot location bias. The design also allows future studies to visit the same plots for further research. Because of natural obstructions (e.g. wetland inclusions), the contract stated actual plot locations were to be within a 20.1 m (1 chain) radius of the predetermined plot.

A Garmin GPS10 GPS receiver connected to the PDA was used to navigate to and record the location of each plot. At each plot, five categories of data were recorded:

- 1) Ecological classification system (ECS) data
- 2) Merchantable tree volume
- 3) Commercial tree species regeneration count
- 4) Dead aspen stem count.
- 5) Damage and disease information

Each data category was stored in a separate .dbf file for each data collection day. Data was stored on a storage card to minimize the risk of data loss.

ECS data (1) was recorded on a 0.008 ha (0.02 acre or 1/50th acre) plot. This data consists of species and shading density for the overstory, subdominant,

tall shrub, intermediate shrub, and short shrub layer. Slope gradient, percent of ground covered by rock fragments, and type of rock fragments (angular or rounded) were also recorded as ECS data.

Merchantable tree volume (2) was recorded using a 20 basal area factor (BAF) prism. Commercial species tree regeneration count (3) and height along with dead aspen stems (4) were recorded on a 0.004 ha (0.01 or 1/100th acre) plot.

Damage and disease percentages (5) were recorded on 0.008 ha (0.02 or 1/50th acre) plot. A scale of 1 to 5 was used to indicate damage and disease percentages.

Data Preparation

Following the data collection, the .dbf files were then placed in their respective Microsoft Access database table. During the data collection process, each record entry automatically stored plot ID, date, time, forester, and NAD83 Zone 15N UTM X and Y coordinates. The coordinate information allowed the creation of a point feature class using the Add XY Data option in the Tools menu of ArcMap. Each category of data is stored as point feature class in a personal geodatabase.

Because the data collected was intended for an overall inventory, the applicable data for this project needed to be extracted. For this study, 5 categories of data were used:

- 1) Merchantable aspen volume
- 2) Aspen regeneration stem count
- 3) Hypoxylon canker (Hypox) and/or *Phellinus igniarius* (*Phellinus*) percentage index
- 4) Shepard's crook percentage index
- 5) Dead aspen stems percentage

The percentage of dead aspen stems per plot was calculated by dividing dead aspen stems by total aspen stems.

Data Interpolation Analysis

Because of the numerous interpolation methods with different parameters, an analysis needed to be conducted to find the most appropriate method (Figure 3). For each of the 5 sets of data, 25 variations of interpolation methods were executed using the Spatial Analyst extension of ArcGIS. To expedite the process, a model was built in ArcGIS Model Builder. The analysis mask was set using a 140 m buffer of each point. The cell size was set to 7 m to reflect actual field-data collection area (Jonker and DeLeo, 2000). To find the most appropriate method with appropriate parameters, a variety of combinations of settings were set for IDW and Spline (Table 1). Natural neighbor does not have any user-defined settings.

Following the raster creation, each point of the input point layers was populated with the corresponding cell value of each respective raster. The goal of this is to compare the predicted cell value with the actual point value. The cell value at each point was found using Hawth's Tool 3.26 Intersect Point tool.

To compare the rasters with their respective point layer, standard raster statistics were compiled. This was accomplished with a script that created a .dbf file. The file contains each raster layer's minimum value, maximum value, and standard deviation.

Table 1. Interpolation methods with different parameters.

Method	Type	Power	Distance (m)
IDW	Fixed	0.5	140
		0.5	280
		2.0	140
		2.0	280
		3.0	140
		3.0	280

Method	Type	Power	Points
IDW	Variable	0.5	8
		0.5	12
		2.0	8
		2.0	12
		3.0	8
		3.0	12

Method	Type	Weight	Points
Spline	Reg	0.0	12
		0.0	8
		0.1	12
		0.1	8
		0.5	12
		0.5	8

Method	Type	Weight	Points
Spline	Tension	1.0	8
		1.0	12
		5.0	8
		5.0	12
		10.0	8
		10.0	12

Method	
Natural Neighbor	No Options

Each point layer's attribute table with corresponding raster values was exported as a .dbf file and imported into a Microsoft Excel workbook. Within Excel, the correlation, standard error, and paired two-tailed *t*-test were calculated. Correlation and standard error illustrated differences between the



Figure 3. The above flow chart shows a simplified version of the steps taken in the data interpolation analysis.

individual point value and its corresponding raster value. If the calculated t value of the paired t -test is above the threshold chosen for statistical significance (0.05 in this analysis) the null hypothesis stating the two groups do not differ is rejected. The correlation and standard error groups were ranked to find the best method of interpolation.

Aspen Quality Analysis

In this study, aspen quality is determined by a combination of all point data gathered. Based on the interpolation method analysis, the most appropriate raster for each point layer was used. The premise of this analysis is to reclassify each cell of each raster based on relative quality and add all rasters together to achieve overall quality (Figure 4). The hope was all five layers would agree on the level of quality. The classification is based on a scale of 1 to 5 with 1 being the least desirable and 5 being the most desirable. A value of zero was used for cells with no data or an original value of 0. These reclassified rasters are then added together to achieve the overall aspen quality.

First attempts to classify aspen quality proved that a cell size of 7 m is too small. While the results are similar, a cell size of 21 m is easier to interpret visually. For this reason, the first step was to use the Aggregate function of Spatial Analyst. This function generates a reduced resolution version of the original raster. A cell factor of 3 was used to create an output cell of 21 m. The aggregation technique parameter of mean was used to determine the value for each output cell. Mean gives an output of the average cell value being aggregated.

The next step was to reclassify each raster. This was completed by using the Reclass by Table tool of Spatial Analyst extension. This tool reclassifies each cell based on a range of values specified by the user. Tables for each data category were created showing the range of the interpolated raster values and the corresponding output value (Table 2). The to and from values were derived from local knowledge of aspen. For example, foresters were asked what values for basal area are good, average, and poor. The reclassified values provide an index of quality for each data category.

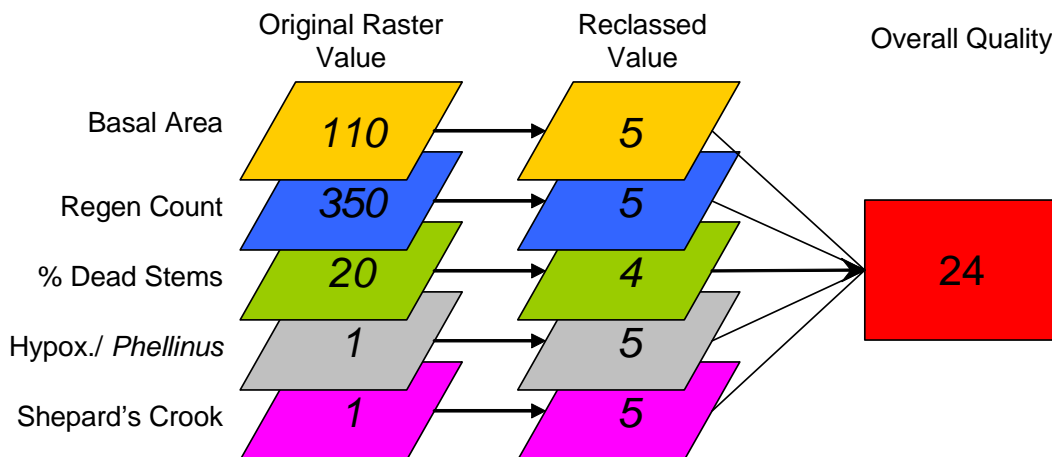


Figure 4. Graphical representation of the simplified steps to achieve overall quality. The stack of layers represents the same location of the forest.

Table 2. Table showing to and from values of raster and subsequent reclassified value.

	From	To	Reclass Value
Sheppard's Crook (% Index)	4	5	1
	3	4	2
	2	3	3
	1	2	4
	0	1	5
Basal Area	0	0	0
	0	50	1
	50	70	2
	70	90	3
	90	120	4
Regen > 15 Years (Stem/Acre)	0	0	0
	0	900	1
	900	1500	3
	1500	14500	5
Regen < 15 Years (Stem/Acre)	0	0	0
	0	1800	1
	1800	3000	3
	3000	14500	5
Hypox. / <i>Phellinus</i> (% Index)	4	5	1
	3	4	2
	2	3	3
	1	2	4
	0	1	5
% Dead Stems (% Index)	0.59	1.00	1
	0.37	0.59	2
	0.21	0.37	3
	0.09	0.21	4
	0.00	0.09	5

The Boundary Clean tool of Spatial Analyst was used to make the resulting raster look natural and easier to interpret. This tool is used for cleaning ragged edges between zones. The smallest size region retained is a 3 by 3 block of cells. Each reclassified raster was run through the Boundary Clean tool producing a raster with more generalized areas.

The final step of the analysis was to add all the rasters together. A value with the range of 0 to 25 is possible. The resulting raster shows the overall quality of aspen. The Cell Statistics tool

of the Spatial Analyst extension was used to accomplish this task. The overlay statistic parameter sum was used to achieve the overall sum of each input raster.

All of the above processes were executed in a model built in ArcGIS ModelBuilder. A model allowed analysis steps to be rerun with different parameters. The model also provided convenient documentation of the analysis.

One observation made by local foresters is the quality of aspen increases with distance from Lake Superior. Aspen closer to Lake Superior appears to be lower quality. To analyze this, a polygon buffer of Lake Superior was created with 2,500 m intervals (Figure 5). These polygon buffers were used as the zone dataset in the Zonal Statistics tool of Spatial Analyst extension. Each polygon was populated with the average cell value of the quality index raster.

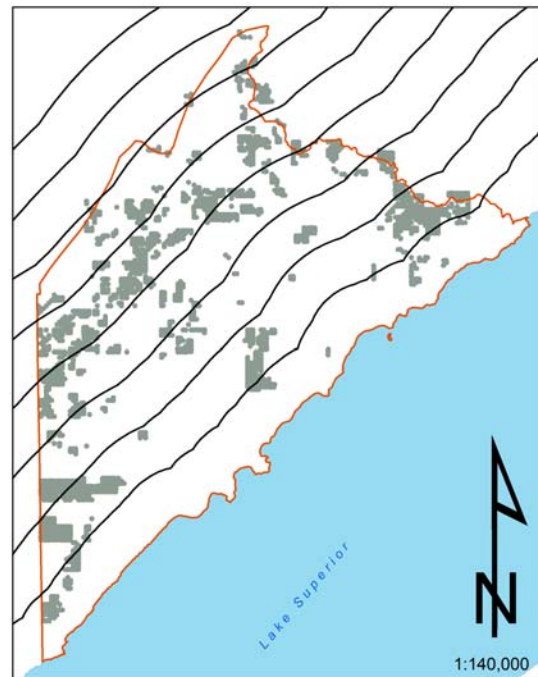


Figure 5. Lake Superior polygon buffers created with 2,500 m intervals.

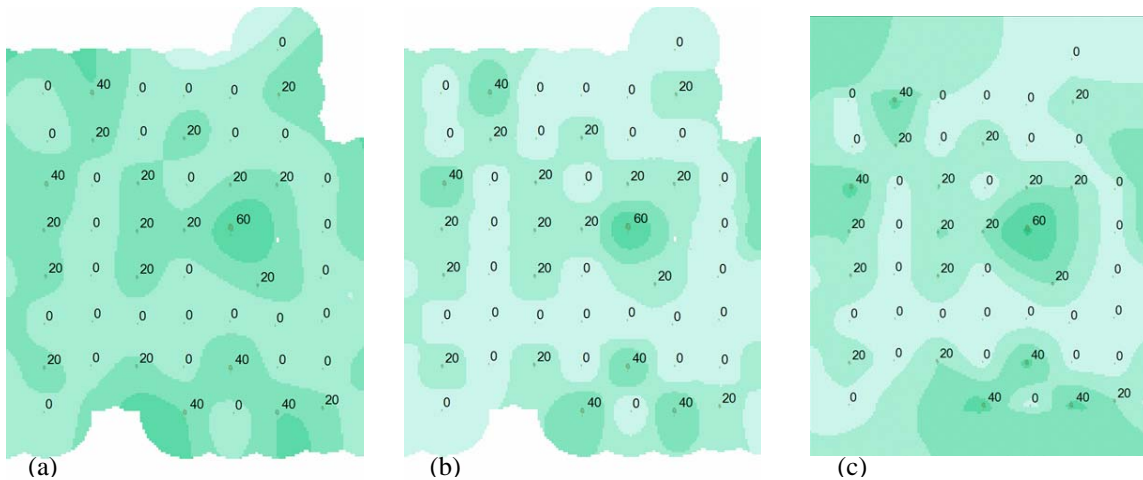


Figure 6. Three samples of interpolation methods. Values indicate value of point data (1:5,426 scale).
 (a) Spline Interpolation
 (b) IDW Interpolation
 (c) Natural neighbor interpolation

Results

Interpolation Methods Results

The results of the point data interpolation were not overwhelmingly obvious (Appendix A). Correlation values were generally closer to 1 for the IDW interpolation method. The standard error was generally lowest in IDW interpolation methods. At the 95% confidence level, all methods were below the critical *t* value of 1.962, signifying the means are not statistically distinct.

The Spline and Natural Neighbor interpolation methods were more visually acceptable. The rasters generated by the IDW methods were bulls-eye shaped in nature. Natural Neighbor and Spline had patterns more “natural” looking (Figure 6). The patterns created looked like what one might expect to occur.

While these rasters were visually appealing, they did have shortcomings. The minimum and maximum values for the Spline rasters were very different from the actual point layer values. All of the Spline rasters had values below zero,

a value that would never occur naturally. IDW had better comparative statistics than Natural Neighbor, making IDW the most appropriate method. It was decided that statistical accuracy was more important than visual appeal.

Within IDW are user-inputted parameters affecting the output raster. For IDW, a power of 3 with a 140 m fixed radius resulted in the most statistically accurate results (Appendix B). The correlation and standard error were consistently ranked very high, demonstrating the accuracy for this interpolation. This combination of parameters was also consistently one of best for all five categories of data. The only data set yielding somewhat different results was the percent of dead stems layer. For this layer, a spline interpolation was ranked at the top.

The models created worked very well. The model could be set to run and left unattended. This was convenient being each interpolation took up to 6 minutes to complete. The model also allows future analysis with different point data.

Aspen Quality Results

With all rasters added together, the aspen quality analysis resulted in quality index values ranging from 5 to 23 out of a possible total of 25. The quality index value of 15 had the most area with 1,541.3 ha, 24.0% of the total (Figure 7). The values were concentrated in the 12 to 16 index value range with 75.1% of the total area. 80.5% of the area was in the upper half of the range of values (13-23). No area scored higher than 23 out of 25. Only 5.3 ha out of 6,415.0 ha (0.1%) are classed as 21 through 23. To put a score of 21 in perspective, each layer contributed an average 4.2 out of 5.

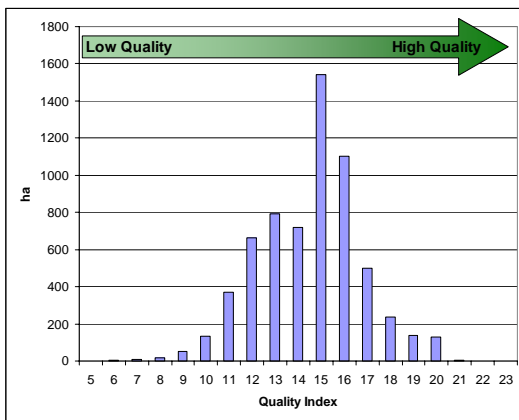


Figure 7. Graph of area (ha) for each index value.

The raster values, when grouped, show areas of relative aspen quality (Figure 8). Higher values indicate high aspen quality. The raster resolution reduction techniques appear to have solved the bulls-eyed appearance. The pattern now is somewhat “natural” looking. The map gives a general idea where aspen quality is low or high. Foresters will have a general idea of the quality of aspen.

As suspected, the quality of aspen increases with distance from Lake Superior (Figure 9). There is a general

upward trend in quality with increased distance from the lake. Foresters have noted lower quality aspen closer to the lake, proving anecdotally that this method of analysis is somewhat accurate.

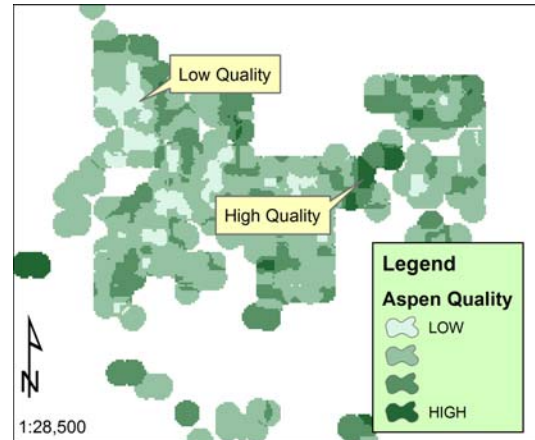


Figure 8. Map showing sample of quality index raster.

Using a model for this analysis was very useful. With many steps in the analysis, a model is very helpful in documentation of each step. The model also permits the analysis to be conducted in a variety of different ways. There is no doubt about what parameters were used and how the analysis was accomplished. Future analysis will easily be able to use the same proven model.

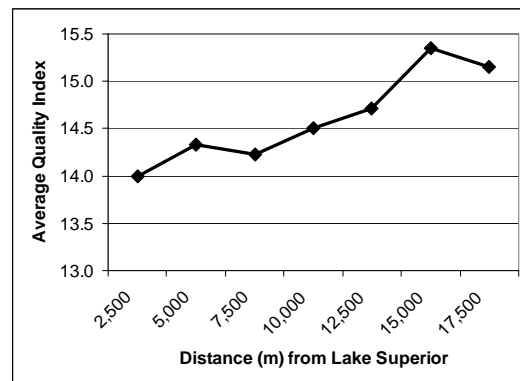


Figure 9. Graph showing quality index value. Notice a higher index value with further distances from Lake Superior.

Discussion

Interpolation Method

This study shows GIS can be used to analyze aspen quality based on point data. Raster interpolation is an excellent way to analyze point data. It provides a statistically verifiable way to analyze the data. It also provides an estimate of values between collection points, allowing for less time and money spent on data collection.

Raster analysis of point data can be a daunting task. The many options in Spatial Analyst extension become overwhelming. However, with a little investigation and knowing the nature of the data, the choices become limited. In this study, data accuracy was more important than visual appeal, making IDW with a fixed radius the interpolation method of choice.

The user-inputted parameters for IDW depend on the nature of the input data. In this case, a power of 3 with a 140 m fixed radius worked the best for data on a 140 m grid. The 140 m fixed radius worked very well with the 140 m grid. Had the data been random or spaced differently, parameters would most likely be different.

Aspen Quality

Point data by itself is difficult to interpret. There are too many variables to analyze at a single point. There is also the question of what is happening in areas between the points. Rasters, however, give the user an idea how all the point data is working together. Patterns of data are more recognizable with a raster. The interpolation of point data is a natural and cognitive way to view data.

This project uses the interpolated point data to achieve a relative quality index for aspen. With aspen quality characteristics, each raster is reclassified. The results give forest managers a visual representation of relative aspen quality. Decisions are now made, with the help of this data, about the future of each stand.

Future Research

Although this study answers many questions, more questions are created throughout the analysis. The resolution of the rasters was an important factor to how the rasters looked. There appears to be a balance between accuracy and appearance. Future studies could look at the affect of raster resolution to find the optimum cell size. Studies could also look at weighting specific rasters based on the significance of aspen quality. In this study, all factors had equal weight. It would be likely that some factors are more important than others are; thus, a higher weight could be incorporated. Adding more variables, such as soil data, could also enhance the predictability of aspen quality. There are many possibilities for future analysis.

Conclusions

Interpolation

ArcGIS Spatial Analyst extension is very suitable for interpolating point data to rasters. Choosing the correct input parameters can be somewhat daunting, but with a little work, suitable inputs can be found. The parameters are based on the spatial arrangement and data characteristics of the point data. Thus, it is the job of the analyst to find the most suitable method.

Aspen Quality

The southwest portion of Lake County has a significant amount of aspen. This study showed that most of this aspen is fair to average quality. There are limited pockets of higher quality aspen.

Foresters now have a valuable tool for forest management. For example, with lower quality aspen identified, foresters have an idea where to look for potential sites to convert to conifer. The results of this study will be a valuable tool for forest management.

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Appendix A. Example of statistics derived from interpolation analysis. This shows the rasters derived from aspen basal area. "Rank" shows how each raster compares with the others.

			Correlation	Rank	Standard Error	Rank	MAX	MIN	Standard Deviation	Variance	Sample Size	t-Score		
IDW	Fixed Radius	140 m radius	2 Power	1	5	0.0171	5	160.0000	0	17.6540	311.6630	2149	0.6005	
			3 Power	1.0000	1	0.0005	1	160.0000	0	18.1215	328.3900	2149	0.4396	
			0.5 Power	0.9849	22	3.0431	22	160.0000	0	16.7306	279.9116	2149	0.3250	
		280 m radius	2 Power	1.0000	7	0.0321	7	159.9371	0	14.6892	215.7739	2149	0.9564	
			3 Power	1	3	0.0009	3	159.9992	0	16.3345	266.8167	2149	0.4484	
			0.5 Power	0.9421	23	4.6855	25	124.5229	0	11.8243	139.8151	2149	0.3341	
	Nearest Neighbor	12 points	2 Power	1.0000	8	0.0347	8	159.9135	0	13.5096	182.5096	2149	0.7774	
			3 Power	1.0000	4	0.0009	4	159.9991	0	15.8376	250.8302	2149	0.3845	
			5 Power	0.9177	25	4.6808	24	96.1705	0	9.2334	85.2557	2149	0.3841	
		8 points	2 Power	1.0000	6	0.0309	6	159.9225	0	14.0407	197.1414	2149	0.3166	
			3 Power	1.0000	2	0.0008	2	159.9991	0	16.0460	257.4751	2149	0.3098	
			5 Power	0.9405	24	4.4722	23	109.1994	0	10.3281	106.6701	2149	0.5088	
	Spline	Regular Spline	0.01 Weight	8 Points	0.9997	15	0.5047	15	336.2281	-194.3940	23.9870	575.3757	2149	0.6781
				12 Points	0.9997	16	0.5123	16	333.8777	-204.0431	24.2729	589.1738	2149	0.4850
			0.1 Weight	8 Points	0.9996	17	0.5405	17	380.4634	-267.8840	25.7199	661.5131	2149	0.4996
				12 Points	0.9996	18	0.5653	18	368.1652	-266.8189	25.5524	652.9248	2149	0.5338
0.5 Weight			8 Points	0.9958	20	1.7231	20	385.2706	-282.0973	25.2490	637.5124	2149	0.5348	
			12 Points	0.9884	21	2.7619	21	377.9783	-259.9873	24.0948	580.5593	2149	0.9140	
Tension Spline		1 Weight	8 Points	0.9998	14	0.3500	14	224.9009	-69.6844	19.0497	362.8925	2149	0.8663	
			12 Points	0.9998	13	0.3498	13	221.1144	-69.1011	19.0176	361.6683	2149	0.5744	
		5 Weight	8 Points	0.9998	11	0.3472	11	217.4961	-62.4434	18.8875	356.7367	2149	0.5614	
			12 Points	0.9998	12	0.3479	12	216.3221	-63.9070	18.9011	357.2513	2149	0.5782	
10 Weight	8 Points	0.9998	9	0.3445	9	211.7260	-57.4147	18.7521	351.6410	2149	0.5606			
	12 Points	0.9998	10	0.3459	10	212.1636	-59.9095	18.8001	353.4456	2149	0.5752			
Natural Neighbor			0.9968	19	1.5450	19	156.6984	0	13.4238	180.1988	2149	0.5598		

Appendix B. Chart showing results of statistical analysis of Spline interpolation with a power of 3 with a 140 m fixed radius. Bold numbers are statistics for original point data.

Data Type	Sample Size	Correlation	Standard Error	MAX	MIN	Standard Deviation	Variance	t-Score
Percent Dead Stems	22178	1.000	0.000	1.000	0.000	0.216	0.047	0.873
				1.000	0.000	0.237	0.056	
Regen Stems	2178	1.000	0.046	144.000	0.000	13.455	181.038	0.091
				144.000	0.000	14.665	215.052	
Sheppard's Crook	2184	1.000	0.002	5.000	0.000	1.470	2.160	0.505
				5.000	0.000	1.623	2.633	
Basal Area	2149	1.000	0.001	160.000	0.000	18.122	328.390	0.440
				160.000	0.000	19.774	391.007	
Hypox. / <i>Phellinus</i>	2201	0.998	0.056	5.000	0.000	0.721	0.489	0.059
				5.000	0.000	0.817	0.667	