Correcting a Previously Published Error in Soil Salinity Comparisons Reported from a West Texas Salt Marsh

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ABSTRACT

In 2007, a book chapter was published concerning monthly changes in soil salinity levels over an annual plant growth cycle in an inland salt marsh. Two figures were published to compare surface plots showing soil salinity in the salt marsh. Unfortunately, one figure was duplicated, so rather than showing a comparison of two techniques, only one was shown. This article is to correct that error. Spatial and seasonal fluctuations of the soil salinity levels in an inland salt marsh were measured and then examined with geographic information system software to gain insight into the cause of the distribution of the plant communities in the marsh. Surface plots were interpolated using the inverse distance weighted method (ArcView 3.3) and the ordinary kriging method (ArcGIS 8). Using the same data, ordinary kriging generated a gradual, smooth surface, which was not correctly published, while the inverse distance weighted surface was irregular. Using the ordinary kriging method, the mean error and root-mean-square error statistics were closer to zero indicating a better estimation of the soil salinity. Generated surfaces showed seasonal fluctuation and well defined spatial changes. Lowest elevation in the center of the salt marsh had lowest levels of soil salinity, while the marsh edges at higher elevations had increased soil salinity. Spatial patterns of soil salinity seem to depend on seasonality of rainfall, plant activity and soil water content. Local surface anomalies often mask these patterns. Use of ordinary kriging and interpolation reduced some of the masking effects and better revealed salinity patterns. Unfortunately, this was stated in the published chapter, but the supporting figures were not presented correctly. Published on-line www.phytologia.org *Phytologia 101(1): 46-57 (March 21, 2019).* ISSN 030319430.

KEY WORDS: soil salinity, geographic information systems, interpolation, kriging, IDW, arid environments, inland salt marshes, spatial changes.

Because our intent is to correct an error in a published document, we will present a limited amount of material about the west Texas salt marsh, the descriptive characteristics of the marsh and techniques used. Readers should refer to the original publication and some others that concern this particular marsh and it characteristics (Grunstra and Van Auken 2007).

Geographical Information Systems (GIS) and Global Positioning Systems (GPS) provide new ways to investigate and display areas both spatially and temporally. Surface contour plots are tools readily available with the emergence of cheaper GIS software. A surface contour plot allows a limited point data set to be expanded to display estimated values at any point within a study area. There are numerous interpolation methods available for the creation of these surface contours (Lam 1983; Isaaks and Srivastava 1989; Burrough and McDonnell 1998). Each interpolation method allows the user to modify characteristics and reduce variation in the output surface. This paper compared output surfaces created using two common interpolation techniques, including the Inverse Distance Weighted method (IDW) and Ordinary Kriging (Franzen and Peck 1995; Weisz et al. 1995). The paper demonstrates how these surfaces were applied to field research by examining the spatial and temporal fluctuations of soil salinity levels in an inland salt marsh. More specifics are presented in the previously published paper (Grunstra and Van Auken 2007).

The IDW method produces accurate surface interpolation as long as a regular distribution is used (ESRI 2000; Johnston et al. 2001; Mitchell 2009). Uneven distributions may produce sharp peaks or troughs in the output surface (ESRI 2000; Johnston et al. 2001; Mitchell 2009). The ArcGIS 8 software allows the use of geostatistics to create surface contour plots. Kriging is a geostatistical technique that can explain the variation of a surface (Isaaks and Srivastava 1989; Burrough and McDonnell 1998; ESRI 2000; Johnston et al. 2001; ESRI 2003; Mitchell 2009). Output from this model includes a mean error, root-mean-square error, average standard error, and the root mean square standardized error (Johnston et al. 2001). Many studies have compared the performance of these methods suggesting careful consideration when determining the method and settings to be used with a given data set.

Many studies of salt marshes have incorporated GIS into their analysis, but none have considered this west Texas salt marsh. The Diamond Y Spring is located on a 6.1 km^2 nature preserve owned by the Nature Conservancy of Texas, approximately 16 km north of Fort Stockton, Texas (Figure 1). The Diamond Y Spring is the last major spring still flowing in Pecos County, Texas (Veni 1991). The Preserve protects six federally endangered or threatened species including the Puzzle Sunflower (*Helianthus paradoxus)*, two fish and three snails (McDonald 1999; TPWD 2003; Bush and Van Auken 2004). The types of soil, water chemistry, as well as the plant communities are all indicators that a large part of the Diamond Y Spring Preserve is a salt marsh.

The Preserve is semi-arid karst with an average precipitation of 33 cm/year and an evaporative rate of 204 cm/year (Larkin and Bomar 1983), with three saline aquifers underlying the area (Figure 1) (Veni 1991; Small and Ozuna 1993; Boghici 1997; USGS 2002). The surface flow is east toward the Pecos River and ephemeral due to low rainfall and high evaporation (Van Auken 1998; Grunstra 2002; Hart 2002). Plant communities within the salt marsh seem to be in fairly distinct locations due to species specific water requirements, salt tolerance, or ability to out-compete rivals (Chapman 1974; Niering and Warren 1980; Bertness 1991; Van Auken and Bush 1998; Bush 2002; Grunstra 2002).

PURPOSE

To gain a greater understanding of the distribution of the salt marsh vegetation, soil salinity data were gathered. Two different geographic information system software interpolation methods were compared. The surface contour plots interpolated values to fill in the entire study area and provide a representative overview of the soil salinity levels throughout the salt marsh.

METHODS

Two different geographic information system software interpolation methods were used on the same input variables to generate two visually different surface contour plots to examine the most useful interpolated surface from the data. These methods will be abbreviated and are mainly presented so the reader has some understanding how the comparative figures were established. More detail is presented in the original publication (Grunstra and Van Auken 2007). A GeoExplorer III GPS receiver was used to map the study area including 7 transects with 87 observation points (Figures 2 and 3). The GPS field data were used to create point shapefiles in the ArcView 3.3 and ArcGIS 8 software (ESRI 1999; Ormsby and Alvi 1999; Mitchell 2009; Allen 2011).

Soil samples from each site were collected monthly beginning in January 2002 and continuing until October 2002 for 870 total samples. Approximately 300 g of surface soil was collected from the top 1 cm of soil below surface litter (TAES 1983). When under water, a sample of water was collected. The soil was collected approximately 2 m from each observation point in a cross pattern. Samples were placed in plastic bags and sealed to prevent evaporation then taken to the laboratory for analyses. Soil salinity was measured by making a 1:1 paste (soil:de-ionized water, V:V) and measured with a salinity probe (TAES 1983; Westerman 1990; Rowell 1994;). These measurements were entered into the attribute table of the GIS shapefiles created in ArcView 3.3 and ArcGIS 8 from the collected GPS field sampling site locations.

Soil salinity point measurements were converted to a raster grid to produce a continuous surface or contour plot across the study area. In ArcView 3.3, the Spatial Analyst extension was used to do this interpolation by the Inverse Distance Weighted (IDW) method. In ArcGIS 8, the Geostatistical Analyst extension was used to create the surface plots by the kriging method. Several iterations were performed for each interpolation method using various initial settings of neighborhood size of analysis, lag spacing, and power of magnification. This was performed in a systematic fashion in order to produce the most logical and representative interpolated surface for each method.

The settings used for the IDW surface displayed in this study were a neighborhood size of 15 with a power magnification of 3. The settings that produced the best cross-validation error statistics for the ordinary kriging method were for an elliptical search neighborhood with no offset and divided into 4 sectors including 5 points per sector. Both methods allowed for the display and investigation of spatial and temporal trends and patterns of soil salinity levels in the marsh. The outputs from the two separate interpolation methods were compared visually as well as by the error statistics produced through cross-validation. The ArcGIS 8.0 software was used to perform cross-validation and generate the mean prediction error and the root-mean-square prediction error.

RESULTS

The ArcView 3.3 soil surface salinity contour plots created using the IDW method showed a range of salinity levels from a low of 3 ppt to a high of 43 ppt (Figure 2). The solid black areas represent the highest salinity levels while lower levels are shown with various patterns. High salinity levels were found along the borders or edges of the study area especially in the northwest with lower salinity levels found towards the center or lower elevations of the marsh associated with the drainage (Figure 2). The surface soils in the eastern half of the study area consistently showed large areas with soil salinity levels in the 3 - 10 ppt salinity range. There was little variation in the soil salinity levels in these locations through the ten-month study period.

Surface soil salinity levels greater than 20 ppt were mainly along the edge of the northwestern part of the study area (Figure 2). Using the IDW method seemed to put more weight on the central measurements on a given transect, thus if the central measurement was very low, then that point showed up lighter in the figures with associated values used to extrapolate the central measurement which were darker indicating higher extrapolated salt values. Accordingly, there were a larger number of higher or lower isolated points or associated map values and the map using the IDW procedure did not show more general and uniform gradients (Figure 2). There seemed to be higher variance in the map when the IDW procedure was used.

The surface contours created using the ordinary kriging method were smoother, showed less variation or were not as ragged as those created using the IDW procedure (comparing Figures 2 and 3; note, comparisons were not possible in the earlier publication because the equivalent of Figure 3 was not correctly presented). In addition, they also show a large portion of the study area with soil salinity in the range from 5 - 10 ppt (Figure 3). The majority of the higher levels of soil salinity in the range of 25 - 43 ppt were found along the northwestern border of the study area with occasional occurrences near the southwestern border. February and October show most of the study area with lower levels of salinity with very little area in the higher ranges (Figure 3). April and September show larger areas with higher levels of salinity covering more of the study area than the rest of the time period (Figure 3). The trend shows higher levels always near the borders and lower levels towards the middle of the study area.

Through visual examination both general differences and similarities of the surface plots created using the IDW and ordinary kriging methods could be observed (Comparing Figures 2 and 3, see previous note). In the IDW surface plots, the sampling points and transects can more readily be observed (Figure 2). The ordinary kriging method depicts more gradual and smoother transitions between soil salinity values (Figure 3). The IDW procedure depicts a larger surface area of the salt marsh covered by the lower values of 3 - 5 ppt while the ordinary kriging method estimates those same areas to have slightly higher values between 5 - 10 ppt (Figures 2 and 3). On the northern border, the IDW method shows localized concentrations of high soil salinity around the sampling locations while the ordinary kriging method shows a banding pattern in those same areas. The IDW method tends to show less area covered by higher salinity and more area covered with lower salinity while the ordinary kriging method tends to show the reverse. Although both methods of visual representation show similar trends, the ordinary kriging surface contour plots are much smoother (Figure 3, not seen in previous publication because of figure duplication). The two methods were evaluated by comparing the overall mean prediction error and root-mean-square prediction error for their surface contour plots (Table 1). The ordinary kriging method consistently produced values closer to zero indicating it would generally yield a better estimation of the soil salinity.

DISCUSSION

The surface contour plots available in GIS software provide many new ways to investigate and display diverse results. They facilitate the ability to produce surface contour plots which can estimate and display values across a large surface area from a limited point data set (Isaaks and Srivastava 1989; Burrough and McDonnell 1998). This allows investigators to quickly identify spatial and temporal patterns and trends as well as possible interactions and influences that different factors may have on plants in their study area which can then be examined more critically.

The GIS user has numerous interpolation techniques from which to choose depending on the software package selected (Isaaks and Srivastava 1989; Burrough and McDonnell 1998; Johnston et al. 2001; Mitchell 2009). Furthermore, variables such as the neighborhood size of analysis, lag spacing and other settings can be changed within a given interpolation method. The surface contour plots created by these methods may show similar characteristics and trends but will often produce visually dissimilar surface contours with considerable differences at specific locations (Brodsky et al. 2001; Bucher and Vckovski 1995; Gotway et al. 1996; Dille et al. 2003; Jones et al. 2003; Kravchenko 2003; Mueller et al. 2004). These dissimilarities are inherent to the mathematical procedures used to create the final surface contour such as the mathematical equations, calculations and estimations used by the method (Isaaks and Srivastava 1989).

In this study, both the IDW and the ordinary kriging methods were used to provide examples of different visual outputs created using the same data. The kriging method produced a smooth, more regular interpolated surface, whereas the IDW method produced a surface that was more strongly influenced by local measurements or the values of the specific soil samples (Comparing Figures 2 and 3). Most likely this was caused by the irregularly spaced pattern of the observation sites which were considerably closer in the north-south direction than the west-east direction. The IDW method produces a fairly exact surface interpolation as long as a regularly distributed sampling pattern is employed (Ormsby and Alvi 1999; ESRI 2000; Johnston et al. 2001; Mitchell 2009; Allen 2011). High point value variance or uneven distribution in the sampling patterns often produces sharp peaks or troughs in the output surface (Ormsby and Alvi 1999; ESRI 2000; Johnston et al. 2001; Mitchell 2009). Care must be taken with different methods and different settings when creating an interpolated surface in order to avoid interjecting various biases (Gotway et al. 1996; Dille et al. 2003; Jones et al. 2003; Kravchenko 2003; Mueller et al. 2004). The results can be useful both visually and in predicting values for variables (in this case salinity) between sample points.

When deciding upon the appropriate interpolation method to use to investigate or display data, one must critically evaluate various methods and program settings in order to obtain the best visual representation of logical values between the sample points (Bucher and Vckovski 1995; Gotway et al. 1996; Brodsky et al. 2001; Dille et al. 2003; Jones et al. 2003; Kravchenko 2003; Mueller et al. 2004). In the current study, the IDW results are ragged with little smoothing between sampling locations because the IDW method uses exact interpolation with contours formed on the specific measurements entered into the program. Consequently, when the plots are examined it is easy to see where the measurements were actually made. For example, when one examines Figure 2, the locations of the transects (and many soil collection sites) are obvious because of the sharp local differences in the places on the plots and the consequent lack of smoothing.

Using the kriging method, the northern and southern borders of the salt marsh consistently show the highest levels of soil salinity. These same areas coincide with elevations that are higher than the center of the salt marsh. The higher salinity values at the northern and southern borders of the salt marsh are attributed to a shallow soil or deeper water table that allows the soil to dry and therefore increase the soil surface salt concentration. More of the salts would be washed out of the surface soils in an area with the water table closer to the surface (Neill 1993; Ala et al. 1995). The areas with high soil salinity can be seen to grow larger as the water table gets deeper and dry areas of the marsh increase in size (see Grunstra 2002). The same high surface soil salinity areas then recede when the water table rises and the salts are flushed out of the soil by the surface water.

Surface soil salinity in the Diamond Y Spring salt marsh was previously found to be at its lowest level in early spring and increased during the summer months (Schmidt 1986; Van Auken and Bush 1993, 1995, 2006). This fluctuation in surface soil salinity was thought to occur in unison with the cyclic pattern of the water table. A higher water table would allow for more of the salts to be washed out of the surface soils while a lower water table would allow the soil to dry and therefore increase the surface soil salt concentration. Soil salinity reduced production of a cool season grass until spring flooding decreased soil salinity (Neill 1993). High levels of soil water allowed salts to be distributed throughout the soil profile while low levels soil water caused salt accumulation in the upper soil layers due to the high evaporation rates (Ala et al. 1995).

The expected annual cycle of salinity in the Diamond Y Spring salt marsh was not as noticeable as expected due to variation in the annual rainfall pattern (NCDC 2002). January of the study year received no precipitation when it usually receives approximately 2 cm while June and July received greater amounts of precipitation than normal. The month of August showed very little precipitation (0.4 cm) compared to the mean precipitation expected during that month (5 cm). The monthly mean soil salinity fluctuations were observed but they were not as large as expected (Figures 2 and 3).

Temporal and spatial distributions of soil moisture, pH, and ionic composition were significant in determining plant community locations in a Mediterranean salt marsh (Rogel et al. 2001). Surface salinity had a negative effect on all growth parameters and aboveground dry mass of *Helianthus paradoxus* at the Diamond Y Spring Preserve (Bush 2002, 2005). In addition these effects were time dependent. Spatial and temporal fluctuations in three halophyte species in upper coastal salt marsh communities were influenced by saline stress and soil nutrient level (Omer 2004). Temporal change in soil salt levels were found to determine plant community locations along the shoreline of a desert basin lake (Toft and Elliot-Fisk 2002). Soil salinity and moisture were also found to effect the spatial and temporal variation in plant germination and establishment in upper tidal marshes of three southern California wetlands (Noe and Zedler 2001). Plant zonation was related to spatial and temporal variations in soil salinity in southeastern Spain

(Ortiz et al. 1995). Vegetation distribution was also determined by soil salinity in spring fed salt marshes in western Utah (Bolen 1964) and around the Great Salt Lake (Flowers 1934).

Through the use and application of GIS, greater knowledge of the spatial and seasonal fluctuations of the soil salinity levels in salt marshes has been obtained. GIS interpolations have been used to determine the spatial dynamics of soil salinity in arid and semiarid regions (Jordan et al. 2004; Shi et al. 2005) as well as to determine the temporal and spatial variability of soil salinity in coastal saline fields and in cotton fields irrigated with low-quality water (Cetin and Kirda 2003). In the current study, the surface contours created for the Diamond Y Spring salt marsh have shown seasonal fluctuations and spatial distribution in the soil salinity across the salt marsh. The varying soil salinity levels probably indicate zonation and probable locations of salt marsh vegetation although this inland salt marsh and is most likely coupled with the interaction of water level at different points in time during the growing season.

LITERATURE CITED

Ala, F., S. Ismael, R. Ahmad and R. Shasheen. 1995. Effects of salinity and waterlogging on physiological processes and ionic regulation in *Atriplex amnícola*. Pakistan Journal of Botany. 27: 283-295.

Allen, D. 2011. GIS Tutorial 2: Spatial Analysis Workbook. Environmental Systems Research Institute. Redlands, California.

Bertness, M.D. 1991. Interspecific interactions among high marsh perennials in a New England salt marsh. Ecology 72:138-148.

Bolen, E.G. 1964. Plant ecology of spring-fed marshes in western Utah. Ecological Monographs 34:143-166.

Brodsky, L., V. Vanek, J. Szakova and K. Stipek. 2001. Spatial heterogeneity of soil properties. Rostlinna Vyroba 47:529-535.

Bucher, F. and A. Vckovski. 1995. Improving the selection of appropriate spatial interpolation methods. *In*: A. U. Frank and K. Werner (eds.) The Proceedings of the International Conference COSIT '95: Spatial Information Theory: A Theoretical Basis for GIS. Semmering, Austria.

Burrough, P.A. and R. McDonnell. 1998. Principles of Geographical Information Systems. Oxford University Press. Oxford, United Kingdom.

Bush, J.K. 2002. The effects of soil moisture, soil oxygen, and soil salinity on the growth of *Helianthus paradoxus*. Doctoral Dissertation. Department of Environmental Science, The University of Texas at El Paso, El Paso, Texas.

Bush, J.K. 2006. The role of soil moisture, salinity, and oxygen on the growth of *Helianthus paradoxus* (Asteraceae) in an inland salt marsh of west Texas. Journal of Arid Environments. 60:22-36.

Bush, J.K. and O.W. Van Auken. 2004. Relative competitive ability of *Helianthus paradoxus* and its progenitors, *H. annus* and *H. petiolaris* (Asteraceae), in varying soil salinities. International Journal of Plant Science 165:303-310.

Cetin, M. and C. Kirda. 2003. Spatial and temporal changes of soil salinity in a cotton field irrigated with low-quality water. Journal of Hydrology 272:238-249.

Chapman, V.J. 1974. Salt marshes and salt deserts of the world. Interscience Publishers, Inc. New York.

Dille, J.A., M. Milner, J.J. Groeteke, D.A. Mortensen and M.M. Williams. 2003. How good is your map? A comparison of spatial interpolators. Weed Science. 51:44-55.

ESRI. 1999. Getting to Know ArcView GIS. Environmental Systems Research Institute. Redlands, California.

ESRI. 2000. ArcView Spatial Analyst, An ESRI White Paper. Environmental Systems Research Institute. Redlands, California.

ESRI. 2003. ArcGIS 8.0 Geostatistical Analyst Extension. Environmental Systems Research Institute. Redlands, California.

Flowers, S. 1934. Vegetation of the Great Salt lake Region. Botanical Gazette 95:353-418.

Franzen, D. and A. Peck. 1995. Field soil sampling density for variable rate fertilization. Journal of Production Agriculture 8:568-574.

Gotway, C.A., R.B. Ferguson, G.W. Hergert and T.A. Peterson. 1996. Comparison of kriging and inverse-distance methods for mapping soil parameters. Soil Science Society of America Journal 60:1237–1247.

Grunstra, M.B. 2002. Spatial and temporal hydrogeological description and ecological community comparison of the Diamond Y Spring Preserve. M.S. thesis. Department of Earth and Environmental Science, University of Texas at San Antonio, San Antonio, Texas.

Grunstra, M.B. and O.W. Van Auken. 2007. Using GIS to display complex soil salinity patterns in an inland salt marsh. In: D. Sarkar, R. Datta and R. Hannigan (eds.) Concepts and applications in environmental geochemistry. Developments in environmental science series, number 5. Pp 407-431. Elsevier, New York.

Isaaks, E.H. and R.H. Srivastava. 1989. Applied Geostatistics. Oxford University Press. New York.

Johnston, K., J. M. Ver Hoef, K. Krivoruchko, and N. Lucas. 2001. Using ArcGIS Geostatistical Analyst. ESRI Inc. Redlands, California.

Jones, N.L., R.J. Davis and W. Sabbah. 2003. A comparison of three-dimensional interpolation techniques for plume characterization. Ground Water 41:411-419.

Jordan, M.M., J. Navarro-Pedreno, E. Garcia-Sanchez, J. Mateu and P. Juan. 2004. Spatial dynamics under arid and semi-arid conditions: geological and environmental implications. Environmental Geology 45:448-456.

Kravchenko, A. 2003. Influence of spatial structure on accuracy of interpolation methods. Soil Science Society of America Journal 67:1564-1571.

Lam, N. 1983. Spatial Interpolation Methods: A Review. The American Cartographer 10:129-149.

McDonald, C. 1999. Endangered and threatened wildlife and plants; determining the status for the plant *Helianthus paradoxus* (Pecos sunflower). Federal Register 64:56582-56590.

Mitchell, A. 2009. The ESRI Guide to GIS Analysis Volume 2: Spatial Measurements and Statistics. Environmental Systems Research Institute. Redlands, California.

Mueller, T.G., N.B. Pusuluri, K.K. Mathius and P.L. Cornelius. 2004. Map quality for ordinary kriging and inverse distance weight interpolation. Soil Science Society of America Journal 68:2042-2047.

NCDC (National Climatic Data Center). 2002. National Oceanic and Atmospheric Administration. U.S. Department of Commerce, Washington.

Neill, C. 1993. Seasonal flooding, soil salinity and primary production in northern prairie marshes. Oecologia 95:499-505.

Niering, W.A. and R.S. Warren. 1980. Vegetational patterns and processes in New England salt marshes. BioScience 30:301-307.

Noe, G.B. and J.B. Zedler. 2001. Spatio-temporal variation of salt marsh seedling establishment in relation to the abiotic and biotic environment. Journal of Vegetation Science 12:61-74.

Odum, W.E. 1988. Comparative ecology of tidal freshwater and salt marshes. Annual Review of Ecology and Systematics 19:147-176.

Omer, L. 2004. Small-scale resource heterogeneity among halophytic plant species in an upper salt marsh community. Aquatic Botany 78:337-448.

Ormsby, T. and J. Alvi. 1999. Extending Arcview GIS. Environmental Systems Research Institute. Redlands, California.

Ortiz, R., J.A. Rogel and F. Alcaraz. 1995. Soil-vegetation in 2 coastal salt marshes in southeastern Spain. Arid Soil Research and Rehabilitation 9:481-493.

Rogel, J.A., R.O. Silla and F.A. Ariza. 2001. Edaphic characterization and soil ionic composition influencing plant zonation in a semiarid Mediterranean salt marsh. Geoderma 99:81-98.

Rowell, D. 1994. Soil Science: Methods and Applications. Longman Group UK Limited. Essex, England.

Schmidt, R.H.J. 1986. Chihuahuan Climate. p. 40-63 *In* J.C. Barlow, A.M. Powell and B.N. Timmermann (eds.) Invited papers from the Second Symposium on the Resources of the Chihuahuan Desert Region. Chihuahuan Desert Research Institute, Fort Davis, Texas.

Shi, Z., Y. Li, R. Wang and F. Makeshine. 2005. Assessment of temporal and spatial variability of soil salinity in a coastal saline field. Environmental Geology 48:171-178.

TAES. 1983. Soil Analysis Texas Agriculture Extension Service. College Station, Texas.

TPWD. 2003. Wetland Ecology. Texas Parks and Wildlife Department. Austin, Texas.

Toft, C. and D. Elliot-Fisk. 2002. Patterns of vegetation along a spatiotemporal gradient on shoreline strands of a basin desert lake. Plant Ecology 158:21-39.

Van Auken, O.W. and J.K. Bush. 1993. Annual Report. The Nature Conservancy of Texas. San Antonio, Texas.

Van Auken, O.W. and J.K. Bush. 1995. Annual Report. The Nature Conservancy of Texas. San Antonio, Texas.

Van Auken, O.W. and J.K. Bush. 1998. Spatial relationships of *Helianthus paradoxus* (Compositae) and associated salt marsh plants. Southwestern Naturalist 43:313-320.

Veni, G. 1991. Delineation and Preliminary Hydrogeologic Investigations of the Diamond Y Spring, Pecos County, Texas. Report to the Nature Conservancy of Texas.

Westerman, R. L. 1990. Soil Testing and Plant Analysis, 3rd Edition. Soil Science Society of America, Inc. Madison.

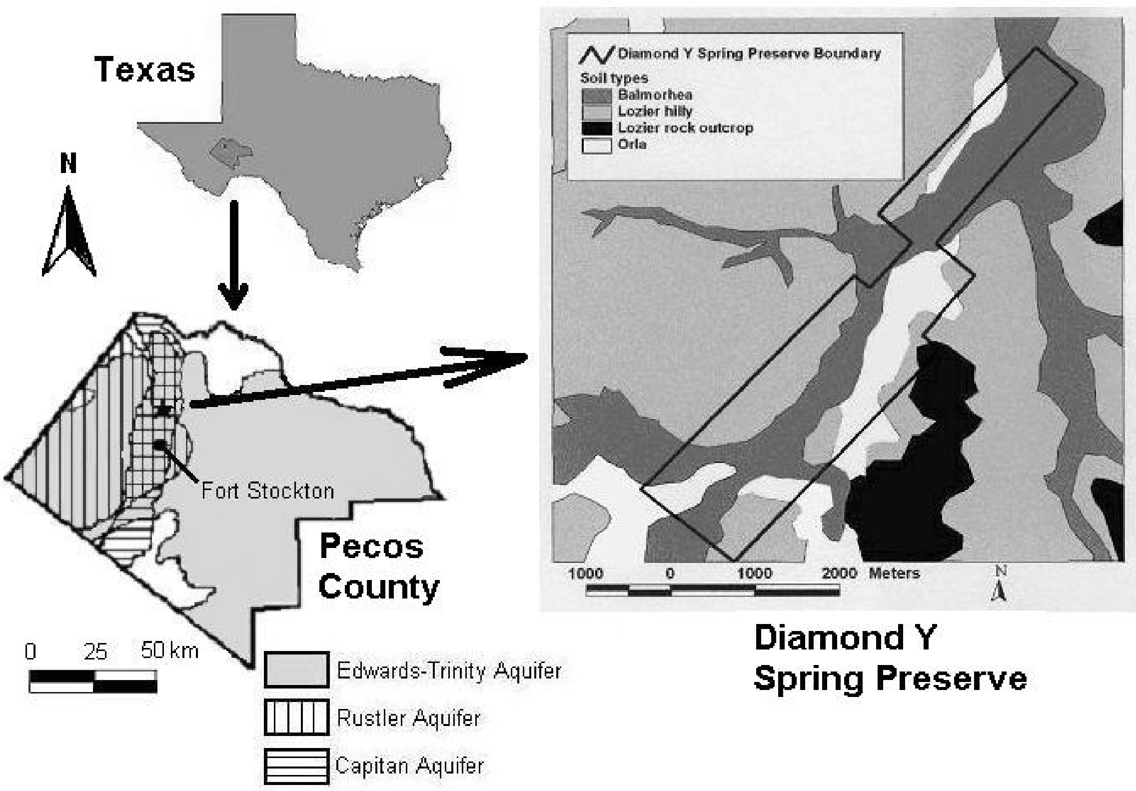

Figure 1. Pecos County is located in west Texas. The major aquifers underlying the Fort Stockton area and Pecos County, Texas include the Edwards-Trinity, Rustler and Capitan Reef. Soil types present in the area of the Diamond Y Spring Preserve include Balmorhea, Orla, and Lozier association soils (Rives 1980).

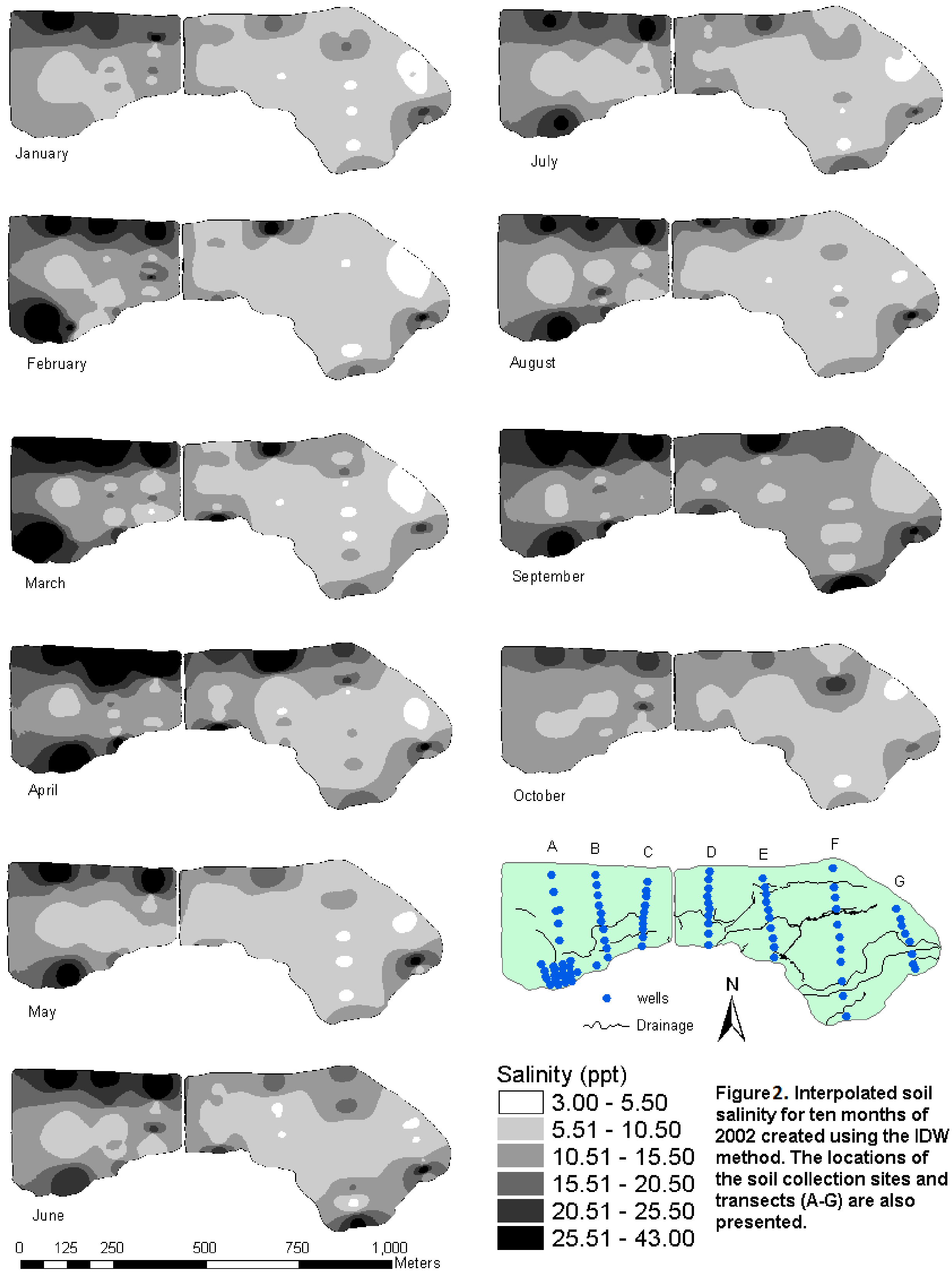

Figure2. Interpolated soil salinity for ten months of 2002 created using the IDW method. The locations of the soil collection sites and transects (A-G) are also presented.

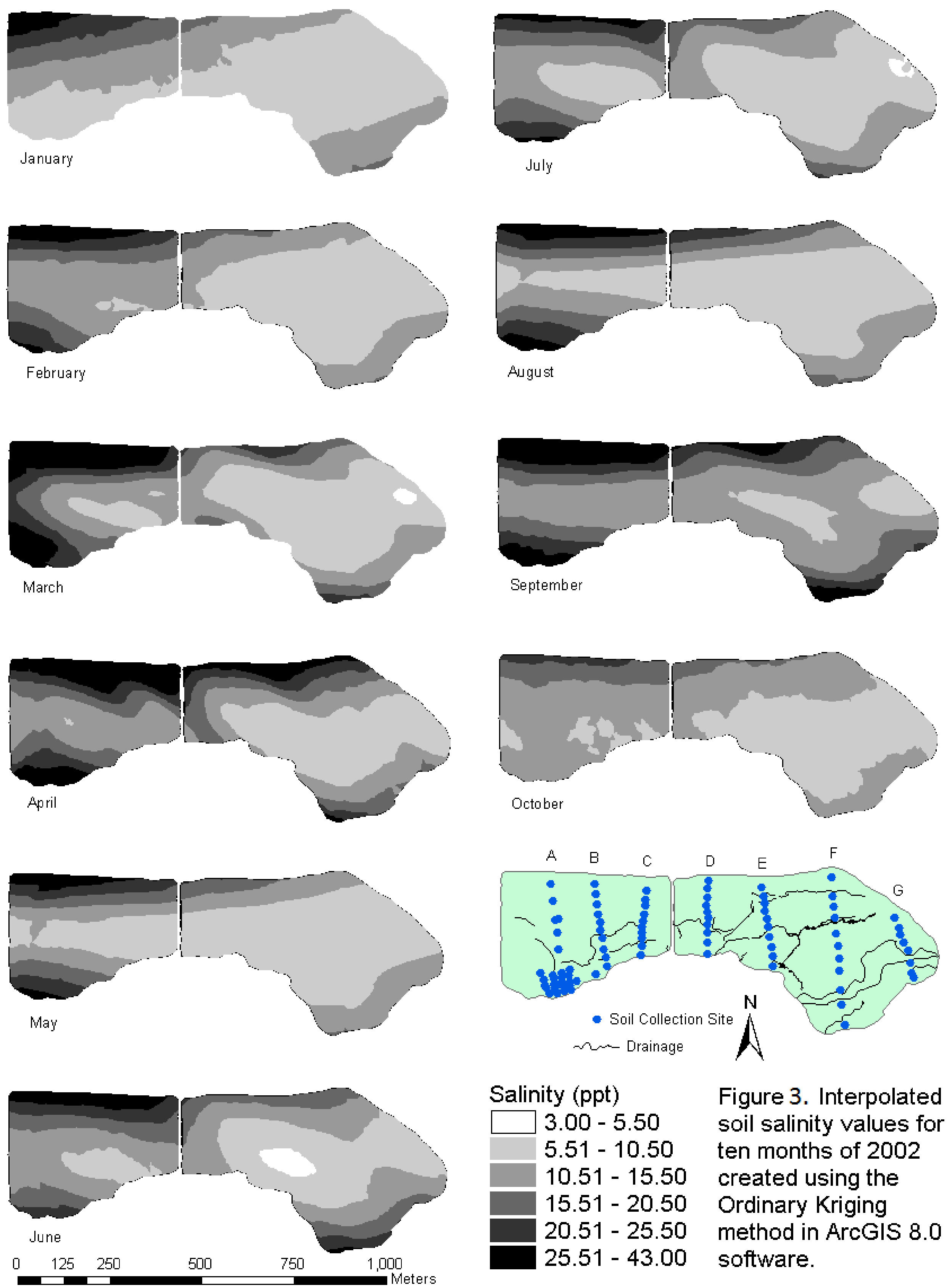

Figure 3. Interpolated soil salinity values for ten months of 2002 created using the Ordinary Kriging method in ArcGIS 8.0 software.

Month	**Mean**		**Root-Mean-Square**	
	IDW	**Kriging**	**IDW**	**Kriging**
January	-0.15	0.05	5.48	5.10
February	-0.69	-0.05	7.31	6.97
March	-1.13	-0.06	7.67	7.30
April	-1.26	-0.29	10.1	8.57
May	-1.02	-0.13	7.63	6.38
June	-1.06	-0.18	8.27	6.59
July	-0.89	-0.36	6.17	5.20
August	-0.87	0.01	7.74	6.07
September	-1.33	-0.27	7.65	6.76
October	-0.46	-0.05	5.97	4.97

Table 1. Mean and Root-Mean-Square error statistics generated for the interpolated surfaces created using the IDW and ordinary kriging methods. The ordinary kriging method consistently produced values closer to zero indicating it would generally yield a better estimation of the soil salinity.