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Comparison of Nitrogenous Ion Deposition and Human and Animal Census Trends in Eastern North Carolina

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by
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Abstract - The presence of several National Acid Deposition Program/National Trends Network sites in North Carolina has provided the opportunity to review the trends of various pollutants in precipitation. Nitrogen containing ions, ammonium and nitrate ions, are found in precipitation in North Carolina. At some sites ammonium ions are found in increasing amounts. Data from the four easternmost NADP/NTN sites (in Bertie, Sampson, Scotland and Wake Counties) were studied.

Agricultural populations in the counties surrounding the NADP/NTN sites may have measurable impacts on nitrogen containing ions in local precipitation. This study was designed to evaluate statistical (not necessarily *causal*) relationships between the ionic concentrations and the population densities of humans, hogs, layer chickens, broilers, turkeys, and wild deer.

In the long-term time frame of this study (1978 to 1995), the only instance of a steadily increasing ammonium trend was at the site in Sampson County. The Bertie and Scotland County sites seem to have increasing (but not significant) trends from 1990 to 1995. No significant time trend was observed for any nitrate concentrations.

Significantly increasing human populations occurred in Wake County and (to a lesser extent) in Scotland County. A significantly decreasing human population occurred in Bertie County.

Hog densities (inventory per square mile) increased significantly in Sampson County and decreased significantly in Wake County. Upward trends are apparent in Bertie and Scotland Counties from 1988 to 1995, but no long term overall significant change can be claimed.

Significantly decreasing chicken densities occurred in Sampson County and Wake County. Bertie and Scotland Counties (and as of 1989 Wake County) have too few chickens to allow the inventories to be reported.

The deer population index in Sandhills Wildlife Management Area, within Scotland County and immediately surrounding the local NADP/NTN monitor has not significantly changed over the long term, although shorter term oscillations are apparent, currently decreasing.

Turkey and Broiler densities are only available for individual counties in the years from 1992 on, and we can not perform a meaningful analysis of trend using only four published years of data. Bertie, Scotland and Wake Counties have not have publishable numbers of turkeys in any year. Wake County has had only one publishable broiler inventory, in 1993.

In Sampson County, both hog and chicken densities are significant predictors of NH_4^+. The regression including hog densities and excluding chicken densities is the most accurate: Ammonium (mg/l) = 0.15 + 0.000 086 × hog density. Sampson County has the largest hog densities of the four counties studied.

In Scotland County, no significant predictor of NH_4^+ is found. However, for the years 1992-95, hog densities are comparable to those found in Sampson County in 1978-86. A regression restricted to these four years has a much smaller significance probability and predicts ammonium = 0.13 + 0.000 15 × hog density.

Scotland County provides an "almost significant" (p=0.051) predictor for NO_3^-: nitrate (mg/l) = -47 + 0.55 × human density. This regression equation is inaccurate, however, consistently overestimating the concentration for 1991-95.

In Wake County, hog densities are a significant predictor of NH_4^+, but are inaccurate for the most recent years. The regression equation is Ammonium (mg/l) = 0.27 - 0.002 × hog density. This equation underestimates concentration for 1989-95. Wake County has the smallest hog densities and the largest human densities of the counties studied. Activities associated with dense urban populations seem more likely to influence observed NH_4^+, even though human density was not a significant predictor.

In Bertie County, the livestock and human population densities are not significant predictors of NH_4^+ or of NO_3^-.

The presence of significant statistical regressions does not prove that any particular activity has *caused* the pollutant concentration trend to exist or change. However, regression results suggest hog densities above 200 per mi^2 (and possibly above 140 per mi^2) are significant and accurate predictors of ammonium concentrations in precipitation. Lower hog densities, and all other available population densities are either not significant predictors or fit the concentrations with consistent inaccuracies for several consecutive years.

Further studies should be conducted, to establish better understanding of nitrogen emissions, dispersion and fate in the environment. The relative impacts attributable to mobile source emissions, large combustion sources, municipal water treatment plants, animal waste disposal and fertilizer applications need to be compared.

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Introduction

For many years the North Carolina Division of Air Quality has participated with other agencies in the support of the approximately 200 National Atmospheric Deposition Program/National Trends Network (NADP/NTN) sites. These sites provide information about the amount and types of pollutants in rain water and, in some locations, pollutants which fall to earth dry. The NADP/NTN historical database includes information about the presence of ammonium ions, which is a reacted form of ammonia, and of nitrate ions, an oxidized form of nitrogen. A map of the NADP/NTN site locations currently operated in North Carolina is displayed in Figure 1.

The swine industry in North Carolina has become a very important factor in the state's economy, and has experienced tremendous growth, 15 to 18 percent annual increases in total hog inventory since about 1990 (Figure 2). In December 1995 there were 8.2 million hogs on North Carolina farms, and there are now about 9.5 million hogs in the state, a population second only to Iowa (which probably has about 12 million). The hog population is heavily concentrated in eastern counties (Figure 3), and in particular, Sampson County had 1.7 million hogs in its December 1995 inventory.

North Carolina also has a growing human population that equals or exceeds 7.2 million people. Recently, the governor of North Carolina appointed a task force to study the issue of odor generated by hog farms, because of many complaints of unpleasant odors thought to be attributable to nearby farms. Swine manure may generate as many as 150 different volatile compounds, and the methods of managing and disposing of it often concentrate the chemicals and the odors (N.C. Agr. Res. Serv. 1995). Using current technologies, odors are evident downwind from many hog farms. Studies in Europe report that measures that reduce ammonia generally also reduce odors from other compounds (N.C. Agr. Res. Serv. 1995).

In addition to swine, farm operators in the Eastern counties of North Carolina grow substantial numbers of turkeys, broilers and layer chickens. These may also be associated with odor complaints in some places, for they likely emit similar volatile chemicals. Thus, any study of indicators of odor associated with an aggricultural population in this region should

not exclude consideration of these poultry species.

Methods

Ammonia (NH_3) is emitted by the application of fertilizer, a few industrial sources, sewage treatment, and the storage, treatment and handling of animal waste. Nearly all combustion sources and certain industrial processes emit oxides of nitrogen (NO_x) which can be changed into ionic nitrate in the atmosphere.

Here we compare ammonium (NH_4^+) and nitrate (NO_3^-) concentrations in precipitation to the human and agricultural population densities in Sampson County, Scotland County, Bertie County and Wake County, North Carolina, using the precipitation-weighted annual mean NH_4^+ and NO_3^- concentrations reported by NADP/NTN at site NC35 in Sampson, NC03 in Bertie County, and NC41 in Wake County from 1978 through 1995 and at NC36 in Scotland County from 1983 through 1995. (Three NADP/NTN sites in Western North Carolina also have precipitation ion data for 1978 through 1995, but they are not included in this study.)

From the statistical service of the North Carolina Department of Agriculture (NCDA), we obtained 1 December hog inventory data in each of these four counties for all of the years of local NADP/NTN site operation, and 1 December production totals for turkeys, broilers, and chickens in each county, for the years in which data were available. (The NCDA does not release county production totals when they are below a specified minimum value for each commodity or when there is only one identifiable producer in the county. Also, turkey and broiler production data were not collected at the level of individual counties prior to 1992.)

We obtained human population data in each of the four counties for 1980 through 1995 from the North Carolina Office of State Planning.

The goal is to determine whether concentrations of nitrogen-bearing ions vary in association with surrounding area population densities, by studying mathematical correlations. **The results can not be used to identify actual sources of NH_4^+ or NO_3^- in precipitation.** (However, failing to detect an association could be interpreted as evidence that the activity in question is possibly not a source.)

Relationships found between ion concentrations and population densities will be expressed as Spearman rank correlation coefficients. When a significant correlation is found, a prediction equation for the ion concentration will be computed using a regression estimate that minimizes the sum of the smallest half of the squared residuals ("least trimmed squares regression") (Rousseeuw and Leroy 1987). Some data series are tested for a time trend using a sign test based on Mann (1945).

NADP/NTN Sampling Methodology

Weekly precipitation samples are collected in an AeroChem Metrics model 301 wet/dry sampler and the "wet-side" sampling container (13 L polyethylene pail) is removed from the sampler every Tuesday. Samples are mailed to Central Analytical Laboratory (CAL) in Champaign, IL for analysis. Prior to 11 January 1994, the sample was mailed in the 13 L polyethylene sampling container. Since that time, the sample has been mailed to the CAL in a 1 L high-density polyethylene bottle. The pH and conductivity are measured at the site if there is adequate sample. (Collection of the "dry-side" sample, which consists primarily of large particle deposition, is optional and is not currently performed at NC03, NC35, NC36 or NC41.)

Chemical constituents measured in wet deposition by the laboratory are: SO_4^{2-}, NO_3^-, Cl^-, PO_4^{3-}, Na^+, K^+, Ca^{2+}, Mg^{2+}, NH_4^+, H^+ (pH) and conductivity. The cations and anions are analyzed by ion chromatography (SO_4^{2-},NO_3^-, Cl^-, PO_4^{3-}), automated colorimetry (NH_4^+), atomic absorption spectroscopy (Na^+, K^+, Ca^{2+}, Mg^{2+}), ion specific electrode (H^+), and conductivity as electric conductance. (For those sites sending the "dry-side" buckets to the laboratory, the same analyses are performed on a distilled water leachate.) More information on field and analytical procedures is found in Bigelow and Dosset (1988) and Peden (1986).

Precipitation amounts are measured using a Belfort Model 5-780 dual-traverse recording rain gauge which has a 12 inch (30 cm) capacity.

Agricultural Research Service Sampling Methodology

Quarterly hog inventory data estimates published by the U.S. Department of Agriculture are based on a random sample of U.S. producers in which larger producers have a greater selection probability

than do smaller ones. (In the 1 December 1994 survey, about 69,000, or 84 percent, of the 82,000 operations responded within the first half of December.) Interviews are conducted variously by using mail survey questionnaires, telephone surveys and face-to-face interviews. Rigid quality controls are used to minimize the effects of nonsampling errors.

Each state office provides an analysis of its own data, and the national and state estimates are compared for reasonableness. They are also compared to estimates derived by adjusting earlier year estimates for estimated births, imports, slaughter, exports and deaths. When the current estimate is complete, four previous quarters are reviewed and may be revised to improve relationships between successive inventories. At each December inventory, hog check-off receipts and slaughter data are used to review the most recent two years of quarterly estimates. A final review is made when the Department of Commerce's subsequent 5-year Census of Agriculture is published. (Thus all estimates through 1 December 1992 are final, and all estimates since 1 March 1993 will remain provisional until the 1997 census is available.)

A "root mean squared error" published with the final estimate of each quarter is computed, based on the difference between the initial and final estimate. It is typically between one and two percent of the inventory estimate.

Broiler and turkey estimates are based mainly on placements of broilers and poults from hatchery production surveys. Death and loss data are obtained from nonprobability surveys. A grower survey is used to estimate turkeys raised. Federally Inspected Slaughter data are used as check data on the number raised. When preliminary estimates for the current year are made in August, estimates for the previous year are subject to revision based on updated hatchery and slaughter data. A final review is made when the Department of Commerce's subsequent 5-year Census of Agriculture is published. At the U.S. level, the final total usually differs by less than one-half of one percent from the first preliminary estimate.

Poultry estimates are based mainly on sample surveys of chicken growers. The 1 December report uses a nearly complete enumeration of the largest growers. Estimates of layer numbers are based on ratio to December hens and pullets of laying age, ratio to the previous year's estimate, and adjustment of the previous estimate of layers for death loss, number

destroyed, layers sold, and pullets added.

Human Demographics Methodology

Annual population estimates for North Carolina counties and municipalities are produced by the North Carolina Office of State Planning State Demographics unit. To produce estimates, the unit develops and enhances complex mathematical computer models and collects and reviews relevant data from federal, state and local government sources. North Carolina municipalities are surveyed annually for annexation data; municipalities and counties are surveyed annually for selected institutional data; and military bases are surveyed annually for barracks population data.

Site Descriptions

NC35 in Sampson County is in a rural location on gently sloping land on the Horticultural Crops Research Station operated by the North Carolina Department of Agriculture. The immediately surrounding area is grassy lawn, with a farm pond on the N side. Agricultural fields for various crops are close by S and W. There are numerous large hog operations in Sampson County, but those located nearest to NC35 are 1 mi (1.5 km) or more E. A large hog processing plant is ~3 mi (5 km) W.

NC36 in Scotland County is in a rural location on gently sloping land in the Jordan Creek watershed, within the Sandhills Wildlife Management Area operated by N.C. Wildlife Resources Commission. The immediately surrounding area is cleared pine forest, and older forest surrounds the site at greater distances. There are no domestic livestock operations nearby, but there is a population of white-tailed deer (*Odocoileus virginianus*) ranging freely in the WMA, with access to within a few meters of the site.

The actual size of the deer population in Sandhills WMA is not available. However, an index proportional to it is computed annually by the Wildlife Resources Commission. Four or five linear transects are selected at random in the "block" east of U.S. Highway 1. A biologist walks the length of each transect and records visual evidence of deer crossings. The average number of crossings per mi is reported as the population index.

NC03 in Bertie County is in a rural location on gently sloping land on the

Peanut Belt Research Station operated by the North Carolina Department of Agriculture. The immediately surrounding area is a grassy lawn. The research station contains 250 acres (100 ha) of cropland. There is a small hog farm (~25 head) within 1 mi (1.5 km) E (J. Stephen Barnes, *pers. comm.*). There is a major chicken processing plant about 3 mi (5 km) SW, which is often directly upwind in the summer.

NC41 in Wake County is in a suburban location (more than 15 buildings per km^2 inside the 1 km radius circle surrounding the site) on gently sloping land on a North Carolina State University Research Farm S of Raleigh. It is surrounded by land in agricultural use. A Swine Educational Unit housing 450 sows and 100 boars and producing 7,500 pigs annually is located 1/4 mi (0.5 km) E with a ridge intervening. Poultry Educational Units for turkeys and chickens, and Dairy and Beef Educational Units are located ≥1/2 mi (0.75 km) S (36,000 chickens, 100 breeder turkeys, 5,000 growing-out turkeys, 150 turkeys used for reproductive studies; 350 dairy animals). Air pollution crop loss studies are conducted in the immediate vicinity of the acid rain sampler; ozone generating equipment is located a few yards immediately N.

Results

Each of the four counties studied here has unique characteristics making it most appropriate to consider the results of each county separately, but organized in a unified way. Each section to follow begins with a table showing the nitrogenous ion concentrations and the available human population and animal inventory, production or index densities (for convenience, all of these may be referred to as "populations"). Second, the time trends for each concentration and population are described and illustrated on charts. Third, correlations between NH_4^+ concentrations and populations are described and illustrated; for significantly (and almost-significantly) correlated variables, a robust linear regression (least trimmed squares) equation is described. Finally, correlations between NO_3^- concentrations and populations are presented, with robust linear regressions where appropriate.

The agricultural population data are not published as densities, but rather as totals within each county. For reference, the published totals are shown in tables in the Appendix: NH_4^+ concentrations in Table A 1, NO_3^- concentrations in Table A 2, human populations in Table A 3, hog

inventories in Table A 4, deer indexes in Table A 5, turkeys in Table A 6, chickens in Table A 7, and broilers in Table A 8.

Sampson County

Table 1 lists concentrations of NH_4^+ and NO_3^- at NC35 and densities per mi^2 for people, hogs, turkeys, broilers and chickens in Sampson County. The land area in Sampson County is 963 mi^2.

In Figure 4 we show NH_4^+ concentration, NO_3^- concentration, and human, hog and chicken population densities as time series. There are very highly significant time trends for NH_4^+ concentration (s*=107, p=0.0001), hog density (s*=139, p<0.0001) and chicken density (s*=-101, p=0.0001). There is no significant trend for NO_3^- concentration (s*=-9, p=0.73) or human population density (s*=-20, p=0.37) . There are too few turkey or broiler population densities for a meaningful test of trend.

In Sampson County there is an upward trend in the ammonium concentration that appears to begin in 1988 or 1989, and there is an upward trend in hog population beginning as early as 1981, and becoming very steep from 1989 onward. Chickens decreased rapidly from 1978 through 1984 and much more gradually from 1985 through 1995.

Scatter plots and significant least trimmed squares regressions of ammonium concentration and nitrate concentration on population densities are presented in Figure 5. The annual mean NH_4^+ concentrations at NC35 exhibit a very highly significant positive rank correlation with Sampson County hog densities (r=0.81, p=0.0008) and a very highly significant negative rank correlation with Sampson County chicken densities (r=-0.63, p=0.010). The rank correlation between NH_4^+ and Sampson County human population densities is not significant (r=0.047, p=0.86).

Robust regression estimates corresponding to the correlated variables indicate that ammonium concentration can be estimated by 0.15 + 0.000 086 times the hog density or by 0.26 - 0.000 29 times the chicken density. Predicted ammonium concentrations from these two regressions are plotted in Figure 6. The ammonium concentrations predicted by the hog density regression (Figure 6A) are very accurate, but those predicted by the chicken density (Figure 6B) consistently underestimate the concentration for 1990-1995.This reflects about 8 percent average annual

increase in ammonium as hog inventories in the county were growing between 15 and 25 percent per year and chicken production was decreasing about 5 percent per year. A least trimmed squares regression with both hog and chicken densities is $[NH_4^+] = 0.153 + 0.000\ 082\ 1\ [Hog] + 0.000\ 010\ 8\ [Chicken]$, almost indistinguishable from the regression with hog densities alone.

There are no significant correlations between NO_3^- concentrations and Sampson County hog densities (r=-0.31, p=0.21), chicken densities (r=0.10, p=0.68) or human population densities (r=0.03, p=0.92). The mean NO_3^- concentration is 9.79 mg/l. Note that the NO_3^- concentration for 1978 is very different from those for 1979 through 1995; therefore, the 1978 datum was excluded from these calculations.

Scotland County

Table 2 lists concentrations of NH_4^+ and NO_3^- at NC36; densities per mi^2 for people, hogs, broilers and chickens in Scotland County; and the deer population index per mi in the Sandhills Wildlife Management Area east of U.S. Highway 1. The land area in Scotland County is 317 mi^2.

In Figure 7 we show NH_4^+ concentration, NO_3^- concentration, and human, hog and chicken population densities as time series. There is a very highly significant time trend for human population density (s*=70, p<0.0001), a significant trend for NO_3^- concentration (s*=34, p=0.038), and an almost-significant trend for NH_4^+ concentration (s*=32, p=0.051). There is no significant trend for hog population density (s*=30, p=0.07) or deer index (s*=-9, p=0.58). There are too few broiler population densities for a meaningful test of trend.

In Scotland County, there is a very modest upward trend in ammonium concentration from 1983 to 1995, while the hog population was steady from 1983 to 1990 and then began a steep trend of 32 percent average annual increase, achieving 347 hogs per mi^2 in 1995. The human population density trend is a steady, but very small, increase, averaging about 0.4 percent per year.

Scatter plots of ammonium concentration and nitrate concentration on population densities are presented in Figure 8. The annual mean NH_4^+ concentrations at NC36 exhibit no significant rank correlations with hog

densities (r=-0.03, p=0.92), human densities (r=0.51, p=0.08) or deer indexes (r=-0.01, p=0.96).

The NH_4^+ concentrations at NC36 are not accurately estimated by any simple regression relationship to the population densities. The mean concentration is 0.152 mg/l. Although the correlation between NH_4^+ and hog densities is not significant, there may be a relationship based on the five most recent hog densities, which include the four highest densities for which a corresponding NH_4^+ concentrations has been measured. Predicted ammonium concentrations from a regression equation based on these data are plotted in Figure 9A. This relationship (rank correlation r=0.67, p=0.22; $[NH_4^+] = 0.13 + 0.000\ 15$ times density) is not significant, but if the density remains very high in future years, the relationship may merit further investigation.

There are no significant correlations between NO_3^- concentrations and Scotland County hog densities (r=-0.26, p=0.38) or deer indices, (r=-0.09, p=0.76). The correlation between NO_3^- concentrations and human population densities is almost significant (r=0.57, p=0.051). The mean NO_3^- concentration is 11.18 mg/l. Note that the NO_3^- concentration for 1983 is very different from those for 1984 through 1995; therefore, the 1983 datum was excluded from these calculations.

The robust regression estimates corresponding to the almost-correlated variables indicate that nitrate concentration can be estimated by -47 + 0.55 times the human density. Predicted nitrate concentrations from this regression are plotted in Figure 9B. This regression should not be extrapolated beyond the range of the data, or about 104 to 110 people per mi^2, and it underestimates NO_3^- during 1987-1990 and overestimates NO_3^- during 1991-1995. This reflects about 0.55 percent average annual increase in nitrate concentrations while human population in the county was growing at about 0.4 percent per year.

Bertie County

Table 3 lists concentrations of NH_4^+ and NO_3^- at NC03 and densities per mi^2 for people, hogs and broilers in Bertie County. The land area in Bertie County is 693 mi^2.

In Figure 10 we show NH_4^+ concentration, NO_3^- concentration, and

human, and hog population densities as time series. There is a highly significant time trend for human population density (s^*=-68, p=0.002) and a significant trend for hog density (s^*=-64, p<0.015). There is no significant trend for NH_4^+ concentration (s^*=36, p=0.17) or NO_3^- concentration (s^*=14, p=0.60). There are too few broiler population densities for a meaningful test of trend.

Bertie County's human population density decreased by 0.3 percent per year (on the average) from 1980 to 1991, and has been increasing by about 0.4 percent per year from 1991 through 1995. The hog density decreased from 1983 to 1988 and began increasing in 1990, at a rate of about 8 percent per year.

Scatter plots of ammonium concentration and nitrate concentration on population densities are presented in Figure 11. The annual mean NH_4^+ concentrations at NC03 exhibit no significant rank correlations with hog densities (r=-0.036, p=0.89) or human densities (r=0.21, p=0.42). The mean NH_4^+ concentration is 0.17 mg/l.

There are no significant correlations between NO_3^- concentrations and Bertie County hog densities (r=-0.11, p=0.64), or human population densities (r=0.13, p=0.63). The mean NO_3^- concentration is 10.33 mg/l. Note that the NO_3^- concentration for 1978 is very different from those for 1979 through 1995; therefore, the 1978 datum was excluded from these calculations.

Wake County

Table 4 lists concentrations of NH_4^+ and NO_3^- at NC41 and densities per mi^2 for people and hogs, broilers and chickens in Wake County. The land area in Wake County is 864 mi^2.

In Figure 12 we show NH_4^+ concentration, NO_3^- concentration, and human, hog and chicken population densities as time series. There are very highly significant time trends for hog density (s^*=-142, p<0.0001) human density (s^*=120, p<0.0001) and chicken density (s^*=-35, p=0.0017). There is no significant trend for NH_4^+ concentration (s^*=45, p=0.09), or NO_3^- concentration (s^*=-9, p=0.73). There is only one published broiler population density.

Unlike the other sites, in Wake County the hog population density has been decreasing in most years since 1979, by an amount averaging 5 percent per year. The chicken density decreased from 1979 to 1982 by about 9 percent per year, then held steady until 1986 and decreased by one half in 1987. From 1988 to the present the chicken production numbers in Wake County have been unpublishable. The human population density has steadily increased by 3.6 percent per year (on the average) from 1980 to 1995.

Scatter plots of ammonium concentration and nitrate concentration on population densities are presented in Figure 13. The annual mean NH_4^+ concentrations at NC41 exhibit a significant *negative* rank correlation with Wake County hog densities (r=0.54, p=0.027).The rank correlation between NH_4^+ concentrations and Wake County chicken densities is not significant (r=-0.22, p=0.50), and the correlation between NH_4^+ concentrations and human population densities is not significant (r=0.44, p=0.09).

The robust regression estimate corresponding to the correlated variables (Figure 13) suggests estimating ammonium concentration as 0.27 - 0.002 times the hog density. Predicted ammonium concentrations from a regression equation based on these data are plotted in Figure 14. This regression consistently underestimates NH_4^+ for the years 1989 through 1995.

There are no significant correlations between NO_3^- concentrations and Wake County hog densities (r=0.21, p=0.41), chicken densities (r=-0.09, p=0.78) or human population densities (r=-0.19, p=0.46). The mean NO_3^- concentration is 10.91 mg/l. Note that the NO_3^- concentration for 1978 is very different from those for 1979 through 1995; therefore, the 1978 datum was excluded from these calculations.

Discussion

Significant Time Trends

We discovered only one significant monotone time trend for NH_4^+ concentrations, an increasing trend at NC35 in Sampson County. No NADP/NTN stations showed a significant trend for NO_3^- concentrations. Hog densities have been increasing in Sampson County for nearly the

entire duration of this study. In Scotland County and Bertie County, while there is no significant trend, visual inspection (Figure 7 and 10) is suggestive of an increasing tendency in the years since 1990. Wake County shows a significant decreasing trend for hogs.

Significant decreasing chicken densities have been observable in Sampson County and Wake County. (Since 1989, Wake County estimates of chicken production have not been published.)

The human population has been increasing in Scotland County (slowly) and Wake County (rapidly) and has been decreasing in Bertie County. There is no significant trend in Sampson County, although visual inspection (Figure 4) suggests a slow monotone decrease from 1980 to 1990 followed by a faster increase from 1990 to 1995.

Significant Regressions of NH_4^+

Significant or "almost significant" regressions of NH_4^+ concentration on population densities were observed in four cases.

In Sampson County, both hog and chicken densities are significant predictors of NH_4^+. The regression including hog densities and excluding chicken densities is the most accurate: $[NH_4^+] = 0.15 + 0.000\ 086$ [Hog].

Wake County yields a significant regression with a decreasing slope, $[NH_4^+] = 0.27 - 0.002$ [Hog]. This regression, however, underestimates the actual concentrations for the recent years, 1989 through 1995.

In Scotland County, we find a regression that is "almost significant", not in the sense of having a nonzero slope with a borderline significance level, but a substantial increase in significance when the regression is limited to the years, 1992-95, when Scotland County hog densities are comparable to the smallest Sampson County hog densities. The apparent regression line is $[NH_4^+] = 0.13 + 0.000\ 15$ [Hog].

Significant Regression of NO_3^-

We observed only one "almost significant" regression involving NO_3^-. In Scotland County, the relationship $[NO_3^-] = -47 + 0.55$ times [Human] has a significance probability of about 5.1 percent. This regression

consistently overestimates the NO_3^- concentration, however, in all years after 1990.

Research Implications

The methods applied in this paper can not identify the actual sources of NH_4^+ or NO_3^- in precipitation; however, they do detect evidence of an association between the county hog density when it is very large (>140 hogs per mi^2)[1] and the concentration of NH_4^+. This information demonstrates the desirability of conducting further studies to establish better understanding of nitrogen emissions, dispersion and fate in the environment.

Comparisons need to be made among the relative impacts attributable to nitrogen compound emissions from mobile sources, large combustion sources, municipal water treatment plants, animal waste disposal and fertilizer applications. These studies need to include ambient monitoring, emission factor development, atmospheric concentration modeling, and study of the fate of ammonia and other nitrogen compounds in the environment.

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[1]Twenty counties had hog densities over 140 in 1995 (Table A 9).

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Appendix.

Table A I. Ammonium Ion Concentrations

Precipitation-weighted annual mean ammonium concentrations in micrograms per cubic meter

year (statistic)	NC03 Bertie	NC35 Sampson	NC36 Scotland	NC41 Wake
1978	0.05	0.09		0.20
1979	0.08	0.12		0.23
1980	0.20	0.17		0.23
1981	0.17	0.17		0.21
1982	0.19	0.17		0.22
1983	0.28	0.17	0.09	0.32
1984	0.13	0.17	0.15	0.20
1985	0.14	0.17	0.09	0.20
1986	0.19	0.20	0.16	0.28
1987	0.18	0.19	0.12	0.23
1988	0.09	0.13	0.12	0.19
1989	0.15	0.21	0.22	0.39
1990	0.22	0.29	0.21	0.32
1991	0.15	0.22	0.16	0.34
1992	0.18	0.19	0.15	0.25
1993	0.25	0.25	0.15	0.29
1994	0.19	0.36	0.17	0.26
1995	0.18	0.37	0.18	0.26
rank correlations with hog inventory				
r	0.036	0.81	0.67	-0.54
p	-0.89	-0.001	-0.22	-0.027

Table A 2. Nitrate Ion Concentrations

Precipitation-weighted annual mean nitrate concentrations in micrograms per cubic meter

year (statistic)	NC03 Bertie	NC35 Sampson	NC36 Scotland	NC41 Wake
1978	0.84	1.11		1.90
1979	8.57	9.57		11.77
1980	11.23	11.51		11.18
1981	7.44	10.51		7.56
1982	11.24	10.80		12.38
1983	12.17	9.89	1.71	13.36
1984	10.63	11.14	10.66	11.17
1985	8.72	8.20	7.92	9.04
1986	10.20	8.66	9.37	10.54
1987	10.84	8.06	10.83	11.20
1988	11.61	9.26	11.22	13.14
1989	12.62	11.85	16.19	16.59
1990	10.23	10.02	11.62	10.09
1991	10.20	10.66	11.85	9.84
1992	10.90	7.82	10.59	8.12
1993	10.20	10.51	9.90	9.58
1994	8.30	8.09	12.67	8.63
1992	10.58	9.89	11.33	11.23
1993	10.20	10.51	9.90	9.58
1994	8.30	8.09	12.67	8.63
1995	10.58	9.89	11.33	11.23
mean[2]	10.24	9.75	11.20	10.74
rank correlations with hog inventory				
r	-0.16	-0.16	-0.2	0.04
p	(0.51)	(0.51)	(0.48)	(0.86)
Mann's test for trend[1]				
*s**	-24	0	22	-26
z	-0.99	0	1.5	-1.07
p	(0.32)	(1.00)	(0.13)	(0.28)

[2]Each site has an atypically low concentration in the first year, which is omitted from the calculation.

Table A 3. Human Population Data.

Annual census estimates

year	Bertie	Sampson	Scotland	Wake	State
80	21,024	49,687	32,273	301,429	5,880,095
81	21,010	49,387	32,551	310,334	5,955,597
82	21,044	49,164	32,841	317,390	6,018,550
83	21,130	48,822	32,963	328,296	6,077,018
84	21,022	48,838	33,250	343,203	6,164,501
85	21,001	48,452	33,016	360,387	6,254,998
86	20,807	48,005	32,994	373,616	6,323,174
87	20,678	48,004	33,440	383,430	6,405,868
88	20,523	47,879	33,698	399,149	6,483,344
89	20,498	47,532	33,576	413,959	6,568,810
90	20,388	47,297	33,763	426,301	6,632,448
91	20,332	47,876	34,160	443,857	6,751,715
92	20,390	48,474	34,365	458,789	6,837,325
93	20,530	49,300	34,464	477,611	6,953,547
94	20,574	49,940	34,648	497,282	7,070,034
95	20,638	50,523	34,718	518,271	7,194,238

Table A 4. Hog Inventory Data.

Thousands of hogs in the 1 December annual inventory.

year	State	Bertie	Sampson	Scotland	Wake
1978	2,350	48.3	191.6	36.0	27.5
1979	2,650	56.0	216.5	46.8	28.5
1980	2,460	55.0	202.5	34.0	27.0
1981	1,980	45.0	170.0	20.0	25.0
1982	2,150	58.6	188.7	20.5	22.6
1983	2,350	59.2	248.7	25.5	22.4
1984	2,300	46.1	264.1	25.8	20.9
1985	2,350	45.0	286.9	26.9	15.8
1986	2,400	41.9	315.7	27.0	14.8
1987	2,580	33.0	370.0	27.0	12.6
1988	2,700	28.0	415.0	25.0	12.5
1989	2,570	28.0	455.0	25.0	10.0
1990	2,800	29.0	570.0	16.0	10.0
1991	3,650	35.0	750.0	25.0	10.0
1992	4,500	35.0	950.0	45.0	10.0
1993	5,400	35.0	1,150.0	76.0	9.0
1994	7,000	39.0	1,450.0	82.0	9.5
1995	8,200	43.0	1,700.0	110.0	9.0

Table A 5. Deer Track Counts Population Index

Mean crossings (using 4 or 5 transects) in the area of Sandhills WMA east of U.S. Highway 1, immediately surrounding NC36 and mainly in Scotland County

year	deer track crossings	
(statistic)	per mi	per km
1978	50.7	31.5
1979	51.8	32.2
1980	42.1	26.2
1981	45.2	28.1
1982	38.1	23.7
1983	40.9	25.4
1984	44.5	27.7
1985	44.3	27.5
1986	32.2	20.0
1987	25.4	15.8
1988	33.7	20.9
1989	38.2	23.7
1990	57.8	35.9
1991	43.0	26.7
1992	44.3	27.5
1993	41.3	25.7
1994	35.1	21.8
1995	27.2	16.9
1996	33.2	20.6
rank correlation with NH_4^+		
r		0.012
p		(0.96)
rank correlation with NO_3^-		
r		-0.11
p		(0.70)

Table A 6. Turkey Inventory Data.

Thousands of turkeys in the 1 December annual inventory.

year	Sampson	State
1992	10,100	62,000
1993	12,350	61,000
1994	10,200	60,000
1995	10,200	61,200

Table A 7. Chicken Inventory Data.

Thousands of chickens in the 1 December annual inventory.

year	Bertie	Sampson	Scotland	Wake
1977	5	540	5	250
1978		550		225
1979		440		210
1980		340		190
1981		320		170
1982		260		155
1983		260		155
1984		255		155
1985		280		155
1986		280		155
1987		270		74
1988		265		
1989		265		
1990		290		
1991		250		
1992		245		
1993		245		
1994		245		
1995		200		

Table A 8. Broiler Inventory Data.

Thousands of broilers in the 1 December annual inventory.

year	Bertie	Sampson	Scotland	Wake	State
1992	21,800	5,000	4,300		559,300
1993	21,200	8,400	4,000	1,000	615,200
1994	26,000	8,400	4,000		643,500
1995	26,900	8,200	4,000		670,100

Table A 9. Hog Densities in All Counties, 1995.

For 27 counties with unpublished inventories, an upper bound of 500 hogs is assumed and used in density calculation.

COUNTY	area	pop	hogs	hogs/mi^2	hogs/mi^2*	county rank
Alamance	434	108,213	1,600	3.69		70
Alexander	255	27,544	500		1.96	78
Alleghany	230	9,590	500		2.17	75
Anson	533	23,474	35,000	65.67		33
Ashe	427	22,209	500		1.17	90
Avery	247	14,867	500		2.02	77
Beaufort	831	42,283	100,000	120.34		26
Bertie	693	20,388	43,000	62.05		34
Bladen	879	28,663	500,000	568.83		6
Brunswick	873	50,985	68,000	77.89		31
Buncombe	645	174,821	500		0.78	99
Burke	506	75,744	4,700	9.29		61
Cabarrus	360	98,935	10,800	30.00		45
Caldwell	476	70,709	3,100	6.51		63
Camden	239	5,904	7,000	29.29		46
Carteret	532	52,556	2,100	3.95		69
Caswell	435	20,693	1,800	4.14		67
Catawba	406	118,412	500		1.23	88
Chatham	707	38,759	10,000	14.14		52
Cherokee	454	20,170	500		1.10	92
Chowan	180	13,506	24,000	133.33		21
Clay	213	7,155	500		2.35	73
Cleveland	466	84,714	5,000	10.73		55
Columbus	939	49,587	170,000	181.04		18
Craven	725	81,613	89,000	122.76		24
Cumberland	661	274,566	85,000	128.59		23
Currituck	273	13,736	14,000	51.28		37
Dare	388	22,746	500		1.29	86
Davidson	546	126,677	3,400	6.23		65
Davie	264	27,859	2,500	9.47		60
Duplin	822	39,995	1,800,000	2,189.78		1
Durham	299	181,835	500		1.67	80
Edgecombe	511	56,558	95,000	185.91		17

COUNTY	area	pop	hogs	hogs/mi^2	hogs/mi^2*	county rank
Forsyth	424	265,878	500		1.18	89
Franklin	494	36,414	23,000	46.56		40
Gaston	358	175,093	500		1.40	83
Gates	343	9,305	45,000	131.20		22
Graham	289	7,196	500		1.73	79
Granville	542	38,345	3,500	6.46		64
Greene	269	15,384	340,000	1,263.94		3
Guilford	651	347,420	12,000	18.43		51
Halifax	722	55,516	65,000	90.03		28
Harnett	606	67,822	46,000	75.91		32
Haywood	543	46,942	500		0.92	98
Henderson	382	69,285	500		1.31	85
Hertford	356	22,523	50,000	140.45		20
Hoke	381	22,856	46,000	120.73		25
Hyde	634	5,411	12,300	19.40		49
Iredell	591	92,931	1,900	3.21		71
Jackson	495	26,846	500		1.01	94
Johnston	795	81,306	190,000	238.99		11
Jones	467	9,414	190,000	406.85		7
Lee	255	41,374	6,000	23.53		47
Lenoir	391	57,274	270,000	690.54		5
Lincoln	308	50,319	3,000	9.74		58
Mc Dowell	442	35,681	500		1.13	91
Macon	517	23,499	500		0.97	95
Madison	456	16,953	500		1.10	93
Martin	481	25,078	20,000	41.58		41
Mecklenbu	542	511,433	500		0.92	97
Mitchell	220	14,433	500		2.27	74
Montgomery	488	23,346	18,000	36.89		42
Moore	705	59,013	60,000	85.11		29
Nash	552	76,677	105,000	190.22		16
New Hanover	194	120,284	500		2.58	72
Northampton	539	20,798	115,000	213.36		13
Onslow	756	149,838	145,000	191.80		15
Orange	398	93,851	8,000	20.10		48
Pamlico	341	11,372	6,600	19.35		50
Pasquotank	229	31,298	7,000	30.57		44

COUNTY	area	pop	hogs	hogs/mi^2	hogs/mi^2*	county rank
Pender	857	28,855	195,000	227.54		12
Perquimans	261	10,447	30,000	114.94		27
Person	400	30,180	14,500	36.25		43
Pitt	656	107,924	240,000	365.85		8
Polk	234	14,416	500		2.14	76
Randolph	801	106,546	40,000	49.94		39
Richmond	477	44,518	25,000	52.41		36
Robeson	944	105,179	250,000	264.83		10
Rockingham	572	86,064	7,500	13.11		53
Rowan	517	110,605	5,000	9.67		59
Rutherford	566	56,918	700	1.24		87
Sampson	963	47,297	1,700,000	1,765.32		2
Scotland	317	33,754	110,000	347.00		9
Stanly	399	51,765	3,000	7.52		62
Stokes	459	37,223	2,700	5.88		66
Surry	537	61,704	6,600	12.29		54
Swain	530	11,268	500		0.94	96
Transylvania	379	25,520	500		1.32	84
Tyrrell	399	3,856	20,000	50.13		38
Union	643	84,211	36,000	55.99		35
Vance	249	38,892	1,000	4.02		68
Wake	864	423,380	9,000	10.42		57
Warren	443	17,265	36,000	81.26		30
Washington	336	13,997	66,000	196.43		14
Watauga	320	36,952	500		1.56	82
Wayne	555	104,666	470,000	846.85		4
Wilkes	765	59,393	500		0.65	100
Wilson	373	66,061	60,000	160.86		19
Yadkin	335	30,488	3,500	10.45		56
Yancey	311	15,419	500	1.61		81

*This column assumes a hog population of 500 for those counties not reporting an inventory. Most such counties probably have fewer than 500 hogs, so that this "density" is generally an upper bound, rather than an unbiased average estimate.

Table 1. Precipitation-weighted mean mg/l concentrations of NH_4^+ and NO_3^- at NC35 and densities per mi² for people, hogs, turkeys, broilers and chickens in Sampson County. The land area in Sampson County is 963 mi². NA means not available.

year	NC35		Sampson County density				
	$NH4^+$	$NO3^-$	human	hog	turkey	broiler	chicken
78	0.09	1.11	(NA)	199	(NA)	(NA)	571
79	0.12	9.57	(NA)	225	(NA)	(NA)	457
80	0.17	11.51	51.6	210	(NA)	(NA)	353
81	0.17	10.51	51.3	177	(NA)	(NA)	332
82	0.17	10.80	51.1	196	(NA)	(NA)	270
83	0.17	9.89	50.7	258	(NA)	(NA)	270
84	0.17	11.14	50.7	274	(NA)	(NA)	265
85	0.17	8.20	50.3	298	(NA)	(NA)	291
86	0.20	8.66	49.8	328	(NA)	(NA)	291
87	0.19	8.06	49.8	384	(NA)	(NA)	280
88	0.13	9.26	49.7	431	(NA)	(NA)	275
89	0.21	11.85	49.4	472	(NA)	(NA)	275
90	0.29	10.02	49.1	592	(NA)	(NA)	301
91	0.22	10.66	49.7	779	(NA)	(NA)	260
92	0.19	7.82	50.3	987	10,500	5,190	254
93	0.25	10.51	51.2	1,194	12,800	8,720	254
94	0.36	8.09	51.9	1,506	10,600	8,720	254
95	0.37	9.89	52.5	1,765	10,600	8,520	208

Table 2. Precipitation-weighted mean mg/l concentrations of NH_4^+ and NO_3^- at NC36 and densities per mi² for people, hogs, and broilers in Scotland County, and deer track counts per linear mile in the included portion of Sandhills Wildlife Management Area. The land area in Scotland County is 317 mi². NA means not available. Turkey and chicken production data in Scotland County are not available for 1983-91 and are not published for 1992-95 because instances with less than 300,000 turkeys or 5,000 chickens, or where individual producer data would be disclosed, are withheld from publication.

year	NC36		Scotland County density			WMA density
	$NH4^+$	$NO3^-$	human	hog	broiler	deer
83	0.09	1.71	104.0	80.4	(NA)	40.9
84	0.15	10.66	104.9	81.4	(NA)	44.5
85	0.09	7.92	104.2	84.9	(NA)	44.3
86	0.16	9.37	104.1	85.2	(NA)	32.2
87	0.12	10.83	105.5	85.2	(NA)	25.4
88	0.12	11.22	106.3	78.9	(NA)	33.7
89	0.22	16.19	105.9	78.9	(NA)	38.2
90	0.21	11.62	106.5	50.5	(NA)	57.8
91	0.16	11.85	107.8	78.9	(NA)	43.0
92	0.15	10.59	108.4	142.0	13,565	44.3
93	0.15	9.90	108.7	239.7	12,618	41.3
94	0.17	12.67	109.3	258.7	12,618	35.1
95	0.18	11.33	109.5	347.0	12,618	27.2

Table 3. Precipitation-weighted mean mg/l concentrations of NH_4^+ and NO_3^- at NC03 and densities per mi^2 for people, hogs, and broilers in Bertie County. The land area in Bertie County is 693 mi^2. NA means not available. Turkey and chicken production data in Bertie County are not available for 1978-91 and are not published for 1992-95 because instances with less than 300,000 turkeys or 5,000 chickens, or where individual producer data would be disclosed, are withheld from publication.

year	NC03		Bertie County density		
	$NH4^+$	$NO3^-$	human	hog	broiler
78	0.05	0.84	(NA)	69.7	(NA)
79	0.08	8.57	(NA)	80.8	(NA)
80	0.20	11.23	30.3	79.4	(NA)
81	0.17	7.44	30.3	64.9	(NA)
82	0.19	11.24	30.4	84.6	(NA)
83	0.28	12.17	30.5	85.4	(NA)
84	0.13	10.63	30.3	66.5	(NA)
85	0.14	8.72	30.3	64.9	(NA)
86	0.19	10.20	30.0	60.5	(NA)
87	0.18	10.84	29.8	47.6	(NA)
88	0.09	11.61	29.6	40.4	(NA)
89	0.15	12.62	29.6	40.4	(NA)
90	0.22	10.23	29.4	41.8	(NA)
91	0.15	10.20	29.3	50.5	(NA)
92	0.18	10.90	29.4	50.5	31,457
93	0.25	10.20	29.6	50.5	30,592
94	0.19	8.30	29.7	56.3	37,518
95	0.18	10.58	29.8	62.0	38,817

Table 4. Precipitation-weighted mean mg/l concentrations of NH_4^+ and NO_3^- at NC41 and densities per mi^2 for people, hogs, broilers and chickens in Wake County. The land area in Wake County is 864 mi^2. NA means not available; NP means not published (instances with less than 200,000 broilers or 5,000 chickens, or where individual producer data would be disclosed, are withheld from publication). Turkey production data in Wake County are not available for 1978-91 and are not published for 1992-95 because instances with less than 300,000 turkeys, or where individual producer data would be disclosed, are withheld from publication.

year	NC41		Wake County density			
	$NH4^+$	$NO3^-$	human	hog	broiler	chicken
78	0.20	1.90	(NA)	31.8	(NA)	289.4
79	0.23	11.77	(NA)	33.0	(NA)	260.4
80	0.23	11.18	348.9	31.3	(NA)	243.1
81	0.21	7.56	359.2	28.9	(NA)	219.9
82	0.22	12.38	367.4	26.2	(NA)	196.8
83	0.32	13.36	380.0	25.9	(NA)	179.4
84	0.20	11.17	397.2	24.2	(NA)	179.4
85	0.20	9.04	417.1	18.3	(NA)	179.4
86	0.28	10.54	432.4	17.1	(NA)	179.4
87	0.23	11.20	443.8	14.6	(NA)	179.4
88	0.19	13.14	462.0	14.5	(NA)	85.6
89	0.39	16.59	479.1	11.6	(NA)	(NP)
90	0.32	10.09	493.4	11.6	(NA)	(NP)
91	0.34	9.84	513.7	11.6	(NA)	(NP)
92	0.25	8.12	531.0	11.6	(NP)	(NP)
93	0.29	9.58	552.8	10.4	1160	(NP)
94	0.26	8.63	575.6	11.0	(NP)	(NP)
95	0.26	11.23	599.9	10.4	(NP)	(NP)

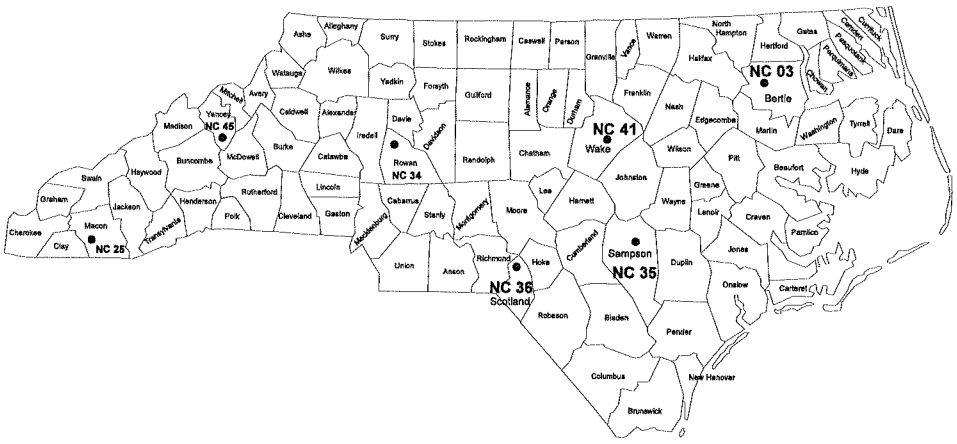

Figure 1. Location of active NADP/NTN monitoring sites in North Carolina.

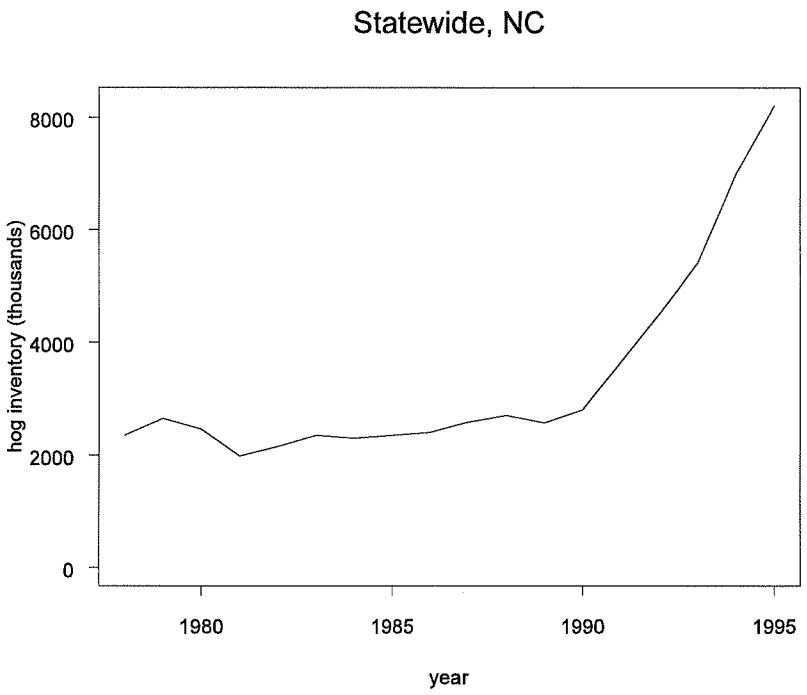

Figure 2. The 1 December hog inventories in North Carolina, 1978-1995.

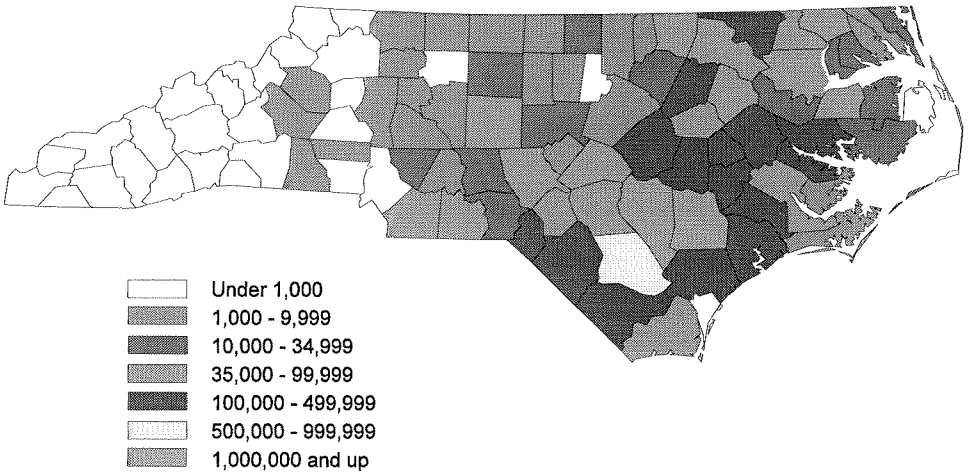

Figure 3. County distribution of the 1 December 1995 North Carolina hog inventories. (Revised from a map published on the Internet by the N.C. Dept. of Agriculture.)

Figure 4. Time series plots of NADP/NTN annual mean (A) ammonium concentrations and (B) nitrate concentrations in mg/l units (first row) and (C) human, (D) hog and (E) chicken population densities per mi^2 (second row) for Sampson County, North Carolina, 1978-1995, with local regression fitted curves to estimate general trends.

Ammonium and nitrate concentrations are from NADP/NTN, hog and chicken densities from NCDA, human density from NCOSP.

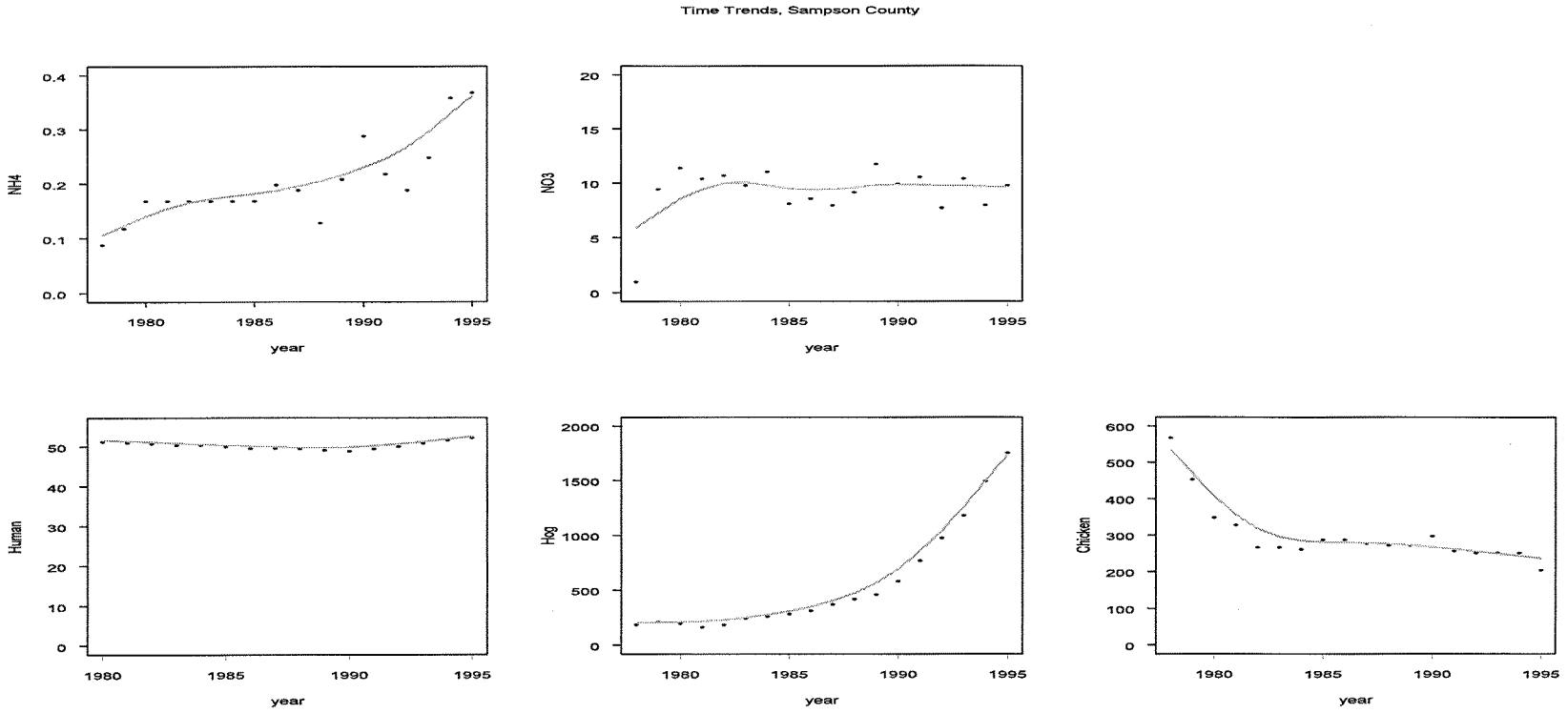
Time Trends, Sampson County
NH4
NO3
Human
Hog
Chicken
year
1980
1985
1990
1995

Figure 4

Figure 5. Scatter plots of annual mean ammonium concentrations (first row) and nitrate concentrations (second row) vs. 1 December hog density (first column), chicken density (second column) and human density (third column) for Sampson County, North Carolina, 1978-1995, with significant least trimmed squares regression lines:

$[NH_4^+] = 0.15 + 0.000\ 086 \times$ hog density (Figure 5A)

$[NH_4^+] = 0.26 - 0.000\ 29 \times$ chicken density (Figure 5B)

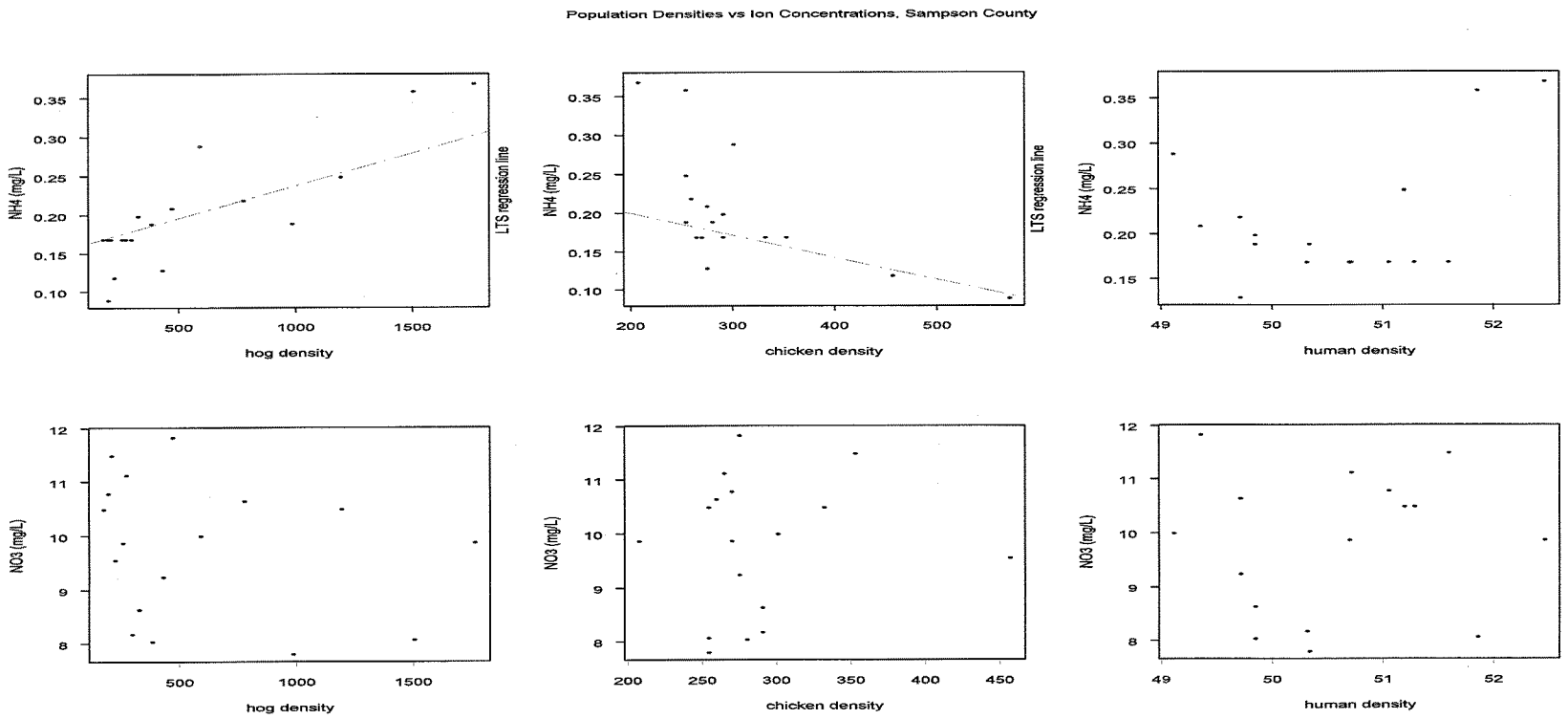
Population Densities vs Ion Concentrations, Sampson County
NH4 (mg/L)
LTS regression line
hog density
chicken density
human density
NO3 (mg/L)

Figure 5

Figure 6. Time series plots of NADP/NTN annual mean ammonium concentrations in mg/l units and predicted concentrations based on (A) hog and (B) chicken population densities per mi^2 for Sampson County, North Carolina, 1978-1995. Regression line parameters are given in the caption of Figure 5.

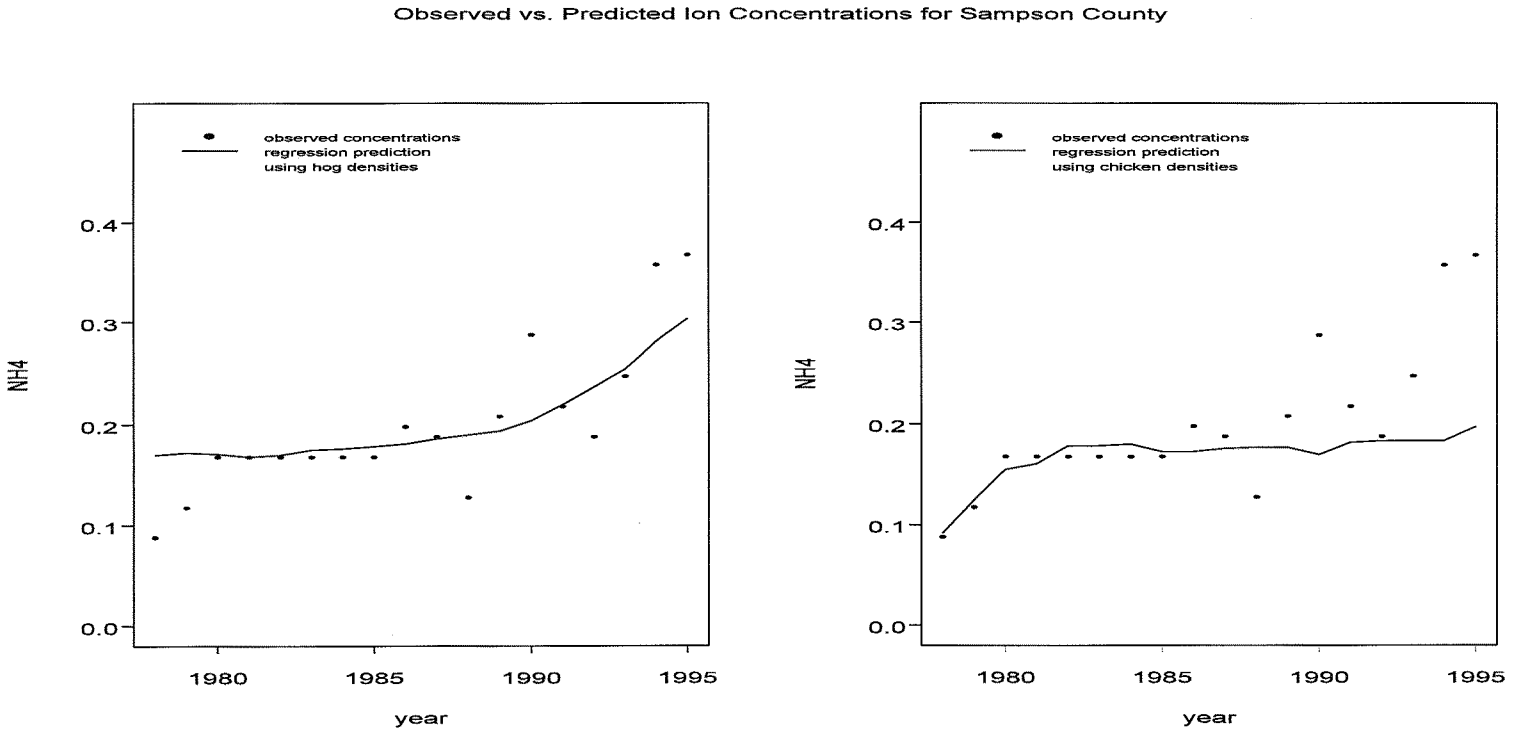
Observed vs. Predicted Ion Concentrations for Sampson County
observed concentrations
regression prediction
using hog densities
NH4
0.0
0.1
0.2
0.3
0.4
1980
1985
1990
1995
year
observed concentrations
regression prediction
using chicken densities
NH4
0.0
0.1
0.2
0.3
0.4
1980
1985
1990
1995
year

Figure 6

Figure 7. Time series plots of NADP/NTN annual mean (A) ammonium concentrations and (B) nitrate concentrations in mg/l units (first row) and (C) human, and (D) hog population densities per mi^2 and (E) deer index values (second row) for ScotlandCounty, North Carolina, 1978-1995, with local regression fitted curves to estimate general trends.

Ammonium and nitrate concentrations are from NADP/NTN, hog densities from NCDA, human density from NCOSP, deer indices from NCWRC.

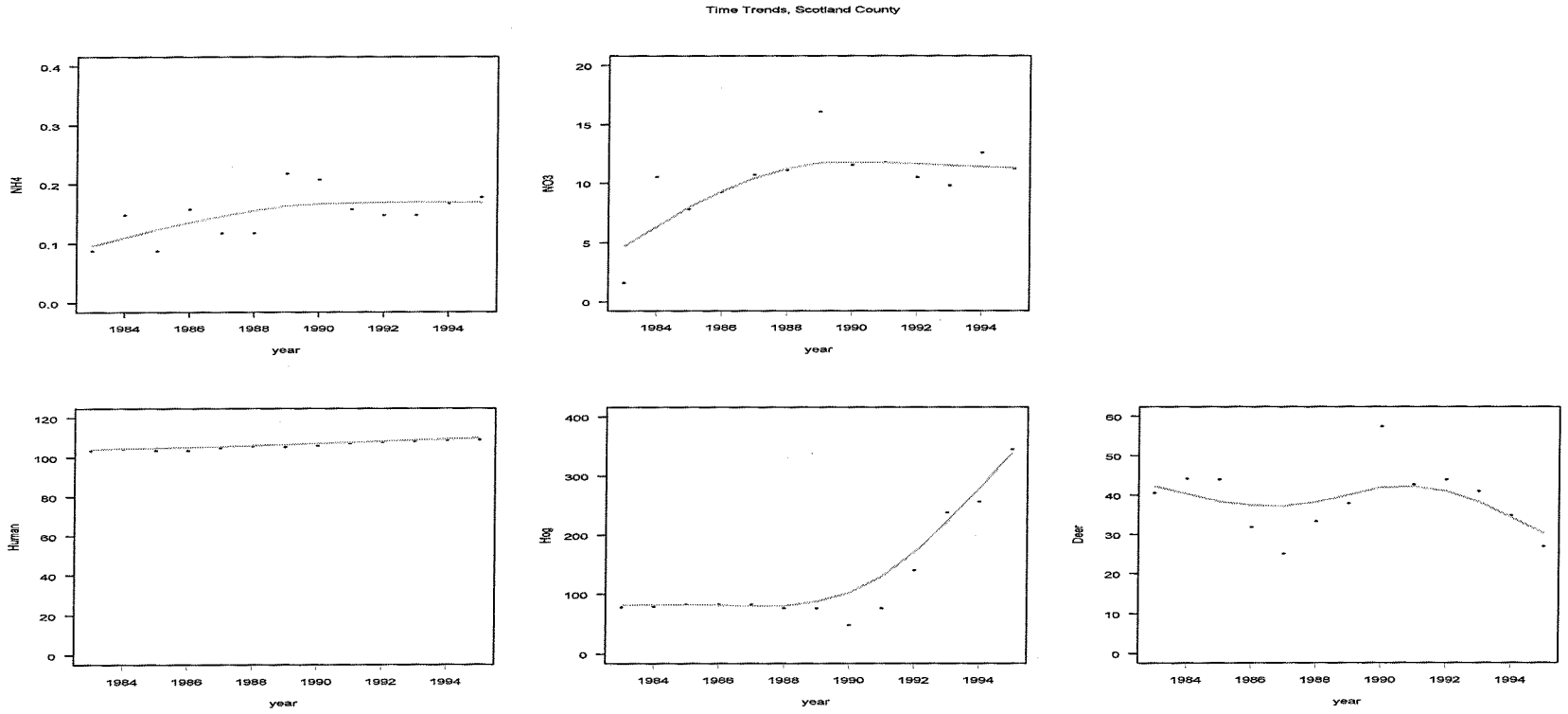
Time Trends, Scotland County
NH4
NO3
Human
Hog
Deer
year
1984
1986
1988
1990
1992
1994

Figure 7

Figure 8. Scatter plots of annual mean ammonium concentrations (first row) and nitrate concentrations (second row) vs. 1 December hog density (first column), deer density (second column) and human density (third column) for Scotland County, North Carolina, 1983-1995, with (almost) significant least trimmed squares regression lines:

$[NH_4^+] = 0.13 + 0.000\ 15 \times$ deer density, $1991 \leq$ year ≤ 1995 (Figure 8A)

$[NO_3^-] = -47.3 + 0.55 \times$ human density (Figure 8B)

Figure 8

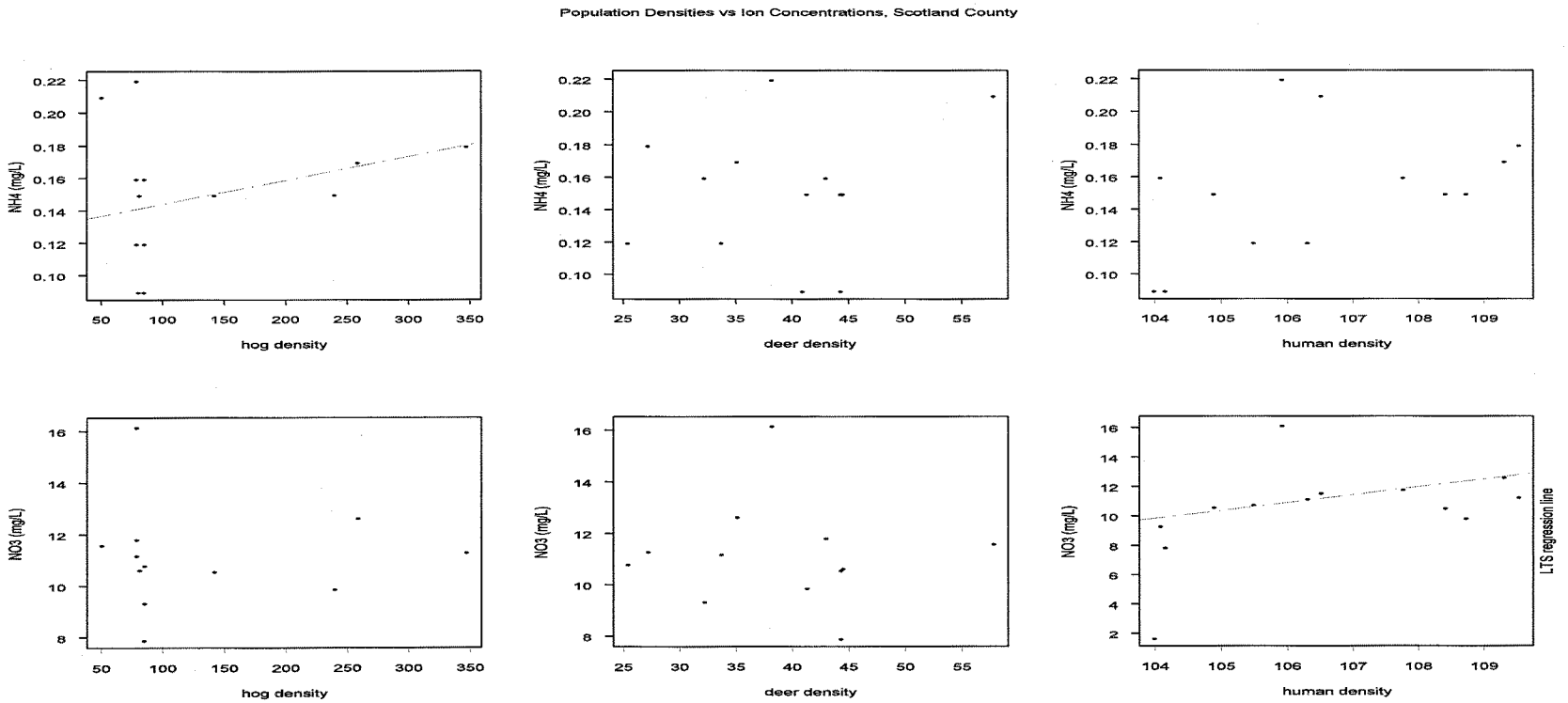
Population Densities vs Ion Concentrations, Scotland County
NH4 (mg/L)
hog density
deer density
human density
NO3 (mg/L)
LTS regression line

Figure 8

Figure 9. Time series plots of NADP/NTN annual mean (A) ammonium concentrations in mg/l units and predicted concentrations based on hog densities and (B) nitrate concentrations in mg/l units based on deer deer population indices for Scotland County, North Carolina, 1983-1995.
Regression line parameters are given in the caption of Figure 8.

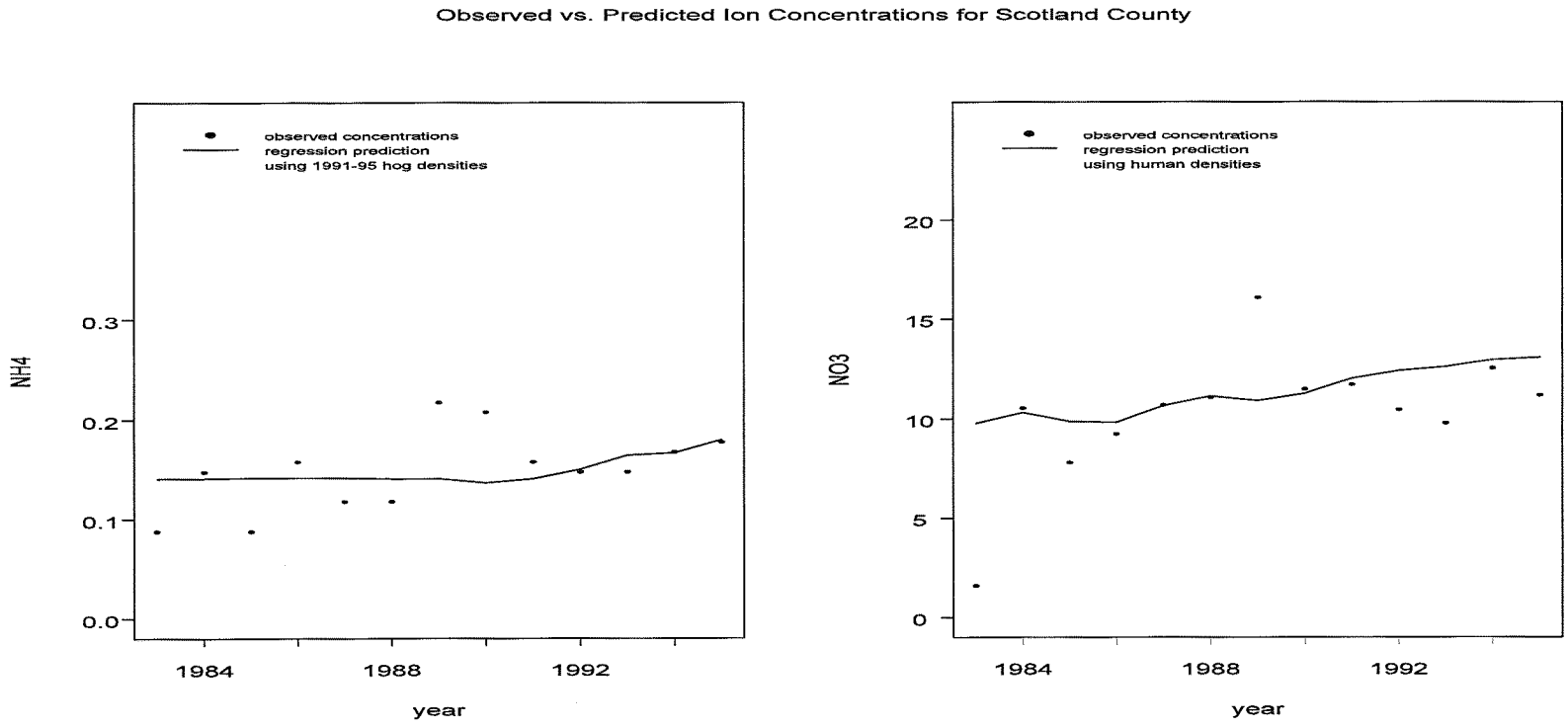
Observed vs. Predicted Ion Concentrations for Scotland County
observed concentrations
regression prediction
using 1991-95 hog densities
NH4
0.0
0.1
0.2
0.3
1984
1988
1992
year
observed concentrations
regression prediction
using human densities
NO3
0
5
10
15
20
1984
1988
1992
year

Figure 9

Figure 10. Time series plots of NADP/NTN annual mean (A) ammonium concentrations and (B) nitrate concentrations in mg/l units (first row) and (C) human, and (D) hog population densities per mi^2 (second row) for BertieCounty, North Carolina, 1978-1995, with local regression fitted curves to estimate general trends.

Ammonium and nitrate concentrations are from NADP/NTN, hog densities from NCDA, human density from NCOSP.

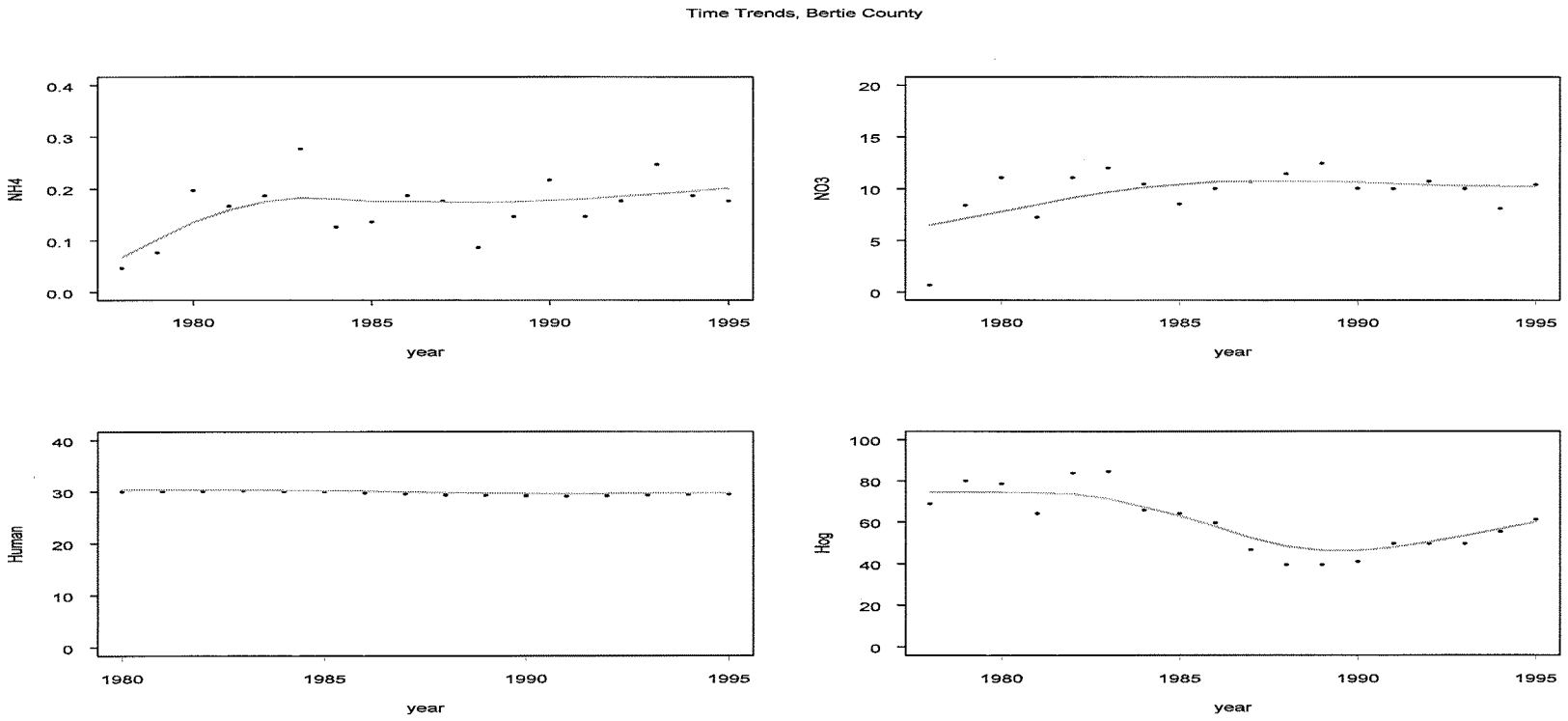
Time Trends, Bertie County
NH4
NO3
Human
Hog
year
1980
1985
1990
1995

Figure 10

Figure 11. Scatter plots of annual mean ammonium concentrations (first row) and nitrate concentrations (second row) vs. 1 December hog density (first column) and human density (second column) for Bertie County, North Carolina, 1983-1995.

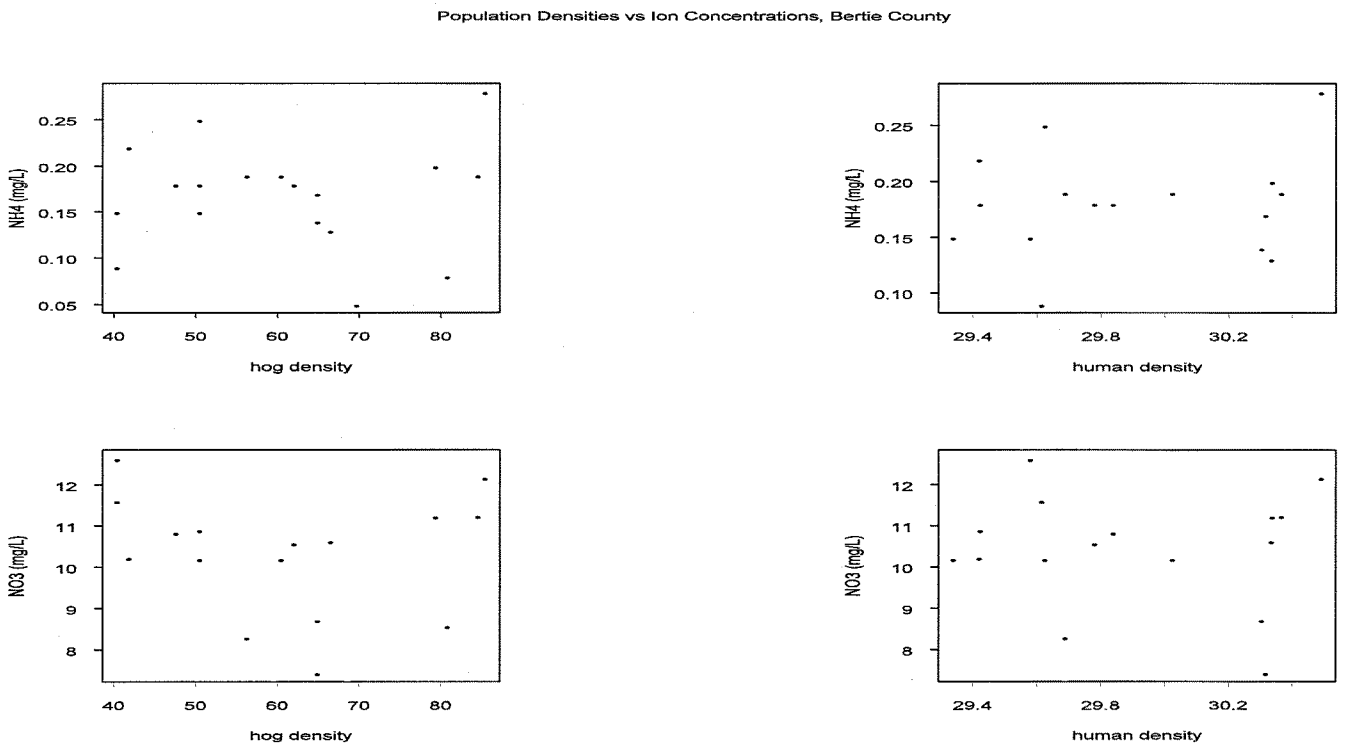
Population Densities vs Ion Concentrations, Bertie County
NH4 (mg/L)
0.25
0.20
0.15
0.10
0.05
40
50
60
70
80
hog density
NH4 (mg/L)
0.25
0.20
0.15
0.10
29.4
29.8
30.2
human density
NO3 (mg/L)
12
11
10
9
8
40
50
60
70
80
hog density
NO3 (mg/L)
12
11
10
9
8
29.4
29.8
30.2
human density

Figure 11

Figure 12. Time series plots of NADP/NTN annual mean (A) ammonium concentrations and (B) nitrate concentrations in mg/l units (first row) and (C) human, (D) hog population densities and (E) chicken population densities per mi^2 (second row) for Wake County, North Carolina, 1978-1995, with local regression fitted curves to estimate general trends.

Ammonium and nitrate concentrations are from NADP/NTN, hog and chicken densities from NCDA, human density from NCOSP.

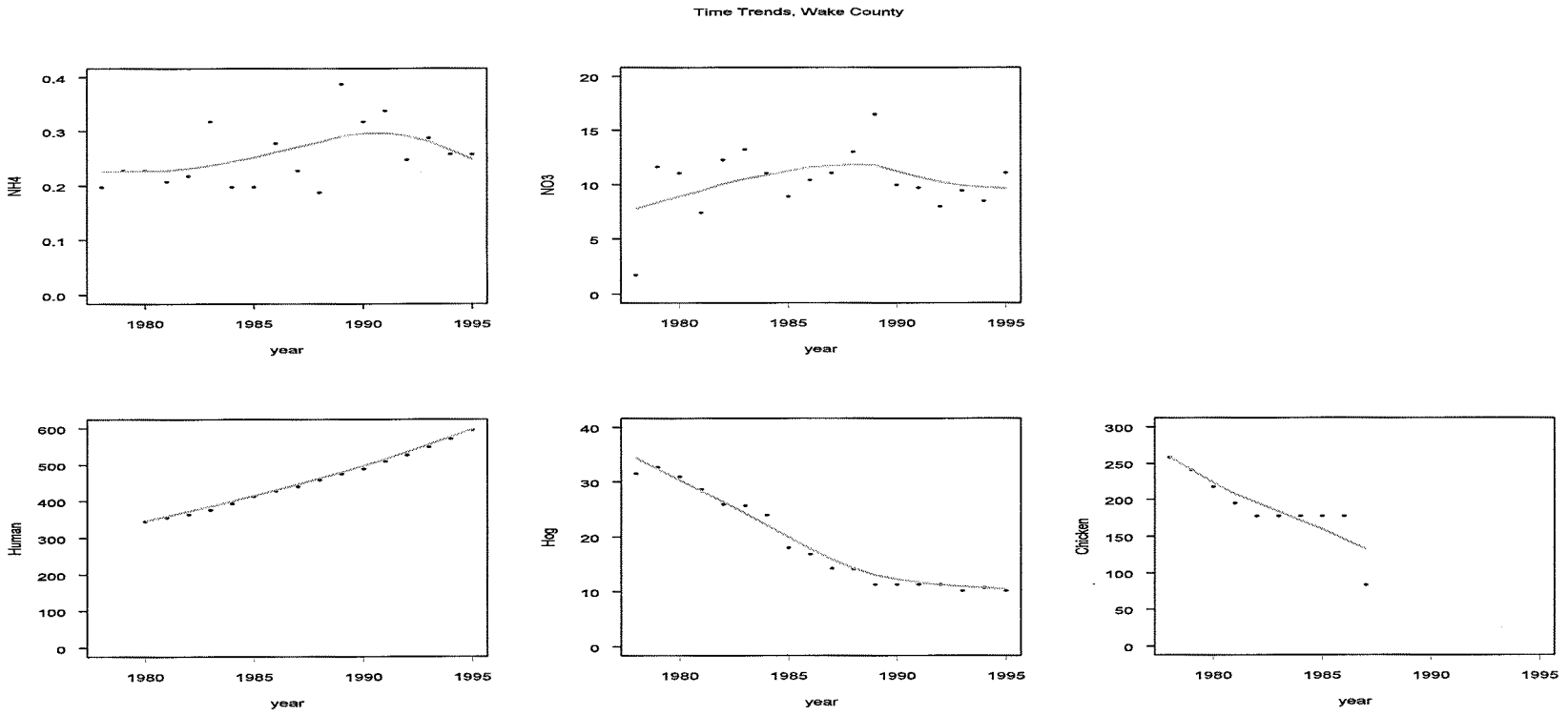
Time Trends, Wake County
NH4
NO3
Human
Hog
Chicken
year
1980
1985
1990
1995

Figure 12

Figure 12

Figure 13. Scatter plots of annual mean ammonium concentrations (first row) and nitrate concentrations (second row) vs. 1 December hog density (first column), chicken density (second column) and human density (third column) for Wake County, North Carolina, 1978-1995, with significant least trimmed squares regression line:

$[NH_4^+] = 0.27 - 0.001\,86 \times$ hog density

(Figure 13)

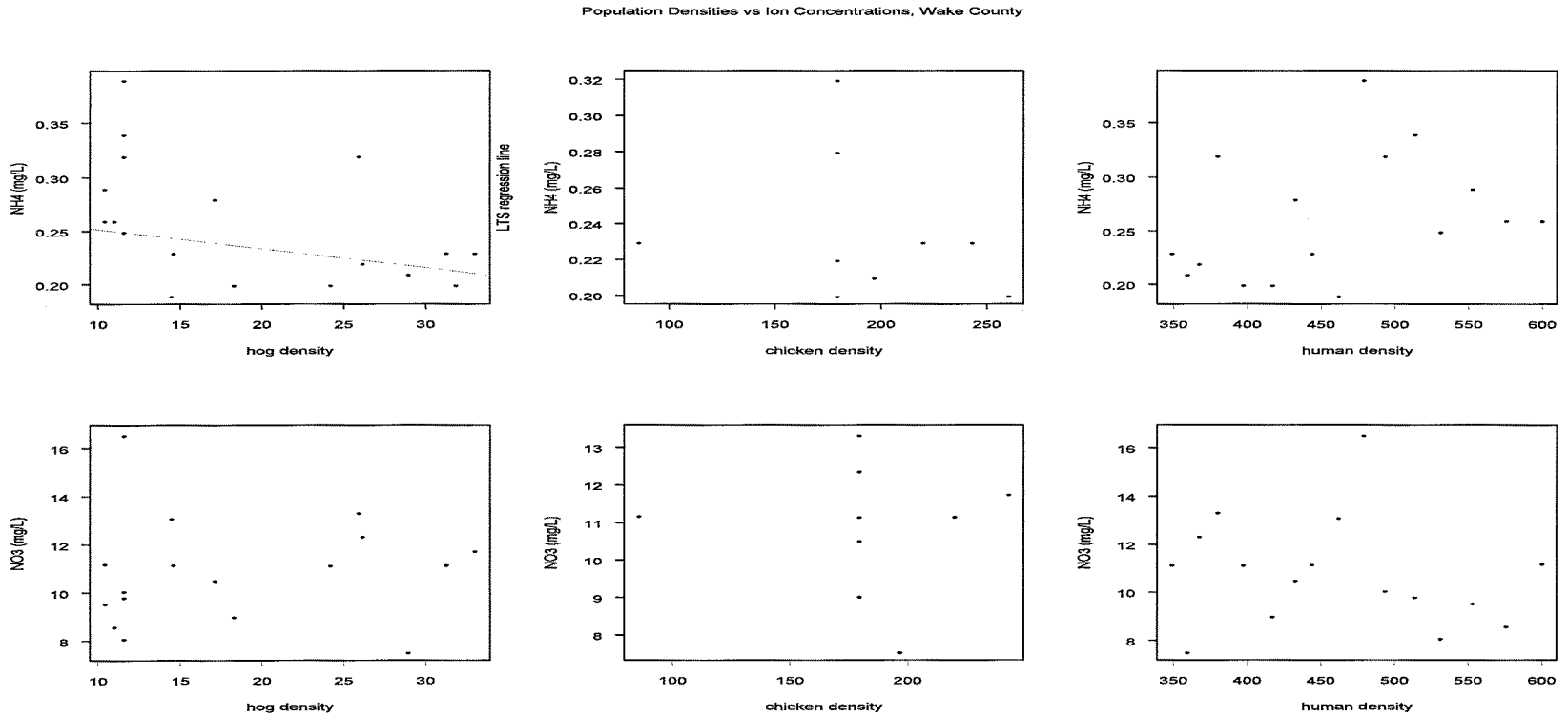
Population Densities vs Ion Concentrations, Wake County
NH4 (mg/L)
LTS regression line
hog density
chicken density
human density
NO3 (mg/L)

Figure 14. Time series plots of NADP/NTN annual mean ammonium concentrations in mg/l units and predicted concentrations based on hog densities for Wake County, North Carolina, 1978-1995. Regression line parameters are given in the caption of Figure 13.

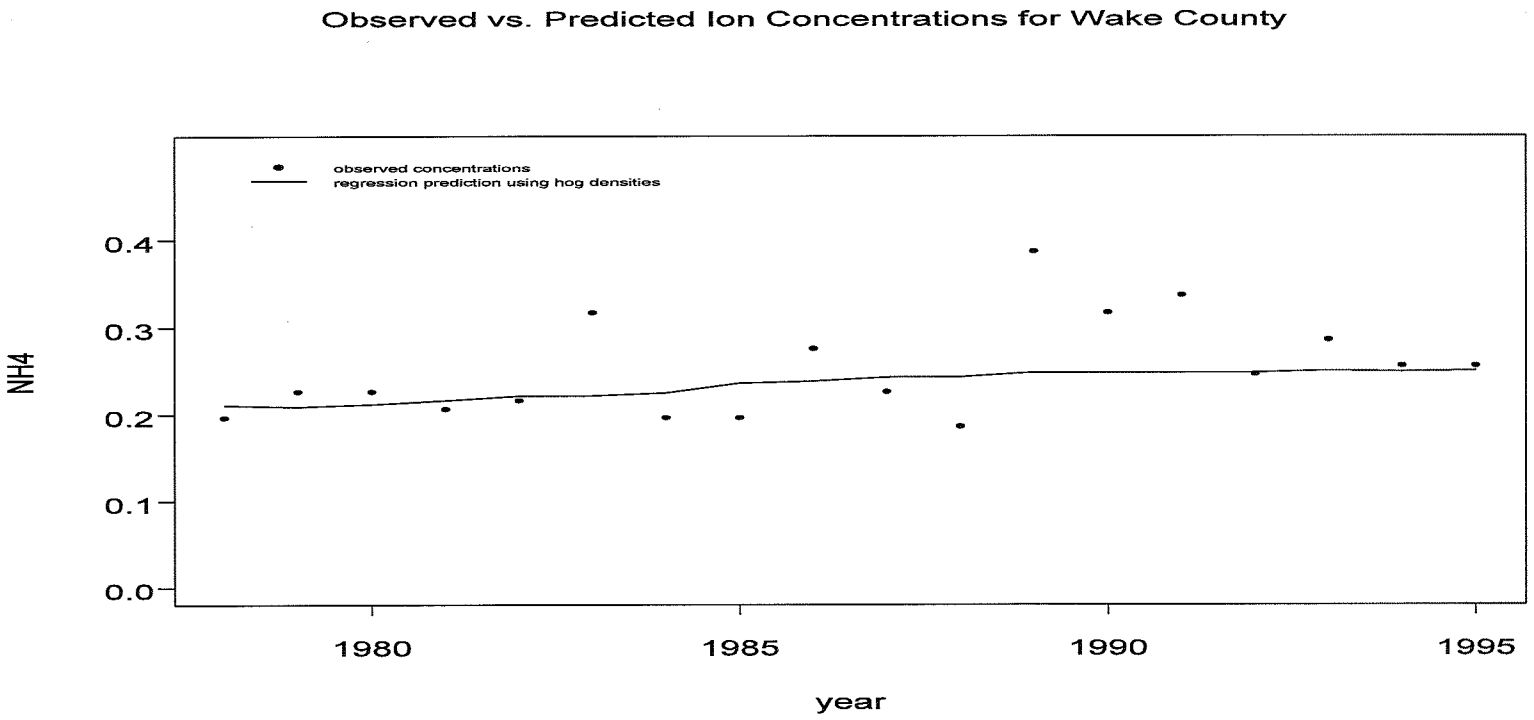
Observed vs. Predicted Ion Concentrations for Wake County
observed concentrations
regression prediction using hog densities
NH4
0.0
0.1
0.2
0.3
0.4
1980
1985
1990
1995
year

Figure 14