Development of Emissions Estimating Methodologies for Dairy Operations

Draft

Prepared by:

U.S. Environmental Protection Agency
Office of Air and Radiation
Office of Air Quality Planning and Standards
109 T.W. Alexander Drive
Research Triangle Park, N.C. 27709

June 2022

This document is a preliminary draft. It has not been formally released by the U.S. Environmental Protection Agency (EPA) and should not at this stage be construed to represent Agency policy. It is being circulated for comments on its technical merit.

Table of Contents

List Of Appendices

List of Tables

List of Figures

GLOSSARY / ACRONYMS

Acronyms	Defintion
-2LogL	negative twice the likelihood
ACI	Akaike information criterion
ACIc	Adjusted Akaike information criterion
ADMs	average daily means
AFO	animal feeding operation
BIC	Schwarz Bayesian Information Criterion
bLS	backward Lagrangian Stochastics
d	day
dsm^3	Dry standard cubic meter
EEMs	Emissions estimating methodologies
EPA	Environmental Protection Agency
FANS	Fan Assessment Numeration System
g	gram
g/d	grams/day
H_2S	hydrogen sulfide
hd	head – inventory of cows
hPa	hectopascal
kg	kilogram
LAW	live animal weight
LNME	Normalized mean bias of natural log data
m	meter
MB	mean bias
MC	milking center
ME	Mean error
MS	Manure solids
MUN	Milk urea nitrogen
NAEMS	National Air Emissions Monitoring Study
NCEI	National Centers for Environmental Information
NH_3	ammonia
NMB	normalized mean bias
NME	normalized mean error
PI	Principal Investigator
PM	particulate matter
PM_{10}	particulate matter with aerodynamic diameters less than 10 micrometers
$PM_{2.5}$	PM with aerodynamic diameters less than 2.5 micrometers
QAPP	quality assurance project plan
QC	quality control
s	second
SAB	science advisory board
SDS	Separated digested solids
SP	Settling ponds
SS	Solid separation
SS	separated solids

Std Dev	Standard deviation
TAN	total ammoniacal nitrogen
TEOM	tapered element oscillating microbalance
TKN	total Kjeldahl nitrogen
TSP	total suspended particulate
USDA	U.S. Department of Agriculture
VOCs	volatile organic compounds
VRPM	vertical radial plume mapping

1 INTRODUCTION

1.1 Confinement Site Descriptions

Five milk production facilities (dairy operations) had barns monitored under NAEMS. The locations were selected based on site-specific factors including representativeness of facility age, size, design and management, and herd diet and genetics. Three free stall and two open free stall dairy facilities were monitored as a part of NAEMS. Table 1-1 summarizes the sites and their characteristics.

Table 1-1: Dairy Confinement Sites Monitored Under NAEMS

Site	Monitoring Period	Site Type	Ventilation type	Number of barns measured	Manure Collection	Manure Storage[4]	Bedding Type[5]
NY5B	10/24/07 – 10/23/09	Free stall	Mechanically Ventilated	1[3]	Scrape	Digester/ SS/SSP	SDS
IN5B	8/24/07 – 8/23/09	Free stall	Mechanically Ventilated	2[3]	Scrape	Digester/ SS/Lagoon	SDS
WI5B[1]	9/12/07 – 10/31/09	Free stall	Mechanically Ventilated	2	Flush	SP/Lagoon	Mattress/ shavings
CA5B	9/26/07 – 2/1/10	Open free stall[2]	Naturally Ventilated	2	Flush	SP/Lagoon	Soil/MS/ Almond shells
WA5B[1]	9/28/07 – 9/27/09.	Open free stall[2]	Naturally Ventilated	2	Flush	SP/SS/ SSP/Basin	MS

[1]Barn sites that also have measured area sources.
[2]Cows are free to walk from open free stall barn into dry lots between the barns.
[3]Monitored units include the milking center.
[4]Labeled consistent with the site reports, where: SP = Settling Pond; SS = solid separation; SSP= Solid Storage Pad
[5]MS = Manure solids; SDS = Separated digested solids

1.1.1 CA5B

In 2010, the California site (CA5B) was a 1,200-cow Holstein dairy farm. The farm has two naturally ventilated free stall barns, a milking center, and a lagoon and settling ponds (Figure 1-1). The farm also included exercise lots, which were located adjacent to each barn. Lactating cows were milked two times daily in the centrally located milking center. The on-site heifer program (i.e., activities to raise their own heifer calves until they can join the milking herd) was held on the north end of the farm, separated from the study area.

The two naturally ventilated free stall barns, barn 1 (B1) and barn 2 (B2), were monitored as part of NAEMS (Zhao, et al., 2010). Each barn had four free stall rows, two on each side of a central feed lane, housing 600 cows each. Barn 1 had the fresher cows (i.e., cows that recently gave birth) and served as the breeder barn, while barn 2 had pregnant lactating cows and the hard breeders (i.e., cows that have a hard time getting pregnant). The cows were generally inside the barns, particularly on hot days to provide shade.

The manure handling system included a barn flushing system, three settling ponds and a lagoon. Manure solids taken from the settling ponds were spread on nearby fields in the spring and fall.

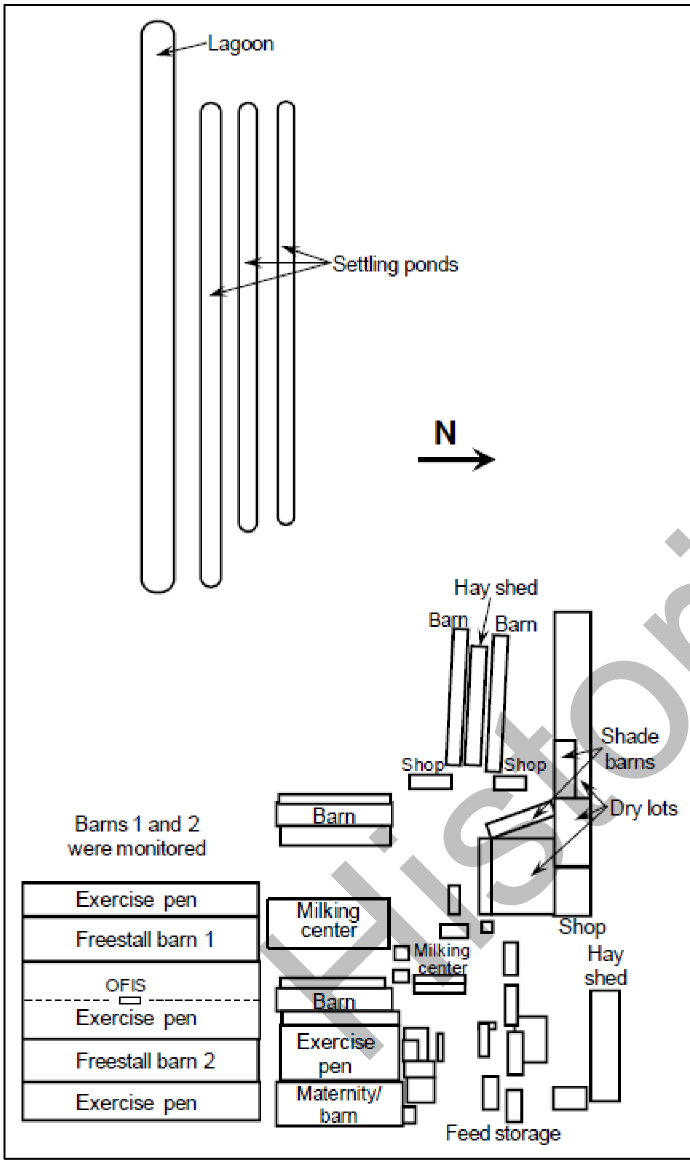


Figure 1-1: CA5B farm layout.
Source: Zhao, et al. (2010)

1.1.2 IN5B

The dairy farm in Indiana (IN5B) had 3,400-head capacity of Holstein cows. The dairy consisted of two free stall barns, a holding barn, milking parlor, and a dry cow barn (Figure 1-2). NAEMS gathered measurements from the two freestall barns, barn 1 (B1) and barn 2 (B2), and the milking center (MC), which consisted of the holding barn (area where cows waited approximately 45 minutes prior to milking) and milking parlor (Lim, et al., 2010). Each barn used a bank of exhaust fans to pull air through the barns. Each barn housed typically housed up to 1,700 cows, with approximately 3,400 Holstein cows were milked three times a day in the 72-stall rotary parlor. For the NAEMS, measurements of airflow and emissions focused on the western half of each of the barns.

The manure was removed from both freestall barns by scraper, while the manure from the holding barn and milking parlor was flushed. The manure removed from the freestall barn and milking center are held in a reception pit, and then then directed to a digester that produced methane gas which was used in generators on the farm. Digester effluent was separated, with the digested solids moved a storage area and the liquid stored in a two-stage pond/lagoon system. The liquid was then either irrigated onto or injected into land in the surrounding area. The separated digested solids were used as bedding in the free stall barns.

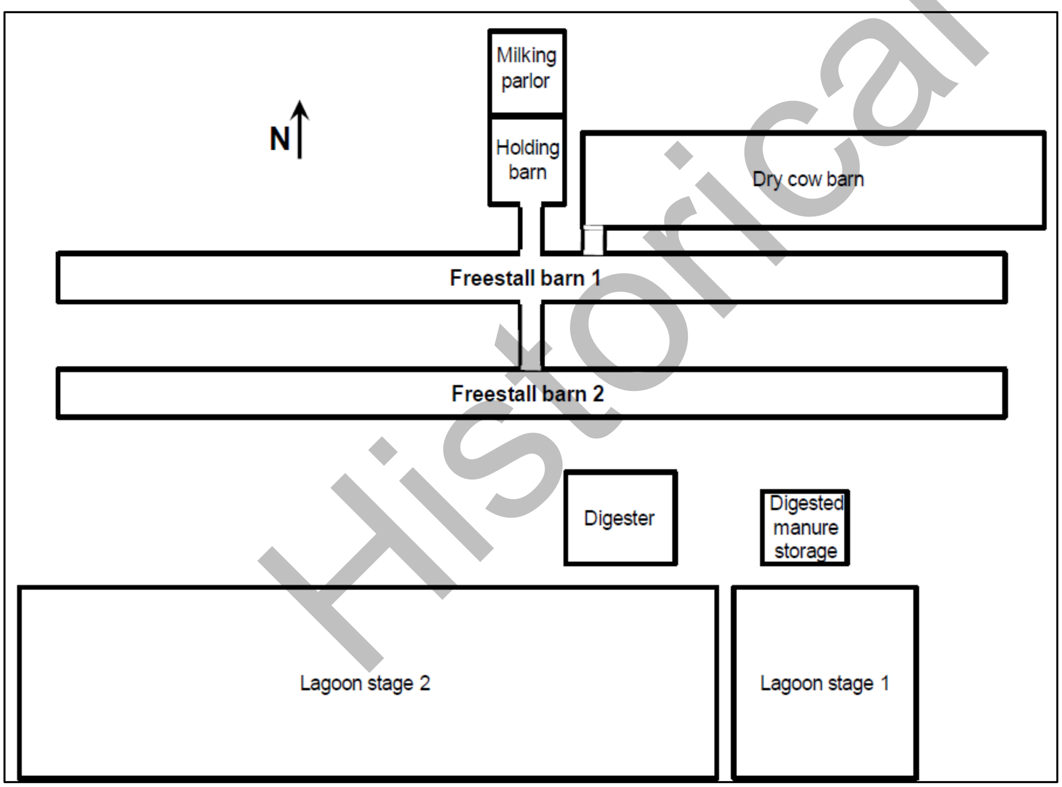


Figure 1-2. IN5B farm layout.
Source: Lim et al. (2010)

1.1.3 NY5B

The dairy facility monitored in New York (NY5B) had a capacity of 1,000 Holstein cows and consisted of a mechanically ventilated free stall barn and a milking center, a naturally ventilated free stall barn, along with housing facilities for dry cows, steers, and calves on the same site (Figure 1-3). Measurements were collected from the mechanically ventilated 6 row free stall barn (barn 1 or B1) and the MC during the study (Bogan, et al., 2010). The MC included a double-20 milking parlor, 31 free stalls and four bedded-pack box stalls for special-needs cows. Cows were brought in for milking three times per day.

The manure was removed from both the B1 and MC by scraper and deposited in a below-grade gravity flow channel that led to a centralized agitation and pumping station located in the covered connecting alley between the structures. From the alley, the manure was transferred to an anaerobic digester. The digester effluent was processed with a screw-press solid-liquid separator. The separated solids were stockpiled as bedding, land-applied to far-off fields, or sold. The liquid was pumped to long-term storage that was about 2.3 km away to the northeast.

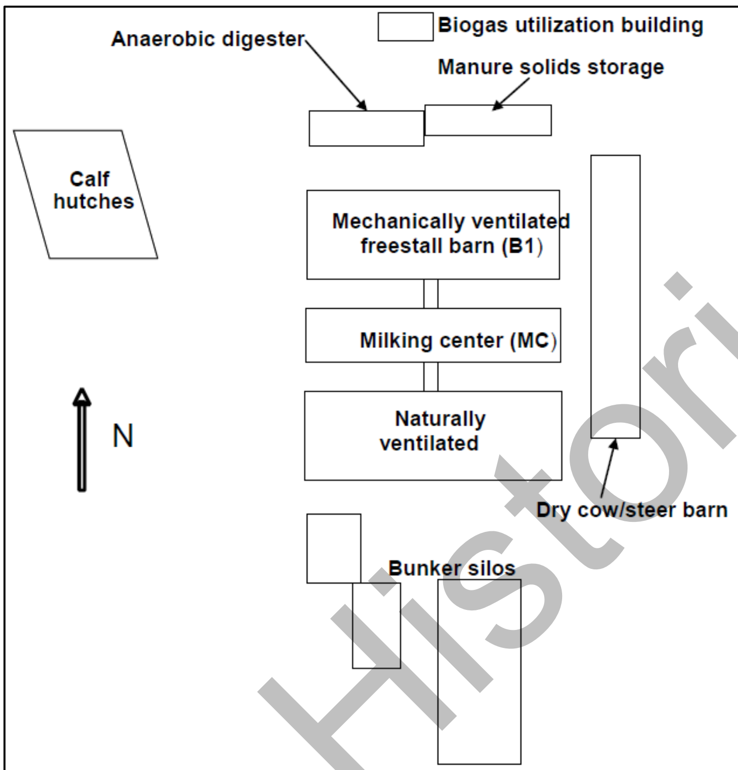


Figure 1-3. NY5B farm layout.
Source: Bogan, et al. (2010)

1.1.4 WA5B

The dairy facility located in Washington State (WA5B) was a 5,600-head Holstein dairy farm. The farm buildings included the milking parlor and six naturally ventilated symmetrically-distributed free stall barns (Figure 1-4). The farm also includes a total of ten corrals/exercise pens that are distributed around the barns. Two of the free stall barns, barn 2 (B2) and barn 4 (B4), were monitored as part of NAEMS (Ramirez-Dorronsoro, et al., 2010). Barn 2 housed 600 cows in four rows of free stalls and Barn 4 housed 700 cows in six free stall rows.

Manure from the free stall barns was flushed automatically three times daily and scraped as needed. The effluent was directed, via pipes, to the waste handling and treatment system that included a sand separation pit, two primary settling ponds, a manure separation pad (which includes screen separators and centrifugal solid separators), and a pair of serpentine settling systems, in which each one had five sequential settling cells. Both serpentine cells then discharged into a central cell. The liquid effluent from the central cell was directed to the storage lagoon. The solid effluent from the sand separation pit, depending on the season and temperature, also was directed to two manure drying ponds, located south of the manure separator pad. The dried manure was used for bedding and land application, and the liquid was applied to surrounding fields. The site's lagoon was also monitored as a part of NAEMS (Section 1.2.3).

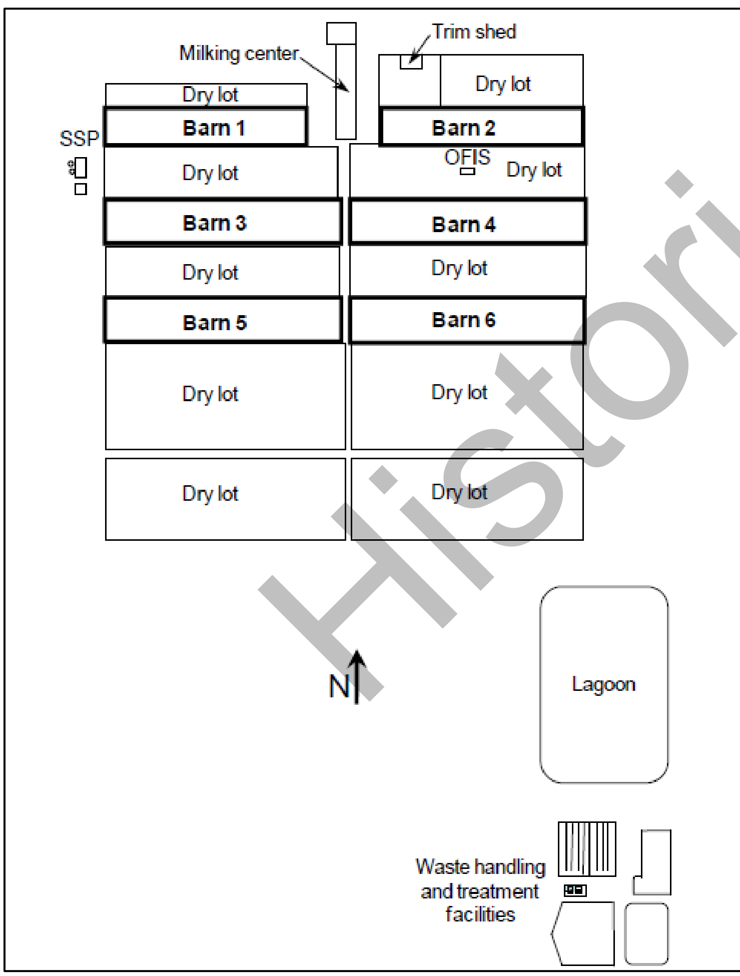


Figure 1-4. WA5B farm layout.
Source: Ramirez-Dorronsoro, et al. (2010)

1.1.5 WI5B

The dairy facility monitored in Wisconsin (WI5B) had a total capacity of 1,700 Holstein dairy cows, and consisted of four free stall barns, a holding barn, and sixth barn that is divided into the calving pen for 2-year-olds and a hospital barn (Figure 1-5). Two of the free stall barns, barns 1 (B1) and 2 (B2), located on the north side of the farm, were monitored as a part of NAEMS (Cortus et al., 2010). Barn 1 (B1) had capacity of 275 cows in four rows of free stalls, and barn 2 (B2) had a capacity of 375 cows housed in five rows of free stalls.

Approximately halfway through the study, the manure removal system was changed in the barns. Initially, manure was removed by flushing three time per day. The manure flushed from the parlor, holding pens, and free stall barns was directed to a solid separator. Solids were directed to pads to wait for land application, while the liquid portion was pumped back into the vertical tanks to flush the barns. After September 19, 2008, the flush system was replaced with a tractor scrape system, which was already in use in barns 5 and 6.

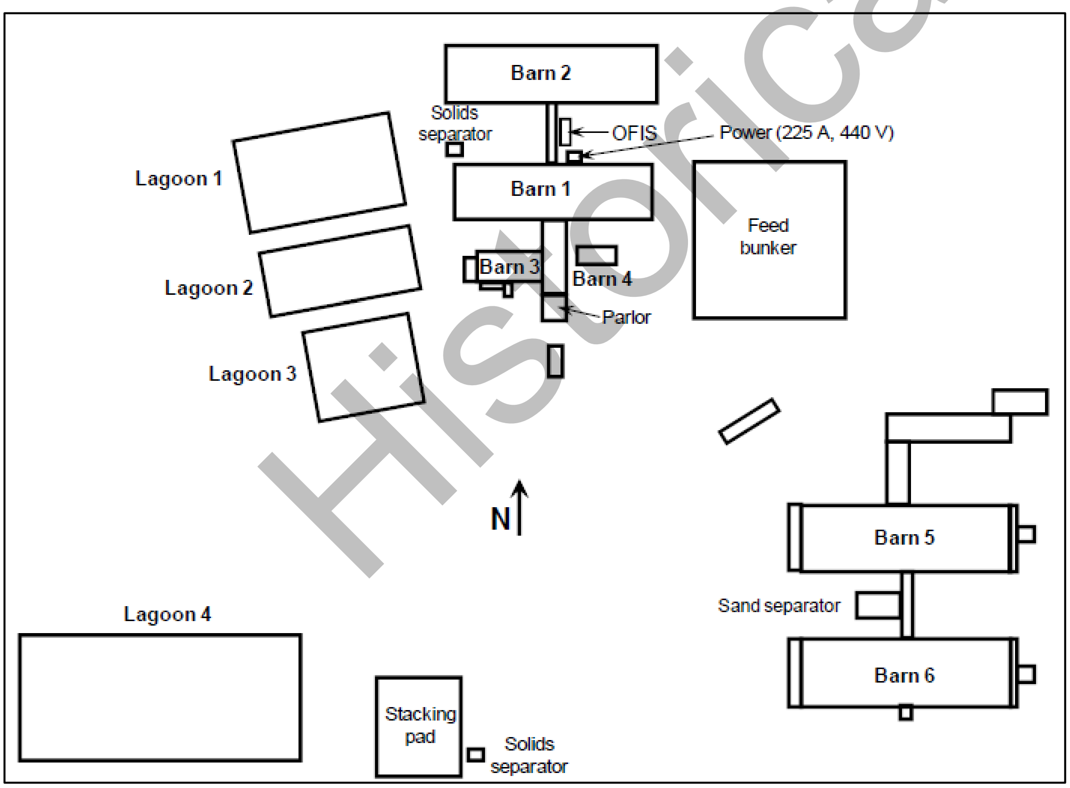


Figure 1-5. WI5B farm layout.
Source: Cortus et al. (2010).

1.2 Open Source Site Descriptions

Three dairy lagoons and a dairy corral (TX5A) were monitored under NAEMS (Table 1-2). Sites were selected to capture different stages and manure practices typical of the industry. The sites selected also represent the broad geographical extent of dairy production to also represent different climatological settings for farm and any regional differences in farm practices.

Dairy lagoon emissions were measured continuously at one farm (IN5A) for one year and for up to 21 days each season for two years at the two other farms (WA5A and WI5A). The dairy corral (TX5A) was also monitored for up to 21 days each season for two years.).

Table 1-2: Dairy Open Source Sites Monitored Under NAEMS

Site	Source Monitored	Manure Collection	Manure Storage[3]
IN5A	Lagoon	Flush	Lagoon
WA5A[1]	Lagoon	Flush	Lagoon
WI5A[1]	Lagoon[2]	Flush	Lagoon
TX5A	Open Corral	Scrape	SB/Lagoon

[1] Site that also had barn monitoring sites during NAEMS
[2] Lagoon can be single or double stage.
[3]SB= Settling Basin

1.2.1 IN5A

The Indiana open source site consisted of three barns, a feed storage area, special needs barn, milking parlor, and an office and tool and repair shops (Figure 1-6). The facility had a capacity of 2,600 cows (Grant and Boehm, 2010a).

The monitored lagoon received effluent from the parlor and holding area. Manure was flushed from the holding area and milking parlor every half hour. A small fraction of waste was held in a slurry tank. The wastewater (flush) from the holding area and milking parlor was transferred to a settling basin before being transferred to the clay-lined lagoon. The clay-lined waste lagoon was 85m (280 ft) wide and 116m (380 ft) long, with a surface area of 9,884 m^2 (106,400 ft^2). Sludge had never been removed from the lagoon (Grant and Boehm, 2010a).

Figure 1-6:Aerial view of IN5A
Source: Grant and Boehm (2010a)

1.2.2 TX5A

The Texas dairy (TX5A) consisted of ten corrals, milking parlor, office, hay shed, commodities barn, calving/fresh cow barn and truck scale (Figure 1-7). The facility had a capacity of 3,400 Holstein cows (Grant and Boehm, 2010b). Wastewater from the dairy drains to two earthen sludge/settling basins before entering a retention/treatment structure. Runoff from the corrals drains to the larger of two retention structures which are connected in series.

Manure was scraped twice a week from the corral surface with some scrapings used as bedding and the remainder was pushed to the south into ditches, which drained into the runoff pond. Manure was vacuumed instead of scraped if persistent wet conditions occurred.

Figure 1-7. Aerial view of TX5A
Source: Grant and Boehm (2010b)

1.2.3 WA5A

The Washington farm (WA5A) consisted of six barns, a milking parlor, and an office (Figure 1-8). The facility has a capacity of 4,400 milking cows and 1,200 dry cows in three units (Grant and Boehm, 2010c). The farm has free stall style barns, with automated flushing that occurred four times daily. Manure was transferred to an upper settling basin from a sand separation pit. Liquids were skim separated and then returned as flush to the barns. One lagoon was actively filled while the other was drying or sludge was being entirely removed. The settled solids (sludge) were completely removed within a year by front end loader. The settled solids (sludge) were removed annually by a front-end loader. These remaining solids were then strained through screens and centrifugal/screw presses, and the liquid transferred to large serpentine concrete basins for secondary settling. These solids are then dried for bedding. The water removed from the settled solids is stored in a large, clarified water storage basin for dilution of barn flush water from the lagoons.

The two upper lagoon/settling basins were measured as part of NAEMS, as well as two free stall barns described as in Section 1.1.4. Gaseous emissions occur both during lagoon filling and during sludge removal. The east lagoon was rectangular with dimensions of 183m (600 ft) by 72 m (235 ft). The west lagoon was five-sided with dimensions of approximately 183 m (600 ft) long and 83m (271 ft) wide with the southwest corner of the lagoon cut off. The east lagoon was measured for gaseous emissions. At maximum capacity this lagoon had a liquid depth of 5 m (18 ft), surface area of 13,098 m^2 (141,000 ft^2) and a volume of 186,300 m^3 (2,005,500 ft^3).

Figure 1-8. Aerial view of WA5A
Source: Grant and Boehm (2010c)

1.2.4 WI5A

In 2010, the Wisconsin farm (WI5A) had a total of six barns, a milking parlor with holding pen, and a special needs area (Figure 1-9). The farm had a capacity of 1,700 Holstein cows (Grant and Boehm, 2010d). Manure from the free stall barns and the milking parlor complex was removed by flushing three times daily. The manure flushed from the parlor, holding pen, and free stall barns flows to a solids separator, from which the solids are removed and stacked on a pad until they were spread on fields. The liquid effluent from the solids separator was pumped back into vertical tanks for reuse to flush the barns. Once a week, enough water was removed from the third stage of the three-stage lagoon and added to the flush tanks to make up for water lost in the recycled flush system. The three-stage lagoon receives effluent from the two free stall barns measured by the barn component of NAEMS (Section 1.1.5), as well as the other barns and milking parlor. The lagoons are pumped out into trucks twice yearly. The first and second stages of the three-stage lagoon system were monitored, as well as two free stall barns as described in Section 1.1.5.

The first lagoon had a width of 52 m (170 ft) and length of 82 m (270 ft). At maximum capacity, the first lagoon had a surface area of 4,264 m2 (45,900 ft^2) and a volume of 10,561 m^3 (373,000 ft^3). The second lagoon had a width of 37 m (120 ft) and length of 79 m (260 ft). At maximum capacity, the second lagoon had a surface area of 2,898 m^2 (31,200 ft^2) and a volume of 6,420 m^3 (226,700 ft^3). Both lagoons had liquid depths of 3 m (11 ft) and sludge was last removed from the second lagoon in 2006.

Figure 1-9. Aerial view of WI5A
Source: Grant and Boehm (2010d)

1.3 Data Sampled

NAEMS collected a host of data from the sites. Data collected included gaseous pollutant samples, particulate matter samples, meteorological data, confinement parameters, and biomaterial samples. All procedures for barn sites were outlined in the project Quality Assurance Project Plan (QAPP) (Heber et al., 2008) and open sources were summarized in open source project QAPP (Grant, 2008), and are summarized in Section 4 of the main report. The following section outlines any collection specific to the dairy sites.

1.3.1 Particulate Matter

At any one time, the sampled filterable particulate matter (PM) size class was either equal to or less than a nominal aerodynamic diameter of 10 micrometers (PM_{10}), and 2.5 micrometers ($PM_{2.5}$) or total suspended particulate (TSP). Appendix A contains summary tables, which note the particulate matter sampling schedules for the confinement sites. Particulate matter emissions data were not collected specific to the open sources.

1.3.2 Animal Husbandry

In general, the producer provided pen inventories and information about changes to site operational procedures like bedding, on a weekly basis. For NY5B, the producer also provided daily milk production.

1.3.3 Biomaterials Sampling Methods and Schedule

All analyses of biomaterials were performed by an independent laboratory (Midwest Laboratories, Omaha, NE). Samples were collected based on procedures outlined in the QAPP (Heber, 2008). Specific sampling details for each site are summarized below. There were no lagoon samples collected for content analysis.

1.3.3.1 CA5B

Manure sampling was conducted approximately bimonthly during the second year of the study, with samples collected from the reception lane for the flushed manure in B1 and B2. The samples were analyzed for solids content, total nitrogen, ammoniacal nitrogen, and ash content to provide data for the nitrogen balance of the barns.

At the same time as manure sampling, samples of feed and fresh bedding (scraped soil and manure solids blended with almond shells or rice hulls) were taken from each barn. The samples were analyzed for solids content, total nitrogen, and ash. Sampling was added late in the study and only cover the second year of the study (Zhao, et al., 2010).

1.3.3.2 IN5B

Manure in the barns was sampled quarterly between 11/26/07 and 1/20/10. For each collection, at least four samples were collected from each of the two barns and analyzed for ammoniacal nitrogen, total nitrogen, pH, total solids, and ash (added later in the study). Samples of feed were also taken quarterly from each barn and analyzed for total nitrogen, total solids, and ash. Sampling was added late in the study and only cover the second year of the study (Lim, et al., 2010).

Bedding and milk tank samples were collected semiannually. Bedding samples were analyzed for total nitrogen and total solids, while the milk tank samples were only analyzed for total nitrogen.

1.3.3.3 NY5B

The daily volume of milk shipped (total milk less non-saleable milk) from the farm was copied manually from the yearly calendar where milk production was recorded daily by farm staff. Milk production data from B1 included the cows housed in the MC. Additionally, the farm reported milk urea nitrogen (MUN) and protein content nearly every day.

Bedding (post-digested separated manure solids) was sampled from each pen on approximately a monthly basis during the study's second year. The samples were analyzed for pH, solids content, total nitrogen, and ammoniacal nitrogen, and ash content. A single sample of the feed and water were taken at the end of the study. The feed was analyzed for solids content, total nitrogen, and ammoniacal nitrogen, and ash content, while the water sample was analyzed for total nitrogen, and ammoniacal nitrogen, and sulfur content.

Representative manure samples were collected in B1 from each the four pens, and the two manure alleys between the outside row of free stalls and the adjacent row of the head-to-head free stalls. Sampling was conducted approximately monthly during the second year. The samples were analyzed for pH, solids content, total nitrogen, and ammoniacal nitrogen.

1.3.3.4 WA5B

Sampling was conducted approximately bimonthly during the second year of the study. Samples of feed, bedding, and manure were taken from each barn. Bedding and feed samples were analyzed for total solids and total nitrogen content. Manure samples were analyzed for pH, total solids, total nitrogen, and ammonia content. Milk samples were taken from the holding tank and analyzed for total nitrogen only.

1.3.3.5 WI5B

Manure in the barns was sampled quarterly for the last year of the study. Each collection was composed of four samples from each of the two barns. Samples were analyzed for ammoniacal nitrogen, pH, and total solids.

2 REVISIONS TO DATA SET AND EMISSIONS DATA SUMMARY

The section catalogs the changes made to the dairy dataset prior to model development (Section 2.1), considers further changes to the data completeness criteria (Section 2.2), and finally compares the model development dataset to the initial dataset received in 2010 (Section 2.3) and published literature (Section 2.4) to determine the effect of the data revisions.

2.1 Revisions to the 2010 Data Set

As described in Section 4.2 of the main report, the NAEMS monitoring data were submitted to EPA in 2010, with revisions submitted in 2015. Revisions included modifying the approach used to determine the inlet concentrations of ammonia (NH_3) and hydrogen sulfide (H_2S) to align time used to determine valid concentrations at the barn inlet and outlet, using a 10-day running average of inlet concentrations rather than interpolation, and invalidating air flow rates for periods when the ventilation system was not operating. Corrections were submitted for IN5B, NY5B, WA5B, and WI5B. A revised file for CA5B was not submitted by the NAEMS principal investigator (PI).

In addition to the revisions submitted by the PI, EPA reviewed the validity of negative emission values present in the data set. Negative calculated emission values can occur in the NAEMS data set due to a range of different scenarios as described in the SAB review of the 2012 emissions estimating methodologies (EEMs) developed by EPA (U.S. EPA SAB, 2013). These different negative emission scenarios include calculation biases for emission values that were close to the instrument's detection limit, biases due to lack of lag time corrections, or from outdoor events that increased pollutant concentration outside of the barns. EPA developed a procedure for removing negative emission values that resulted from elevated background concentrations. For this procedure, EPA determined the median emission value for each pollutant., then excluded negative emissions values that fell outside of a range based on uncertainty range established in the QAPP for each pollutant the. Appendix B describes this process in more detail. The negative emissions removed accounted for between 2% (NH_3 and TSP) and 26% ($PM_{2.5}$) of the total number of average daily emission values available for the pollutant. Appendix B provides a summary of the number of values removed due to this process by barn for each pollutant.

The 2010 data sets for dairy open sources (lagoons, basins, and corrals) were provided to EPA by the NAEMS PI. The datasets contain 30-minute NH_3 values obtained using the backward Lagrangian Stochastics (bLS) model and vertical radial plume mapping (VRPM), and H_2S emissions obtained using the bLS model. The extensive data sets also include fields used to determine the quality and validity of the emissions data. Based on a literature review of papers published since NAEMS (Grant & Boehm 2020, Grant et al., 2020, Grant & Boehm 2015, Grant et al., 2013a), EPA revised the acceptance criteria for the 30-minute data. Overall, the number of valid 30 minute bLS NH_3 values for lagoons increased and H_2S decreased. The opposite occurred for the corral site, TX5A, as the number of bLS measure estimates NH_3 and H_2S decreased and increased, respectively. Appendix B summarizes the changes in data acceptance criteria and the affects it had on the number of 30-minute values available for each site.

Literature (Grant et al., 2013a) also suggested bLS measurements could be adjusted to be comparable to VRPM results. To prepare the 2012 NAEMS data sets of 30-minute values for use in calculating daily averages, the bLS NH_3 values for sites IN5A and WI5A were adjusted by multiplying the emissions values by 1.19 (Grant & Boehm 2020) and 1.13 (Grant & Boehm 2020), respectively. After the adjustment, the bLS and VRPM data were used together to determine which day had more than 24 half hour values to meet the revised 52% completeness criteria days. In cases where 30-minute emissions flux values were available for both the bLS model and VRPM, the average of the bLS and VRPM values were used. A practical example of the calculation is provided in Appendix B. The Table B-23 presents an example calculation for two days at site IN5A, (one day with both bLS and VRPM data, and one day with only bLS data).

2.2 Comparison between the 2010 and Revised Barn Data Sets

The influence of the previous described corrections on the revised data sets can be observed by comparing the summary statistics of all the valid emission values (at 75% data completeness) between the 2010 dataset, as summarized in the final site reports, and the revised data set. The following sections summarize the differences between the 2010 data set and revised data set for each of the barn types for a set of standard summary statics (e.g., mean, standard deviation, count (N), minimum, maximum, and number less than 0 (N<0)) of the average daily emissions. For summary tables presented, the percent difference was calculated as the revised data set minus the 2010 version of the data set, divided by the 2010 version of the data set (e.g., % Diff = (Revised - $Data_{2010}$)/$Data_{2010}$ * 100). This calculation yields negative values when decreases were seen in the revised version of the dataset.

2.2.1 Mechanically Ventilated Barns

In general, the 2010 and revised data set vary less than 10% for the barns at IN2B for NH_3 (Table 2-1) and H_2S (Table 2-2), while the data sets for the PM size fractions (Table 2-3) were not changed. The exceptions are the increase in the number of H_2S values less than zero (N<0) at IN2B (Table 2-2). There was more of a difference in the data sets for NY5B, particularly with the minimum value of H_2S (Table 2-2), which was revised from a very large negative value (-226 g/d) to a small positive value (34.05 g/d). NY5B was the only site that had changes to the particulate matter data set (Table 2-3), most notable of which was a decrease in the number of negative values for PM_{10}. The WI5B saw some of the biggest differences in NH_3 data, largely due to the increase in the number of valid average daily means (ADM) available for NH_3 after the revisions. The WI5B data sets for PM_{10}, $PM_{2.5}$, and TSP were unchanged.

Table 2-1. Percent difference in NH_3 summary statistics between the 2010 and revised dataset (at 75% data completeness).

Parameter	IN5B B1	IN5B B2	NY5B B1	WI5B B1	WI5B B2
Mean	3%	3%	6%	-4%	-3%
Standard Deviation	5%	5%	5%	-11%	-3%
N	0%	0%	-12%	19%	20%
Minimum	-6%	-6%	-1%	25%	-26%
Maximum	4%	9%	7%	-2%	-2%
N<0	0%	0%	0%	0%	0%

Table 2-2. Percent difference in H_2S summary statistics between the 2010 and revised dataset (at 75% data completeness).

Parameter	IN5B B1	IN5B B2	NY5B B1	WI5B B1	WI5B B2
Mean	1%	-2%	10%	0%	0%
Standard Deviation	0%	1%	3%	0%	-3%
N	2%	4%	-12%	-3%	-2%
Minimum	2%	2%	764%	0%	0%
Maximum	-2%	8%	-3%	4%	-5%
N<0	47%	67%	0%	33%	-88%

Table 2-3. Percent difference in PM summary statistics between the 2010 and revised dataset (at 75% data completeness).

Parameter	NY5B B1, PM_{10}	NY5B B1, $PM_{2.5}$	NY5B B1, TSP	IN5B, PM	WI5B, PM
Mean	5%	2%	2%	No difference	No difference
Standard Deviation	5%	1%	0%	No difference	No difference
N	0%	2%	0%	No difference	No difference
Minimum	0%	0%	0%	No difference	No difference
Maximum	7%	1%	1%	No difference	No difference
N<0	-50%	13%	0%	No difference	No difference

2.2.2 Naturally Ventilated Barns

For the naturally ventilated barns, there were no changes in the CA5B datasets for any pollutant and no changes in the WA5B datasets for NH_3, H_2S, or $PM_{2.5}$. For PM_{10} (Table 2-4), both WA5B barns saw an increase in the number of valid ADM, including new maximums more than 50% larger than in the 2010 data set. The TSP data set (Table 2-5) also changed, most notably there was an 18% decrease in the number of valid ADM at both barns and an increase in the minimum value for barn 2.

Table 2-4. Percent difference in PM_{10} summary statistics between the 2010 and revised dataset (at 75% data completeness).

Parameter	CA5B B1	CA5B B2	WA5B B1	WA5B B2
Mean	No difference	No difference	20%	12%
Standard Deviation	No difference	No difference	63%	38%
N	No difference	No difference	1%	1%
Minimum	No difference	No difference	0%	0%
Maximum	No difference	No difference	83%	68%
N<0	No difference	No difference	0%	0%

Table 2-5. Percent difference in TSP summary statistics between the 2010 and revised dataset (at 75% data completeness).

Parameter	CA5B B1	CA5B B2	WA5B B1	WA5B B2
Mean	No difference	No difference	3%	1%
Standard Deviation	No difference	No difference	5%	6%
N	No difference	No difference	-18%	-18%
Minimum	No difference	No difference	522%	0%
Maximum	No difference	No difference	0%	0%
N<0	No difference	No difference	0%	0%

2.2.3 Milking Centers

For the IN5B MC, most changes were minor for NH_3 (Table 2-6) and H_2S (Table 2-7). The most notable change is the increase in the number of negative ADM for both gaseous pollutants due to the changes in emission calculation. There were no measurements of PM_{10}, $PM_{2.5}$ or TSP made at the IN5B milking center.

The NY5B MC had minor changes to the NH_3 dataset and mostly minor changes to the H_2S data set. One of the largest changes was an increase in the minimum value for H_2S (Table 2-7), which was the result of the removal of a large negative ADM. The data sets for the PM size fractions (Table 2-8) generally saw minor changes. The notable exception is the 33% decrease in the number of negative values for ADM. This statistic is a little misleading, as there were only four values, and one of which was dropped during the revision.

Table 2-6. Percent difference in NH_3 summary statistics between the 2010 and revised dataset (at 75% data completeness).

Parameter	IN5B	NY5B
Mean	7%	0%
Standard Deviation	8%	0%
N	0%	-7%
Minimum	0%	15%
Maximum	4%	-2%
N<0	8%	0%

Table 2-7. Percent difference in H_2S summary statistics between the 2010 and revised dataset (at 75% data completeness).

Parameter	IN5B	NY5B
Mean	2%	-2%
Standard Deviation	-4%	0%
N	1%	1%
Minimum	0%	764%
Maximum	-12%	-2%
N<0	39%	0%

Table 2-8. Percent difference in NY5B MC PM summary statistics between the 2010 and revised dataset (at 75% data completeness).

Parameter	PM_{10}	$PM_{2.5}$	TSP
Mean	-1%	2%	1%
Standard Deviation	11%	1%	0%
N	8%	0%	0%
Minimum	0%	11%	0%
Maximum	0%	1%	1%
N<0	-33%	0%	0%

2.3 Data Completeness Criteria for the Revised Data Set

The appropriate data completeness criteria to use in a study depends on the size of the dataset and the accuracy needed. A study by Grant et al. (2013b), in which NH_3 emissions were modeled from swine lagoons based on NAEMS data, investigated data completeness and associated accuracy. The swine lagoon NH_3 emissions dataset had limited data availability at a data completeness of 75%. Grant et al. (2013b) explored how much the data completeness criteria could be relaxed but still result in data with acceptable error. The study suggested an error of ±25% to be acceptable and determined that a daily data completeness of 52% (or 25 out of 48 30-minute periods) gave less than ±25% error (see Figure 2-1). Using this revised daily completeness criteria resulted in a substantial increase in the size of the dataset.

Based on Figure 2-1 from the Grant et al. (2013b) study, it can be observed that a daily completeness criterion of 75% (36 out of 48 30-minute periods) would give an error of approximately 10%. If it is assumed that the relationship between data completeness and error from the Grant et al. (2013b) study is representative of other NAEMS datasets, the effect of relaxed data completeness criteria can be investigated for other NAEMS sources.

The NAEMS PI provided EPA with additional analysis that examined the effect of different completeness criteria by comparing the number of valid ADM. EPA reviewed these data for the barn data site and retained the 75% completeness criterion. For the open source sites, EPA review found that adjusting the daily data completeness to 52% provided significantly more data and justified the increase in the error. The full analysis can be found in Appendix C.

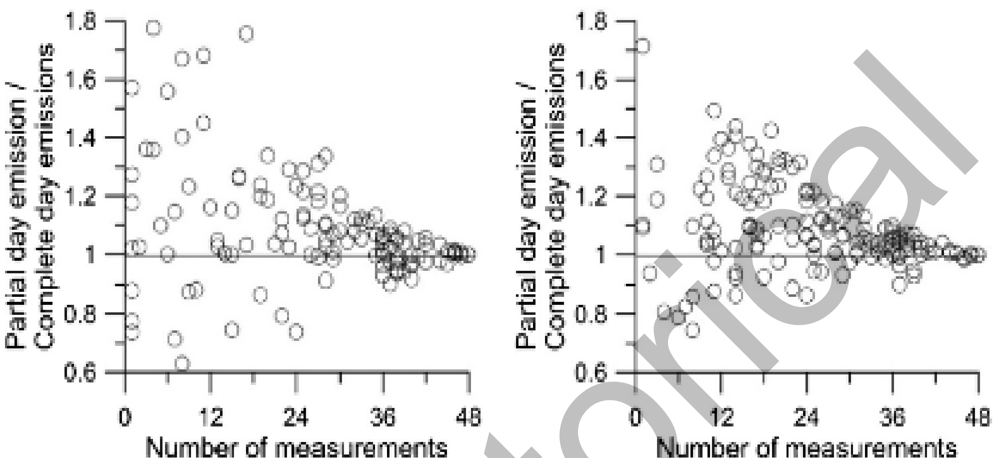


Figure 2-1. Ratio of mean predicted emissions for portion of day with valid emissions measurements to mean predicted emissions for the complete day at the finishing (A) and sow (B) farm. Error plotted against number of valid 30-minute measurements (from Grant et al., 2013b).

2.4 Comparison Between the Revised Data Sets and NAEMS Datasets Used in Peer-reviewed Published Papers

Where possible, EPA compared the revised dataset developed for this report to values presented in peer reviewed journals and reports to quantify any differences due to the application of the revised calculation methods and other adjustments discussed in Section 2.1. Summaries of the gaseous emissions from naturally ventilated barns can be found in Joo et al. (2015). Lagoon and basin summaries have been presented in Grant and Boehm (2015), and corrals in Grant et al. (2020). Summaries of the mechanically ventilated barn data and particulate matter data could not be found at the time of writing.

A simple comparison of the summary statistics presented in these papers and the summary statistics of the revised dataset is presented in the following sections. Overall, the dataset used for model development and presented in the papers are different due to difference in data screening methods. For NH_3 and H_2S at naturally ventilated barns, the model development dataset contains at least twice the number of observations than used in the article due to different choices in processing the data. Similarly, the revisions to the acceptance criteria for open sources noted in Section 2.1 also resulted in difference in differences between the published data set and the modeling data set. For the open sources, the acceptance criteria used by EPA are the culmination of several published papers aiming to improve the data quality and go beyond what was discussed in the compared work. Overall, the comparison highlights that EPA has done extensive analysis and review of the dairy data sets to obtain a robust data set for model development.

2.4.1 Naturally Ventilated Barns

Despite no difference between NH_3 and H_2S in the revised data set and the submitted 2010 data set (Section 2.2.2) for WA5B, the published data has different maximum, minimum, and average values for both (Table 2-9 and Table 2-10). A closer examination of Joo et al. (2015) reveals a more extensive outlier removal process, whereby anything outside 1.5 times the interquartile range were designated as outliers. The article also only reports on data collected in the second year of the study (November 2008 to October 2009) since there were "more and longer trouble-free periods" (Joo et al., 2015). The article further truncates the data by focusing on one-week data sets of continuously collected measurements selected every two months, for a total of 7 weeks (49 days) of data. The model data set contains at least twice as many days as the published data set, which quickly explains the differences seen.

Table 2-9. Comparison of naturally ventilated NH_3 emissions in the model dataset to published datasets.

Site	Units	Statistic	Model Dataset	Published Studies	Study
WA5B B2	Emissions (kg day^{-1})	Mean	26.6	14.1	Joo et al. 2015
		Minimum	-156.4	10.8	
		Maximum	96.6	19.7	
WA5B B4	Emissions (kg day^{-1})	Mean	54.7	19.4	Joo et al. 2015
		Minimum	9.0	17.2	
		Max	170.9	21.2	

Table 2-10. Comparison of naturally ventilated H_2S emissions in the model dataset to published datasets.

Site	Units	Statistic	Model Dataset	Published Studies	Study
WA5B B2	Emissions (g day^{-1})	Mean	555.6	397.4	Joo et al. 2015
		Minimum	-5,400.9	123.5	
		Maximum	6,513.6	542.4	
WA5B B4	Emissions (g day^{-1})	Mean	1,130.9	627.7	Joo et al. 2015
		Minimum	-11,640.1	0.0	
		Max	17,960.3	1711.8	

2.4.2 Open sources

Section 2.1 and Appendix B outline how EPA altered the acceptance criteria for the open sources. The changes were culled from several peer reviewed journal articles (Grant & Boehm 2020, Grant et al., 2020, Grant & Boehm 2015, Grant et al., 2013a) published since the 2010 receipt of the NAEMS data. While each of the articles referenced typically focus on one site, EPA developed a list of revisions to be applied to each site that represent the state of the science for the method. As such, the lagoon NH_3 values (Table 2-11) differ from the values published in Grant & Boehm (2020) due to difference in the acceptance criteria.

Table 2-11. Comparison of lagoon and basin NH_3 emissions in the model dataset to published datasets.

Site	Units	Statistic	Model Dataset	Published Studies	Study
IN5A	Emissions (g s^{-1})	Mean	0.23	0.27	Grant & Boehm 2020
		Minimum	-0.14	0.17	
		Maximum	1.07	0.39	
WI5A	Emissions (g s^{-1})	Mean	0.07	0.22	Grant & Boehm 2020
		Minimum	-0.04	0.07	
		Maximum	0.91	0.42	

Similarly, NH_3 emissions from dairy corrals varied from the published work due to revisions to the acceptance criteria that EPA implemented. These revisions resulted in 6 additional daily average emission values from the Grant publication (Table 2-12). These additional days shift the average of the daily means higher than in the published work and increased the variability, as shown by the increase in the standard deviation. As noted previously, the acceptance criteria used by EPA are an attempt to apply the revisions from several published papers aiming to improve the data quality and go beyond what was discussed in the compared work. Overall, the comparison highlights that EPA has done extensive analysis and review of the dairy sets to obtain a robust data set for model development.

Table 2-12. Comparison of corral (TX5A) NH_3 emissions in the model dataset to published datasets.

Source	N	Mean (kgd^{-1})	Standard Deviation
Revised	73	755.0	317.5
Grant et al. 2020	67	287.6	144.7

3 RELATIONSHIPS ESTABLISHED IN LITERATURE

Developing EEMs for dairy AFOs is complex as many variables potentially influence emissions. Therefore, to be efficient as possible in this study, a focused approach was used. The focused approach involved developing models based on variables that could potentially have a major influence on air emissions. This assessment was made based on theoretical considerations and observations reported by previous studies that have investigated the influence of variables on emissions from dairy AFOs.

3.1 NH_3 and H_2S from Confinement Sources

Emissions from barns originate from the nitrogen and sulfur content in urine and manure deposited in pits or on the floor along with any bedding material present in the barn. The amount of NH_3 and H_2S emitted depend on the amount of manure produced and its characteristics, that is the total ammoniacal nitrogen (TAN) and sulfur content, (Sanchis, Calvet, del Prado, and Estelles (2019)). Multiple factors influence the generation and release of NH_3 and H_2S emissions, such as the type of building and its volume, flooring type, housing density, manure management, livestock management practices, milk yield, diet, animal behavior, and factors affecting the microclimate within the buildings (e.g., temperature, humidity, airflow) (Bjerg et al., 2013, Bougouin et al. 2016, Herbut and Angrecka 2014). The following section outlines the relationship between these specific parameters and emission rates, as well as whether the parameter, or suitable proxy, is available in the NAEMS data set.

Manure volume is a key factor influencing NH_3 and H_2S emissions in both mechanically ventilated and naturally ventilated barns. That is, the more manure and urine there is, the more precursor material there is for NH_3 and H_2S emissions. No estimates or measurements on the amount of manure generated were taken at any of the dairy sites. However, other parameters, such as inventory and live animal weight (LAW), can be used as proxies for fresh waste generation as more or larger animals would produce more waste. Both inventory and LAW were determined daily at each site and were selected for further investigation.

Second to volume, the compositional characteristics—that is nitrogen, ammonia, and sulfur content of the waste—provides information on the amount of NH_3 and H_2S than can form and be emitted by the barn. As noted in Section 2.3, sampling for total ammoniacal nitrogen content (TAN), total Kjeldahl nitrogen (TKN), and sulfur content occurred for various components of the barn, including bedding material and the waste collected from the floor. However, a limited number of samples were taken over the course of the study. Including them in the regression analysis would limit the number of days available for model development, and thereby the variability of other factors included in the model. EPA has looked at interpolating the data between samplings to extend the data to more days, however, this does require assumptions about the behavior of nitrogen and sulfur content in the manure between samples. Knowing the incoming nitrogen and sulfur content of the feed, water, and bedding would inform the interpolation process, leading to better assumptions as this would indicate the maximum amount of nitrogen and sulfur introduced into the system, allowing from mass balance checks. However, data on feed and water and was not provided by the producers. As such, the limited data available on waste characteristics (i.e., TAN, TKN, sulfur content) were excluded from the model development dataset.

Manure pH has a strong correlation with both NH_3 and H_2S emissions (Rotz et al. 2014, Montes et al., 2009). The ammonia fraction of TAN is partly a function of pH, so pH would provide an indication of NH_3 available in the manure (Montes et al., 2009). For H_2S, water with an acidic pH has an increased concentration of molecular hydrogen sulfide, which increases the potential for H_2S emissions. However, like TAN and TKN measurements, only limited pH data were collected during NAEMS. As such, the limited data available were excluded from the model development dataset.

The Sanchis et al. (2019) review overwhelmingly found air temperature in the barn had a positive relationship with NH_3 emissions for both mechanically and naturally ventilated barns. The higher temperatures increase NH_3 losses by decreasing the solubility of NH_3 and increasing the proportion of TAN as NH_3 gas (Meisinger and Jokela, 2000). For a similar reason, manure temperature is highly correlated to NH_3 emissions. NAEMS collected barn exhaust temperature and ambient temperature at all sites and these factors were selected for further investigation. Ambient temperature was chosen for further investigation, as it is related to barn conditions and would provide an alternative barn based temperature monitoring for operators.

The studies cited by Sanchis et al. (2019) found, in some cases, the relationship between temperature was affected by the floor type (e.g., slatted versus solid) and manure handling system. EPA investigated the type of manure management system (i.e., flush or scrape) for the mechanical barns for further analysis. A similar analysis was not included for the naturally ventilated barns, as both sites used flush systems. Bedding type was also considered, however the study data only indicated in general the type of bedding used in the barns. In the case of CA5B, the operator used several bedding types as they were available (Zhao et al., 2010) with no reliable indication of when those changes occur or what the percentage of each bedding type was on any given day.

Schmithausen et al. (2018) also noted permanent under floor storage of slurry potentially contributed to higher NH_3 emissions. The site description of two mechanically ventilated sites, IN5B and NY5B, suggest that they utilize a reception pit to hold scraped material as part of their manure management system. While the NY5B notes the deep reception pit is in the connecting alley between the freestall barn and milking center, the location of the pit at IN5B was not documented. It was noted that the material in the reception pits, at both sites, were transferred to a digester on a regular basis. Because the material was transferred on a regular basis and was not long term, a variable to account for under floor storage was not included at this time.

The ventilation rate of mechanically ventilated barns has been shown as having a positive correlation to NH_3 emissions across several studies (Kavolelis, 2003; Philippe, et al., 2011; Samer et al., 2012). Ventilation rates are typically driven by the temperature inside the barn, which is affected by the outside temperature. For modeling purposes, this suggests that temperature, either barn or ambient, might make a good proxy for ventilation rate.

For naturally ventilated barns, the ventilation or air flow through the barn is driven by the wind. Many studies (Arogo et al., 1999; Bjerg et al. 2013, Wu et al. 2012; Schrade et al., 2012; and Herbut and Angrecka, 2014) have found a strong correlation between emissions and wind speed, and occasionally wind direction (Feidler and Müller (2011)). However, Saha et al. (2014) did not find the clear relationship between wind speed and emissions. Saha et al. (2014) suggested that the effects of wind speed might be masked by other environmental parameters, such as temperature and relative humidity, or the presence of other buildings and slurry tanks that might influence wind entering the building. Bjerg et al. (2013) noted that the more important component to release was air velocity over the manure, which is not necessarily correlated to wind speed in the barn, as air movement could be affected by numerous things, such as animals and other obstructions in the barn. For modeling purposes, wind speed was selected for further study for naturally ventilated barns.

The literature review did not find references showing a correlation between either NH_3 or H_2S emission in mechanically ventilated barns and relative humidity. Sanchis et al. (2019) suggests that there are no significant effects due to the high variability of relative humidity in the barn environment. However, Sanchis et al. (2019) noted studies of naturally ventilated barns showed that higher relative air humidity leads to reduced NH_3 emission rates. In general, higher air humidity values are expected to yield reduced NH_3 concentrations, since NH_3 is highly water-soluble and would be absorbed by the water vapor in the air and less gaseous NH_3 would be measured. However, this is only true within a certain temperature range and the management strategies would also affect this relationship. Saha et al. (2014) also noted the effect of relative humidity might be related to the changes in animal activity and performance in response to heat stress. Because of the potential relationship between NH_3 and moisture, relative humidity was selected for further study for both mechanically and naturally ventilated barns.

Animal and management activities, such as feeding and milking, can affect emission rates (Ngwabie, et al. 2011, Hempel 2016). There was no specific daily information on management activities recorded by NAEMS.

3.2 Particulate Matter from Barns

The release of PM_{10}, TSP, and $PM_{2.5}$ (collectively referred to as PM) into the air of dairy barns is caused by the physical suspension of a range of different materials in the barns including feed, manure, bedding, and skin or hair (Cambra-Lopez et al., 2011). Accordingly, the EPA chose live animal weight and inventory as predictor variables, as they are related to the amount of source material. One study, Garcia et al. (2013), found an inverse relationship between milking center capacity and $PM_{2.5}$ concentration on the farm, which was attributed to the larger dairies being newer and more efficiently operated. This suggests there are different management practices at newer barn that can affect particulate emissions. Likely making the use of inventory more nuanced than with other animal types.

Physical suspension of PM from barn surfaces can be caused by air flow, animal activity, and human activity (Aarnink and Ellen, 2007); however, EPA did not receive barn activity measurements and could not explore the influence of this variable further. Airflow, or ventilation rate, was recorded for all barn sources. As mentioned in the previous section, mechanical ventilation rates are related to ambient and barn temperature, thus meaning that temperature could be a potential surrogate variable that represents airflow. For naturally ventilated buildings wind speeds may have an influence on the air flow, which in turn could potentially affect the PM emissions from the buildings. Accordingly, EPA selected the airflow for further review, as well as wind speed from naturally ventilated barns. Temperature was selected for both mechanically ventilated barns, due to the correlation with airflow, and naturally ventilated barns. While Takai et al. (1998) did not find seasonal variation with PM emission from naturally ventilated barns, Mostafa et al. (2016) did see greater emissions in summer and lower values in winter. The longer observation periods of PM during NAEMS showed some seasonality, with the highest values occurring in the summer.

Physical suspension may also be influenced by moisture conditions and relative humidity (Cambra-Lopez et al., 2010). A study by Takai et al. (1998) examined PM emissions from a variety of livestock types including dairy cattle and reported that relative humidity greater than 70% contributed to particles aggregating together and thus reducing emissions. Accordingly, for dairy barns, the variables ambient relative humidity and barn relative humidity were selected for further investigation.

3.3 NH_3 and H_2S for Open Sources

The release of NH_3 and H_2S from open sources follows similar mechanics as release from waste in the barns. That is, the amount of NH_3 and H_2S emitted will depend on some of the same factors as the barn, such as the compositional characteristics. With lagoons and basins, the amount of waste can be characterized by the lagoon surface area in addition to farm level inventory and live animal weight. For open source model development, EPA used lagoon surface area to normalize emissions, as it represents the amount of the manure that can exchange gas with the atmosphere. For corrals, the area of the corrals was selected along with the inventory for the farm since the emissions measurements covered a wider area. As with barn sources, TAN, TKN, and sulfide content of the manure has a major influence on dairy open source NH_3 and H_2S emissions (see section 3.1 for details). For NAEMS open source sites, there were no measurements of TAN, TKN, or sulfide at the three sites. As a result, EPA could not investigate these parameters further.

Like barn sources, NH_3 and H_2S emissions are a function of the pH, specifically the pH at the surface of the manure, and temperature as both parameters affect the chemistry associated with the generation and release of the pollutants (Arogo et al., 2006, Rotz et al., 2014). Ambient temperature, along with turbulence, typically represented by wind speed, affect the diffusion and dispersion of the released gases from the lagoon surface (Arogo et al., 2006, Sommer et al., 2013). There were continuous measurements of lagoon temperature, lagoon pH for lagoon/basin sites, and air temperature and wind speed for all NAEMS open sources. Accordingly, these four variables were selected for further analysis for lagoon/basin sources and air temperature and wind speed were selected for corral sources.

Like manure in barns, moisture levels can affect the volatilization of NH_3 and H_2S. In drier environments, evaporation and volatilization are going to occur more rapidly. In a lagoon, where waste is held as a slurry, it is likely less of a factor than in a corral where manure is often mixed into the soil creating a drier environment. Grant et al. (2020) suggested that the vapor pressure deficit might be a more compelling parameter than relative humidity to represent the potential for volatilization from the manure and soil mixture present in corrals. The vapor pressure deficit is the difference between how much moisture the air can hold when saturated and the actual amount of moisture in the air. Unlike relative humidity, the vapor pressure deficit is not a function of temperature, which also allows for a more consistent comparison between days. EPA chose to include both relative humidity and vapor pressure deficit to further investigate their relationship with emissions from the corral.

The presence of a crust or cover on a lagoon or basin will inhibit the transfer of NH_3 to the atmosphere, reducing emissions. Similarly, frozen lagoon surfaces will also stop emissions from the surface of the lagoon. The NAEMS made limited observation of the state of the lagoon (e.g., color, crust) during the study. The lack of daily observations would limit the number of days available for EEMs development, as the dataset would be limited to only those days with lagoon surface observations. Due to the limited nature of the observations available, this variable was not explored further.

4 SITE COMPARISON, TRENDS, AND ANALYSIS

Before developing the EEMs, EPA evaluated NAEMS data for each pollutant to identify patterns and trends in the emissions data using a combination of summary statistics (mean, standard deviation, number of data values, median, minimum, maximum, coefficient of variation, and number of data values less than zero) and time series plots. Section 4.1 summarizes the emissions trends from the sites, while Appendix D contains the tables of summary statistics. Appendix E presents the time series plots of the site-specific emissions, environmental and production parameters, and manure data collected under NAEMS.

Based on the analysis described in Section 3.0, EPA identified the key environmental and manure parameters that potentially affect emissions from dairy barns and associated open sources. Parameters of particular interest included inventory, barn conditions (exhaust temperature, exhaust relative humidity, and airflow), ambient temperature, ambient relative humidity, and wind speed.

The next step of the analysis was to look at the key environmental and manure parameters compared to emissions trends. The exploratory data analysis was conducted to confirm that the variables were selected based on the following criteria: (1) data analysis in this study and in the literature suggested that these variables had an influence on emissions; (2) the variables should be easy to measure; and (3) the variables were already in the daily average NAEMS data and were available for most days of monitored emissions. This third selection criterion particularly applies to the manure parameters, such as moisture content and TAN concentration, which were infrequent due to the intensive collection and analysis methods. Additional time could be taken to develop an appropriate methodology for interpolating between the few data points available for these parameters in the dataset. However, these parameters are difficult to acquire as they require chemical analysis from a laboratory.

The exploratory data analysis was also used to explore whether additional parameters could be included to explain trends. To further explore the trends between the predictor variables and emissions and determine whether the parameter should be included in developing an EEM, EPA prepared scatter plots of emissions versus the process, environmental, and manure parameters and conducted least squares regression analysis to assess the influence of each variable on emissions. For the regressions, EPA classified the linear relationships based on the ranges in Table 4-1.

A summary of this analysis for environmental parameters is discussed in Section 4.2. Again, Appendix D contains summary statistics, Appendix E contains the relevant time series plots, and Appendix F contains least squares regression analyses between the identified parameters and emissions.

Table 4-1: Relationship classification based on R^2 values

Range of R^2	Relationship strength
$R^2 \leq 0.001$	none
$0.001 < R^2 \leq 0.2$	slight or weak
$0.2 < R^2 \leq 0.4$	modest
$0.4 < R^2 \leq 0.6$	moderate
$0.6 < R^2 \leq 0.8$	moderately strong
$R^2 > 0.8$	strong

4.1 Mechanically Ventilated Dairy Barns (IN5B-B1, IN5B-B2, NY5-B1, WI5B-B1 and WI5B-B2)

4.1.1 Emissions data

Appendix D, Table D-1 and D-2 presents the summary statistics for daily average emissions of NH_3 for the mechanically ventilated sites in kilograms per day and grams per day per head (kg d^{-1} and g d^{-1} hd^{-1}), respectively. Based on Table D-1, the emissions appear to vary across sites. However, when presented in a per head basis, as in Appendix D, Table D-2, the emissions are consistent across sites with average daily emissions ranging from 31.35 kg d^{-1} hd^{-1} at WIB5-B2 to 48.28 kg d^{-1} hd^{-1} at IN5B-B1. Appendix E, Figure E-1 showed that the emissions follow a seasonal cycle, with greater emissions typically occurring in the summer and decreasing to lows in winter months. Emissions from the WI5B site have a more muted seasonal cycle on the first year, with slightly increased values in the second year of the study. This appears to correlate to a changing from a flush system to a scrape system in September of 2008. As noted in Section 3, manure management systems can affect the emissions generated in the barn. Appendix E, Figure E-1 suggests it is worth pursuing modeling options that account for the manure management system.

The summary statistics for daily average H_2S emissions are presented in Appendix D, Table D-3 and D-4 for g d^{-1} and mg d^{-1} hd^{-1}, respectively. Unlike NH_3, the per head values in Table D-4 show emission values 2 to 4 times greater at the WI5B barns than the other sites. Appendix E, Figure E-2 showed the time series plot for H_2S emissions. The plot showed a seasonal trend in H_2S emissions for the IN5B and NY5B site, with emissions trending higher in warmer months. However, the WI5B barns show a very different trend. The H_2S emission for both barns are quite high and variable for the first half of the plot, and then fall to lower levels. Like the shift with the NH_3 emissions, this change corresponds to the switch to a scrape system in the barns.

Appendix D, Table D-5 and D-6 presents the summary statistics in g d^{-1} and mg d^{-1} hd^{-1}, respectively, for the daily average emissions of PM_{10} for the mechanically ventilated sites. There was variation in emissions between sites, both in the total for the day and when normalized on a per head basis. The average daily emissions ranged from 9.73 g d^{-1} (12.49 mg d^{-1} hd^{-1}) at INB5-B1 to 562.91 g d^{-1} (1,571.90 mg d^{-1} hd^{-1}) at WI5B-B2. The time series plot (Appendix E, E-3) showed readings hovering between 0 and 500 g d^{-1}, with greater spikes typically occurring in the summer months. WI5B does experience maximum values that are twice as high as the other sites. These peaks occur both in the summer of 2008 and 2009, suggesting the change to a scrape manure management system did not contribute to the highest emission days. The dataset used for the exploratory data analysis has several negative values, which were further reviewed during the data review process described in Section 2.

Like, PM_{10}, the $PM_{2.5}$ average daily emissions vary substantially across sites. The average daily emissions summarized in Appendix D, Table D-7, indicate that WI5B emissions are much greater than the other barns. The emissions across all sites range from 21.18 g d^{-1} at IN5B-B1 up to 186.75 g d^{-1} at WI5B-B2. When accounting for inventory difference (Appendix D, Table D-8), the WI5B are still more than twice any other mechanically ventilated barn monitored during NAEMS, with an average value of 662.17 mg d^{-1} hd^{-1} at WI5B-B1 compared to 25.89 mg d^{-1} hd^{-1} at IN5B-B1. Appendix E, Figure E-4 showed the temporal variability of the $PM_{2.5}$ emissions. The plot for IN5B does show some rather large negative numbers in the exploratory data analysis, which were further reviewed during the data set review process described in Section 2. The inclusion of these points is likely reason for the lower average values at IN5B compared to the other sites. The sparse temporal nature of the daily $PM_{2.5}$ values, due to a rotating monitoring schedule for the PM size fractions at the NAEMS sites, makes it hard to determine if there is a seasonal trend to the data. The number of negative daily averages from the sites varied greatly. The barns at IN2B had the least negative values with 28 and 29 at B1 and B2, respectively. The remaining sites had nearly twice as many negative values; NY5B-B1 had 53, while WI5B had 53 and 45 at B1 and B2, respectively.

The daily average TSP emissions followed a similar trend to PM_{10} and $PM_{2.5}$. That is WI5B had average emissions substantially greater than the other two sites (Appendix D, Table D-9), even after accounting for difference in inventory levels (Appendix D, Table D-10). Like $PM_{2.5}$, the sparse temporal nature of the daily TSP values makes it hard to determine if there is a seasonal trend to the data. The plot of WI5B does suggest some seasonality, with slightly greater emissions in the summer. However, a similar pattern is not obvious at the other sites. There were fewer negative daily TSP values, with all sites reporting less than 10 negative values.

4.1.2 Environmental data

The statistical summary of the environmental parameters associated with mechanically ventilated barns are presented in Appendix D, Table D-11. The inventory was varied across the sites, ranging from an average of 211 head at WI5B-B1 to 864 head at IN5B-B2. Appendix E,

Figure E-6 showed that the number of cows present over the course of NAEMS was consistent, with any one barn varying by less than 112 cows over the study duration. Of note, the first-year inventory data from WI5B appears to be based on average inventory of the barn and not actual inventory levels. Appendix F, Figures F-1 through F-5 show the scatter plots of inventory versus each pollutant. A summary of the findings is provided in Table 4-2. In general, there is a weak relationship with inventory across all pollutants, except that NH_3 has a moderate positive relationship. Of note, all the PM size fractions show a weak negative linear relationship with inventory, as the smaller barns have greater emissions. Further investigation showed the barns with greater inventory are newer, which is consistent with the finding from the literature review that newer barns had lower PM emissions. As noted in Section 3.2, the difference between the newer facilities is likely a management practice applied in the newer construction. It is currently unknown what leads to the decrease in emissions for larger newer farms. A possibility to somehow account for this unknown factor is to consider the age of the facility in modeling; however, the limited range in ages (Table 4-1) makes it difficult to incorporate at this time. EPA will continue to pursue identifying the physical or chemical property driving this decrease in Pm emissions in newer barns, and a way to incorporate this into the modeling.

Table 4-2. Year mechanically ventilated barns were constructed

Barn	Year Constructed
WI5B B1	1990
WI5B B2	1994
NY5B B1	1998
IN5B B1	2004
IN5B B2	2004

Average animal weight for the IN5B and WI5B barns were reported as a constant value. For NY5B, the daily value reported only vary by less than 5 kg (576 to 580 kg). This limited range of daily average animal weight is apparent in the time series (Appendix E, Figure E-7). The regression analyses in Appendix F, Figures F-6 through F-10, summarized in Table 4-2, showed only a slight or weak relationship between average animal weight and each pollutant. Trends in live animal weight (i.e., inventory * average animal weight) do not vary dramatically over the monitoring period (Appendix E, Figure E-8). The regression analyses in Appendix F, Figures F-11 through F-15 showed similar relationships as inventory, which is the most variable component of live animal weight.

Exhaust temperatures were comparable across all the sites, ranging from an average of 10.55°C at WI5B-B2 to 12.89°C at NY5B-B1. The time series in Appendix E, Figure E-9 show the typical seasonal trend, where temperatures peak in the summer, decrease to minimums around the new year, and then trend upwards during the spring. The linear regression analyses

(Appendix F, Figures F-16 through F-20) only shows a weak to modest positive relationship to temperature. However, the figure for IN5B suggests a nonlinear relationship with temperature, which might be reducing the overall strength of the correlation. The shift in manure management system at WI5B affected the strength of the relationship for those barns. For example, R^2 reached 0.72 with NH_3 emissions while the house was scrape and only 0.21 as scrape for NH_3. A summary of the findings is provided in Table 4-2.

A review of the exhaust relative humidity summary (Appendix D, Table D-11), were comparable across all the sites, ranging from an average of 66.8% at WI5B-B2 to 75.4% at NY5B-B1. The time series (Appendix E, Figure E-10) show the relative humidity is variable, as there is a spread in the data for any time of the year. The plots suggest dips in humidity for the spring, with IN5B also suggesting a dip in the fall. When regressed with the emissions (Figures F-21 through F-25), there are only slight or weak relationships, which are positive for gaseous pollutants and negative with particulate matter daily emissions (kg/d).

The measured airflow through the barn was comparable across sites and ranged from 131. dry standard cubic meter per second (dsm^3s^{-1}) at WI5B-B1 to 210. dsm^3s^{-1} at IN5B-B1. The time series (Appendix E, Figure E-11) showed a seasonal pattern, as ventilation rates would increase to maintain barn temperatures during warm months. The regression analyses (Appendix F, Figures F-26 through F-30) showed weak to modest positive relationships with emissions, which is supported by literature.

Table 4-3. Mechanically ventilated environmental parameter regression analyses

Pollutant	Parameter	R	R^2	Strength	Figure
NH_3	Inventory	0.660	0.435	moderate	Appendix F, F-1
H_2S	Inventory	0.002	< 0.001	slight or weak	Appendix F, F-2
PM_{10}	Inventory	-0.292	0.085	slight or weak	Appendix F, F-3
$PM_{2.5}$	Inventory	-0.319	0.102	slight or weak	Appendix F, F-4
TSP	Inventory	-0.327	0.107	slight or weak	Appendix F, F-5
NH_3	Average animal weight	-0.423	0.179	slight or weak	Appendix F, F-6
H_2S	Average animal weight	0.114	0.013	slight or weak	Appendix F, F-7
PM_{10}	Average animal weight	0.240	0.058	slight or weak	Appendix F, F-8
$PM_{2.5}$	Average animal weight	0.384	0.148	slight or weak	Appendix F, F-9
TSP	Average animal weight	0.384	0.147	slight or weak	Appendix F, F-10
NH_3	Live animal weight	0.653	0.426	moderate	Appendix F, F-11
H_2S	Live animal weight	0.014	< 0.001	slight or weak	Appendix F, F-12
PM_{10}	Live animal weight	-0.278	0.077	slight or weak	Appendix F, F-13
$PM_{2.5}$	Live animal weight	-0.283	0.080	slight or weak	Appendix F, F-14
TSP	Live animal weight	-0.307	0.094	slight or weak	Appendix F, F-15
NH_3	Exhaust temperature	0.493	0.243	modest	Appendix F, F-16
H_2S	Exhaust temperature	0.323	0.104	slight or weak	Appendix F, F-17
PM_{10}	Exhaust temperature	0.410	0.168	slight or weak	Appendix F, F-18

Pollutant	Parameter	R	R^2	Strength	Figure
$PM_{2.5}$	Exhaust temperature	0.484	0.234	modest	Appendix F, F-19
TSP	Exhaust temperature	0.406	0.165	slight or weak	Appendix F, F-20
NH_3	Exhaust relative humidity	0.390	0.152	slight or weak	Appendix F, F-21
H_2S	Exhaust relative humidity	0.193	0.037	slight or weak	Appendix F, F-22
PM_{10}	Exhaust relative humidity	-0.269	0.072	slight or weak	Appendix F, F-23
$PM_{2.5}$	Exhaust relative humidity	-0.414	0.171	slight or weak	Appendix F, F-24
TSP	Exhaust relative humidity	-0.322	0.104	slight or weak	Appendix F, F-25
NH_3	Airflow	0.536	0.287	modest	Appendix F, F-26
H_2S	Airflow	0.232	0.054	slight or weak	Appendix F, F-27
PM_{10}	Airflow	0.425	0.180	slight or weak	Appendix F, F-28
$PM_{2.5}$	Airflow	0.449	0.202	modest	Appendix F, F-29
TSP	Airflow	0.376	0.141	slight or weak	Appendix F, F-30

4.1.3 Ambient Data

The statistical summary of the ambient parameters associated with mechanically ventilated barns are presented in Appendix D, Table D-12. The average daily temperatures were cooler at WI5B at 7.2°C, compared to 12.2°C at IN5B. The time series in Appendix E, Figure E-12 show the typical seasonal pattern to temperatures (i.e., maximum in summer and minimums in winter). Of note, data is missing starting in January 2008 at IN5B. No reason for the data loss was provided in the final site report. With the inclusion of three sites, there are ample measurements of emissions at the anticipated temperature range for model development. The scatter plots of ambient temperature (Appendix F, Figures F-31- F-35), summarized in Table 4-3, show weak-to-modest positive relationships with emissions. The NH_3 plots (Appendix F, Figures F-31) indicate emissions increased more rapidly with temperature at IN5B than the remaining sites.

Ambient relative humidity is similar between sites, ranging from an average value of 67.8% at NY5B to 68.4% at WI5B. The time series (Appendix E, Figure E-13) show the values vary by at least 20% for any given time of the year. Like the exhaust relative humidity, there is an indication that minimum values are more likely in both spring and fall, though the scatter to the data makes a seasonal pattern hard to discern. The regression analyses (Appendix F, Figures F-36 – F-40) indicate slight or weak negative relationships between ambient relative humidity and emissions, even when looking at sites individually.

Table 4-4. Mechanically ventilated ambient parameter regression analyses

Pollutant	Parameter	R	R^2	Strength	Figure
NH_3	Ambient temperature	0.537	0.289	modest	Appendix F, F-31
H_2S	Ambient temperature	0.257	0.066	slight or weak	Appendix F, F-32
PM_{10}	Ambient temperature	0.370	0.137	slight or weak	Appendix F, F-33
$PM_{2.5}$	Ambient temperature	0.398	0.159	slight or weak	Appendix F, F-34
TSP	Ambient temperature	0.348	0.121	slight or weak	Appendix F, F-35
NH_3	Ambient relative humidity	-0.110	0.012	slight or weak	Appendix F, F-36

Pollutant	Parameter	R	R^2	Strength	Figure
H_2S	Ambient relative humidity	<0.001	<0.001	slight or weak	Appendix F, F-37
PM_{10}	Ambient relative humidity	-0.129	0.017	slight or weak	Appendix F, F-38
$PM_{2.5}$	Ambient relative humidity	-0.331	0.109	slight or weak	Appendix F, F-39
TSP	Ambient relative humidity	-0.155	0.024	slight or weak	Appendix F, F-40

4.2 Milking Centers (IN5B-MC and NY5B-MC)

4.2.1 Emissions Data

Appendix D, Table D-13 and Table D-14 presents the summary statistics, in kg d^{-1} and g d^{-1} hd^{-1}, for daily average emissions of NH_3 for the MCs monitored during NAEMS. The total emissions (kg d^{-1}) are relatively similar between the barns, though IN5B has a larger standard deviation. When scaled for the capacity of the MC (Appendix D, Table D-14), NY5B, at 30.3 g d^{-1} hd^{-1}, was nearly double the average emission of 15. 7 g d^{-1} hd^{-1}at IN5B. The time series plot of NH_3 emissions (Appendix E, Figure E-14) showed some seasonality in the data. The plots for IN5B suggest greater emissions in the warmer months, particularly in the summers of 2008 and 2009. The data at NY5B does not have as strong of a seasonal pattern as IN5B.

In a reversal of what was seen with the NH_3 statistics, IN5B had greater overall H_2S emissions (Appendix D, Table D-15) than NY5B and greater scaled emissions (Appendix D, Table D-16). Average emissions at IN5B were 1,207 g d^{-1} (2,148 mg d^{-1} hd^{-1}) compared to 129g d^{-1} (2,681 mg d^{-1} hd^{-1}). The time series plot of H_2S emissions (Appendix E, Figure E-15) suggests some seasonality to the data, with higher readings in the summer months, which may be related to ventilation rates, and indirectly related to ambient temperature. The peaks at IN5B were much greater than NY5B, suggesting an additional difference in the site. Further review showed that IN5B used a flush system and NY5B used a scrape system for manure removal. Like the emission shift seen at WI5B, it is possible that the manure management system is influencing the emission levels.

Particulate matter emissions observations were only taken at NY5B. Appendix, Table D-17 provides the statistical summary in g d^{-1} and Appendix D, Table D-18 provide them in mg d^{-1} hd^{-1}. Appendix E, Figure E-16 shows the time series of PM_{10} emission estimates. The plot suggests some seasonality to the data, with higher readings in the summer months, which may relate to ventilation rates. The time series of $PM_{2.5}$ emission is in Appendix E, Figure E-17, while Appendix E, Figure E-18 showed the time series for TSP. The sparse nature of the $PM_{2.5}$ and TSP data makes it hard to determine if there is any seasonality to the data.

4.2.2 Environmental data

The statistical summary of the environmental parameters associated with MCs is presented in Appendix D, Table D-19. Daily inventory number were not reported for the MCs. The capacity of the milking center was used to represent the inventory levels. This is evident in the time series (Appendix E, Figure E-19) and the scatter plots (Appendix F, Figures F-41-F-45). Average animal weight for the IN5B MC was reported as a constant value. For NY5B, the daily value reported only vary by less than 5 kg (576 to 580 kg), like the mechanically ventilated barn. This limited range of daily average animal weight is apparent in the time series (Appendix E, Figure E-20). The regression analyses in Appendix F, Figures F-46 through F-50, summarized in Table 4-4, showed only a slight or weak relationship between average animal weight and each pollutant. Because of the constant inventory and near constant average animal weight, trends in live animal weight (i.e., capacity * average animal weight) do not vary dramatically over the monitoring period (Appendix E, Figure E-21). The regression analyses in Appendix F, Figures F-51 through F-55 showed only slight relationships with emissions. To include size of the operation in the models as a proxy for volume of manure produced, EPA opted to test models where the emissions were normalized by the capacity of the MC. The models will yield an estimate of emissions per head capacity of the MC.

Exhaust temperature was comparable between sites (Appendix E, Figure E-22), with average daily means of 12.8°C at NY5B and 13.2°C at IN5B. The regression analyses (Appendix F, Figures F-56 - F-60) showed a weak-to-modest correlation between exhaust temperature and emissions, like the mechanically ventilated barns. Exhaust relative humidity was also comparable between sites (Appendix E, Figure E-23), with average daily values of 74.2% and 73.8% at IN5B and NY5B, respectively. Like with mechanically ventilated barns, there is a tendency for the lowest values to occur in the spring and fall. However, the wide scatter of values for any time of the year, makes any strong seasonal pattern hard to discern. The regression analyses (Appendix F, Figures F-61 - F-65), only showed slight-to-weak positive correlation with emissions.

Airflow rates were much lower at NY5B than IN5B, which is clearly demonstrated in the time series plot (Appendix E, Figure E-24). Average airflow rates were 39.90 dsm^3s^{-1} at NY5B and 183.33 dsm^3s^{-1} at IN5B. The MC at IN5B is connected to Barn 1 at the site (see Figure 1-2 in Section 1), while the MC at NY5B is connected to both Barn 1 and a naturally ventilated barn (see Figure 1-3 in Section 1). It is possible the connection to the naturally ventilated barn reduced the ventilation needs at the MC. The regression analyses (Appendix F, Figures F-66 - F-70) showed only a slight to weak correlation with emissions, except for PM_{10}, which has a modest correlation.

Table 4-5. Milking center environmental parameter regression analyses

Pollutant	Parameter	R	R^2	Strength	Figure
NH_3	Inventory (MC Capacity)	0.279	0.078	slight or weak	Appendix F, F-41
H_2S	Inventory (MC Capacity)	0.360	0.130	slight or weak	Appendix F, F-42
PM_{10}	Inventory (MC Capacity)			None	Appendix F, F-43
$PM_{2.5}$	Inventory (MC Capacity)			None	Appendix F, F-44
TSP	Inventory (MC Capacity)			None	Appendix F, F-45
NH_3	Average animal weight	0.279	0.078	slight or weak	Appendix F, F-46
H_2S	Average animal weight	0.360	0.130	slight or weak	Appendix F, F-47
PM_{10}	Average animal weight	-0.005	< 0.001	slight or weak	Appendix F, F-48
$PM_{2.5}$	Average animal weight	-0.161	0.026	slight or weak	Appendix F, F-49
TSP	Average animal weight	0.154	0.024	slight or weak	Appendix F, F-50
NH_3	Live animal weight	0.279	0.078	slight or weak	Appendix F, F-51
H_2S	Live animal weight	0.360	0.130	slight or weak	Appendix F, F-52
PM_{10}	Live animal weight	-0.005	< 0.001	slight or weak	Appendix F, F-53
$PM_{2.5}$	Live animal weight	-0.161	0.026	slight or weak	Appendix F, F-54
TSP	Live animal weight	0.154	0.024	slight or weak	Appendix F, F-55
NH_3	Exhaust temperature	0.518	0.268	modest	Appendix F, F-56
H_2S	Exhaust temperature	0.322	0.104	slight or weak	Appendix F, F-57
PM_{10}	Exhaust temperature	0.550	0.303	modest	Appendix F, F-58
$PM_{2.5}$	Exhaust temperature	0.401	0.160	slight or weak	Appendix F, F-59
TSP	Exhaust temperature	0.348	0.121	slight or weak	Appendix F, F-60
NH_3	Exhaust relative humidity	-0.188	0.035	slight or weak	Appendix F, F-61
H_2S	Exhaust relative humidity	-0.378	0.143	slight or weak	Appendix F, F-62
PM_{10}	Exhaust relative humidity	-0.111	0.012	slight or weak	Appendix F, F-63
$PM_{2.5}$	Exhaust relative humidity	-0.241	0.058	slight or weak	Appendix F, F-64
TSP	Exhaust relative humidity	0.184	0.034	slight or weak	Appendix F, F-65
NH_3	Airflow	0.381	0.146	slight or weak	Appendix F, F-66
H_2S	Airflow	0.332	0.110	slight or weak	Appendix F, F-67
PM_{10}	Airflow	-0.458	0.210	modest	Appendix F, F-68
$PM_{2.5}$	Airflow	-0.009	< 0.001	slight or weak	Appendix F, F-69
TSP	Airflow	0.106	0.011	slight or weak	Appendix F, F-70

4.2.3 Ambient Data

The statistical summary of the ambient parameters associated with MCs are presented in Appendix D, Table D-20. The summary statistics indicate the ambient temperatures are similar for both sites, with average daily mean of 11.13°C at NY5B and 12.20°C at IN5B. Ambient temperature trends (Appendix E, Figure E-27) follow seasonal patterns, as expected, and the time series reiterates the similarity in temperatures at both sites. The regression analyses (Appendix F, Figures F-71 - F-75) summarized in Table 4-5, showed weak-to-modest positive correlation with emissions.

Ambient relative humidity was also similar between the sites with average daily mean of 67.81% at NY5B and 67.90% at IN5B. The time series (Appendix E, Figure E-28) showed variability in average daily humidity values, with the lowest values occurring in the spring. The regression analyses (Appendix F, Figures F-76 - F-80), summarized in Table 4-5, showed only a slight-to-weak correlation with emissions.

Table 4-6. Milking center ambient parameters regression analyses

Pollutant	Parameter	R	R^2	Strength	Figure
NH_3	Ambient temperature	0.495	0.245	modest	Appendix F, F-71
H_2S	Ambient temperature	0.296	0.088	slight or weak	Appendix F, F-72
PM_{10}	Ambient temperature	0.568	0.323	modest	Appendix F, F-73
$PM_{2.5}$	Ambient temperature	0.399	0.159	slight or weak	Appendix F, F-74
TSP	Ambient temperature	0.348	0.121	slight or weak	Appendix F, F-75
NH_3	Ambient relative humidity	-0.043	0.002	slight or weak	Appendix F, F-76
H_2S	Ambient relative humidity	0.039	0.002	slight or weak	Appendix F, F-77
PM_{10}	Ambient relative humidity	-0.421	0.178	slight or weak	Appendix F, F-78
$PM_{2.5}$	Ambient relative humidity	0.043	0.002	slight or weak	Appendix F, F-79
TSP	Ambient relative humidity	0.066	0.004	slight or weak	Appendix F, F-80

4.3 Naturally Ventilated Barns (CA5B-B1, CA5B-B2, WA5B-B2 and WA5B-B4)

4.3.1 Emissions Data

Appendix D, Table D-21 and Table D-22 presents the summary statistics, in kg d^{-1} and g d^{-1} hd^{-1}, for daily average emissions of NH_3 for the naturally ventilated sites. The average daily emission rate is substantially different between the sites, ranging from 2.76 kg d^{-1} (4.98 g d^{-1} hd^{-1}) at CA5B-B1 to 54.65 kg d^{-1} (56.51 g d^{-1} hd^{-1}) at WA5B-B4. The time series plot (Appendix E, Figure E-29) showed the highest emissions at WA5B occurring in late spring to early summer of 2008. After a break in observations, the emission levels mostly drop to lower levels, though it is still greater than CA5B. CA5B does have quite a few negative days, 37 at B1 and 42 at B2, which are contributing to the lower overall average compared to WA5B. These negative numbers were further reviewed during the data set review process described in Section 2, prior to inclusion in the model development dataset. Appendix E, Figure E-29 also showed the emissions are variable across the year with no obvious seasonal pattern.

The summary statistics for daily average H_2S emissions are presented in Appendix D, Table D-23 and D-24 for g d^{-1} and mg d^{-1} hd^{-1}, respectively. Unlike the NH_3 emissions, the average of the daily emissions are more comparable across the sites. However, reviewing the time series plot (Appendix E, Figure E-30) showed more variability at WA5B, including a few very high values and extreme negative values. There were several negative values at each barn, ranging from 18 values at CA5B-B2 to 45 values at WA5B-B2. Some of the negative numbers were quite large, -609.00 g d^{-1} at CA5B-B2 to -11,640.14 g d^{-1} at WA5B-B2. These negative numbers were further reviewed during the dataset review process described in Section 2, prior to inclusion in the model development dataset. Appendix E, Figure E-30 also showed the emissions are variable across the year with no obvious seasonal pattern.

The summary statistics for PM_{10} are presented in Appendix D, Table D-25 and D-26 for g d^{-1} and mg d^{-1} hd^{-1}, respectively. Like NH_3, the PM_{10} emissions vary between the barns, even when accounting for the differences in inventory. Average daily emissions range from -325.80 g d^{-1} (-636.79 mg d^{-1} hd^{-1}) at CA5B-B1 to 11,391.71 g d^{-1} (11,794.47 mg d^{-1} hd^{-1}) at WA5B-B4. CA5B has quite a few negative days, 372 at B1 and 221 at B2, which are contributing to the lower overall average compared to WA5B, and the overall negative average for CA5B-B1. These negative numbers were further reviewed during the dataset review process described in Section 2, prior to inclusion in the model development dataset. The time series plot (Appendix E, Figure E-31) showed the frequency of the negatives at CA5B, as well as the extremely high values seen at WA5B.

$PM_{2.5}$ was like PM_{10} in that there is a substantial number of negative daily emission values at CA5B (Appendix D, D-27, and D-28). Specifically, at B1, 44 of the 47 values are negative and 40 of 54 are negative at B2. This results in a negative overall average value for CA5B barns. The WA5B site has fewer negative values, 0 at WA5B-B2 and 6 at WA5B-B4. These negative numbers were further reviewed during the dataset review process described in Section 2, prior to inclusion in the model development dataset. The time series plot (Appendix E, Figure E-32) showed the frequency of the negatives at CA5B, as well as the spread in values seen in at WA5B. No seasonal pattern was apparent.

Regarding the TSP summary statistics (Appendix D, D-29, and D-30), the two sites have different daily average values despite fewer negative daily emission values for CA5B than the other PM size fractions. Average TSP daily emissions ranged from 4,766g d^{-1} (9113mg d^{-1} hd^{-1}) at CA5B-B1 to 47,389g d^{-1} (49,099mg d^{-1} hd^{-1}) at WA5B-B4. The time series plot (Appendix E, Figure E-33) showed a lot of variability in readings, which makes a seasonal pattern hard to discern.

4.3.2 Environmental Data

The statistical summary of the environmental parameters associated with naturally ventilated barns are presented in Appendix D, Table D-31. The average inventory for most of the barns is between 514 at WA5B-B2 to 558 at WA5B-B2. WA5B-B4 is the exception, with an average inventory almost double the other barn of 963.20 head. The time series (Appendix E, Figure E-34) showed there is some variability in the inventory at the site, with most only varying by 100 head from the average. The regression analyses (Appendix F, Figures F-81 - F-85) , summarized in Table 4-6, generally showed only slight or weak linear relationship with emissions, except for NH_3, which had a moderate positive linear relationship.

Average animal mass was provided as a single value and not reported daily. The summary table (Appendix D, Table D-31) and the time series (Appendix E, Figure E-35) reiterate the single value. With constant values, the regression analyses (Appendix F, Figures F-86 - F-90) showed only slight or weak relationship with emissions. Combining inventory and average weight into live animal weight produces a size variable with trends (Appendix E, Figure E-36), like inventory. Like the inventory regression analyses, Appendix F, Figures F-91 - F-95 showed a light or weak relationship with all pollutants except NH_3, which had a moderate positive relationship.

Average daily mean exhaust temperatures were slightly higher at CA5B. The means ranged from 11.41°C at WA5B-B2 to 18.75°C at CA5B-B1. The time series (Appendix E, Figure E-37) show similar trends and ranges between the sites, with lower values at the WA5B barns. The regression analyses (Appendix F, Figures F-96 - F-100) indicated modest positive relationships with NH_3 and PM_{10} emissions and slight or weak relationships with other pollutants.

The average daily exhaust relative humidity values are also slightly higher at CA5B. The mean values ranged from 45.16% at WA5B-B4 to 58.49% at CA5B-B1. The time series (Appendix E, Figure E-38) show the highest levels in the winter and lower values in the summer at both sites. There is a lack of variability at the WA5B barns around January 2008 which will be further investigated prior to finalizing the models. The regression analyses (Appendix F, Figures F-101 - F-105) showed only slight to weak relationships with emissions, which were positive for the gaseous pollutants and negative for the all the particulate matter size fractions.

Estimated airflows at the naturally ventilated barns were comparable and ranged from 882.65 dsm^3s^{-1} to 1,151.61 dsm^3s^{-1} at CA5B. The time series (Appendix E, Figure E-39) show variability across the year, with slightly enhanced airflow during the summer. However, peak values can occur at any time of year. The regression analyses (Appendix F, Figures F-106 - F-110) showed modest positive linear relationship with NH_3 and $PM_{2.5}$ emissions. All other pollutants had a slight positive relationship with airflow.

Table 4-7. Naturally ventilated environmental parameter regression analyses

Pollutant	Parameter	R	R^2	Strength	Figure
NH_3	Inventory	0.660	0.435	moderate	Appendix F, F-81
H_2S	Inventory	0.002	< 0.001	slight or weak	Appendix F, F-82
PM_{10}	Inventory	-0.292	0.085	slight or weak	Appendix F, F-83
$PM_{2.5}$	Inventory	-0.319	0.102	slight or weak	Appendix F, F-84
TSP	Inventory	-0.327	0.107	slight or weak	Appendix F, F-85
NH_3	Average animal weight	-0.423	0.179	slight or weak	Appendix F, F-86
H_2S	Average animal weight	0.114	0.013	slight or weak	Appendix F, F-87
PM_{10}	Average animal weight	0.240	0.058	slight or weak	Appendix F, F-88
$PM_{2.5}$	Average animal weight	0.384	0.148	slight or weak	Appendix F, F-89
TSP	Average animal weight	0.384	0.147	slight or weak	Appendix F, F-90

Pollutant	Parameter	R	R^2	Strength	Figure
NH_3	Live animal weight	0.653	0.426	moderate	Appendix F, F-91
H_2S	Live animal weight	0.014	< 0.001	slight or weak	Appendix F, F-92
PM_{10}	Live animal weight	-0.278	0.077	slight or weak	Appendix F, F-93
$PM_{2.5}$	Live animal weight	-0.283	0.080	slight or weak	Appendix F, F-94
TSP	Live animal weight	-0.307	0.094	slight or weak	Appendix F, F-95
NH_3	Exhaust temperature	0.493	0.243	modest	Appendix F, F-96
H_2S	Exhaust temperature	0.323	0.104	slight or weak	Appendix F, F-97
PM_{10}	Exhaust temperature	0.410	0.168	slight or weak	Appendix F, F-98
$PM_{2.5}$	Exhaust temperature	0.484	0.234	modest	Appendix F, F-99
TSP	Exhaust temperature	0.406	0.165	slight or weak	Appendix F, F-100
NH_3	Exhaust relative humidity	0.390	0.152	slight or weak	Appendix F, F-101
H_2S	Exhaust relative humidity	0.193	0.037	slight or weak	Appendix F, F-102
PM_{10}	Exhaust relative humidity	-0.269	0.072	slight or weak	Appendix F, F-103
$PM_{2.5}$	Exhaust relative humidity	-0.414	0.171	slight or weak	Appendix F, F-104
TSP	Exhaust relative humidity	-0.322	0.104	slight or weak	Appendix F, F-105
NH_3	Airflow	0.536	0.287	modest	Appendix F, F-106
H_2S	Airflow	0.232	0.054	slight or weak	Appendix F, F-107
PM_{10}	Airflow	0.425	0.180	slight or weak	Appendix F, F-108
$PM_{2.5}$	Airflow	0.449	0.202	modest	Appendix F, F-109
TSP	Airflow	0.376	0.141	slight or weak	Appendix F, F-110

4.3.3 Ambient Data

The statistical summary of the ambient parameters associated with naturally ventilated barns are presented in Appendix D, Table D-32. Ambient temperatures were generally higher at CA5B leading to an average of the daily mean of 16.34°C compared to 10.07°C at WA5B. The time series (Appendix E, Figure E-40) showed the typical seasonal trend. Of note, the temperatures in summer 2008 were substantially lower than summer 2009. The site report noted the temperature sensor produced a “noisy signal” from late October 2007 to March of 2008. The average of the sonic anemometers was used as a substitute after analysis to confirm agreement with the remaining dates (Ramirez-Dorronsoro et al., 2010). The regression analyses (Appendix F, Figures F-111 - F-115), summarized in Table 4-7, showed a modest positive relationship with temperature and weak positive correlations with all other pollutants.

On average, the ambient relative humidity was lower at WA5B (45.81%) than CA5B (62.01%). The time series (Appendix E, Figure E-41) showed a muted peak around January 2008 for WA5B, like the exhaust relative humidity for the site. The site report offered no explanation for the plateau to the values. The regression analyses (Appendix F, Figures F-116 - F-120) showed slight or weak negative relationships with the emission value. The negative relationship between NH_3 emission and relative humidity is consistent with Sanchis et al. (2019).

Wind speeds averaged slightly higher at WA5B (2.59 ms^{-1}) than CA5B (1.97ms^{-1}). The time series (Appendix E, Figure E-42) showed no distinct seasonal trends, as peak and minimum values occurred throughout the year. The regression analyses (Appendix F, Figures F-121 - F-125) showed a modest positive relationship with NH_3 emissions, and weak positive relationships with all other pollutants.

Table 4-8. Naturally ventilated ambient parameters regression analyses

Pollutant	Parameter	R	R^2	Strength	Figure
NH_3	Ambient temperature	0.537	0.289	modest	Appendix F, F-111
H_2S	Ambient temperature	0.257	0.066	slight or weak	Appendix F, F-112
PM_{10}	Ambient temperature	0.370	0.137	slight or weak	Appendix F, F-113
$PM_{2.5}$	Ambient temperature	0.398	0.159	slight or weak	Appendix F, F-114
TSP	Ambient temperature	0.348	0.121	slight or weak	Appendix F, F-115
NH_3	Ambient relative humidity	-0.110	0.012	slight or weak	Appendix F, F-116
H_2S	Ambient relative humidity	< 0.001	< 0.001	none	Appendix F, F-117
PM_{10}	Ambient relative humidity	-0.129	0.017	slight or weak	Appendix F, F-118
$PM_{2.5}$	Ambient relative humidity	-0.331	0.109	slight or weak	Appendix F, F-119
TSP	Ambient relative humidity	-0.155	0.024	slight or weak	Appendix F, F-120
NH_3	Wind speed	0.537	0.289	modest	Appendix F, F-121
H_2S	Wind speed	0.257	0.066	slight or weak	Appendix F, F-122
PM_{10}	Wind speed	0.370	0.137	slight or weak	Appendix F, F-123
$PM_{2.5}$	Wind speed	0.398	0.159	slight or weak	Appendix F, F-124
TSP	Wind speed	0.348	0.121	slight or weak	Appendix F, F-125

4.4 Open Sources (IN5A, WI5A and TX5A)

4.4.1 Emissions Data

Appendix D, Table D-33 presents the summary statistics for daily average emissions of NH_3 for the open source sites, including corrals. Appendix D, Table D-34 presents the emissions per square meter of surface area. The emissions from the sites with lagoons, IN5A and WI5A, were comparable, with emissions ranging from 19.83 kg d^{-1} (2.01 g d^{-1} m^{-2}) at IN5A to 11.45 kg d^{-1} (1.61 g d^{-1} m^{-2}) at WI5A. The time series (Appendix E, Figures E-43, and E-45) showed the observations from IN5A in the same year and show a seasonal pattern. The observations from WI5B are more spread out over the two-year monitoring period and showed a subtle seasonal pattern. The NH_3 emissions for corrals was higher than for the lagoons on a per day basis with average emissions of 754.97 kg d^{-1} (222.1 g d^{-1} hd^{-1}). However, when normalized for the surface area, it was slightly greater at 3.12 g d^{-1} m^{-2}. The time series for the corral site (TX5A) is available in Appendix E, Figure E-52. There are not many summertime observations, so seasonality is hard to discern.

Appendix D, Table D-35 presents the summary statistics for daily average emissions of NH_3 for the open source sites, including corrals. Appendix D, Table D-36 presents the emissions per square meter of surface area. The average H_2S emissions from the lagoon sites, showed more of a difference, with emissions ranging from to 0.42 kg d^{-1} (0.06 kg d^{-1} m^{-2}) at WI5A to 9.39 kg d^{-1} (0.95 kg d^{-1} m^{-2}) at IN5A. The time series (Appendix E, Figure E-44, and E-46) showed the observations from IN5A in the same year and show a seasonal pattern. The observations from WI5B are more spread out over the two-year monitoring period and showed a subtle seasonal pattern. The H_2S emissions for the corral was greater than for the lagoons at 10.69 kg d^{-1} (3.14 g d^{-1} hd^{-1}) but was much less when normalized by area (44.18 mg d^{-1} m^{-2}). The time series for the corral site is available in Appendix E, Figure E-53. No seasonal pattern was apparent.

4.4.2 Environmental Data

The statistical summary of the environmental parameters associated with dairy lagoons are presented in Appendix D, Table D-37. Lagoon temperatures were colder at WI5A, which had an average daily mean temperature of 18.35°C compared to 21.57°C at IN5A. The time series (Appendix E, Figure E-47) shows the spare nature of the observations but does suggest the expected trend of lagoon temperatures following seasonal temperature patterns. The regression analyses (Appendix F, Figures F-126 - F-127; summarized in Table 4-8) shows moderate relationships with daily emissions (kg/d).

Lagoon pH was consistent between the sites, with average daily mean values at 7.02 and 7.43 for WI5A and IN5A, respectively. The time series (Appendix E, Figure E-48) shows values typically between 7.0 and 7.5 for most of the observations. There is a small cluster of readings for IN5A above 8.0 for Fall 2008. The regression analyses (Appendix F, Figures F-128 - F-129), summarized in Table 4-8, showed only slight or weak relationships with daily emissions (kg/d).

Table 4-9. Open source environmental parameter regression analyses

Pollutant	Parameter	R	R^2	Strength	Figure
NH_3	Lagoon temperature	0.66	0.436	moderate	Appendix F, F-126
H_2S	Lagoon temperature	-0.68	0.462	moderate	Appendix F, F-127
NH_3	Lagoon pH	-0.2	0.040	slight or weak	Appendix F, F-128
H_2S	Lagoon pH	0.4	0.160	slight or weak	Appendix F, F-129

4.4.3 Ambient Data

The statistical summary of the ambient parameters associated with dairy lagoons are presented in Appendix D, Table D-38. The average ambient temperature observed during monitoring periods for WI5A (-3.41°C) was much lower than IN5A (6.25°C). The time series (Appendix E, Figure E-49) show the expected seasonal trend in temperatures. The regression analyses (Appendix F, Figures F-130 - F-131), summarized in Table 4-9, show modest and moderately strong positive relationships with H_2S and NH_3 daily emissions (kg/d), respectively.

Observed ambient relative humidity were comparable between sites, with average daily means ranging from 71.53% at WI5A to 72.02% at IN5A. The time series (Appendix E, Figure E-50) show the relative humidity values vary throughout the year with no seasonal pattern. The regression analyses (Appendix F, Figures F-132 - F-133) shows a slight negative relationship with daily emissions (kg/d) of both NH_3 and H_2S.

Wind speeds were also comparable between sites and ranged from 3.28 m s^{-1} at IN5A to 3.45 m s^{-1} at WI5A. The time series (Appendix E, Figure E-51) average daily wind speeds were equally variable throughout the year at both sites. The regression analyses (Appendix F, Figures F-134 - F-135) showed only slight correlation with daily emissions (kg/d), which was negative for NH_3 and positive for H_2S.

Table 4-10. Open source ambient parameters regression analyses

Pollutant	Parameter	R	R^2	Strength	Figure
NH_3	Ambient temperature	0.84	0.706	moderately strong	Appendix F, F-130
H_2S	Ambient temperature	0.59	0.348	modest	Appendix F, F-131
NH_3	Ambient relative humidity	-0.34	0.116	slight or weak	Appendix F, F-132
H_2S	Ambient relative humidity	-0.18	0.032	slight or weak	Appendix F, F-133
NH_3	Wind speed	-0.25	0.063	slight or weak	Appendix F, F-134
H_2S	Wind speed	0.1	0.010	slight or weak	Appendix F, F-135

The statistical summary of the ambient parameters associated with the monitored dairy corral are presented in Appendix D, Table D-39. Observations of ambient temperature ranged from -5.64°C to 27.50°C, and followed expected seasonal trends (Appendix E, Figure E-54). The regression analyses (Appendix F, Figures F-136 - F-137; summarized in Table 4-10) showed a slight positive relationship between temperature and emissions.

Average daily ambient relative humidity values ranged from 22.3% to 78.54% over the study at TX5A. The time series (Appendix E, Figure E-55) do not suggest any seasonal trends. The regression analyses (Appendix F, Figures F-138 - F-139) shows slight positive relationships with emissions. Average daily wind speeds ranged from 2.35 to 6.79 ms^{-1} and showed no trends in the time series (Appendix E, Figure E-56). The time series did show a peak value in late winter to spring of 2009. The regression analyses (Appendix F, Figures F-140 - F-141) do not show a relationship between wind speed and emissions.

Water vapor deficit estimates ranged from 2.09 to 26.88 hectopascal (hPa) and showed some tendency for higher values in the summer and fall (Appendix E, Figure E-57). The regression analyses (Appendix F, Figures F-142 - F-143) summarized in Table 4-10 indicated a slight relationship between emissions that was positive for NH_3 and negative for H_2S.

Table 4-11. Corral ambient parameters regression analyses

Pollutant	Parameter	R	R^2	Strength	Figure
NH_3	Ambient temperature	0.17	0.029	slight or weak	Appendix F, F-136
H_2S	Ambient temperature	0.003	< 0.001	slight or weak	Appendix F, F-137

NH_3	Ambient relative humidity	0.17	0.029	slight or weak	Appendix F, F-138
H_2S	Ambient relative humidity	0.15	0.023	slight or weak	Appendix F, F-139
NH_3	Wind speed	0.002	< 0.001	slight or weak	Appendix F, F-140
H_2S	Wind speed	0.003	< 0.001	slight or weak	Appendix F, F-141
NH_3	Water vapor deficit	0.32	0.102	slight or weak	Appendix F, F-142
H_2S	Water vapor deficit	-0.16	0.026	slight or weak	Appendix F, F-143

5 DEVELOPMENT AND SELECTION OF MODELS FOR DAILY EMISSIONS

5.1 Mechanically Ventilated Barns

The literature review (Section 3) and exploratory data analysis (Section 4) suggested that EPA should consider ambient temperature, exhaust temperature, ambient relative humidity, exhaust relative humidity, manure management system, and inventory in the development of the emission models for mechanically ventilated barns. Barn airflow, or ventilation rate, can have a substantial influence on the emission rate of gaseous pollutants, but was not included in the parameter list as it may not be easily obtained at all farms. Since ventilation rate is essentially driven by the temperature (i.e., the higher ambient temperature the higher the ventilation rate), the ambient temperature provides an indication of airflow in the models tested.

The various combinations of these parameters were used in test models. For NH_3 and H_2S, 9 different combinations were tested as potential models (Table 5-1). There were 17 models (Table 5-2) tested for particulate matter emissions, which had variations to predict the emissions normalized by inventory.

Table 5-1. Parameter combinations tested as mechanically ventilated barn models for NH_3 and H_2S emissions.

Model	Parameters
MV-G1	Inventory, manure management system (Flush, Scrape)
MV-G2	Inventory, exhaust temperature, Exhaust relative humidity, manure management system (Flush, Scrape)
MV-G3	Inventory, exhaust temperature, manure management system (Flush, Scrape)
MV-G4	Inventory, exhaust relative humidity, manure management system (Flush, Scrape)
MV-G5	Inventory, ambient relative humidity, ambient temperature, manure management system (Flush, Scrape)
MV-G6	Inventory, ambient temperature, manure management system (Flush, Scrape)
MV-G7	Inventory, ambient relative humidity, manure management system (Flush, Scrape)
MV-G8	Inventory, ambient temperature, exhaust relative humidity, manure management system (Flush, Scrape)
MV-G9	Inventory, exhaust temperature, ambient relative humidity, manure management system (Flush, Scrape)

Table 5-2. Parameter combinations tested as mechanically ventilated barn models for PM_{10}, $PM_{2.5}$, and TSP emissions.

Model	Parameters
MV-P1	Intercept, inventory
MV-P2	Intercept, inventory, exhaust temperature, exhaust relative humidity
MV-P3	Intercept, inventory, exhaust temperature
MV-P4	Intercept, inventory, exhaust relative humidity
MV-P5	Intercept, inventory, ambient relative humidity, ambient temperature
MV-P6	Intercept, inventory, ambient temperature

Model	Parameters
MV-P7	Intercept, inventory, ambient relative humidity
MV-P8	Intercept, inventory, ambient temperature, exhaust relative humidity
MV-P9	Intercept, inventory, exhaust temperature, ambient relative humidity
MV-P10	Intercept, exhaust temperature, exhaust relative humidity (Emissions normalized by inventory)
MV-P11	Intercept, exhaust temperature (emissions normalized by inventory)
MV-P12	Intercept, exhaust relative humidity (emissions normalized by inventory)
MV-P13	Intercept, ambient temperature, ambient relative humidity (Emissions normalized by inventory)
MV-P14	Intercept, ambient temperature (emissions normalized by inventory)
MV-P15	Intercept, ambient relative humidity (emissions normalized by inventory)
MV-P16	Intercept, ambient temperature, exhaust relative humidity (Emissions normalized by inventory)
MV-P17	Intercept, ambient relative humidity, exhaust temperature (Emissions normalized by inventory)

For both NH_3 (Appendix G, Table G-3) and H_2S (Appendix G, Table G-5), models MV-G5 and MV-G7 had terms that were not statistically significant ($p > 0.05$) for both pollutants and were removed from further consideration. For H_2S, model MV-G4 and G9 had insignificant terms. The model fit (-2 log likelihood, AIC, AICc, and BIC) and evaluation statistics (ME, NME, MB, NMB) for NH_3 (Appendix G, Table G-4) and H_2S (Appendix G, Table G-5) indicate the remaining models had comparable performance, which suggested that using ambient parameters was as effective as models that included barn specific parameters. As noted in the Process Overview report, the model selection process also looked at how easily obtainable the parameters are as not to create an undue burden on the operators. Generally, ambient parameters were preferred since ambient meteorological data is actively recorded across the country and representative site data is accessible through the National Centers for Environmental Information (NCEI) website. To further ease any burden, the EPA plans to provide a tool that automatically populates relevant ambient parameters for any given location instead of requiring producers to measure and record environmental parameters either inside or outside of the barn to further reduce the burden of use on the producer.

Therefore, considering ambient temperature is a suitable proxy for barn airflow as exhaust temperature and representative ambient temperature data is accessible, the EPA concluded that a model using ambient temperature and relative humidity would be preferable to one with exhaust temperature and relative humidity. Of the remaining models that used ambient parameters (MV-G1, and G6), EPA selected model MV-G6 (including the parameters: inventory, ambient temperature, and manure management system) for further analysis for both NH_3 and H_2S as it had the best normalized mean bias of the remaining models. The final form of these models is presented in Table 5-3.

Table 5-3. Selected daily models for mechanically ventilated barns.

Pollutant	Formula	Units	Equation Number
NH_3, Flush	$ln(NH_3) = 1.746585 + 1.773832 * Inventory + 0.029586 * Amb_T$	kg/d	Equation 1
NH_3, Scrape	$ln(NH_3) = 1.864935 + 1.773832 * Inventory + 0.029586 * Amb_T$	kg/d	Equation 2
H_2S, Flush	$ln(H_2S) = 7.406887 + 0.86173 * Inventory + 0.012786 * Amb_T$	g/d	Equation 3
H_2S, Scrape	$ln(H_2S) = 6.287004 + 0.86173 * Inventory + 0.012786 * Amb_T$	g/d	Equation 4

For PM_{10} models (Appendix G, Table G-7), models MVP-1 through MVP-9 include inventory as a proxy for volume of manure produced. While all model terms were statistically significant ($p > 0.05$), coefficients for inventory were negative which suggests that emissions decrease as inventory increases. The negative coefficients for inventory are also seen in models MVP-1 through MVP-9 for $PM_{2.5}$ (Appendix G, Table G-9) and TSP (Appendix G, Table G-11). As noted in Section 3.2, Garcia et al. (2012) found a similar inverse relationship with $PM_{2.5}$ concentrations and inventory for MCs, which was attributed to the larger dairies being newer and more efficiently operated. Based on the site reports, the older barns have the lowest average inventory (Table 5-4), which lines up with Garcia et al. (2012). Still unknown is the management practice in the newer barns contributing to the reduced emissions and how to account for that practice in the model. Age of the barn and construction year were discussed as a possible parameter; however, there is not enough variability in construction year available in the NAEMS data for model construction.

Table 5-4. Summary of barn construction dates for mechanically ventilated barns.

Barn	Year Constructed	Average Inventory
IN5B-B1	2004	833
IN5B-B2	2004	864
NY5B-B1	1998	467
WI5B-B1	1990	211
WI5B-B2	1994	355

EPA tested a set of models that normalized emissions by inventory, MVP-10 through MVP-17, which use the same environmental and barn parameters as models MVP-2 through MVP-9. The goal was to determine if these models could be predictive based on the other environmental and ambient parameters alone. The model performance statistics (i.e., ME, NME, MB, NMB) did increase for these models (Appendix G, Tables G-8, G-10, and G-12), suggesting accounting for the difference in newer barns is needed for a successful model. Therefore, EPA is not selecting a model at this time to allow for more research into the reason newer barns have lower particulate matter emissions, despite increased animal populations.

5.2 Milking Centers

The literature review (Section 3) and exploratory data analysis (Section 4) suggested that EPA should consider ambient temperature, exhaust temperature, ambient relative humidity, exhaust relative humidity, milk production, and inventory in the development of the emission models for MCs. Barn airflow, or ventilation rate, can have a substantial influence on the emission rate, but was not included in the parameter list as it may not be easily obtained at all farms. Since ventilation rate is essentially driven by the temperature (i.e., the higher ambient temperature the higher the ventilation rate), the ambient temperature provides an indication of airflow in the models tested. EPA tested 24 combinations of these parameters as potential models (Table 5-5), including which had variations to predict the emissions normalized by inventory (MC-25 through MC-32). The models to predict normalized emissions were added to incorporate a barn size into the model, as the relatively consistent inventory of the MCs could reduce the significance if inventory was used as a predictive parameter. This is demonstrated with the NH_3 modeling results (Appendix G, Table G-13), as inventory is insignificant in models MC-10 through MC-16.

Milk production values were only available for NY5B, and when combined with a static value for barn inventory, as in models MC-1 through MC-8, inventory was dropped from the model, making the result equivalent to models MC-17 through MC-24 for all pollutants. Therefore, the summary presented in this section will focus on models MC-8 through MC-32. Results for all models is summarized in Appendix G.

Table 5-5. Parameter combinations tested as milking center models.

Model	Parameters
MC-1	Intercept, inventory, milk production, exhaust temperature, exhaust relative humidity
MC-2	Intercept, inventory, milk production, exhaust temperature
MC-3	Intercept, inventory, milk production, exhaust relative humidity
MC-4	Intercept, inventory, milk production, ambient relative humidity, ambient temperature
MC-5	Intercept, inventory, milk production, ambient temperature
MC-6	Intercept, inventory, milk production, ambient relative humidity
MC-7	Intercept, inventory, milk production, ambient temperature, exhaust relative humidity
MC-8	Intercept, inventory, milk production, exhaust temperature, ambient relative humidity
MC-9	Intercept, inventory, exhaust temperature, exhaust relative humidity
MC-10	Intercept, inventory, exhaust temperature
MC-11	Intercept, inventory, exhaust relative humidity
MC-12	Intercept, inventory, ambient relative humidity, ambient temperature

MC-13	Intercept, inventory, ambient temperature
MC-14	Intercept, inventory, ambient relative humidity
MC-15	Intercept, inventory, ambient temperature, exhaust relative humidity
MC-16	Intercept, inventory, exhaust temperature, ambient relative humidity
MC-17	Intercept, milk production, exhaust temperature, exhaust relative humidity
MC-18	Intercept, milk production, exhaust temperature
MC-19	Intercept, milk production, exhaust relative humidity
MC-20	Intercept, milk production, ambient relative humidity, ambient temperature
MC-21	Intercept, milk production, ambient temperature
MC-22	Intercept, milk production, ambient relative humidity
MC-23	Intercept, milk production, ambient temperature, exhaust relative humidity
MC-24	Intercept, milk production, exhaust temperature, ambient relative humidity
MC-25	Intercept, exhaust temperature, exhaust relative humidity (Emissions normalized by inventory)
MC-26	Intercept, exhaust temperature (emissions normalized by inventory)
MC-27	Intercept, exhaust relative humidity (emissions normalized by inventory)
MC-28	Intercept, ambient temperature, ambient relative humidity (Emissions normalized by inventory)
MC-29	Intercept, ambient temperature (emissions normalized by inventory)
MC-30	Intercept, ambient relative humidity (emissions normalized by inventory)
MC-31	Intercept, ambient temperature, exhaust relative humidity (Emissions normalized by inventory)
MC-32	Intercept, ambient relative humidity, exhaust temperature (Emissions normalized by inventory)

For NH_3 (Appendix G, Table G-13) models MC-1 through MC-24 had terms that were not statistically significant ($p > 0.05$). All the models predicting NH_3 emissions per head (MC-25 through MC-32) were comprised of significant parameters. The model fit (-2 log likelihood, AIC, AICc, and BIC) and evaluation statistics (ME, NME, MB, NMB) for these models are presented in Appendix G, Table G-14. The ambient parameter models performed comparably to their barn parameter counterparts, suggesting selecting the models with the easier to obtain ambient parameter would be as effective. Therefore, EPA concluded that a model using ambient temperature and relative humidity would be preferable to one with exhaust temperature and relative humidity. Of the remaining models that used ambient parameters (MC-28, MC-29, and MC-30), the NME and ME are comparable for the models. Model MC-30 has a substantially lower MB and NMB. However, this model only includes relative humidity and not temperature. The literature search (Section 3) noted that temperature is strongly linked to NH_3 emissions and should be included in the selected model. The model performance plots (Appendix G, Figures G-20 & G-24) also show better scatter across the one-to-one (1:1) for models MC-28, MC-29, indicating better predictive performance than model MC-30. Therefore, EPA selected model MC-29 (including ambient temperature as the predictive parameter) for further analysis for NH_3

as it had the best NMB of the remaining models. The final form of these models is presented in Table 5-6.

In addition to the models predicting normalized emissions, models MC-9, MC-10, MC-11, MC-13, MC-15, MC-18, and MC-21 were comprised of significant parameters for H_2S (Appendix G, Table G-15). Of the seven additional models, all but MC-11 contained either exhaust temperature or ambient temperature. as well as models MC-25 through MC-32. Comparing the model fit and evaluation statistics (Appendix G, Table G-16) the ambient parameter models performed comparably to their barn parameter counterparts, suggesting models utilizing the easier to obtain ambient parameter would be as effective. Therefore, EPA concluded that a model using ambient temperature and ambient relative humidity would be preferable to one with exhaust temperature and relative humidity. Of the remaining models that used ambient parameters (MC-13, MC-21, MC-28, MC-29, and MC-30), the error statistics (NME and ME) are lower for models MC-13 and MC-21, while the bias statistics (MB and NMB) are lower for MC-21 and MC-30, with other models being comparable. The scatter plots of observed versus predicted (Appendix G, Figures G-26 through G-32) for model MC-21 has more variability in the scatter across the 1:1 line, indicating a slightly better fit. However, this model includes milk production, which is only available for one site. For this study, it is preferred to include multiple sites in the model development dataset to represent variability across the country. Therefore, EPA selected model MC-29 (including ambient temperature as the predictive parameter) for further analysis for H_2S as it had the best NMB the remaining models (i.e., MC-13, MC-30). The final form of these models is presented in Table 5-6.

For the particulate matter size fractions, only NY5B reported emissions. With the dataset dropping to one site with a constant value for MC capacity, the coefficient of inventory in models MC-9 through MC-16 is estimated at zero and eliminates a size estimate from the model. The focus for the particulate matter model narrowed to just models MC-17 through MC-32. For PM_{10}, models MC-17, MC-18, MC-19, MC-20, MC-21, and MC-23 have parameters that are statistically insignificant (Appendix G, Table G-17). The model fit and evaluation statistics (Appendix G, Table G-18) for models with ambient parameters performed comparably to their barn parameter counterparts, suggesting models utilizing the easier to obtain ambient parameter would be as effective. Of the remaining models that used ambient parameters (MC-28, MC-29, and MC-30), the NME and ME are slightly lower for Model 28, and the bias parameters are similar. EPA selected model MC-28 (including ambient temperature and ambient relative humidity as the predictive parameter) for further analysis for PM_{10} as it had the best NMB of the remaining models. The final form of these models is presented in Table 5-6.

As noted in Section 6.4 of the main report, the particulate matter model selection starts with PM_{10} due to the greater quantity of emissions data. The PM_{10} models had between 315 and

436 records available depending on the completeness of the various predictive parameters. For $PM_{2.5}$ and TSP the number of records available ranged between 40 – 44 for $PM_{2.5}$ and 29 – 40 for TSP. This is substantially less data that were available for PM_{10} and does not necessarily cover the breadth of conditions that the PM_{10} data does. Therefore, the models generated with these smaller datasets were examined mainly for consistency with the PM_{10} results to build confidence in using the same model form for all the particulate matter species.

Compared to the PM_{10} models, more of the $PM_{2.5}$ and TSP models have insignificant terms. For both $PM_{2.5}$ (Appendix G, Table G-19) and TSP (Appendix G, Table G-21), only models MC-26 and MC-29 are comprised of significant parameters. Despite the insignificance of the parameters for most of the models, the relationships were consistent with the PM_{10} models and literature. The model performance statistics for $PM_{2.5}$ (Appendix G, Table G-20) and the model performance plots (Appendix G, Figures G-41 through G-48) were consistent, with slightly lower bias metric for model MC-29. For TSP, the performance metrics (Appendix G, Table G-22) and plots (Appendix G, Figures G-49 through G-56) were comparable. Therefore, EPA selected model MC-29 for $PM_{2.5}$ (including ambient temperature as the predictive parameter) and model MC-28 (including ambient temperature and ambient relative humidity as the predictive parameter) for TSP to conduct further evaluation and analysis as an emission estimation method. The full forms of the models are presented in Table 5-6.

Table 5-6. Selected daily models for milking centers.

Pollutant	Formula	Units	Equation Number
NH_3	$ln(NH_3) = 2.505637 + 0.046434 * Amb_T$	g/d/hd	Equation 5
H_2S	$ln(H_2S) = 6.898188 + 0.024053 * Amb_T$	kg/d/hd	Equation 6
PM_{10}	$ln(PM_{10}) = 8.042215 + 0.006791 * Amb_T - 0.003552 * Amb_{RH}$	g/d/hd	Equation 7
$PM_{2.5}$	$ln(PM_{2.5}) = 6.58377 + 0.006698 * Amb_T$	g/d/hd	Equation 8
TSP	$ln(TSP) = 7.457268 + 0.010997 * Amb_T - 0.003639 * Amb_{RH}$	g/d/hd	Equation 9

5.3 Naturally Ventilated Barns

The literature review (Section 3) and exploratory data analysis (Section 4) suggested that EPA should consider ambient temperature, ambient relative humidity, exhaust relative humidity, wind speed, and inventory in the development of the emission models for naturally ventilated barns. EPA tested 8 combinations of these parameters as potential models (Table 5-5). Models predicting emissions normalized by inventory were not pursued at this time. However, based on the initial results of MCs, normalized inventory models may be considered for the final models.

Table 5-7. Parameter combinations tested as naturally ventilated barns models.

Model	Parameters
NV-1	Intercept, inventory
NV-2	Intercept, inventory, ambient temperature, ambient relative humidity, wind speed
NV-3	Intercept, inventory, ambient temperature
NV-4	Intercept, inventory, ambient relative humidity
NV-5	Intercept, inventory, wind speed
NV-6	Intercept, inventory, ambient temperature, ambient relative humidity
NV-7	Intercept, inventory, ambient relative humidity, wind speed
NV-8	Intercept, inventory ambient temperature, wind speed

For the gaseous species, models NV-3 and NV-8 had terms that were not statistically significant ($p > 0.05$) for NH_3 (Appendix G, Table G-24), and models NV-2, NV-3, NV-4, NV-6, NV-7, and NV-8 had insignificant terms for H_2S (Appendix G, Table G-26). The model fit (-2 log likelihood, AIC, AICc, and BIC) and evaluation statistics (ME, NME, MB, NMB) for these models are presented in Appendix G, Table G-25, and Table G-27 for NH_3 and H_2S, respectively. For both pollutants, the statistics for the models were comparable. Therefore, EPA selected model NV-5 (including as the predictive parameters: inventory and wind speed) for further analysis for NH_3 and H_2S as it had the best NMB of the remaining models. The final form of these models is presented in Table 5-8.

For PM_{10}, all models were comprised of statistically significant parameters (Appendix G, Table G-28). The model fit and evaluation statistics (Appendix G, Table G-29) suggested comparable performance across all models, with model NV-2 having slightly better error metrics. EPA selected model NV-2 (including the predictive parameters: inventory, ambient temperature, ambient relative humidity, and wind speed) for further analysis. The final form of the model is presented in Table 5-8.

As noted in Section 6.4 of the main report and with the MC model selection, the particulate matter model selection starts with the PM_{10} due to the greater quantity of emissions data. For naturally ventilated barns, the PM_{10} models had between 1,457 and 1,469 records available depending on the completeness of the various predictive parameters. For $PM_{2.5}$ and TSP, the number of records available was 93 for $PM_{2.5}$ and 205 for TSP. The $PM_{2.5}$ models (Appendix G, Table G-30) all have insignificant parameters. The relationship generally follows the expected trend from literature (e.g., negative relationship with relative humidity). However, inventory has a negative coefficient in each model. For TSP (Appendix G, Table G-32), all models are comprised entirely of significant parameters and the predictive parameters have the same relationships as with PM_{10}. Model NV-2 had reasonable performance for both $PM_{2.5}$ (Appendix G, Table G-31) and TSP (Appendix G, Table G-33) and would be consistent with the PM_{10} formulation that was developed from a much larger dataset. Therefore, EPA selected model NV-2 (including the predictive parameters: inventory, ambient temperature, ambient relative humidity, and wind speed) for further analysis. The final form of the models for $PM_{2.5}$ and TSP are presented in Table 5-8.

Table 5-8. Selected daily models for naturally ventilated barns.

Pollutant	Formula	Units	Equation Number
NH_3	$ln(NH_3) = 0.188357 + 3.451939 * Inventory + 0.048153 * WindSpeed$	g/d	Equation 10
H_2S	$ln(H_2S) = 6.541057 + 0.587702 * Inventory + 0.062678 * WindSpeed$	kg/d	Equation 11
PM_{10}	$ln(PM_{10}) = 7.64258 + 1.525009 * Inventory + 0.011864 * Amb_T - 0.01521 * Amb_{RH} + 0.173698 * WindSpeed$	g/d	Equation 12
$PM_{2.5}$	$ln(PM_{2.5}) = 7.068797 - 0.220453 * Inventory + 0.01121 * Amb_T - 0.003808 * Amb_{RH} + 0.218968 * WindSpeed$	g/d	Equation 13
TSP	$ln(TSP) = 7.868847 + 2.953893 * Inventory + 0.034508 * Amb_T - 0.033997 * Amb_{RH} + 0.248191 * WindSpeed$	g/d	Equation 14

5.4 Open Sources

The literature review (Section 3) and exploratory data analysis (Section 4) suggested that EPA should consider lagoon pH, lagoon temperature, ambient temperature, and wind speed in the development of the emission models for open sources. EPA tested 15 combinations of these parameters as potential models (Table 5-9). Models were developed to predict daily emissions per meter squared (m^2) of surface area of the open source.

Table 5-9. Parameter combinations tested as open source models for NH_3 and H_2S emissions.

Model	Parameters
LB-1	Lagoon pH, lagoon temperature
LB-2	Lagoon pH

LB-3	Lagoon temperature
LB-4	Ambient temperature, wind speed
LB-5	Ambient temperature
LB-6	Wind speed
LB-7	Lagoon pH, lagoon temperature, ambient temperature, wind speed
LB-8	Lagoon pH, lagoon temperature, ambient temperature
LB-9	Lagoon pH, lagoon temperature, wind speed
LB-10	Lagoon pH, ambient temperature, wind speed
LB-11	Lagoon temperature, ambient temperature, wind speed
LB-12	Lagoon pH, ambient temperature
LB-13	Lagoon pH, wind speed
LB-14	Lagoon temperature, ambient temperature
LB-15	Lagoon temperature, wind speed

For NH_3, of the 15 models tested, only LB-3, LB-5, LB-6, and LB-15 were comprised of significant parameters (Appendix G, Table G-34). The model fit (-2 log likelihood, AIC, AICc, and BIC) and evaluation statistics (ME, NME, MB, NMB) for these models are presented in Appendix G, Table G-35, and were consistent across the models with significant terms. This suggests that models with ambient temperature (model LB-5) perform as well as models with lagoon specific parameters (LB-3 and LB-15). Therefore, EPA selected model NV-5 (including ambient temperature as the predictive parameter) for further analysis for NH_3. The final form of this model is presented in Table 5-10.

For H_2S, of the 15 models tested, only LB-3, LB-5, and LB-6 were comprised entirely of significant parameters (Appendix G, Table G-36). The model fit and evaluation statistics (Appendix G, Table G-37), and were consistent across the models with significant terms. This suggests that models with ambient temperature (model LB-5) perform as well as models with lagoon specific parameters (LB-3). Therefore, EPA selected model NV-5 (including ambient temperature as the predictive parameter) for further analysis for H_2S. The final form of this model is presented in Table 5-10.

Table 5-10. Selected daily models for lagoons sources.

Pollutant	Formula	Units	Equation Number
NH_3	$ln(NH_3) = 1.396734 + 0.027201 * Amb_T$	kg/d m^2	Equation 15
H_2S	$ln(H_2S) = 1.189272 + 0.010557 * Amb_T$	kg/d m^2	Equation 16

5.5 Corrals

The literature review (Section 3) and exploratory data analysis (Section 4) suggested that EPA should consider ambient temperature, ambient relative humidity, water vapor deficit, and wind speed in the development of the emission models for corrals. EPA tested 15 combinations of these parameters as potential models (Table 5-11). Models were developed to predict daily emissions per meter squared (g/d-m^2) of surface area of the corral, as well as emissions per m2 per 1,000 head (g/d-m^2-1,000 hd), to account for the stock density of the corral. In total, 30 models were tested to account for the 15 different parameter combinations and two forms of the emissions.

Table 5-11. Parameter combinations tested as corral models for NH_3 and H_2S emissions.

Model	Emissions	Parameters
CR-1a	g/d-m^2	Ambient temperature, ambient relative humidity, wind speed, water vapor deficit
CR-2a	g/d-m^2	Ambient temperature, ambient relative humidity, water vapor deficit
CR-3a	g/d-m^2	Ambient temperature, ambient relative humidity, wind speed
CR-4a	g/d-m^2	Ambient relative humidity, wind speed, water vapor deficit
CR-5a	g/d-m^2	Ambient temperature, wind speed, water vapor deficit
CR-6a	g/d-m^2	Ambient temperature, ambient relative humidity
CR-7a	g/d-m^2	Ambient temperature, water vapor deficit
CR-8a	g/d-m^2	Ambient relative humidity, water vapor deficit
CR-9a	g/d-m^2	Ambient temperature, wind speed
CR-10a	g/d-m^2	Ambient relative humidity, wind speed
CR-11a	g/d-m^2	Wind speed, water vapor deficit
CR-12a	g/d-m^2	Ambient temperature
CR-13a	g/d-m^2	Ambient relative humidity
CR-14a	g/d-m^2	Water vapor deficit
CR-15a	g/d-m^2	Wind speed
CR-1b	g/d-m^2-1,000 hd	Ambient temperature, ambient relative humidity, wind speed, water vapor deficit
CR-2b	g/d-m^2-1,000 hd	Ambient temperature, ambient relative humidity, water vapor deficit
CR-3b	g/d-m^2-1,000 hd	Ambient temperature, ambient relative humidity, wind speed
CR-4b	g/d-m^2-1,000 hd	Ambient relative humidity, wind speed, water vapor deficit
CR-5b	g/d-m^2-1,000 hd	Ambient temperature, wind speed, water vapor deficit
CR-6b	g/d-m^2-1,000 hd	Ambient temperature, ambient relative humidity
CR-7b	g/d-m^2-1,000 hd	Ambient temperature, water vapor deficit
CR-8b	g/d-m^2-1,000 hd	Ambient relative humidity, water vapor deficit
CR-9b	g/d-m^2-1,000 hd	Ambient temperature, wind speed
CR-10b	g/d-m^2-1,000 hd	Ambient relative humidity, wind speed
CR-11b	g/d-m^2-1,000 hd	Wind speed, water vapor deficit
CR-12b	g/d-m^2-1,000 hd	Ambient temperature
CR-13b	g/d-m^2-1,000 hd	Ambient relative humidity
CR-14b	g/d-m^2-1,000 hd	Water vapor deficit
CR-15b	g/d-m^2-1,000 hd	Wind speed

Models CR-3a, CR-4a, CR-6a, CR-8a, CR-12a, CR-13a, CR-14a, CR-4b, CR-6b, CR-8b, CR-12b, CR-13b, CR-14b, CR-15b were comprised of significant parameters for NH_3 (Appendix G, Table G-38). The model fit (-2 log likelihood, AIC, AICc, and BIC) and evaluation statistics (ME, NME, MB, NMB) for these models are presented in Appendix G, Table G-39, and were consistent across all the models. The models predicting the emissions in g/d-m^2-1,000 hd have lower mean bias and mean error values than their counterpart predicting emissions as g/d-m^2. EPA selected model CR-3b (including the predictive parameters: ambient temperature, ambient relative humidity, and wind speed) for further analysis for NH_3. The final form of this model is presented in Table 5-12.

For H_2S, only model CR-13a was comprised entirely of statistically significant parameters (Appendix G, Table G-40). Like NH_3, the model fit and evaluation statistics (Appendix G, Table G-41) for the version of the model predicting emissions as g/d-m^2-1,000 hd (i.e., CR-13b) has slightly lower mean bias and mean error values. EPA selected model CR-13b (including the predictive parameter ambient relative humidity) for further analysis for corral H_2S emissions. The final form of this model is presented in Table 5-12.

Table 5-12. Selected daily models for corrals.

Pollutant	Formula	Units	Equation Number
NH_3	$ln(NH_3) = 1.053805 + 0.004993 * Amb_T + 0.0031 * Amb_{RH} + 0.017832 * WindSpeed$	g/d-m^2-1,000 hd	Equation 17
H_2S	$ln(H_2S) = 2.404792 + 0.007177 * Amb_{RH}$	g/d-m^2-1,000 hd	Equation 18

6 MODEL COEFFICIENT EVALUATION

To ensure reliable prediction of the emissions, the model coefficients were evaluated with the jackknife method (Christensen et al., 2016; Leeden et al., 2008), which examined the cumulative effect on coefficient estimates of multiple "minus-one" runs. The jackknife approach called for removing one of the independent sample units from the dataset. For NAEMS, the individual barns at each site and the lagoons are the mutually exclusive independent sample units. EPA then determined the associated parameter estimates for the selected model based on this dataset. This was repeated for each of the sample units. These results were then compared to the model coefficients based on the full dataset (full model). For each jackknife model, the ME, NME, MB, and NMB were calculated, based on the equations outlined in Section 6 of the main report, to facilitate comparison.

EPA also prepared plots showing the variation in coefficients and standard errors for the selected models and compared to each of the jackknife models. EPA interpreted these plots similar to Tukey confidence interval plots in that if the result for the jackknife model overlapped the results for the full model (i.e., the area highlighted in gray on the figures), then the model coefficients are not inconsistent with one another. If the omission of one monitoring unit (e.g., a barn or lagoon) resulted in a coefficient that was outside ± 1 standard error of the full model, the sample unit was reviewed to determine if a specific characteristic of that unit (e.g., animal placement strategy, manure handling system) might have caused the inconsistency. If the difference could not be ascribed to an operational characteristic of the unit, the data were reviewed for outliers that could be removed from analysis, and other potential remediation measures considered.

6.1 Mechanically Ventilated Barns Model

6.1.1 NH_3 Model Evaluation

Table 6-1 and Figure 6-1 show the variation in coefficients and standard errors for the selected model ("None") and each of the jackknife models. The model coefficients from the jackknife approach were comparable across the withheld sets (Table 6-1) and remained significant (p-value <0.05) across all models. The plots in Figure 6-1 show that the results for all jackknife models overlap the full model estimate ± 1 standard error, except for ambient temperature. In comparison to the full model, that is where the barn removed is "None", the maximum percent differences for parameter estimates across the three models were 7%, 23%, 3%, and 4% for inventory, ambient temperature, intercept for the flush barns, and intercept for scrape barns, respectively. Across all models, the difference in NME and NMB (Table 6-2) in comparison to the selected model were minor. For NME the values differed by less than 8%. For NMB the values varied by less than 34%. The largest difference was seen when WI5B B1 was withheld from the dataset, which decreased the NME and NMB by 8% and 34%, respectively.

Table 6-1. Model coefficients developed using the jackknife approach for NH_3 emissions from mechanically ventilated barns.

Barn out	Effect	Estimate	Standard Error	p-value
NONE	Inventory	1.773832	0.06477	<.0001
	Ambient Temperature	0.029586	0.00088	<.0001
	Flush	1.746585	0.03789	<.0001
	Scrape	1.864935	0.04253	<.0001
IN5BB1	Inventory	1.736301	0.07221	<.0001
	Ambient Temperature	0.024312	0.00093	<.0001
	Flush	1.793836	0.03772	<.0001
	Scrape	1.925841	0.04232	<.0001
IN5BB2	Inventory	1.898712	0.07457	<.0001
	Ambient Temperature	0.024229	0.00091	<.0001
	Flush	1.748491	0.03749	<.0001
	Scrape	1.869675	0.0425	<.0001
NY5BB1	Inventory	1.824003	0.06932	<.0001
	Ambient Temperature	0.030506	0.00095	<.0001
	Flush	1.72461	0.03966	<.0001
	Scrape	1.798078	0.04787	<.0001
WI5BB1	Inventory	1.722238	0.07977	<.0001
	Ambient Temperature	0.036382	0.00101	<.0001
	Flush	1.693687	0.05244	<.0001
	Scrape	1.832478	0.05634	<.0001
WI5BB2	Inventory	1.703501	0.07134	<.0001
	Ambient Temperature	0.032999	0.00105	<.0001
	Flush	1.765095	0.04896	<.0001
	Scrape	1.891018	0.05005	<.0001

Table 6-2. Model fit statistics for the mechanically ventilated barns NH3 jackknife.

Barn out	n	LNME[a] (%)	NME[b] (%)	ME[b] (kg day^{-1})	MB[b] (kg day^{-1})	NMB[b] (%)	Corr
NONE	2192	7.322	24.573	5.959	-0.583	-2.404	0.917
IN5BB1	1771	7.213	25.072	5.003	-0.542	-2.717	0.911
IN5BB2	1762	7.148	25.329	5.042	-0.472	-2.372	0.905
NY5BB1	1846	7.403	24.716	6.115	-0.701	-2.835	0.924
WI5BB1	1676	6.866	22.488	6.538	-0.459	-1.579	0.918
WI5BB2	1713	7.212	23.375	6.523	-0.547	-1.961	0.919

[a] Based on transformed data (i.e., ln(NH_3)).
[b] Based on back-transformed data.

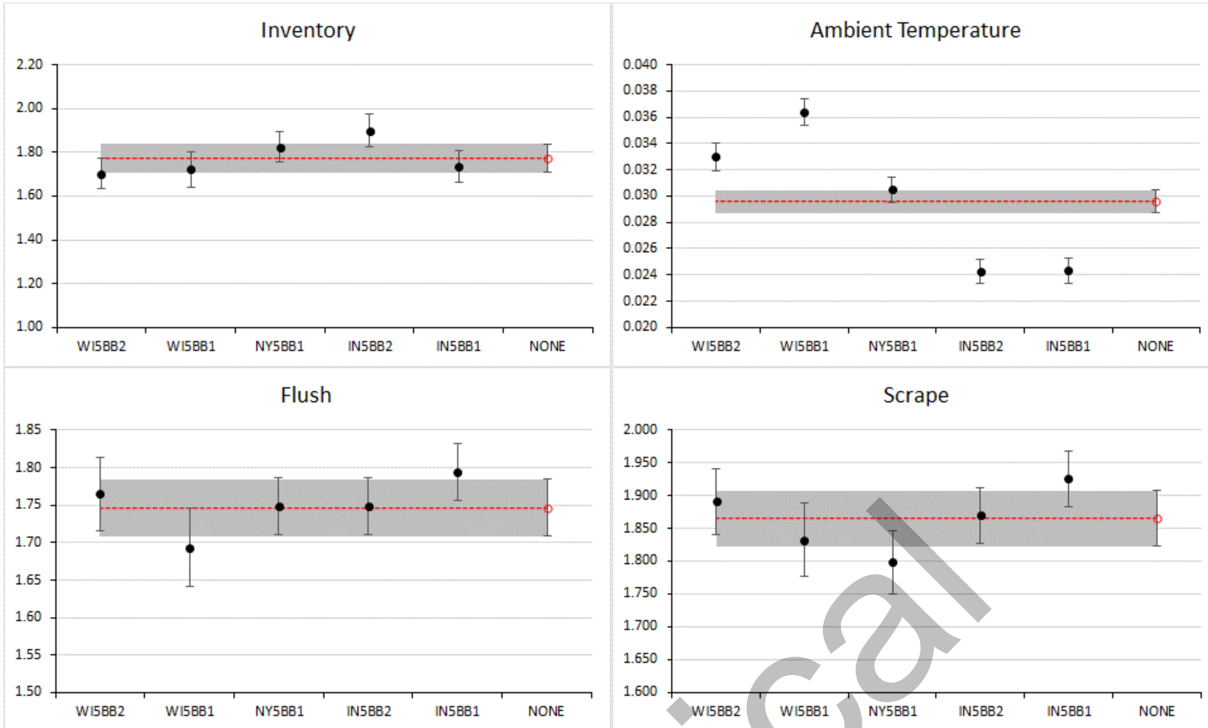


Figure 6-1. Comparison of variation in coefficients and standard errors for NH_3 mechanically ventilated barn model.
Variation in coefficients and standard errors (black closed circle and ± SE bar) for each jackknife model with the selected NH_3 mechanically ventilated model coefficient ("None", gray band for ± SE) for each model parameter.

6.1.2 H_2S Model Evaluation

The variation in coefficients and standard errors for the selected model ("None") and each of the H_2S jackknife models is shown in Table 6-3 and Figure 6-2. The model coefficients from the jackknife approach were comparable across the withheld sets (Table 6-3) and remained significant (p-value <0.05) across all models. The plots in Figure 6-2 show that the results for all jackknife models overlap the full model estimate ± 1 standard error, except for WI5B B1 for ambient temperature. In comparison to the full model, where the barn removed is "None", the maximum percent differences for parameter estimates across the three models were 14%, 26%, 2%, and 1% for inventory, ambient temperature, intercept for the flush barns, and intercept for scrape barns, respectively. Across all models, the difference in NME and NMB (Table 6-4) in comparison to the selected model were minor for NME (< 8%) and more substantial for NMB (<32%).

Table 6-3. Model coefficients developed using the jackknife approach for H_2S emissions from mechanically ventilated barns.

Barn out	Effect	Estimate	Standard Error	p-value
NONE	Inventory	0.86173	0.08664	<.0001
	Ambient Temperature	0.012786	0.00127	<.0001
	Flush	7.406887	0.05129	<.0001
	Scrape	6.287004	0.05691	<.0001
IN5BB1	Inventory	0.974345	0.08989	<.0001
	Ambient Temperature	0.010264	0.00134	<.0001
	Flush	7.389176	0.04755	<.0001
	Scrape	6.282462	0.053	<.0001
IN5BB2	Inventory	0.73697	0.09126	<.0001
	Ambient Temperature	0.010959	0.00124	<.0001
	Flush	7.453061	0.04624	<.0001
	Scrape	6.355244	0.0521	<.0001
NY5BB1	Inventory	0.915728	0.09384	<.0001
	Ambient Temperature	0.012973	0.00147	<.0001
	Flush	7.389581	0.05383	<.0001
	Scrape	6.222805	0.06537	<.0001
WI5BB1	Inventory	0.897494	0.11836	<.0001
	Ambient Temperature	0.016059	0.00149	<.0001
	Flush	7.285544	0.07955	<.0001
	Scrape	6.224063	0.08308	<.0001
WI5BB2	Inventory	0.817846	0.10259	<.0001
	Ambient Temperature	0.014378	0.00148	<.0001
	Flush	7.495271	0.07179	<.0001
	Scrape	6.313356	0.07154	<.0001

Table 6-4. Model fit statistics for the mechanically ventilated barns H_2S jackknife.

Barn out	n	LNME[a] (%)	NME[b] (%)	ME[b] (g day^{-1})	MB[b] (g day^{-1})	NMB[b] (%)	Corr
NONE	2454	4.46	64.308	553.14	-38.66	-4.495	0.58
IN5BB1	1993	4.088	61.644	533.71	-34.72	-4.01	0.592
IN5BB2	1954	3.911	59.42	464	-25.36	-3.248	0.677
NY5BB1	1992	4.736	65.587	615.71	-39.17	-4.173	0.565
WI5BB1	1920	4.696	66.693	561.9	-47.91	-5.686	0.543
WI5BB2	1957	4.653	64.785	564.15	-51.6	-5.925	0.582

[a] Based on transformed data (i.e., ln(H_2S)).
[b] Based on back-transformed data.

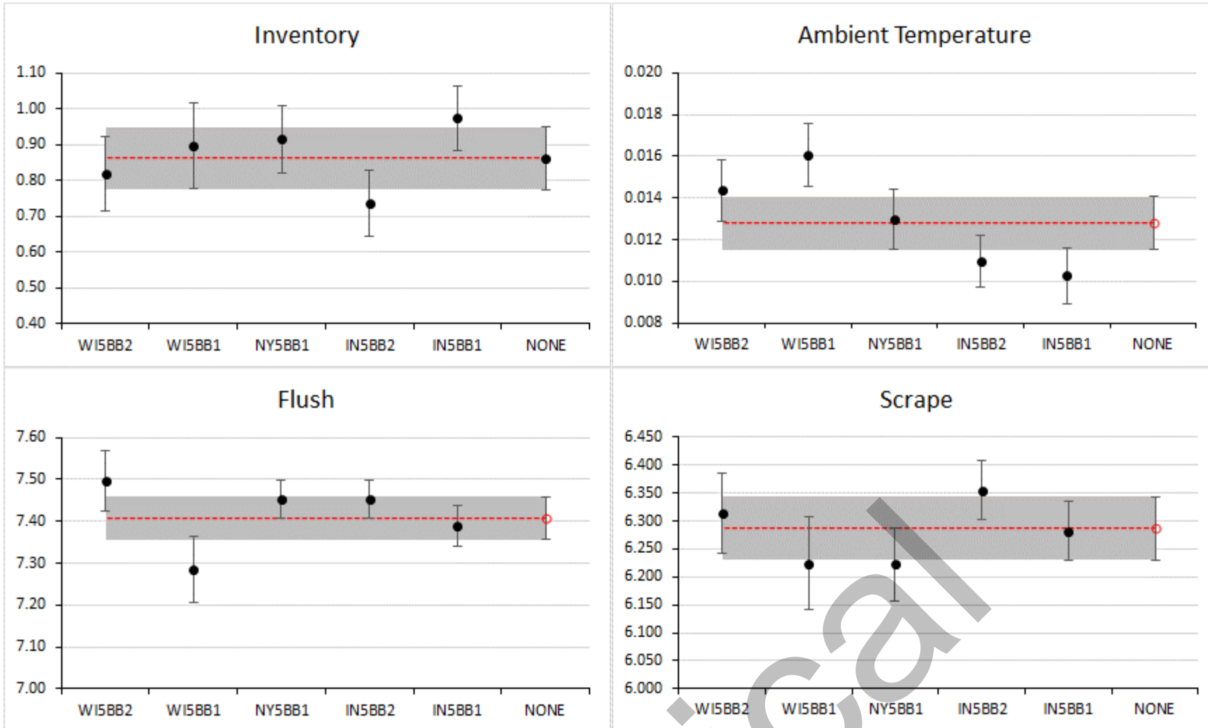


Figure 6-2. Comparison of variation in coefficients and standard errors for H_2S mechanically ventilated barn model.

Variation in coefficients and standard errors (black closed circle and ± SE bar) for each jackknife model with the selected H_2S mechanically ventilated barn model coefficient ("None", gray band for ± SE) for each model parameter.

6.1.3 Particulate Matter Models

Particulate matter models were not selected at this time.

6.2 Milking Centers

6.2.1 NH_3 Model Evaluation

Table 6-5 and Figure 6-3 show the variation in coefficients and standard errors for the selected model ("None") and each of the jackknife models. The model coefficients from the jackknife approach were comparable across the withheld sets (Table 6-5) and remained significant (p-value <0.05) across all models. The plots in Figure 6-3 show that the results for all jackknife models do not overlap the full model estimate ± 1 standard error. The standard error was very small for the full model, where the Barn removed is "None", which prevented the overlap. In comparison to the full model, the maximum percent differences for parameter estimates across the two models were 29% and 44% for the intercept and ambient temperature, respectively. Across all models, the difference in NME and NMB (Table 6-6) in comparison to the selected model were substantial for NME and NMB, with values differing by up to 44% and 104%, respectively. Upon further review, it was determined that the MCs utilize different manure handling techniques. Specifically, IN5B used a flush system while NY5B used a scrape system. Additional models using this distinction will be tested for the final report.

Table 6-5. Model coefficients developed using the jackknife approach for NH_3 emissions from milking centers.

Site out	Effect	Estimate	Standard Error	p-value
NONE	Intercept	2.505637	0.10119	<.0001
	Ambient Temperature	0.046434	0.00335	<.0001
IN5BMC	Intercept	3.155214	0.06261	<.0001
	Ambient Temperature	0.026195	0.00297	<.0001
NY5BMC	Intercept	1.783938	0.09766	<.0001
	Ambient Temperature	0.064815	0.0051	<.0001

Table 6-6. Model fit statistics for the milking center NH_3 jackknife.

Site out	n	LNME[a] (%)	NME[b] (%)	ME[b] (kg day^{-1})	MB[b] (kg day^{-1})	NMB[b] (%)	Corr
NONE	713	18.245	54.184	12.63	3.017	12.941	0.364
IN5BMC	376	8.032	30.564	9.232	1.475	4.884	0.264
NY5BMC	337	16.728	43.666	6.819	-0.088	-0.561	0.706

[a] Based on transformed data (i.e., ln(NH_3)).
[b] Based on back-transformed data.

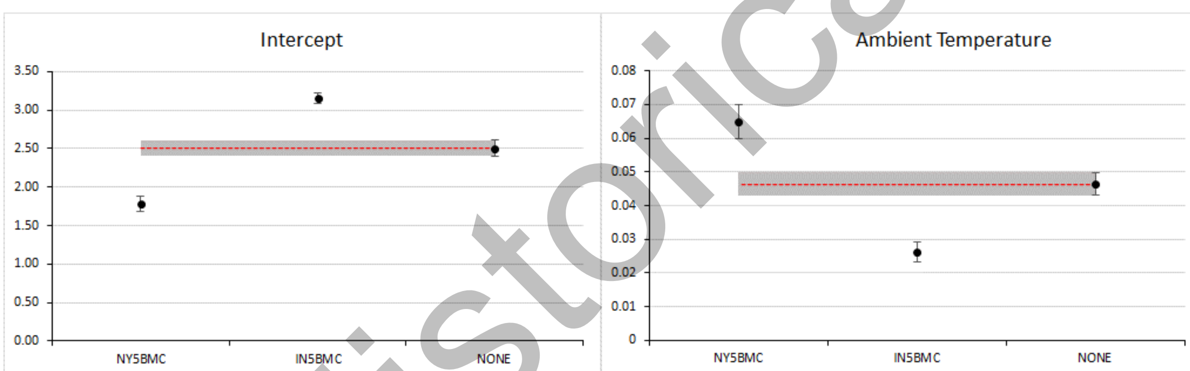


Figure 6-3. Comparison of variation in coefficients and standard errors for NH_3 milking center model.
Variation in coefficients and standard errors (black closed circle and ± SE bar) for each jackknife model with the selected NH_3 for milking center model coefficient ("None", gray band for ± SE) for each model parameter.

6.2.2 H_2S Model Evaluation

Table 6-7 and Figure 6-4 show the variation in coefficients and standard errors for the selected H_2S MC model ("None") and each of the jackknife models. The model coefficients from the jackknife approach were comparable across the withheld sets (Table 6-7) and remained significant (p-value <0.05) across all models. The plots in Figure 6-4 show that the results for all jackknife models do not overlap the full model estimate ± 1 standard error, except the intercept for the IN5B withheld model. Like the NH_3 model, the standard error was very small for the full model, where the Barn removed is "None", which prevented the overlap. In comparison to the full model, the maximum percent differences for parameter estimates across the two models were 4% and 120% for the intercept and ambient temperature, respectively. Across all models, the difference in NME and NMB (Table 6-8) in comparison to the selected model were substantial for NME and NMB, with values differing by less than 32% and 79%, respectively. As with the NH_3 models, adding a parameter for manure management system may account for the variability between sites. Additional models using this distinction will be tested for the final report.

Table 6-7. Model coefficients developed using the jackknife approach for H_2S emissions from milking centers.

Site out	Effect	Estimate	Standard Error	p-value
NONE	Intercept	6.898188	0.07052	<.0001
	Ambient Temperature	0.024053	0.00361	<.0001
IN5BMC	Intercept	6.99747	0.05042	<.0001
	Ambient Temperature	0.006415	0.0025	*0.011*
NY5BMC	Intercept	6.621331	0.13313	<.0001
	Ambient Temperature	0.052894	0.00711	<.0001

Table 6-8. Model fit statistics for the milking center H_2S jackknife.

Site out	n	LNME[a] (%)	NME[b] (%)	ME[b] (g day^{-1})	MB[b] (g day^{-1})	NMB[b] (%)	Corr
NONE	926	6.611	90.97	1204.3	-113.5	-8.571	0.347
IN5BMC	540	4.099	61.55	413.65	-12.28	-1.827	0.466
NY5BMC	386	8.707	84.8	1895.8	-284.9	-12.74	0.448

[a] Based on transformed data (i.e., $\ln(H_2S)$).
[b] Based on back-transformed data.

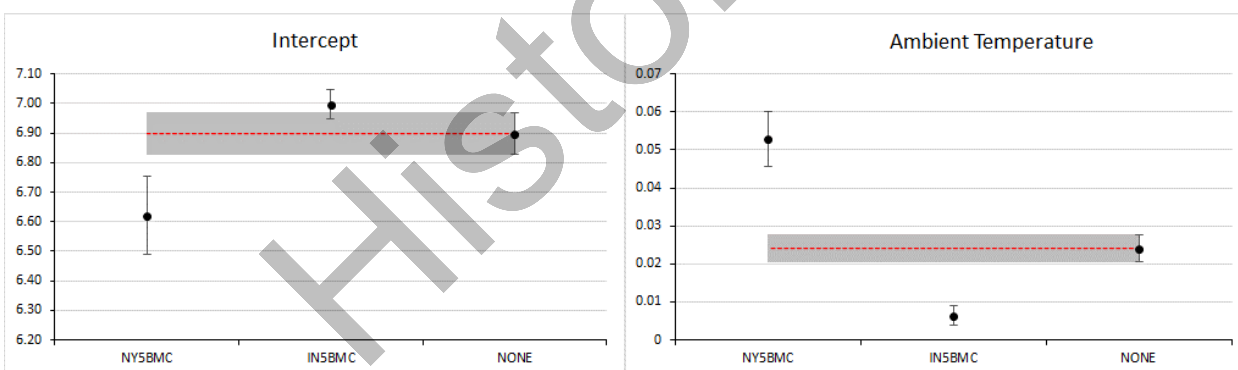


Figure 6-4. Comparison of variation in coefficients and standard errors for H2S milking center model.
Variation in coefficients and standard errors (black closed circle and ± SE bar) for each jackknife model with the selected H_2S milking center model coefficient ("None", gray band for ± SE) for each model parameter.

6.2.3 Particulate Matter Model Evaluation

For the MC particulate matter models, we did not complete jackknife analysis because there was only one site in the dataset. We also did not pursue a model evaluation using a k-fold cross validation technique based on previous SAB comments (SAB, 2013) recommending against using this method to select data for temporally correlated data. Future EPA efforts will investigate obtaining additional data that would allow for further model testing and evaluation and an improved emission model.

6.3 Naturally Ventilated Barn Model

A theme across all the results presented below is withholding WA4B B4 from the data set produces the largest differences across the models. This is likely due to WA4B B4 having an average daily inventory almost twice the other three barns included in NAEMS. Removing this barn greatly reduced the variability of inventory values in the data set that the model must capture.

6.3.1 NH_3 Model Evaluation

Table 6-9 and Figure 6-5 show the variation in coefficients and standard errors for the selected NH_3 naturally ventilated barn model ("None") and each of the jackknife models. The model coefficients from the jackknife approach had some differences, most notable in the models with WA5B barns withheld (Table 6-9). For the models where WA4B B2 and B4 were withheld, one or both parameters were insignificant (p-value >0.05). The plots in Figure 6-5 show that the coefficients for these models also fall outside the full model estimate ± 1 standard error, except for wind speed. In comparison to the full model, where the barn removed is "None", the maximum percent differences for parameter estimates across the models were 2292%, 235%, and 23% for the intercept, inventory, and wind speed, respectively. These largest differences all occurred for the model where WA5B B4 was removed. Across all models, the difference in NME and NMB (Table 6-10) in comparison to the selected model were the largest when WA5B B4 was withheld from the dataset, which increased the NME by 32% and decreased NMB by 174%. This is likely due to the reduced variability in inventory values caused by withholding WA4B B4.

Table 6-9. Model coefficients developed using the jackknife approach for NH_3 emissions from naturally ventilated barns.

Site out	Effect	Estimate	Standard Error	p-value[a]
NONE	Intercept	0.188357	0.2678	0.484
	Inventory	3.451939	0.4106	<.0001
	Wind Speed	0.048153	0.01837	0.009
CA5BB1	Intercept	0.734625	0.34491	*0.0385*
	Inventory	2.885717	0.49667	<.0001
	Wind Speed	0.043071	0.01873	*0.022*
CA5BB2	Intercept	0.730143	0.31533	*0.0253*
	Inventory	2.985909	0.45768	<.0001
	Wind Speed	0.040555	0.01847	*0.0288*
WA5BB2	Intercept	-0.84424	0.13064	<.0001
	Inventory	4.709923	0.19931	<.0001
	Wind Speed	0.019312	0.02201	**0.3808**
WA5BB4	Intercept	4.505901	1.29423	0.0009
	Inventory	-4.658465	2.41694	**0.0582**
	Wind Speed	0.037293	0.02361	**0.1149**

[a]Bold indicates insignificant p-values (i.e., > 0.05)

Table 6-10. Model fit statistics for the naturally ventilated barns NH_3 jackknife.

Site out	n	LNME[a] (%)	NME[b] (%)	ME[b] (kg day^{-1})	MB[b] (kg day^{-1})	NMB[b] (%)	Corr
NONE	605	27.084	75.233	12.818	0.828	4.862	0.636
CA5BB1	431	27.885	72.445	16.265	0.754	3.36	0.601
CA5BB2	396	25.139	69.96	16.995	1.728	7.114	0.599
WA5BB2	482	20.19	51.412	7.179	-0.504	-3.611	0.793
WA5BB4	506	32.404	98.929	9.575	-0.249	-2.571	0.207

[a] Based on transformed data (i.e., ln(NH_3)).
[b] Based on back-transformed data.

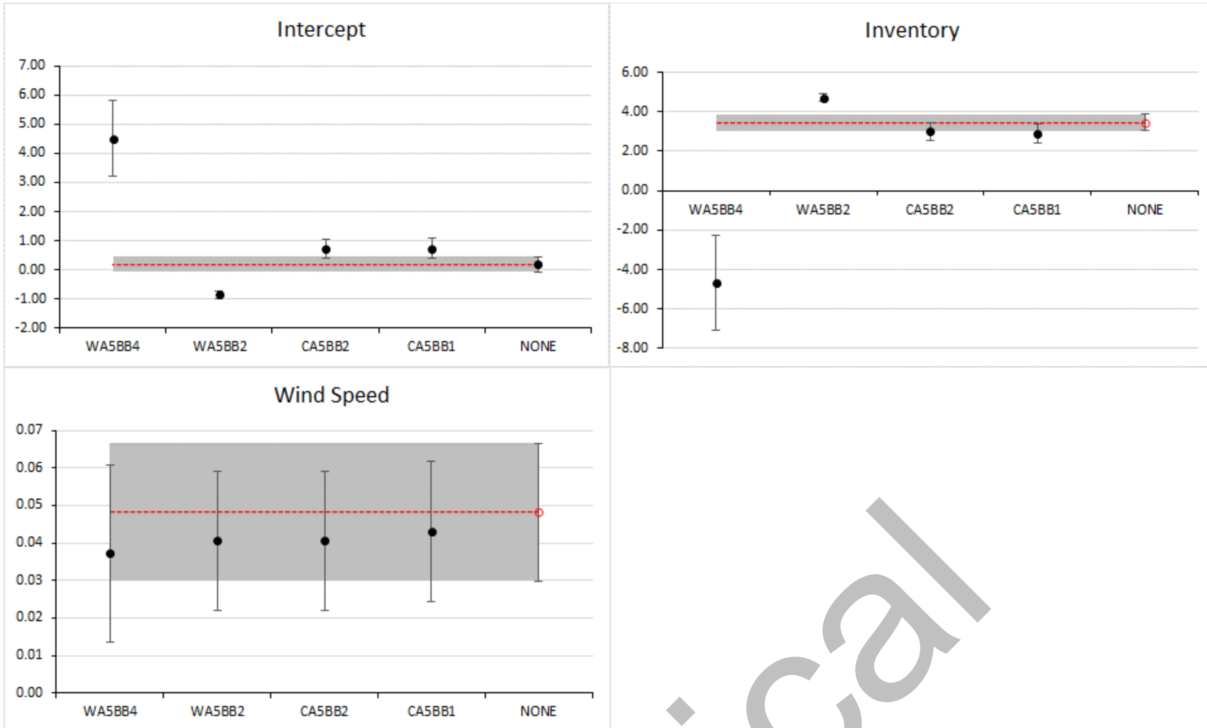


Figure 6-5. Comparison of variation in coefficients and standard errors for NH_3 naturally ventilated barn model.

Variation in coefficients and standard errors (black closed circle and ± SE bar) for each jackknife model with the selected NH_3 naturally ventilated barn model coefficient ("None", gray band for ± SE) for each model parameter.

6.3.2 H_2S Model Evaluation

Table 6-11 and Figure 6-6 show the variation in coefficients and standard errors for the selected H_2S naturally ventilated barn model ("None") and each of the jackknife models. The model coefficients from the jackknife approach had some differences, most notable the coefficient for inventory switched to negative in the model with WA5B B4 withheld (Table 6-11) and was insignificant (p-value >0.05). For the models where CA4B B1 and B2 were withheld, the coefficient from wind speed became insignificant. The plots in Figure 6-6 show that the coefficients for the model where WA5B B4 was withheld fall outside the full model estimate ± 1 standard error, except for wind speed. In comparison to the full model, where the barn removed is "None", the maximum percent differences for parameter estimates across the models occurred when WA5B was withheld and were 12%, 307%, and 75% for the intercept, inventory, and wind speed, respectively. Across all models, the difference in NME and NMB (Table 6-12) in comparison to the selected model were the largest when WA5B B4 was withheld from the dataset, which increased the NME by 17% and decreased NMB by 92%. Withholding WA4B B4 from the dataset reduced variability in inventory, which changed the significance of inventory as a predictive parameter and lowered the bias seen in the model.

Table 6-11. Model coefficients developed using the jackknife approach for H_2S emissions from naturally ventilated barns.

Site out	Effect	Estimate	Standard Error	p-value[a]
NONE	Intercept	6.541057	0.14434	<.0001
	Inventory	0.587702	0.21921	0.008
	Wind Speed	0.062678	0.02193	0.0044
CA5BB1	Intercept	6.593149	0.17451	<.0001
	Inventory	0.661236	0.24717	0.0083
	Wind Speed	0.036373	0.02762	**0.1886**
CA5BB2	Intercept	6.557214	0.18007	<.0001
	Inventory	0.6616	0.24813	0.0085
	Wind Speed	0.03755	0.03114	**0.2288**
WA5BB2	Intercept	6.559682	0.14376	<.0001
	Inventory	0.520217	0.21815	0.0182
	Wind Speed	0.075574	0.02381	0.0016
WA5BB4	Intercept	7.344257	0.58948	<.0001
	Inventory	-1.214405	1.08122	**0.2645**
	Wind Speed	0.109848	0.01931	<.0001

[a]Bold indicates insignificant p-values (i.e., > 0.05)

Table 6-12. Model fit statistics for the naturally ventilated barns H_2S jackknife.

Site out	n	LNME[a] (%)	NME[b] (%)	ME[b] (g day^{-1})	MB[b] (kg day^{-1})	NMB[b] (%)	Corr
NONE	647	6.461	77.092	677.49	-29.02	-3.302	0.33
CA5BB1	449	6.937	80.862	807.4	-34.82	-3.487	0.326
CA5BB2	380	7.784	89.878	915.9	-39.6	-3.886	0.32
WA5BB2	550	5.832	69.934	603.45	-36.4	-4.218	0.371
WA5BB4	562	5.662	69.734	490.88	-1.791	-0.254	0.249

[a] Based on transformed data (i.e., $\ln(H_2S)$).
[b] Based on back-transformed data.

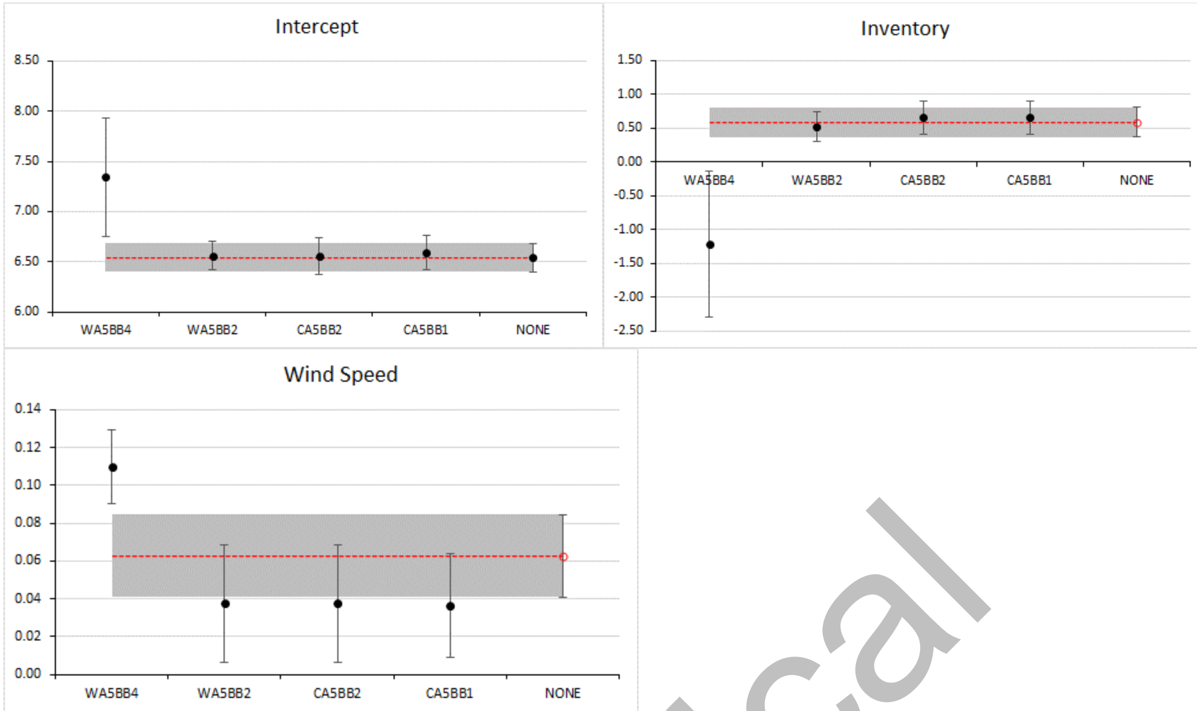


Figure 6-6. Comparison of variation in coefficients and standard errors for H_2S naturally ventilated barn model.

Variation in coefficients and standard errors (black closed circle and ± SE bar) for each jackknife model with the selected H_2S naturally ventilated barns model coefficient ("None", gray band for ± SE) for each model parameter.

6.3.3 PM_{10} Model Evaluation

Table 6-13 and Figure 6-7 show the variation in coefficients and standard errors for the selected PM_{10} naturally ventilated barn model ("None") and each of the jackknife models. The model coefficients from the jackknife approach had some differences, most notably the coefficient for inventory switched to negative in the model with WA5B B4 withheld (Table 6-13) and became insignificant. For the models where WA4B4 was withheld, the coefficient for ambient temperature also became insignificant (p-value >0.05). The plots in Figure 6-7 show that the coefficients for the model where WA5B B4 fall outside the full model estimate ± 1 standard error, except for ambient relative humidity. In comparison to the full model, where the barn removed is "None", the maximum percent differences for parameter estimates across the three models were 15%, 138%, 80%, 24%, and 20% for the intercept, inventory, ambient temperature, ambient relative humidity, and wind speed, respectively. Across all models, the difference in NME and NMB (Table 6-14) in comparison to the selected model were the largest when WA5B B4 was withheld from the dataset, which increased the NME by 16% and decreased NMB by 37%.

Table 6-13. Model coefficients developed using the jackknife approach for PM_{10} emissions from naturally ventilated barns.

Site out	Effect	Estimate	Standard Error	p-value[a]
NONE	Intercept	7.64258	0.16783	<.0001
	Inventory	1.525009	0.14917	<.0001
	Ambient Temperature	0.011864	0.00333	0.0004
	Ambient Relative Humidity	-0.01521	0.00154	<.0001
	Wind Speed	0.173698	0.01064	<.0001
CA5BB1	Intercept	7.695149	0.18357	<.0001
	Inventory	1.399494	0.16322	<.0001
	Ambient Temperature	0.018588	0.00384	<.0001
	Ambient Relative Humidity	-0.01564	0.00178	<.0001
	Wind Speed	0.181527	0.0118	<.0001
CA5BB2	Intercept	7.726456	0.19289	<.0001
	Inventory	1.420078	0.16427	<.0001
	Ambient Temperature	0.014917	0.00397	0.0002
	Ambient Relative Humidity	-0.015634	0.00196	<.0001
	Wind Speed	0.175816	0.01265	<.0001
WA5BB2	Intercept	6.831711	0.24796	<.0001
	Inventory	2.045075	0.17514	<.0001
	Ambient Temperature	0.020629	0.00419	<.0001
	Ambient Relative Humidity	-0.0115	0.00199	<.0001
	Wind Speed	0.192966	0.01355	<.0001
WA5BB4	Intercept	8.81874	0.46389	<.0001
	Inventory	-0.576586	0.90282	**0.5241**
	Ambient Temperature	0.002425	0.00354	**0.494**
	Ambient Relative Humidity	-0.012854	0.00154	<.0001
	Wind Speed	0.138497	0.01071	<.0001

[a]Bold indicates insignificant p-values (i.e., > 0.05)

Table 6-14. Model fit statistics for the naturally ventilated barns PM_{10} jackknife.

Site out	N	LNME[a] (%)	NME[b] (%)	ME[b] (g day^{-1})	MB[b] (kg day^{-1})	NMB[b] (%)	Corr
CA5BB1	1214	5.102	79.404	4772.9	-701.9	-11.68	0.372
CA5BB2	1088	5.412	81.443	5265.9	-688.8	-10.65	0.358
NONE	1457	4.896	82.575	4195.9	-668.8	-13.16	0.374
WA5BB2	1024	4.537	76.692	3944.7	-926.4	-18.01	0.462
WA5BB4	1045	4.156	95.397	2384	-277.5	-11.1	0.208

[a] Based on transformed data (i.e., ln(PM_{10})).
[b] Based on back-transformed data.

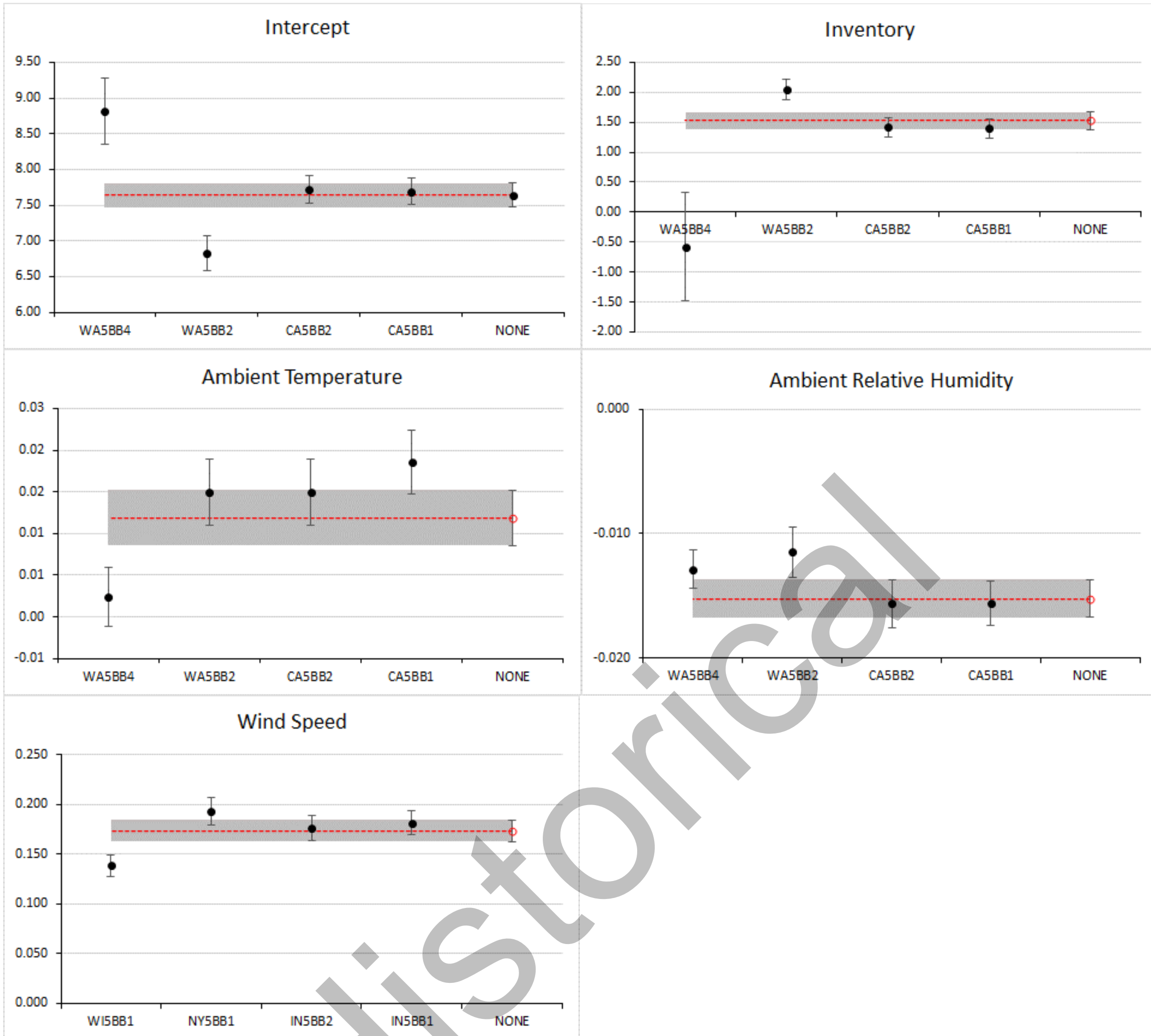


Figure 6-7. Comparison of variation in coefficients and standard errors for PM_{10} naturally ventilated barn model.

Variation in coefficients and standard errors (black closed circle and ± SE bar) for each jackknife model with the selected PM_{10} naturally ventilated barns model coefficient ("None", gray band for ± SE) for each model parameter.

6.3.4 $PM_{2.5}$ Model Evaluation

The analysis for the $PM_{2.5}$ naturally ventilated barns was a departure from the other evaluations, more of the models have coefficients that vary and are insignificant (Table 6-15). When compared to the full model, the coefficients vary up to 125%, 4,370%, 406%, 21,410%, and 25% for the intercept, inventory, ambient temperature, ambient relative humidity, and wind speed, respectively, and the large differences are not limited to the model with WA5B B4 withheld. Table 6-15 and Figure 6-8 show the variation in coefficients and standard errors for the selected $PM_{2.5}$ naturally ventilated barn model ("None") and each of the jackknife models. The plots in Figure 6-8 show that most of the coefficients for the models overlapped the full model estimate ± 1 standard error. The models for the WA5B barn both fell outside for the intercept and inventory, and the WA5B B1 model fell outside for ambient relative humidity. The difference in NME and NMB (Table 6-16) across the models with a barn withheld compared to the selected model changed by as much as 40% for NME and 1,566% for NMB.

Table 6-15. Model coefficients developed using the jackknife approach for $PM_{2.5}$ emissions from naturally ventilated barns.

Site out	Effect	Estimate	Standard Error	p-value[a]
NONE	Intercept	7.068797	1.15954	<.0001
	Inventory	-0.220453	0.75959	**0.7753**
	Ambient Temperature	0.01121	0.02585	**0.6681**
	Ambient Relative Humidity	-0.003808	0.01023	**0.7125**
	Wind Speed	0.218968	0.0563	0.0002
CA5BB1	Intercept	6.922323	1.15234	<.0001
	Inventory	-0.432386	0.76218	**0.579**
	Ambient Temperature	0.015697	0.02584	**0.5493**
	Ambient Relative Humidity	0.001448	0.01082	**0.8946**
	Wind Speed	0.232037	0.05911	0.0002
CA5BB2	Intercept	5.999344	0.97451	<.0001
	Inventory	-0.637279	0.60064	**0.3062**
	Ambient Temperature	0.056741	0.02418	0.0293
	Ambient Relative Humidity	0.012843	0.00944	**0.1876**
	Wind Speed	0.237943	0.06181	0.0002
WA5BB2	Intercept	-1.742952	1.50484	**0.2592**
	Inventory	4.220142	0.79698	<.0001
	Ambient Temperature	0.135315	0.02619	<.0001
	Ambient Relative Humidity	0.049877	0.01071	0.0001
	Wind Speed	0.221498	0.0743	0.0044
WA5BB4	Intercept	13.01778	2.71873	0.0035
	Inventory	-9.854431	5.35402	**0.1099**
	Ambient Temperature	-0.005191	0.0234	**0.8255**
	Ambient Relative Humidity	-0.012329	0.00844	**0.1545**
	Wind Speed	0.163688	0.02852	<.0001

[a]Bold indicates insignificant p-values (i.e., > 0.05)

Table 6-16. Model fit statistics for the naturally ventilated barns $PM_{2.5}$ jackknife.

Site out	n	LNME[a] (%)	NME[b] (%)	ME[b] (g day^{-1})	MB[b] (kg day^{-1})	NMB[b] (%)	Corr
CA5BB1	89	8.295	59.345	1154	9.362	0.481	0.651
CA5BB2	78	6.288	37.718	820.71	50.306	2.312	0.821
NONE	93	8.789	62.65	1167	-19.48	-1.046	0.665
WA5BB2	56	5.461	48.197	625.08	198.89	15.335	0.901
WA5BB4	56	5.877	54.701	1018.8	-91.41	-4.908	0.718

[a] Based on transformed data (i.e., ln(NH_3)).
[b] Based on back-transformed data.

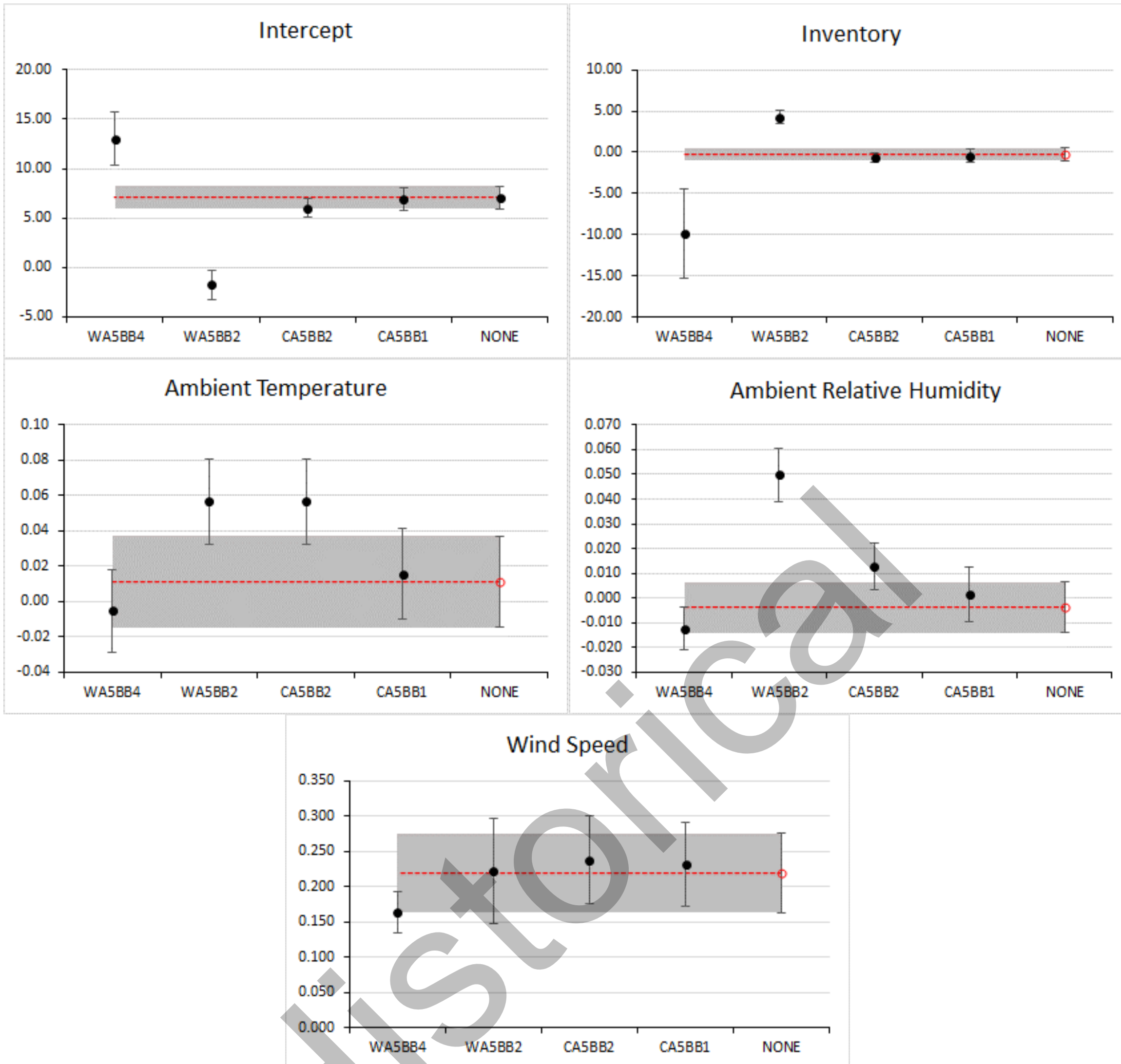


Figure 6-8. Comparison of variation in coefficients and standard errors for $PM_{2.5}$ naturally ventilated barn model.

Variation in coefficients and standard errors (black closed circle and ± SE bar) for each jackknife model with the selected $PM_{2.5}$ naturally ventilated barn model coefficient ("None", gray band for ± SE) for each model parameter.

6.3.5 TSP Model Evaluation

Table 6-17 and Figure 6-9 show the variation in coefficients and standard errors for the selected TSP naturally ventilated barn model ("None") and each of the jackknife models. The model coefficients from the jackknife approach were comparable across the withheld sets (Table 6-17) and remained significant (p-value <0.05) across all models, except for ambient temperature in the model where WA5BB4 was removed. The plots in Figure 6-9 show that all the coefficients overlap the full model estimate ± 1 standard error, except for inventory for the model where WA5BB4 was removed. In comparison to the full model, that is where the barn removed is "None", the maximum percent differences for parameter estimates across the three models were

17%, 141%, 56%, 25%, and 18% for the intercept, inventory, ambient temperature, ambient relative humidity, and wind speed, respectively. Across all models, the difference in NME and NMB (Table 6-18) in comparison to the selected model changed by as much as 16% for NME and 160% for NMB.

Table 6-17. Model coefficients developed using the jackknife approach for TSP emissions from naturally ventilated barns.

Site out	Effect	Estimate	Standard Error	p-value[a]
NONE	Intercept	7.868847	0.58294	<.0001
	Inventory	2.953893	0.48928	<.0001
	Ambient Temperature	0.034508	0.01069	0.0021
	Ambient Relative Humidity	-0.033997	0.00508	<.0001
	Wind Speed	0.248191	0.04211	<.0001
CA5BB1	Intercept	7.667585	0.48937	<.0001
	Inventory	2.477977	0.44054	<.0001
	Ambient Temperature	0.048926	0.01002	<.0001
	Ambient Relative Humidity	-0.026332	0.00445	<.0001
	Wind Speed	0.294612	0.03075	<.0001
CA5BB2	Intercept	7.786063	0.68673	<.0001
	Inventory	2.998098	0.56151	<.0001
	Ambient Temperature	0.034621	0.01325	0.0127
	Ambient Relative Humidity	-0.032651	0.00638	<.0001
	Wind Speed	0.238451	0.05294	<.0001
WA5BB2	Intercept	6.616785	0.81649	<.0001
	Inventory	3.762081	0.52641	<.0001
	Ambient Temperature	0.048947	0.01322	0.0005
	Ambient Relative Humidity	-0.026808	0.00659	0.0001
	Wind Speed	0.235277	0.04912	<.0001
WA5BB4	Intercept	6.558937	1.4622	<.0001
	Inventory	7.12147	2.73945	0.0131
	Ambient Temperature	0.0151	0.01245	**0.2317**
	Ambient Relative Humidity	-0.042411	0.0058	<.0001
	Wind Speed	0.203451	0.05134	0.0001

[a]Bold indicates insignificant p-values (i.e., > 0.05)

Table 6-18. Model fit statistics for the naturally ventilated barns TSP jackknife.

Site out	n	LNME[a] (%)	NME[b] (%)	ME[b] (g day^{-1})	MB[b] (kg day^{-1})	NMB[b] (%)	Corr
CA5BB1	135	4.902	44.574	9954.9	-1381	-6.185	0.875
CA5BB2	146	6.598	55.473	10927	-932.6	-4.734	0.799
NONE	205	6.07	52.783	8639.5	-492.6	-3.009	0.807
WA5BB2	167	5.659	49.037	7695.7	-297.8	-1.898	0.821
WA5BB4	167	6.446	57.093	5315	12.023	0.129	0.666

[a] Based on transformed data (i.e., ln(TSP)).
[b] Based on back-transformed data.

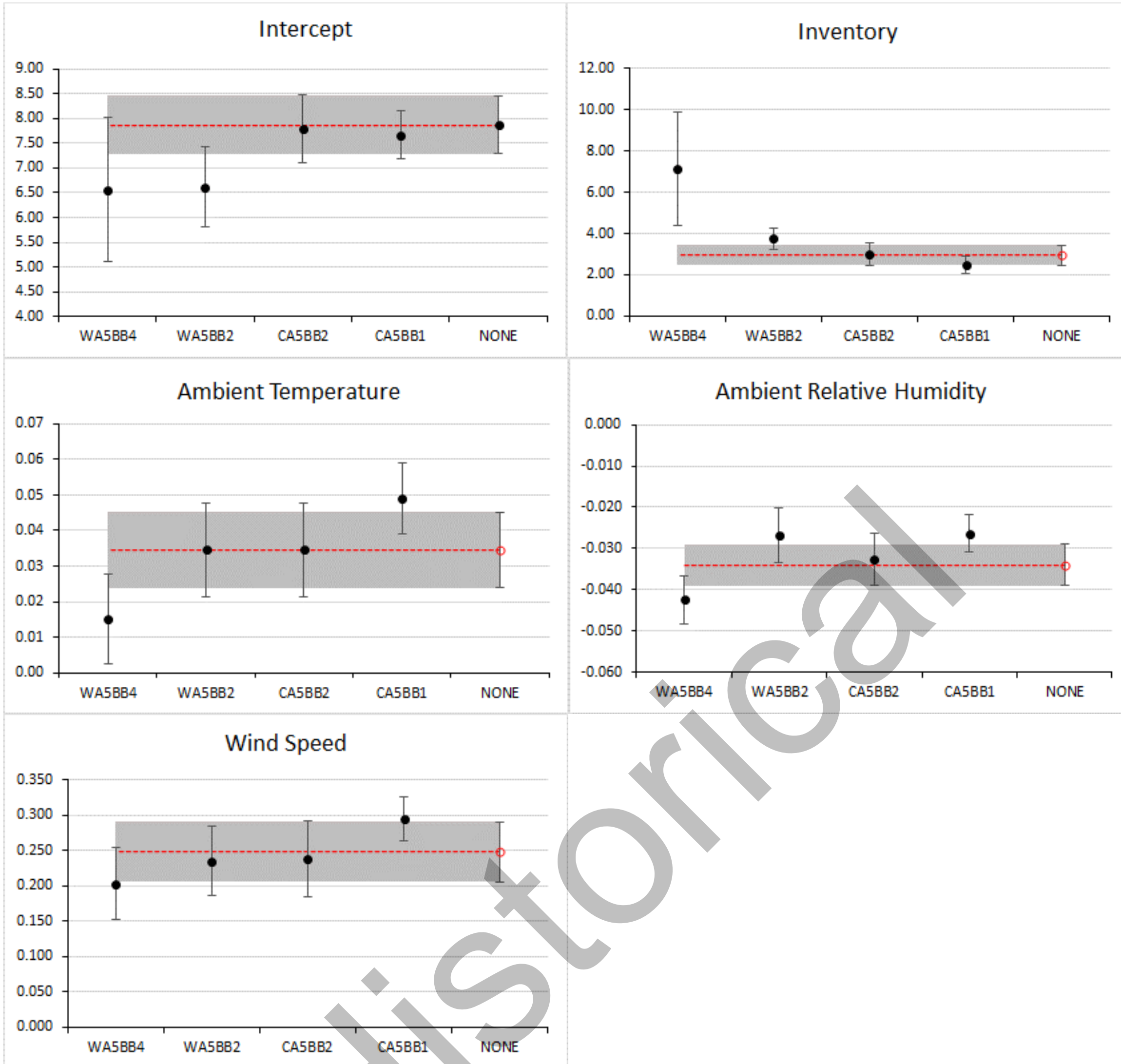


Figure 6-9. Comparison of variation in coefficients and standard errors for TSP naturally ventilated barn model.
Variation in coefficients and standard errors (black closed circle and ± SE bar) for each jackknife model with the selected TSP naturally ventilated barn model coefficient (“None”, gray band for ± SE) for each model parameter.

6.4 Open Sources

For the corral models, we did not complete jackknife analysis because there was only one site in the dataset. We also did not pursue a model evaluation using a k-fold cross validation technique based on previous SAB comments (SAB, 2013) recommending against using this method to select data for temporally correlated data. Future EPA efforts will look into obtaining additional data that would allow for further model testing and evaluation and an improved emission model.

6.4.1 NH_3 Model Evaluation

Table 6-19 and Figure 6-10 show the variation in coefficients and standard errors for the selected NH_3 open source model ("None") and each of the jackknife models. The model coefficients from the jackknife approach were comparable across the withheld sets (Table 6-19) and remained significant (p-value <0.05) across all models. The plots in Figure 6-10 show that the results for all jackknife models do not overlap the full model estimate ± 1 standard error, except the model where IN5A was withheld for ambient temperature. In comparison to the full model, the maximum percent differences for parameter estimates across the two models were 13% and 24% for the intercept and ambient temperature, respectively. Across all models, the difference in NME and NMB (Table 6-20) in comparison to the selected model were substantial for NME and NMB, with values differing by up to 38% and 77%, respectively.

Table 6-19. Model coefficients developed using the jackknife approach for NH_3 emissions from open sources.

Site out	Effect	Estimate	Standard Error	p-value
NONE	Intercept	1.396734	0.0248	<.0001
	Ambient Temperature	0.027201	0.00195	<.0001
IN5A	Intercept	1.576653	0.06521	<.0001
	Ambient Temperature	0.033848	0.00616	<.0001
WI5A	Intercept	1.323888	0.01843	<.0001
	Ambient Temperature	0.031531	0.00152	<.0001

Table 6-20. Model fit statistics for the open sources NH_3 jackknife.

Site out	n	LNME[a] (%)	NME[b] (%)	ME[b] (g day^{-1})	MB[b] (kg day^{-1})	NMB[b] (%)	Corr
IN5A	28	12.225	53.586	0.865	-0.048	-2.958	0.84
NONE	157	9.709	38.766	0.712	-0.034	-1.859	0.821
WI5A	129	8.159	31.915	0.601	-0.008	-0.433	0.887

[a] Based on transformed data (i.e., ln(NH_3)).
[b] Based on back-transformed data.

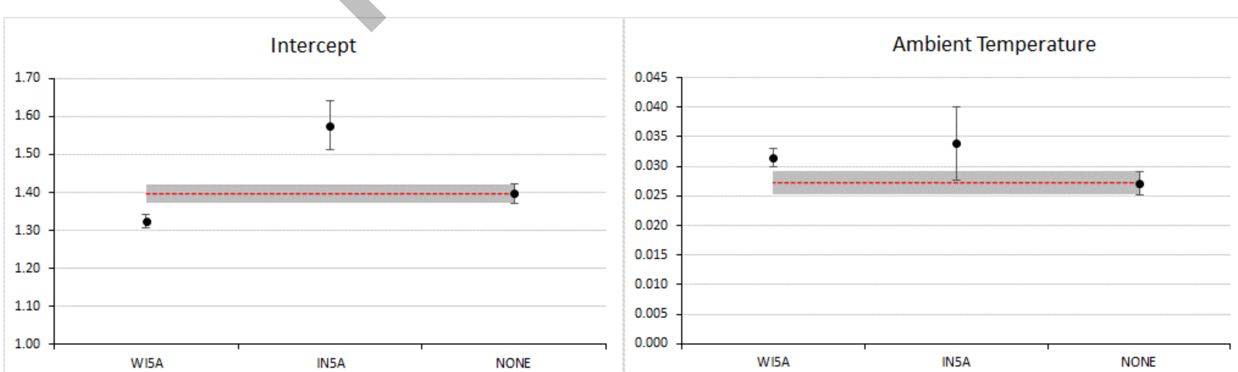


Figure 6-10. Comparison of variation in coefficients and standard errors for NH_3 open source model. Variation in coefficients and standard errors (black closed circle and ± SE bar) for each jackknife model with the selected NH_3 open source model coefficient ("None", gray band for ± SE) for each model parameter.

6.4.2 H_2S Model Evaluation

Table 6-21 and Figure 6-11 show the variation in coefficients and standard errors for the selected H_2S open source model (“None”) and each of the jackknife models. The model coefficients from the jackknife approach were comparable across the withheld sets (Table 6-21) and remained significant (p-value <0.05) across all models. The plots in Figure 6-11 show that the results for all jackknife models do not overlap the full model estimate ± 1 standard error, except the model where IN5A was withheld. In comparison to the full model, the maximum percent differences for parameter estimates across the two models were 7% and 68% for the intercept and ambient temperature, respectively. Across all models, the difference in NME and NMB (Table 6-22) in comparison to the selected model were substantial for NME and NMB, with values differing by up to 20% and 98%, respectively.

Table 6-21. Model coefficients developed using the jackknife approach for H2S emissions from open sources.

Site out	Effect	Estimate	Standard Error	p-value
NONE	Intercept	1.189272	0.03163	<.0001
	Ambient Temperature	0.010557	0.0022	<.0001
IN5A	Intercept	1.109037	0.01639	<.0001
	Ambient Temperature	0.003382	0.00127	0.0203
WA5A	Intercept	1.189558	0.03019	<.0001
	Ambient Temperature	0.011581	0.00218	<.0001
WI5A	Intercept	1.226774	0.04029	<.0001
	Ambient Temperature	0.009725	0.00256	0.0005

Table 6-22. Model fit statistics for the open source H_2S jackknife.

Site out	n	LNME[a] (%)	NME[b] (%)	ME[b] (g day^{-1})	MB[b] (kg day^{-1})	NMB[b] (%)	Corr
NONE	70	9.258	63.688	0.499	-0.011	-1.403	0.587
IN5A	13	1.475	76.161	0.052	0	-0.032	0.782
WA5A	69	8.922	61.188	0.484	-0.01	-1.321	0.615
WI5A	58	9.575	58.078	0.542	-0.009	-0.914	0.525

[a] Based on transformed data (i.e., ln(H_2S)).
[b] Based on back-transformed data.

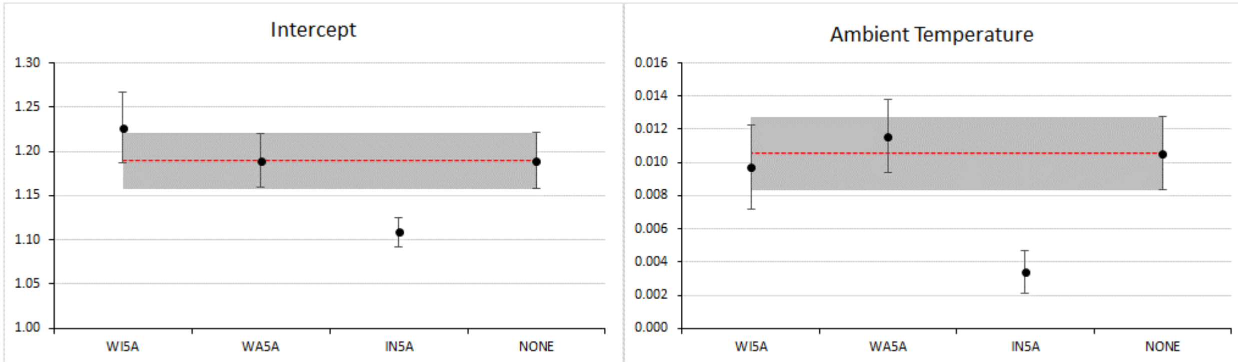


Figure 6-11. Comparison of variation in coefficients and standard errors for H_2S open source model. Variation in coefficients and standard errors (black closed circle and ± SE bar) for each jackknife model with the selected H_2S open source model coefficient ("None", gray band for ± SE) for each model parameter.

7 ANNUAL EMISSION ESTIMATES AND MODEL UNCERTAINTY

To estimate annual pollutant emissions, the results of the daily emission models are summed over the number of operating days per year. This approach requires values for the necessary ambient and barn parameters. For an actual emissions estimate, the daily estimates are based on meteorology from nearby monitors and barn occupancy and weight records for the year from the producer. For farms with multiple barns, annual emissions are determined for individual barns and summed across barns to calculate total annual farm-scale emissions.

As noted in Section 6 of the main report, the model results are transformed values of the emissions. To convert to the native emission units (e.g., kg or g), the back transformation equation (Equation from Section 6 of the main All Sector report) is applied using the values of $\overline{E_i}$ and C provided in Table 7-1 for each emission model. Section 8 contains an example of this calculation.

Table 7-1. Back transformation parameters

Animal Type	Pollutant	$\overline{E_i}$	C	Resulting units
Mechanically Ventilated barn	NH_3	1.03966	3	kg/d
Mechanically Ventilated barn	H_2S	1.11434	628	g/d
Mechanically Ventilated barn	PM_{10}	[a]	[a]	[a]
Mechanically Ventilated barn	$PM_{2.5}$	[a]	[a]	[a]
Mechanically Ventilated barn	TSP	[a]	[a]	[a]
Milking Center	NH_3	1.21693	3	g/d/hd
Milking Center	H_2S	1.30119	628	kg/d/hd
Milking Center	PM_{10}	1.0057	2200	g/d/hd
Milking Center	$PM_{2.5}$	1.00796	680	g/d/hd
Milking Center	TSP	1.0311	978	g/d/hd
Naturally Ventilated barn	NH_3	1.46499	3	g/d
Naturally Ventilated barn	H_2S	1.23366	628	kg/d
Naturally Ventilated barn	PM_{10}	1.27211	2200	g/d
Naturally Ventilated barn	$PM_{2.5}$	1.33005	680	g/d
Naturally Ventilated barn	TSP	1.25126	978	g/d
Lagoon/basin	NH_3	1.0079	3	kg/d m^2
Lagoon/basin	H_2S	1.03006	3	kg/d m^2
Corral	NH_3	1.0066	3	g/d-m^2-1,000 hd
Corral	H_2S	1.00007	3	g/d-m^2-1,000 hd

[a] Annual models were not calculated to allow time to optimize the daily models.

EPA also developed an estimate of uncertainty for total annual emissions, characterized by the random error in the model prediction using an approach similar to the Monte Carlo analysis. Under this approach, EPA developed the statistical properties of predicted annual emissions by replicating annual sums of daily emissions. EPA ran these simulations for several different intervals of a predictor variable that fell within the observed range. For example, naturally ventilated barn inventory ranged from 500 to 600 head. The simulations were then run for inventory intervals of 5 head (e.g., 500, 505, 510). Table 7-2 lists the predictor variable and the number of intervals used for the annual uncertainty simulations for each model.

Table 7-2. Annual Uncertainty Model Details

Source Type	Pollutant	Simulation Variable	Number of Simulations	k	Emission Units
Mechanically ventilated barn - Flush	H_2S	Inventory	10,000	3,457,126	g/d
Mechanically ventilated barn - Scrape	H_2S	Inventory	10,000	3,453,490	g/d
Mechanically ventilated barn - Flush	NH_3	Inventory	10,000	35,180	kg/d
Mechanically ventilated barn - Scrape	NH_3	Inventory	10,000	35,258	kg/d
Mechanically ventilated barn	PM_{10}	[a]			
Mechanically ventilated barn	$PM_{2.5}$	[a]			
Mechanically ventilated barn	TSP	[a]			
Milking Center	H_2S	Ambient temperature	10,000	9,392,217	g/d-1,000 hd
Milking Center	NH_3	Ambient temperature	10,000	55,494	kg/d-1,000 hd
Milking Center	PM_{10}	Ambient temperature	10,000	1,082,872	g/d-1,000 hd
Milking Center	$PM_{2.5}$	Ambient temperature	10,000	498,298	g/d-1,000 hd
Milking Center	TSP	Ambient temperature	10,000	1,557,418	g/d-1,000 hd
Naturally ventilated barn	H_2S	Inventory	10,000	4,963,976	g/d
Naturally ventilated barn	NH_3	Inventory	10,000	73,495.7	kg/d
Naturally ventilated barn	PM_{10}	Inventory	10,000	59,332,385	g/d
Naturally ventilated barn	$PM_{2.5}$	Inventory	10,000	5,181,114	g/d
Naturally ventilated barn	TSP	Inventory	10,000	83,299,795	g/d
Lagoon/basin	H_2S	Ambient temperature	10,000	2,606.3	g/d m^2
Lagoon/basin	NH_3	Ambient temperature	10,000	4,114.1	g/d m^2
Corral	H_2S	Ambient relative humidity	10,000	18,479.4	mg/d-m^2-1,000 hd
Corral	NH_3	Ambient temperature	10,000	1,278.5	g/d-m^2-1,000 hd

[a] Annual models were not calculated to allow time to optimize the daily models.

Simulations were run 10,000 times for each day for each interval to create an average uncertainty associated with the annual emissions from a single barn. EPA added a random residual to each day of the simulation to replicate the variability that would be seen in a realworld application of the model. For each of the intervals run, EPA calculated standard statistics (i.e., minimum, median, mean, maximum, range) and used these to calculate the uncertainty for a single source via:

$$Single\ source\ uncertainty\ =\ 0.5 \times \left(\frac{Range}{Median\ annual\ emission}\right) \times 100 \qquad \text{Equation 19}$$

EPA then plotted this single barn uncertainty against its associated annual emissions. This plot was then fit with a curve to model annual percent uncertainty for a single source (i.e., barn, lagoon, basin). For all uncertainty models, the curve took the form of:

$$Uncertainty\ (\%) = \frac{k}{Annual\ Emissions} \qquad \text{Equation 20}$$

Where:

k is a constant, listed in Table 7-2, and
Annual Emissions are the total sum from the daily models.

EPA has not calculated particulate matter annual uncertainty models for the mechanically ventilated barns in order to allow more time to optimize the models. EPA will include the annual uncertainty models in the final report.

Multiplying this percentage by the annual emissions calculated for the source provides the resulting uncertainty in the native emission units (e.g., kg or g), demonstrated in Equation 21.

$$Resulting\ Uncertainty = \frac{Percent\ uncertainty\ \times Annual\ emissions}{100} \qquad \text{Equation 21}$$

To propagate the uncertainty across all sources at a farm, EPA combined the estimates of absolute uncertainty for each source according to:

$$Total\ farm\ uncertainty = \sqrt{(U_{B1})^2 + \cdots + (U_{Bi})^2 + (U_{L1})^2 + \cdots + (U_{Lj})^2} \qquad \text{Equation 22}$$

Where:

Total farm uncertainty = total uncertainty for the total emissions from all farm sources.
UBi = the resulting uncertainty for barns, with i representing the total number of barns on the farm,
ULj = the resulting uncertainty for manure sheds, with j representing the total number of open sources on the farm.

EPA notes that the uncertainty framework described above reflects the random uncertainty (error) in the prediction of daily emissions calculated using the emission models, which includes the random uncertainty in the measurements used to develop the equation. This framework does not, however, consider systematic error (e.g., bias) in either NAEMS measurements or the emission model. Section 8 provides an example of how the daily, annual, and annual uncertainty calculations are completed.

8 MODEL APPLICATION AND ADDITIONAL TESTING

Key to the development of any model is the demonstration of the use and practical examples of how the model behaves and replicates independent data. This section provides a series of example calculations to demonstrate the application of the models (Section 8.1), the sensitivity of the models to their inputs (Section 8.2), a comparison of the models developed to literature (section 8.3), and a test of model performance against an independent data set (Section 8.4). Finally, this section wraps up with a discussion of data limitations that could be driving sensitivity or performance issues.

8.1 Model Application Example

The following sections demonstrate how the daily emission models from Section 5 and the annual uncertainty from Section 7 are used to calculate emissions for an example farm for each structure type. Details about the use of the emission models to demonstrate compliance with Clean Air Act (CAA) permitting thresholds will be addressed in a forthcoming implementation document. This example is provided to walk through a calculation to demonstrate how the system of equations is intended to work.

In Section 6.4 of the main report, the data were log-transformed prior to developing the models, the results of the models will need to be back-transformed per Equation 7 to represent emissions in units of grams or kilograms.

$$Y_{bp} = e^{\widehat{(y_p)}} * \overline{E_\iota} - C$$

Where:

Y_{bp} is the back transformed predicted emissions;
y_p is the model predicted (log transformed) emissions;
$\overline{E_i}$ is the average residual between model-predicted and observed (or measured) emissions on the natural log scale; and
C is a constant added to the data prior to the log transformation.

To complete the back transformation, users need two parameters that are specific to each model: 1) $\overline{E_\iota}$, the residual between model-predicted and observed (or measured) emissions on the natural log scale; and 2) C, which is a constant added to the data prior to the log transformation. The values for $\overline{E_\iota}$ and C for the dairy models are provided in Table 7-1.

Once the emission models are finalized, EPA will work with stakeholders to develop a tool to facilitate the calculation of barn and open source emissions. For transparency and to help stakeholders better understand the process of calculating emissions, this section will walk through example calculations to estimate NH_3 emissions from a mechanically ventilated barn, milking center, naturally ventilated barn, and lagoon.

The examples in this section use a fictional farm located in Brown County, Wisconsin on January 1, 2021. Wisconsin was chosen as it is a top five milk producing state according to the USDA Economic Research Service data (https://www.ers.usda.gov/webdocs/DataFiles/48685/milkcowsandprod.xlsx?v=9708). The ambient weather data used in each equation can be obtained for free from several sources including the National Centers for Environmental Information (NCEI; https://www.ncdc.noaa.gov/cdo-web/). NCEI stores hourly and daily ambient data from various monitors located across the country that can be used for emission estimation. The Green Bay International Airport, WI site (WBAN: 14898), a Local Climatological Data (LCD) Station located in Brown County was selected as to represent the meteorological information for a theoretical farm for testing. Its data file provides the daily average values of the key meteorological parameters needed for calculations.

The naturally ventilated barn and corral models presented in this report use wind speed in the model calculations. The height at which wind speed is measured influences the observation as friction with the surface will affect the observation. That means, the closer to the ground the measurement is made, the more friction will act to slow the speed. NAEMS winds were monitored at a height of approximately 2.5 meters at open sources and site specific heights at barn sources, while the National Weather Service (NWS) sites archived at NCEI are typically monitored at 10m. Therefore, the difference in measurement heights between NAEMS and NWS requires an adjustment to the wind. The relationship between wind speed and height is well established and can be written as:

$$\frac{V}{V_r} = \left(\frac{Z}{Z_r}\right)^m \qquad \text{Equation 23}$$

Where V_r is the wind velocity at a height of 10 m (Z_r) and V is the wind velocity height at 2.5 m (Z), and m is the friction coefficient, which is a function of atmospheric stability and the underlying surface roughness. The value of m can vary, ranging from 0 to 1, with lower values over low roughness surfaces (water) and higher values for rougher terrain (e.g., rolling terrain or urban settings) (Arya, 1999). To adjust the 10m NWS wind measurement to a height comparable to the study data used to develop the model, the equation can be rewritten, resulting in

$$V_{2.5m} = \left(\frac{2.5}{10}\right)^m \times V_{10m} \qquad \text{Equation 23}$$

EPA is determining the best value of m to use for corrals and naturally ventilated barns. For the purposes of the example calculations, we will use the average daily wind speed from the NWS site.

In addition to weather information, the models also use the number of cows present in the barn. For this fictitious farm, we assume the barn has a capacity of 500 cows. The equations use thousands of cows, so this value will be divided by 1,000 for use in the emission models. A summary of the input values for the example calculations is provided in Table 8-1.

Table 8-1. Daily calculation parameter values

Parameter	Value
Daily Average Ambient Temperature (°C)	-9.4
Daily Average Relative Humidity (%)	86
Average Wind Speed (ms^{-1})	2.55
Inventory (thousand head)	0.50

8.1.1 Mechanically Ventilated Barn Example

For this example, we will assume the barn uses a scrape manure management system, which would use Equation 1, in Section 5.1, to calculate the log transformed values as follows:

$$ln(NH_3) = 1.86494 + 1.773832 * Inventory + 0.029586 * Amb_T$$

$$\ln(NH_3) = 1.86494 + 0.1.773832 * \left(\frac{500}{1{,}000}\right) + 0.029586 * -9.4$$

$$\ln(NH_3) = 1.86494 + 0.8869 - 0.2781$$

$$\ln(NH_3) = 2.4737$$

To back transform the results to NH_3 in kg, use Equation 7, from the main report. For a flush managed mechanically ventilated barn, $\overline{E_\iota}$ is 1.03966 and C is 3.

$$NH_3 = e^{2.4731} \times 1.03966 - 3$$

This comes to 9.34 kg NH_3 for the day. This process is repeated for each day, then the daily emissions are added together to get an annual estimate of emissions. After considering the values for each day in 2021, the total annual emission for the barn was calculated at 7,108 kg. To calculate the uncertainty associated with this estimate, use Equation 17 with the value of k from Table 7-1. This results in an annual uncertainty of:

$$Uncertainty\ (\%) = \frac{35{,}180}{7{,}108.31} = 4.95\%$$

This translates to an uncertainty of ± 351kg. Thus, the final annual estimate for this barn is 7,108kg ± 352 kg. This calculation would be repeated for any other mechanically ventilated barn on the site.

8.1.2 Milking Center Example

For this example, we will use Equation 5, in Section 5.2, to calculate the log transformed values as follows:

$$ln(NH_3) \; = \; 2.505637 + 0.046434 * Amb_T$$

$$\ln(NH_3) = \; 2.505637 + 0.04643 * -9.4$$

$$\ln(NH_3) = \; 2.505637 - 0.4368$$

$$\ln(NH_3) = \; 2.0692$$

To back transform the results to NH_3 in kg, use Equation 7, from the main report. For a milking center, $\overline{E_\iota}$ is 1.03966 and C is 3.

$$NH_3(\frac{\text{kg}}{\text{d} \cdot 1{,}000 \text{ head}}) = \; e^{2.0692} \times 1.2169 - 3$$

$$NH_3(\frac{\text{kg}}{\text{d} \cdot 1{,}000 \text{ head}}) = \; 6.64$$

This comes to 6.64 kg NH_3/d-1,000 head, which we can multiply by the 0.5 thousand head to get 3.32 kg NH_3 for the day. This process is repeated for each day, then the daily emissions are added together to get an annual estimate of emissions. After considering the values for each day in 2021, the total annual emissions for the milking center were calculated at 4,161.53 kg. To calculate the uncertainty associated with this estimate, use Equation 17 with the value of k from Table 7-1. This results in an annual uncertainty of:

$$Uncertainty\ (\%) = \; \frac{55{,}494}{4{,}161.53} = 13.33\%$$

This translates to an uncertainty of ± 555 kg. Thus, the final annual estimate for this milking center is 4,161.53 kg ± 554.94 kg.

8.1.3 Naturally Ventilated Barn Example

For this example, we will use Equation 10, in Section 5.3, to calculate the log transformed values as follows:

$$ln(NH_3) = \; 0.188357 + 3.451939 * Inventory + 0.048153 * WindSpeed$$

$$ln(NH_3) = \; 0.188357 + 3.451939 * Inventory + 0.048153 * WindSpeed$$

$$\ln(NH_3) = \; 0.188357 + 3.451939 * \left(\frac{500}{1{,}000}\right) + 0.048153 * 2.55$$

$$\ln(NH_3) = \; 0.188357 + 1.7260 + 0.1228$$

$$\ln(NH_3) = 2.0371$$

To back transform the results to NH_3 in kg, use Equation 7, from the main report. For a naturally ventilated barn, $\overline{E_\iota}$ is 1.03966 and C is 3.

$$NH_3 = e^{2.0371} \times 1.46499 - 3$$

This comes to 8.23 kg NH_3 for the day. This process is repeated for each day, then the daily emissions are added together to get an annual estimate of emissions. After considering the values for each day in 2021, the total annual emissions for the barn were calculated at 3,462.82 kg. To calculate the uncertainty associated with this estimate, use Equation 17 with the value of k from Table 7-1. This results in an annual uncertainty of:

$$Uncertainty\ (\%) = \frac{73{,}495.70}{3{,}462.82} = 21.\%$$

This translates to an uncertainty of ± 734.96 kg. Thus, the final annual estimate for this barn is 6,192.70 kg ± 351.80 kg. This calculation would be repeated for any other naturally ventilated barn on the site.

8.1.4 Lagoon Example

For this example, we will use Equation 15, in Section 5.4, to calculate the log transformed values as follows:

$$ln(NH_3) = 1.396734 + 0.027201 * Amb_T$$

$$ln(NH_3) = 1.396734 + 0.027201 * -9.4$$

$$ln(NH_3) = 1.396734 - 0.2557$$

$$\ln(NH_3) = 1.1410$$

To back transform the results to NH_3 in kg, use Equation 7, from the main report. For a lagoon, $\overline{E_\iota}$ is 1.0079 and C is 3.

$$NH_3 = e^{1.1410} \times 1.0079 - 3$$

This comes to 0.1548g NH_3/d m^2. This is multiplied by the surface area of the lagoon to estimate emissions for the whole lagoon. For this example, we will assume the lagoon is 10,000 m^2, which would result in emissions of 1,547 kg NH_3 for the day.

This process is repeated for each day, then the daily emissions are added together to get an annual estimate of emissions. After considering the values for each day in 2021, the total annual emissions for the lagoon were calculated at 8,961.21 kg. To calculate the uncertainty associated with this estimate, use Equation 17 with the value of k from Table 7-1. This results in an annual uncertainty of:

$$Uncertainty\ (\%) = \frac{4{,}114.1}{8{,}961.21} = 0.46\%$$

This translates to an uncertainty of ± 41.14 kg. Thus, the final annual estimate for this lagoon is 8,961.21 kg ± 41.14 kg. This calculation would be repeated for any other lagoon on the site.

8.1.5 Corral Example

For this example, we will use Equation 17, in Section 5.5, to calculate the log transformed values as follows:

$$ln(NH_3) = 1.053805 + 0.004993 * Amb_T + 0.0031 * Amb_{RH} + 0.017832 * WindSpeed$$

$$n(NH_3) = 1.053805 + 0.004993 * -9.4 + 0.0031 * 86 + 0.017832 * 2.55$$

$$ln(NH_3) = 1.053805 - 0.0469 + 0.266 + 0.0455$$

$$\ln(NH_3) = 1.3189$$

To back transform the results to NH_3 in kg, use Equation 7, from the main report. For a corral, $\overline{E_\iota}$ is 1.0066 and C is 3.

$$NH_3 = e^{1.3189} \times 1.0066 - 3$$

This comes to 0.07641 g NH_3/d m^2 1,000 head. This is multiplied by the surface area of the corral and inventory to estimate emissions for the whole corral. For this example, we will assume the surface area of the corral is 100,000 m^2 and the farm population is 3,400 head, which would result in emissions of 260 kg NH_3 for the day.

This process is repeated for each day, then the daily emissions are added together to get an annual estimate of emissions. After considering the values for each day in 2021, the total annual emissions for the corral were calculated to be 124,562.33 kg. To calculate the uncertainty associated with this estimate, use Equation 17 with the value of k from Table 7-1. This results in an annual uncertainty of:

$$Uncertainty\ (\%) = \frac{1{,}278.5}{124{,}562.33} = 0.01\%$$

This translates to an uncertainty of ± 12.79 kg. Thus, the final annual estimate for this corral is 124,562.33 kg ± 12.79 kg.

8.1.6 Combining Structures

To calculate total farm emissions, the emissions from each unit are added. As an example, consider a farm with a 500 head mechanically ventilated barn, 500 head naturally ventilated barn, milking center with a 500 head capacity at any given time, and 10,000 m^2 lagoon. That is, the same emissions as the examples in sections 8.1.1 through 8.1.4. The annual farm emission estimate from four sources is:

$$Farm\ Total\ Emissions = 7{,}108.31\ + 4{,}161.53 + 6{,}192.70 + 2{,}439.20$$

$$Farm\ Total\ Emissions = 19{,}901.74\ kg\ NH_3$$

To estimate the total farm uncertainty, use Equation 41:

$$Total\ Farm\ Uncertainty = \sqrt{{U_{barn\ 1}}^2 + {U_{barn\ 2}}^2 + {U_{milking\ center}}^2 + {U_{lagoon}}^2}$$

$$Total\ Farm\ Uncertainty = \sqrt{(351.80)^2 + (554.94)^2 + (734.96)^2 + (41.41)^2}$$

$$Total\ Farm\ Uncertainty = 986.71\ \mathrm{kg}$$

The final annual NH_3 estimate for the farm is 19,901.74 ± 986.71 kg. Once the emission models are finalized, EPA will work with stakeholder to develop a tool to facilitate the calculation of barn and open source emissions.

8.2 Model Sensitivity Testing

To further test the models, EPA varied the model parameters to ensure the model results would vary based on these key parameters. Two different tests were conducted: 1) the number of cows was increased while the meteorological parameters were held constant, and 2) inventory was held constant while the meteorological parameters were replaced with the values for a warmer climate.

8.2.1 Sensitivity to Inventory

To test the sensitivity of the confinement sources to inventory, the initial placement was doubled to 1,000 cows. Using the same meteorology from Section 8.1, the emissions for the dairy barns on January 1, 2020, is summarized in Table 8-2. For mechanically ventilated barns and milking centers, doubling the inventory at least doubled the NH_3 emissions for the same meteorological conditions. For naturally ventilated barns, doubling the inventory resulted in a sevenfold increase in NH_3 emissions. The large increase in the naturally ventilated barn emissions is further discussed in Section 8.2.3.3. These same ratios are seen when considering a year's worth of meteorology (Table 8-3).

Table 8-2. Comparison of confinement source NH_3 emissions (kg) on January 1, 2021, for different inventory levels at a theoretical Brown County farm.

Source Type	500 head	1,000 head
Mechanically Ventilated	9.34	26.91
Milking center	3.32	6.62
Naturally ventilated	8.23	62.49

Table 8-3. Comparison of confinement source total 2021 NH_3 emissions (kg) for different inventory levels at a theoretical Brown County farm.

Source Type	500 head	1,000 head
Mechanically Ventilated	7,108	18,820
Milking center	4,162	8,323
Naturally ventilated	3,463	24,511

For lagoons, doubling the surface area of the lagoon doubles both the daily and annual NH_3 emissions (Table 8-4). For corrals, doubling the inventory present doubles both the daily and annual NH_3 emissions (Table 8-5). The observed relationships suggest the models are sensitive to the size parameters, while scaling appropriately.

Table 8-4. Comparison of lagoon NH_3 emissions (kg) for different surface areas for theoretical Brown County farm.

NH_3 Emissions (kg)	10,000 m^2	20,000 m^2
Daily (1/1/2021)	1.51	3.02
Annual (2021)	8,961	17,922

Table 8-5. Comparison of estimated corral NH_3 emissions (kg) for different inventory levels for theoretical Brown County farm.

NH_3 Emissions (kg)	3,400 head	6,800 head
Daily (1/1/2021)	259.48	518.96
Annual (2021)	124,562	249,125

8.2.2 Sensitivity to Climate

To further test model sensitivity, specifically that climate differences were producing different emission results, EPA calculated the emissions for the same farm in two distinctly different climate regions. The first was the theoretical farm in Brown County, Wisconsin from the previous examples (Section 8.1). The NH_3 emission for these same theoretical barns were calculated using meteorological data from Livermore Municipal Airport in Alameda County, California. These locations were chosen based on 2017 Census of agriculture data indicating areas of high dairy inventory (Figure 8-1). USDA Economic Research Service data (available at: https://www.ers.usda.gov/webdocs/DataFiles/48685/milkcowsandprod.xlsx?v=9708) also notes California and Wisconsin are the top two dairy producing states in the country, further affirming the reasonableness of the testing locations.

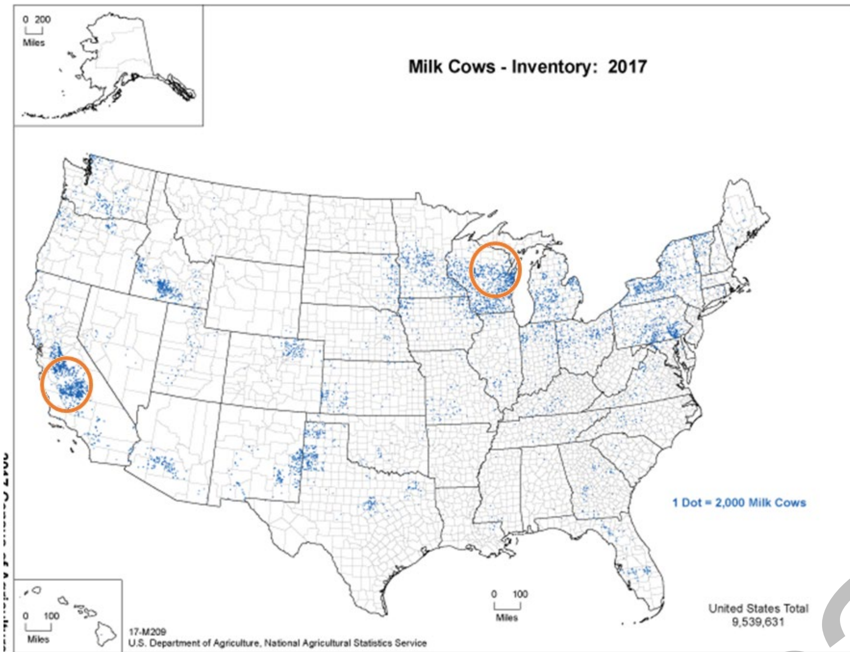


Figure 8-1. 2017 Census of Agriculture plot indicating dairy inventory.
Orange circles indicate approximate locations of test meteorology from Wisconsin (WI) and California (CA). Source: https://www.nass.usda.gov/Publications/AgCensus/2017/Online_Resources/Ag_Atlas_Maps/17-M209g.php

For the test sites, the temperatures from the Wisconsin (WI) site were generally less than the California (CA) site (Figure 8-2). On average, the temperatures in Wisconsin were 7°C less than those in California (Table 8-6), with difference between individual monthly averages varying from 1.6 to 20.8°C lower, except for July when Wisconsin edged 0.6°C higher. With respect to relative humidity, the California and Wisconsin sites experienced a similar range of daily average relative humidities throughout the year (Figure 8-3 and Table 8-7). Wisconsin edged a little higher July through October, leading to an overall average 1.6% higher. Average daily wind speeds (Figure 8-4 and Table 8-7) were generally lower in California, with monthly average barely higher June through August. The following sections provide a summary of the calculations using the California meteorological data compared to the previous examples.

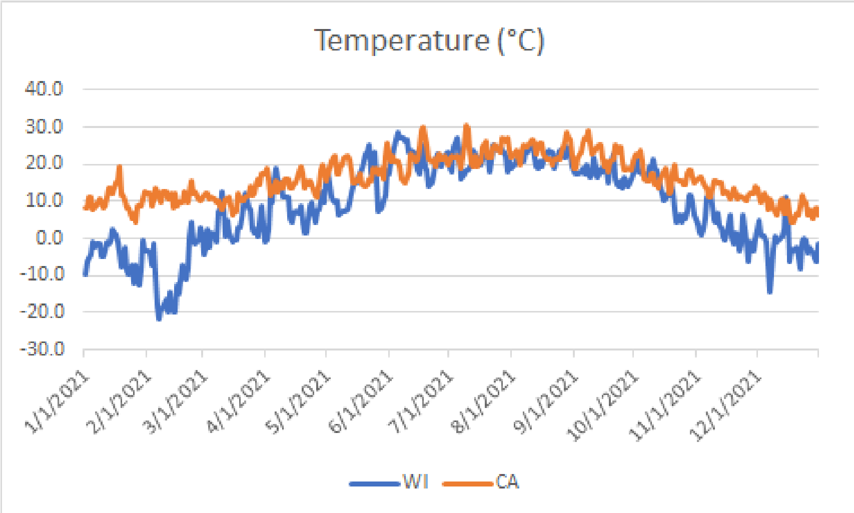


Figure 8-2. Comparison on average daily temperatures at test locations in Wisconsin (WI) and California (CA).

Table 8-6. Summary of average daily temperature at the two meteorological sites.

Site	Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Overall
WI	Min	-12.8	-21.7	-2.8	1.7	6.1	13.9	16.1	17.8	13.3	3.9	-6.1	-14.4	-21.7
	Max	2.2	4.4	12.8	18.9	25.0	28.3	27.2	25.0	22.8	21.7	12.8	11.1	28.3
	Average	-4.8	-9.5	3.4	9.1	14.0	21.9	21.5	21.9	17.3	12.6	2.2	-2.0	9.0
CA	Min	4.4	8.3	6.1	11.1	13.9	15.0	18.9	18.9	17.8	12.2	10.0	0.0	0.0
	Max	19.4	15.6	18.9	20.0	25.6	30.0	30.6	28.3	28.9	23.9	16.7	12.2	30.6
	Average	10.3	11.3	11.5	15.1	18.4	21.3	23.5	23.4	22.4	16.9	13.0	8.0	16.3

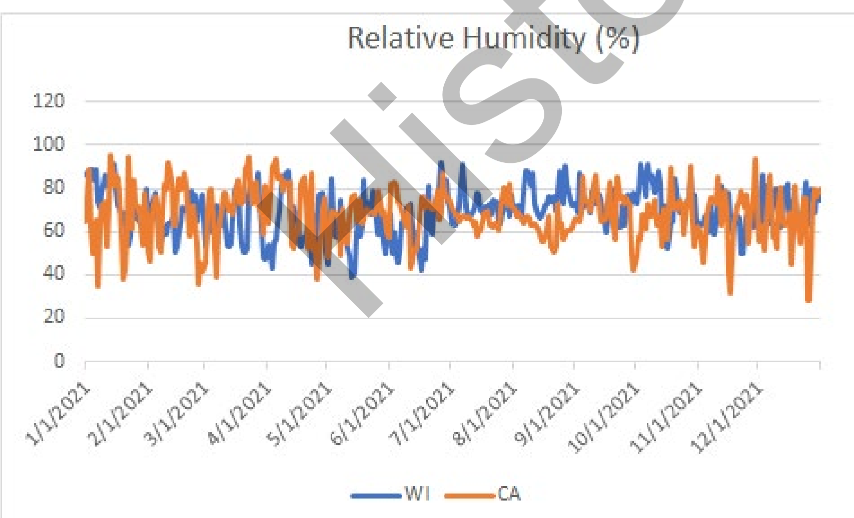


Figure 8-3. Comparison of average daily relative humidities at test locations in Wisconsin (WI) and California (CA).

Table 8-7. Summary of average daily relative humidity at the two meteorological sites.

Site	Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Overall
WI	Min	54.0	51.0	47.0	43.0	39.0	42.0	63.0	66.0	60.0	52.0	50.0	0.0	0.0
	Max	91.0	79.0	87.0	88.0	85.0	92.0	91.0	90.0	87.0	91.0	81.0	86.0	92.0
	Average	75.9	66.4	64.2	63.7	63.1	64.9	72.1	76.1	72.3	75.8	66.5	69.4	69.2
CA	Min	35.0	35.9	39.4	38.6	49.2	42.7	58.1	51.0	42.3	53.0	31.8	28.0	28.0
	Max	95.3	92.0	94.4	93.5	82.0	86.7	82.1	73.0	86.4	90.7	93.9	86.3	95.3
	Average	68.3	66.2	73.0	70.3	67.5	69.9	67.3	62.3	70.3	67.6	67.5	64.6	67.8

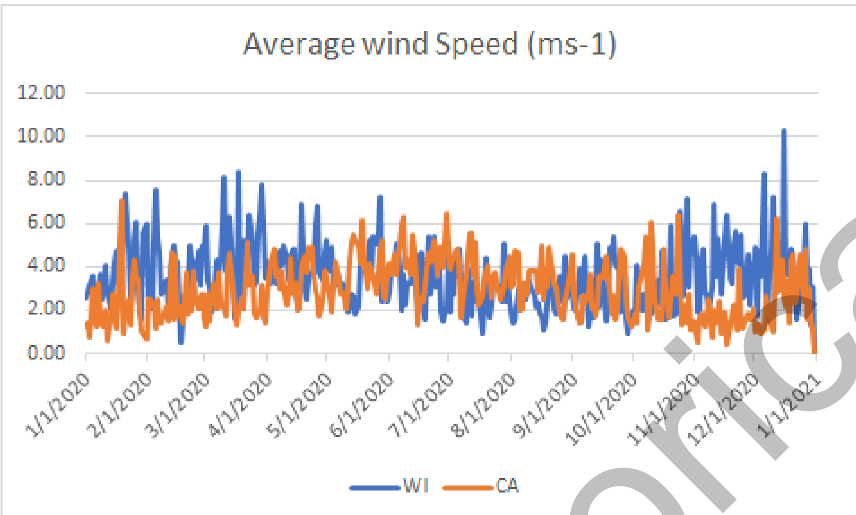


Figure 8-4. Comparison of average daily wind speeds at test locations in Wisconsin (WI) and California (CA).

Table 8-8. Summary of average daily wind speeds at the two meteorological sites.

Site	Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Overall
WI	Min	1.4	0.5	1.5	2.2	1.8	1.5	0.9	1.1	0.9	1.6	1.9	0.0	0.0
	Max	7.4	7.6	8.4	6.9	7.2	5.4	5.1	4.5	5.4	7.2	6.9	10.3	10.3
	Average	3.6	3.8	4.5	4.1	3.6	3.5	2.9	2.5	3.0	3.4	3.9	4.0	3.6
CA	Min	0.6	1.2	1.2	1.7	1.9	1.3	1.7	1.6	1.2	1.1	0.4	0.0	0.0
	Max	7.0	4.6	5.1	4.9	6.2	6.4	5.6	5.0	4.8	6.4	3.9	6.2	7.0
	Average	2.2	2.4	2.6	3.4	3.7	4.2	3.7	3.2	2.6	2.7	1.6	2.5	2.9

8.2.2.1 Mechanically Ventilated Barn

When the daily calculations are performed for the entire year for a mechanically ventilated dairy barn with 500 cows, the California site typically has higher daily emissions for both NH_3 and H_2S and for either manure management system than the Wisconsin site (Figure 8-5). Table 8-9 contains the estimated annual emissions for the different combinations of pollutant and manure management system. For the mechanically ventilated scrape barn from the example in Section 8.1.1, the total annual NH_3 emissions estimate for the farm using meteorological data from California was 8,689 kg— a 1,581 kg increase from the same mechanically ventilated barn with meteorological data from Wisconsin. A similar trend is seen across the other pollutant and manure management system combinations. This is consistent with the trend of lower temperatures yielding lower emissions seen during the data exploration in Section 4. Overall, this suggests that the emission models can account for regional temperature differences in the results for mechanically ventilated barns.

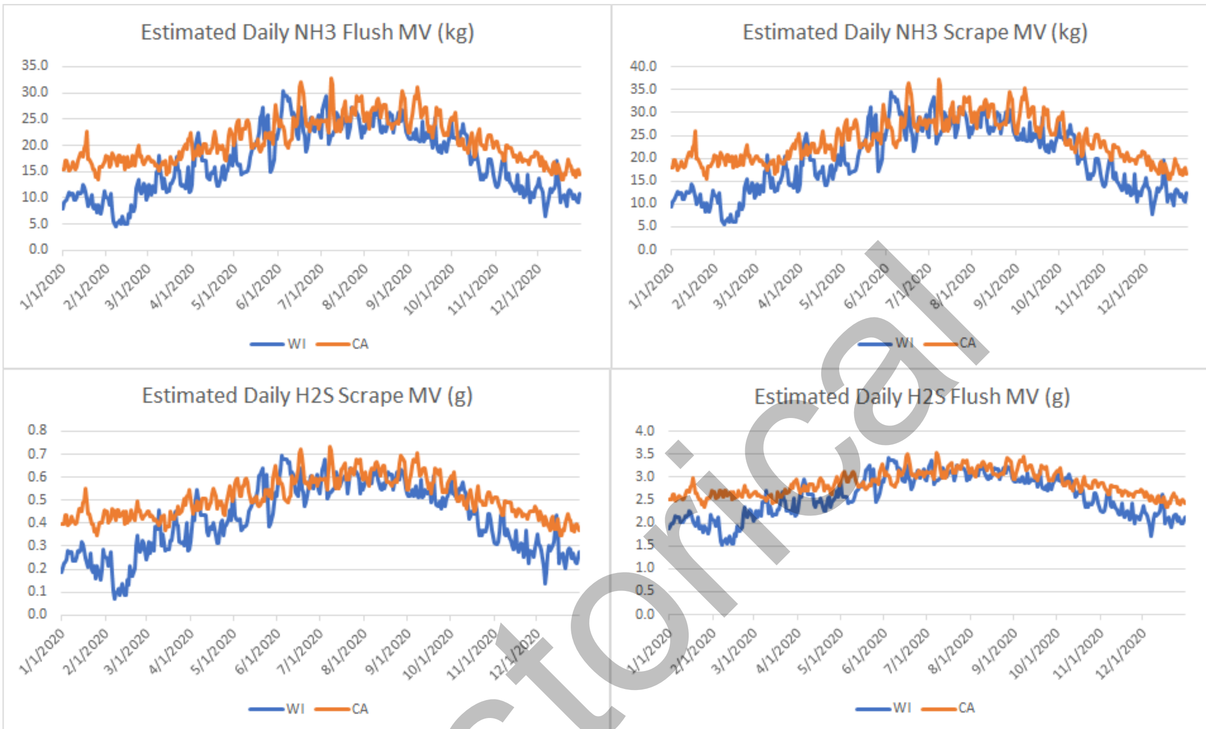


Figure 8-5. Comparison of daily mechanically ventilated barn emission at test dairy in locations WI and CA.

Table 8-9. Total annual emission from a theoretical mechanically ventilated barn in WI and CA.

Pollutant	WI Emissions (kg per year)	CA Emissions (kg per year)
H2S - Flush	152	186
H_2S - Scrape	940	1,044
NH3 - Flush	6,193	7,597
NH3 - Scrape	7,108	8,689

8.2.2.2 Milking Center

Repeating the daily calculations for a 500 head capacity milking center using the California meteorological data show the warmer site typically has greater daily emissions for all pollutants (Figure 8-6). Table 8-10 has the estimated annual emissions of each pollutant studied. For the milking center from the example in Section 8.1.2, the total estimated annual NH_3 emissions increase by 1,317 kg by using California meteorological data. A similar trend is seen across the other pollutants, with increases ranging from 38% to 152%. This is consistent with the trend of lower temperatures yielding lower emissions seen during the data exploration in Section 4. Overall, this suggests that the emission models can account for regional temperature differences in the results for milking centers.

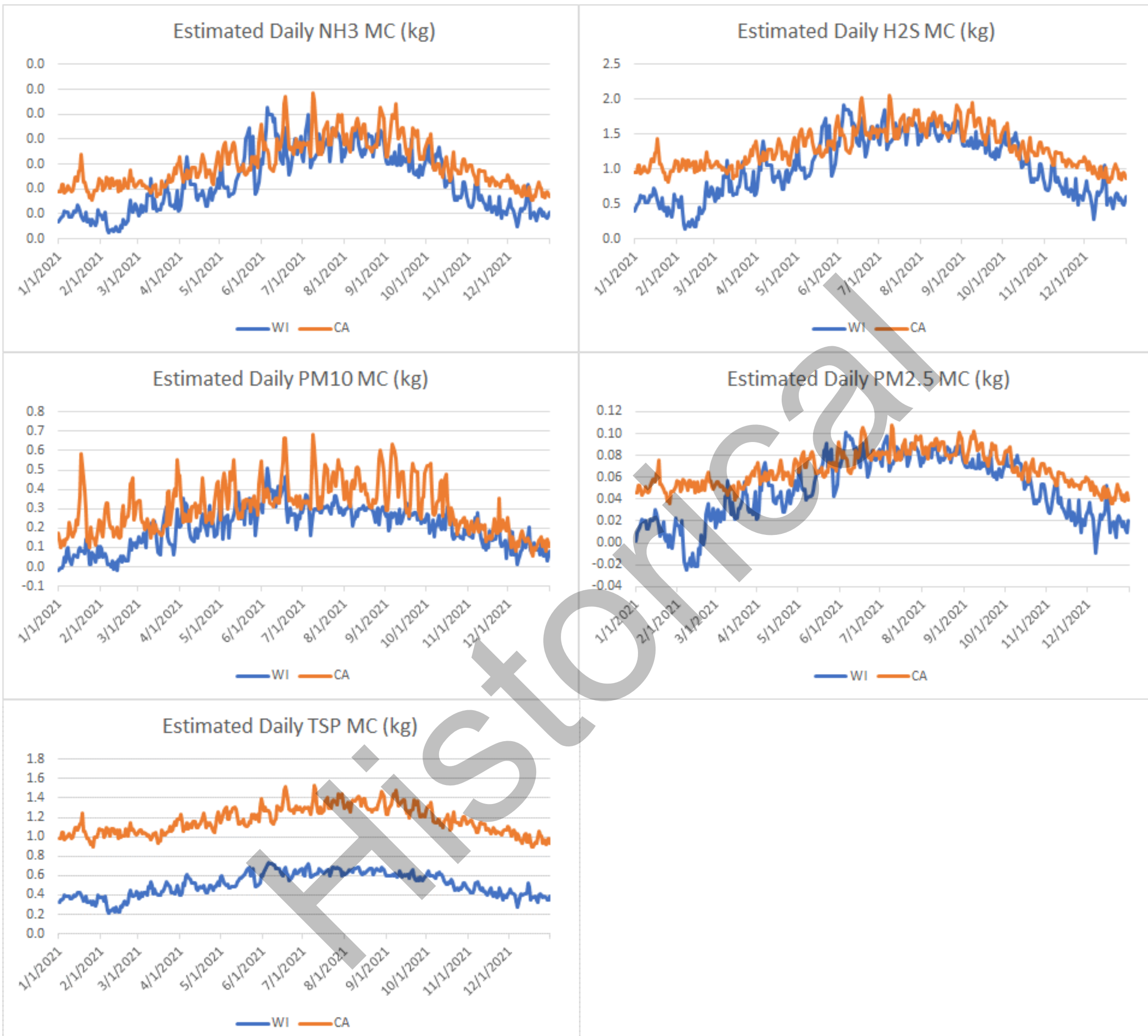


Figure 8-6. Comparison of daily milking center emission at test dairy locations in WI and CA.

Table 8-10. Total annual emission from a theoretical milking center in WI and CA.

Pollutant	WI Emissions (kg per year)	CA Emissions (kg per year)
NH_3	4,162	5,479
H_2S	189	474
PM_{10}	74	112
$PM_{2.5}$	18	24
TSP	185	427

8.2.2.3 Naturally Ventilated Barn

A naturally ventilated dairy barn with 500 cows in California typically has lower daily emissions than the same barn in Wisconsin (Figure 8-7) for gaseous pollutants and $PM_{2.5}$. Table 8-11 has the estimated annual emissions of the pollutants studied. The differences in the annual gaseous pollutants are minor, as the models are based on average daily wind speed which is only slightly different between the sites. Table 8-11 shows a larger difference with the $PM_{2.5}$ annual emissions, and the plot shows several large spikes when using the Wisconsin meteorological data. Looking into the data, these data points are associated with days with high average daily wind speeds and suggests some limitation in the model performance for these instances. This is discussed further in Section 8.2.3.3. For PM_{10} and TSP, the spikes in emissions are generally due to higher wind speeds combined with lower relative humidities to mitigate the emission. These relationships are explored more in section 8.2.3.3.

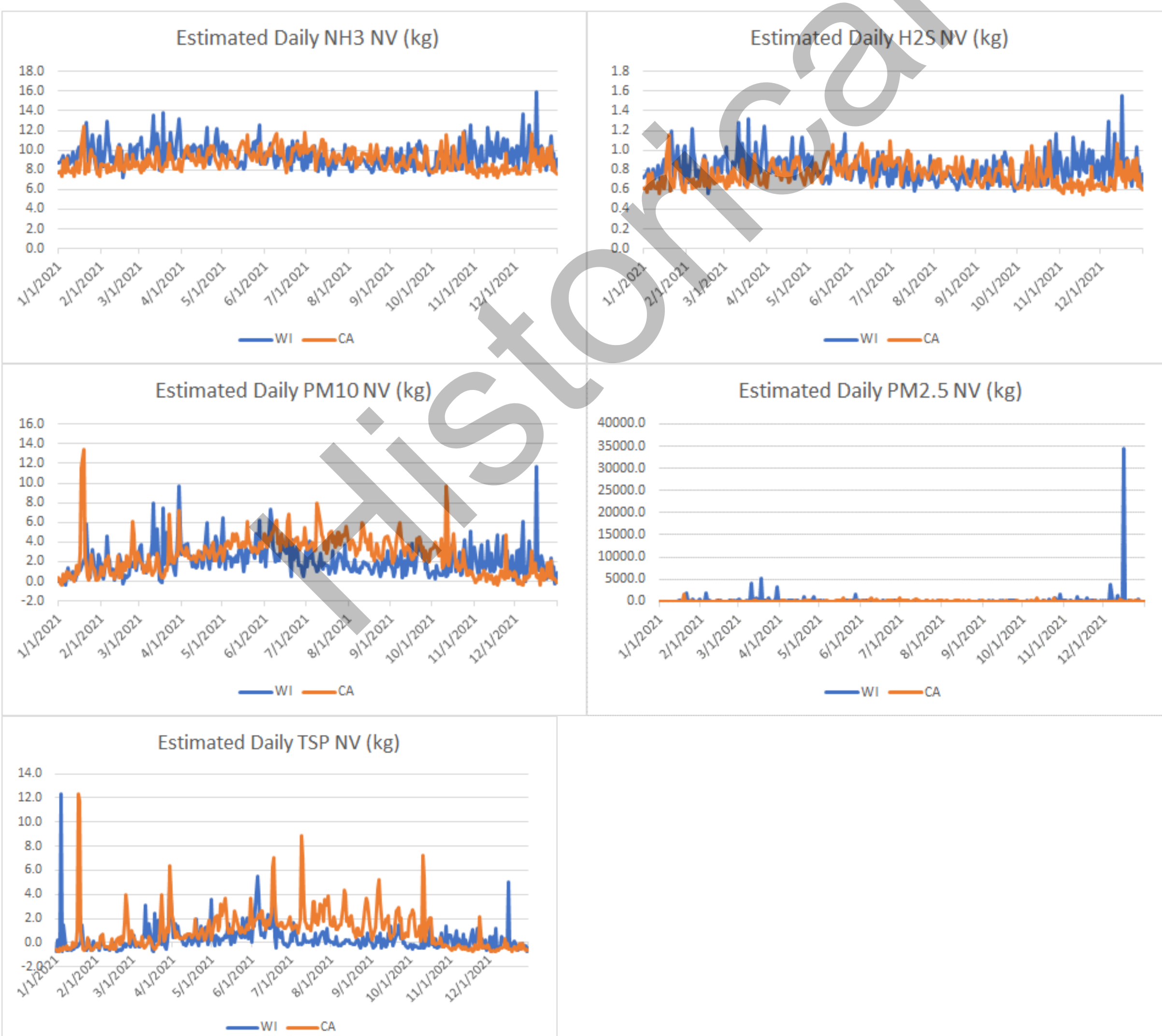


Figure 8-7. Comparison of daily naturally ventilated barn emission at test dairy locations in WI and CA.

Table 8-11. Total annual emission from a theoretical milking center in WI and CA.

Pollutant	WI Emissions (kg per year)	CA Emissions (kg per year)
NH_3	3,463	3,274
H_2S	297	275
PM_{10}	777	962
$PM_{2.5}$	89,168	23,113
TSP	112	369

8.2.2.4 Lagoon

Repeating the daily calculations for the dairy lagoon using the California meteorological data typically has higher daily emission values than when using the Wisconsin meteorological data (Figure 8-8). Table 8-12 has the estimated annual emissions of each pollutant studied and shows a roughly 40% increase for both pollutants using the warmer temperatures from California. This is consistent with the trend of warmer temperatures yielding greater emissions seen during the data exploration in Section 4 and noted in the literature review in Section 3. Overall, this suggests that the emission models are capable of accounting for the different growing regions in the lagoon results.

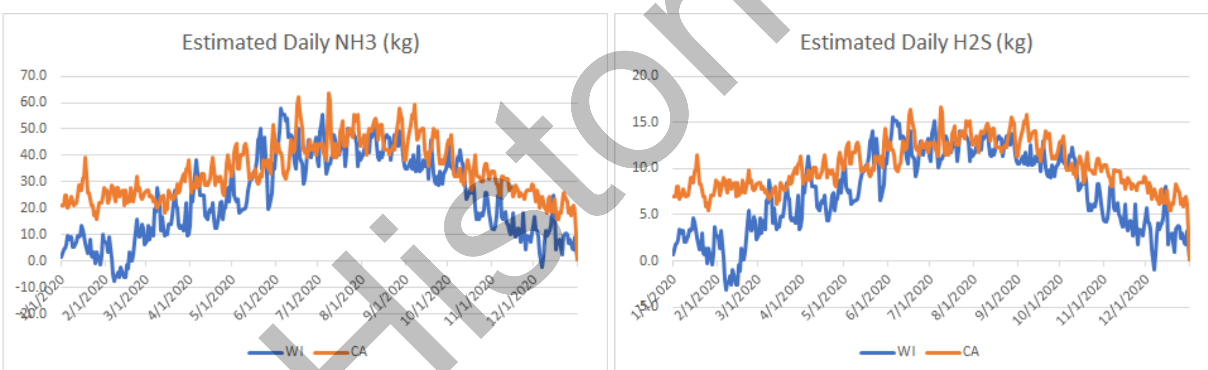


Figure 8-8. Comparison of daily lagoon emission at test dairy locations in WI and CA.

Table 8-12. Total annual emission from a theoretical lagoon in WI and CA.

Pollutant	WI Emission (kg per year)	CA Emission (kg per year)
NH_3	8,961	12,525
H_2S	2,734.2	3,748.8

8.2.2.5 Corral

The emission estimates for a corral using the meteorological data from California, are slightly lower than calculations with the Wisconsin meteorological data (Figure 8-9). Table 8-13 has the estimated annual emissions of each pollutant and shows the total annual NH_3 emissions estimate for the theoretical California corral was 124,261 kg, which is a 302 kg decrease from the same theoretical corral in Wisconsin. The H_2S model only shows a minor difference between the emissions for the two climates. This generally limited sensitivity is discussed more in Section 8.2.3.5.

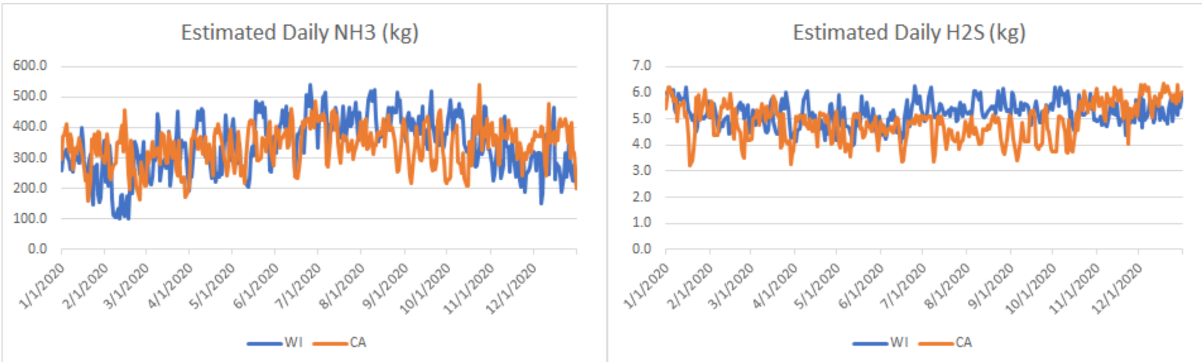


Figure 8-9. Comparison of daily milking center emission at test dairy locations in WI and CA.

Table 8-13. Total annual emission from a theoretical milking center in WI and CA.

Pollutant	WI Emission (kg per year)	CA Emission (kg per year)
NH_3	124,562	124,261
H_2S	1,902.7	1,789.7

8.2.3 Model Limitations

As noted in the 2013 SAB review (US EPA SAB, 2013), extrapolating to conditions beyond those represented in the model development dataset could produce unrealistic results. To test the limitations of the model, EPA conducted a series of emission calculations over a range of conditions that could be seen at a farm in the US. These emission calculations tested one parameter at a time, with the selected parameter varied by a constant value through the range. For example, ambient temperature was increased by 1°C from the minimum value in the model development dataset up to the maximum value. While one parameter was tested, the remaining parameters were held constant at the average value seen in the model development dataset. The resulting emission values were reviewed and plotted to determine if the model resulted in unrealistic emission values, such as negative emissions or rapid increases in emission rates.

The dairy equations included some combination of inventory, ambient temperature, ambient relative humidity, and wind speed. The ranges of ambient parameters are based on the NAEMS dataset. The number of cows in a single barn or milking center are based on barn capacity numbers provided by consent agreement participants. The range values tested for each parameter are in Table 8-14.Table 8-14

This analysis does not account for interaction between multiple terms within an equation, which could further affect the results. For example, a dairy barn with higher ambient temperatures would be able to cover a larger range of inventory per barn before producing negative NH_3 emissions. Conversely, a barn with lower ambient temperatures would cover a smaller range of inventory before producing negative NH_3 emission values. However, the analysis does provide a general range where the model produces reasonable results.

To further explore any limitations in the models, emissions were calculated for all combinations across the range of values specified in Table 8-14. A list of all the combinations of the three inputs was created using the R statistical software. R was then used to calculate the emissions using the method shown in section 8.1. The results were then filtered down to only the results that produced negative values to generate the plots for each pollutant. The following sections outline the analysis for each of the selected models.

Table 8-8-14. Parameter ranges tested for the dairy models.

Parameter	Upper limit	Lower limit	Average Value	Increment
Ambient temperature (°C)	32.0	-23	10.0	0.8
Ambient relative humidity (%)	93	24	68.1	1
Wind speed (ms^{-1})	11.2	0.00	2.3	0.15
Inventory (head)	5,000	0	1,000	70

8.2.3.1 Mechanically Ventilated Barn

The initial analysis for mechanically ventilated barns is presented in Figure 8-10 and Figure 8-11. Neither the H_2S (Figure 8-10) nor NH_3 (Figure 8-11) models produce negative emissions under average conditions. Additional analysis of the 5,110 combinations of conditions tested produced negative values. The models also produce a rapid increase in emissions when estimating barns with inventories greater than 2,000 head. The largest barn in the NAEMS had an average daily population of 833, which would account for the unrealistic behavior with extreme inventory numbers. Based on the consent agreement participant data, more than 90% of the participating barns fall below a capacity of 2,000 head. This suggests the model would still be appropriate for the bulk of the participants. EPA will explore models that predict emissions normalized by inventory, as these models will produce a linear relationship between inventory and emissions (with other factors constant), regardless of the size of the operation.

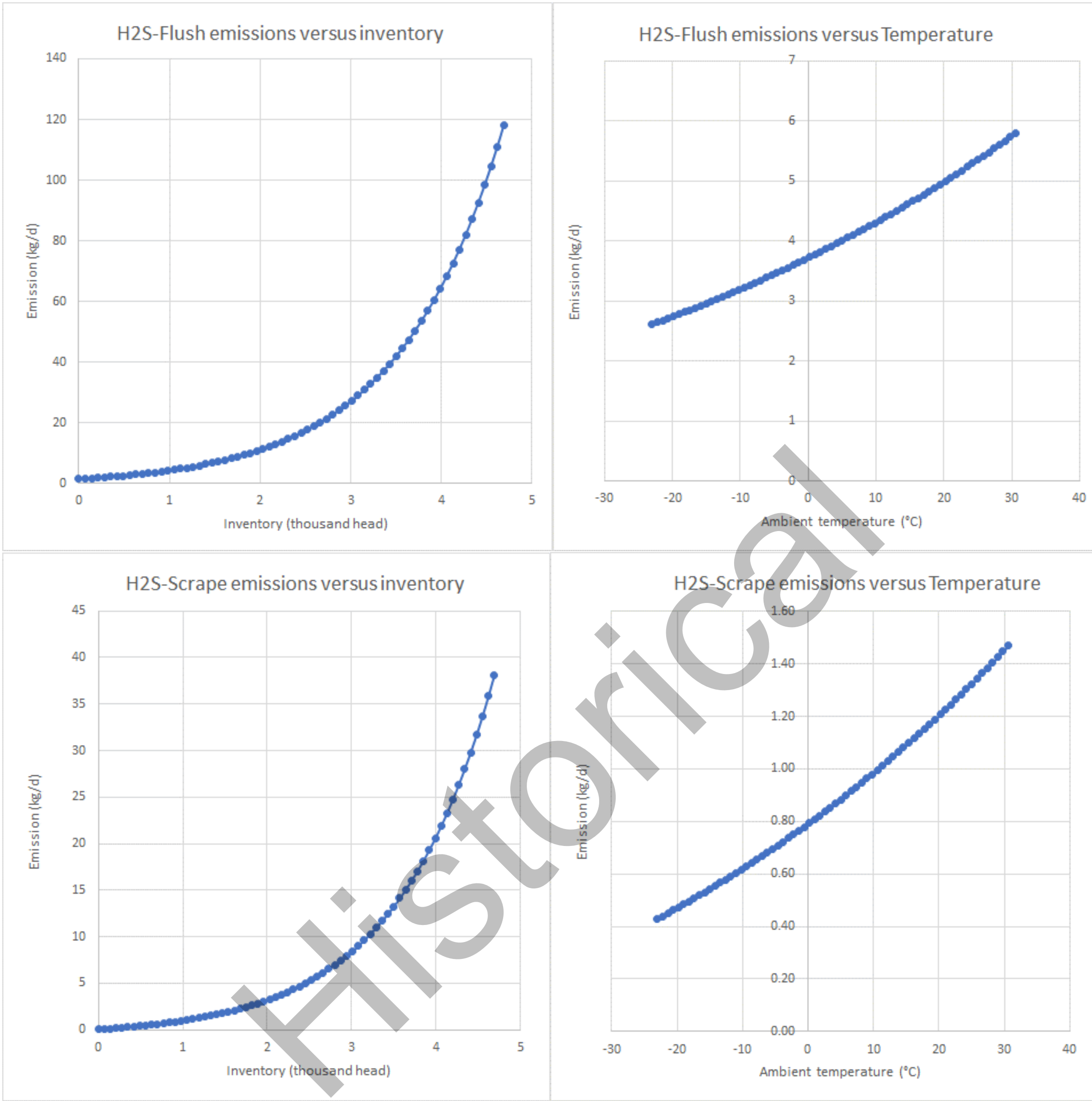


Figure 8-10. Mechanically ventilated barn limitation tests for H_2S.
Visualization of the results for H_2S – Flush (top row) and H_2S – Scrape (bottom row) tests of inventory (left) and ambient temperature (right).

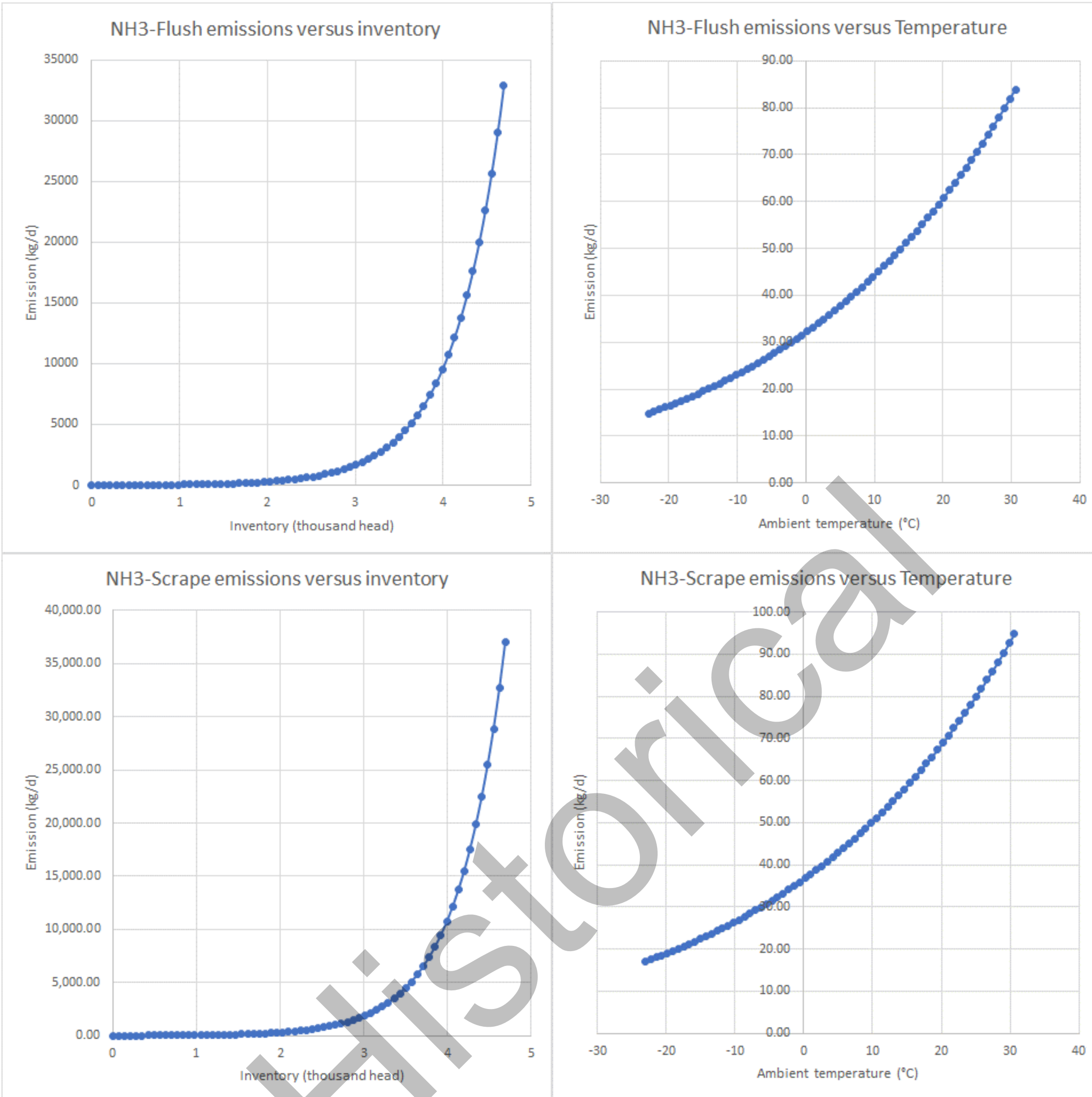


Figure 8-11. Mechanically ventilated barn limitation tests for NH_3.
Visualization of the results for NH_3 – Flush (top row) and NH_3 – Scrape (bottom row) tests of inventory (left) and ambient temperature (right).

8.2.3.2 Milking Center

The milking centers analysis for gaseous pollutants is presented in Figure 8-12 and particulate matter is presented in Figure 8-13. Neither the H_2S nor NH_3 (Figure 8-12) models produce negative emissions under average conditions. The relationship of emissions to increasing temperature is fairly linear through the expected conditions and does not display any extreme behavior that would suggest extrapolation issues.

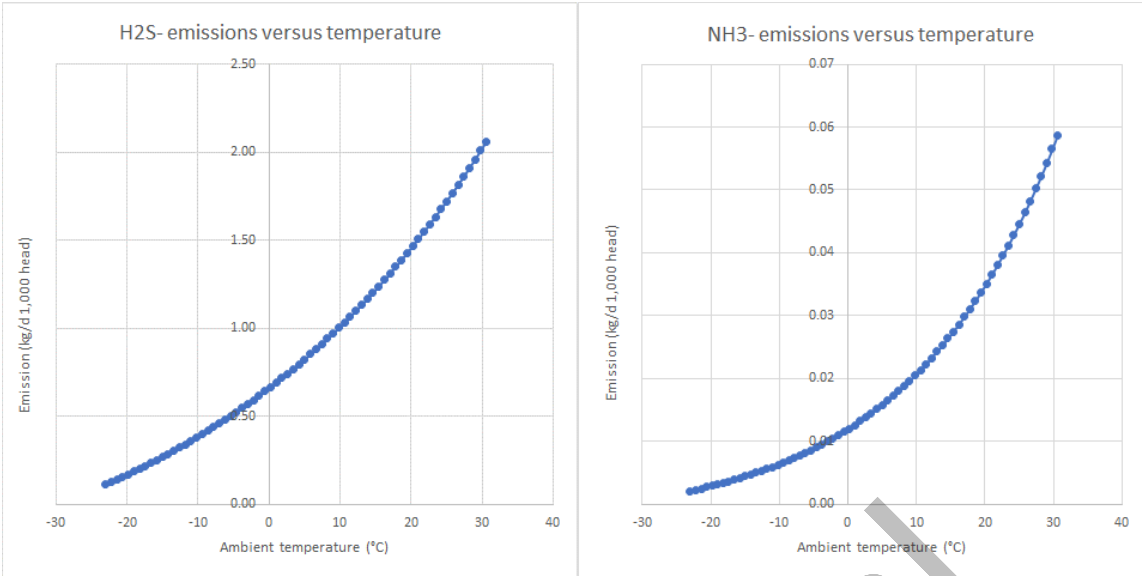


Figure 8-12. Milking center limitation tests for gaseous pollutants.
Visualization of the results for H_2S (left) and NH_3 (right) tests of ambient temperature.

The PM_{10} and $PM_{2.5}$ models (Figure 8-13) do produce negative emission values less than -11°C and -18.2°C for PM_{10} and $PM_{2.5}$ models, respectively, at average relative humidity levels. Additional analysis of 5,390 combinations of temperature and relative humidity values shows the PM_{10} model (Figure 8-14) will produce negative emission estimates when temperatures fall below zero in an increasingly drier environment. That is, the lower the temperature, the lower the relative humidity needed to produce a negative emissions value. For example, the equation for PM_{10} will produce negative emissions at any level of relative humidity when ambient temperature falls just below zero. Similarly, at -21.4°C, the equation can produce negative number when relative humidity is less than or equal to ~60%.

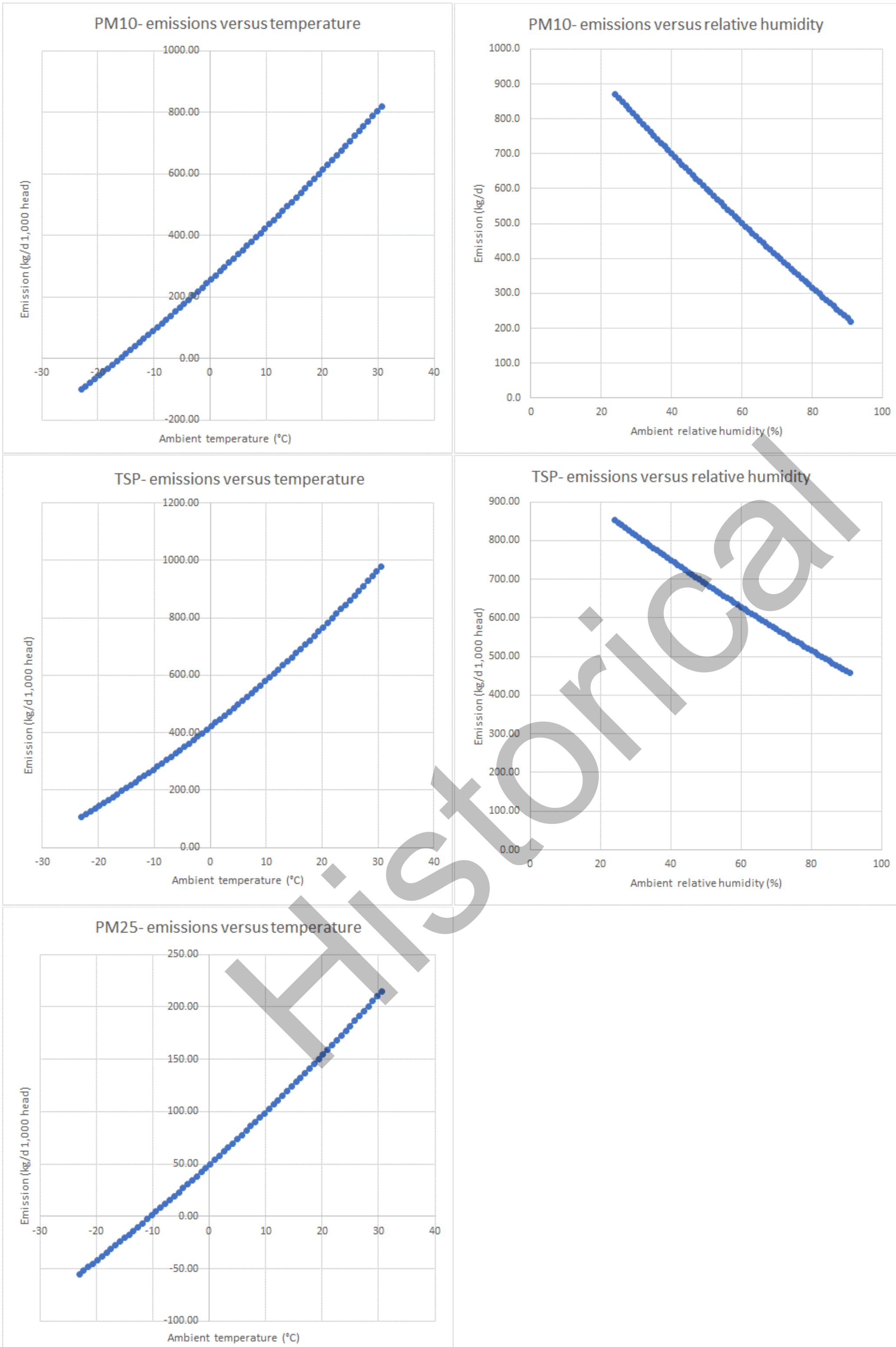


Figure 8-13. Milking center limitation tests for particulate matter.
Visualization of the results for PM10 (top row), TSP (center row), and $PM_{2.5}$ (bottom row) tests of ambient temperature (left) and ambient relative humidity(right).

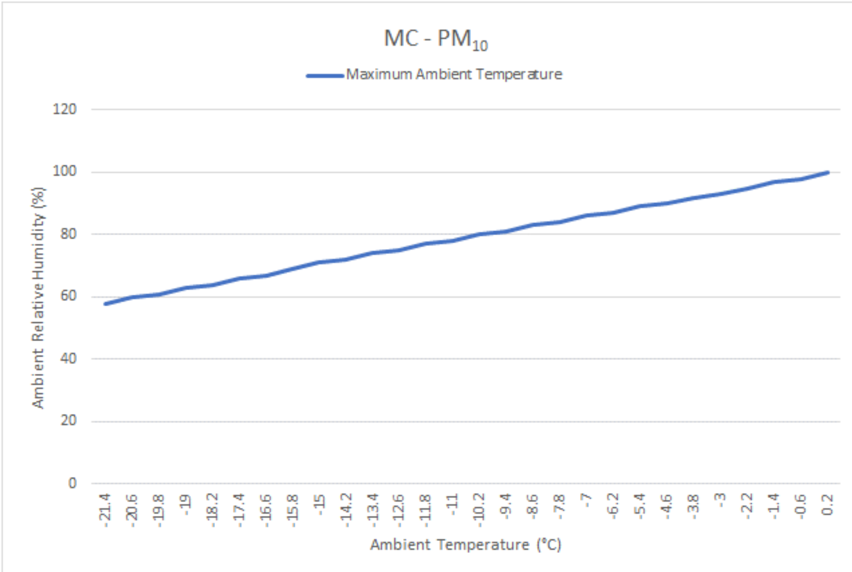


Figure 8-14. Maximum values of relative humidity for each temperature at which the PM10 equation yields negative emissions.

8.2.3.3 Naturally Ventilated Barn

The naturally ventilated barn analysis for gaseous pollutants is presented in Figure 8-15. Analysis for PM_{10}, $PM_{2.5}$, and TSP are presented in Figure 8-17, Figure 8-19, and Figure 8-18, respectively, and particulate matter is presented in Figure 8-13. The H_2S (Figure 8-12) model does not produce negative emissions under average conditions with varying inventory. The NH_3 model will produce negative emission for very small inventories (i.e., less than 70 head) under average conditions. Further testing of 5,548 combinations of wind speed and inventory show at very low wind speeds (< 1 ms^{-1}), an inventory as large as 140 cows will produce negative emissions. As wind speed increases, the corresponding inventory needed to produce a negative number also decreases. These thresholds are demonstrated in Figure 8-16. The sensitivity analysis testing shows rapid increases in NH_3 and H_2S emissions at high inventories. EPA will explore models that predict emissions normalized by inventory, as these models will produce a linear relationship between inventory and emissions (with other factors constant), regardless of the size of the operation.

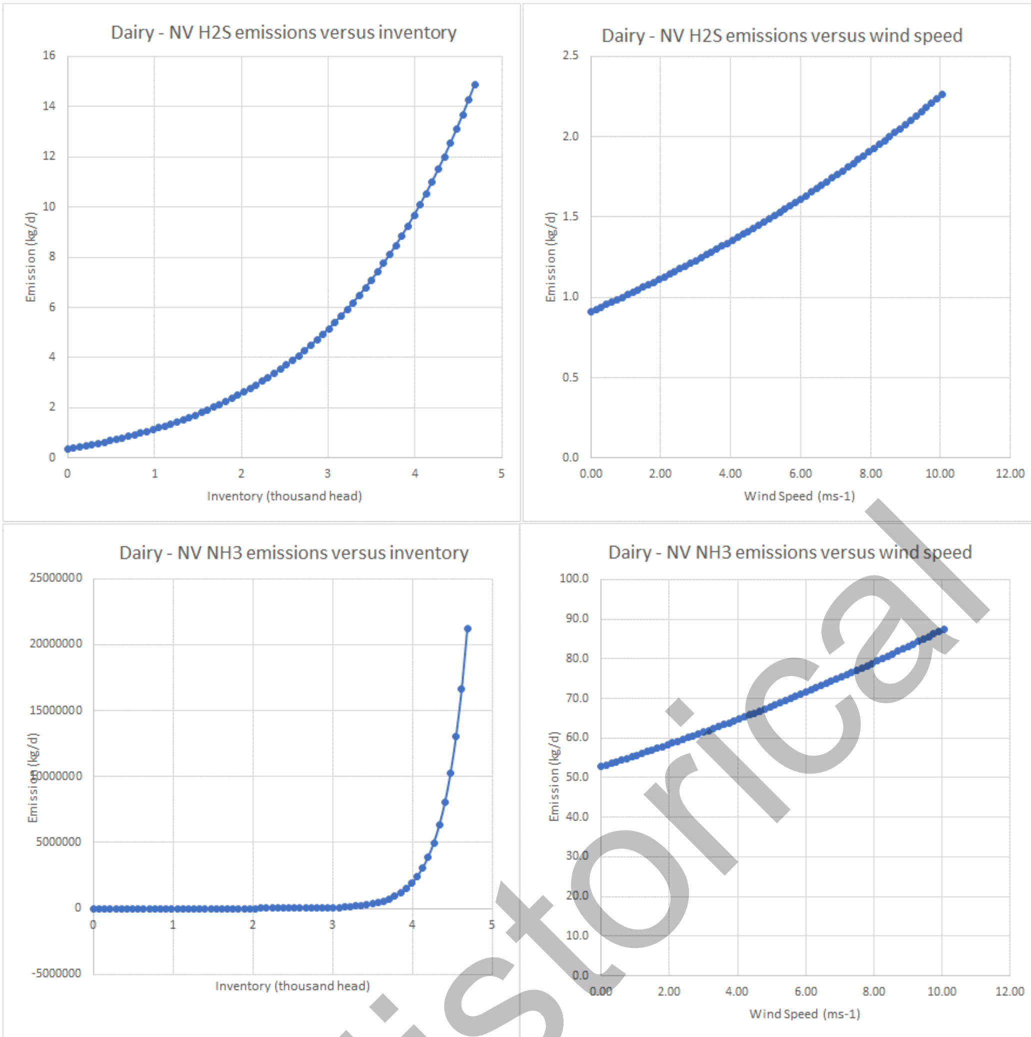


Figure 8-15. Naturally ventilated barn limitation tests for gaseous pollutants.
Visualization of the results for H_2S (top row) and NH_3 (bottom row) tests of inventory (left) and wind speed (right).

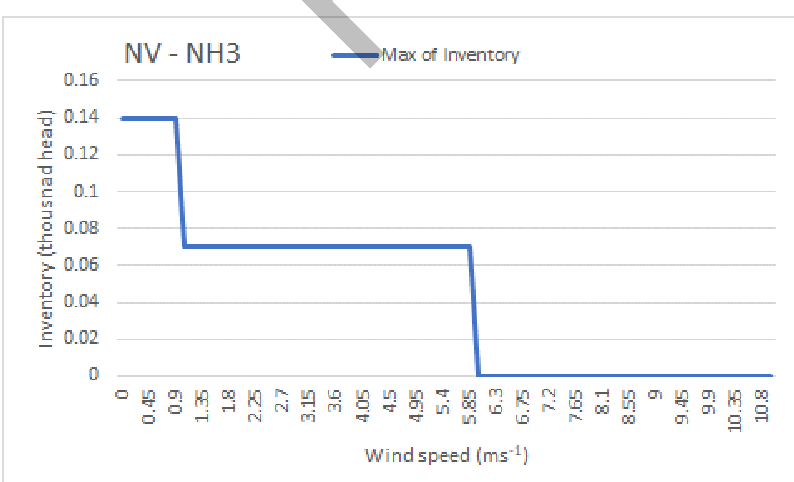


Figure 8-16. Maximum values of inventory for each wind speed at which the NH_3 equation yields negative emissions.

Though it is hard to see on the figures, the PM_{10} and TSP models (Figure 8-17, and Figure 8-18) produce negative values under average conditions for very small inventory levels. Further analysis of 29,903,720 combinations of inventory, ambient temperature, ambient relative humidity, and wind speed show that the models will produce negative values for progressively lower temperatures and winds speeds for increasing temperatures (Figure 8-20). For example, with the PM_{10} model (top graph, Figure 8-20) for an empty barn, the model will produce a negative emission value for temperatures less than 32°C and wind speed less than 9 ms^{-1}. As inventory increases to 1,050 head, negative emissions only occur at temperatures below -30°C and wind speeds less than 1 ms^{-1}. The sensitivity analysis testing shows rapid increases in PM_{10} and TSP emissions at high inventories. EPA will explore models that predict emissions normalized by inventory, as these models will produce a linear relationship between inventory and emissions (with other factors constant), regardless of the size of the operation.

The $PM_{2.5}$ model (Figure 8-19) did not produce negative values under average conditions. However, looking across the combinations of inventory, ambient temperature, ambient relative humidity, and wind speed, the $PM_{2.5}$ model produces negative emission estimates at low wind speeds and temperatures combined with low inventory levels (Figure 8-20). As inventory levels increase, the negative emission estimates can occur at higher values of temperature and wind speed. This is due to the negative relationship between $PM_{2.5}$ and inventory in the model, which will need to be further explored. One option is to explore models that predict emissions normalized by inventory, as these models will produce a positive linear relationship between inventory and emissions (with other factors constant), regardless of the size of the operation.

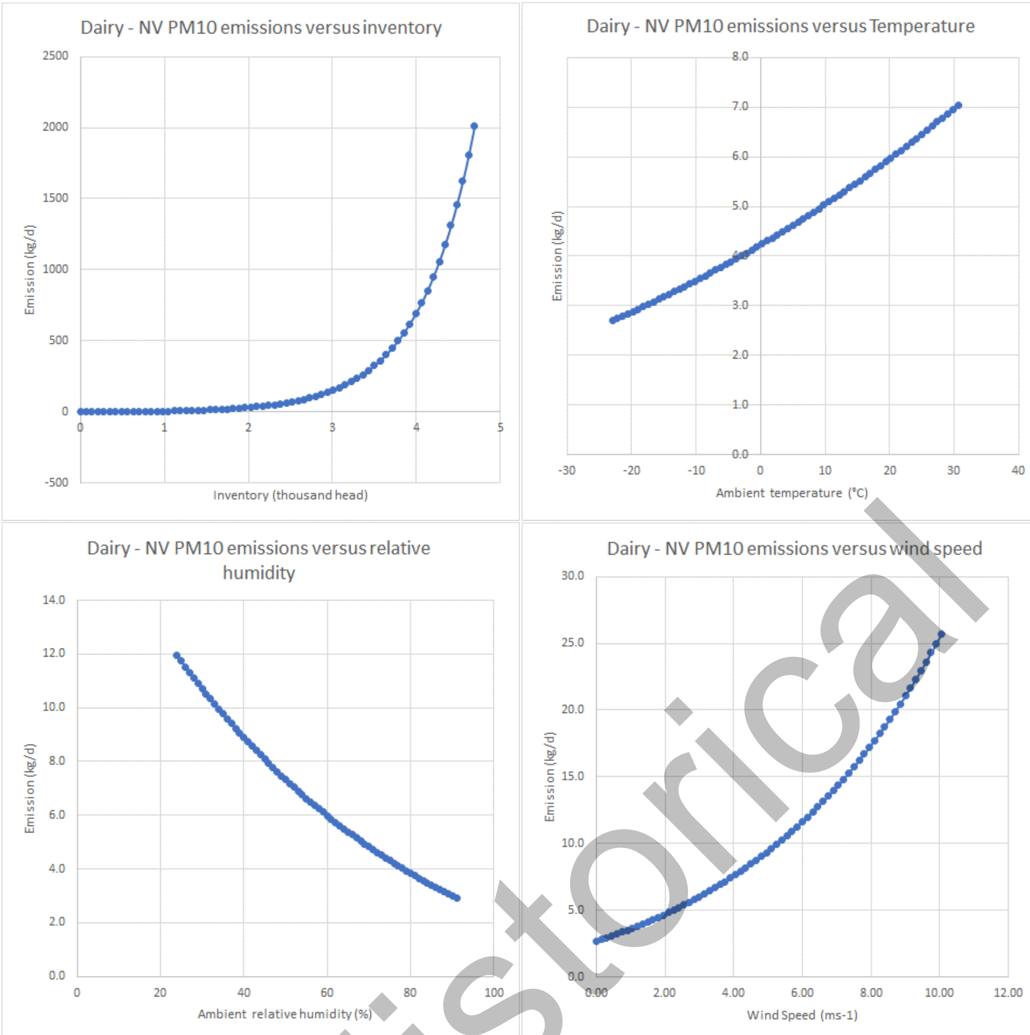


Figure 8-17. Naturally ventilated barn limitation tests for PM_{10}.
Visualization of the results for PM_{10} tests of inventory (top left), ambient temperature (top right), relative humidity (bottom left), and wind speed (bottom right).

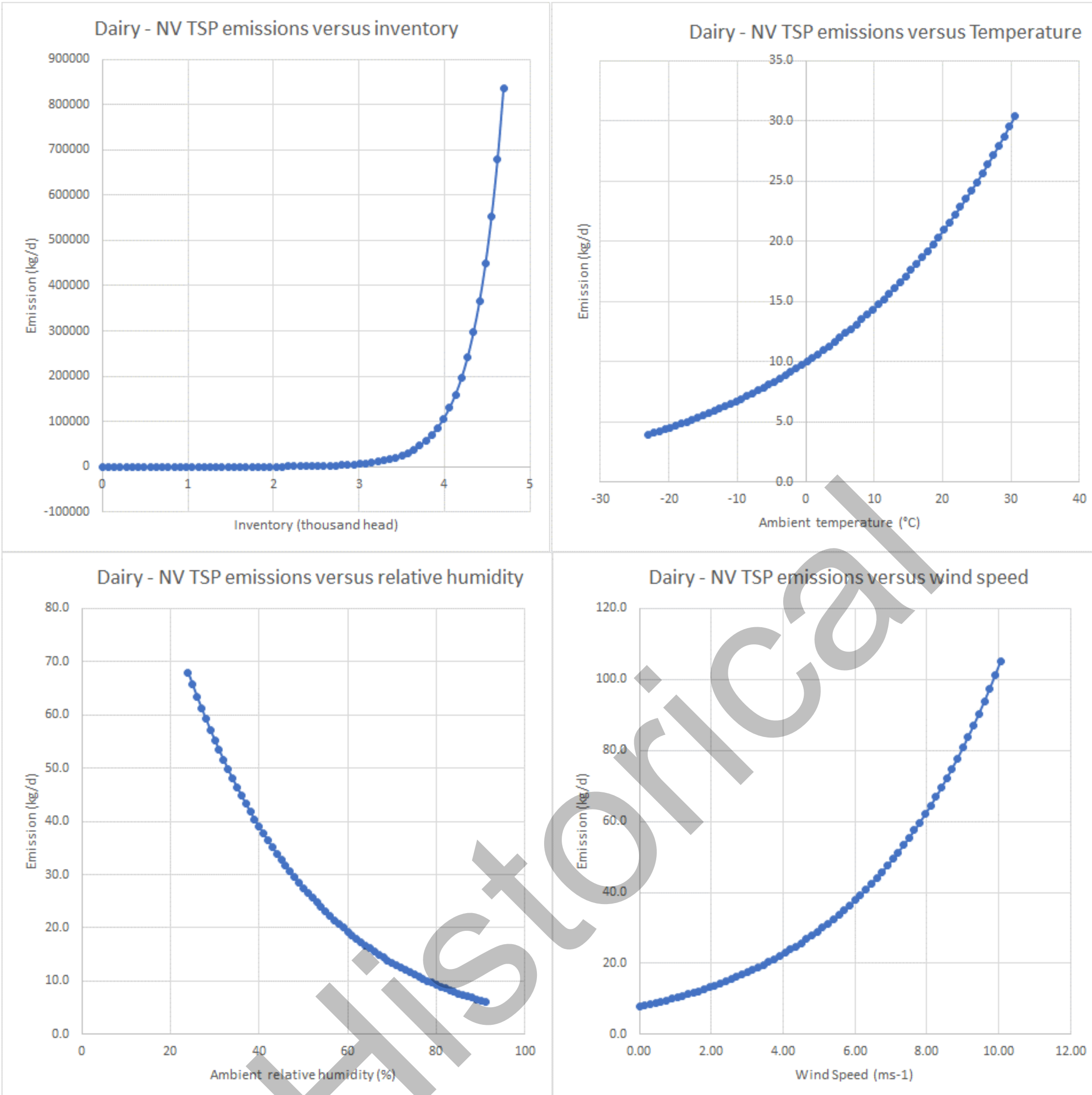


Figure 8-18. Naturally ventilated barn limitation tests for TSP.
Visualization of the results for TSP tests of inventory (top left), ambient temperature (top right), relative humidity (bottom left), and wind speed (bottom right).

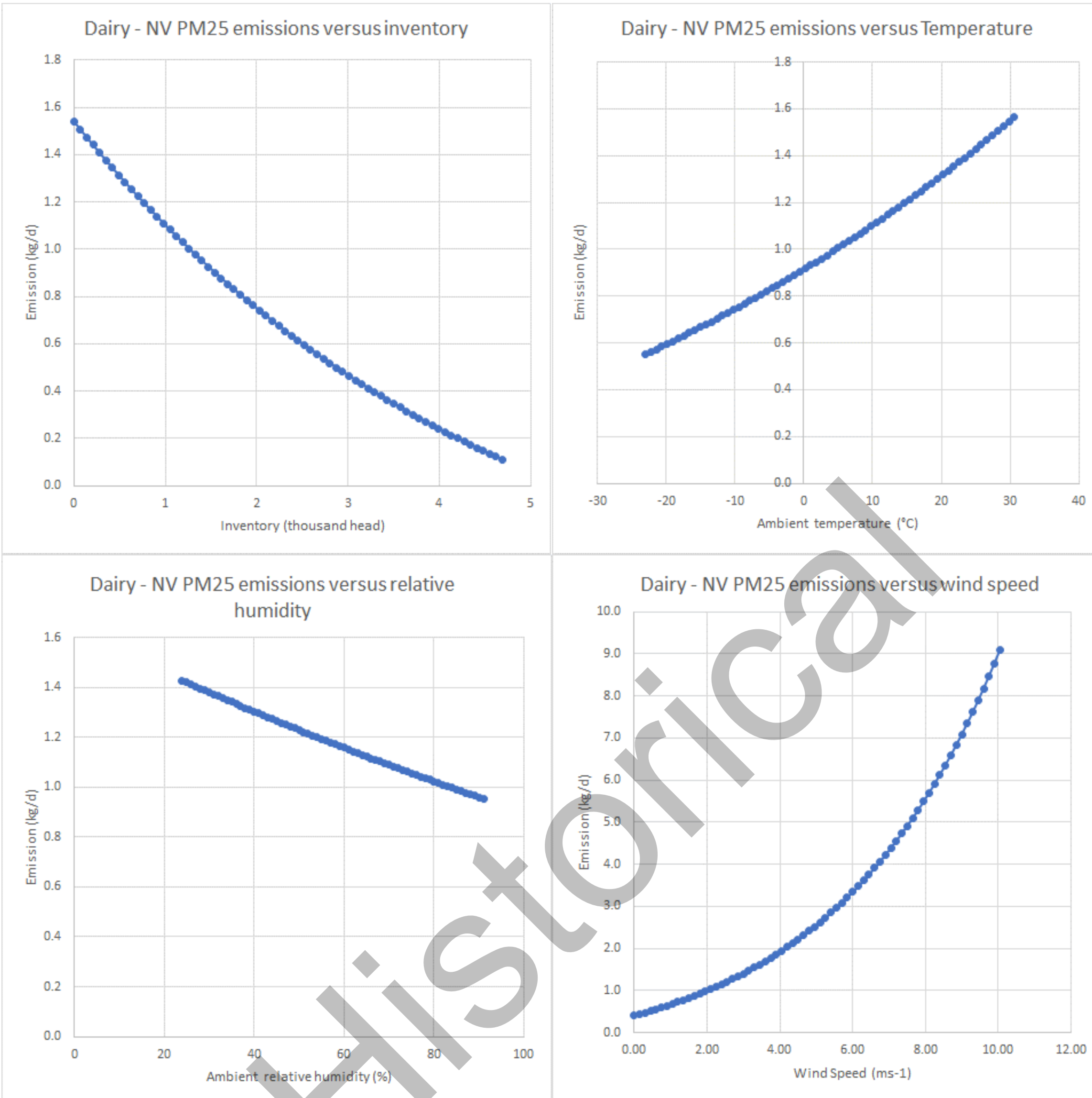


Figure 8-19. Naturally ventilated barn limitation tests for $PM_{2.5}$.
Visualization of the results for $PM_{2.5}$ tests of inventory (top left), ambient temperature (top right), relative humidity (bottom left), and wind speed (bottom right).

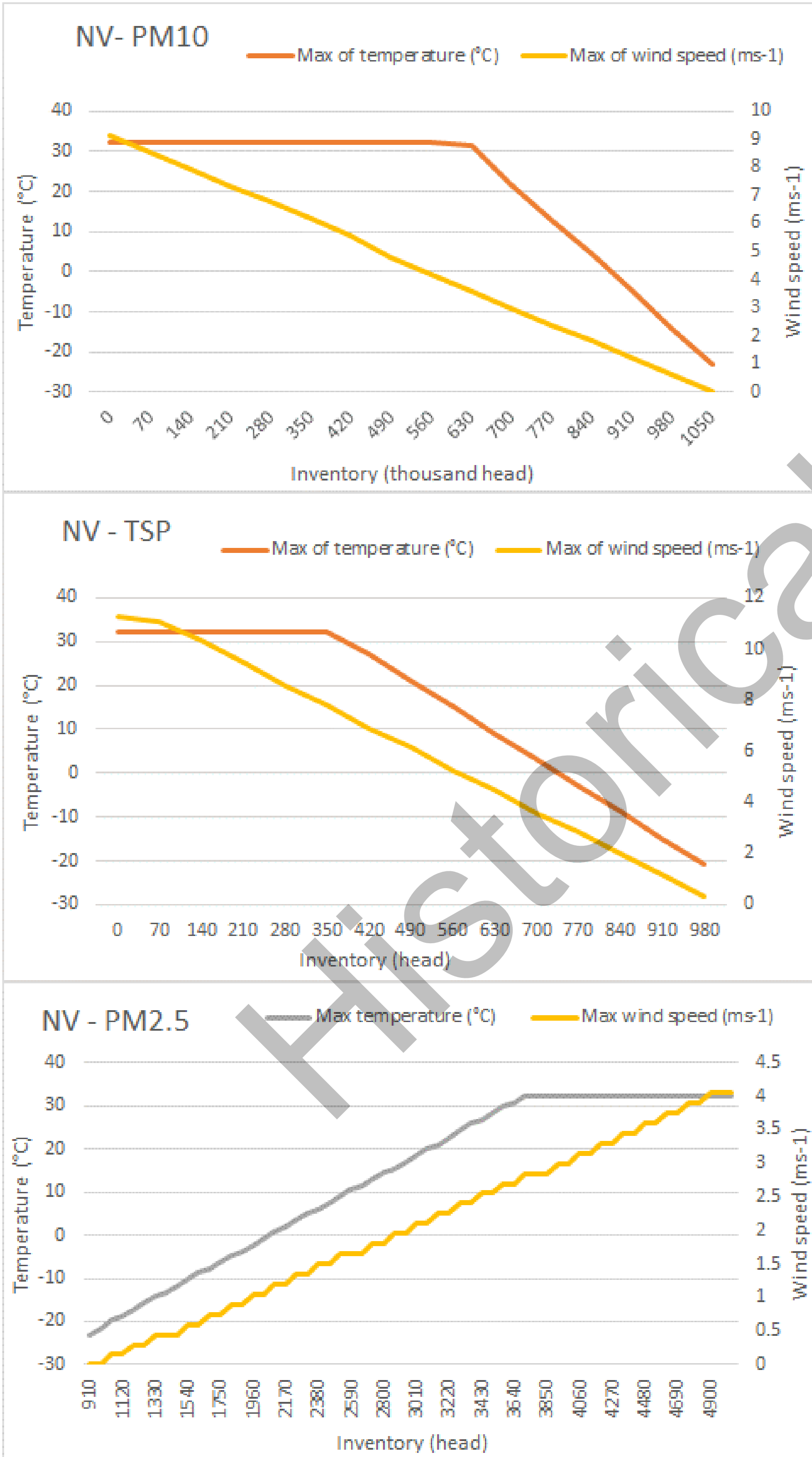


Figure 8-20. Maximum values of wind speed and temperature for each inventory level at which the particulate matter equations yields negative emissions.

Visualizations of the results for PM_{10} (top), TSP (middle) and $PM_{2.5}$ (bottom).

8.2.3.4 Lagoon

The lagoon analysis for gaseous pollutants is presented in Figure 8-21. Both NH_3 and H_2S will produce negative emission values when temperatures dip below -11.8°C. EPA will evaluate whether the model should include a "floor", that is past a certain temperature it is assumed the lagoon is frozen and is producing minimal emissions. The relationship between temperature and emissions is positive with no large changes in emission sensitivity.

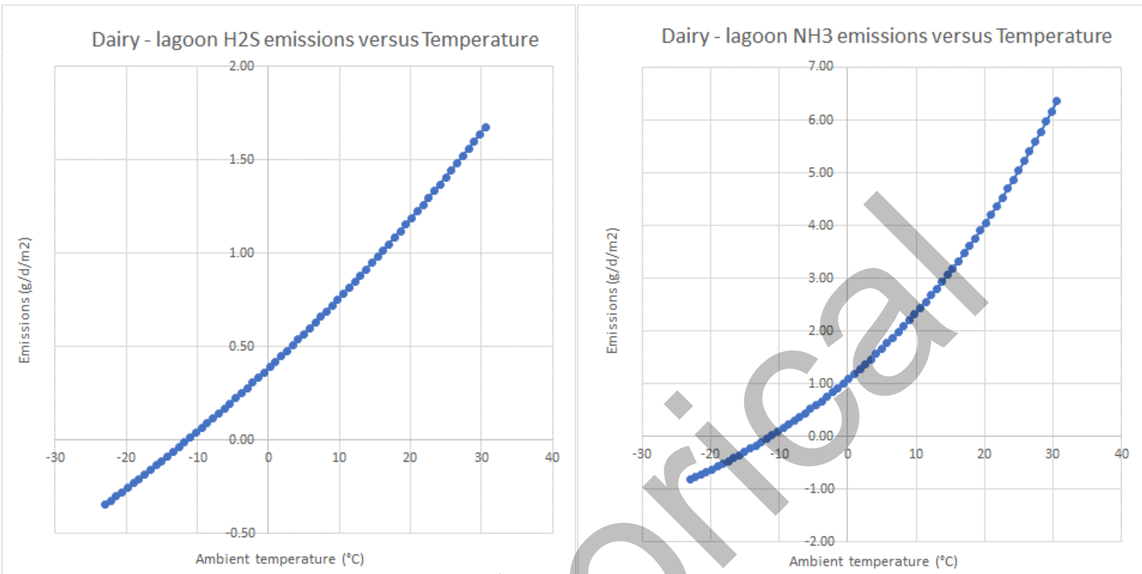


Figure 8-21. Lagoon limitation tests for gaseous pollutants.
Visualization of the results for tests of ambient temperature for H_2S (left) and NH_3 (right).

8.2.3.5 Corral

The corral analyses for H_2S and NH_3 are presented in Figure 8-22 and Figure 8-23, respectively. Neither the H_2S nor the NH_3 model produce negative emissions under average conditions. However, analyzing 397, 936 combinations of temperature, relative humidity, and wind speed, found that the NH_3 model will produce negative emission estimates at low temperatures (<7.8°C) combined with low relative humidities (<46%) and low wind speeds (<3.9 ms^{-1}). Figure 8-24 show that as temperature increases, there is a smaller range of relative humidity and wind speeds that produce negative emissions. Otherwise, the relationships between emissions and predictors do not show any rapid changes in emission sensitivity that are causes of concern.

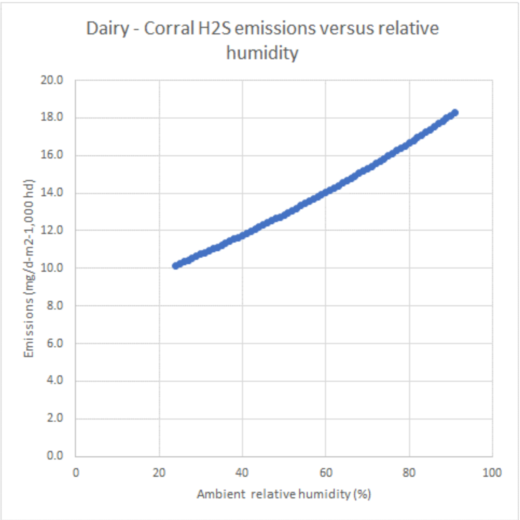


Figure 8-22. Corral limitation tests for H_2S.
Visualization of the results for tests of relative humidity for H_2S.

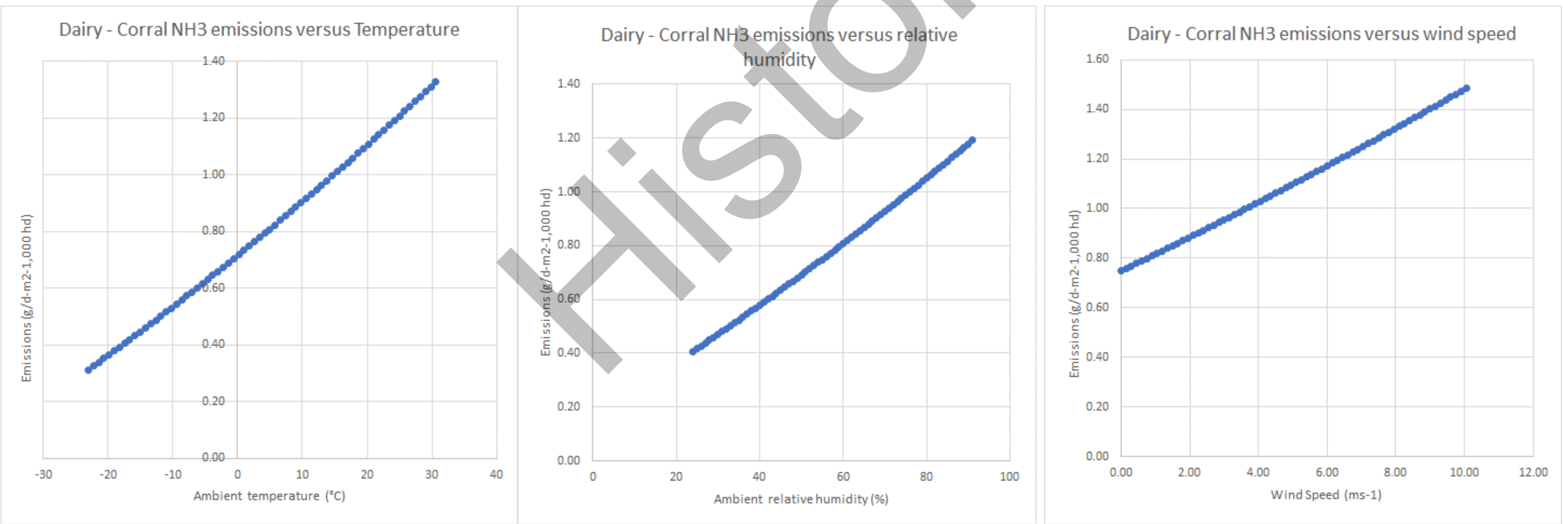


Figure 8-23. Corral limitation tests for NH_3.
Visualization of the results for NH_3 tests of ambient temperature (left), relative humidity (center), and wind speed (right).

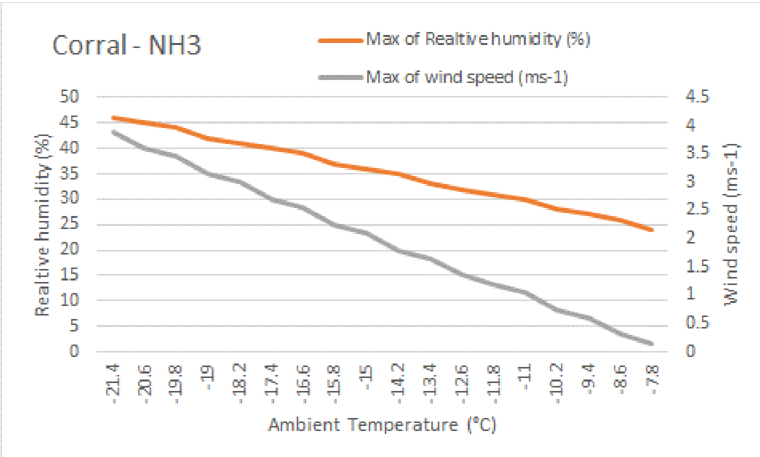


Figure 8-24. Maximum values of wind speed and relative humidity for each temperature at which the particulate matter equations yields negative emissions.

8.3 Comparison to Literature

To further validate the EEMs developed under this effort, EPA compared the results for the emission models to the emissions calculated using emission factors found in literature. EPA scanned the literature for a variety of emission factors for this comparison. EPA selected a variety of recent factors not derived from the NAEMS for comparison, which are summarized separately for barns, lagoons, and corrals in Table 8-15, Table 8-16, and Table 8-17, respectively. There were no emission factors identified for milking centers during the literature review. For the mechanically ventilated barns, the original units provided in Teye, F.K and Hautala, M. (2010) were g m^{-2} hr^{-1}, which were converted to kg hd^{-1} yr^{-1} based on the reported floor area of 774 m^2 and inventory of 65 head. For naturally ventilated barns, values were converted based on 500 kg AU^{-1}, and an average weight of 635 kg per head, based on the NAEMS farms. For the lagoon and corral sources, surface areas in hectare were converted using the standard factor of 10000 m^2/ha. These converted emission factors were then applied to the theoretical farm sources from the previous example calculations. The following sections summarize the results for each source type.

Table 8-15. Emission factors for dairy barns from literature.

Source	Farm Source	Pollutant	mg sec^{-1} hd^{-1}	µg sec^{-1} hd^{-1}	kg hd^{-1} d^{-1}	g m^2 hr	kg hd^{-1} yr^{-1}
Teye, F.K and Hautala, M. (2010)	Mechanically ventilated barn	NH_3				0.12[a]	12.52
Huang (2017)	Naturally ventilated barn	NH_3	0.98[a]				30.91
Leytem, et al. (2012)	Naturally ventilated barn	NH_3			0.08[a]		29.20
Huang (2017)	Naturally ventilated barn	H_2S		18.5[a]			0.58

[a] as reported in source.

Table 8-16. Emission factors for dairy lagoons from literature.

Source	Farm Source	Pollutant	kg/ha-d	g/m^2-d	kg/m^2-yr
Leytem, A.B., et al. (2011)	Lagoon[a]	NH3		2.0[b]	0.73
Leytem, A.B., et al. (2018)	Lagoon	NH3	43[a,c]		1.57

[a] Identified in the study as a wastewater pond
[b] as reported in source.
[c] rate reported for lagoon associated with a freestall barn (location ID D4)

Table 8-17. Emission factors for dairy corrals from literature.

Source	Farm Source	Pollutant	g/hd-d	kg/hd-d
Leytem, A.B., et al. (2011)	Corral	NH_3		0.13[a]
Moore, K.D., (2014)	Corral	NH_3	134.2[a]	0.134
Bonifacio, H.F., et al. (2015)	Corral	NH_3	155[a]	0.155

[a] as reported in source.

8.3.1 Mechanically Ventilated Barn

Comparisons were made for an inventory of 500 cows and 1,000 cows for both a cold weather location (Wisconsin) and a warm weather location (California). The results for comparing the calculations for NH_3 emissions for mechanically ventilated scrape barns are presented in Table 8-18, and flush barn in Table 8-19. For both inventory levels, the emission factor from Teye and Hautala (2010) produces an estimate that falls just below the estimate produced by the emission models developed in this report. For the flush barns, the estimates based on Teye and Hautala (2010) fall between the estimate for the smaller barn (500 head) and just below the model estimates for the larger barn (1,000). For both manure management types, the models developed in the text represent an increase from previously published literature.

Table 8-18. Comparison of resulting mechanically ventilated scrape barn NH_3 emission from various estimation methods.

Meteorology site	Inventory (hd)	NH_3 Emissions (kg yr^{-1})	
		EPA 2022 models	Teye and Hautala (2010)
WI	500	7,098	6,259
CA	500	8,689	6,259
WI	1000	18,794	12,517
CA	1000	22,657	12,517

Table 8-19. Comparison of resulting mechanically ventilated flush barn NH_3 emission from various estimation methods.

Meteorology site	Inventory (hd)	NH_3 Emissions (kg yr^{-1})	
		EPA 2022 models	Teye and Hautala (2010)
WI	500	6,183	6,259
CA	500	7,597	6,259
WI	1000	16,574	12,517
CA	1000	20,006	12,517

8.3.2 Naturally Ventilated Barn

Like the mechanically ventilated examples, comparisons were made for an inventory of 500 cows and 1,000 cows for both a cold weather location (WI) and a warm weather location (CA). The results for NH_3 are presented in Table 8-20. For the smaller barn (500 head), the estimates for both the cold and warm meteorological conditions fall well below the estimates generated by the factors from literature. The estimates for the larger barn (1,000) the models presented in this work are closer to the estimates provided by emission factors from literature. This reiterates the results from the sensitivity analysis, where the emission estimates from the models increase rapidly with size.

For H_2S (Table 8-21), the estimates based on the models developed in this report are slightly greater for the smaller barn in a cold climate compared to literature. The large inventory examples and the 500 head barn in a warm climate are slightly lower than estimates based on literature.

Table 8-20. Comparison of resulting naturally ventilated barn NH_3 emission from various estimation methods.

Meteorology site	Inventory (hd)	NH_3 Emissions (kg yr^{-1})		
		EPA 2022 models	Huang (2017)	Leytem, et al. (2012)
WI	500	4,194	15,453	14,600
CA	500	3,816	15,453	14,600
WI	1,000	28,137	30,905	29,200
CA	1,000	26,050	30,905	29,200

Table 8-21. Comparison of resulting naturally ventilated barn H_2S emission from various estimation methods.

Meteorology site	Inventory (hd)	H2S Emissions (kg yr^{-1})	
		EPA 2022 models	Huang (2017)
WI	500	310	292
CA	500	289	292
WI	1,000	477	583
CA	1,000	447	583

8.3.3 Lagoon

For lagoons, comparisons were made for both a cold weather location (WI) and a warm weather location (CA) assuming a surface area of 10,000 m^2. The NH_3 results in Table 8-22 show the models developed in this report generate an estimate that falls between the factors from literature.

Table 8-22. Comparison of resulting dairy lagoon NH_3 emission from various estimation methods.

Meteorology site	Surface Area (m2)	NH3 Emissions (kg yr-1)		
		EPA 2022 models	Leytem, A.B., et al. (2011)	Leytem, A.B., et al. (2018)
WI	10,000	8,961	7,300	15,695
CA	10,000	12,525	7,300	15,695

8.3.4 Corral

For corrals, the comparison was made for both cold (WI) and warm (CA) meteorological scenarios. Calculations were also made for a small farm (500 head) and a larger farm (1,000 head), assuming a surface area of 10,000 m^2 for each farm for the method developed in this report. The summary for NH_3 in Table 8-22 shows the estimates based on the EPA 2022 draft methods are comparable to the estimates based on emission factors from literature.

Table 8-23. Comparison of resulting dairy corral NH_3 emission from various estimation methods.

Meteorology site	Inventory (hd)	Surface Area (m^2)	NH3 Emissions (kg yr-1)			
			EPA 2022 models	Leytem, A.B., et al. (2011)	Moore, K.D., et al. (2014)	Bonifacio, H.F., et al. (2015)
WI	500	10,000	23,975	23,725	28,288	24,492
CA	500	10,000	22,551	23,725	28,288	24,492
WI	1000	10,000	47,949	47,450	56,575	48,983
CA	1000	10,000	45,101	47,450	56,575	48,983

8.4 Replication of Independent Measurements

A final test of the developed emission models is to compare the predicted emissions to observed values from an independent study. For this test, EPA was able to obtain some of the data from the Harper, et al. (2009) study of lagoons in Wisconsin. The data available are for NH_3 emissions for two of the three sites, for fall and summer monitoring periods. EPA was also able to obtain data from the Leytem et al. (2013) study, where an open-freestall production facility was monitored in southern Idaho. Measurements were collected for both the open-freestall area and the wastewater ponds. The data from the Idaho open-freestall area was used to test the corral model and data from the Wisconsin lagoons and the Idaho wastewater pond data was used to test the lagoon model.

The data provided included the necessary information to estimate emissions using the developed emission models. These estimates were then compared to the observed values, when available, using the same model performance statistics noted in Section 6 of the main report. Scatter plots were also developed to present the ordered pairs with observations on the x-axis and the model predicted values on y-axis. These plots are useful for indicating trends of either over-, or under-prediction across the range of values. The plots include the 1:1 line (solid line) and the 1:0.5 and 1:2 lines (dashed lines). Points that fall on the 1:1 line were predicted correctly, and points that fall between the 1:0.5 and 1:2 are within a factor of two observations. Good model performance would be indicated by scatter contained within a factor of two of the 1:1 line, that is between the 1:0.5 and 1:2 lines. Looking for scatter confined to within a factor of two of the observation has been used as a model performance metric in air quality modeling by EPA for some time (Chang & Hanna, 2004) and continues to be included in EPA's Atmospheric Model Evaluation Tool (Appel, et al. 2011), which is the current model evaluation platform. The following sections summarize the result for each source type.

8.4.1 Lagoon

The model performance statistics (Table 8-24) indicate an under-prediction of emissions at both sites. Figure 8-25 shows that the largest under-predictions occur for observations greater than 10 g d^{-1} 1000 hd^{-1}, as indicated by the drop below the 1:1.05 line on the plot for the Idaho site. This suggests the current formulation of the model underestimates the highest emissions.

Table 8-24. Model performance evaluation statistics for lagoon NH_3 estimates.

Site	n	LNME[a] (%)	NME[b] (%)	ME[b] (g d^{-1} 1000 hd^{-1})	MB[b] (g d^{-1} 1000 hd^{-1})	NMB[b] (%)	Corr.
ID	23	26.177	69.196	4.800	-4.681	-67.47	0.497
WI	3	20.271	48.388	3.209	-3.209	-48.39	0.999

[a] Based on transformed data (i.e., ln(NH_3)).
[b] Based on back-transformed data.

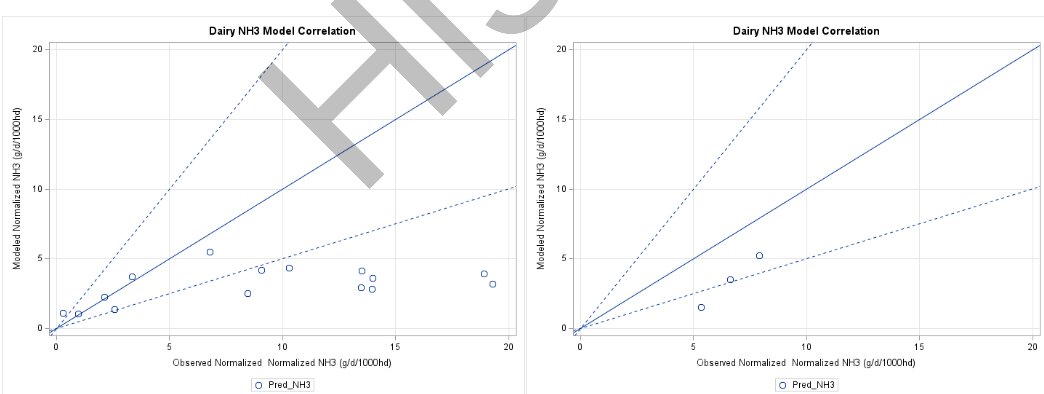


Figure 8-25. Scatter plot of the observed lagoon NH_3 emissions versus the emission model estimates.
Results from the Idaho site (left) and Wisconsin site (right).

8.4.2 Corral

The model performance statistics (Table 8-25) show an under-prediction of emissions from the corral. The plot of observed versus estimated emissions (Figure 8-26) show there are slight overpredictions at low emission levels, as the points fall above the 1:1 line, and an underprediction at higher observed emission levels. As with the lagoon model, this suggests an underprediction of highest emission values in the model.

Table 8-25. Model performance evaluation statistics for corral NH_3 estimates.

Site	n	LNME[a] (%)	NME[b] (%)	ME[b] (g d^{-1} 1000 hd^{-1})	MB[b] (g d^{-1} 1000 hd^{-1})	NMB[b] (%)	Corr.
WI	18	17.371	70.689	1.316	-0.574	-30.84	-0.351

[a] Based on transformed data (i.e., ln(NH_3)).
[b] Based on back-transformed data.

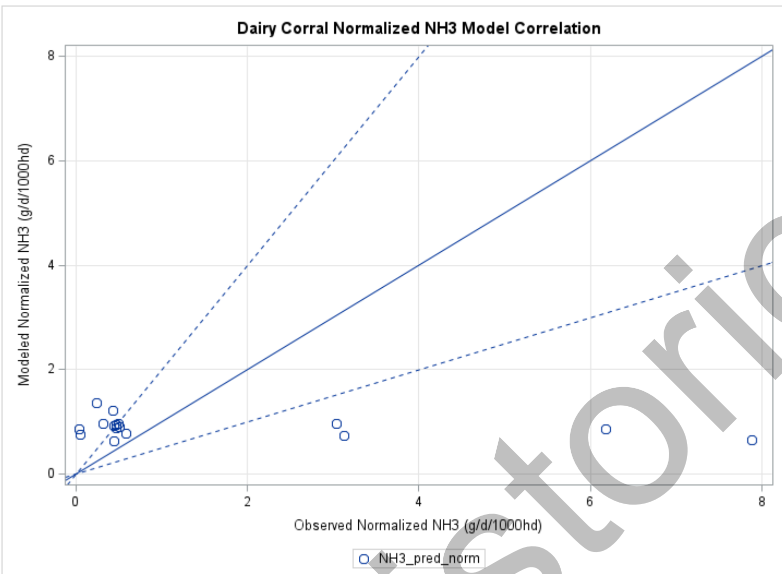


Figure 8-26. Scatter plot of the observed corral NH_3 emissions versus the emission model estimates.

9 CONCLUSIONS

Consistent with the Air Compliance Agreement with the AFO industry, EPA has developed emission estimation methods for NH_3, H_2S, PM_{10}, $PM_{2.5}$, and TSP for confinement and open sources associated with dairy operations. These draft statistical models focus on parameters that have been identified in published peer-reviewed journals as having empirical relationships with emissions. These relationships were evaluated within the NAEMS dataset before selecting parameters for emission model development. EPA also considered which variables could be measured or obtained with minimal effort.

The inventory was identified as a key parameter and is used in all the models as a proxy for the volume of manure generated. Temperature and relative humidity parameters were also identified as important variables for emission rates in the barn emission models. Relative humidity parameters proved to be key for particulate matter prediction, as the higher moisture levels keep barn materials from entraining into the air with mechanical disruptions. Confinement parameters specific to the barn, like exhaust temperature, showed promise as predictive parameters. However, these parameters are not routinely measured at farms and would therefore represent an increased burden to operators should they be required for emissions estimation. As such, all of the draft dairy emission models put forward for potential future use in this document use parameters that are already routinely collected as part of the standard farm operation (e.g., inventory) or are ambient meteorological parameters, which are freely available from public sources such as National Center for Environmental Information (NCEI, https://gis.ncdc.noaa.gov/maps/).

Overall, the method used to develop the emission models allows for the incorporation of additional emissions and monitoring datasets from other studies, should they become available to EPA after the release of the emission models. Revised emission models for any individual farm type could be issued once significant additional data becomes available. Similarly, if monitoring options for barn parameters become more widespread as automation options grow, future evaluations could assess whether emission models should be developed to include these parameters.

EPA recognizes the scientific and community desire for process-based models. The data collected during NAEMS, and the emission models developed here lay the groundwork for developing these more process-related emission estimates. EPA supports the future development of process-based models which account for the entire animal feeding process. While the interim statistical models allow estimation of emissions from barns and open sources at dairy operations across the U.S., process-based models would allow producers to estimate the impacts of different management practices to reduce air emissions, helping to incentivize change.

10 REFERENCES

Aarnink, A.J.A., Ellen, H.H., 2007. Processes and factors affecting dust emissions from livestock production. In: Proceedings of DustConf 2007. How to Improve Air Quality. International Conference, Maastricht, The Netherlands

Appel, K.W., Gilliam, R.C., Davis, N., Zubrow, A., and Howard, S.C. (2011). Overview of the Atmospheric Model Evaluation Tool (AMET) v1.1 for evaluating meteorological and air quality models, Environ. Modell. Softw., 26(4), 434-443.

Arogo, J., Zhang, R., Riskowski, G. L., Christianson, L. L., & Day, D. L. (1999). Mass transfer coefficient of ammonia in liquid swine manure and aqueous solution. Journal of Agricultural Engineering Research, 73(1), 77e86.

Arogo, Jactone, Philip W. Westerman, Albert J. Heber, Wayne P. Robarge, and John J. Classen. Ammonia Emissions from Animal Feeding Operations. Animal Agriculture and the Environment, National Center for Manure & Animal Waste Management White Papers. St. Joseph, MI: ASABE, 2006. doi:https://doi.org/10.13031/2013.20247.

Arya, S.P. (1999). Air pollution meteorology and dispersion. Oxford University Press. Blunden, J., & Aneja, V.P. (2008). Characterizing ammonia and hydrogen sulfide emissions from a swine waste treatment lagoon in North Carolina. Atmospheric Environment 42, 3277-3290.

B. Bjerg, T. Norton, T. Banhazi, G. Zhang, T. Bartzanas, P. Liberati, G. Cascone, I.-B. Lee, and A. Marucci. "Modelling of ammonia emissions from naturally ventilated livestock buildings. Part 1: Ammonia release modelling" Biosystems engineering 116, no. 3 (2013): 232-245. doi: 10.1016/j.biosystemseng.2013.08.001

Bogan, B.W., A. Chandrasekar, S. McGlynn, C.A. Gooch, and A.J. Heber. 2010. National Air Emissions Monitoring Study: Data from Dairy Freestall Barn and Milking Center in New York- Site NY5B. Final Report. Purdue University, West Lafayette, IN, July 2

Bonifacio, Henry & Rotz, C.A. & Leytem, A.B. & Waldrip, Heidi & R.W.Todd. (2015). Process-based modeling of ammonia and nitrous oxide emissions from open-lot beef and dairy facilities. Transactions of the ASABE (American Society of Agricultural and Biological Engineers). 58. 827-846.

Bougouin, A., Leytem, A., Dijkstra, J., Dungan, R. S., & Kebreab, E. (2016). Nutritional and Environmental Effects on Ammonia Emissions from Dairy Cattle Housing: A Meta-Analysis. Journal of environmental quality, 45(4), 1123-1132.

Cambra-López, M., Aarnink, A.J.A., Zhao, Y., Calvet, S., & Torres, A.G. (2010). Airborne particulate matter from livestock production systems: A review of an air pollution problem. *Environmental Pollution 158*, 1-17.

Cambra-López, M., Torres, A. G., Aarnink, A. J. A., & Ogink, N. W. M. (2011). Source analysis of fine and coarse particulate matter from livestock houses. Atmospheric Environment, 45(3), 694-707. doi:10.1016/j.atmosenv.2010.10.018

Chang, J., Hanna, S. Air quality model performance evaluation. Meteorol Atmos Phys 87, 167–196 (2004). https://doi.org/10.1007/s00703-003-0070-7

Christensen J.R., Nash, M.S., Chaloud D., and Pitchford A. 2016. Spatial Distribution of Small Water Body Types Across Indiana Ecoregions. *Ecohydrology*. 9,122-137. Available at: https://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=308263&Lab=NERL

Cortus, E.L., L. D. Jacobson, B.P. Hetchler, and A.J. Heber. 2010. National Air Emissions Monitoring Study: Emissions Data from Two Freestall Dairy Barns in Wisconsin - Site WI5B. Final Report. Purdue University, West Lafayette, IN, July 2.

Dandan Huang & Huiqing Guo (2017) Diurnal and seasonal variations of odor and gas emissions from a naturally ventilated free-stall dairy barn on the Canadian prairies, Journal of the Air & Waste Management Association, 67:10, 1092-1105, DOI:10.1080/10962247.2017.1329172

Feidler, A.M., Müller, H.J., 2011. Emissions of ammonia and methane from a livestock building natural cross ventilation. Meteorologische Zeitschrift 20 (1), 059e065.

Garcia, J., Bennett, D. H., Tancredi, D., Schenker, M. B., Mitchell, D., & Mitloehner, F. M. (2013). A survey of particulate matter on California dairy farms. Journal of environmental quality, 42(1), 40-47.

Grant, R.H. 2008, Quality Assurance Project Plan for the National Air Emissions Monitoring Study (Open Source Emissions Component), Ver. 4, Purdue Applied Meteorology Laboratory, Department of Agronomy, Purdue University

Grant, R.H. and M.T. Boehm. (2010a). National Air Emissions Monitoring Study: Data from the eastern US milk production facility IN5A. Final Report to the Agricultural Air Research Council. Purdue University, West Lafayette, IN, June 4.

Grant, R.H. and M.T. Boehm. (2010b). National Air Emissions Monitoring Study: Data from the southwest milk producer facility TX5A. Final Report to the Agricultural Air Research Council. Purdue University, West Lafayette, IN, July 2.

Grant, R.H. and M.T. Boehm. (2010c.) National Air Emissions Monitoring Study: Data from the northwestern US milk production facility WA5A. Final Report to the Agricultural Air Research Council. Purdue University, West Lafayette, IN, July 2.

Grant, R.H. and M.T. Boehm. (2010d). National Air Emissions Monitoring Study: Data from the midwestern US milk production facility WI5A. Final Report to the Agricultural Air Research Council. Purdue University, West Lafayette, IN, July 2.

Grant, R. H., Boehm, M. T., & Lawrence, A. F. (2013). Comparison of a backward-Lagrangian stochastic and vertical radial plume mapping methods for estimating animal waste lagoon emissions. Agricultural and Forest Meteorology, 180, 236-248. doi:10.1016/j.agrformet.2013.06.013

Grant, R.H., Boehm, M.T., Lawrence, A.F., & Heber, A.J. (2013b). Ammonia emissions from anaerobic treatment lagoons at sow and finishing farms in Oklahoma. Agricultural and Forest Meteorology 180, 203-210.

Grant, R.H. and Boehm, M.T (2015). Manure ammonia and hydrogen sulfide emissions from a western storage basin. Journal of environmental quality, 45, 127-136.

Grant, R. H., & Boehm, M. T. (2020). Ammonia Emissions from Differing Manure Storage Facilities at Two Midwestern Free-Stall Dairies. Atmosphere, 11(10), 1108.

Grant, R. H., Boehm, M. T., & Hagevoort, G. R. (2020). Ammonia Emissions from a Western Open-Lot Dairy. Atmosphere, 11(9), 913.

Harper, L.A. , T.K. Flesch, J.M. Powell, W.K. Coblentz, W.E. Jokela, N.P. Martin, Ammonia emissions from dairy production in Wisconsin, Journal of Dairy Science, Volume 92, Issue 5, 2009, Pages 2326-2337, ISSN 0022-0302, https://doi.org/10.3168/jds.2008-1753.

Heber A.J., Ni, J-Q., Ramirez, J.C., Schrock, W., & Elkins, J. (2008). Quality assurance project plan for the National Air Emissions Monitoring Study (barn component). Purdue University.

Herbut, P., & Angrecka, S. (2014). Ammonia Concentrations in a Free-Stall Dairy Barn. Annals of Animal Science, 14(1), 153-166. doi:10.2478/aoas-2013-0065

Joo, H., Ndegwa, P.M., Wang, X., Heber, A.J., Ni, J.Q., Cortus, E.L., Ramirez-Dorronsoro, J.C., Bogan, B.W. and Chai, L., 2015. Ammonia and hydrogen sulfide concentrations and emissions for naturally ventilated freestall dairy barns. Transactions of the ASABE, 58(5), pp.1321-1331.

Kavolelis, B. (2003). Influence ventilation rate on ammonia concentration and emission in animal house. Polish Journal of Environmental Studies, 12(6), 709-712.

Leeden, Rien & Meijer, Erik & Busing, Frank. (2008). Resampling Multilevel Models. 10.1007/978-0-387-73186-5_11.

Leytem, A. B., Dungan, R. S., Bjorneberg, D. L., & Koehn, A. C. (2011). Emissions of ammonia, methane, carbon dioxide, and nitrous oxide from dairy cattle housing and manure management systems. Journal of environmental quality, 40(5), 1383–1394. https://doi.org/10.2134/jeq2009.0515

Leytem, A. B., Dungan, R. S., Bjorneberg, D. L., & Koehn, A. C. (2013). Greenhouse gas and ammonia emissions from an open-freestall dairy in southern Idaho. Journal of Environmental Quality, 42, 10-20.

Leytem, A. B., Bjorneberg, D. L., Al Rotz, C., Moraes, L. E., Kebreab, E., & Dungan, R. S. (2018). Ammonia emissions from dairy lagoons in the western US. Transactions of the ASABE, 61(3), 1001-1015.

Lim, T.T., Y. Jin, J.H. Ha, and A.J. Heber. 2010. National Air Emissions Monitoring Study: Emissions Data from Two Freestall Barns and a Milking Center at a Dairy Farm in Indiana - Site IN5B. Final Report. Purdue University, West Lafayette, IN, July 30.

Maasikmets, Marek, Erik Teinemaa, Allan Kaasik, Veljo Kimmel, Measurement and analysis of ammonia, hydrogen sulphide and odour emissions from the cattle farming in Estonia, Biosystems Engineering, Volume 139, 2015, Pages 48-59, ISSN 1537-5110, https://doi.org/10.1016/j.biosystemseng.2015.08.002.

Meisinger, J. J., & Jokela, W. E. (2000). Ammonia volatilization from dairy and poultry manure. Proc Managing nutrients and pathogens from animal agriculture. Camp Hill, PA, 28-30.

Montes, F., C.A. Rotz, and H. Chaoui. 2009. Process modeling of ammonia volatilization from ammonium solution and manure surfaces. Trans. ASABE 52(5):1707-1719.

Moore, K. D.; Young, E.; Gurell, C.; Wojcik, M. D.; Martin, R. S.; Bingham, G. E.; Pfeiffer, R. L.; Prueger, J. H.; and Hatfield, J. L., "Ammonia Measurements and Emissions from a California Dairy Using Point and Remote Sensors" (2014). Space Dynamics Lab Publications. Paper 95.

Mostafa, E., Nannen, C., Henseler, J., Diekmann, B., Gates, R., & Buescher, W. (2016). Physical properties of particulate matter from animal houses-empirical studies to improve emission modelling. Environ Sci Pollut Res Int, 23(12), 12253-12263. doi:10.1007/s11356-016-6424-8

Ngwabie, N. M., K. H. Jeppsson, G. Gustafsson, and S. Nimmermark. "Effects of Animal Activity and Air Temperature on Methane and Ammonia Emissions from a Naturally Ventilated Building for Dairy Cows." *Atmospheric Environment* 45, no. 37 (Dec 2011): 6760-68. https://doi.org/10.1016/j.atmosenv.2011.08.027.

Philippe, F. X., Cabaraux, J. F., & Nicks, B. (2011). Ammonia emissions from pig houses: Influencing factors and mitigation techniques. Agriculture, Ecosystems & Environment, 141(3e4),245e260. http://doi.org/10.1016/j.agee.2011.03.012.

Samer, M., C. Ammon, C. Loebsin, M. Fiedler, W. Berg, P. Sanftleben, and R. Brunsch. "Moisture balance and tracer gas technique for ventilation rates measurement and greenhouse gases and ammonia emissions quantification in naturally ventilated buildings." Building and Environment 50 (2012): 10-20.

Ramirez-Dorronsoro, J.C., H.S. Joo, P. Ndegwa, and A.J. Heber. 2010. National Air Emissions Monitoring Study: Data from Two Dairy Freestall Barns in Washington WA5B, Final Report. Purdue University, West Lafayette, IN, July 30.

Rotz, C Alan, Dawn S Chianese, Felipe Montes, Sasha Hafner, and Henry F Bonifacio. "Dairy Gas Emissions Model." (2014).

Saha, C. K., C. Ammon, W. Berg, M. Fiedler, C. Loebsin, P. Sanftleben, R. Brunsch, and T. Amon. "Seasonal and diel variations of ammonia and methane emissions from a naturally ventilated dairy building and the associated factors influencing emissions." Science of the total environment 468 (2014): 53-62.

Sanchis, E., Calvet, S., del Prado, A., & Estelles, F. (2019). A meta-analysis of environmental factor effects on ammonia emissions from dairy cattle houses. Biosystems Engineering, 178, 176-183. doi:10.1016/j.biosystemseng.2018.11.017

Schmithausen**,** A. J., Schiefler, I., Trimborn, M., Gerlach, K., Sudekum, K. H., Pries, M., & Buscher, W. (2018). Quantification of Methane and Ammonia Emissions in a Naturally Ventilated Barn by Using Defined Criteria to Calculate Emission Rates. Animals, 8(5), 75. doi:ARTN 7510.3390/ani8050075

Schrade, S., Zeyer, K., Gygax, L., Emmenegger, L., Hartung, E., & Keck, M. (2012). Ammonia emissions and emission factors of naturally ventilated dairy housing with solid floors and an outdoor exercise area in Switzerland. Atmospheric Environment, 47, 183-194. doi:10.1016/j.atmosenv.2011.11.015

Shi, Zhifang, Xiaoqin Sun, Yao Lu, Lei Xi, and Xin Zhao. "Emissions of ammonia and hydrogen sulfide from typical dairy barns in central China and major factors influencing the emissions." Scientific Reports 9, no. 1 (2019): 1-12. https://doi.org/10.1038/s41598-019-50269-y

Sommer, S.G., Christensen, M.L., Schmidt, T., Jensen, L.S., 2013. Animal Manure Recycling: Treatment and Management. John Wiley Sons Ltd, West Sussex, UK.

Takai H., Pedersen S., Johnsen J.O., Metz J.H.M., Koerkamp P.W.G.G., Uenk G.H., Phillips V.R., Holden M.R., Sneath R.W., Short J.L., White R.P., Hartung J., Seedorf J., Schroder M., Linkert K.H., Wathes C.M. 1998. Concentrations and emissions of airborne dust in livestock buildings in Northern Europe. J. Agr. Eng. Res., 70: 59-77. doi: 10.1006/jaer.1997.0280

Teye, F. K., & Hautala, M. (2010). A comparative assessment of four methods for estimating ammonia emissions at microclimatic locations in a dairy building. International journal of biometeorology, 54(1), 63–74. https://doi.org/10.1007/s00484-009-0255-y

U.S. EPA Science Advisory Board (SAB), 2013. SAB Review of Emissions-Estimating Methodologies for Broiler Animal Feeding Operations and for Lagoons and Basins at Swine and Dairy Animal Feeding Operations, EPA-SAB-13-003.

Wu, W., Zhang, G., & Kai, P. (2012). Ammonia and methane emissions from two naturally ventilated dairy cattle buildings and the influence of climatic factors on ammonia emissions. Atmospheric Environment, 61, 232-243. doi:10.1016/j.atmosenv.2012.07.050

Zhao, Y., F.M. Mitloehner, L. Chai, J.C. Ramirez, K. Wang, J. Ni, C. Diehl, E.L. Cortus, T.T. Lim, B.W. Bogan, I. Kilic, and A.J. Heber. 2010. National Air Emissions Monitoring Study: Data from Two Dairy Freestall Barns in California - Site CA5B. Final Report. Purdue University, West Lafayette, IN, July 30.

Appendix A: PM Sampling

Table of Contents

List of Tables

A.1 Overall Sampling Schedule

Table A-1. Open Source Sampling Schedule

Site	Source Type	Manure Collection	Period										
			1	2	3	4	5	6	7a	7b	8	9	10
IN5A	Lagoon	Flush						9/11/08 - 12/10/08	12/11/08 - 2/25/09		3/11/09 - 5/28/09	5/29/09 - 8/24/2009	
WA5A[3]	Lagoon	Flush			2/25/08 - 3/12/08	3/12/08 - 3/26/08	8/8/08 - 9/3/08	9/3/08 - 9/26/08			5/18/09 - 6/4/09	6/4/09 - 6/20/09	
WI5A[3]	Lagoon[2]	Flush	7/18/07 - 8/28/07	11/13/07 - 11/28/07	11/28/07 - 12/18/07	4/23/08 - 5/13/08	6/25/08 - 7/14/08	10/21/08 - 11/11/08	12/17/08 - 1/7/09		3/10/09 - 4/7/09		
TX5A	Corral	Dry lot		9/19/07 - 11/6/07	1/8/08 - 1/23/08	4/1/08 - 4/23/08	6/10/08 - 7/1/08	10/15/08 - 11/4/08	12/16/08 - 1/6/09	1/27/09 - 2/19/09	2/19/09 - 3/18/09	8/3/09 - 8/27/09	

[1] Characterizes type of farm.
[2] Lagoon can be single or double stage
[3] Area site that also had barn monitoring sites during NAEMS

A.2 PM Sampling Schedules

Table A-2. PM Sampling Schedule CA5B

Day, m/d/y		Test duration (days)		
Start	Stop	PM_{10}	TSP	$PM_{2.5}$
9/26/07	1/20/08	116.5		
1/20/08	2/18/08		29.0	
2/18/08	2/29/08			11.0
2/29/08	6/4/08	95.9		
6/4/08	6/12/08		7.8	
6/12/08	6/23/08		10.9*	
6/12/08	6/23/08	10.9**		
6/23/08	9/11/08	80.1		
9/11/08	10/2/08		20.8	
10/2/08	10/11/08			8.8
10/11/08	1/14/09	95.6		
1/14/09	1/27/09		12.9	
1/27/09	2/23/09			26.7
2/23/09	6/15/09	112.2		
6/15/09	7/7/09		22.0	
7/7/09	7/17/09			9.8
7/17/09	7/22/09			5.1‡‡
7/17/09	7/22/09	5.0 ††		
7/22/09	9/26/09	66.0		
Totals		566	70	56

*All except ambient
**Only ambient
††Only B1
‡‡All except B1

Table A-3. PM Sampling Schedule IN5B

Time and day, m/d/y		Test duration, d		
Start	Stop	PM_{10}	TSP	$PM_{2.5}$
9/8/07 0:00	11/5/07 10:30	58.4		
11/5/07 10:30	11/14/07 10:30		9.0	
11/14/07 10:30	1/4/08 13:00	51.1		
1/4/08 13:00	1/11/08 12:00		7.0	
1/11/08 13:00	1/25/08 16:00			14.1
1/25/08 16:00	3/20/08 12:10	54.8		
3/20/08 12:10	3/27/08 12:40		7.0	
3/27/08 12:40	6/16/08 12:55	81.0		
6/16/08 12:55	6/24/08 10:00		7.9	
6/24/08 10:00	9/10/08 14:25	78.2		
9/10/08 14:25	9/19/08 13:45		9.0	
9/19/08 13:45	9/25/08 9:25	5.8		
9/25/08 9:25	9/29/08 8:30			4.0
9/29/08 8:30	9/29/08 14:37		0.3	
9/29/08 14:37	10/1/08 9:10			1.8
10/1/08 9:10	10/13/08 12:39		12.1	
10/13/08 12:39	11/25/08 9:58	42.9		
11/25/08 9:58	11/25/08 12:30			0.1
11/25/08 12:30	12/2/08 14:15	7.1		
12/2/08 14:15	12/4/08 14:13		2.0	
12/4/08 14:13	12/8/08 9:27	3.8		
12/8/08 11:21	12/10/08 10:44			
12/20/08 9:00	12/29/08 13:57		9.2	
12/29/08 13:42	2/2/09 11:52	34.9		
2/2/09 11:52	2/16/09 14:49			14.1
2/16/09 14:49	3/3/09 12:32		14.9	
3/3/09 12:45	3/23/09 12:01	20.0		
3/23/09 13:00	3/30/09 10:00		6.9	
3/30/09 11:00	4/17/09 11:30	18.0		
4/17/09 11:30	4/20/09 8:15			2.9
4/20/09 8:15	5/27/09 11:00	37.1		
5/27/09 11:00	6/1/09 11:27		5.0	
6/1/09 11:27	7/13/09 10:38	42.0		
7/13/09 10:38	7/24/09 9:55		11.0	
7/24/09 10:16	8/10/09 7:50			16.9
8/10/09 8:11	9/12/09 23:59	33.7		
Totals:		569	101	54

Table A-4. PM Sampling Schedule NY5B

Day, m/d/y		Test duration, d		
Start	Stop	PM_{10}	TSP	$PM_{2.5}$
10/24/07	12/14/07	51.6		
12/14/07	12/21/07		7.0	
12/21/07	1/11/08	20.8		
1/11/08	1/25/08			14.0
1/25/08	2/13/08	19.1		
2/13/08	2/21/08		7.7	
2/21/08	4/4/08	43.1		
4/4/08	4/11/08		7.0	
4/11/08	6/24/08	73.9		
6/24/08	7/10/08		15.9	
7/10/08	7/24/08	13.8		
7/24/08	8/27/08			34.2
8/27/08	11/4/08	68.6		
11/4/08	11/24/08			19.9
11/24/08	1/13/09	49.9		
1/13/09	1/20/09		6.9	
1/20/09	3/13/09	52.0		
3/13/09	3/19/09		5.9	
3/19/09	5/11/09	52.9		
5/11/09	5/18/09		7.0	
5/18/09	9/8/09	113.0		
9/8/09	10/24/09	45.6†		
9/8/09	9/21/09		13.0‡	
9/21/09	10/24/09	32.6‡		
Totals		636.9	70.5	68.1

† Only B1F15
‡All except B1F15

Table A-5. PM Sampling Schedule WA5B

Day, m/d/y		Test duration, d		
Start	Stop	PM_{10}	TSP	$PM_{2.5}$
9/28/07	1/17/08	111.6		
1/17/08	2/7/08			21.1
2/7/08	4/10/08	62.9		
4/10/08	4/24/08		13.9	
4/24/08	6/12/08	49.1		
6/12/08	6/18/08		6.0	
6/18/08	7/10/08	22.0		
7/10/08	7/23/08			12.9
7/23/08	9/12/08	50.9		
9/12/08	9/18/08		6.0	
9/18/08	11/13/08	56.0		
11/13/08	11/21/08		8.0	
11/21/08	2/12/09	82.9		
2/12/09	2/26/09			14.0
2/26/09	3/4/09		6.1	
3/4/09	4/30/09	57.0		
4/30/09	5/7/09		7.0	
5/7/09	7/8/09	62.1		
7/8/09	7/22/09			14.0
7/22/09	7/30/09	7.9		
7/30/09	8/5/09		6.2	
8/5/09	9/27/09	53.4		
Totals		615.8	53.1	62.1

Table A-6. PM Sampling Schedule WI5B

Time and day (m/d/y)		Test duration, d		
Start	Stop	PM_{10}	TSP	$PM_{2.5}$
9/12/07	12/11/07	90.5		
12/11/07	12/17/07		6.1	
12/17/07	1/15/08	28.9		
1/15/08	2/5/08			21.0
2/5/08	2/19/08	14.0		
2/19/08	2/26/08		6.9	
2/26/08	3/17/08	20.1		
3/17/08	3/25/08		7.9	
3/25/08	4/29/08	34.9		
4/29/08	5/5/08		6.0	
5/5/08	6/19/08	45.0		
6/19/08	6/26/08		7.0	
6/26/08	8/1/08	35.9		
8/1/08	8/18/08			17.0
8/18/08	8/25/08		7.1	
8/25/08	10/14/08	50.0		
10/14/08	10/28/08		14.2	
10/28/08	12/16/08	48.8		
12/16/08	12/30/08		14.0	
12/30/08	1/13/09	13.9		
1/13/09	1/27/09			14.0
1/27/09	2/17/09	21.0		
2/17/09	2/24/09		6.9	
2/24/09	4/6/09	41.1		
4/6/09	4/14/09		7.9	
4/14/09	6/3/09	50.0		
6/3/09	6/8/09		5.3	
6/8/09	7/6/09	28.0		
7/6/09	7/21/09			14.7
7/21/09	8/4/09	14.0		
8/4/09	8/11/09		7.0	
8/11/09	9/15/09	35.0		
Totals		571.2	96.3	66.7

Appendix B: Data Processing

Table of Contents

List of Tables

B.1 Negative Emission Value Assessment Method

Negative calculated emission values can occur in NAEMS data set due to a range of different scenarios as described in the SAB review of the 2012 EEMs developed by EPA (U.S. EPA SAB, 2013). A summary of these scenarios and whether SAB recommended the data should be retained or removed is provided below:

1. A calculation bias may occur when measured values are at or close to the detection limit, or negative. This scenario should result in small negative values, which should be retained.

2. In NAEMS, the background and source measurements were measured either intermittently (twice a day for gaseous pollutant), or continuously without correction for lag time in the barn (PM). The limited and uncorrected background concentrations can be biased, either negatively or positively, due to instrument "noise" or adjustment of calibration offset procedure. When this bias is negative, it introduces the potential for negative emission values. Negative emission values should be retained because omitting this data could bias the model high.

3. Outdoor events may affect background and barn concentrations. For example, if there was activity outside an animal barn which resulted in increased pollutant concentration (e.g., manure cleanout of another barn)), the measured background values would create a negative bias. Alternatively, a positive bias could occur if meteorological conditions caused the barn exhaust air to return into the barn, thus affecting measured barn concentrations.

To avoid bias from the true value, the SAB suggests keeping calculated values from scenario 1 and 2 and removing values identified to be caused by scenario 3, however the NAEMS did not record outdoor events that may affect background concentration (scenario 3), therefore it could not be determined if negative emissions were caused by scenario 2 or 3. It is likely that scenarios 1 and 2 result in smaller negative (closer to zero) emissions than scenario 3. Therefore, a methodology was developed to remove large negative emissions likely associated with scenario 3. In the NAEMS QAPP, the gas and PM barn emission uncertainty were determined to be ±27% and ±32% for mechanically ventilated barns and ±50% and ±53% for naturally ventilated barns (Heber et al. 2008). Cut-offs for valid negative data were therefore determined for each pollutant by multiplying the emission uncertainty by the median of the positive measured emission values. Tables B-1 through B-10 summarize the changes to the data set due to the negative emission removal.

Table B-1. Summary of the effect of applying the negative emission cut-off to dairy barn NH_3 emissions (kg/d) data.

Site	Description	Avg	St Dev	N	Median	Min	Max	CV (%)	N < 0
CA5B B1	Original Data Set	2.95	4.11	191	2.54	-8.57	21.16	1.39	37
	Revised Data Set	3.75	3.54	170	3.29	-0.86	21.16	0.95	16
	Difference	0.80	-0.57	21	0.75	7.71	0.00	-0.45	21
CA5B B2	Original Data Set	2.76	3.76	223	2.67	-10.77	15.37	1.36	42
	Revised Data Set	3.64	3.01	194	3.16	-0.91	15.37	0.83	13
	Difference	0.88	-0.76	29	0.49	9.86	0.00	-0.54	29
IN5B B1	Original Data Set	40.34	25.27	467	33.71	3.42	122.62	0.63	0
	Revised Data Set	40.34	25.27	467	33.71	3.42	122.62	0.63	0
	Difference	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
IN5B B2	Original Data Set	39.79	24.10	478	34.47	3.03	119.73	0.61	0
	Revised Data Set	39.79	24.10	478	34.47	3.03	119.73	0.61	0
	Difference	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
NY5B B1	Original Data Set	21.69	8.09	350	20.17	6.81	45.26	0.37	0
	Revised Data Set	21.69	8.09	350	20.17	6.81	45.26	0.37	0
	Difference	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
WA5B B2	Original Data Set	26.60	29.43	125	21.91	-156.36	96.60	1.11	2
	Revised Data Set	29.09	21.81	123	22.06	0.52	96.60	0.75	0
	Difference	2.49	-7.62	2	0.16	156.88	0.00	-0.36	2
WA5B B4	Original Data Set	54.65	31.64	99	45.13	9.03	170.93	0.58	0
	Revised Data Set	54.65	31.64	99	45.13	9.03	170.93	0.58	0
	Difference	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
WI5B B1	Original Data Set	8.58	2.83	564	8.22	3.75	19.14	0.33	0
	Revised Data Set	8.58	2.83	564	8.22	3.75	19.14	0.33	0
	Difference	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
WI5B B2	Original Data Set	11.22	4.56	524	10.74	3.37	26.55	0.41	0
	Revised Data Set	11.22	4.56	524	10.74	3.37	26.55	0.41	0
	Difference	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

n/a = No change in dataset

Table B-2. Summary of the effect of applying the negative emission cut-off to dairy barn H_2S emissions (g/d) data.

Site	Description	Avg	St Dev	N	Median	Min	Max	CV (%)	N < 0
CA5B B1	Original Data Set	487.25	740.76	212	569.87	-2,418.29	3,775.09	1.52	37
	Revised Data Set	634.01	558.98	192	646.11	-175.56	3,775.09	0.88	17
	Difference	146.76	-181.78	20	76.24	2,242.72	0.00	-0.64	20
CA5B B2	Original Data Set	669.69	515.92	269	680.39	-609.03	2,644.93	0.77	18
	Revised Data Set	690.49	497.50	264	691.60	-166.03	2,644.93	0.72	13
	Difference	20.79	-18.41	5	11.21	443.00	0.00	-0.05	5
IN5B B1	Original Data Set	1,480.66	16,908.71	522	228.55	-284.20	386,451.70	11.42	49
	Revised Data Set	758.10	949.99	512	236.80	-80.10	5,809.50	1.25	40
	Difference	-722.56	-15,958.73	10	8.25	204.10	-380,642.20	-10.17	9
IN5B B2	Original Data Set	1,067.52	1,500.87	552	463.35	-226.60	11,093.10	1.41	24
	Revised Data Set	1,069.87	1,501.22	551	479.00	-139.90	11,093.10	1.40	23
	Difference	2.35	0.35	1	15.65	86.70	0.00	0.00	1
NY5B B1	Original Data Set	523.69	430.82	467	378.91	34.05	2,183.82	0.82	0
	Revised Data Set	523.69	430.82	467	378.91	34.05	2,183.82	0.82	0
	Difference	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
WA5B B2	Original Data Set	555.61	1,746.24	116	192.14	-5,400.93	6,513.61	3.14	45
	Revised Data Set	1,054.52	1,529.29	91	431.84	-240.39	6,513.61	1.45	20
	Difference	498.91	-216.95	25	239.70	5,160.54	0.00	-1.69	25
WA5B B4	Original Data Set	1,130.95	3,503.40	104	690.94	-11,640.14	17,960.29	3.10	30
	Revised Data Set	2,159.19	3,002.40	81	1,189.54	-324.98	17,960.29	1.39	7
	Difference	1,028.24	-501.00	23	498.60	11,315.16	0.00	-1.71	23
WI5B B1	Original Data Set	1.04	1.30	582	0.39	-0.01	8.20	1.24	3
	Revised Data Set	1.04	1.30	582	0.39	-0.01	8.20	1.24	3
	Difference	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
WI5B B2	Original Data Set	0.86	1.08	545	0.23	-0.20	5.31	1.25	8
	Revised Data Set	0.87	1.08	541	0.24	-0.07	5.31	1.24	4
	Difference	0.01	0.00	4	0.01	0.14	0.00	-0.01	4

n/a = No change in dataset

Table B-3. Summary of the effect of applying the negative emission cut-off to dairy barn PM_{10} emissions (g/d) data.

Site	Description	Avg	St Dev	N	Median	Min	Max	CV (%)	N < 0
CA5B B1	Original Data Set	-325.77	1,108.73	520	-302.25	-5,733.05	6,135.13	-3.40	372
	Revised Data Set	559.36	926.13	205	271.63	-150.91	6,135.13	1.66	57
	Difference	885.13	-182.60	315	573.88	5,582.15	0.00	5.06	315
CA5B B2	Original Data Set	592.97	2,143.17	451	11.58	-7,732.99	14,371.93	3.61	221
	Revised Data Set	1,200.13	2,163.40	324	416.48	-320.54	14,371.93	1.80	94
	Difference	607.15	20.23	127	404.90	7,412.45	0.00	-1.81	127
IN5B B1	Original Data Set	19.41	300.16	368	18.31	-1,376.97	3,571.86	15.46	158
	Revised Data Set	121.56	179.18	234	78.85	-23.80	2,069.94	1.47	25
	Difference	102.15	-120.97	134	60.54	1,353.17	-1,501.92	-13.99	133
IN5B B2	Original Data Set	130.40	209.40	348	141.52	-1,161.89	1,083.87	1.61	71
	Revised Data Set	182.07	159.76	302	166.63	-55.35	1,083.87	0.88	25
	Difference	51.67	-49.64	46	25.11	1,106.54	0.00	-0.73	46
NY5B B1	Original Data Set	223.73	337.46	328	72.89	-406.14	2,101.45	1.51	8
	Revised Data Set	229.12	335.64	324	73.93	-21.40	2,101.45	1.46	4
	Difference	5.39	-1.82	4	1.05	384.74	0.00	-0.04	4
WA5B B2	Original Data Set	4,497.74	17,839.79	452	1,590.37	-20,331.95	353,457.48	3.97	53
	Revised Data Set	5,001.87	18,160.35	428	1,734.92	-547.21	353,457.48	3.63	29
	Difference	504.12	320.56	24	144.55	19,784.73	0.00	-0.34	24
WA5B B4	Original Data Set	11,391.71	24,574.35	418	4,958.78	-7,473.60	367,744.48	2.16	14
	Revised Data Set	11,664.78	24,691.71	411	5,080.35	-1,591.37	367,744.48	2.12	7
	Difference	273.08	117.36	7	121.57	5,882.23	0.00	-0.04	7
WI5B B1	Original Data Set	363.37	578.04	400	117.65	-553.04	3,888.47	1.59	37
	Revised Data Set	376.45	577.56	391	120.67	-41.61	3,888.47	1.53	28
	Difference	13.08	-0.48	9	3.02	511.44	0.00	-0.06	9
WI5B B2	Original Data Set	562.91	818.39	362	169.16	-462.86	4,553.70	1.45	9
	Revised Data Set	571.92	818.28	358	171.73	-43.53	4,553.70	1.43	5
	Difference	9.00	-0.11	4	2.57	419.33	0.00	-0.02	4

n/a = No change in dataset

Table B-4. Summary of the effect of applying the negative emission cut-off to dairy barn $PM_{2.5}$ emissions (g/d) data.

Site	Description	Avg	St Dev	N	Median	Min	Max	CV (%)	N < 0
CA5B B1	Original Data Set	-905.18	1,423.62	47	-573.67	-9,203.14	101.31	-1.57	44
	Revised Data Set	63.26	36.78	3	60.56	27.90	101.31	0.58	0
	Difference	968.44	-1,386.84	44	634.23	9,231.04	0.00	2.15	44
CA5B B2	Original Data Set	-607.29	1,570.75	54	-303.17	-9,932.95	458.02	-2.59	40
	Revised Data Set	260.77	122.84	14	260.50	82.11	458.02	0.47	0
	Difference	868.06	-1,447.91	40	563.66	10,015.06	0.00	3.06	40
IN5B B1	Original Data Set	21.18	114.16	28	32.61	-329.99	208.10	5.39	11
	Revised Data Set	69.60	65.33	21	74.59	-29.74	208.10	0.94	4
	Difference	48.42	-48.83	7	41.99	300.25	0.00	-4.45	7
IN5B B2	Original Data Set	44.96	129.13	29	69.94	-304.84	206.93	2.87	10
	Revised Data Set	102.14	72.20	22	122.98	-21.95	206.93	0.71	3
	Difference	57.18	-56.93	7	53.04	282.89	0.00	-2.17	7
NY5B B1	Original Data Set	36.66	29.81	53	27.52	-3.16	113.84	0.81	2
	Revised Data Set	36.66	29.81	53	27.52	-3.16	113.84	0.81	2
	Difference	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
WA5B B2	Original Data Set	2,719.21	1,828.35	37	2,818.24	347.76	7,247.60	0.67	0
	Revised Data Set	2,719.21	1,828.35	37	2,818.24	347.76	7,247.60	0.67	0
	Difference	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
WA5B B4	Original Data Set	1,863.35	1,779.09	37	1,362.29	-676.29	6,474.69	0.95	6
	Revised Data Set	1,933.90	1,751.06	36	1,404.24	-401.24	6,474.69	0.91	5
	Difference	70.55	-28.03	1	41.95	275.05	0.00	-0.05	1
WI5B B1	Original Data Set	141.51	145.45	53	86.92	-27.13	538.99	1.03	7
	Revised Data Set	141.51	145.45	53	86.92	-27.13	538.99	1.03	7
	Difference	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
WI5B B2	Original Data Set	186.74	203.76	45	95.71	-4.26	805.76	1.09	1
	Revised Data Set	186.74	203.76	45	95.71	-4.26	805.76	1.09	1
	Difference	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

n/a = No change in dataset

Table B-5. Summary of the effect of applying the negative emission cut-off to dairy barn TSP emissions (g/d) data.

Site	Description	Avg	St Dev	N	Median	Min	Max	CV (%)	N < 0
CA5B B1	Original Data Set	4,766.27	7,249.04	71	2,525.45	-2,055.21	45,690.25	1.52	7
	Revised Data Set	4,863.72	7,254.39	70	2,902.71	-973.38	45,690.25	1.49	6
	Difference	97.45	5.35	1	377.25	1,081.82	0.00	-0.03	1
CA5B B2	Original Data Set	8,128.69	8,699.37	59	5,578.41	-235.60	43,350.07	1.07	4
	Revised Data Set	8,128.69	8,699.37	59	5,578.41	-235.60	43,350.07	1.07	4
	Difference	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
IN5B B1	Original Data Set	347.60	333.86	77	310.35	-158.33	1,841.13	0.96	9
	Revised Data Set	367.18	325.66	74	317.81	-80.18	1,841.13	0.89	6
	Difference	19.58	-8.19	3	7.46	78.14	0.00	-0.07	3
IN5B B2	Original Data Set	328.95	273.76	67	267.19	-88.83	1,225.92	0.83	2
	Revised Data Set	328.95	273.76	67	267.19	-88.83	1,225.92	0.83	2
	Difference	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
NY5B B1	Original Data Set	218.66	308.10	41	208.45	-505.43	1,572.59	1.41	5
	Revised Data Set	271.81	270.81	37	216.50	-3.71	1,572.59	1.00	1
	Difference	53.15	-37.30	4	8.05	501.72	0.00	-0.41	4
WA5B B2	Original Data Set	19,331.70	25,603.35	38	8,286.13	1,413.48	122,272.14	1.32	0
	Revised Data Set	19,331.70	25,603.35	38	8,286.13	1,413.48	122,272.14	1.32	0
	Difference	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
WA5B B4	Original Data Set	47,389.03	71,484.69	38	25,605.49	4,817.02	374,175.36	1.51	0
	Revised Data Set	47,389.03	71,484.69	38	25,605.49	4,817.02	374,175.36	1.51	0
	Difference	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
WI5B B1	Original Data Set	849.92	827.35	82	505.92	-450.25	3,302.96	0.97	6
	Revised Data Set	909.68	803.45	78	530.54	-110.45	3,302.96	0.88	2
	Difference	59.76	-23.90	4	24.62	339.80	0.00	-0.09	4
WI5B B2	Original Data Set	878.88	943.01	76	451.11	14.99	4,198.23	1.07	0
	Revised Data Set	878.88	943.01	76	451.11	14.99	4,198.23	1.07	0
	Difference	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

n/a = No change in dataset

Table B-6. Summary of the effect of applying the negative emission cut-off to dairy milking center NH_3 emissions (kg/d) data.

Site	Description	Avg	St Dev	N	Median	Min	Max	CV (%)	N < 0
IN5B MC	Original Data Set	8.81	7.35	338	7.36	-0.66	35.89	0.83	0
	Revised Data Set	8.81	7.35	338	7.36	-0.66	35.89	0.83	0
	Difference	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
NY5B MC	Original Data Set	5.76	2.07	385	5.68	1.27	13.69	0.36	0
	Revised Data Set	5.76	2.07	385	5.68	1.27	13.69	0.36	0
	Difference	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

n/a = No change in dataset

Table B-7. Summary of the effect of applying the negative emission cut-off to dairy barn H_2S emissions (g/d) data.

Site	Description	Avg	St Dev	N	Median	Min	Max	CV (%)	N < 0
IN5B MC	Original Data Set	1,207.31	2,122.15	400	305.05	-478.50	17,787.00	1.76	79
	Revised Data Set	1,254.65	2,137.31	388	345.95	-191.00	17,787.00	1.70	67
	Difference	47.34	15.15	12	40.90	287.50	0.00	-0.05	12
NY5B MC	Original Data Set	129.49	113.00	551	92.13	7.20	628.84	0.87	0
	Revised Data Set	129.49	113.00	551	92.13	7.20	628.84	0.87	0
	Difference	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

n/a = No change in dataset

Table B-8. Summary of the effect of applying the negative emission cut-off to dairy barn PM_{10} emissions (g/d) data.

Site	Description	Avg	St Dev	N	Median	Min	Max	CV (%)	N < 0
NY5B MC	Original Data Set	89.97	73.40	438	65.31	-81.12	484.51	0.82	3
	Revised Data Set	90.68	72.79	436	65.64	-1.42	484.51	0.80	1
	Difference	0.72	-0.61	2	0.34	79.70	0.00	-0.01	2

n/a = No change in dataset

Table B-9. Summary of the effect of applying the negative emission cut-off to dairy barn $PM_{2.5}$ emissions (g/d) data.

Site	Description	Avg	St Dev	N	Median	Min	Max	CV (%)	N < 0
NY5B MC	Original Data Set	26.56	27.50	44	23.70	2.80	188.76	1.04	0
	Revised Data Set	26.56	27.50	44	23.70	2.80	188.76	1.04	0
	Difference	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

n/a = No change in dataset

Table B-10. Summary of the effect of applying the negative emission cut-off to dairy barn TSP emissions (g/d) data.

Site	Description	Avg	St Dev	N	Median	Min	Max	CV (%)	N < 0
NY5B MC	Original Data Set	115.88	95.69	42	100.22	-79.12	321.67	0.83	3
	Revised Data Set	124.73	89.02	40	101.04	-0.67	321.67	0.71	1
	Difference	8.84	-6.67	2	0.83	78.45	0.00	-0.11	2

n/a = No change in dataset

B.2 Open Source Data Preparation

The 2012 data sets for dairy open sources (lagoons, basins, and corrals) were provided to EPA by the principal investigator (PI) for the National Air Emissions Monitoring Study (NAEMS). The datasets contain 30-minute data values for ammonia (NH_3), obtained using the backward Lagrangian Stochastics (bLS) model and vertical radial plume mapping (VRPM), and hydrogen sulfide (H_2S) emissions, obtained using the bLS model only. The 2012 NAEMS data sets also included 30-minute data values for meteorological conditions (e.g., air temperature, relative humidity) for the dairy lagoon/basin and corral sites and lagoon/basin conditions (e.g., pH).

This appendix presents the analysis used to prepare the 2012 data for use in developing daily emissions estimating methodologies (EEMs) for dairy open sources. Section B.2.1 presents the original acceptance criteria, while Section B.2.2 presents the analysis of the revised bLS model acceptance criteria for dairy lagoons/basins and corrals. Section B.2.3 presents the processing and calculation steps followed to prepare the average daily emissions records from the NAEMS 30-minute data.

B.2.1 Acceptance Criteria of 2012 Data Sets

The 2012 bLS NH_3 data sets for lagoons and basins provided to EPA followed a set of acceptance criteria (i.e., all valid NH_3 bLS records meet these criteria), summarized in Table B-11. These criteria are the same criteria specified in Grant, et al. (2013). For bLS H_2S, the 2012 data sets for lagoons and basins reflect the acceptance criteria presented in Table B-12.

Table B-11. Summary of 2012 acceptance criteria for NH_3 bLS data for lagoons and basins.

Parameter	Acceptance Criteria
Monin-Obukov Length	Abs[>2 m]
Friction velocity (u*)	> 0.15 m/s
Standard deviation of wind direction	< 30°
Touchdown fraction	> 0.1
Background concentration	-0.1 to 0.1 ppmv

Table B-12. Summary of 2012 acceptance criteria for H_2S bLS data for lagoons and basins.

Parameter	Acceptance Criteria
Monin-Obukov Length	Abs[>2 m]
Friction velocity (u*)	> 0.15 m/s
Standard deviation of wind direction	< 30°
Touchdown fraction	> 0.1

However, it does not appear that the 2012 bLS H_2S data account for background concentration. Table B-13 shows the range of background concentrations for the valid bLS H_2S emissions records.

Table B-13. Summary of the effect of applying the negative emission cut-off to dairy barn data.

Site	Background Concentration Range
IN5A	-631.27 to 5,292.58 ppbv
WA5A	-377.79 to 757.18 ppbv
WI5A	-147.99 to 593.45 ppbv

The 2012 bLS NH_3 and H_2S data sets for TX5A provided to EPA reflect the acceptance criteria (i.e., all the valid emissions records meet these criteria) presented in Table B-14. However, all background concentration values for the valid bLS NH_3 and H_2S emissions records are 0.

Table B-14. Summary of 2012 acceptance criteria for NH_3 and H_2S bLS data for corrals.

Parameter	Acceptance Criteria
Monin-Obukov Length	Abs[>2 m]
Friction velocity (u*)	> 0.15 m/s
St dev of wind direction	< 30º
Touchdown fraction	> 0.1

B.2.2 Acceptance Criteria of Post-2012 Data Sets

For bLS NH3, increasing the touchdown fraction from > 0.1 to > 0.2 and revising the background concentration from a range to < 0.15 ppmv, as described in Grant and Boehm (2020), increases the number of available bLS NH_3 emissions records for IN5A (+ 225 records) and WI5A (+ 278 records). EPA assumed that the standard deviation of wind speed criteria remained < 30º (Grant and Boehm 2020 does not mention this criteria).

For bLS H_2S, reducing the touchdown fraction from > 0.1 to > 0.05 and revising the background concentration from a range to < 3.4 ppbv for WA5A, as described in Grant and Boehm (2015), decreases the number of available bLS H_2S emissions records for WA5A (- 55 records).

For bLS NH_3, increasing the Monin-Obukov length from Abs[>2 m] to Abs[>4 m] and the touchdown fraction from > 0.1 to > 0.4, and using 17 $\mu g/m^3$ as the background concentration criteria, as described in Grant, et al. (2020), decreases the number of available bLS NH_3 emissions records for TX5A (- 747 records).

B.2.2.1 NH_3 Emissions from Lagoons/Basins

Table B-15 presents the bLS NH_3 acceptance criteria applied by the NAEMS PI to the 2012 dairy lagoon/basin data sets of 30-minute emissions values and the revised acceptance criteria provided by EPA.

Table B-15. Dairy Lagoon/Basin Acceptance Criteria for the 2012 bLS NH_3 30-Minute Emissions Values

Parameter	Value	
	2012 Data Set	EPA Revised
Touchdown (TD) fraction	> 0.1	> 0.2
Background concentration (Cbg)	-0.1 < Cbg < 0.1	Cbg < 0.15
Standard deviation of wind direction (sigma-dir)	< 30	No change.
Friction velocity (u*)	> 0.15	No change.

Table B-16 presents the number of 30-minute bLS NH_3 emissions flux values available after applying the revised set of acceptance criteria shown in Table 2-1.

Table B-16. Number of Available 30-Minute bLS NH_3 Emissions Flux Values Based on the 2012 and Revised Acceptance Criteria

NAEMS Site	2012 Data Set	EPA Revised	Difference
IN5A	6,753	6,781	28
WA5A	153	269	116
WI5A	1,832	2,044	212

B.2.2.2 H_2S Emissions from Lagoons/Basins

Table B-17 presents the bLS H_2S acceptance criteria applied by the NAEMS PI to the 2012 dairy lagoon/basin data sets of 30-minute emissions values and the revised acceptance criteria provided by EPA.

Table B-17. Dairy Lagoon/Basin Acceptance Criteria for the 2012 bLS H2S 30-Minute Emissions Values

Parameter	Value	
	2012 Data Set	EPA Revised
TD fraction	> 0.1	> 0.05
Cbg	This parameter was not explicitly applied as an acceptance criterion in the 2012 data sets.	Cbg < 3.4
Sigma-dir	< 30	No change.
Wind direction attack angle (WD-Perp)	This parameter was not explicitly applied as an acceptance criterion in the 2012 data sets.	< 60
u*	> 0.15[a]	No change.

[a] The data header in the 2012 data sets says “<” rather than “>”.

Table B-18 presents the number of 30-minute bLS H_2S emissions flux values available after applying the revised set of acceptance criteria shown in Table B-17.

Table B-18. Number of Available 30- Minute bLS H_2S Emissions Flux Values Based on the 2012 and Revised Acceptance Criteria

NAEMS Site	2012 Data Set	EPA Revised	Difference
IN5A	5,338	4,668	-670
WA5A	501	407	-94
WI5A	1,658	1,099	-559

B.2.2.3 NH_3 Emissions from Corrals

Table B-19 presents the bLS NH_3 acceptance criteria applied by the NAEMS PI to the 2012 dairy corral data set of 30-minute emissions values and the revised acceptance criteria provided by EPA.

Table B-20 presents the number of 30-minute bLS NH_3 emissions flux values available after applying the revised set of acceptance criteria shown in Table B-19.

Table B-19. Dairy Corral Acceptance Criteria for the 2012 bLS NH_3 30-Minute Emissions

Parameter	Value	
	2012 Data Set	EPA Revised
TD fraction	> 0.1	> 0.4
Cbg	N/A[a]	N/A
Sigma-dir	< 30	No change.
u*	> 0.15[b]	No change.
M-O Length (absolute value)	> 2	> 4
Sigw homogeneity fraction (σ_W)	This parameter was not explicitly applied as an acceptance criterion in the 2012 data set.	< 0.4

[a] The Cbg criteria for NH_3 at TX5A is not applicable (N/A) because all values in the NAEMS data set provided to EPA are 0.
[b] The data header in the 2012 data sets says “<” rather than “>”.

Table B-20. Number of Available 30-Minute bLS NH_3 Emissions Flux Values Based on the 2012 and Revised Acceptance Criteria

Site	2012 Data Set	EPA Revised	Difference
TX5A	4,671	3,724	-947

B.2.2.4 H_2S Emissions from Corrals

Table B-21 presents the bLS H_2S acceptance criteria applied by the NAEMS PI to the 2012 dairy corral data set of 30-minute emissions values and the revised acceptance criteria provided by EPA.

Table B-21. Dairy Corral Acceptance Criteria for the 2012 bLS H_2S 30-Minute Emissions Values

Parameter	Value	
	2012 Data Set	EPA Revised
TD fraction	> 0.1	> 0.05
Cbg	N/A[a]	N/A
Sigma-dir	< 30	No change.
u*	> 0.15[b]	No change.
WD-Perp	This parameter was not explicitly applied as an acceptance criterion in the 2012 data set.	< 60
M-O Length (absolute value)	> 2	> 4
σ_W	This parameter was not explicitly applied as an acceptance criterion in the 2012 data set.	< 0.4

[a] The Cbg criteria for NH_3 at TX5A is not applicable (N/A) because all values in the NAEMS data set provided to EPA are 0.
[b] The data header in the 2012 data sets says "<" rather than ">".

Table B-22 presents the number of 30-minute bLS H_2S emissions flux values available after applying the revised set of acceptance criteria shown in Table B-21.

Table B-22. Number of Available 30-Minute bLS H_2S Emissions Flux Values Based on the 2012 and Revised Acceptance Criteria

Site	2012 Data Set	EPA Revised	Difference
TX5A	3,028	3,033	5

B.2.3 Calculation of Average Daily Values

To prepare the 2012 NAEMS data sets of 30-minute values for use in calculating daily averages, EPA adjusted the bLS NH_3 values for sites IN5A and WI5A by multiplying the emissions values by 1.19 (Grant & Boehm 2020) and 1.13 (Grant & Boehm 2020), respectively. Adjustments factors were not provided in literature for the bLS NH_3 values for the WA5A and TX5A sites. In cases where 30-minute emissions flux values were available for both the bLS model and VRPM, we used the average of the bLS and VRPM values. Table B-23 presents an example calculation for two days at site IN5A (one day with both bLS and VRPM data, and one day with data from only measurement methodology).

Table B-23. Example Calculation of Average NH3 Emissions for IN5A

Date and Time	Emissions Flux Data Values (g/s)			Average of VRPM and Adjusted bLS 30-min Values (g/s)
	2012 NAEMS		Adjusted	
	VRPM	bLS	bLS	
9/30/08 12:15 AM	0.450	0.630	0.750	0.600
9/30/08 12:45 AM	0.410	0.491	0.584	0.497
9/30/08 1:15 AM	0.420	0.474	0.564	0.492
9/30/08 4:15 AM	0.130	0.014	0.017	0.073
9/30/08 4:45 AM		0.064	0.076	0.076
9/30/08 6:15 AM	0.080	0.027	0.032	0.056
9/30/08 6:45 AM		0.040	0.047	0.047
9/30/08 7:15 AM		0.002	0.002	0.002
9/30/08 12:15 PM		0.037	0.044	0.044
9/30/08 12:45 PM		0.038	0.045	0.045
9/30/08 1:15 PM	0.110	0.090	0.107	0.108
9/30/08 1:45 PM	0.160	0.125	0.149	0.154
9/30/08 2:15 PM	0.130	0.139	0.165	0.148
9/30/08 2:45 PM	0.200	0.213	0.253	0.227
9/30/08 3:15 PM	0.140	0.166	0.198	0.169
9/30/08 4:15 PM	0.190	0.179	0.213	0.202
9/30/08 4:45 PM	0.190	0.169	0.201	0.196
9/30/08 5:15 PM	0.250	0.239	0.284	0.267
9/30/08 5:45 PM	0.240	0.236	0.281	0.260
9/30/08 6:45 PM	0.270	0.199	0.237	0.253
9/30/08 7:15 PM	0.350	0.341	0.406	0.378
9/30/08 7:45 PM		0.308	0.367	0.367
9/30/08 8:15 PM	0.370	0.560	0.666	0.518
9/30/08 9:15 PM		0.478	0.569	0.569
9/30/08 9:45 PM		0.553	0.658	0.658
9/30/08 10:15 PM	0.340	0.380	0.452	0.396
9/30/08 10:45 PM	0.370	0.479	0.570	0.470
9/30/08 11:45 PM	0.190	0.153	0.182	0.186
2/1/09 12:45 AM		0.115	0.137	0.137
2/1/09 1:15 AM		0.111	0.132	0.132
2/1/09 1:45 AM		0.071	0.085	0.085
2/1/09 2:15 AM		0.121	0.144	0.144
2/1/09 3:15 AM		0.113	0.134	0.134
2/1/09 3:45 AM		0.127	0.151	0.151
2/1/09 4:15 AM		0.111	0.132	0.132
2/1/09 4:45 AM		0.094	0.111	0.111
2/1/09 5:15 AM		0.137	0.163	0.163
2/1/09 5:45 AM		0.129	0.154	0.154
2/1/09 6:15 AM		0.154	0.183	0.183
2/1/09 6:45 AM		0.109	0.130	0.130
2/1/09 7:15 AM		0.098	0.117	0.117

Table B-23. Example Calculation of Average NH3 Emissions for IN5A

Date and Time	Emissions Flux Data Values (g/s)			Average of VRPM and Adjusted bLS 30-min Values (g/s)
	2012 NAEMS		Adjusted	
	VRPM	bLS	bLS	
2/1/09 7:45 AM		-0.006	-0.007	-0.007
2/1/09 8:15 AM		0.073	0.087	0.087
2/1/09 9:15 AM		0.085	0.101	0.101
2/1/09 9:45 AM		0.076	0.091	0.091
2/1/09 10:15 AM		0.051	0.060	0.060
2/1/09 10:45 AM		0.028	0.033	0.033
2/1/09 11:15 AM		0.013	0.015	0.015
2/1/09 11:45 AM		0.017	0.020	0.020
2/1/09 4:15 PM		0.032	0.038	0.038
2/1/09 5:15 PM		0.013	0.016	0.016
2/1/09 5:45 PM		0.004	0.005	0.005
2/1/09 6:45 PM		-0.003	-0.003	-0.003
2/1/09 7:15 PM		0.007	0.009	0.009
2/1/09 7:45 PM		-0.020	-0.024	-0.024
2/1/09 8:15 PM		-0.004	-0.005	-0.005
2/1/09 9:15 PM		-0.012	-0.014	-0.014
2/1/09 10:15 PM		-0.002	-0.003	-0.003
2/1/09 10:45 PM		-0.011	-0.012	-0.012
2/1/09 11:15 PM		0.003	0.004	0.004
2/1/09 11:45 PM		0.020	0.024	0.024

B.3 References

Grant, R. H., Boehm, M. T., & Lawrence, A. F. (2013). Comparison of a backward-Lagrangian stochastic and vertical radial plume mapping methods for estimating animal waste lagoon emissions. Agricultural and Forest Meteorology, 180, 236-248. doi:10.1016/j.agrformet.2013.06.013

Grant, R. H., & Boehm, M. T. (2015). Manure ammonia and hydrogen sulfide emissions from a Western dairy storage basin. J Environ Qual, 44(1), 127-136. doi:10.2134/jeq2014.05.0196

Grant, R. H., & Boehm, M. T. (2020). Ammonia Emissions from Differing Manure Storage Facilities at Two Midwestern Free-Stall Dairies. Atmosphere, 11(10), 1108. doi:10.3390/atmos11101108

Grant, R. H., Boehm, M. T., & Hagevoort, G. R. (2020). Ammonia Emissions from a Western Open-Lot Dairy. Atmosphere, 11(9), 913. doi:10.3390/atmos11090913

Heber A.J., Ni J-Q., Ramirez J.C., Schrock W., and Elkins J. 2008. Quality assurance project plan for the National Air Emissions Monitoring Study (barn component). Purdue University, West Lafayette, IN.

U.S. EPA Science Advisory Board (SAB), 2013. SAB Review of Emissions-Estimating Methodologies for Broiler Animal Feeding Operations and for Lagoons and Basins at Swine and Dairy Animal Feeding Operations, EPA-SAB-13-003.

Appendix C: Data Completeness

Table of Contents

List of Tables

List of Figures

C.1.1 Data Completeness Criteria for the Revised Data Set

The appropriate data completeness criteria to use in a study depends on the size of the dataset and the accuracy needed. A study by Grant et al. (2013), in which NH_3 emissions were modeled from swine lagoons based on NAEMS data, investigated data completeness and associated accuracy. The swine lagoon NH_3 emissions dataset had limited data availability at a data completeness of 75%. Grant et al. (2013) explored how much the data completeness criteria could be relaxed but still result in data with acceptable error. The study suggested an error of ±25% to be acceptable and determined that a daily data completeness of 52% (or 25 out of 48 30-minute periods) gave less than ±25% error (see Figure B-1). Using this relaxed daily completeness criteria resulted in a substantial increase in the size of the dataset.

Based on Figure C-1 from the Grant et al. (2013) study, it can be observed that a daily completeness criterion of 75% (36 out of 48 30-minute periods) would give an error of approximately 10%. If it is assumed that the relationship between data completeness and error from the Grant et al. (2013) study is representative of other NAEMS datasets, the effect of relaxed data completeness criteria can be investigated for other NAEMS sources.

The following sections examine the effect of a reduced data completeness criterion on the number of valid average daily means (ADM) for both the layer barns and manure shed, based on additional analysis completed by Heber that examined the effect of different completeness criteria by comparing the number of valid ADM.

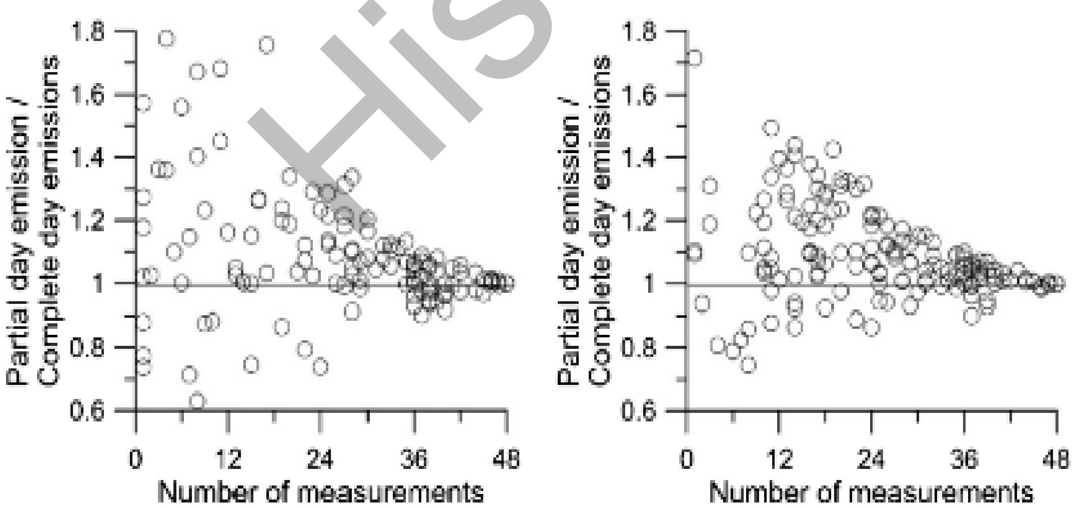


Figure C-1. Ratio of mean predicted emissions for portion of day with valid emissions measurements to mean predicted emissions for the complete day at the finishing (A) and sow (B) farm. Error plotted against number of valid 30-minute measurements (from Grant et al. 2013)

C.1.2 Data Completeness Review and Conclusions for Mechanically Ventilated Barns

The number of average daily means (ADM) for NH_3 emissions at varying percentages of data completeness for the revised data set are shown in Table C-1. For the mechanically ventilated site data set, decreasing the daily completeness criteria from 75% to 50% would increase the number of valid days by 397 (16.66 %). A summary of the ADM available for H_2S is provided in Table C-2. For H2S a shift to 50% completeness criteria would increase the ADM available by 391, a 14.66% increase. For the particulate matter size fractions, PM_{10} (Table C-3) would increase by 338 (18.73%), $PM_{2.5}$ (Table C-4) would increase by 29 (13.94%) and TSP (Table C-5) would increase by 99 (28.86%).

Based on the Grant et al. (2013) study there would be an approximate 15% increase in error with the shift to 50% completeness criteria. Since the small increase in the number of ADM values for mechanically ventilated barns does not justify the 15% increase in error, a daily completeness criterion of 75% was chosen for the revised mechanically ventilated data set.

Table C-1. The number of mechanically ventilated barn ADM for NH_3 at varying percentages of data completeness.

% Valid Data	0	10	20	30	40	50	60	70	75	80	90	100
IN5B B1	606	599	596	582	566	552	522	486	467	436	422	344
IN5B B2	613	608	605	592	578	562	530	495	478	446	434	356
NY5B B1	442	440	435	420	410	399	382	360	350	336	296	90
WI5B B1	697	696	692	682	664	641	613	585	564	549	525	314
WI5B B2	710	705	696	682	658	626	593	549	524	498	448	190
Total	**3068**	**3048**	**3024**	**2958**	**2876**	**2780**	**2640**	**2475**	**2383**	**2265**	**2125**	**1294**

Table C-2. The number of mechanically ventilated barn ADM for H_2S at varying percentages of data completeness.

% Valid Data	0	10	20	30	40	50	60	70	75	80	90	100
IN5B B1	638	634	629	616	596	586	566	540	521	489	477	388
IN5B B2	657	652	650	639	625	616	597	567	552	521	510	412
NY5B B1	608	603	646	578	567	546	516	480	467	443	392	140
WI5B B1	718	716	713	706	686	661	634	607	582	565	538	319
WI5B B2	732	725	717	703	680	649	616	572	545	518	465	198
Total	**3353**	**3330**	**3355**	**3242**	**3154**	**3058**	**2929**	**2766**	**2667**	**2536**	**2382**	**1457**

Table C-3. The number of mechanically ventilated barn ADM for PM_{10} at varying percentages of data completeness.

% Valid Data	0	10	20	30	40	50	60	70	75	80	90	100
IN5B B1	474	463	455	449	435	415	393	371	367	364	343	232
IN5B B2	426	422	414	409	398	379	365	351	348	339	323	205
NY5B B1	496	491	492	471	454	431	397	343	328	303	240	43
WI5B B1	534	528	526	516	500	469	437	416	400	391	359	181
WI5B B2	531	523	519	504	484	449	416	383	362	348	305	104
Total	**2461**	**2427**	**2406**	**2349**	**2271**	**2143**	**2008**	**1864**	**1805**	**1745**	**1570**	**765**

Table C-4. The number of mechanically ventilated barn ADM for $PM_{2.5}$ at varying percentages of data completeness.

% Valid Data	0	10	20	30	40	50	60	70	75	80	90	100
IN5B B1	42	41	39	36	33	32	31	29	28	27	27	22
IN5B B2	44	41	39	39	35	32	32	30	29	29	29	21
NY5B B1	70	69	68	66	65	60	56	56	53	52	43	1
WI5B B1	68	67	66	65	62	59	56	54	53	53	49	26
WI5B B2	67	66	64	60	56	54	47	47	45	45	42	16
Total	**291**	**284**	**276**	**266**	**251**	**237**	**222**	**216**	**208**	**206**	**190**	**86**

Table C-5. The number of mechanically ventilated barn ADM for TSP at varying percentages of data completeness.

% Valid Data	0	10	20	30	40	50	60	70	75	80	90	100
IN5B B1	105	104	102	99	93	86	77	77	77	77	74	57
IN5B B2	90	89	87	86	83	76	68	67	67	67	66	47
NY5B B1	62	61	89	59	54	77	48	42	41	37	35	12
WI5B B1	118	118	118	117	111	100	95	86	82	81	75	38
WI5B B2	130	130	126	124	118	103	87	78	76	73	59	22
Total	**505**	**502**	**522**	**485**	**459**	**442**	**375**	**350**	**343**	**335**	**309**	**176**

C.1.3 Data Completeness Review and Conclusions for Naturally Ventilated Barns

The number of ADM of NH_3 for the naturally ventilated barn revised data set are shown in Table C-6. The table shows decreasing the daily completeness criteria from 75% to 50% would increase the number of valid days by 630 (98.75 %). For H_2S (Table C-7), a shift to 50% completeness would increase ADM to 680, a 97.00% increase. For the particulate matter size fractions, PM_{10} (Table C-8) would increase by 108 (4.87%), $PM_{2.5}$ (Table C-9) by 7 (4.00%) and TSP (Table C-10) by 28 (13.59%).

EPA considered shifting the completeness criteria to 50% for the naturally ventilated barns. However, concerns about data quality at both CA5B and WA5B led to questions on whether the approximate 15% increase in error suggested by the Grant et al. (2013) study would hold for these sources or introduce more additional error. EPA elected to leave the completeness criteria at 75% at this time and will revisit prior to the finalization of the emission models.

Table C-6. The number of naturally ventilated barn ADM for NH_3 at varying percentages of data completeness.

% Valid Data	0	10	20	30	40	50	60	70	75	80	90	100
CA5B B1	524		486		399	349	282		191	160		9
CA5B B2	557		516		431	381	316		223	188		8
WA5B B2	562	504	458	410	359	294	270	158	125	96	43	1
WA5B B4	454	398	368	336	290	244	226	124	99	73	34	2
Total	**2097**	**902**	**1828**	**746**	**1479**	**1268**	**1094**	**282**	**638**	**517**	**77**	**20**

Table C-7. The number of naturally ventilated barn ADM for H_2S at varying percentages of data completeness.

% Valid Data	0	10	20	30	40	50	60	70	75	80	90	100
CA5B B1	550		510		420	367	296		212	175		9
CA5B B2	625		582		497	443	372		269	227		9
WA5B B2	626	545	501	449	385	314	283	158	116	87	41	1
WA5B B4	518	439	404	369	324	257	229	128	104	73	37	2
Total	**2319**	**984**	**1997**	**818**	**1626**	**1381**	**1180**	**286**	**701**	**562**	**78**	**21**

Table C-8. The number of naturally ventilated barn ADM for PM_{10} at varying percentages of data completeness.

% Valid Data	0	10	20	30	40	50	60	70	75	80	90	100
CA5B B1	563		560		553	547	531		520	517		332
CA5B B2	491		488		478	470	457		451	448		284
WA5B B2	513	513	511	506	499	482	466	455	452	450	447	373
WA5B B4	482	481	479	473	463	450	433	421	418	417	416	340
Total	**2049**	**994**	**2038**	**979**	**1993**	**1949**	**1887**	**876**	**1841**	**1832**	**863**	**1329**

Table C-9. The number of naturally ventilated ADM for $PM_{2.5}$ at varying percentages of data completeness.

% Valid Data	0	10	20	30	40	50	60	70	75	80	90	100
CA5B B1	60		57		52	48	48		47	46		27
CA5B B2	68		64		58	56	54		54	53		35
WA5B B2	44	43	43	42	42	39	38	37	37	37	37	32
WA5B B4	44	43	43	42	42	39	38	37	37	37	37	26
Total	**216**	**86**	**207**	**84**	**194**	**182**	**178**	**74**	**175**	**173**	**74**	**120**

Table C-10. The number of naturally ventilated barn ADM for TSP at varying percentages of data completeness.

% Valid Data	0	10	20	30	40	50	60	70	75	80	90	100
CA5B B1	88		85		82	81	75		71	71		49
CA5B B2	76		72		71	69	63		59	59		38
WA5B B2	53	52	52	52	51	42	39	38	38	38	37	34
WA5B B4	53	52	52	52	52	42	39	38	38	38	37	33
Total	**270**	**104**	**261**	**104**	**256**	**234**	**216**	**76**	**206**	**206**	**74**	**154**

C.1.4 Data Completeness Review and Conclusions for Milking Centers

The number of ADM for NH_3 emissions for the milking center revised data set at varying percentages of data completeness are shown in Table C-11. Decreasing the daily completeness criteria from 75% to 50% would increase the number of valid days by 74 (10.24 %) for NH3. Similarly, shifting to 50% completeness criteria would increase H_2S (Table C-12) ADM by 80 (8.41%), PM_{10} (Table C-13) by 43 (9.82%), $PM_{2.5}$ (Table C-14) by 4 (9.09%), and TSP (Table C-15) by 9 (21.43%). EPA decide the modest increases in available ADM obtained by decreasing the completeness criteria to 50% did not justify the approximate 15% increase in error estimated by the Grant et al. (2013) study. Therefore, a daily completeness criterion of 75% was chosen for the milking center data set.

Table C-11. The number of milking centers ADM for NH_3 at varying percentages of data completeness.

% Valid Data	0	10	20	30	40	50	60	70	75	80	90	100
IN5B MC	423	422	420	414	402	387	373	350	338	301	300	259
NY5B MC	432	430	430	427	419	410	404	393	385	381	358	153
Total	**855**	**852**	**850**	**841**	**821**	**797**	**777**	**743**	**723**	**682**	**658**	**412**

Table C-12. The number of milking centers ADM for H_2S at varying percentages of data completeness.

% Valid Data	0	10	20	30	40	50	60	70	75	80	90	100
IN5B MC	480	479	477	474	463	447	434	412	400	368	366	317
NY5B MC	608	606	654	601	592	584	576	562	551	545	520	225
Total	**1088**	**1085**	**1131**	**1075**	**1055**	**1031**	**1010**	**974**	**951**	**913**	**886**	**542**

Table C-13. The number of milking centers ADM for PM_{10} at varying percentages of data completeness.

% Valid Data	0	10	20	30	40	50	60	70	75	80	90	100
IN5B MC												
NY5B MC	510	507	511	499	490	481	465	448	438	431	400	148
Total	**510**	**507**	**511**	**499**	**490**	**481**	**465**	**448**	**438**	**431**	**400**	**148**

Table C-14. The number of milking centers ADM for $PM_{2.5}$ at varying percentages of data completeness.

% Valid Data	0	10	20	30	40	50	60	70	75	80	90	100
IN5B MC												
NY5B MC	50	50	50	49	48	48	44	44	44	44	43	6
Total	**50**	**50**	**50**	**49**	**48**	**48**	**44**	**44**	**44**	**44**	**43**	**6**

Table C-15. The number of milking centers ADM for TSP at varying percentages of data completeness.

% Valid Data	0	10	20	30	40	50	60	70	75	80	90	100
IN5B MC												
NY5B MC	61	61	89	59	53	51	49	43	42	40	36	15
Total	**61**	**61**	**89**	**59**	**53**	**51**	**49**	**43**	**42**	**40**	**36**	**15**

C.1.5 Data Completeness Review and Conclusions for Open Sources

For lagoons and basins, the number of ADM for NH_3 (Table C-16) increased by 84 (118%) when considering the combined bLS and VRPM dataset. For H_2S (Table C-17), where there are only bLS estimates, the number of ADM increased by 56 (266%) when looking at all three sites combined. For corrals (Table C-18), the number of NH_3 ADM increased by 41 (66.13%) and H_2S ADM increased to 25 (119.05%) when shifting to 52% completeness criteria. For all the open sources, EPA concluded the increases in available ADM obtained by decreasing the completeness criteria to 52% did justify the approximate 15% increase in error estimated by the Grant et al. (2013) study. Therefore, a daily completeness criterion of 52% was chosen for all the open source types.

Table C-16. The number of lagoon and basin ADM for NH_3 at varying percentages of data completeness.

Percent Completeness	ADM by NAEMS Site								
	IN5A			WA5A			WI5A		
	bLS	VRPM	bLS or VRPM	bLS	VRPM	bLS or VRPM	bLS	VRPM	bLS or VRPM
0%	281	215	283	42	58	71	113	77	124
52%	110	71	131	0	2	2	22	1	22
75%*	49	18	59	0	0	0	12	1	12

Table C-17. The number of lagoon and basin ADM for H_2S at varying percentages of data completeness.

Percent Completeness	ADM by NAEMS Site		
	IN5A	WA5A	WI5A
0%	303	61	77
52%	59	1	17
75%*	17	0	4

Table C-18. The number of corral ADM for NH_3 at varying percentages of data completeness.

Percent Completeness	NH3	H2S
0%	163	140
52%	103	46
75%*	62	21

C.2 Reference

Grant, R.H., Boehm, M.T., Lawrence, A.F., & Heber, A.J. (2013). Ammonia emissions from anaerobic treatment lagoons at sow and finishing farms in Oklahoma. Agricultural and Forest Meteorology 180, 203-210

Appendix D: Summary Statistics

Table of Contents

List of Tables

D.1 Mechanically Ventilated Barns

D.1.1 Emissions

Table D-1. NH_3 emission summary statistics for mechanically ventilated dairy barns (kg d^{-1}).

Statistic	IN5B-B1	IN5B-B2	NY5B-B1	WI5B-B1	WI5B-B2
Mean	40.34	39.79	21.69	8.58	11.22
Std Dev	25.27	24.10	8.09	2.83	4.56
Median	33.71	34.47	20.17	8.22	10.74
Minimum	3.42	3.03	6.81	3.75	3.37
Maximum	122.62	119.73	45.26	19.14	26.55
N	467	478	350	564	524
N<0	0	0	0	0	0
N>0	467	478	350	564	524
Q25	20.85	19.90	15.14	6.64	7.64
Q75	59.57	56.54	27.45	10.26	14.13
CV	0.63	0.61	0.37	0.33	0.41

Table D-2. NH_3 emission summary statistics for mechanically ventilated dairy barns (g d^{-1} hd^{-1}).

Statistic	IN5B-B1	IN5B-B2	NY5B-B1	WI5B-B1	WI5B-B2
Mean	48.28	46.02	46.12	41.37	31.35
Std Dev	30.04	27.91	17.34	15.07	12.19
Median	40.32	39.29	43.35	38.97	30.34
Minimum	4.32	3.72	14.40	17.76	9.93
Maximum	142.91	140.20	99.43	102.90	70.59
N	467	478	348	564	524
N<0	0	0	0	0	0
N>0	467	478	348	564	524
Q25	25.23	23.59	32.57	30.99	21.79
Q75	71.46	65.38	58.47	48.98	39.36
CV	0.62	0.61	0.38	0.36	0.39

Table D-3. H_2S emission summary statistics for mechanically ventilated dairy barns (g d^{-1}).

Statistic	IN5B-B1	IN5B-B2	NY5B-B1	WI5B-B1	WI5B-B2
Mean	741.75	1,067.52	523.69	1,044.63	863.83
Std Dev	949.82	1,500.87	430.82	1,296.09	1,076.46
Median	228.50	463.35	378.91	385.90	234.90
Minimum	-284.20	-226.60	34.05	-14.60	-204.80
Maximum	5,809.50	11,093.10	2,183.82	8,195.10	5,311.90
N	521	552	467	582	545
N<0	49	24	0	3	8
N>0	472	528	467	579	537
Q25	48.70	85.50	165.46	67.68	72.90
Q75	1,380.80	1,519.30	815.87	1,654.68	1,470.30
CV	1.28	1.41	0.82	1.24	1.25

Table D-4. H_2S emission summary statistics for mechanically ventilated dairy barns (mg d^{-1} hd^{-1}).

Statistic	IN5B-B1	IN5B-B2	NY5B-B1	WI5B-B1	WI5B-B2
Mean	882.68	1,227.17	1,117.85	4,959.69	2,430.89
Std Dev	1,123.02	1,715.62	917.68	6,137.03	3,033.68
Median	272.86	543.04	816.72	1,803.41	663.56
Minimum	-356.06	-261.36	72.59	-69.19	-576.90
Maximum	6,685.27	12,605.80	4,810.18	38,839.34	14,963.10
N	521	552	465	582	545
N<0	49	24	0	3	8
N>0	472	528	465	579	537
Q25	56.43	99.94	348.01	317.31	208.38
Q75	1,694.23	1,789.39	1,731.89	7,842.06	4,141.69
CV	1.27	1.40	0.82	1.24	1.25

Table D-5. PM_{10} emission summary statistics for mechanically ventilated dairy barns (g d^{-1}).

Statistic	IN5B-B1	IN5B-B2	NY5B-B1	WI5B-B1	WI5B-B2
Mean	9.73	130.40	223.73	363.37	562.91
Std Dev	236.15	209.40	337.46	578.04	818.39
Median	18.10	141.52	72.89	117.65	169.16
Minimum	-1,376.97	-1,161.89	-406.14	-553.04	-462.86
Maximum	2,069.94	1,083.87	2,101.45	3,888.47	4,553.70
N	367	348	328	400	362
N<0	158	71	8	37	9
N>0	209	277	320	363	353
Q25	-82.23	20.08	41.10	50.09	81.16
Q75	109.19	230.37	266.11	349.08	709.92
CV	24.26	1.61	1.51	1.59	1.45

Table D-6. PM_{10} emission summary statistics for mechanically ventilated dairy barns (mg d^{-1} hd^{-1}).

Statistic	IN5B-B1	IN5B-B2	NY5B-B1	WI5B-B1	WI5B-B2
Mean	12.49	150.98	484.46	1,751.03	1,571.90
Std Dev	282.64	240.94	730.05	2,761.49	2,283.70
Median	20.97	162.03	153.71	548.83	483.51
Minimum	-1,625.70	-1,311.39	-858.64	-2,621.05	-1,168.84
Maximum	2,530.49	1,266.20	4,424.10	17,594.87	12,827.33
N	367	348	326	400	362
N<0	158	71	8	37	9
N>0	209	277	318	363	353
Q25	-97.97	24.26	87.53	237.40	233.43
Q75	132.50	263.25	572.32	1,692.10	1,927.75
CV	22.62	1.60	1.51	1.58	1.45

Table D-7. $PM_{2.5}$ emission summary statistics for mechanically ventilated dairy barns (g d^{-1}).

Statistic	IN5B-B1	IN5B-B2	NY5B-B1	WI5B-B1	WI5B-B2
Mean	21.18	44.96	36.66	141.51	186.74
Std Dev	114.16	129.13	29.81	145.45	203.76
Median	32.61	69.94	27.52	86.92	95.71
Minimum	-329.99	-304.84	-3.16	-27.13	-4.26
Maximum	208.10	206.93	113.84	538.99	805.76
N	28	29	53	53	45
N<0	11	10	2	7	1
N>0	17	19	51	46	44
Q25	-30.32	-21.95	11.36	26.37	33.73
Q75	103.66	147.51	59.75	217.78	265.95
CV	5.39	2.87	0.81	1.03	1.09

Table D-8. $PM_{2.5}$ emission summary statistics for mechanically ventilated dairy barns (mg d^{-1} hd^{-1}).

Statistic	IN5B-B1	IN5B-B2	NY5B-B1	WI5B-B1	WI5B-B2
Mean	25.89	52.40	77.60	662.17	529.22
Std Dev	139.99	151.79	62.99	672.35	576.34
Median	39.17	81.80	60.21	413.36	275.03
Minimum	-406.89	-360.33	-6.56	-128.58	-12.58
Maximum	255.96	239.78	240.69	2,427.87	2,269.74
N	28	29	53	53	45
N<0	11	10	2	7	1
N>0	17	19	51	46	44
Q25	-35.79	-25.82	23.97	124.95	99.20
Q75	126.96	172.22	126.32	981.01	749.17
CV	5.41	2.90	0.81	1.02	1.09

Table D-9. TSP emission summary statistics for mechanically ventilated dairy barns (g d^{-1}).

Statistic	IN5B-B1	IN5B-B2	NY5B-B1	WI5B-B1	WI5B-B2
Mean	347.60	328.95	218.66	849.92	878.88
Std Dev	333.86	273.76	308.10	827.35	943.01
Median	310.35	267.19	208.45	505.92	451.11
Minimum	-158.33	-88.83	-505.43	-450.25	14.99
Maximum	1,841.13	1,225.92	1,572.59	3,302.96	4,198.23
N	77	67	41	82	76
N<0	9	2	5	6	0
N>0	68	65	36	76	76
Q25	95.63	127.69	100.53	286.11	254.70
Q75	531.98	437.08	285.95	1,615.04	1,173.63
CV	0.96	0.83	1.41	0.97	1.07

Table D-10. TSP emission summary statistics for mechanically ventilated dairy barns (mg d^{-1} hd^{-1}).

Statistic	IN5B-B1	IN5B-B2	NY5B-B1	WI5B-B1	WI5B-B2
Mean	423.48	385.29	466.35	4,195.58	2,436.47
Std Dev	406.65	317.70	654.51	4,161.36	2,600.30
Median	390.40	325.05	452.18	2,597.63	1,290.02
Minimum	-188.48	-101.17	-1,061.83	-2,133.91	42.23
Maximum	2,248.03	1,410.72	3,338.84	17,853.82	11,826.00
N	77	67	41	82	76
N<0	9	2	5	6	0
N>0	68	65	36	76	76
Q25	113.30	146.73	217.59	1,408.67	701.60
Q75	654.34	519.21	583.12	7,785.34	3,169.67
CV	0.96	0.82	1.40	0.99	1.07

D.1.2 Environmental

Table D-11. Environmental parameter summary statistics for mechanically ventilated dairy barns.

Parameter	Statistic	IN5B-B1	IN5B-B2	NY5B-B1	WI5B-B1	WI5B-B2
Inventory (hd)	Mean	833.33	863.76	466.99	211.12	354.52
	Std Dev	21.95	17.2	11.14	9.9	14.43
	Median	836	866	467	211	355
	Minimum	767	789	435	183	324
	Maximum	883	901	503	236	398
	N	761	761	728	783	783
	N<0	0	0	0	0	0
	N>0	761	761	728	783	783
	Q25	818	854	460	211	345.5
	Q75	851	876	474	216	355
	CV	0.03	0.02	0.02	0.05	0.04
Average Animal Mass (kg)	Mean	635	635	577.71	703	703
	Std Dev			0.8		
	Median			578		
	Minimum			576		
	Maximum			580		
	N			728		
	N<0			0		
	N>0			728		
	Q25			577		
	Q75			578		
	CV			0		
Live animal weight (Mg)	Mean	529.17	548.49	269.79	148.42	249.23
	Std Dev	13.94	10.92	6.45	6.97	10.16
	Median	530.86	549.91	269.93	148.33	249.57
	Minimum	487.05	501.02	251.87	128.65	227.77
	Maximum	560.71	572.14	291.24	165.91	279.79
	N	761	761	728	781	781
	N<0	0	0	0	0	0
	N>0	761	761	728	781	781
	Q25	519.43	542.29	265.18	148.33	242.54
	Q75	540.39	556.26	273.97	151.85	249.57
	CV	0.03	0.02	0.02	0.05	0.04
Exhaust Temperature (°C)	Mean	11.78	12.16	12.89	10.56	10.55
	Std Dev	8.25	8.08	6.51	8.29	8.47
	Median	12.9	13.1	12.6	10.6	10.7
	Minimum	-9.9	-9.2	-1.8	-6.3	-7.4
	Maximum	26.4	26.8	28.6	25.8	26.4
	N	721	721	701	723	723
	N<0	66	58	6	92	102
	N>0	655	663	695	631	621
	Q25	5.3	5.9	7.6	3.6	3.5
	Q75	18.6	18.9	18.3	18.1	18.4
	CV	0.7	0.66	0.51	0.79	0.8

Parameter	Statistic	IN5B-B1	IN5B-B2	NY5B-B1	WI5B-B1	WI5B-B2
Exhaust Relative Humidity (%)	Mean	74.97	75.38	72.79	69	66.79
	Std Dev	7.36	7.37	7.5	9.36	10.41
	Median	75.3	75.5	73.7	70.5	67.9
	Minimum	53.2	53.9	39.3	37.6	30.9
	Maximum	89.5	88.1	86.9	85.5	87.8
	N	714	717	683	644	705
	N<0	0	0	0	0	0
	N>0	714	717	683	644	705
	Q25	69.6	70	68.9	63.6	60.6
	Q75	81.3	81.9	77.7	76.1	73.7
	CV	0.1	0.1	0.1	0.14	0.16
Airflow (dsm^3s^{-1})	Mean	210.14	204.68	135.03	131.28	150.04
	Std Dev	56.09	58.96	107.61	87.81	105.16
	Median	244.00	238.00	103.00	116.00	134.00
	Minimum	67.70	47.00	20.00	16.90	26.10
	Maximum	286.00	278.00	312.00	355.00	378.00
	N	673	693	649	630	589
	N<0	0	0	0	0	0
	N>0	673	693	649	630	589
	Q25	146	144	33.3	49.025	40
	Q75	256.00	252.00	251.00	200.75	234.00
	CV	0.27	0.29	0.80	0.67	0.70

D.1.3 Ambient

Table D-12. Ambient parameter summary statistics for mechanically ventilated dairy barns.

Parameter	Statistic	IN5B	NY5B	WI5B
Ambient Temperature (°C)	Mean	12.20	11.13	7.21
	Std Dev	10.43	10.11	12.08
	Median	14.7	11.7	9.0
	Minimum	-22.4	-11.5	-23.5
	Maximum	29.4	31.6	27.9
	N	663	692	672
	N<0	110	116	192
	N>0	553	576	480
	Q25	3.8	2.6	-1.4
	Q75	21.2	20.2	17.9
	CV	0.85	0.91	1.67
Ambient Relative Humidity (%)	Mean	67.90	67.81	68.40
	Std Dev	8.31	10.56	11.39
	Median	68.7	68.9	69.5
	Minimum	40.7	29.4	24.4
	Maximum	93.0	91.8	91.7
	N	673	674	672
	N<0	0	0	0
	N>0	673	674	672
	Q25	62.4	61.0	61.9
	Q75	73.8	75.3	76.0
	CV	0.12	0.16	0.17

D.2 Milking Centers

D.2.1 Emissions

Table D-13. NH_3 emission summary statistics for milking centers (kg d^{-1}).

Statistic	IN5B-MC	NY5B-MC
Mean	8.81	5.76
Std Dev	7.35	2.07
Median	7.36	5.68
Minimum	-0.66	1.27
Maximum	35.89	13.69
N	338	385
N<0	13	0
N>0	325	385
Q25	2.37	4.31
Q75	14.26	6.93
CV	0.83	0.36

Table D-14. NH_3 emission summary statistics for milking centers (g d^{-1} hd^{-1}).

Statistic	IN5B-MC	NY5B-MC
Mean	15.67	30.29
Std Dev	13.08	10.92
Median	13.10	29.87
Minimum	-1.17	6.66
Maximum	63.87	72.07
N	338	385
N<0	13	0
N>0	325	385
Q25	4.21	22.68
Q75	25.37	36.45
CV	0.83	0.36

Table D-15. H_2S emission summary statistics for milking centers (g d^{-1}).

Statistic	IN5B-MC	NY5B-MC
Mean	1,207.31	129.49
Std Dev	2,122.15	113.00
Median	305.05	92.13
Minimum	-478.50	7.20
Maximum	17,787.00	628.84
N	400	551
N<0	79	0
N>0	321	551
Q25	12.90	46.04
Q75	1,816.55	170.65
CV	1.76	0.87

Table D-16. H_2S emission summary statistics for milking centers (mg d^{-1} hd^{-1}).

Statistic	IN5B-MC	NY5B-MC
Mean	2,148.23	681.54
Std Dev	3,776.07	594.75
Median	542.79	484.91
Minimum	-851.42	37.90
Maximum	31,649.47	3,309.71
N	400	551
N<0	79	0
N>0	321	551
Q25	22.95	242.32
Q75	3,232.30	898.16
CV	1.76	0.87

Table D-17. PM emission summary statistics for milking centers (g d^{-1}).

Statistic	NY5B-MC, PM10	NY5B-MC, PM2.5	NY5B-MC, TSP
Mean	89.97	26.56	115.88
Std Dev	73.40	27.50	95.69
Median	65.31	23.70	100.22
Minimum	-81.12	2.80	-79.12
Maximum	484.51	188.76	321.67
N	438	44	42
N<0	3	0	3
N>0	435	44	39
Q25	41.86	13.53	50.29
Q75	113.41	29.49	182.55
CV	0.82	1.04	0.83

Table D-18. PM emission summary statistics for milking centers (mg d^{-1} hd^{-1}).

Statistic	NY5B-MC, PM10	NY5B-MC, PM2.5	NY5B-MC, TSP
Mean	473.52	139.78	609.90
Std Dev	386.31	144.73	503.63
Median	343.71	124.76	527.46
Minimum	-426.93	14.72	-416.41
Maximum	2,550.03	993.45	1,692.99
N	438	44	42
N<0	3	0	3
N>0	435	44	39
Q25	220.29	71.23	264.71
Q75	596.88	155.21	960.77
CV	0.82	1.04	0.83

D.2.2 Environmental

Table D-19. Environmental parameter summary statistics for milking centers.

Parameter	Statistic	IN5B-MC	NY5B-MC
Inventory (hd)	Mean	72	190
Average Animal Mass (kg)	Mean	635	577.71
	Std Dev		0.80
	Median		578.0
	Minimum		576.0
	Maximum		580.0
	N		728
	N<0		0
	N>0		728
	Q25		577.0
	Q75		578.0
	CV		0.00
Live animal weight (kg)	Mean	356.87	109.76
	Std Dev	.00	0.15
	Median	356.87	109.82
	Minimum	356.87	109.44
	Maximum	356.87	110.20
	N	761	728
	N<0	0	0
	N>0	761	728
	Q25	356.87	109.63
	Q75	356.87	109.82
	CV	0.00	0.00
Exhaust Temperature (°C)	Mean	13.21	12.83
	Std Dev	7.66	6.76
	Median	14.8	12.4
	Minimum	-7.0	-4.6
	Maximum	27.1	28.8
	N	721	701
	N<0	28	9
	N>0	693	692
	Q25	6.2	7.3
	Q75	19.5	18.5
	CV	0.58	0.53
Exhaust Relative Humidity (%)	Mean	74.18	73.81
	Std Dev	10.64	8.45
	Median	75.2	74.2
	Minimum	41.1	30.7
	Maximum	92.7	91.0
	N	697	547
	N<0	0	0
	N>0	697	547
	Q25	67.1	69.7
	Q75	83.4	79.9

Parameter	Statistic	IN5B-MC	NY5B-MC
	CV	0.14	0.11
Airflow (dsm3s-1)	Mean	183.33	39.90
	Std Dev	43.13	26.40
	Median	200.00	35.60
	Minimum	74.10	6.70
	Maximum	241.00	84.40
	N	471	692
	N<0	0	0
	N>0	471	692
	Q25	148.5	15.7
	Q75	220.00	73.00
	CV	0.24	0.66

D.2.3 Ambient

Table D-20. Ambient parameter summary statistics for milking centers.

Parameter	Statistic	IN5B	NY5B
Ambient Temperature (°C)	Mean	12.20	11.13
	Std Dev	10.43	10.11
	Median	14.7	11.7
	Minimum	-22.4	-11.5
	Maximum	29.4	31.6
	N	663	692
	N<0	110	116
	N>0	553	576
	Q25	3.8	2.6
	Q75	21.2	20.2
	CV	0.85	0.91
Ambient Relative Humidity (%)	Mean	67.90	67.81
	Std Dev	8.31	10.56
	Median	68.7	68.9
	Minimum	40.7	29.4
	Maximum	93.0	91.8
	N	673	674
	N<0	0	0
	N>0	673	674
	Q25	62.4	61.0
	Q75	73.8	75.3
	CV	0.12	0.16

D.3 Naturally Ventilated Barns

D.3.1 Emissions

Table D-21. NH_3 emission summary statistics for naturally ventilated dairy barns (kg d^{-1}).

Statistic	CA5B-B1	CA5B-B2	WA5B-B2	WA5B-B4
Mean	2.95	2.76	26.60	54.65
Std Dev	4.11	3.76	29.43	31.64
Median	2.54	2.67	21.91	45.13
Minimum	-8.57	-10.80	-156.36	9.03
Maximum	21.20	15.40	96.60	170.93
N	191	223	125	99
N<0	37	42	2	0
N>0	154	181	123	99
Q25	0.61	0.59	12.89	31.83
Q75	4.92	4.77	36.98	70.84
CV	1.39	1.36	1.11	0.58

Table D-22. NH_3 emission summary statistics for naturally ventilated dairy barns (g d^{-1} hd^{-1}).

Statistic	CA5B-B1	CA5B-B2	WA5B-B2	WA5B-B4
Mean	5.59	4.98	51.69	56.51
Std Dev	7.76	6.75	57.53	33.20
Median	5.01	4.83	41.49	47.99
Minimum	-18.20	-19.64	-305.38	9.48
Maximum	36.93	28.71	188.67	174.24
N	191	223	125	99
N<0	37	42	2	0
N>0	154	181	123	99
Q25	1.11	1.09	25.15	33.31
Q75	9.85	8.63	71.38	72.51
CV	1.39	1.36	1.11	0.59

Table D-23. H_2S emission summary statistics for naturally ventilated dairy barns ($g\ d^{-1}$).

Statistic	CA5B-B1	CA5B-B2	WA5B-B2	WA5B-B4
Mean	487.15	669.69	555.61	1,130.95
Std Dev	741.02	515.83	1,746.24	3,503.40
Median	569.50	680.00	192.14	690.94
Minimum	-2,420.00	-609.00	-5,400.93	-11,640.14
Maximum	3,780.00	2,640.00	6,513.61	17,960.29
N	212	269	116	104
N<0	37	18	45	30
N>0	175	251	71	74
Q25	97.28	316.00	-224.53	-204.79
Q75	838.50	927.00	1,058.48	2,099.26
CV	1.52	0.77	3.14	3.10

Table D-24. H_2S emission summary statistics for naturally ventilated dairy barns ($mg\ d^{-1}\ hd^{-1}$).

Statistic	CA5B-B1	CA5B-B2	WA5B-B2	WA5B-B4
Mean	963.53	1,209.21	1,082.24	1,145.11
Std Dev	1,454.39	941.36	3,406.70	3,579.39
Median	1,148.73	1,255.81	373.21	693.25
Minimum	-4,708.17	-1,067.03	-10,548.68	-12,291.59
Maximum	7,354.09	4,817.52	12,721.89	17,888.74
N	212	269	116	104
N<0	37	18	45	30
N>0	175	251	71	74
Q25	183.69	530.88	-426.06	-217.13
Q75	1,647.26	1,693.63	2,027.32	2,176.33
CV	1.51	0.78	3.15	3.13

Table D-25. PM_{10} emission summary statistics for naturally ventilated dairy barns ($g\ d^{-1}$).

Statistic	CA5B-B1	CA5B-B2	WA5B-B2	WA5B-B4
Mean	-325.80	593.25	4,497.74	11,391.71
Std Dev	1,108.87	2,144.54	17,839.79	24,574.35
Median	-302.00	11.60	1,590.37	4,958.78
Minimum	-5,730.00	-7,730.00	-20,331.95	-7,473.60
Maximum	6,140.00	14,400.00	353,457.48	367,744.48
N	520	451	452	418
N<0	372	221	53	14
N>0	148	230	399	404
Q25	-797.25	-373.50	640.75	1,342.88
Q75	90.50	1,035.00	5,104.78	13,052.63
CV	-3.40	3.61	3.97	2.16

Table D-26. PM_{10} emission summary statistics for naturally ventilated dairy barns ($mg\ d^{-1}\ hd^{-1}$).

Statistic	CA5B-B1	CA5B-B2	WA5B-B2	WA5B-B4
Mean	-636.79	1,040.62	8,711.99	11,794.47
Std Dev	2,120.47	3,785.44	34,798.09	25,929.03
Median	-596.11	20.21	3,049.49	5,077.18
Minimum	-11,147.86	-13,513.99	-40,909.35	-7,633.91
Maximum	11,455.22	26,815.64	690,346.65	392,470.09
N	520	451	452	418
N<0	372	221	53	14
N>0	148	230	399	404
Q25	-1,470.78	-666.53	1,254.50	1,443.15
Q75	170.73	1,942.62	9,942.48	13,316.10
CV	-3.33	3.64	3.99	2.20

Table D-27. $PM_{2.5}$ emission summary statistics for naturally ventilated dairy barns ($g\ d^{-1}$).

Statistic	CA5B-B1	CA5B-B2	WA5B-B2	WA5B-B4
Mean	-905.01	-607.24	2,719.21	1,863.35
Std Dev	1,422.96	1,570.36	1,828.35	1,779.09
Median	-574.00	-303.00	2,818.24	1,362.29
Minimum	-9,200.00	-9,930.00	347.76	-676.29
Maximum	101.00	458.00	7,247.60	6,474.69
N	47	54	37	37
N<0	44	40	0	6
N>0	3	14	37	31
Q25	-919.50	-583.25	1,197.81	681.90
Q75	-338.50	28.33	3,632.30	3,090.90
CV	-1.57	-2.59	0.67	0.95

Table D-28. $PM_{2.5}$ emission summary statistics for naturally ventilated dairy barns ($mg\ d^{-1}\ hd^{-1}$).

Statistic	CA5B-B1	CA5B-B2	WA5B-B2	WA5B-B4
Mean	-1,831.84	-1,164.93	5,250.37	1,903.81
Std Dev	3,028.26	3,049.97	3,509.23	1,819.72
Median	-1,125.49	-568.84	5,504.37	1,314.33
Minimum	-19,532.91	-19,356.73	679.22	-679.00
Maximum	196.50	825.23	13,991.51	6,829.84
N	47	54	37	37
N<0	44	40	0	6
N>0	3	14	37	31
Q25	-1,823.11	-1,056.61	2,330.37	669.18
Q75	-669.58	41.87	6,958.43	3,263.89
CV	-1.65	-2.62	0.67	0.96

Table D-29. TSP emission summary statistics for naturally ventilated dairy barns ($g\ d^{-1}$).

Statistic	CA5B-B1	CA5B-B2	WA5B-B2	WA5B-B4
Mean	4,766.04	8,132.82	19,331.70	47,389.03
Std Dev	7,250.11	8,706.46	25,603.35	71,484.69
Median	2,530.00	5,580.00	8,286.13	25,605.49
Minimum	-2,060.00	-236.00	1,413.48	4,817.02
Maximum	45,700.00	43,400.00	122,272.14	374,175.36
N	71	59	38	38
N<0	7	4	0	0
N>0	64	55	38	38
Q25	570.00	1,615.00	4,547.87	9,331.36
Q75	6,530.00	13,550.00	25,279.09	51,921.98
CV	1.52	1.07	1.32	1.51

Table D-30. TSP emission summary statistics for naturally ventilated dairy barns ($mg\ d^{-1}\ hd^{-1}$).

Statistic	CA5B-B1	CA5B-B2	WA5B-B2	WA5B-B4
Mean	9,113.52	14,642.34	37,190.29	49,099.58
Std Dev	13,726.86	15,653.06	48,828.63	74,726.49
Median	4,922.18	10,730.77	16,143.11	25,774.94
Minimum	-4,364.41	-425.99	2,760.70	5,007.30
Maximum	86,389.41	81,886.79	230,702.15	388,551.77
N	71	59	38	38
N<0	7	4	0	0
N>0	64	55	38	38
Q25	1,108.95	2,909.91	8,745.90	8,889.25
Q75	12,783.26	22,666.73	48,836.86	54,748.26
CV	1.51	1.07	1.31	1.52

D.3.2 Environmental

Table D-31. Environmental parameter summary statistics for naturally ventilated dairy barns.

Parameter	Statistic	CA5B-B1	CA5B-B2	WA5B-B2	WA5B-B4
Inventory (hd)	Mean	519.19	558.07	513.83	963.20
	Std Dev	39.80	26.62	7.20	48.98
	Median	519.0	555.0	512.0	961.0
	Minimum	416.0	501.0	492.0	739.0
	Maximum	588.0	607.0	530.0	1066.0
	N	859	859	734	734
	N<0	0	0	0	0
	N>0	859	859	734	734
	Q25	506.5	540.0	512.0	937.0
	Q75	548.5	580.5	517.0	993.8
	CV	0.08	0.05	0.01	0.05
Average Animal Mass (kg)	Mean	635	635	635	635
Live animal weight (Mg)	Mean	329.68	354.37	326.28	611.63
	Std Dev	25.27	16.90	4.57	31.10
	Median	329.57	352.43	325.12	610.24
	Minimum	264.16	318.14	312.42	469.27
	Maximum	373.38	385.45	336.55	676.91
	N	859	859	734	734
	N<0	0	0	0	0
	N>0	859	859	734	734
	Q25	321.63	342.90	325.12	595.00
	Q75	348.30	368.62	328.30	631.03
	CV	0.08	0.05	0.01	0.05
Exhaust Temperature (°C)	Mean	18.75	18.00	11.41	11.90
	Std Dev	6.67	6.62	8.89	8.00
	Median	18.8	17.4	10.4	10.8
	Minimum	5.2	5.0	-12.1	-5.6
	Maximum	34.5	33.9	31.9	31.3
	N	673	795	613	590
	N<0	0	0	49	28
	N>0	673	795	564	562
	Q25	13.2	12.4	5.0	6.1
	Q75	24.5	23.6	18.6	17.7
	CV	0.36	0.37	0.78	0.67
Exhaust Relative Humidity (%)	Mean	58.49	57.89	45.86	45.16
	Std Dev	13.87	13.09	13.79	13.70
	Median	58.2	57.0	44.0	43.2
	Minimum	28.0	27.6	0.0	0.0
	Maximum	88.4	84.8	80.2	78.6
	N	704	796	678	678
	N<0	0	0	0	0
	N>0	704	796	678	678
	Q25	47.2	47.6	36.4	35.5
	Q75	69.2	68.6	51.7	51.9
	CV	0.24	0.23	0.30	0.30

Parameter	Statistic	CA5B-B1	CA5B-B2	WA5B-B2	WA5B-B4
Airflow (dsm3s-1)	Mean	1,151.61	1,151.61	886.51	882.65
	Std Dev	694.46	694.46	509.85	542.87
	Median	1,020.00	1,020.00	851.00	835.00
	Minimum	225.00	225.00	0.00	0.00
	Maximum	6,230.00	6,230.00	2,790.00	3,100.00
	N	766	766	677	677
	N<0	0	0	0	0
	N>0	766	766	677	677
	Q25	667.5	667.5	475	438
	Q75	1,410.00	1,410.00	1,190.00	1,240.00
	CV	0.60	0.60	0.58	0.62

D.3.3 Ambient

Table D-32. Ambient parameter summary statistics for naturally ventilated dairy barns.

Parameter	Statistic	CA5B	WA5B
Ambient Temperature (°C)	Mean	16.34	10.07
	Std Dev	6.50	9.22
	Median	15.8	9.1
	Minimum	3.7	-11.0
	Maximum	31.7	33.2
	N	778	670
	N<0	0	87
	N>0	778	583
	Q25	10.9	3.3
	Q75	21.8	15.3
	CV	0.40	0.92
Ambient Relative Humidity (%)	Mean	62.01	45.81
	Std Dev	13.74	15.00
	Median	61.5	42.9
	Minimum	29.5	21.7
	Maximum	91.2	87.8
	N	785	671
	N<0	0	0
	N>0	785	671
	Q25	51.4	34.9
	Q75	73.4	52.1
	CV	0.22	0.33
Wind Speed (ms^{-1})	Mean	1.97	2.59
	Std Dev	1.17	1.63
	Median	1.8	2.2
	Minimum	0.3	0.4
	Maximum	10.1	10.2
	N	770	671
	N<0	0	0
	N>0	770	671
	Q25	1.2	1.5
	Q75	2.4	3.2
	CV	0.60	0.63

D.4 Open sources

D.4.1 Emissions

Table D-33. NH_3 emission summary statistics for dairy open sources (kg d^{-1}).

Statistic	IN5A	WI5A	TX5A
Mean	19.83	11.45	754.97
Std Dev	19.04	16.35	317.45
Median	17.46	6.27	698.23
Minimum	-11.73	-3.55	240.56
Maximum	92.30	79.00	1,719.29
N	133	28	73
N<0	17	4	0
N>0	116	24	73
Q25	5.93	2.46	582.16
Q75	29.78	13.49	874.68
CV	0.96	1.43	0.42

Table D-34. NH_3 emission summary statistics for dairy open sources (g d^{-1} m^{-2}).

Statistic	IN5A	WI5A	TX5A
Mean	2.01	1.61	3.12
Std Dev	1.93	2.31	1.31
Median	1.77	0.88	2.89
Minimum	-1.19	-0.50	0.99
Maximum	9.34	11.14	7.10
N	133	28	73
N<0	17	4	0
N>0	116	24	73
Q25	0.60	0.35	2.41
Q75	3.01	1.90	3.61
CV	0.96	1.43	0.42

Table D-35. H_2S emission summary statistics for dairy open sources (kg d^{-1}).

Statistic	IN5A	WI5A	TX5A
Mean	9.39	0.42	10.69
Std Dev	8.20	0.89	4.32
Median	9.09	0.05	9.93
Minimum	-0.06	-0.05	4.84
Maximum	35.24	3.08	29.53
N	62	12	49
N<0	3	3	0
N>0	59	9	49
Q25	1.54	0.01	8.14
Q75	13.02	0.32	11.84
CV	0.87	2.11	0.40

Table D-36. H_2S emission summary statistics for dairy open sources (g d^{-1} hd^{-1}).

Statistic	IN5A	WI5A	TX5A
Mean	0.95	0.06	44.18
Std Dev	0.83	0.13	17.84
Median	0.92	0.01	41.03
Minimum	-0.01	-0.01	19.99
Maximum	3.57	0.43	122.03
N	62	12	49
N<0	3	3	0
N>0	59	9	49
Q25	0.16	0.00	33.62
Q75	1.32	0.05	48.94
CV	0.87	2.11	0.40

D.4.2 Environmental

Table D-37. Environmental parameter summary statistics for dairy open sources.

Parameter	Statistic	IN5A	WI5A
Lagoon pH	Mean	7.43	7.02
	Std Dev	0.52	0.04
	Median	7.17	7.01
	Minimum	7.02	6.98
	Maximum	8.37	7.09
	N	29	6
	N<0	0	0
	N>0	29	6
	Q25	7.06	7.00
	Q75	8.19	7.04
	CV	0.07	0.01
Lagoon Temperature (°C)	Mean	21.57	5.22
	Std Dev	4.64	1.27
	Median	22.18	4.75
	Minimum	11.27	4.57
	Maximum	27.63	7.80
	N	29	6
	N<0	0	0
	N>0	29	6
	Q25	19.95	4.61
	Q75	25.11	4.84
	CV	0.22	0.24

D.4.3 Ambient

Table D-38. Ambient parameter summary statistics for dairy open sources.

Parameter	Statistic	IN5A	WI5A
Ambient Air Temperature (°C)	Mean	6.25	-3.41
	Std Dev	10.20	8.95
	Median	5.66	-1.80
	Minimum	-19.73	-21.50
	Maximum	27.11	16.75
	N	129	28
	N<0	38	16
	N>0	91	12
	Q25	-0.67	-9.36
	Q75	13.49	1.03
	CV	1.63	-2.62
Ambient Relative Humidity (%)	Mean	72.02	71.53
	Std Dev	12.20	9.85
	Median	73.85	71.33
	Minimum	38.05	46.35
	Maximum	94.35	94.18
	N	133	28
	N<0	0	0
	N>0	133	28
	Q25	64.20	66.32
	Q75	81.55	77.03
	CV	0.17	0.14
Wind Speed (ms^{-1})	Mean	3.28	3.45
	Std Dev	1.23	1.23
	Median	3.22	3.37
	Minimum	1.12	1.58
	Maximum	7.75	6.28
	N	133	28
	N<0	0	0
	N>0	133	28
	Q25	2.32	2.56
	Q75	4.02	3.97
	CV	0.38	0.36

Table D-39. Ambient parameter summary statistics for dairy corrals.

Parameter	Statistic	TX5A
Ambient Air Temperature (°C)	Mean	14.26
	Std Dev	8.41
	Median	13.41
	Minimum	-5.64
	Maximum	27.50
	N	62
	N<0	2
	N>0	60
	Q25	9.36
	Q75	22.24
	CV	0.59
Ambient Relative Humidity (%)	Mean	47.49
	Std Dev	12.99
	Median	48.16
	Minimum	22.73
	Maximum	78.54
	N	62
	N<0	0
	N>0	62
	Q25	37.84
	Q75	57.39
	CV	0.27
Water Vapor Deficit (hPa)	Mean	11.28
	Std Dev	5.86
	Median	10.26
	Minimum	2.09
	Maximum	26.88
	N	62
	N<0	0
	N>0	62
	Q25	7.19
	Q75	13.60
	CV	0.52
Wind Speed (ms^{-1})	Mean	4.48
	Std Dev	1.10
	Median	4.43
	Minimum	2.35
	Maximum	6.79
	N	73
	N<0	0
	N>0	73
	Q25	3.69
	Q75	5.13
	CV	0.25

Appendix E: Time Series Plots

Table of Contents

List of Figures

E.1 Mechanically Ventilated Barns

E.1.1 Emissions

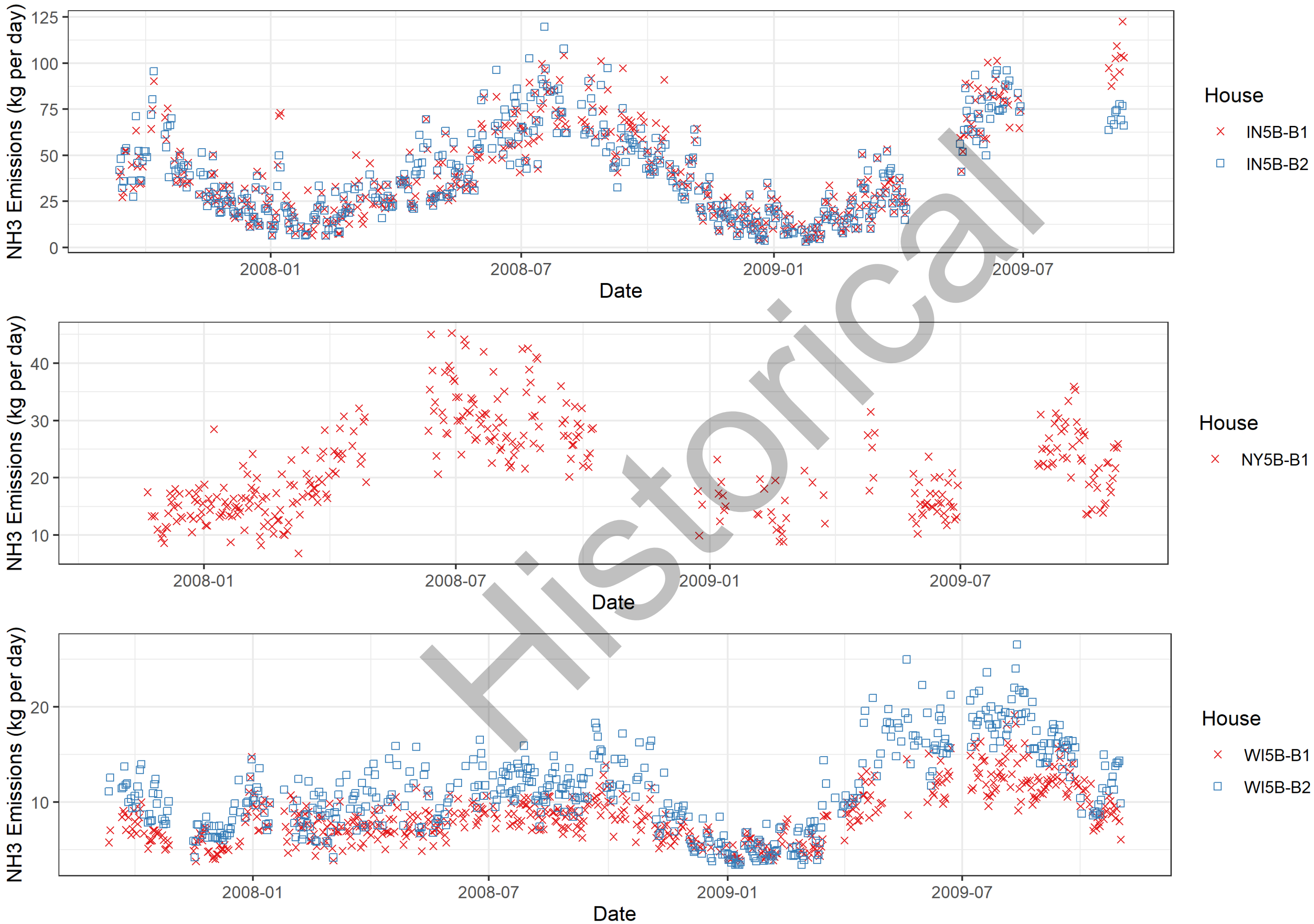


Figure E-1. Trends in NH_3 emissions at mechanically ventilated barns, by site, during the NAEMS monitoring period.

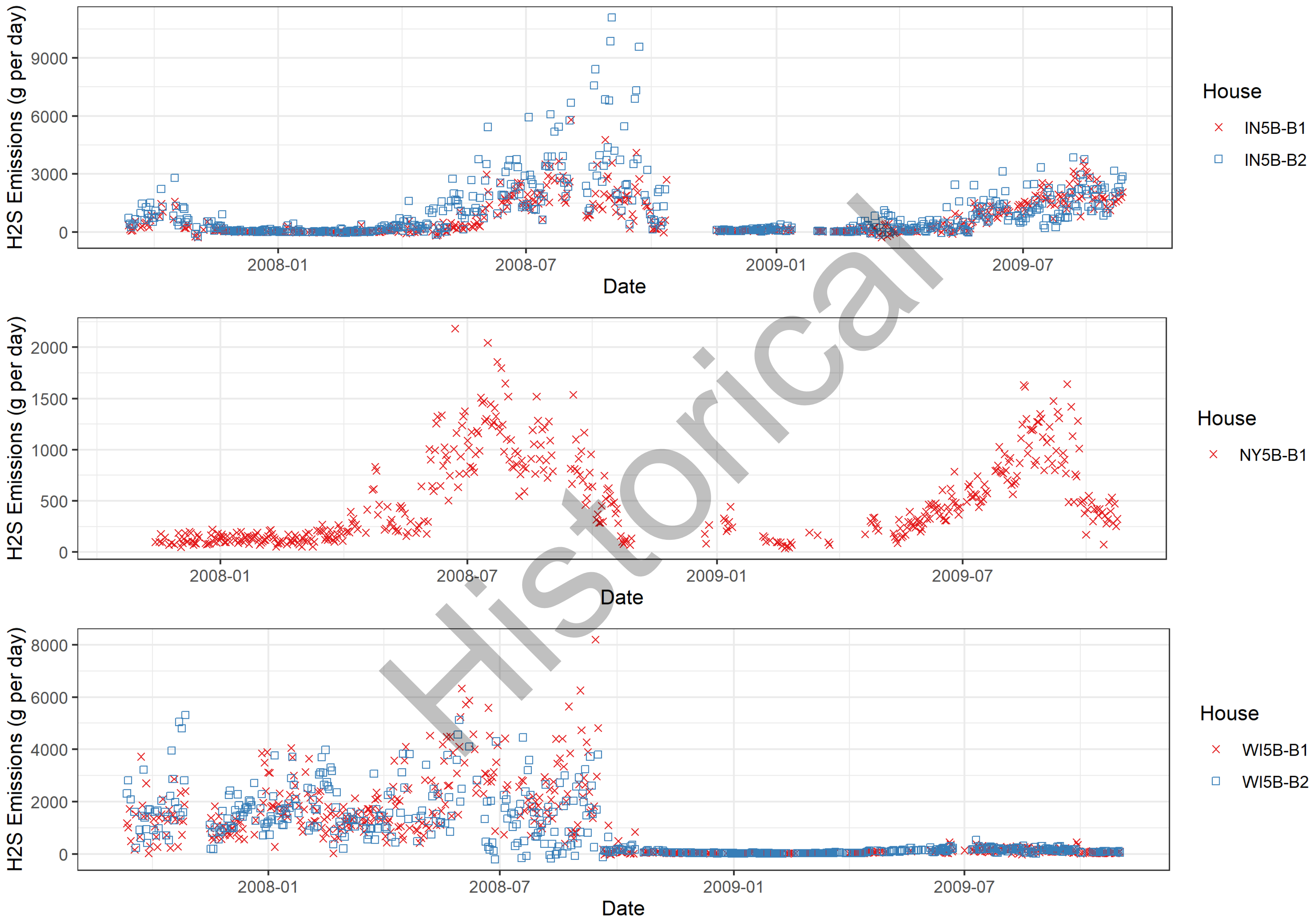


Figure E-2. Trends in H_2S emissions at mechanically ventilated barns, by site, during the NAEMS monitoring period.

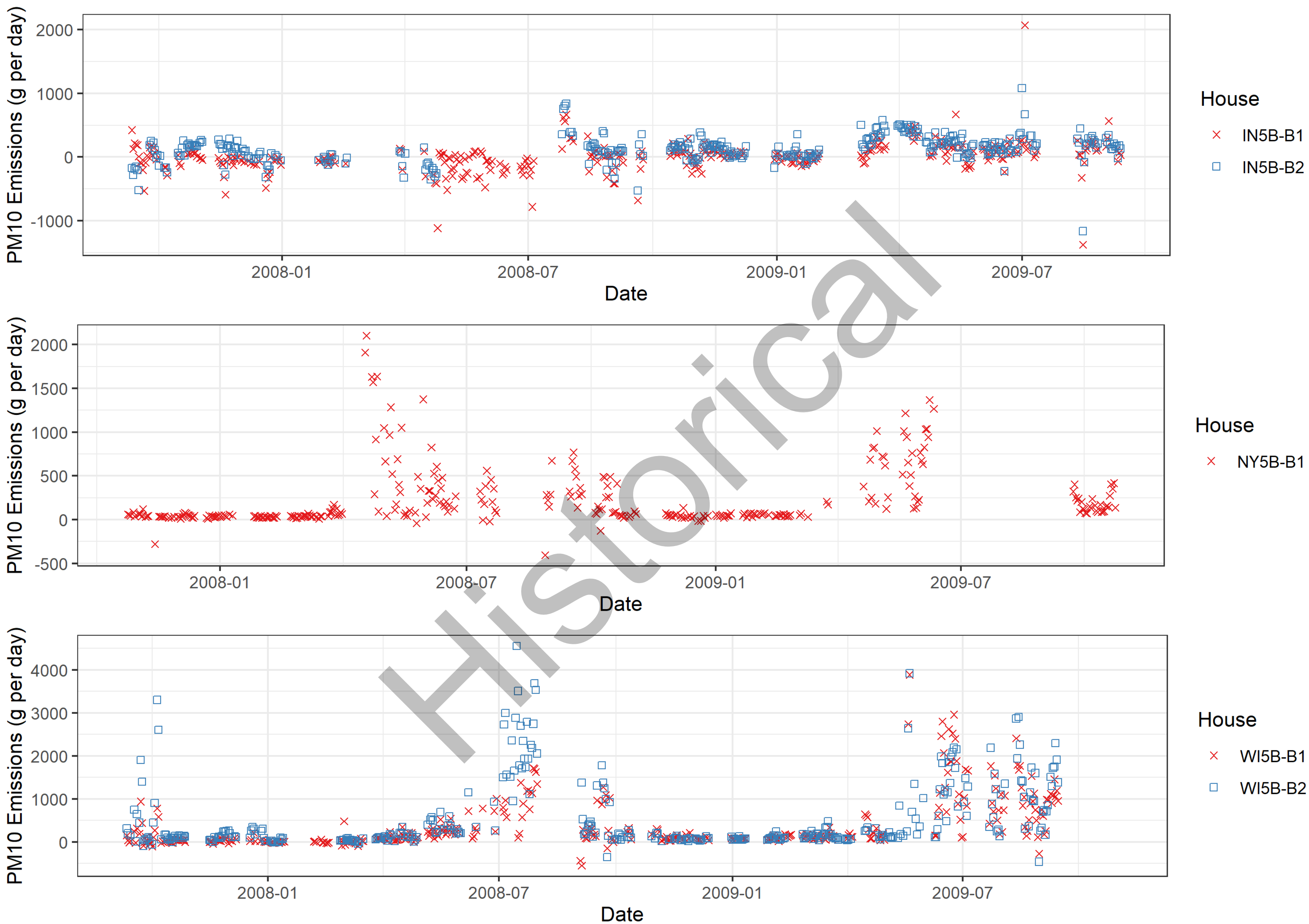


Figure E-3. Trends in PM_{10} emissions at mechanically ventilated barns, by site, during the NAEMS monitoring period.

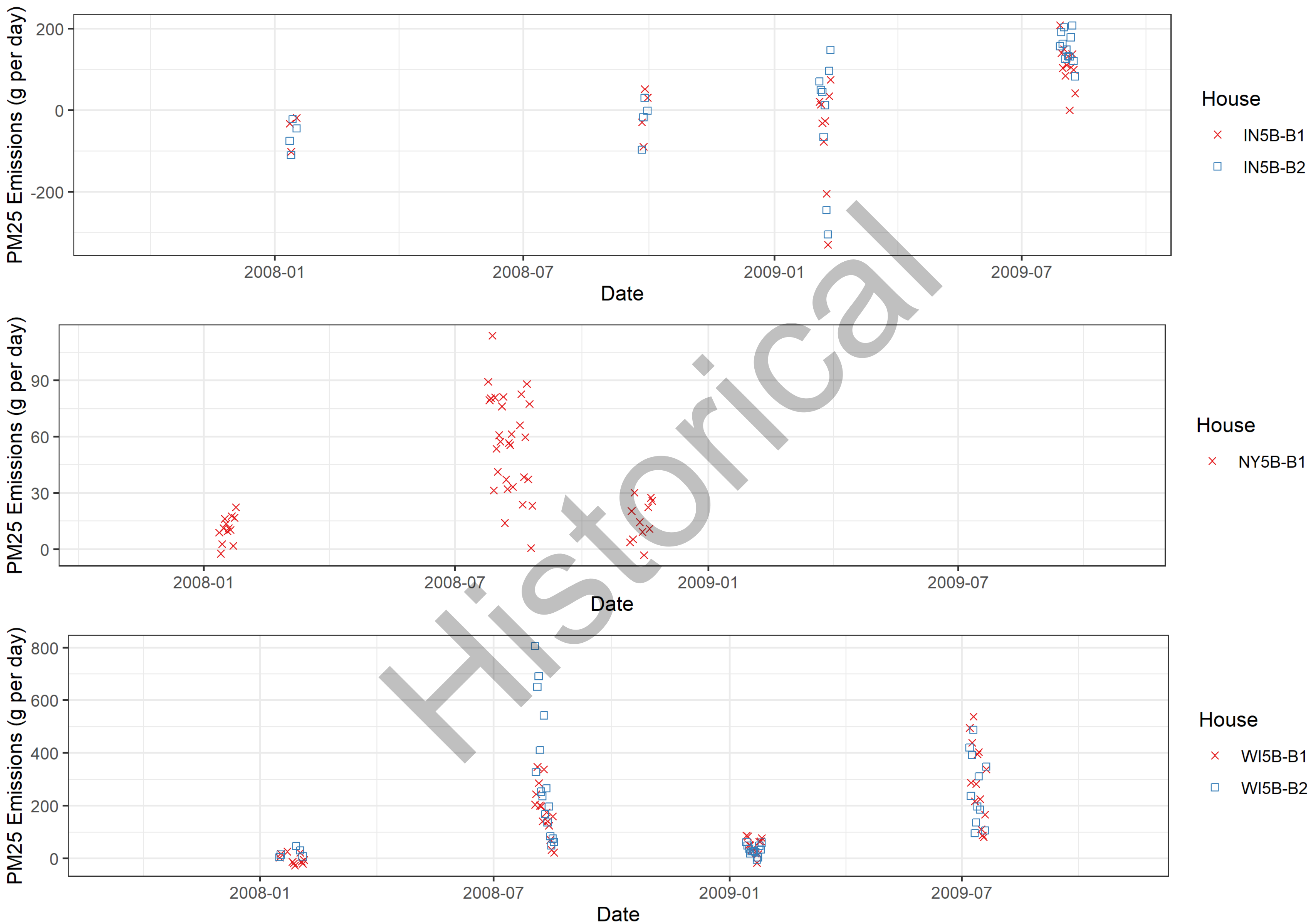


Figure E-4. Trends in $PM_{2.5}$ emissions at mechanically ventilated barns, by site, during the NAEMS monitoring period.

Figure E-5. Trends in TSP emissions at mechanically ventilated barns, by site, during the NAEMS monitoring period.

E.1.2 Environmental Parameters

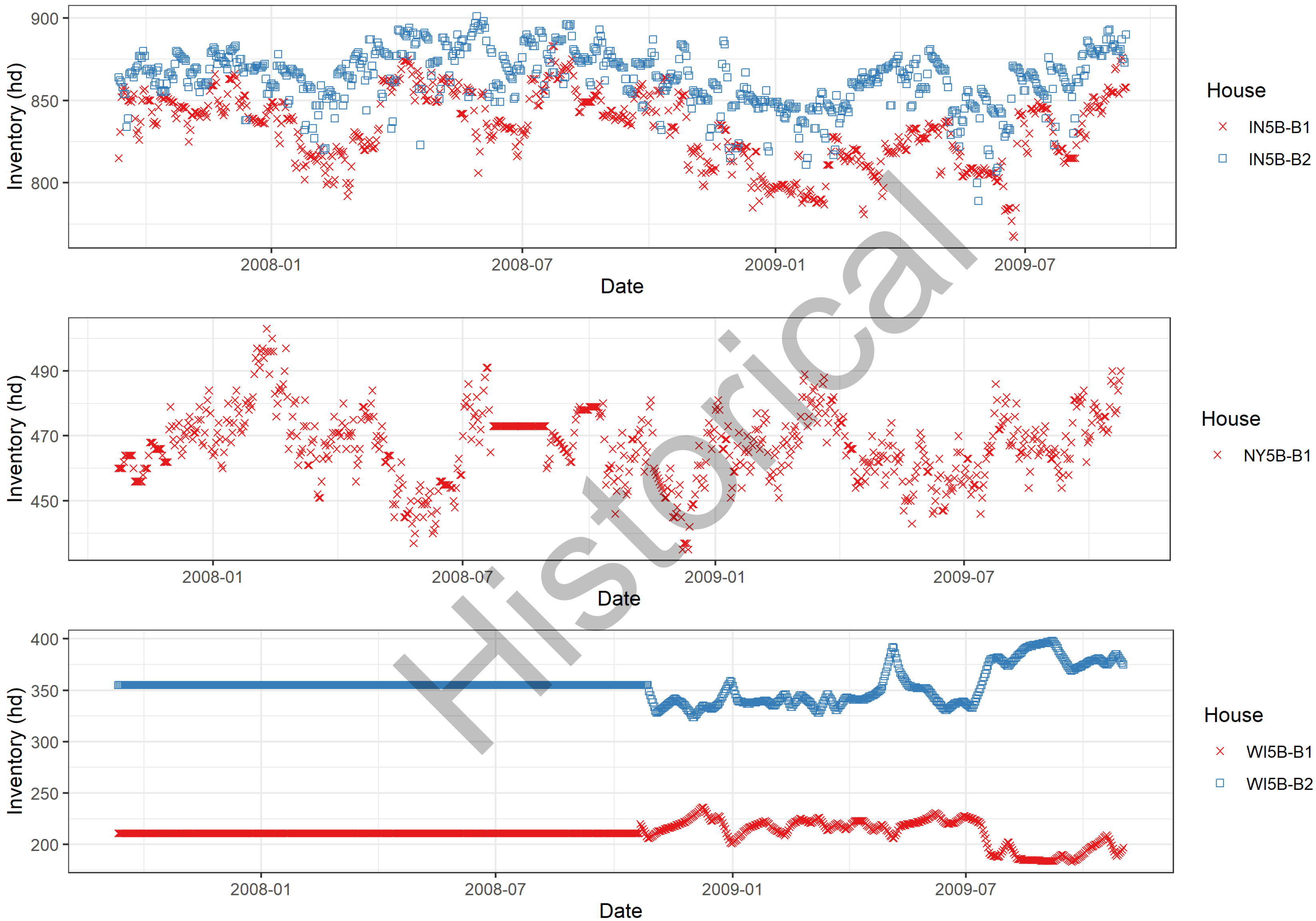


Figure E-6. Trends in inventory at mechanically ventilated barns, by site, during the NAEMS monitoring period.

Figure E-7. Trends in average animal mass at mechanically ventilated barns, by site, during the NAEMS monitoring period.

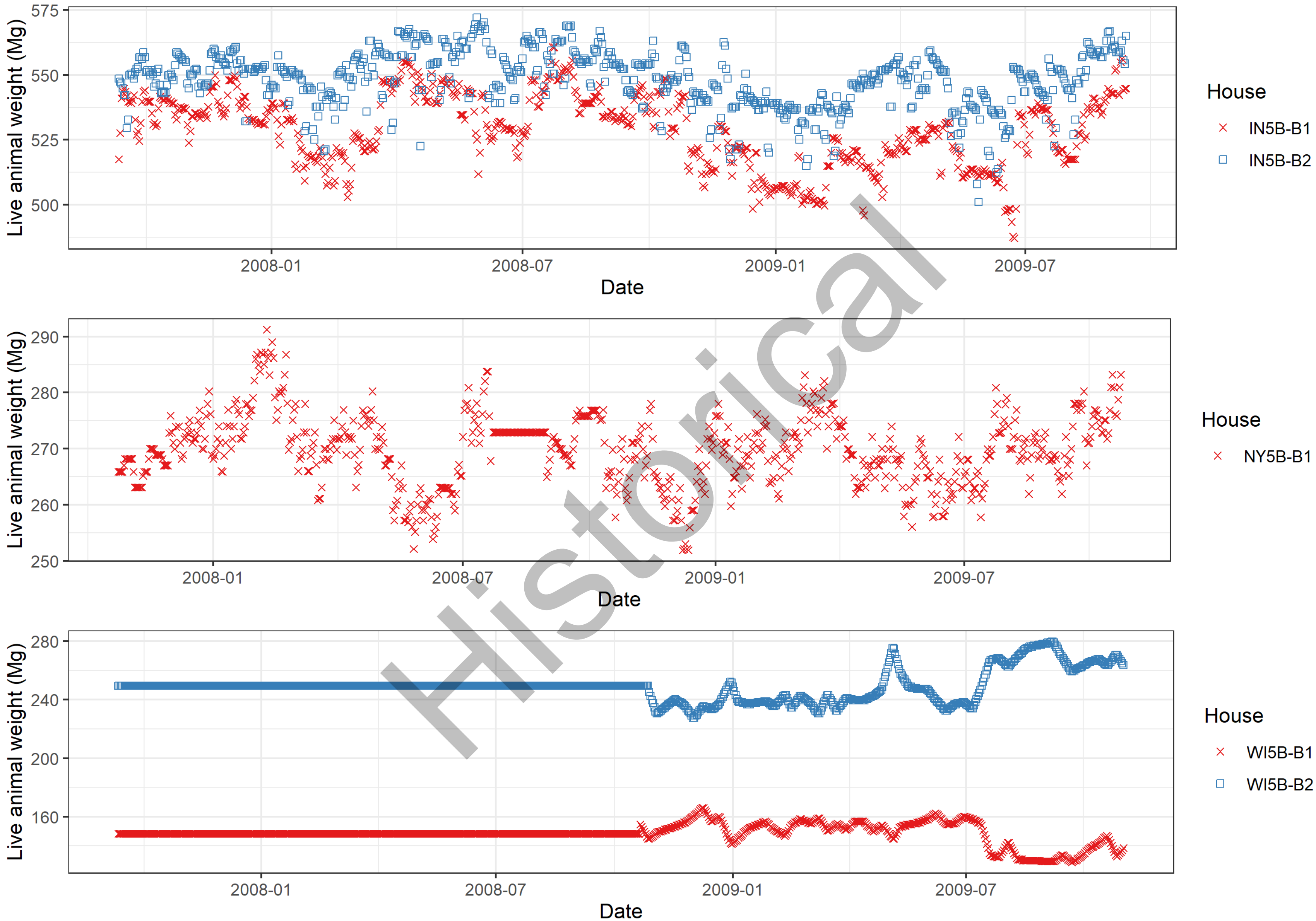


Figure E-8. Trends in live animal weight at mechanically ventilated barns, by site, during the NAEMS monitoring period.

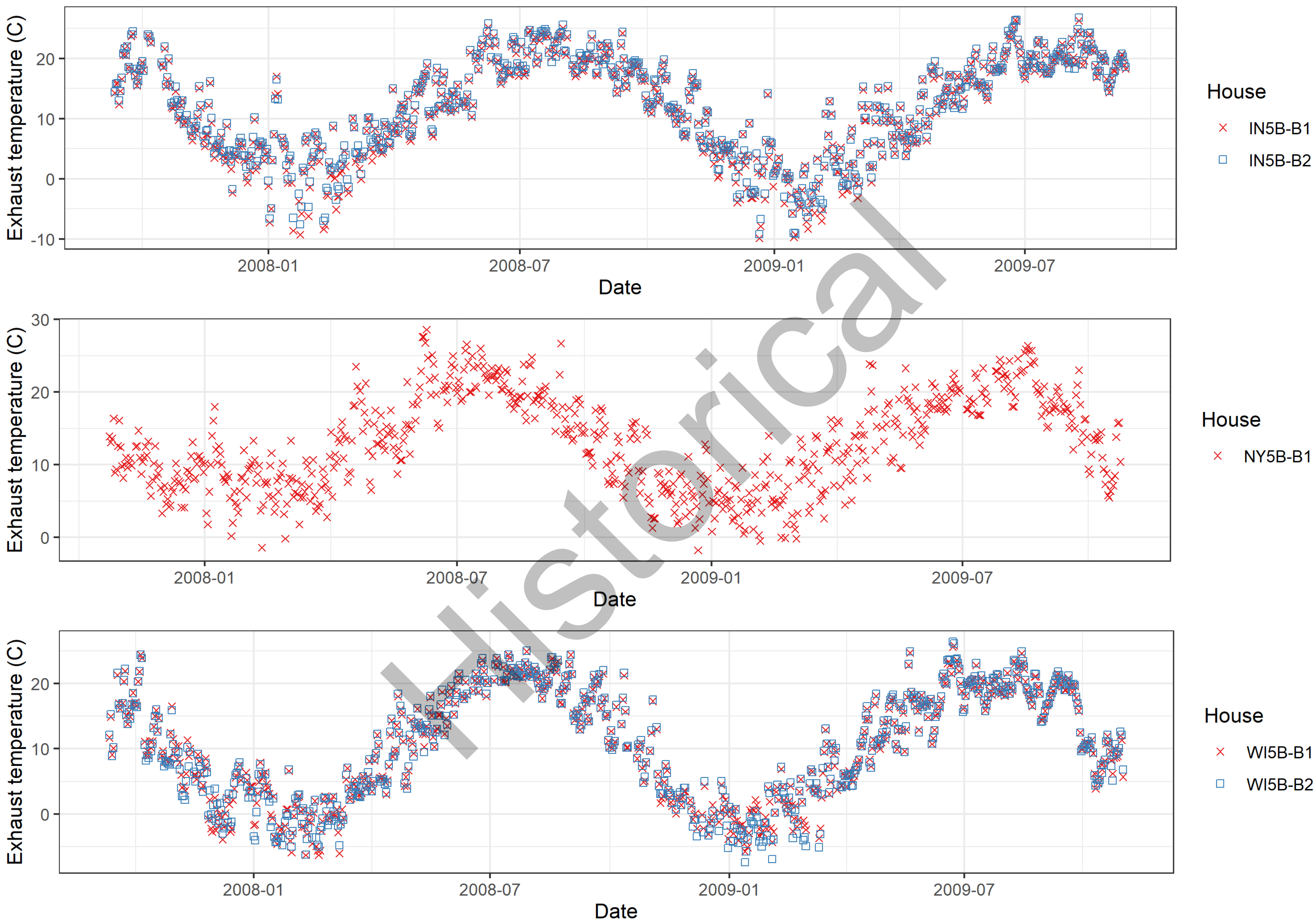


Figure E-9. Trends in exhaust temperature at mechanically ventilated barns, by site, during the NAEMS monitoring period.

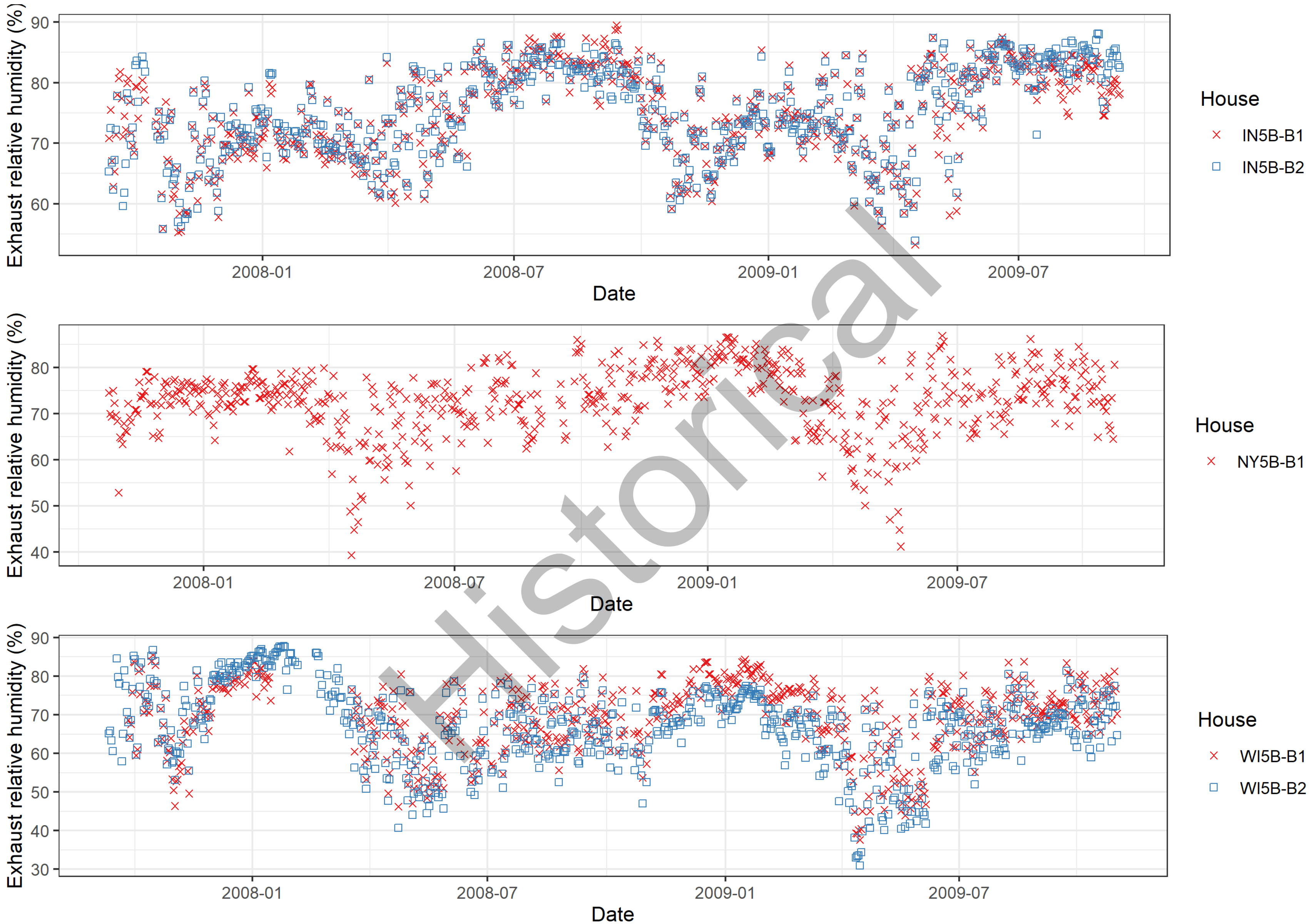


Figure E-10. Trends in exhaust relative humidity at mechanically ventilated barns, by site, during the NAEMS monitoring period.

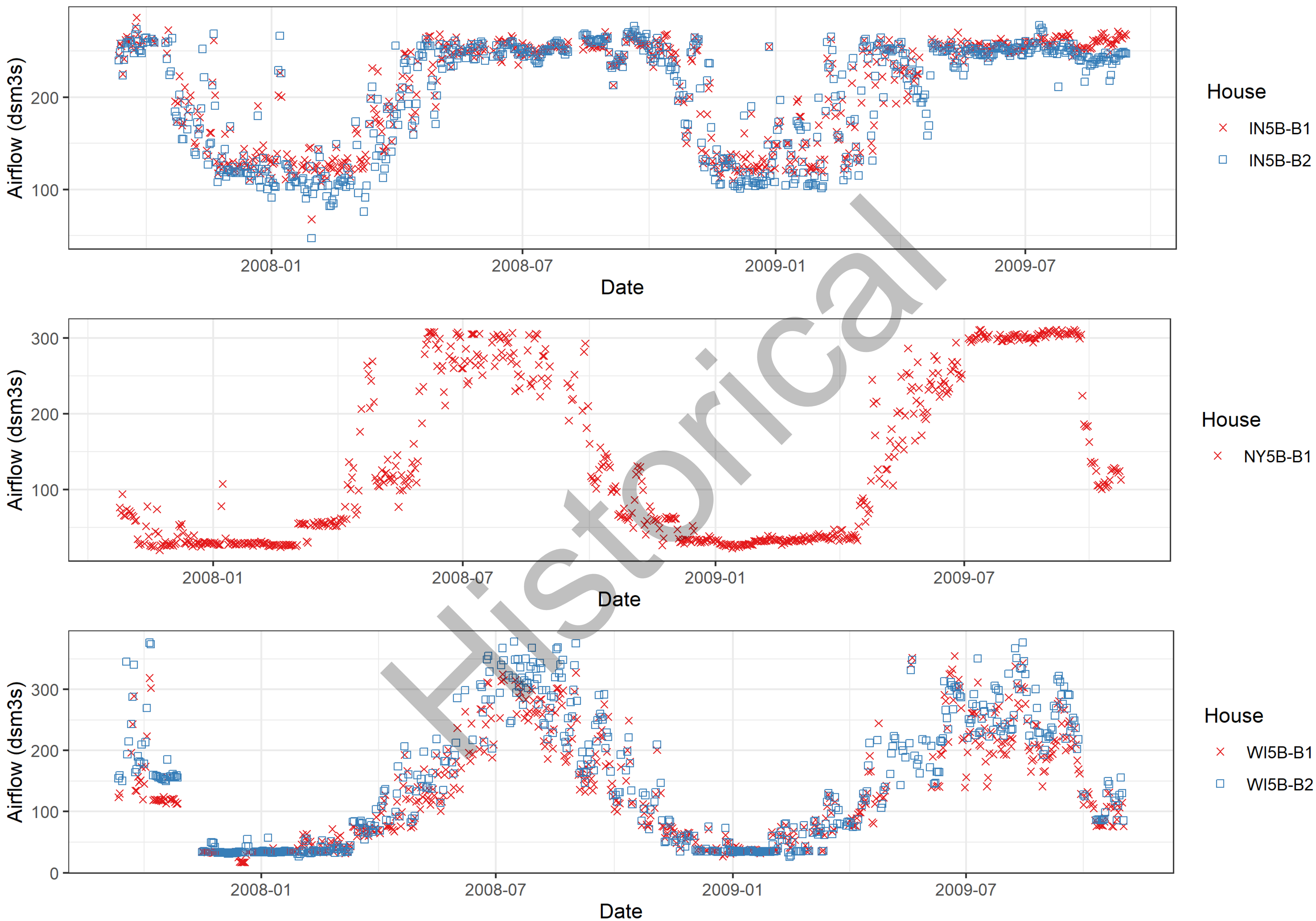


Figure E-11. Trends in airflow at mechanically ventilated barns, by site, during the NAEMS monitoring period.

E.1.3 Ambient Parameters

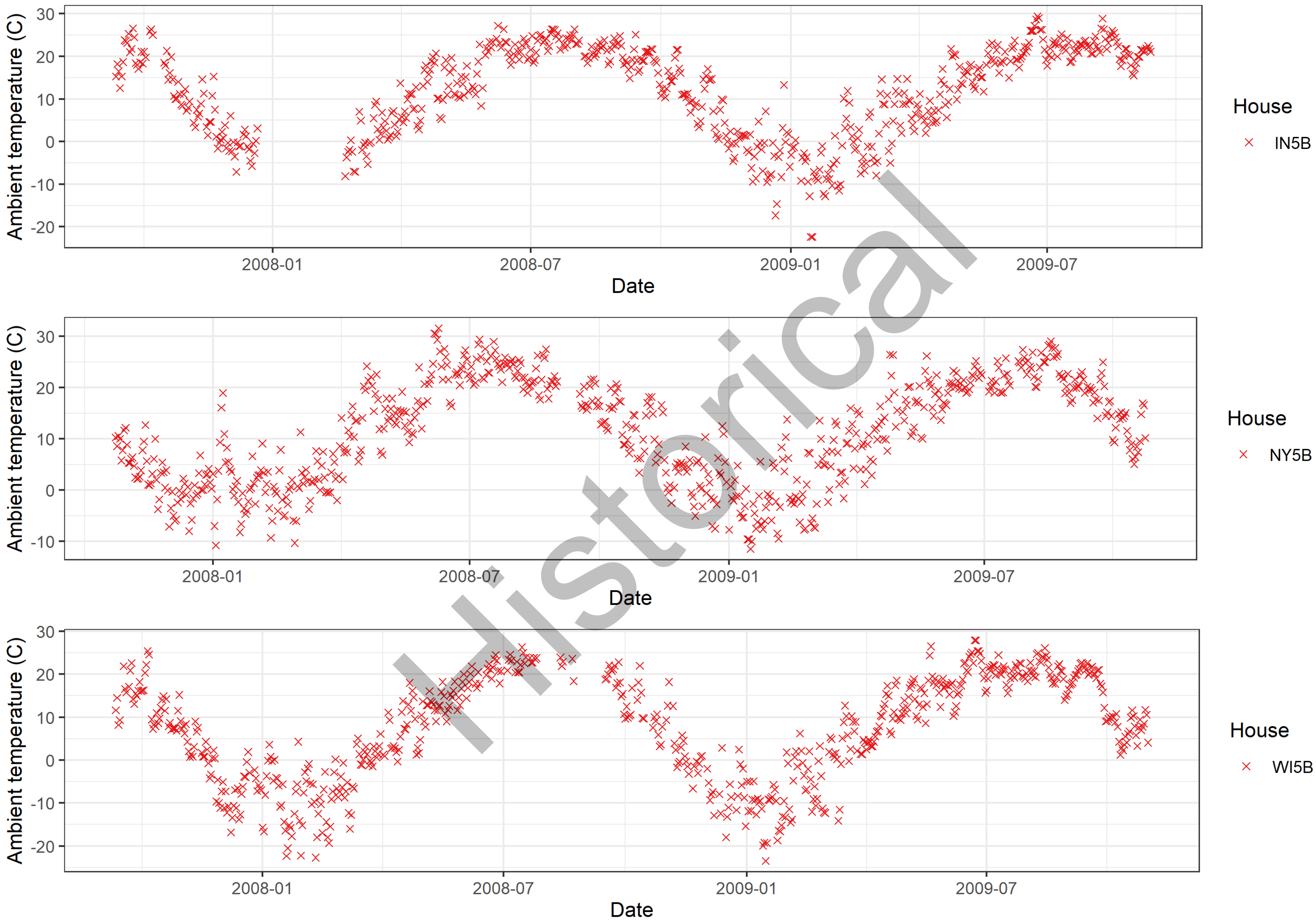


Figure E-12. Trends in ambient temperature at mechanically ventilated barns, by site, during the NAEMS monitoring period.

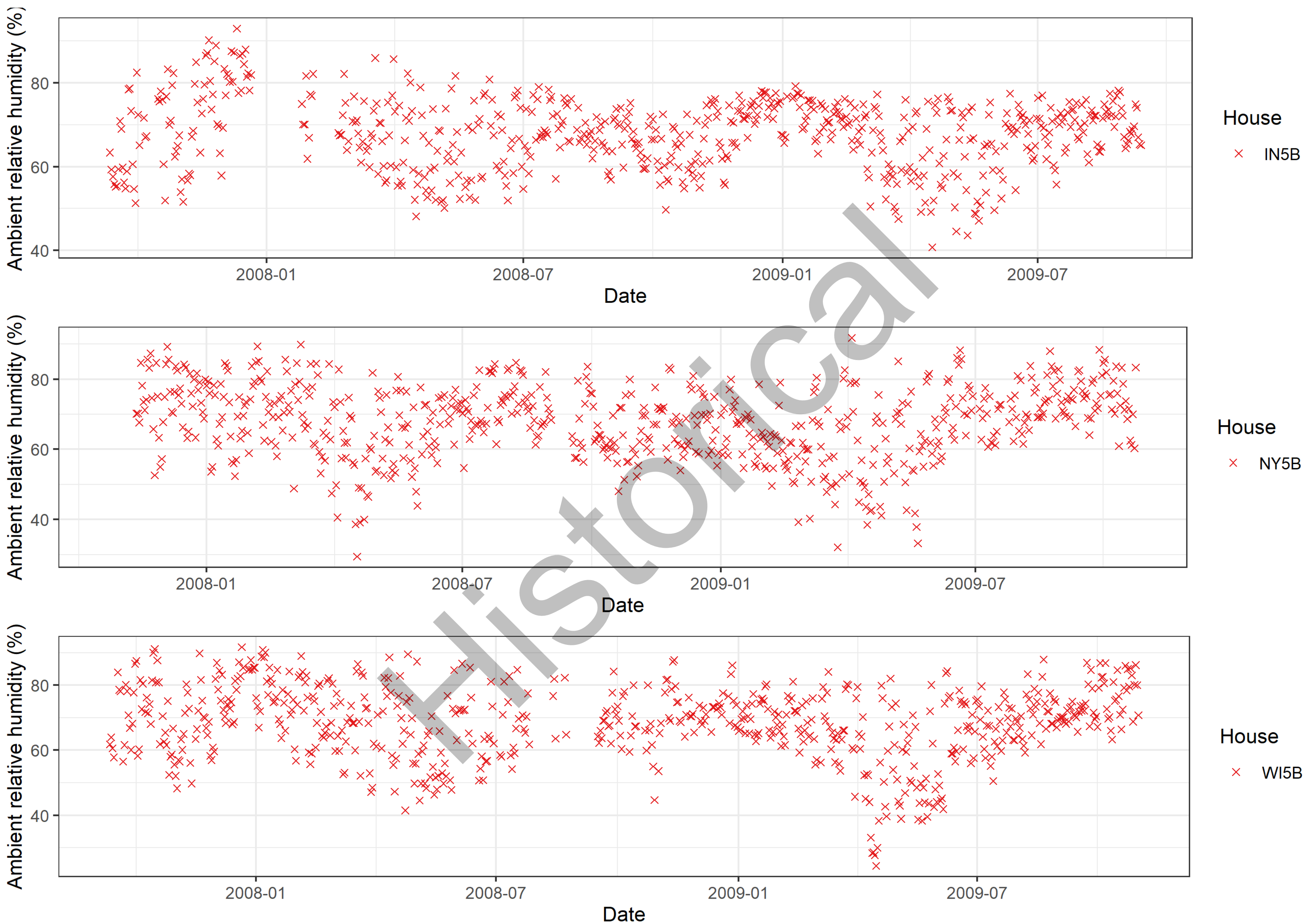


Figure E-13. Trends in ambient relative humidity at mechanically ventilated barns, by site, during the NAEMS monitoring period.

E.2 Milking Centers

E.2.1 Emissions

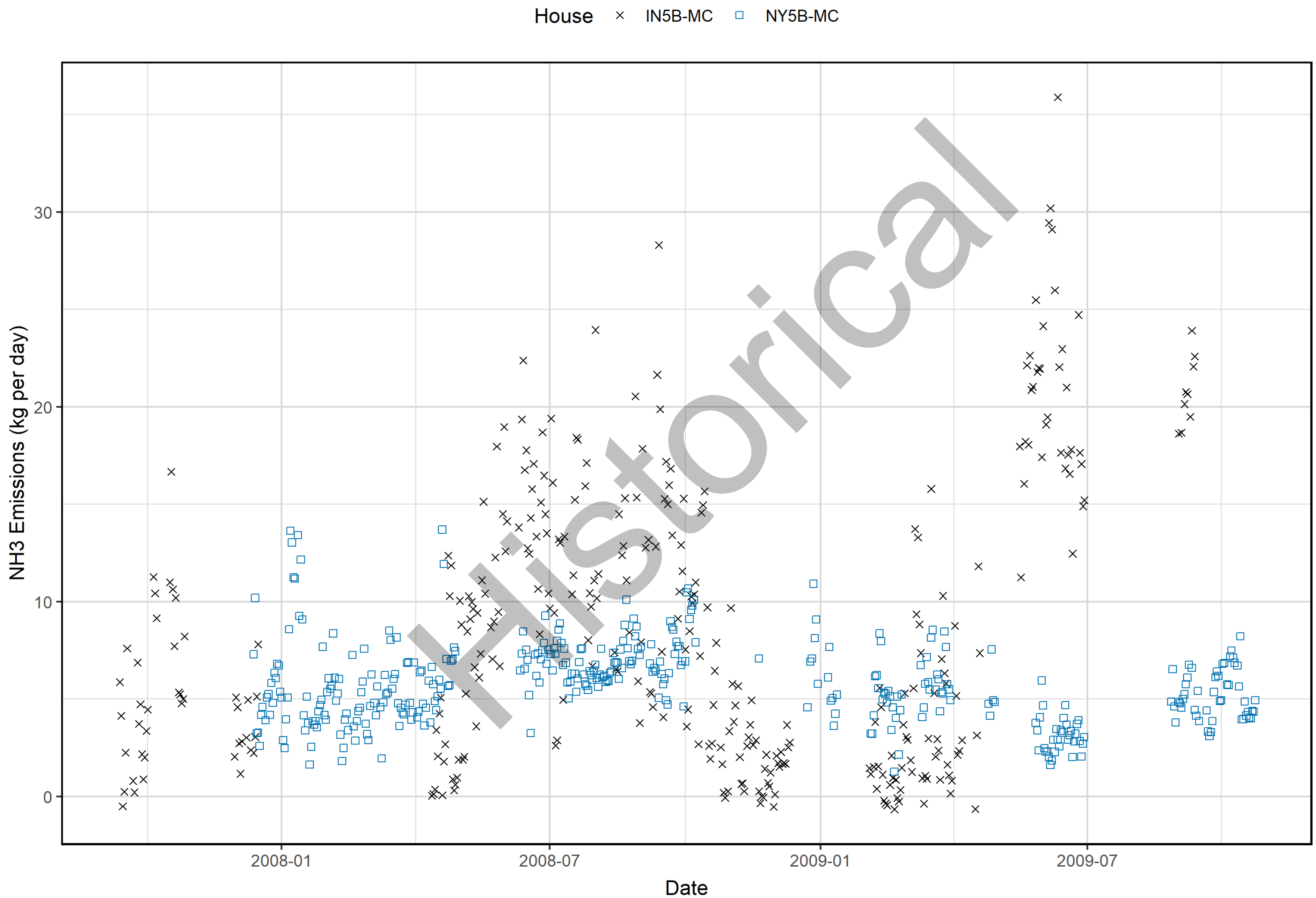


Figure E-14. NAEMS milking center NH_3 emission trends, by site.

Figure E-15. NAEMS milking center H_2S emission trends, by site.

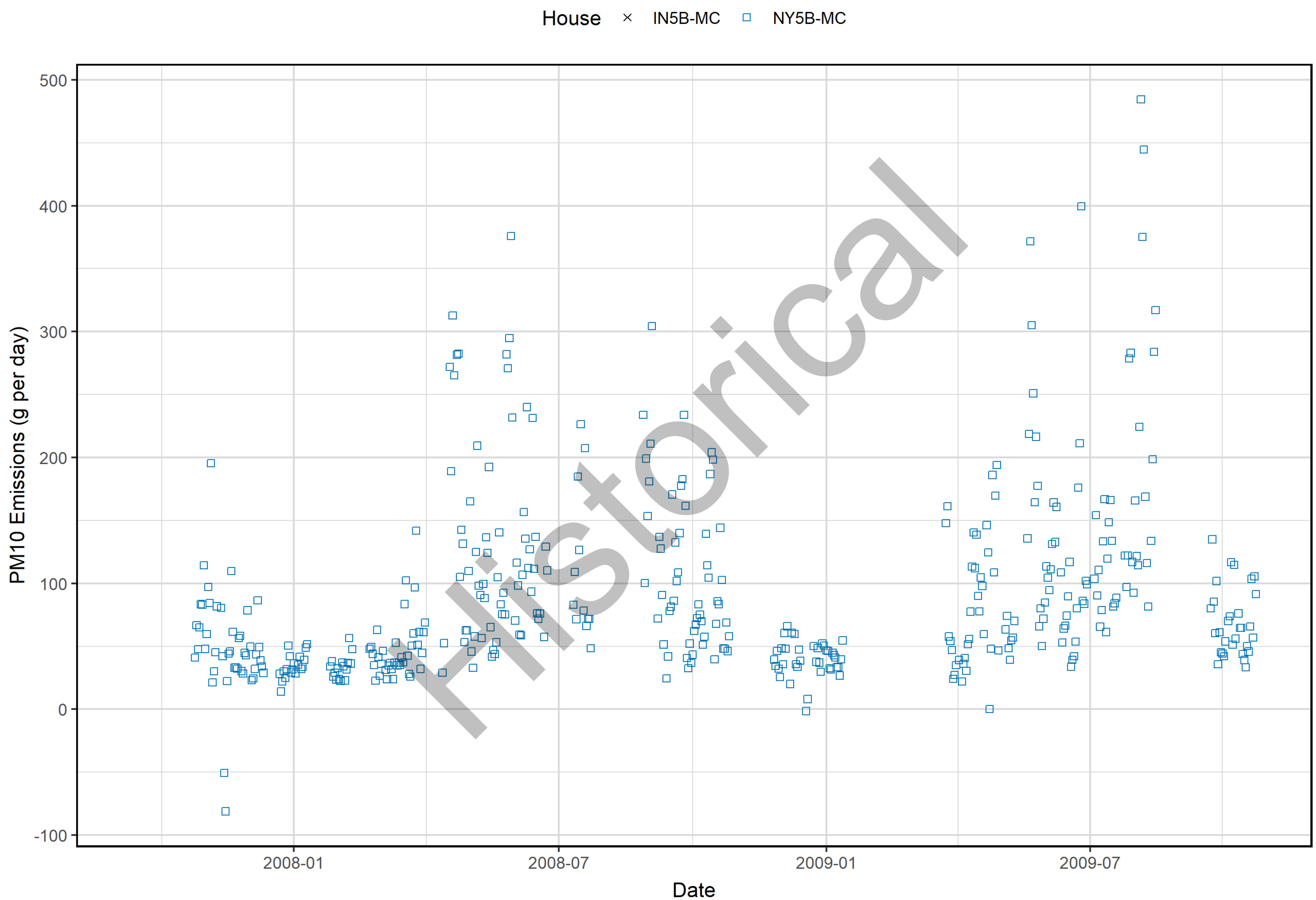


Figure E-16. NAEMS milking center PM_{10} emission trends, by site.

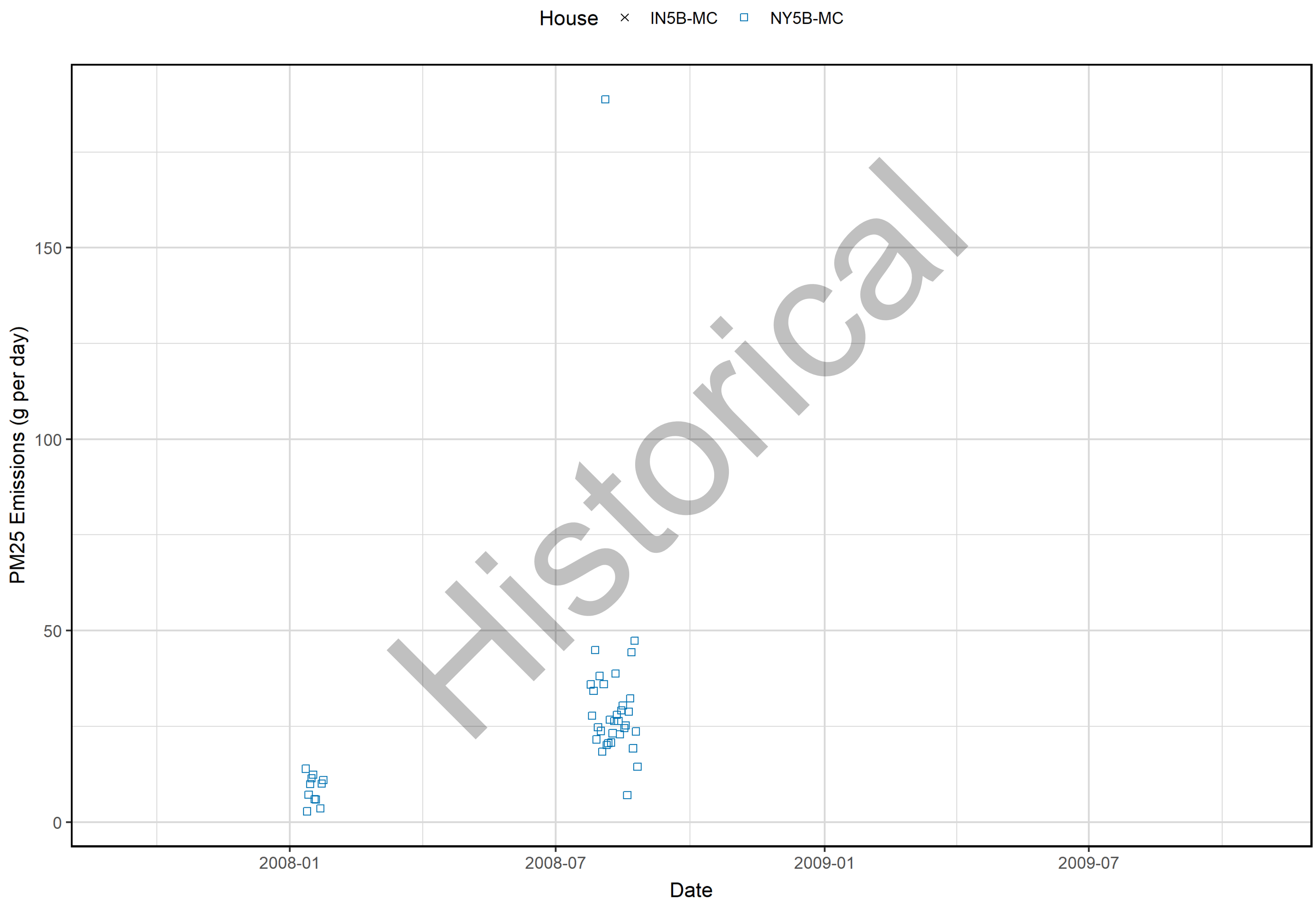


Figure E-17. NAEMS milking center $PM_{2.5}$ emission trends, by site.

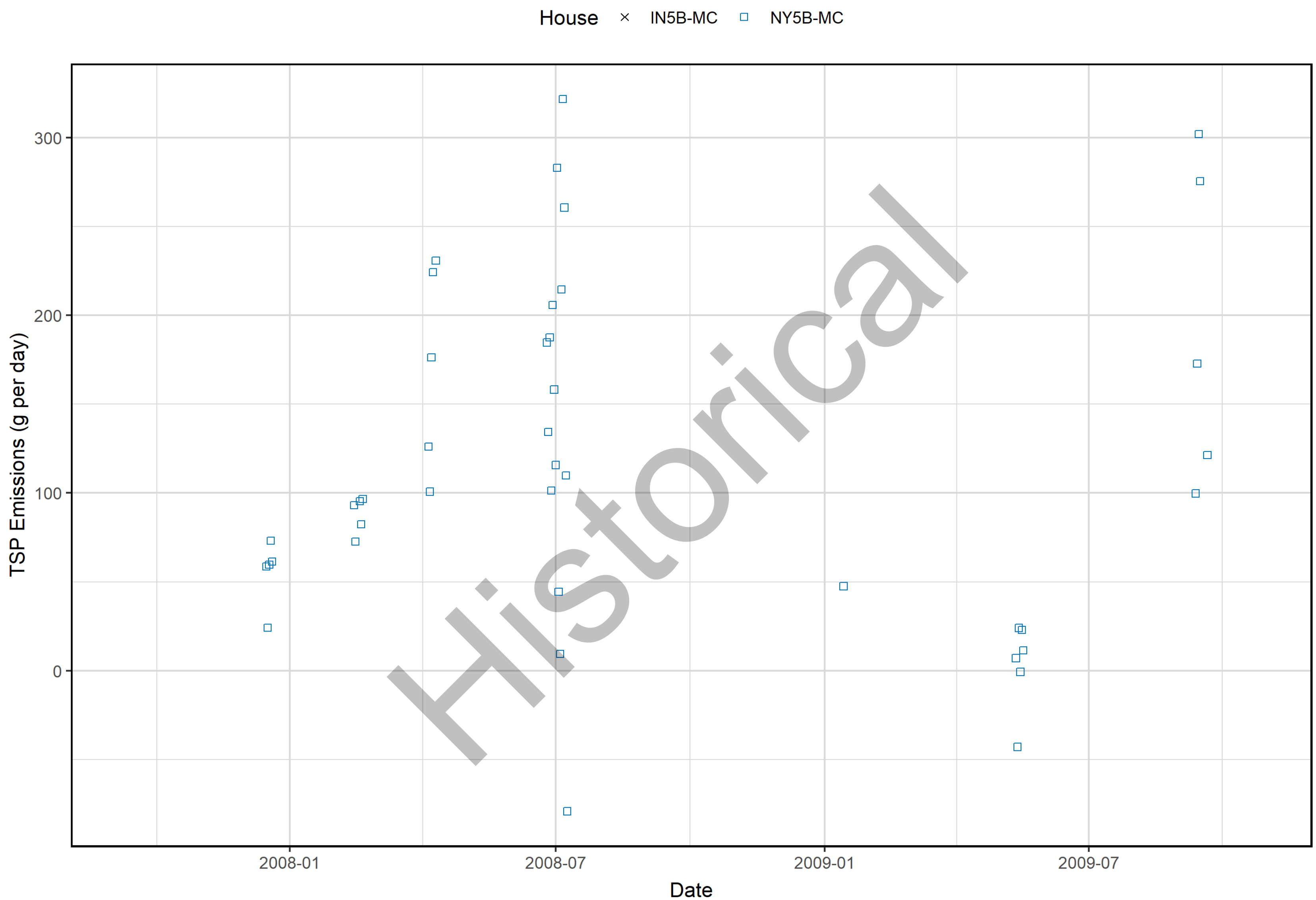


Figure E-18. NAEMS milking center TSP emission trends, by site.

E.2.2 Environmental Parameters

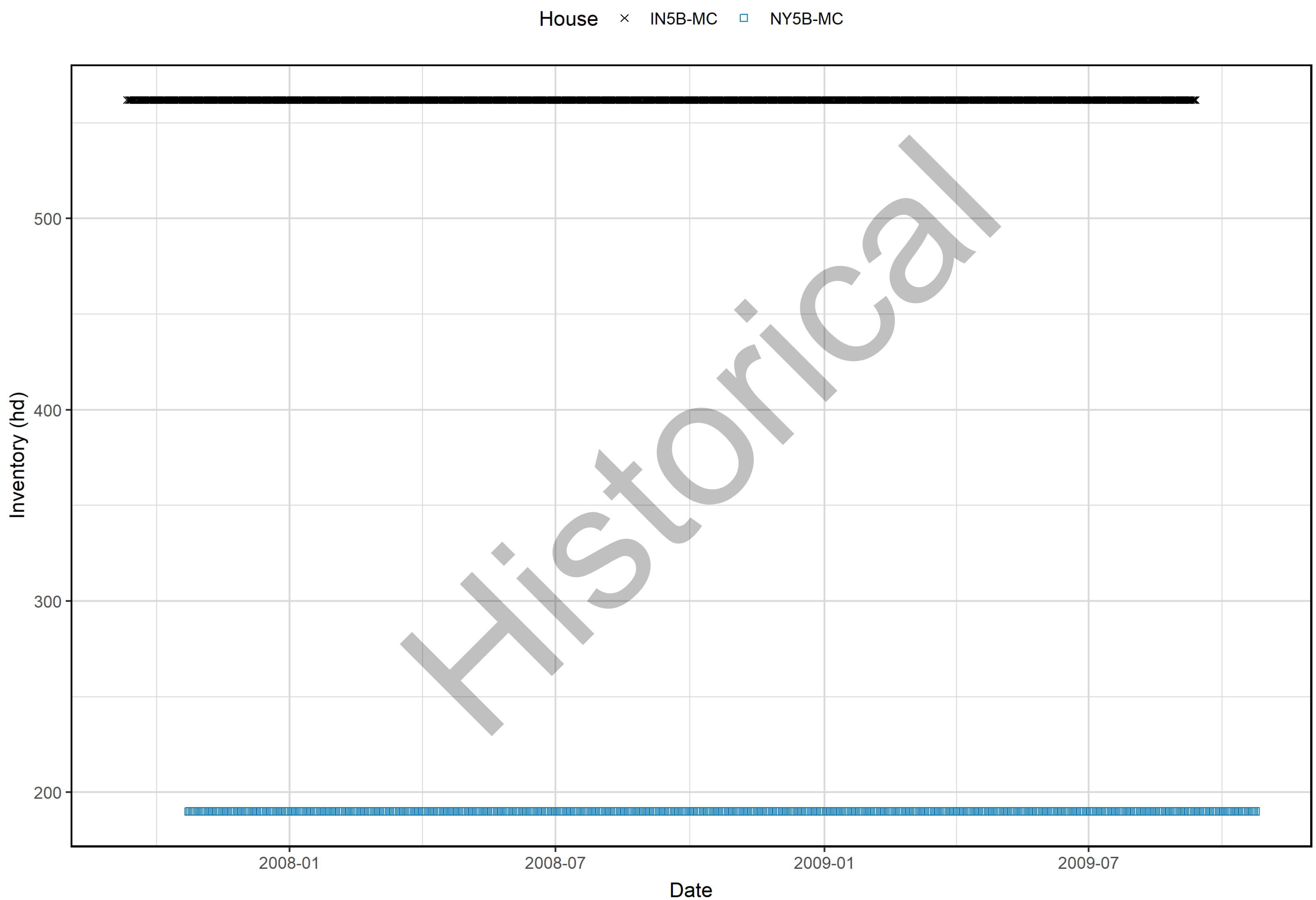


Figure E-19. Trends in inventory at milking centers, by site, during the NAEMS monitoring period.

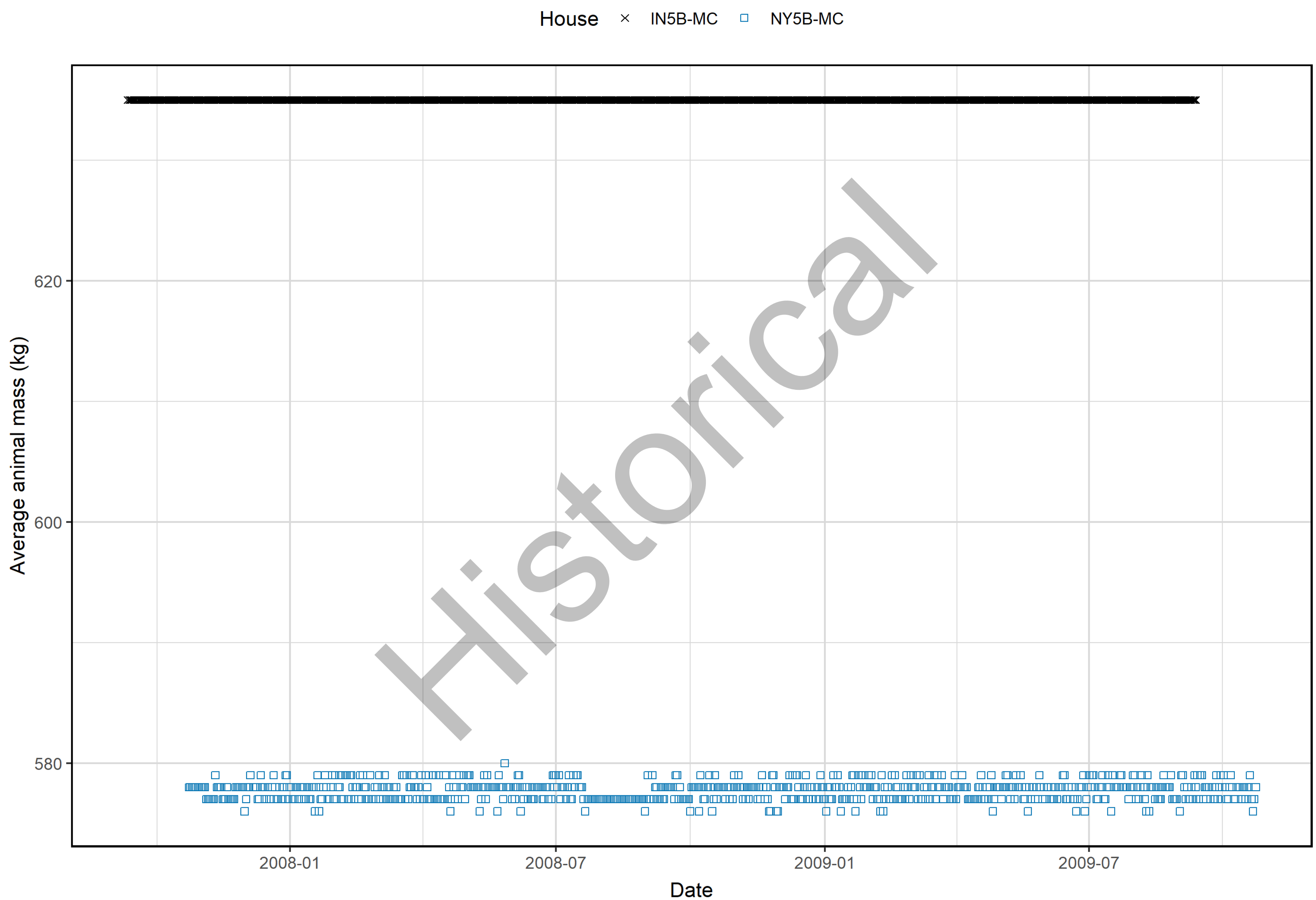


Figure E-20. Trends in average animal mass (kg) at milking centers, by site, during the NAEMS monitoring period.

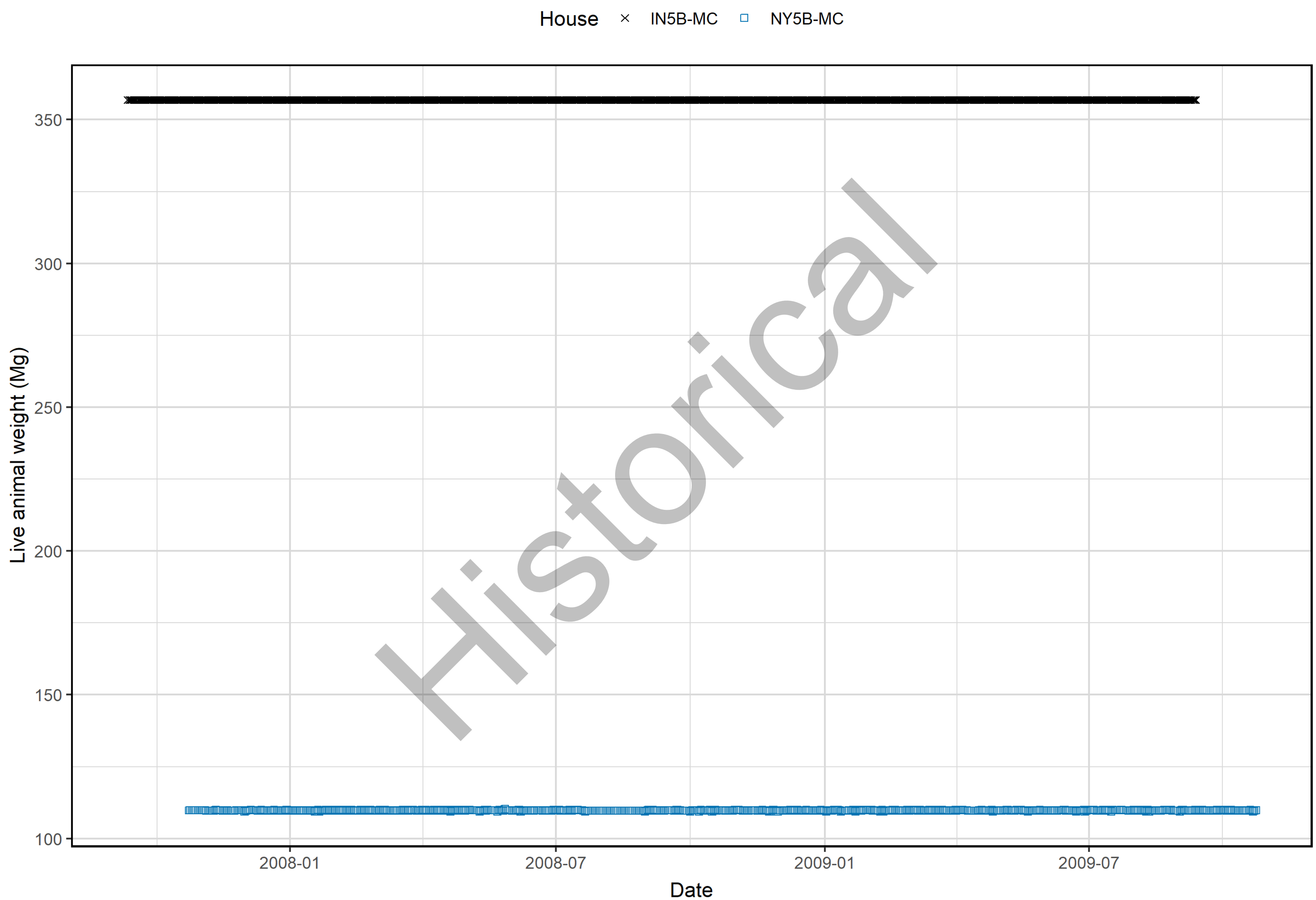


Figure E-21. Trends in live animal weight at milking centers, by site, during the NAEMS monitoring period.

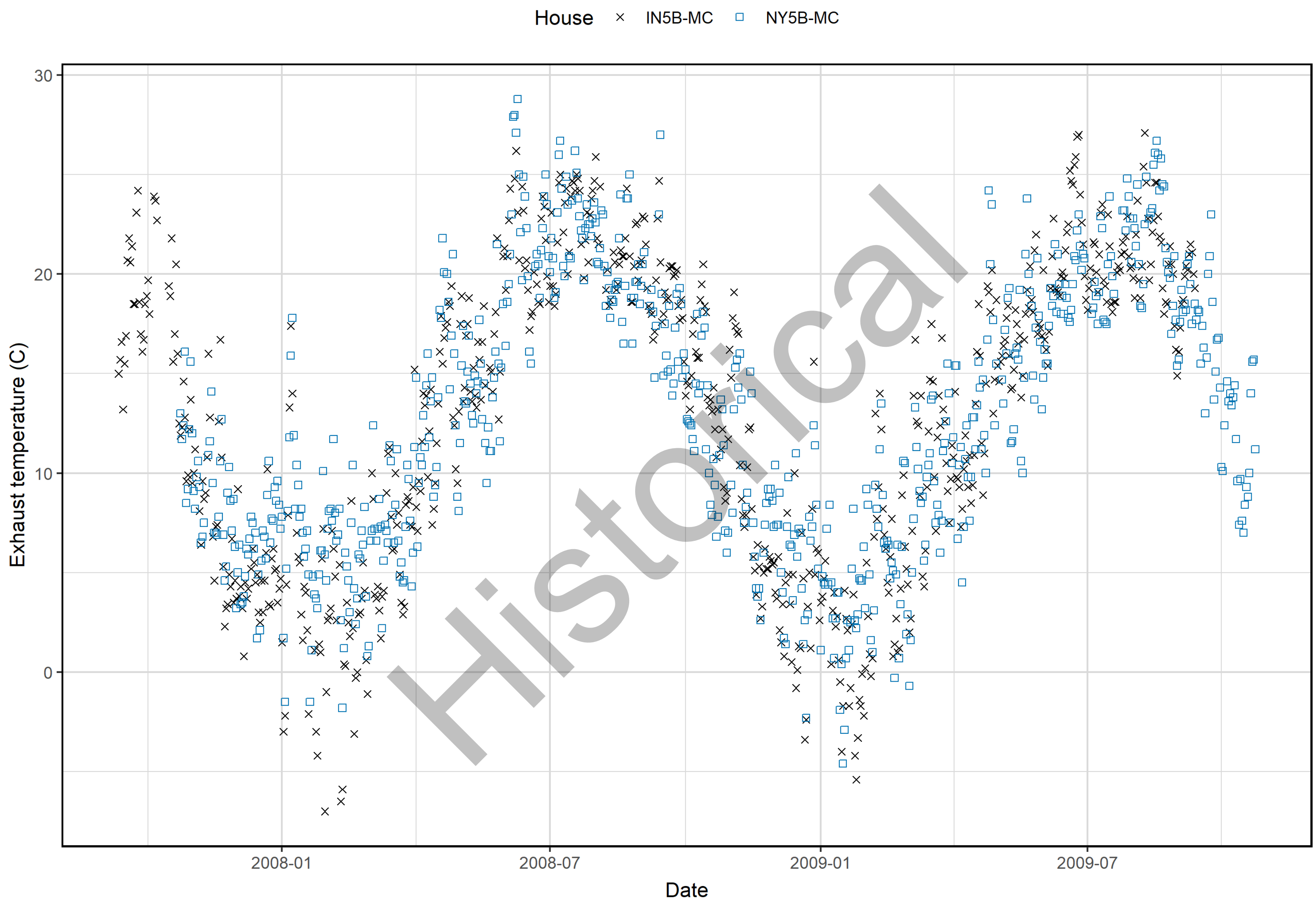


Figure E-22. Trends in exhaust temperature at milking centers, by site, during the NAEMS monitoring period.

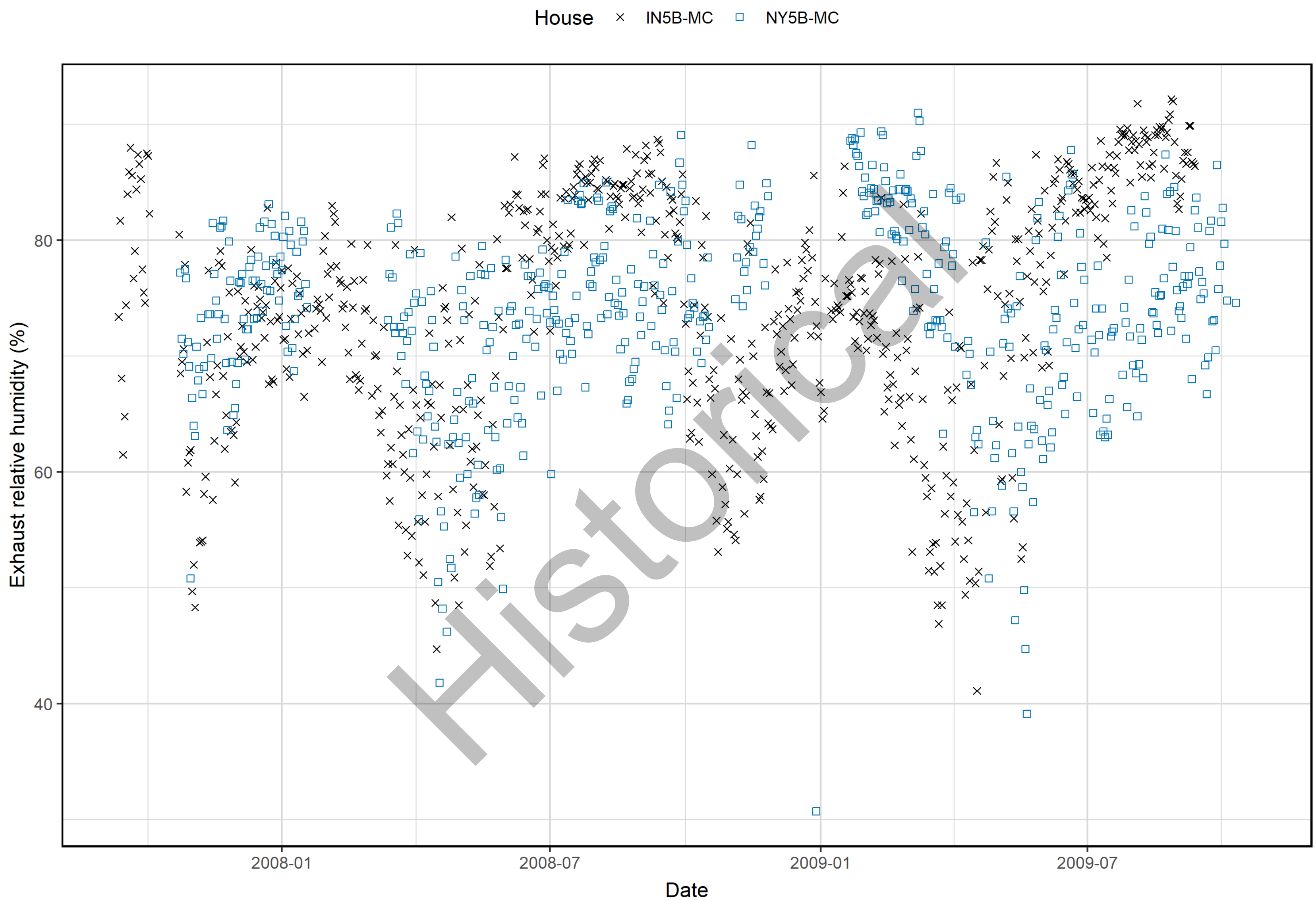


Figure E-23. Trends in exhaust relative humidity at milking centers, by site, during the NAEMS monitoring period.

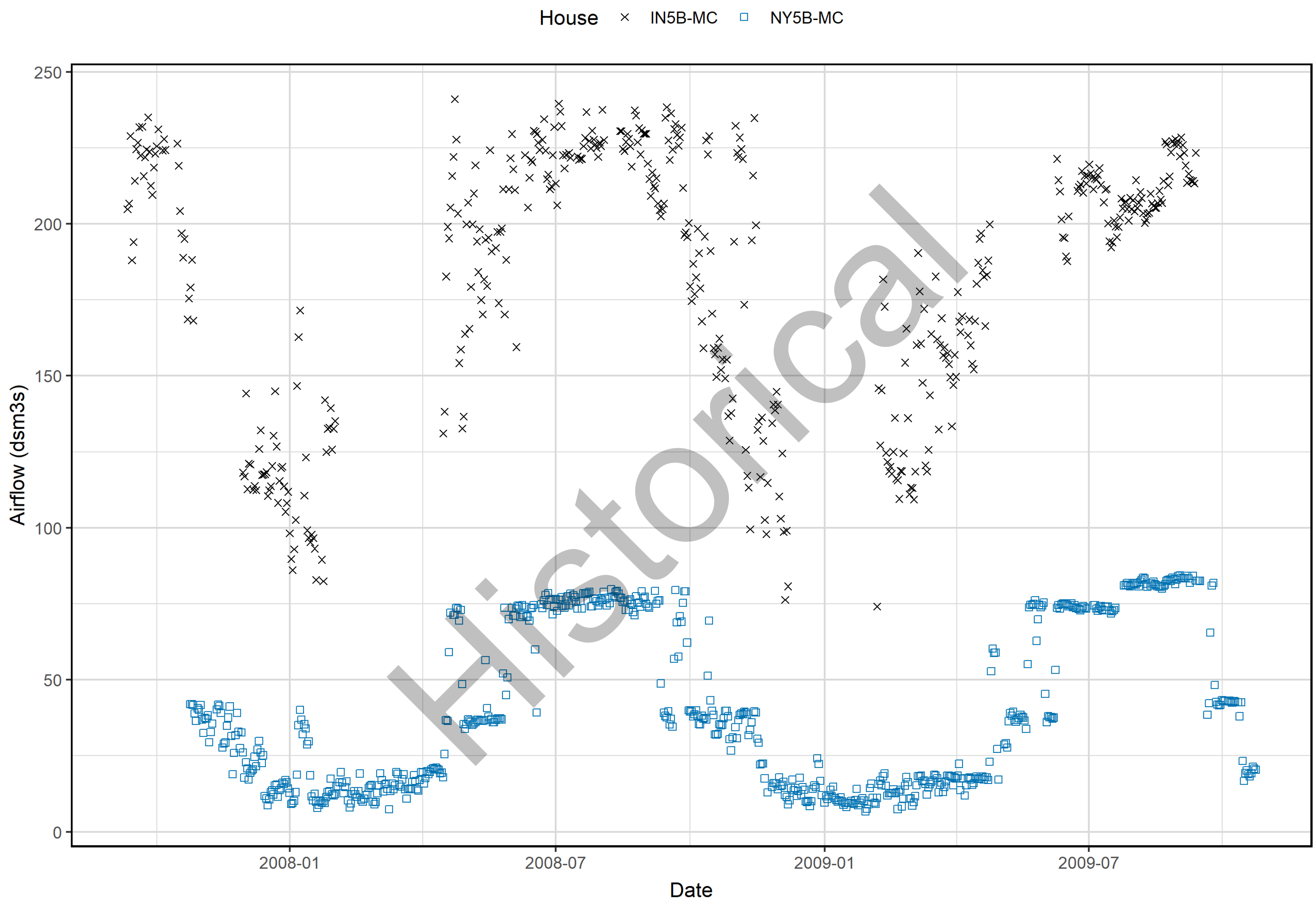


Figure E-24. Trends in ventilation rate at milking centers, by site, during the NAEMS monitoring period.

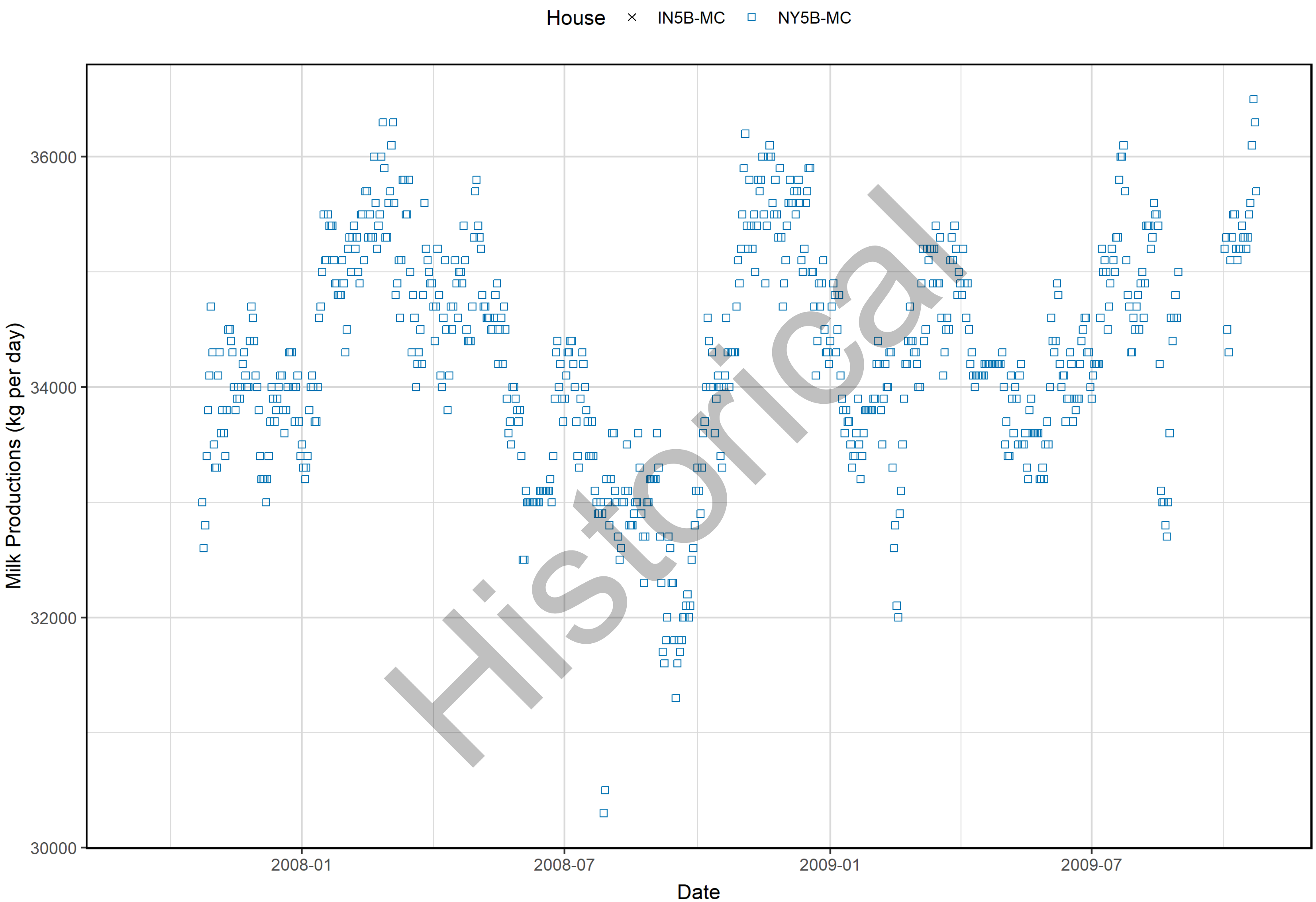


Figure E-25. Trends in milk production (kg per day) at milking centers, by site, during the NAEMS monitoring period.

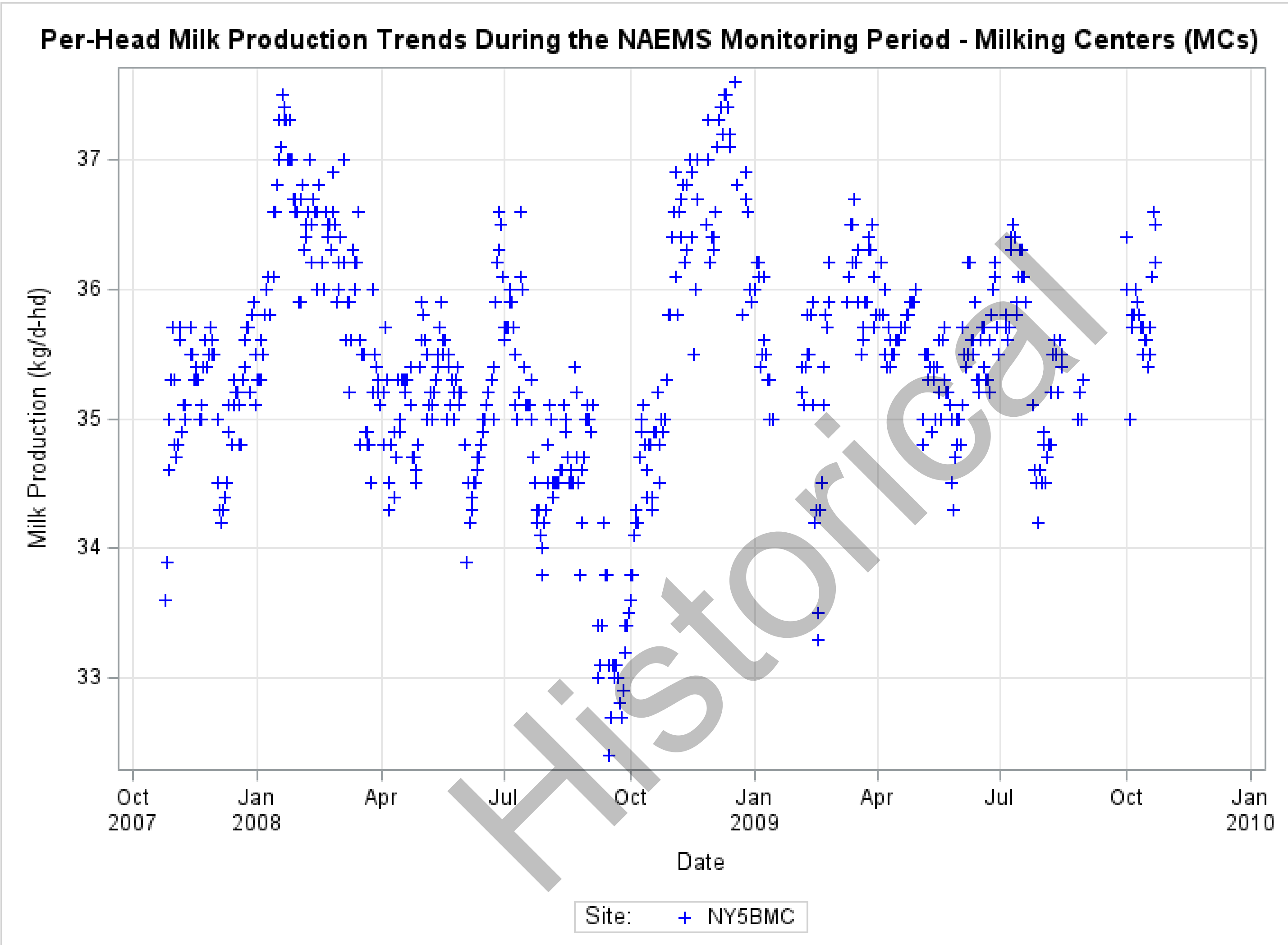


Figure E-26. Trends in milk production (kg per day per head) at milking centers, by site, during the NAEMS monitoring period.

E.2.3 Ambient Parameters

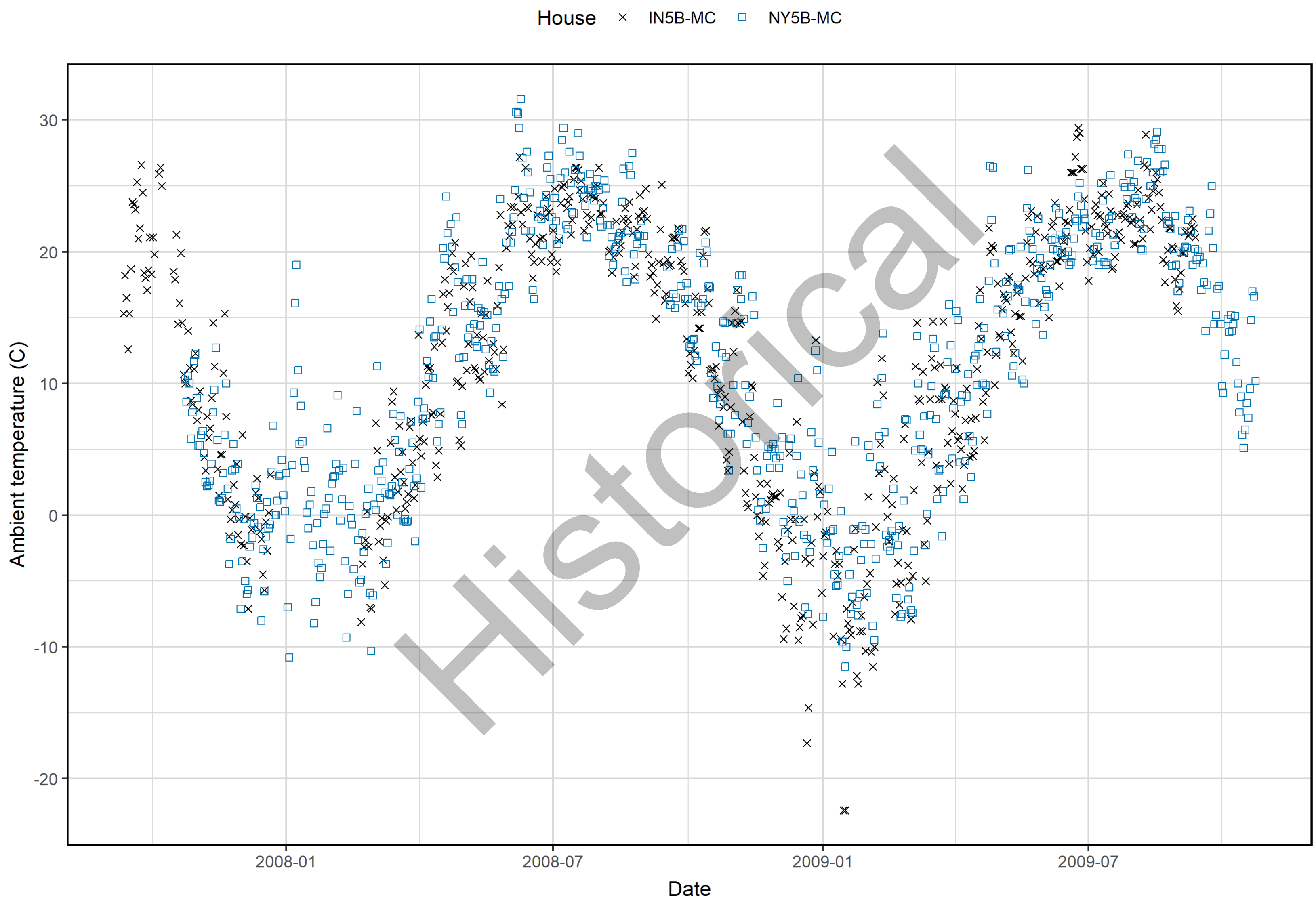


Figure E-27. Trends in ambient temperature at milking centers, by site, during the NAEMS monitoring period.

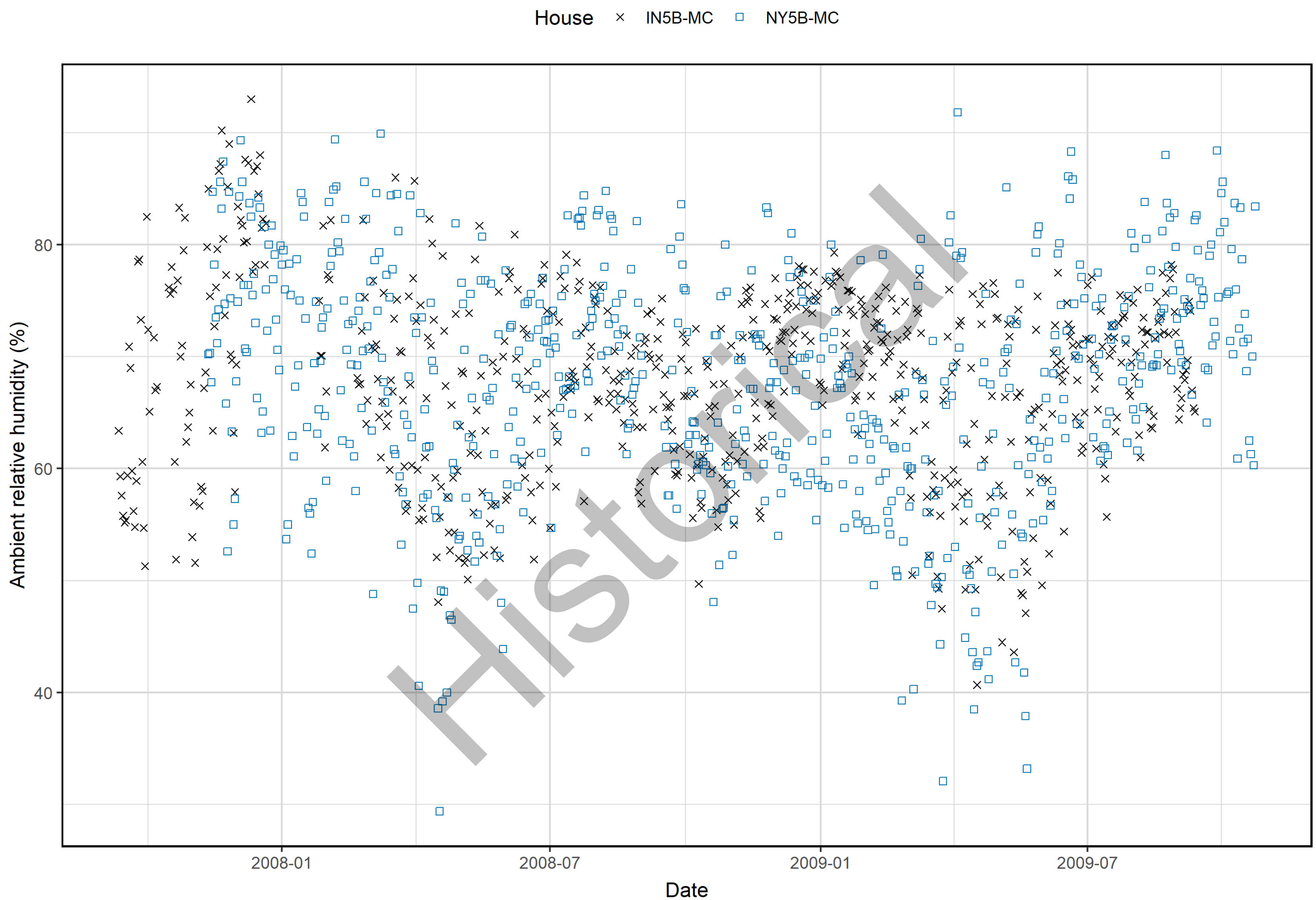


Figure E-28. Trends in ambient relative humidity at milking centers, by site, during the NAEMS monitoring period.

E.3 Naturally Ventilated Barns

E.3.1 Emissions

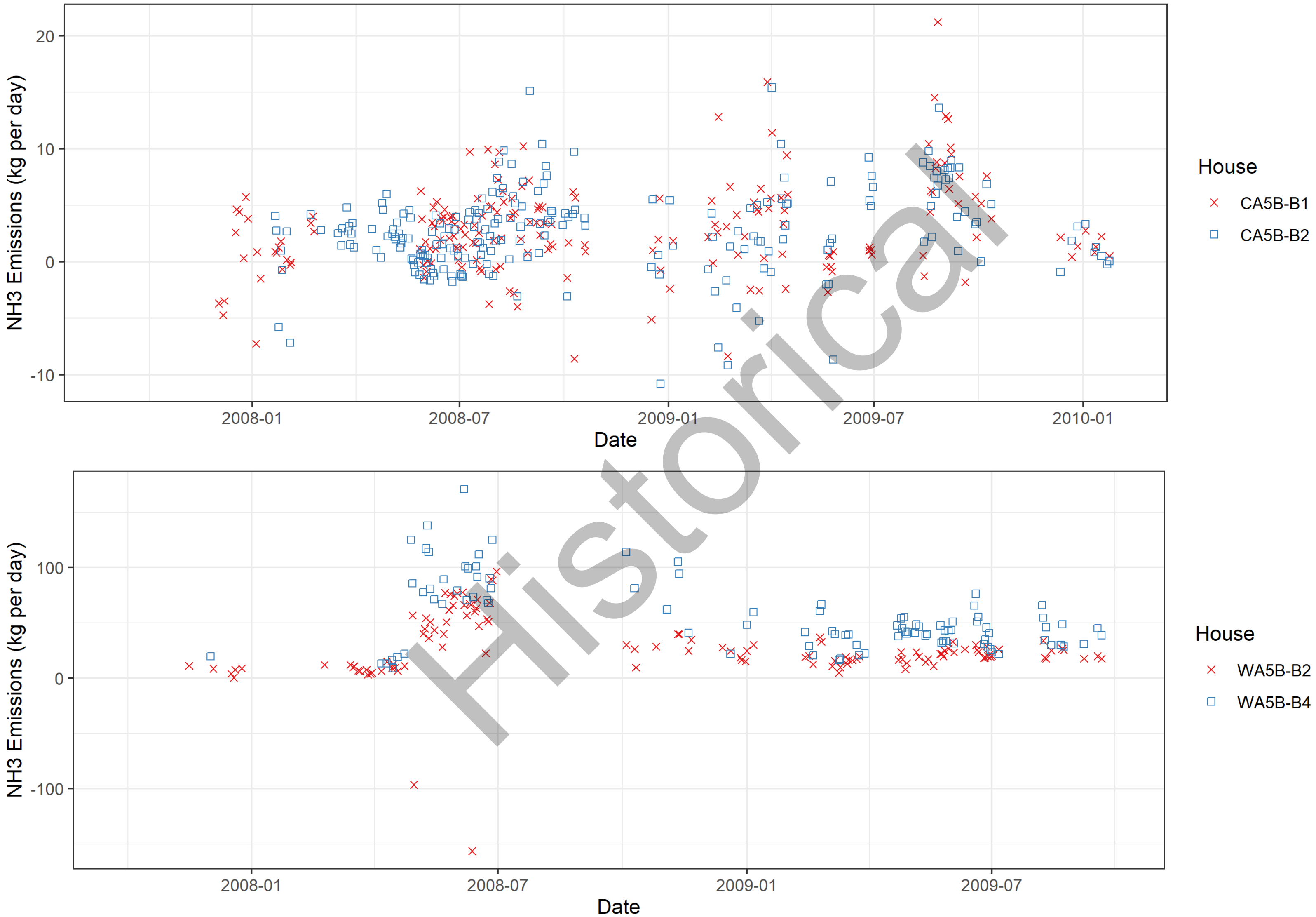


Figure E-29. Trends in NH_3 emissions at naturally ventilated barns, by site, during the NAEMS monitoring period.

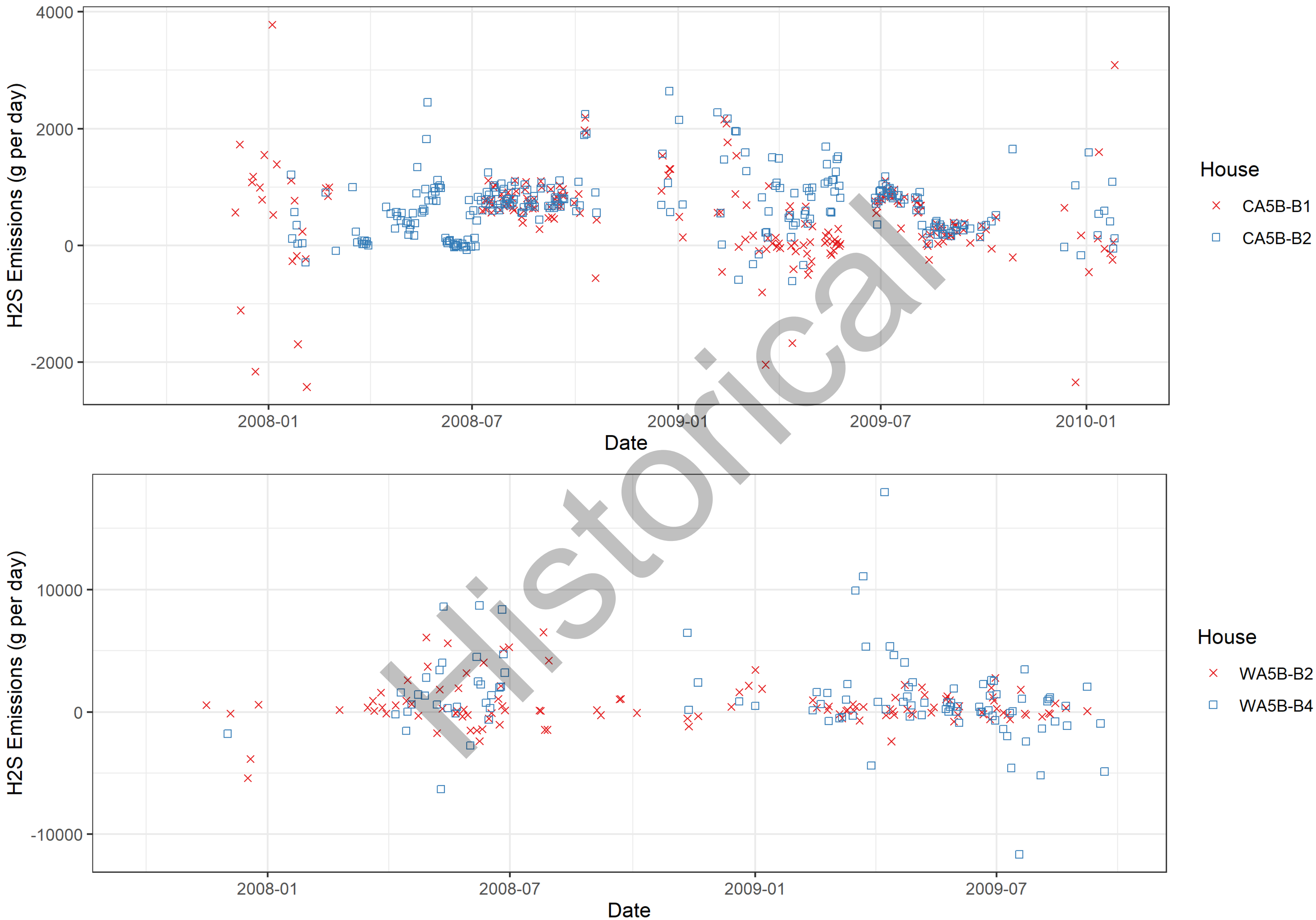


Figure E-30. Trends in H_2S emissions at naturally ventilated barns, by site, during the NAEMS monitoring period.

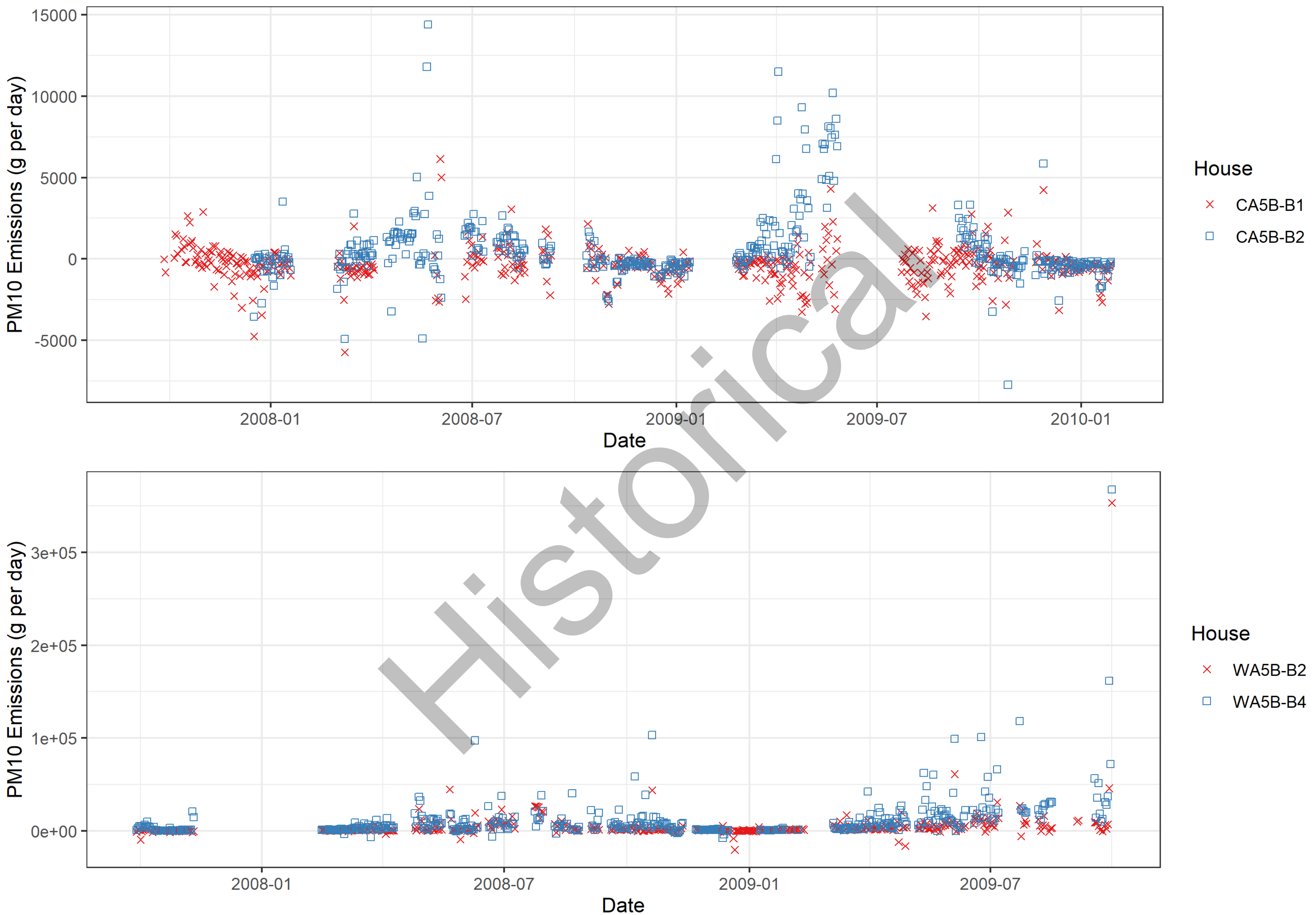


Figure E-31. Trends in PM_{10} emissions at naturally ventilated barns, by site, during the NAEMS monitoring period.

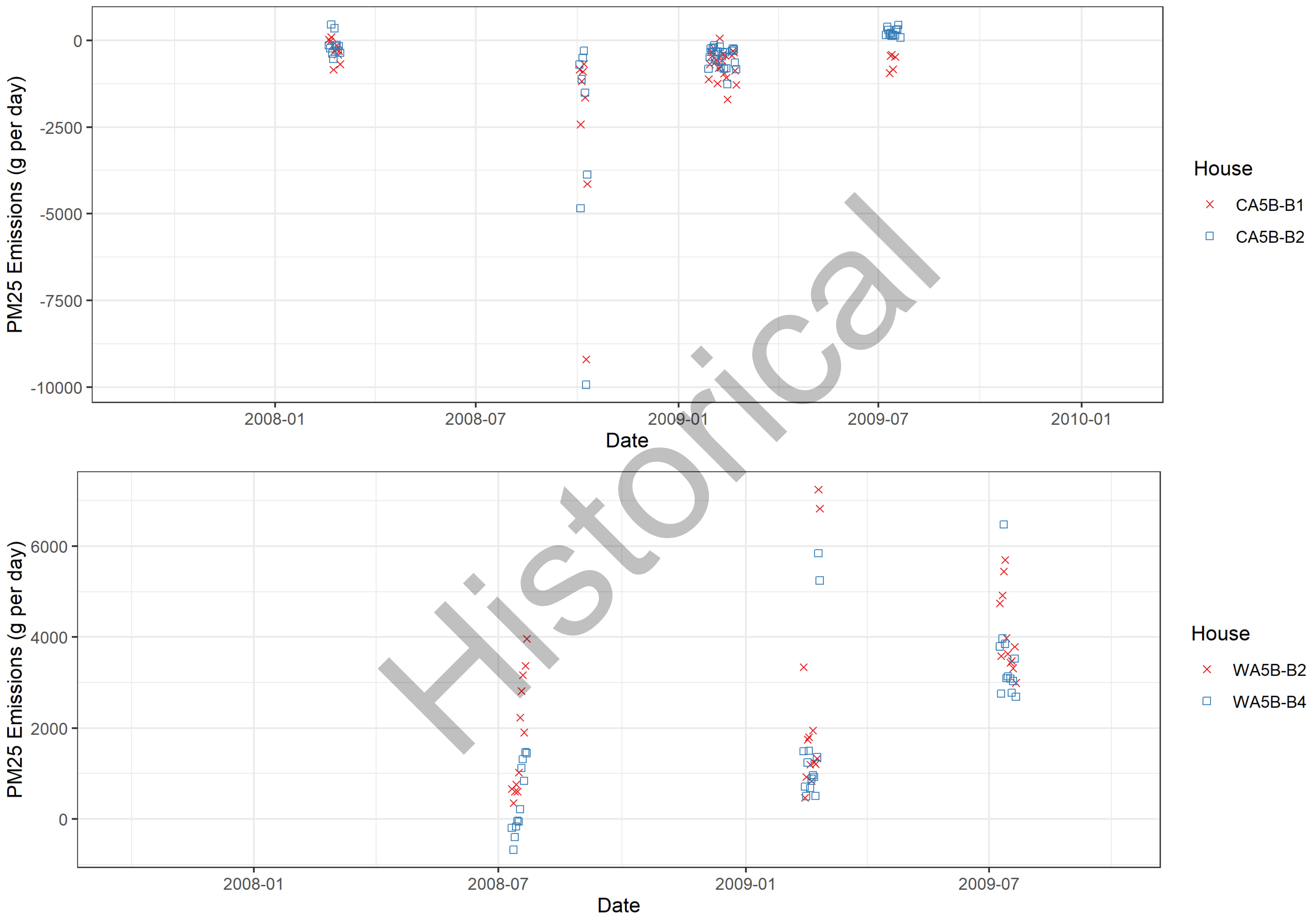


Figure E-32. Trends in $PM_{2.5}$ emissions at naturally ventilated barns, by site, during the NAEMS monitoring period.

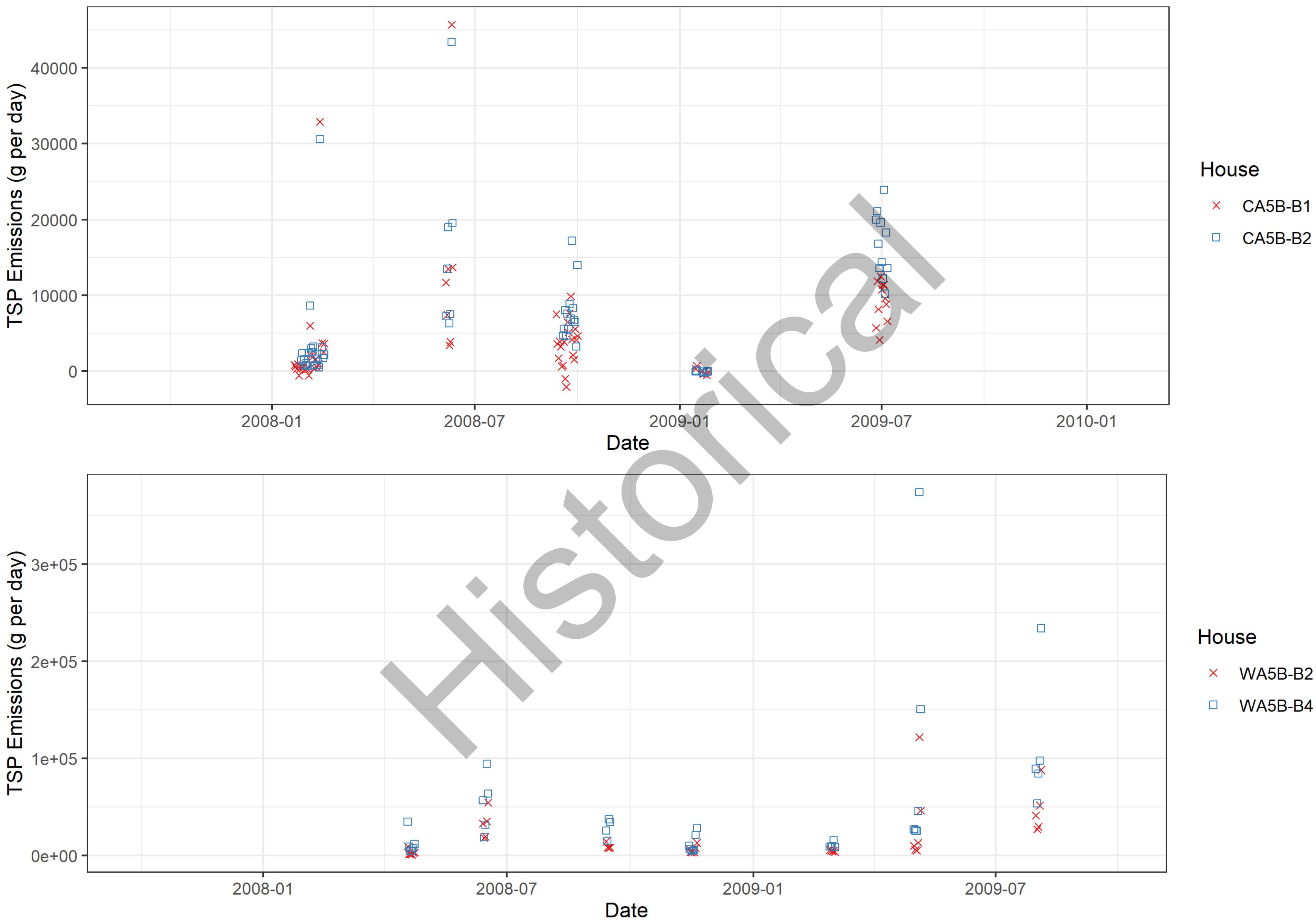


Figure E-33. Trends in TSP emissions at naturally ventilated barns, by site, during the NAEMS monitoring period.

E.3.2 Environmental Parameters

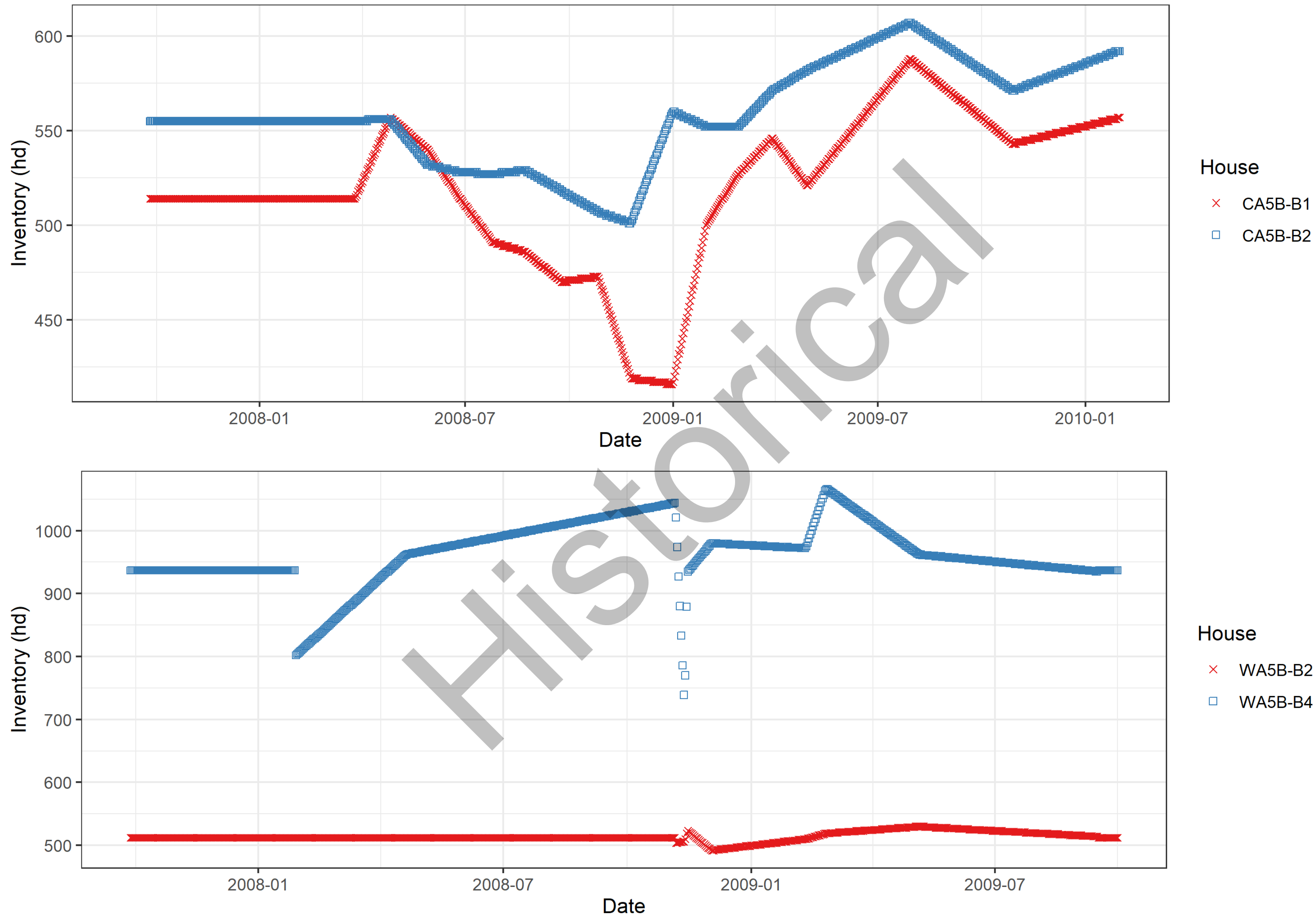


Figure E-34. Trends in Inventory at naturally ventilated barns, by site, during the NAEMS monitoring period.

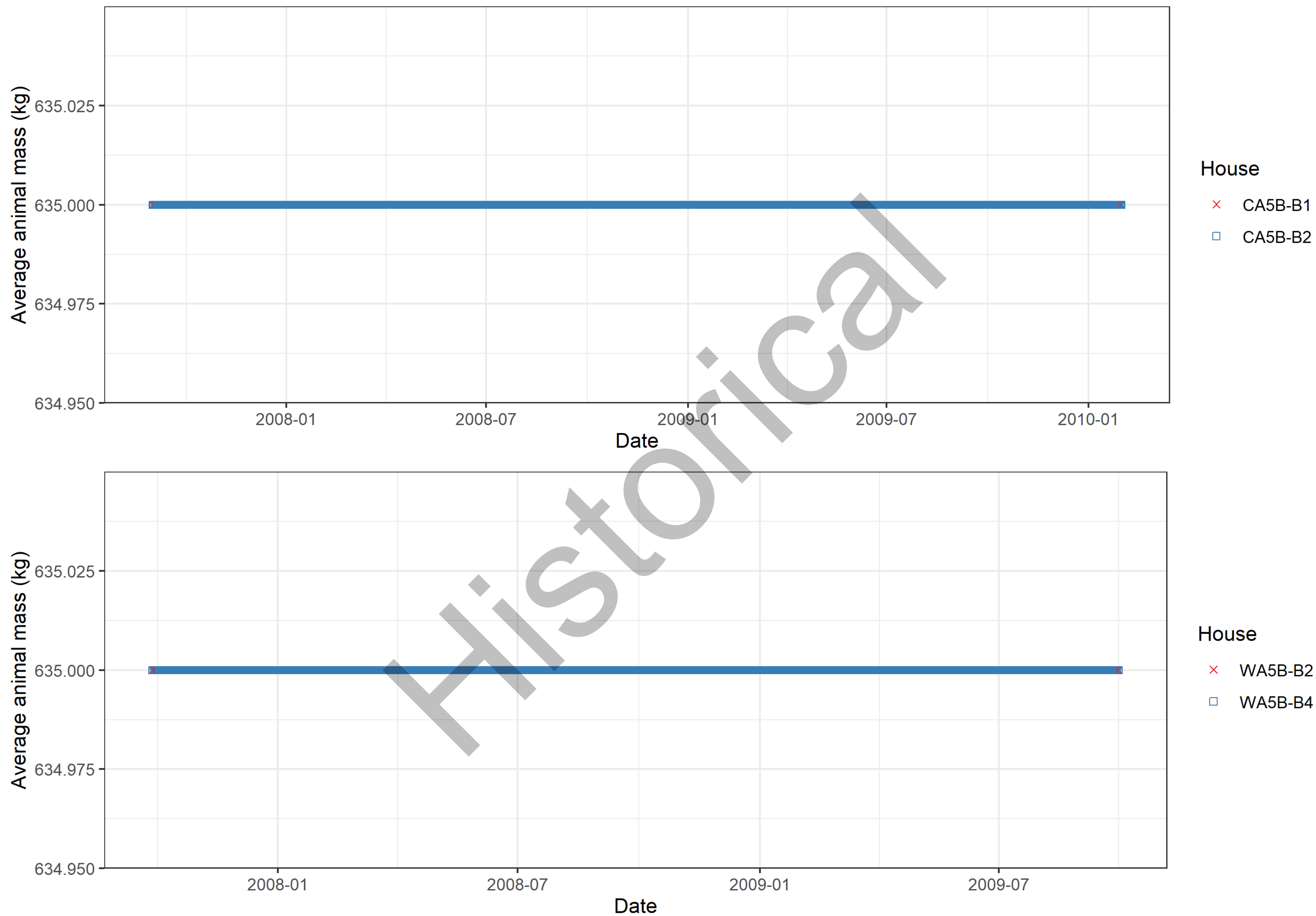


Figure E-35. Trends in average animal mass at naturally ventilated barns, by site, during the NAEMS monitoring period.

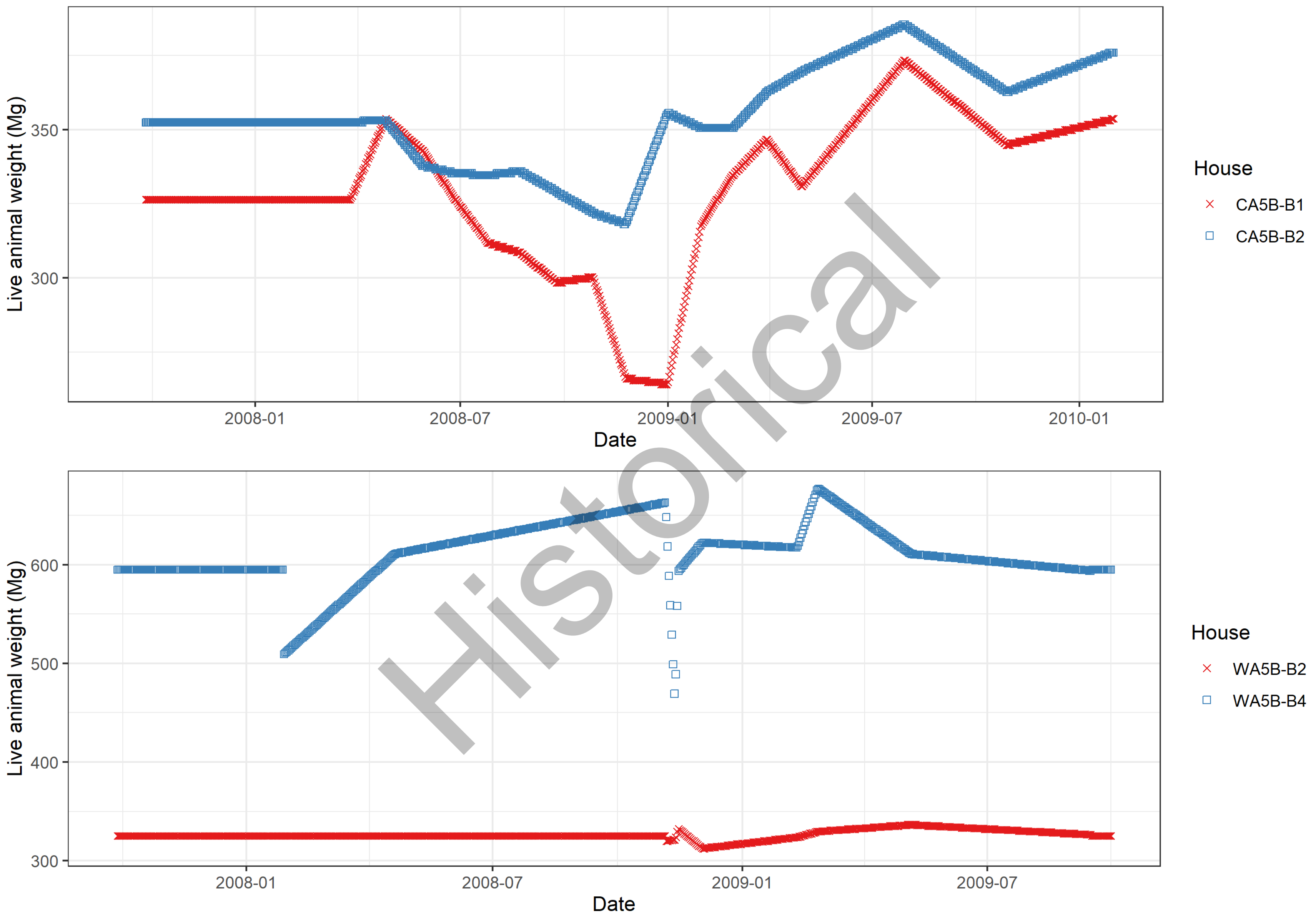


Figure E-36. Trends in live animal weight at naturally ventilated barns, by site, during the NAEMS monitoring period.

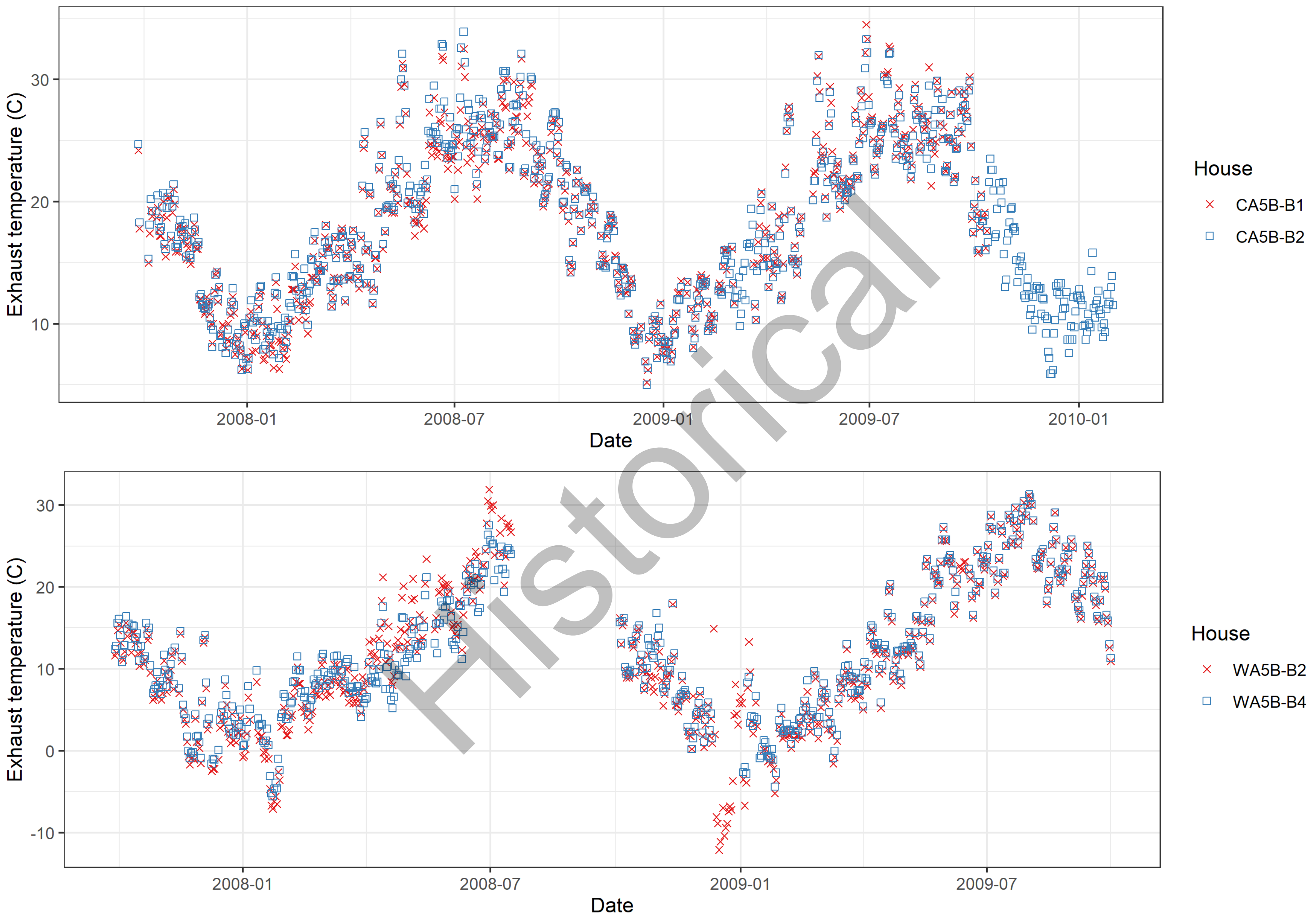


Figure E-37. Trends in exhaust temperature at naturally ventilated barns, by site, during the NAEMS monitoring period.

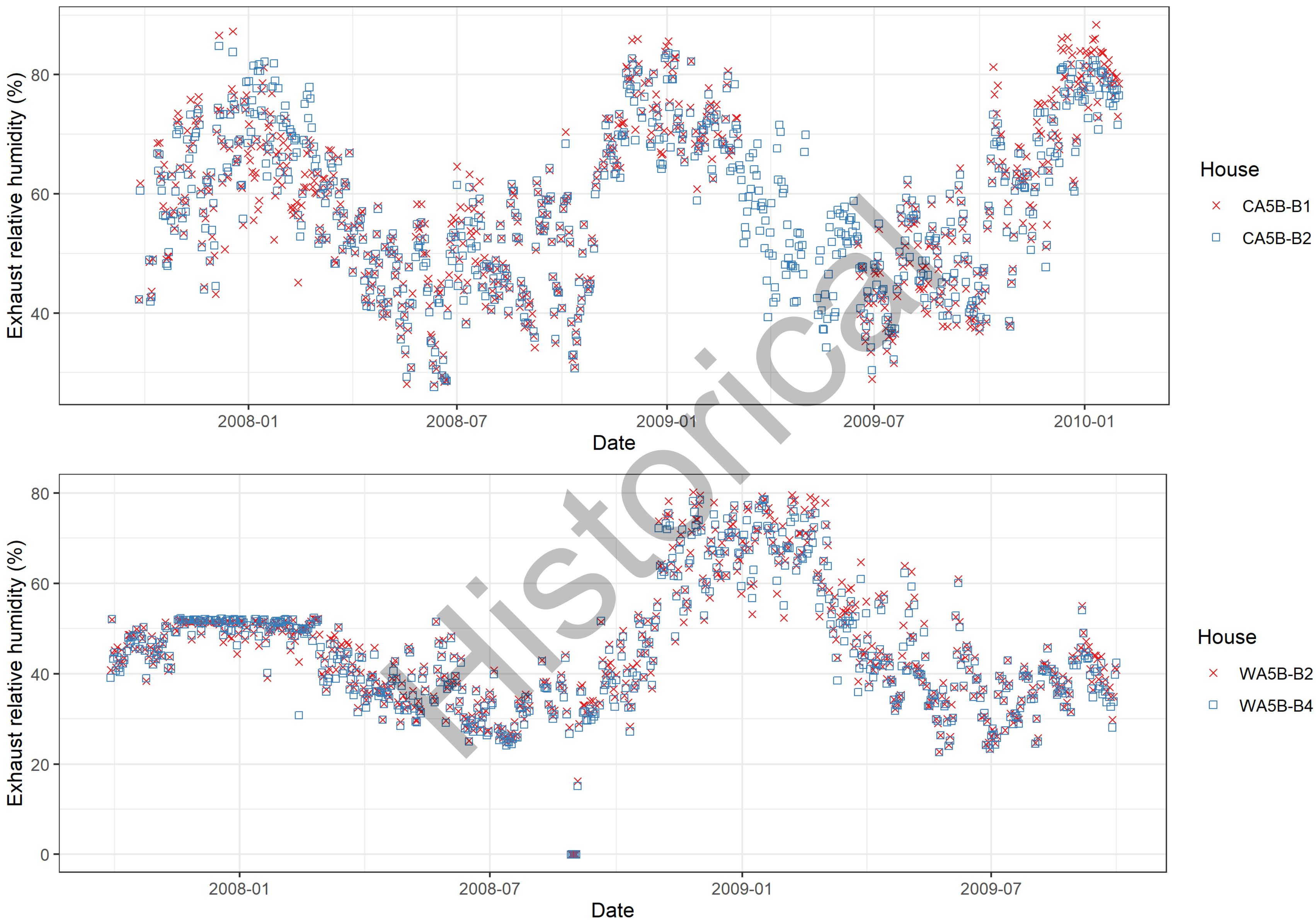


Figure E-38. Trends in exhaust relative humidity at naturally ventilated barns, by site, during the NAEMS monitoring period.

Figure E-39. Trends in airflow rate at naturally ventilated barns, by site, during the NAEMS monitoring period.

E.3.3 Ambient Parameters

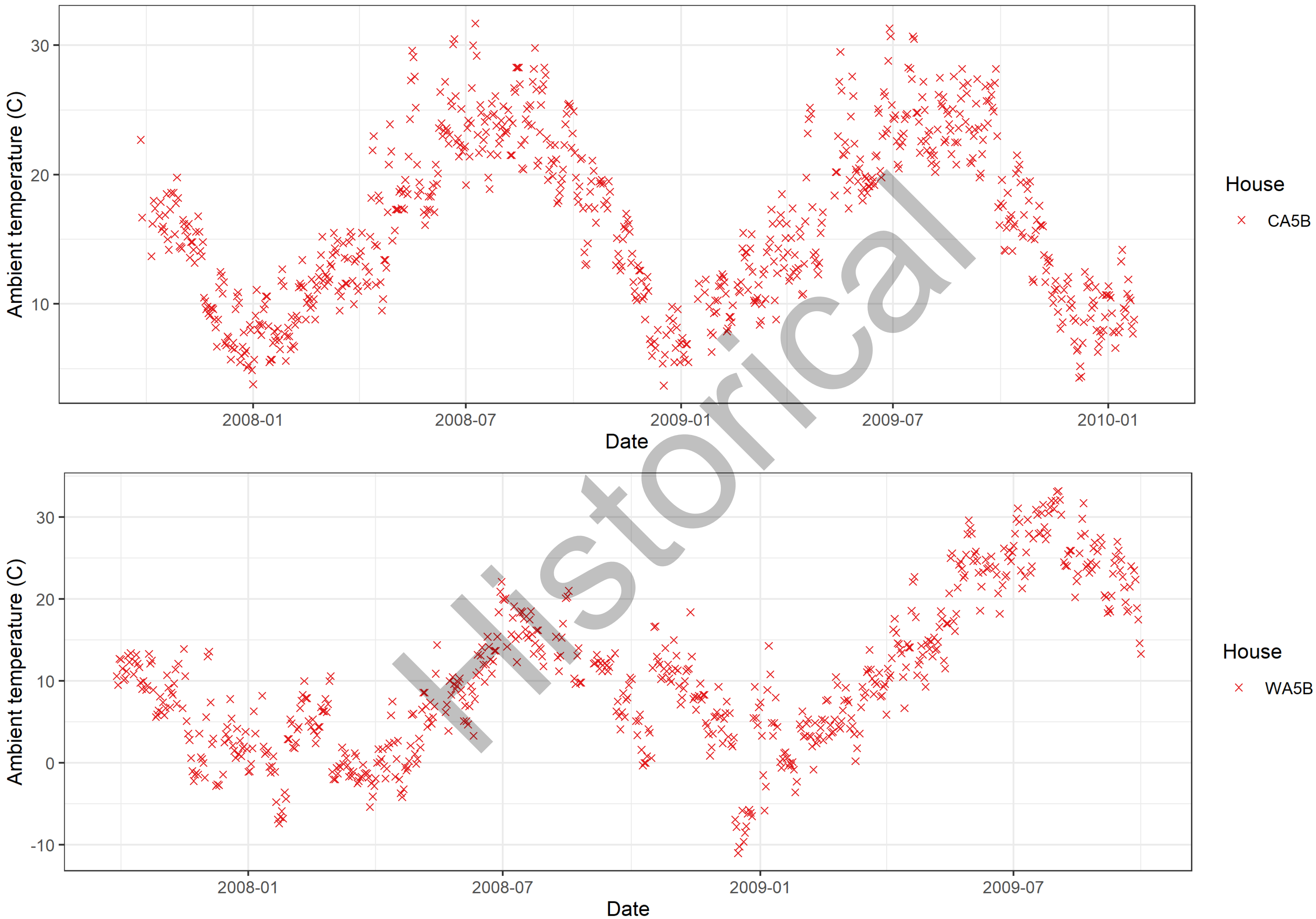


Figure E-40. Trends in ambient temperature at naturally ventilated barns, by site, during the NAEMS monitoring period.

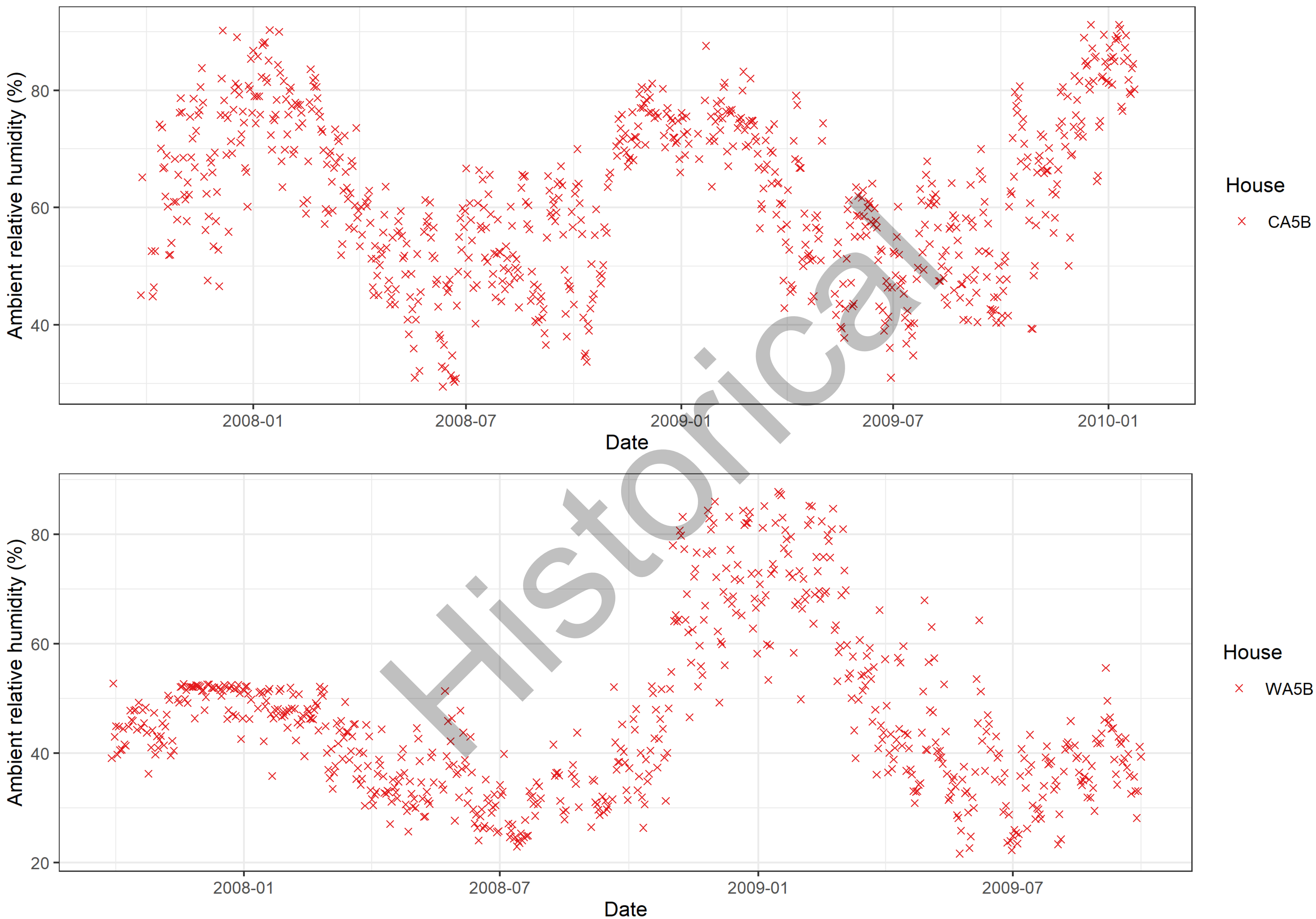


Figure E-41. Trends in ambient relative humidity at naturally ventilated barns, by site, during the NAEMS monitoring period.

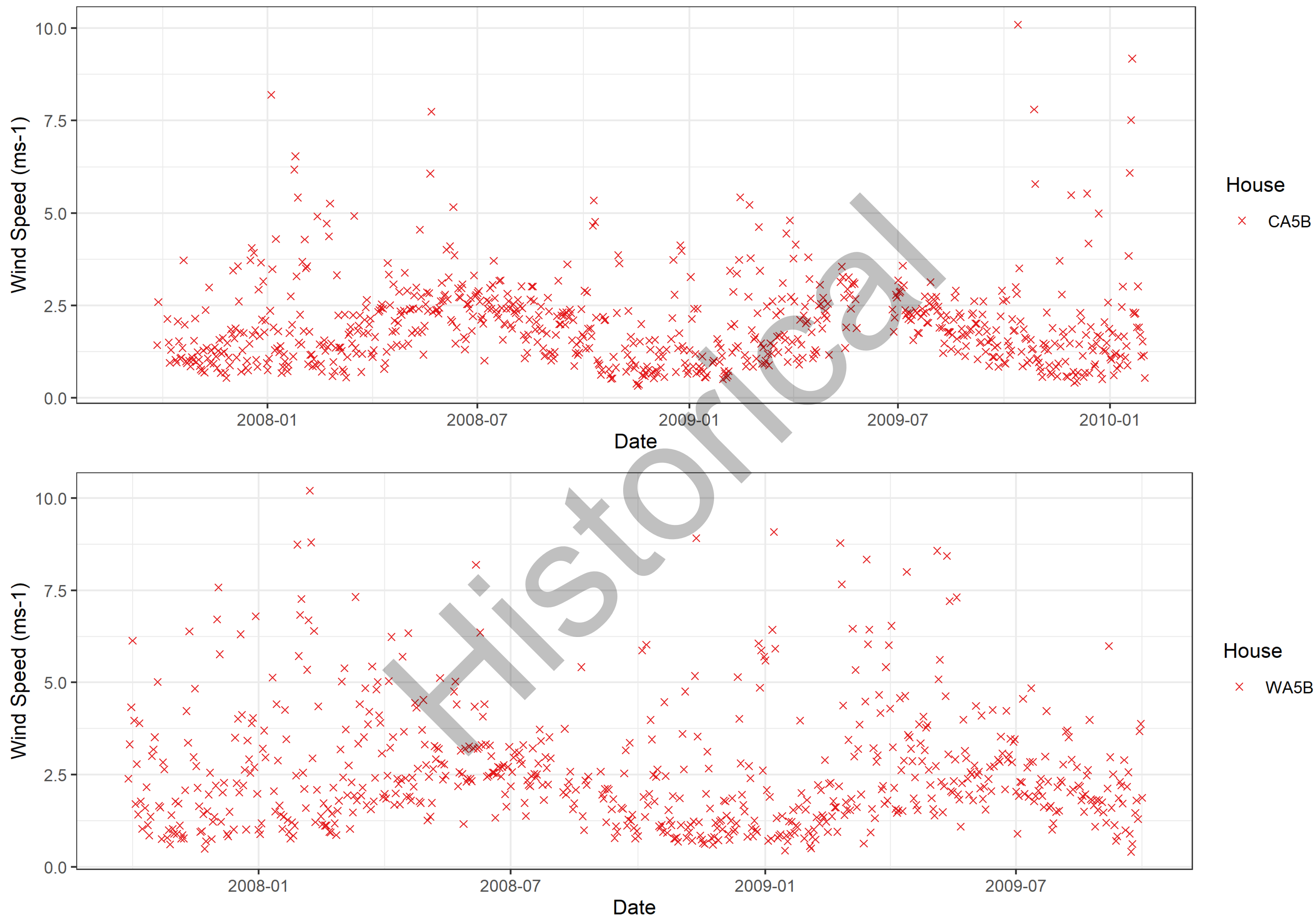


Figure E-42. Trends in wind speed at naturally ventilated barns, by site, during the NAEMS monitoring period.

E.4 Lagoon

E.4.1 Emissions

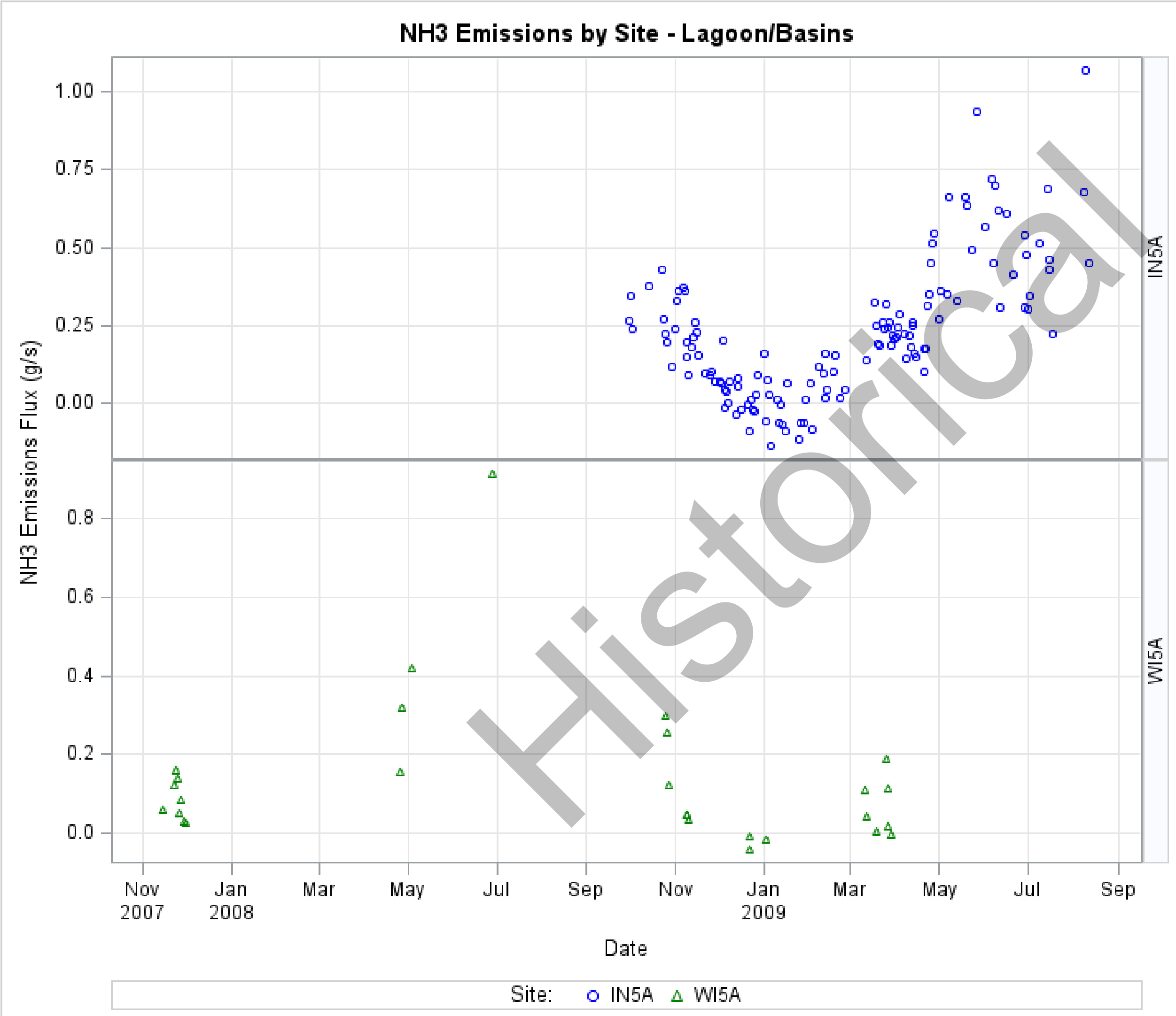


Figure E-43. Trends in NH_3 emissions at dairy lagoons, by site, during the NAEMS monitoring period.

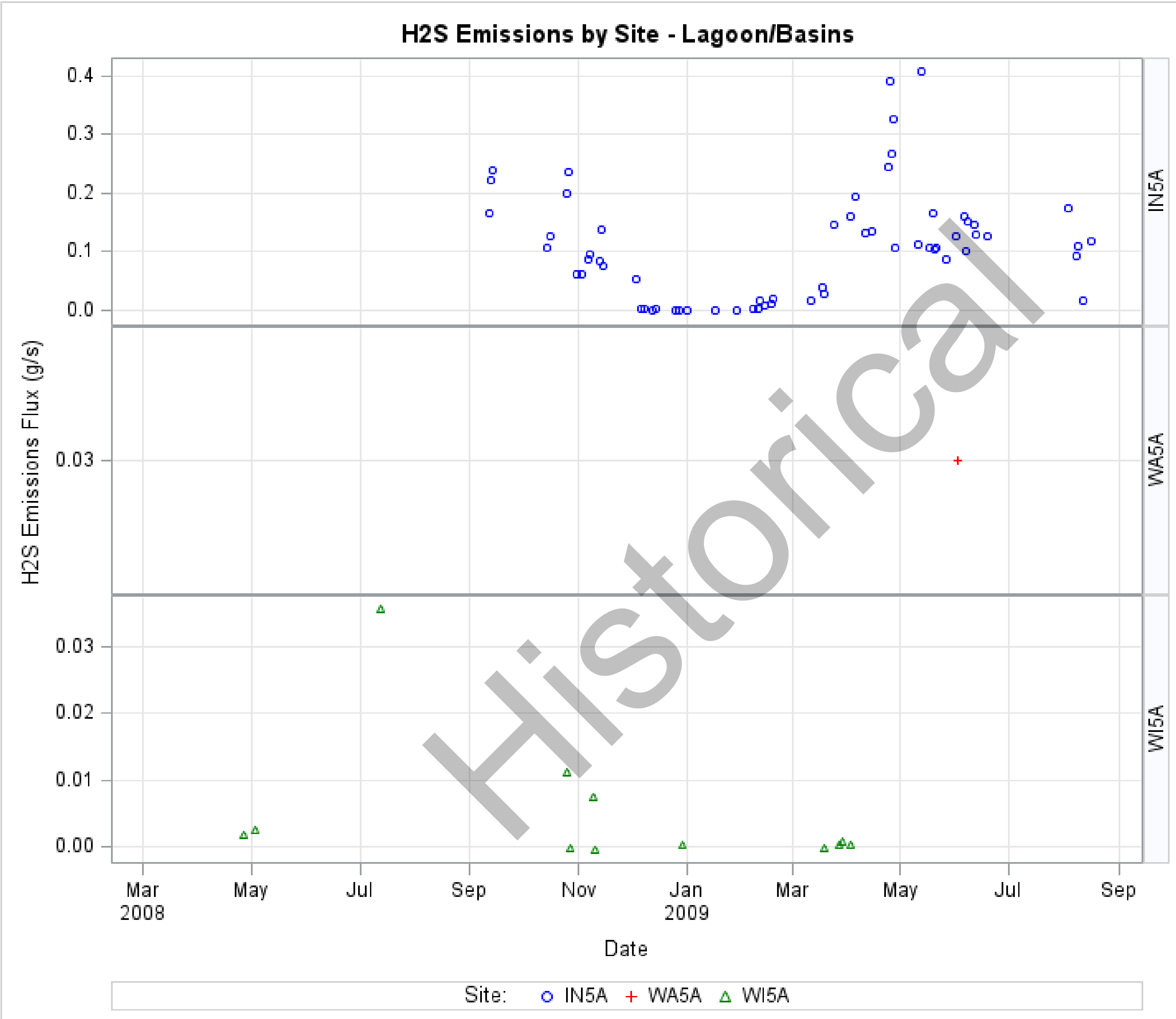


Figure E-44. Trends in H_2S emissions at dairy lagoons, by site, during the NAEMS monitoring period.

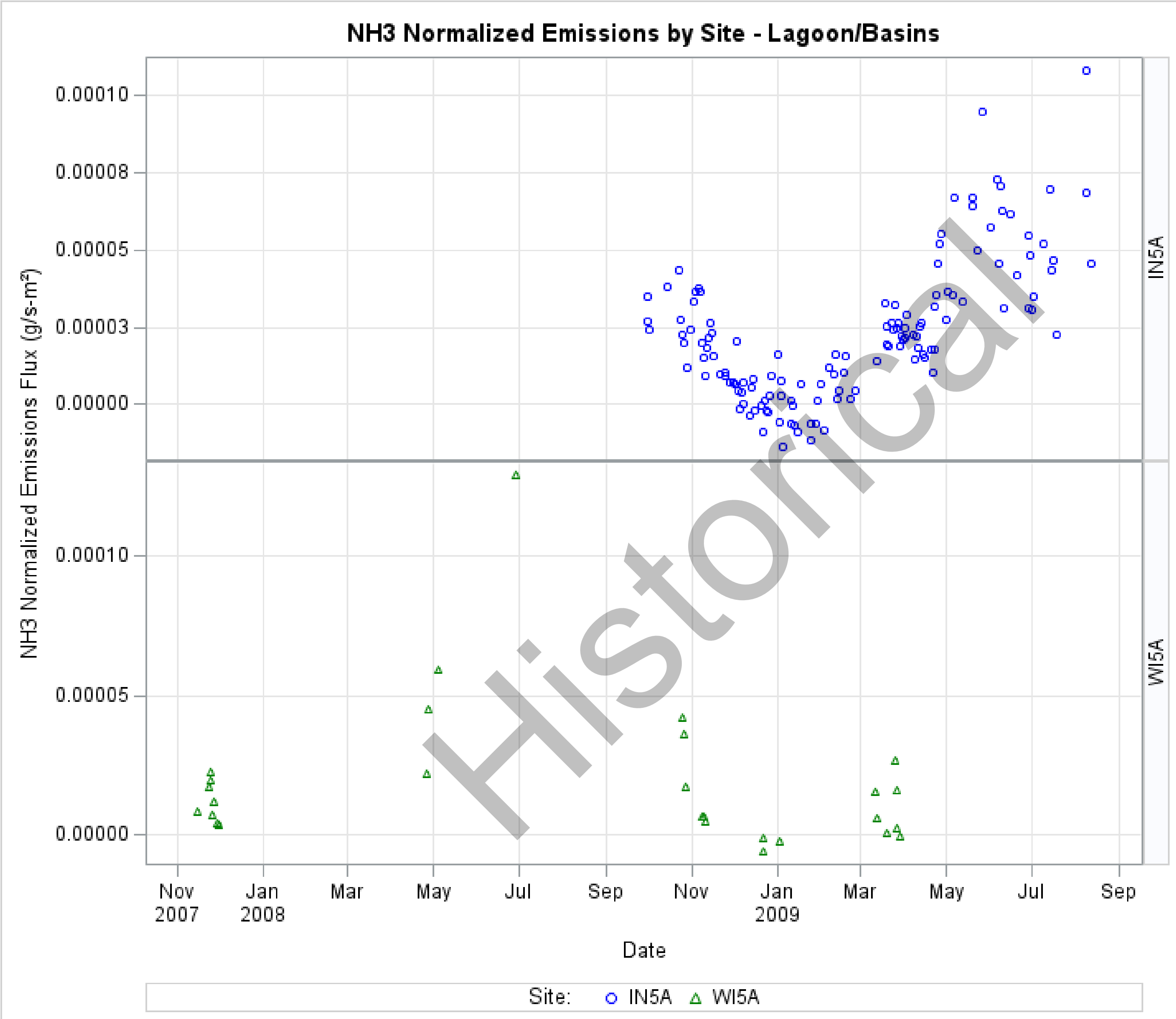


Figure E-45. Trends in NH_3 emissions normalized by surface area, by site, during the NAEMS monitoring period.

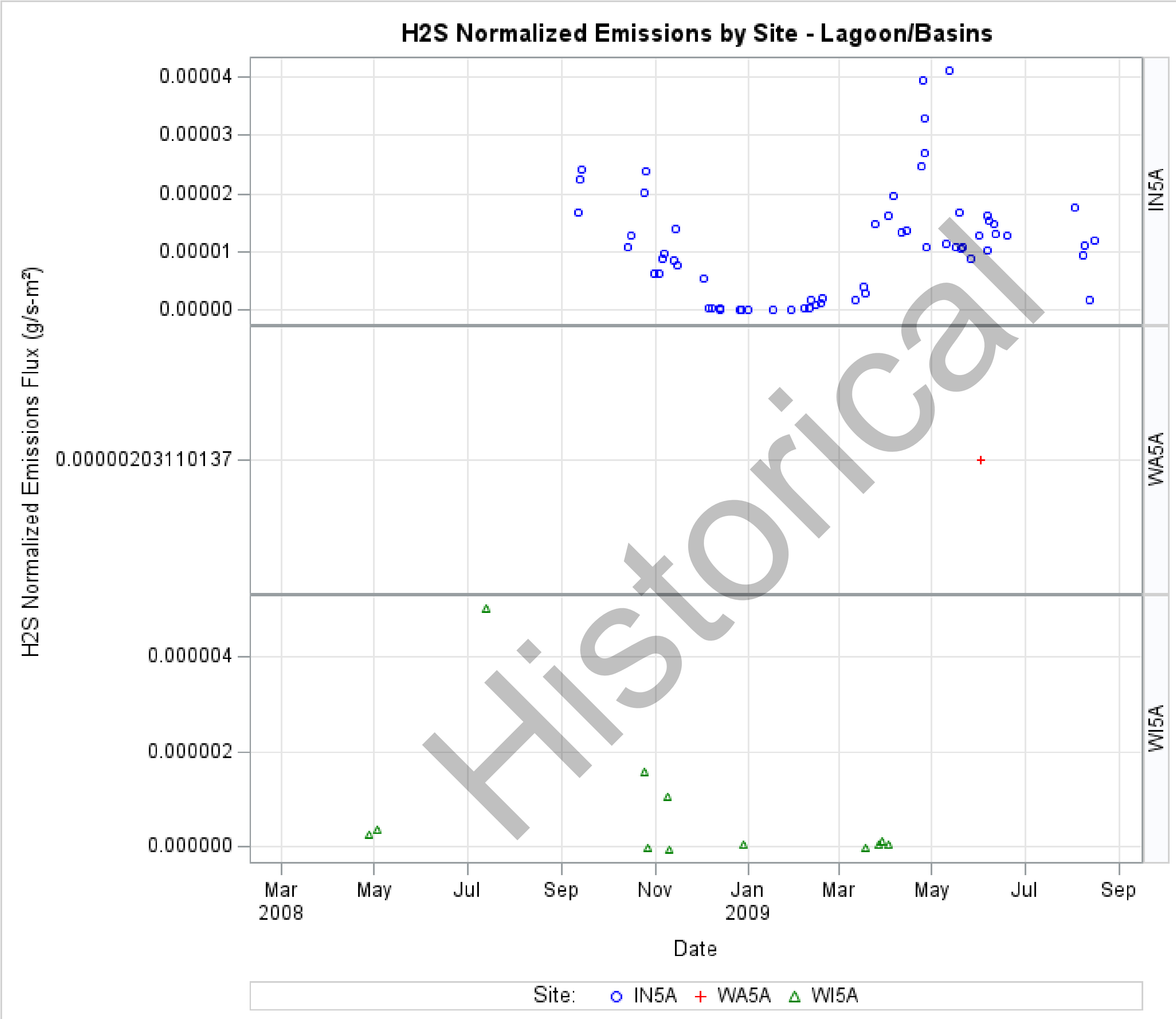


Figure E-46. Trends in H_2S emissions normalized by surface area, by site, during the NAEMS monitoring period.

E.4.2 Environmental Parameters

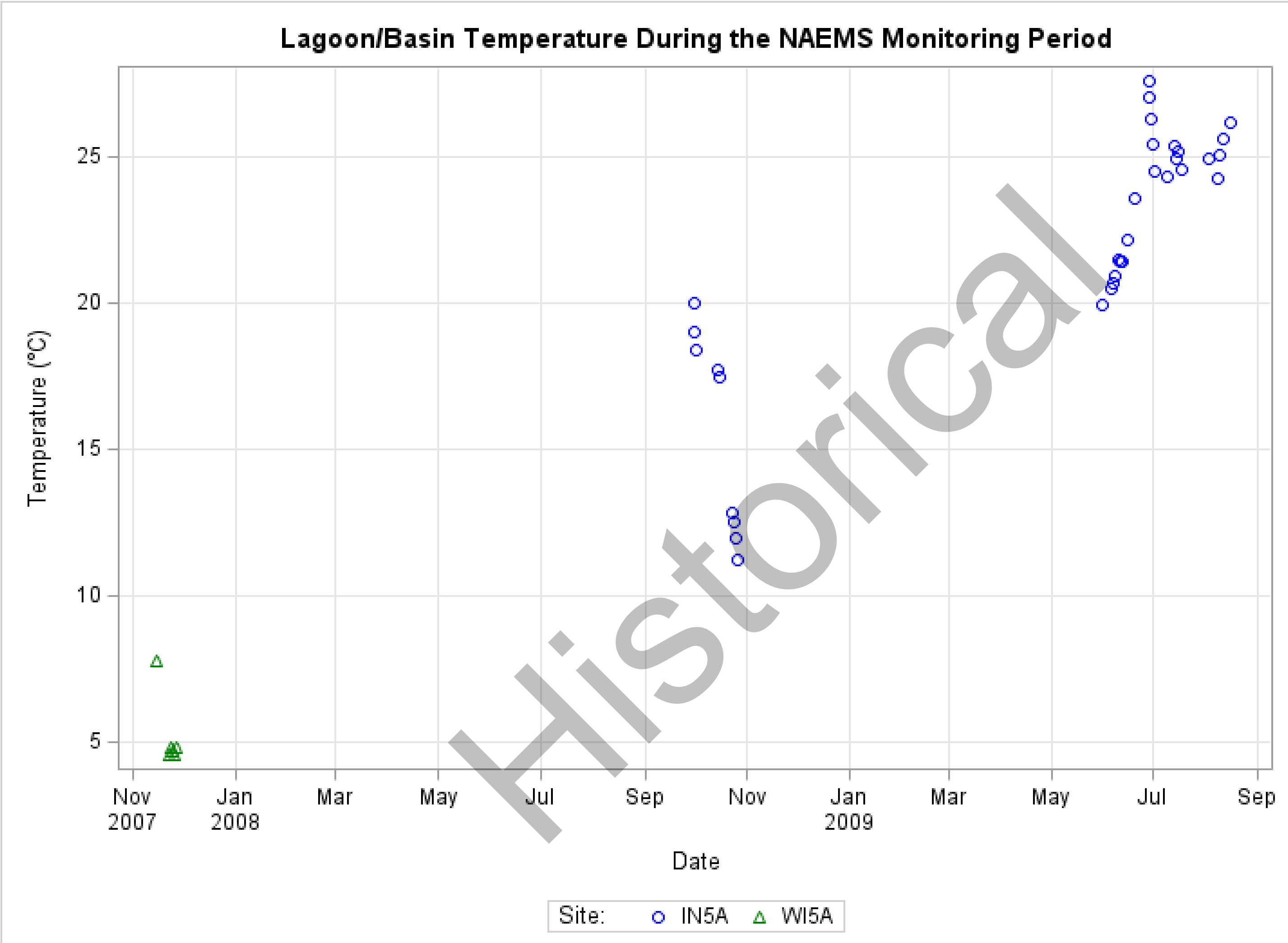


Figure E-47. Trends in lagoon/basin temperature, by open source site, during the NAEMS monitoring period.

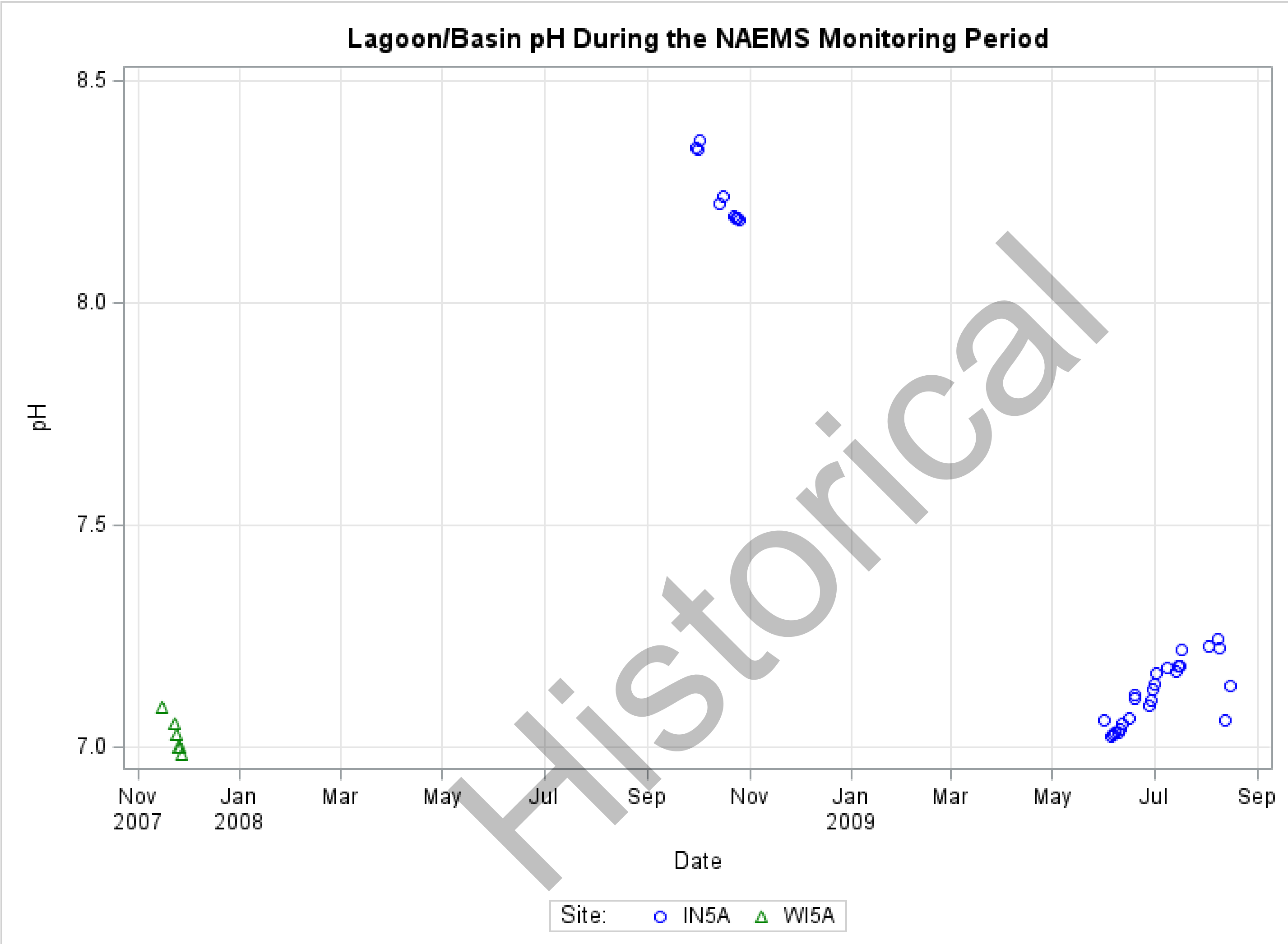


Figure E-48. Trends in pH, by open source site, during the NAEMS monitoring period.

E.4.3 Ambient Parameters

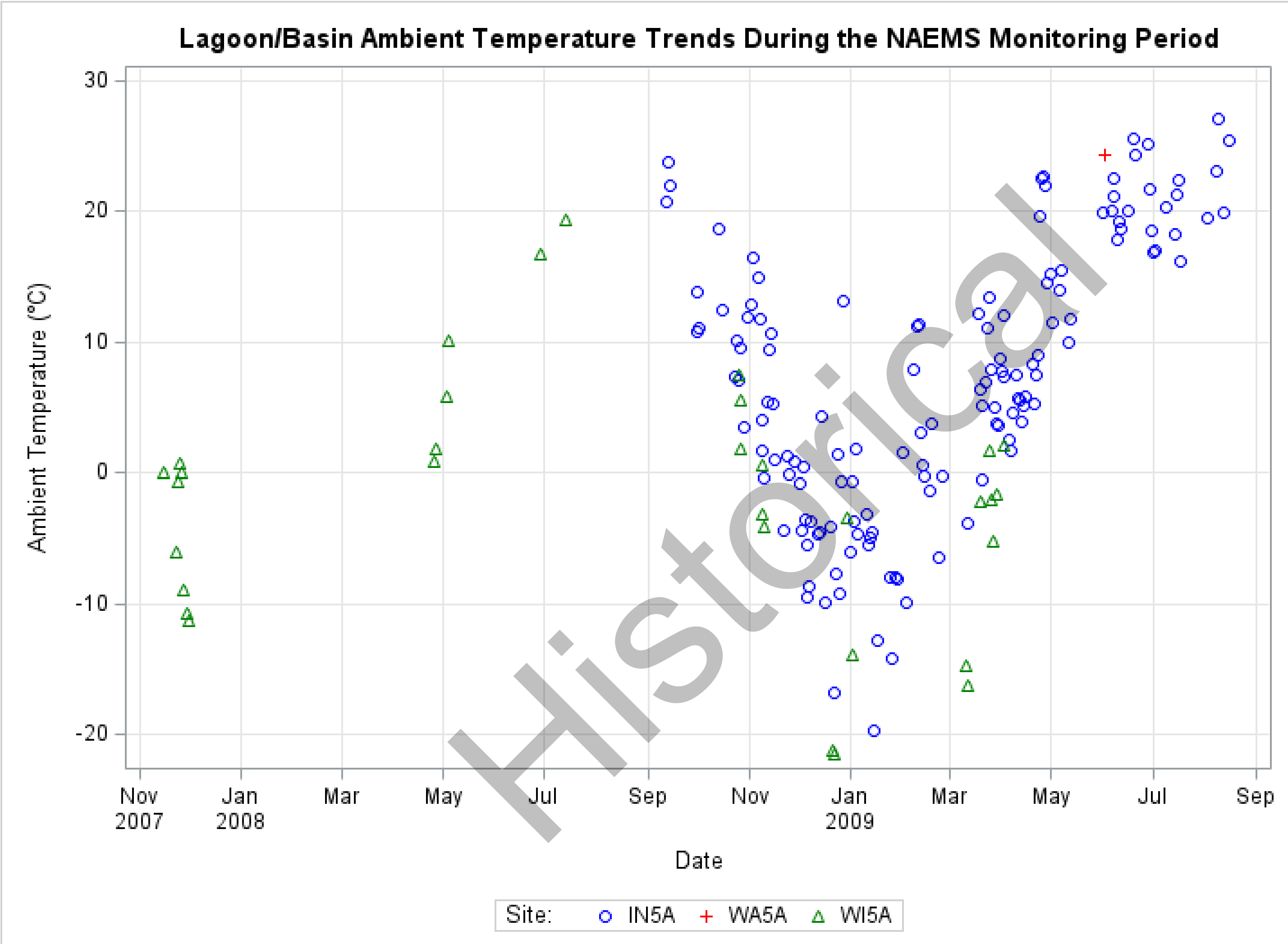


Figure E-49. Trends in ambient temperature, by open source site, during the NAEMS monitoring period.

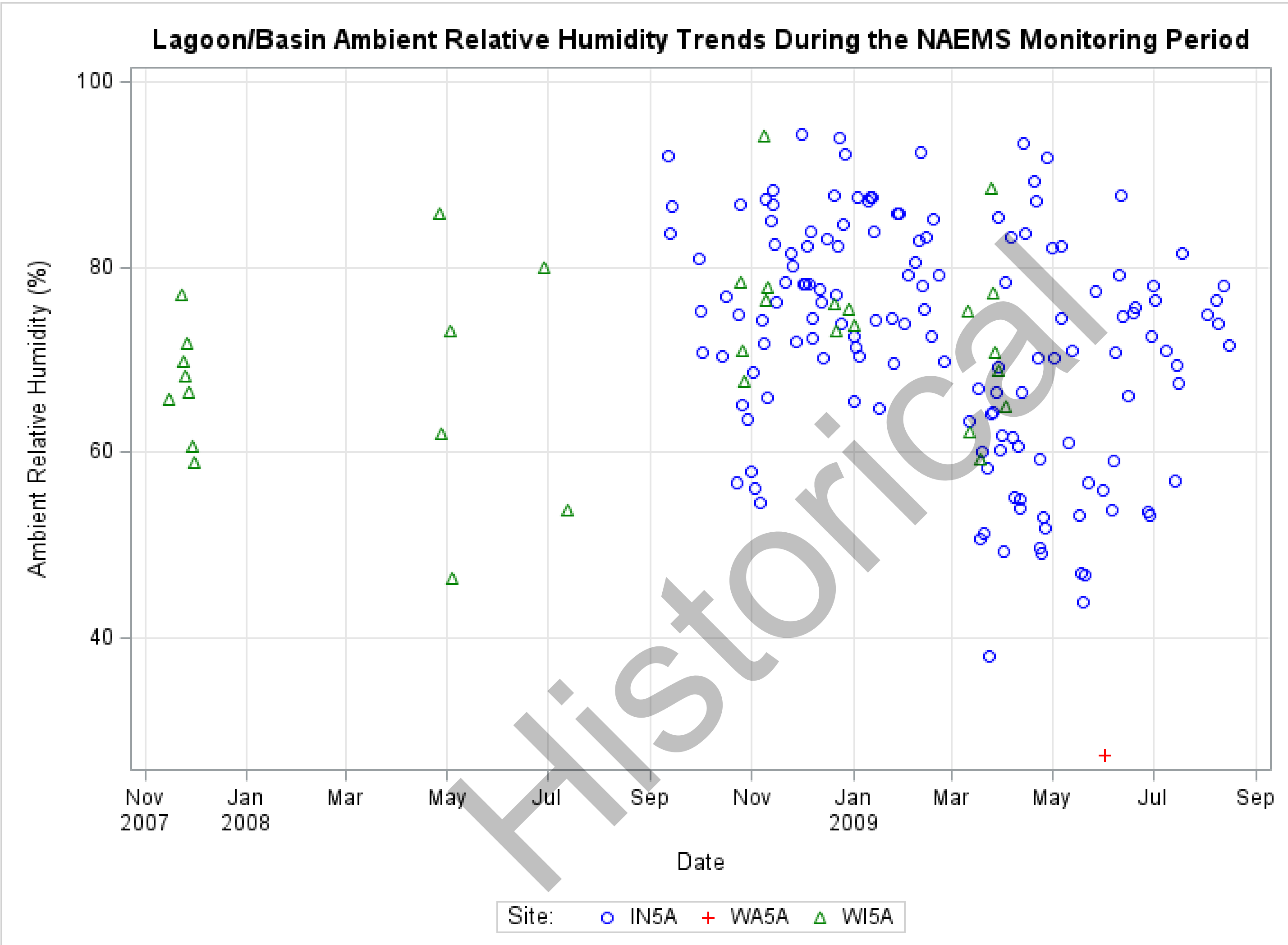


Figure E-50. Trends in ambient relative humidity, by open source site, during the NAEMS monitoring period.

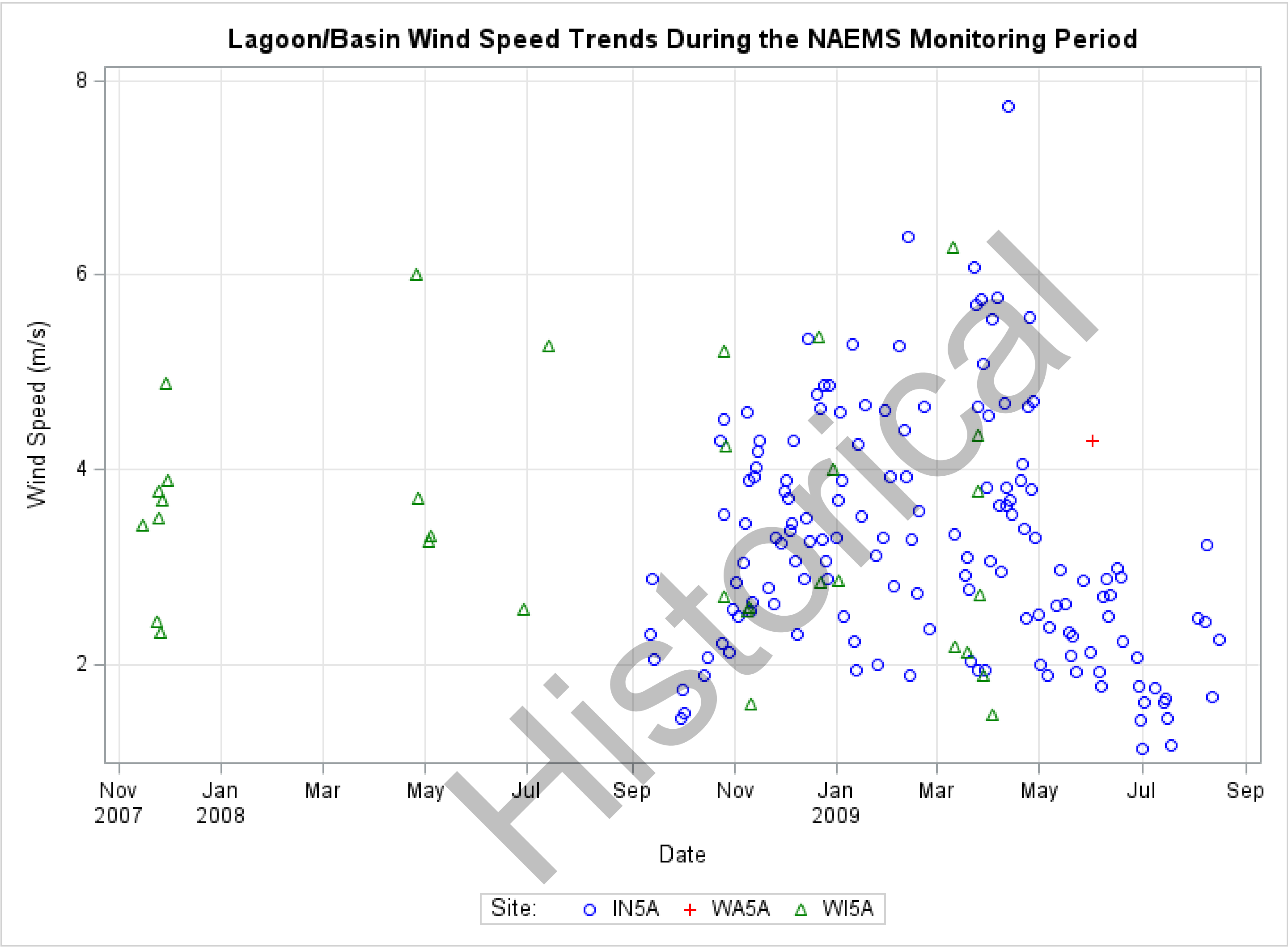


Figure E-51. Trends in wind speed, by open source site, during the NAEMS monitoring period.

E.5 Corral

E.5.1 Emissions

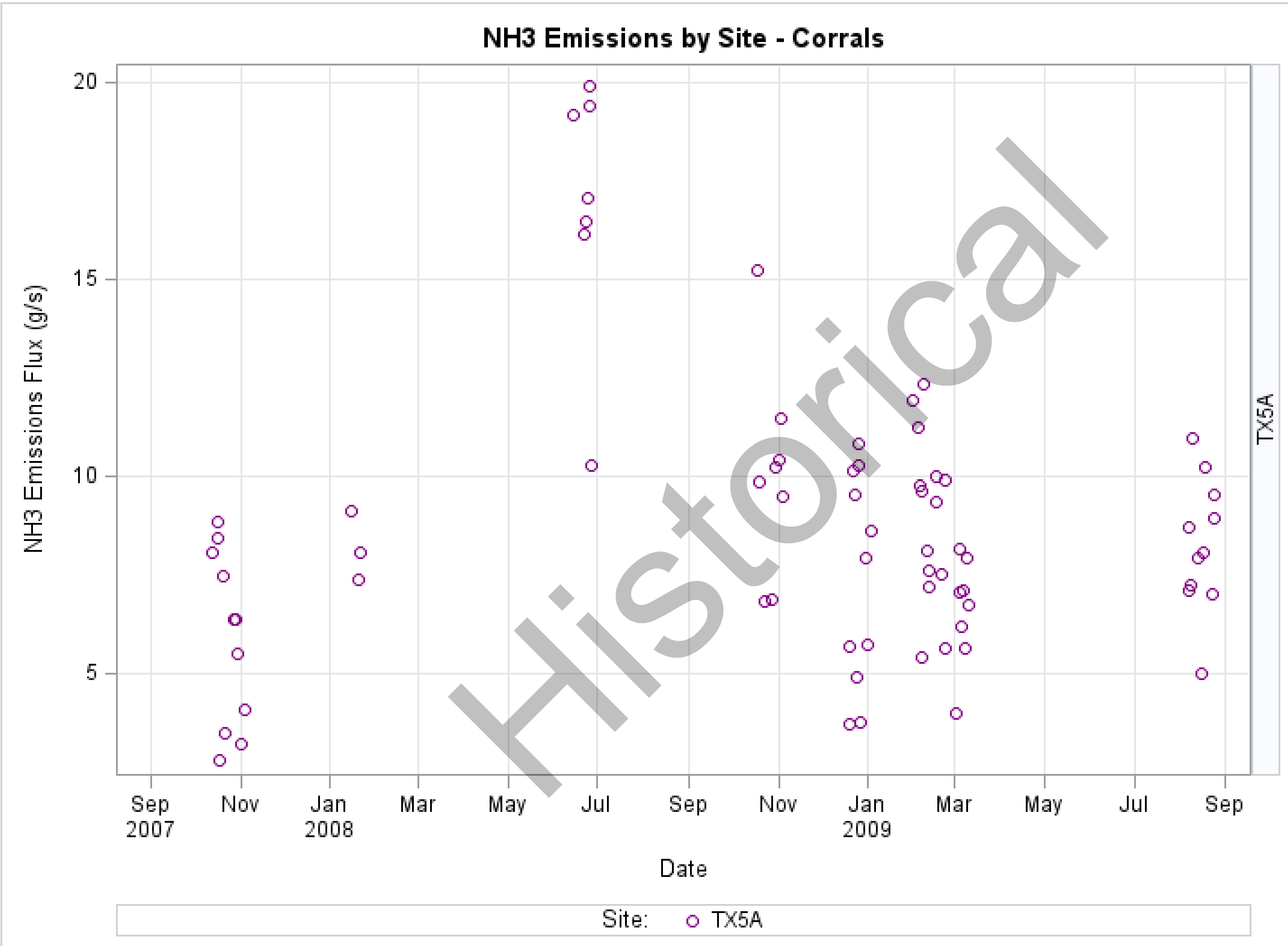


Figure E-52. Trends in corral NH_3 emissions, during the NAEMS monitoring period.

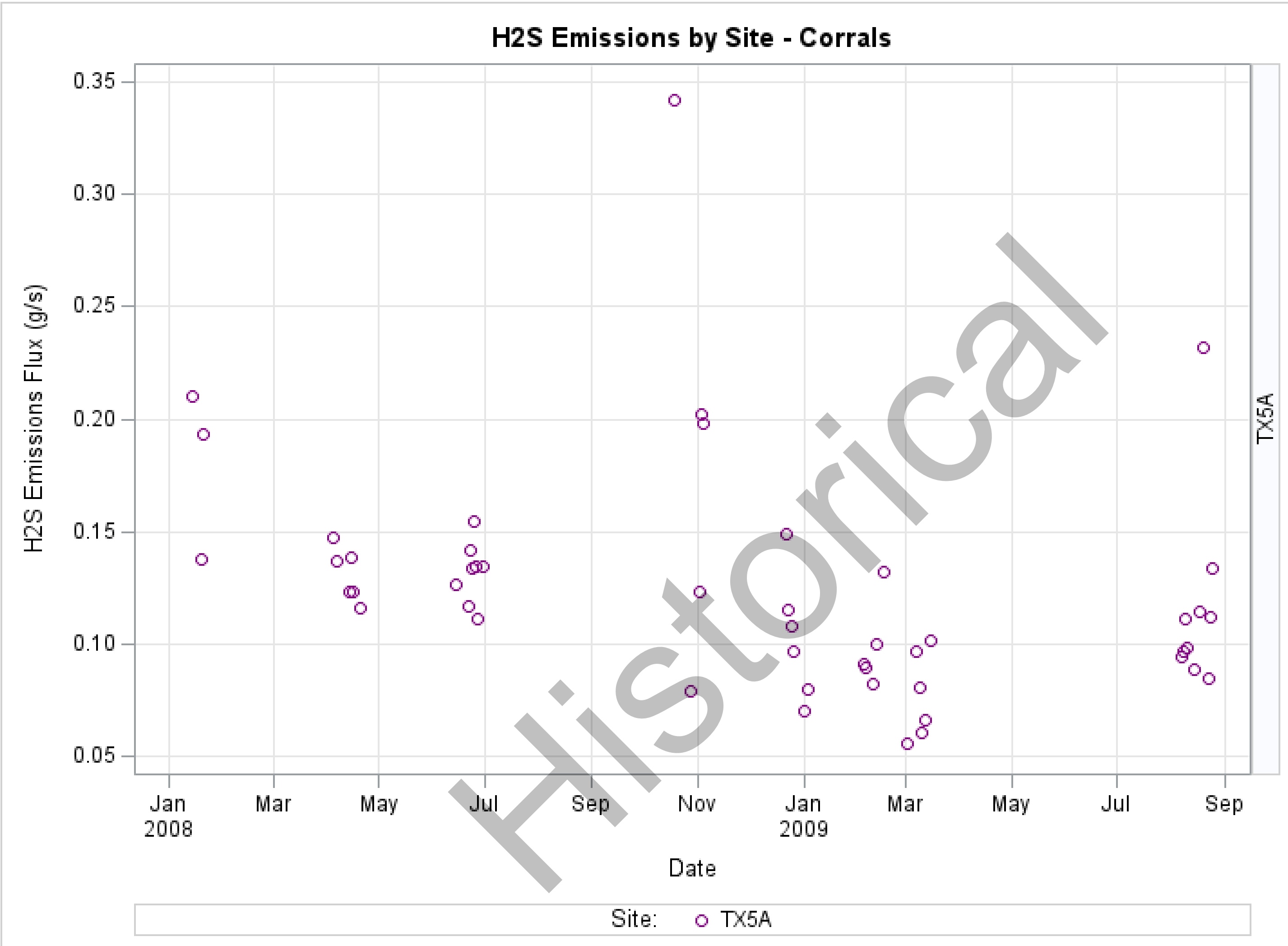


Figure E-53. Trends in corral H_2S emissions, during the NAEMS monitoring period.

E.5.2 Ambient Parameters

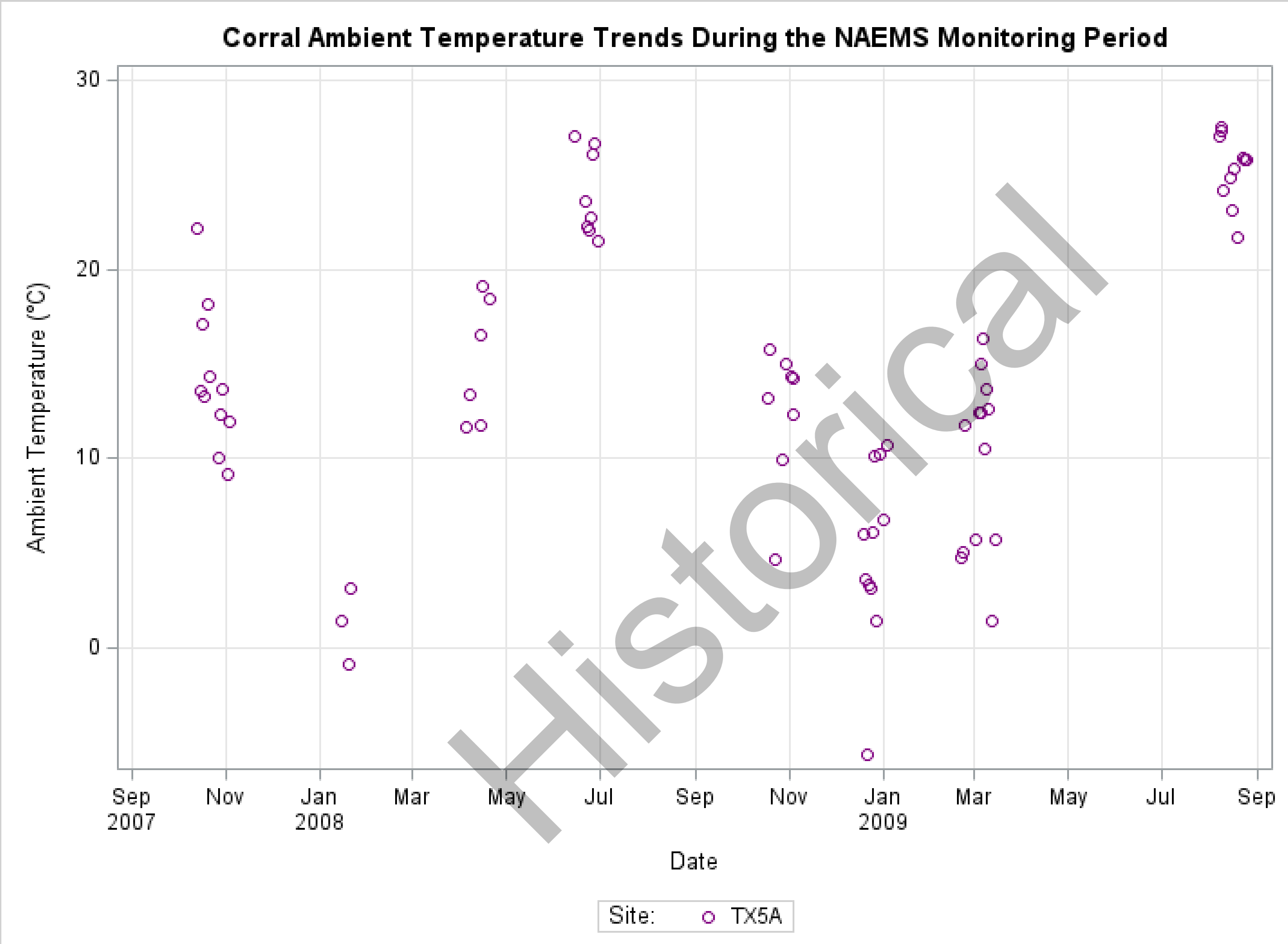


Figure E-54. Trends in corral ambient temperature, during the NAEMS monitoring period.

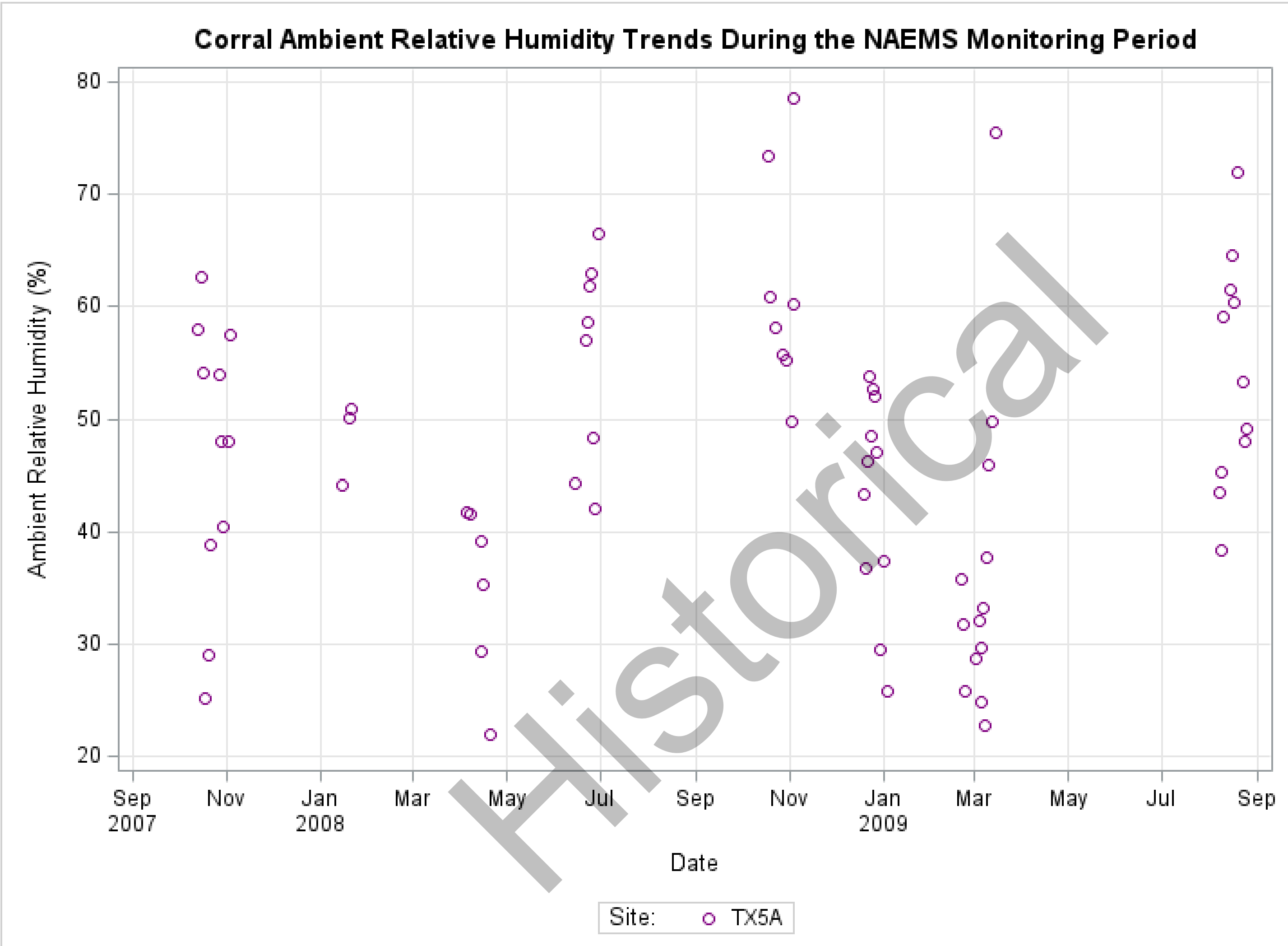


Figure E-55. Trends in corral ambient relative humidity, during the NAEMS monitoring period.

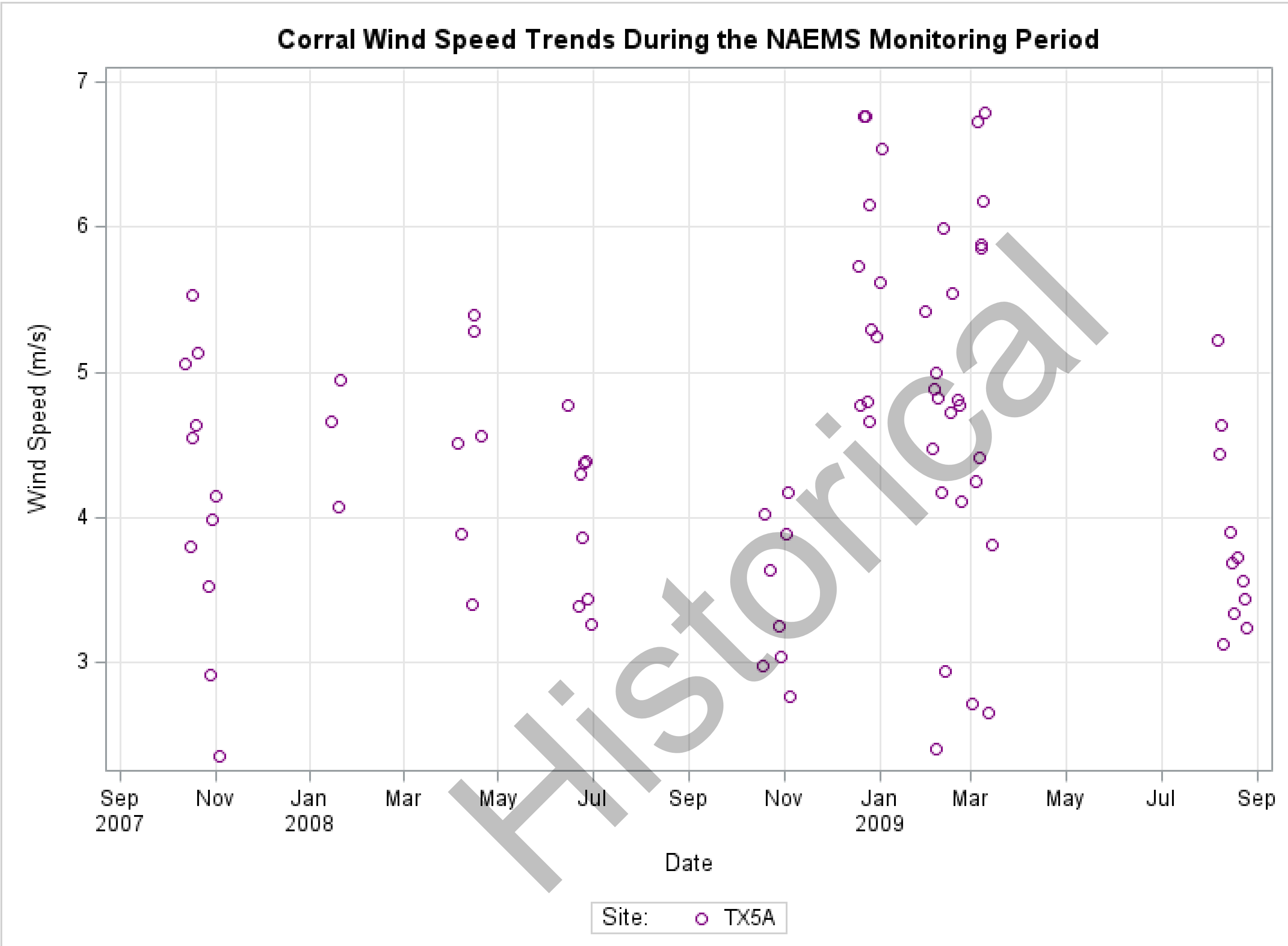


Figure E-56. Trends in corral wind speed, during the NAEMS monitoring period.

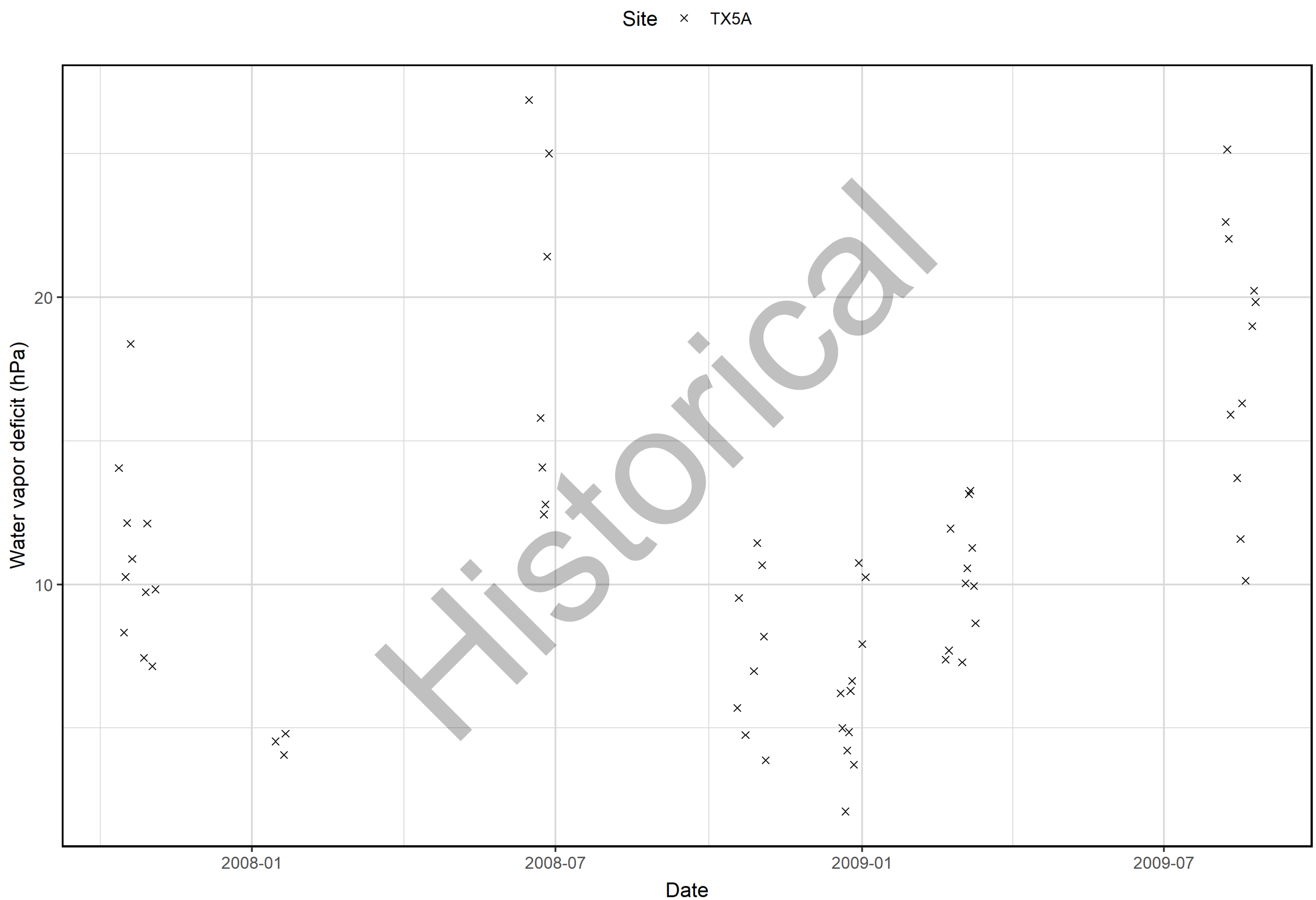


Figure E-57. Trends in corral water vapor deficit, during the NAEMS monitoring period.

Appendix F: Scatter Plots

Table of Contents

List of Tables

List of Figures

To further explore the trends between the predictor variables and emissions and determine whether the parameter should be included in developing an EEM, EPA prepared scatter plots of emissions versus the process, environmental, and manure parameters and conducted least squares regression analysis to assess the influence of each variable on emissions. For the regressions, EPA classified the linear relationships based on the ranges in Table F-1.

Table F-1: Relationship classification based on R^2 values

Range of R^2	Relationship strength
$R^2 = 0$	none
$0 < R^2 \leq 0.2$	slight or weak
$0.2 < R^2 \leq 0.4$	modest
$0.4 < R^2 \leq 0.6$	moderate
$0.6 < R^2 \leq 0.8$	moderately strong
$R^2 > 0.8$	strong

F.1 Mechanically Ventilated Barns

F.1.1 Environmental Parameters

Table F-2. Summary of mechanically ventilated barn R^2 values for environmental parameters.

Pollutant	Parameter	R	R^2	Strength	Figure
NH_3	Inventory	0.660	0.435	moderate	F-1
H_2S	Inventory	0.002	0.000	slight or weak	F-2
PM_{10}	Inventory	-0.292	0.085	slight or weak	F-3
$PM_{2.5}$	Inventory	-0.319	0.102	slight or weak	F-4
TSP	Inventory	-0.327	0.107	slight or weak	F-5
NH_3	Average animal weight	-0.423	0.179	slight or weak	F-6
H_2S	Average animal weight	0.114	0.013	slight or weak	F-7
PM_{10}	Average animal weight	0.240	0.058	slight or weak	F-8
$PM_{2.5}$	Average animal weight	0.384	0.148	slight or weak	F-9
TSP	Average animal weight	0.384	0.147	slight or weak	F-10
NH_3	Live animal weight	0.653	0.426	moderate	F-11
H_2S	Live animal weight	0.014	0.000	slight or weak	F-12
PM_{10}	Live animal weight	-0.278	0.077	slight or weak	F-13
$PM_{2.5}$	Live animal weight	-0.283	0.080	slight or weak	F-14
TSP	Live animal weight	-0.307	0.094	slight or weak	F-15
NH_3	Exhaust temperature	0.493	0.243	modest	F-16
H_2S	Exhaust temperature	0.323	0.104	slight or weak	F-17
PM_{10}	Exhaust temperature	0.410	0.168	slight or weak	F-18
$PM_{2.5}$	Exhaust temperature	0.484	0.234	modest	F-19
TSP	Exhaust temperature	0.406	0.165	slight or weak	F-20
NH_3	Exhaust relative humidity	0.390	0.152	slight or weak	F-21
H_2S	Exhaust relative humidity	0.193	0.037	slight or weak	F-22
PM_{10}	Exhaust relative humidity	-0.269	0.072	slight or weak	F-23
$PM_{2.5}$	Exhaust relative humidity	-0.414	0.171	slight or weak	F-24
TSP	Exhaust relative humidity	-0.322	0.104	slight or weak	F-25
NH_3	Airflow	0.536	0.287	modest	F-26
H_2S	Airflow	0.232	0.054	slight or weak	F-27
PM_{10}	Airflow	0.425	0.180	slight or weak	F-28
$PM_{2.5}$	Airflow	0.449	0.202	modest	F-29
TSP	Airflow	0.376	0.141	slight or weak	F-30

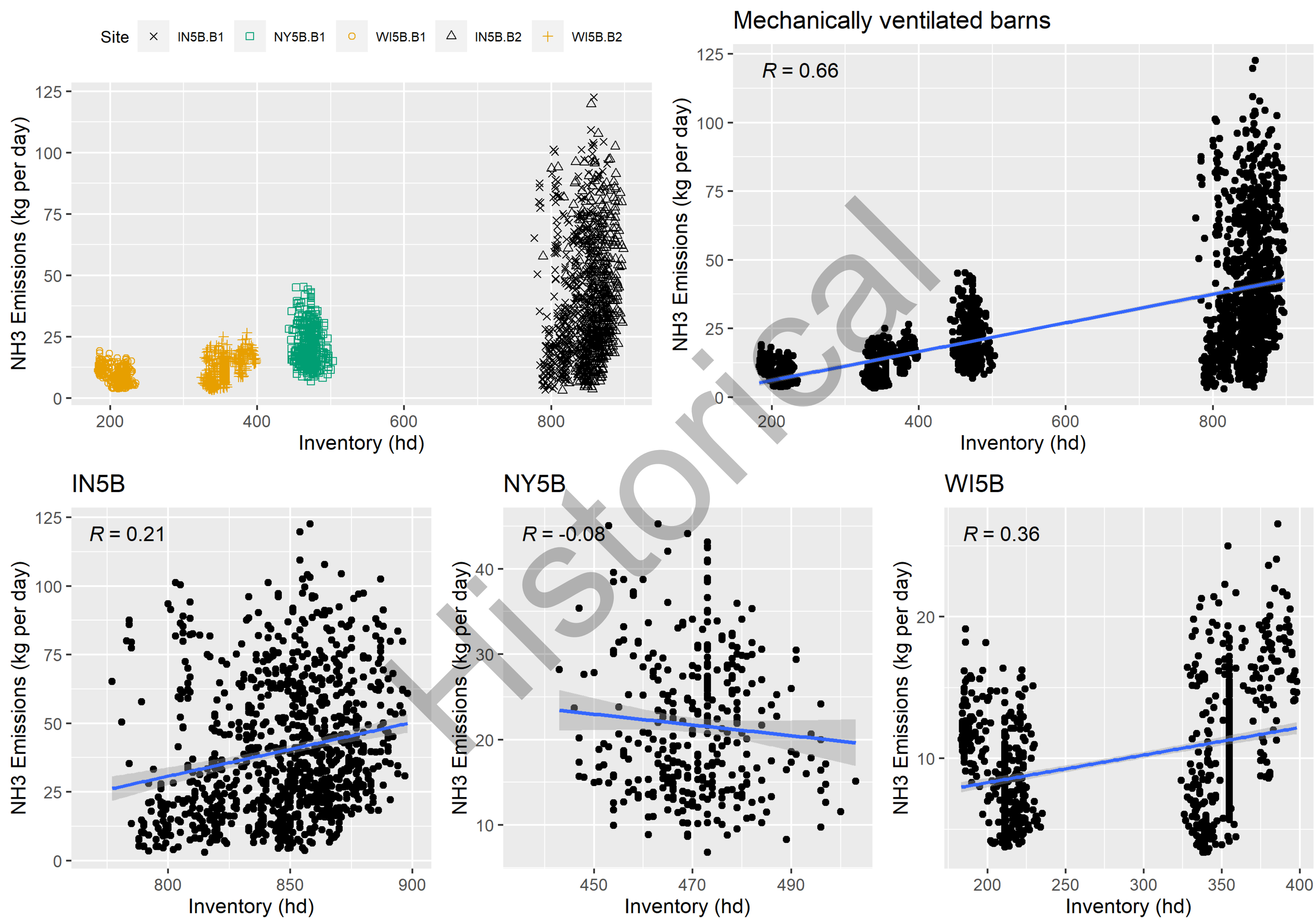


Figure F-1. Scatter plot of mechanically ventilated NH_3 emissions versus inventory and scatter plot with regression.

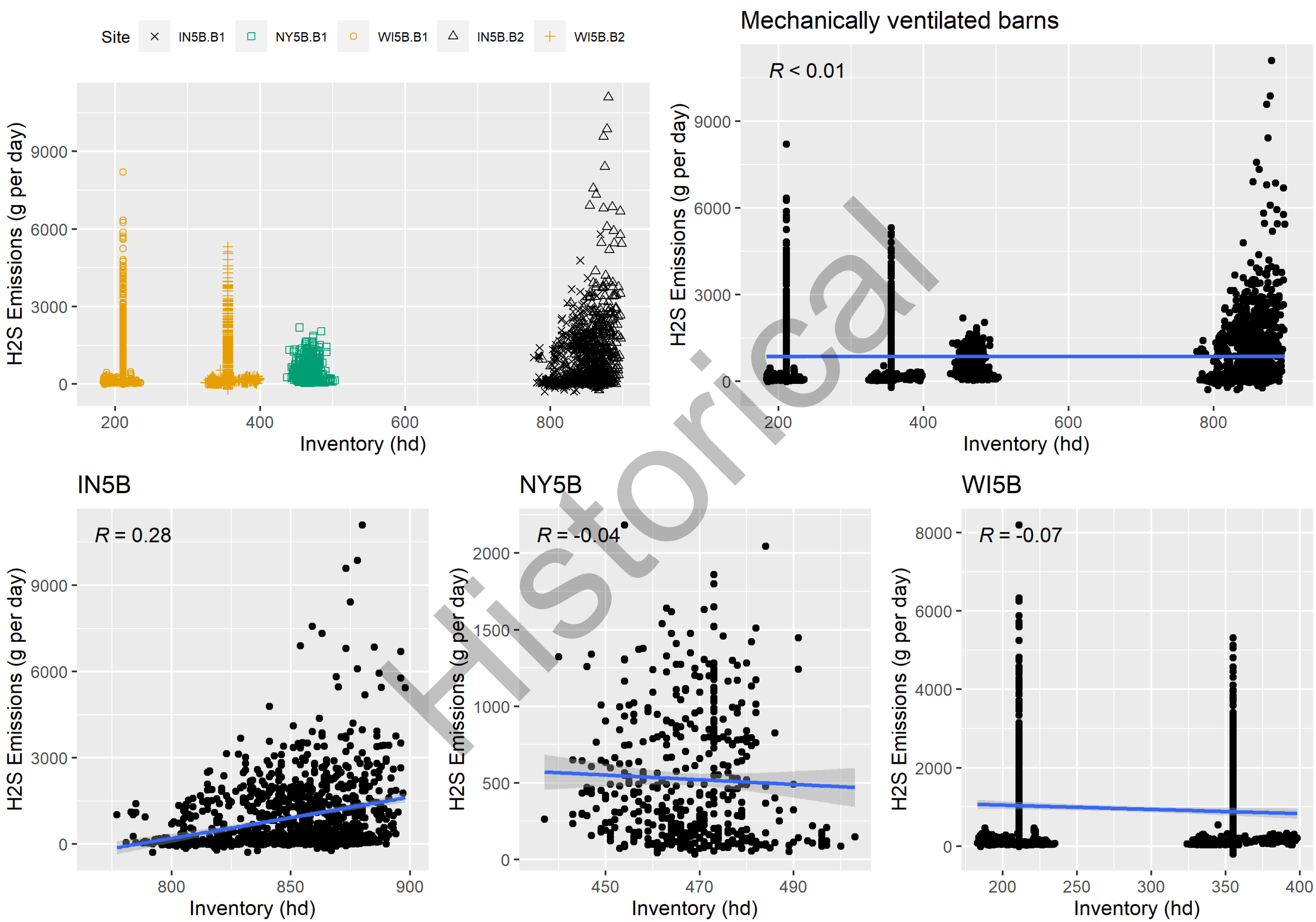


Figure F-2. Scatter plot of mechanically ventilated H_2S emissions versus inventory and scatter plot with regression.

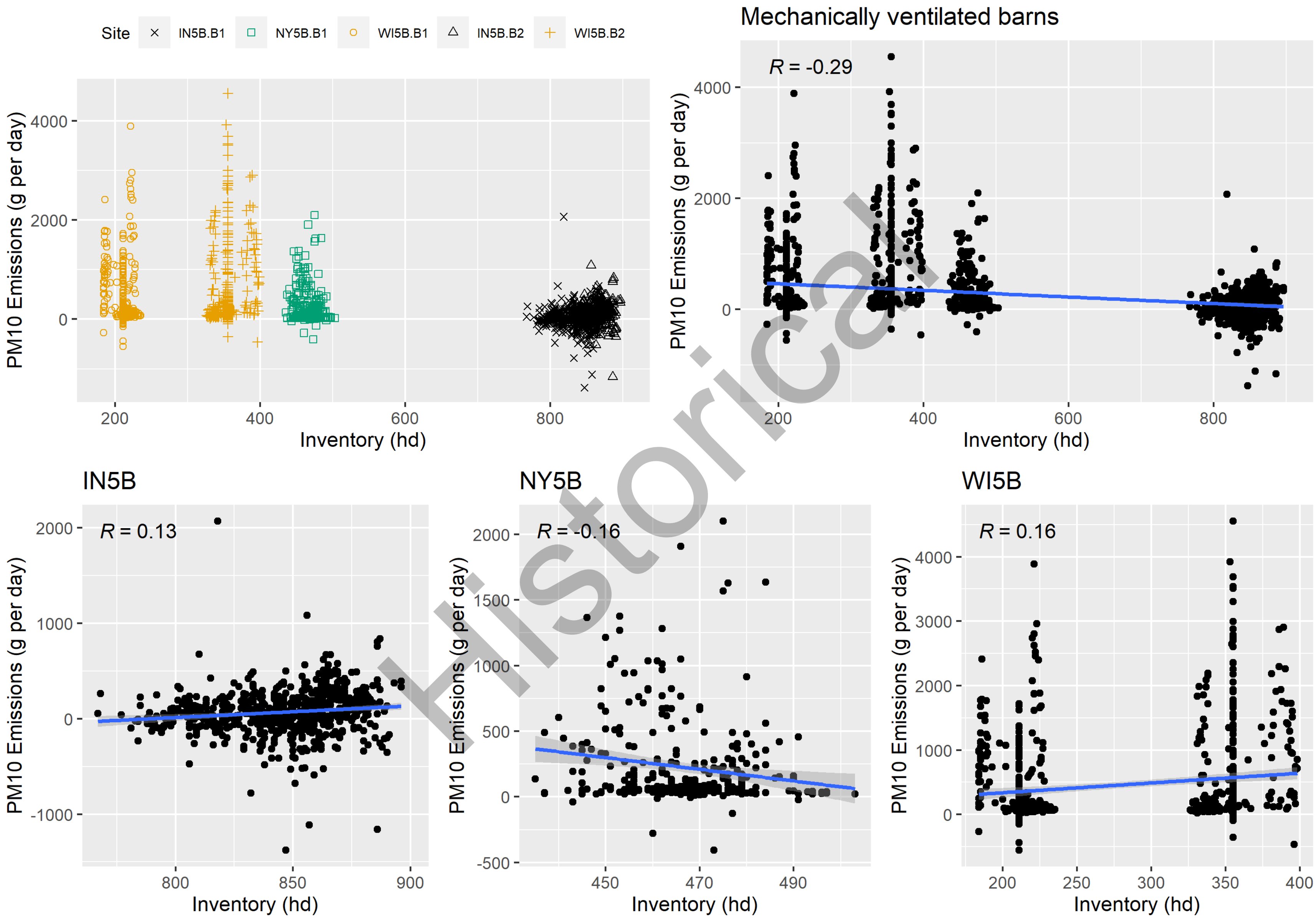


Figure F-3. Scatter plot of mechanically ventilated PM_{10} emissions versus inventory and scatter plot with regression.

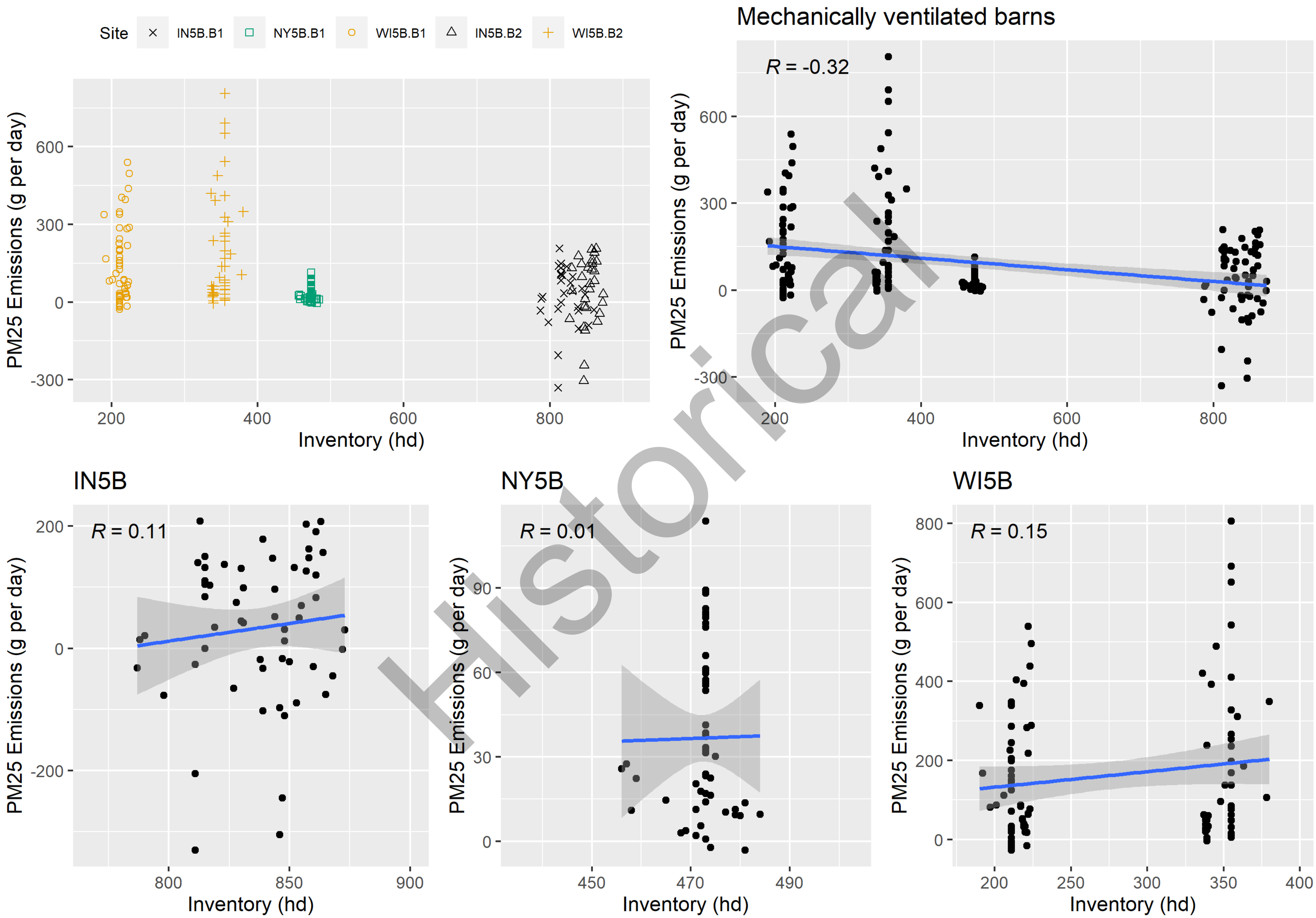


Figure F-4. Scatter plot of mechanically ventilated PM2.5 emissions versus inventory and scatter plot with regression.

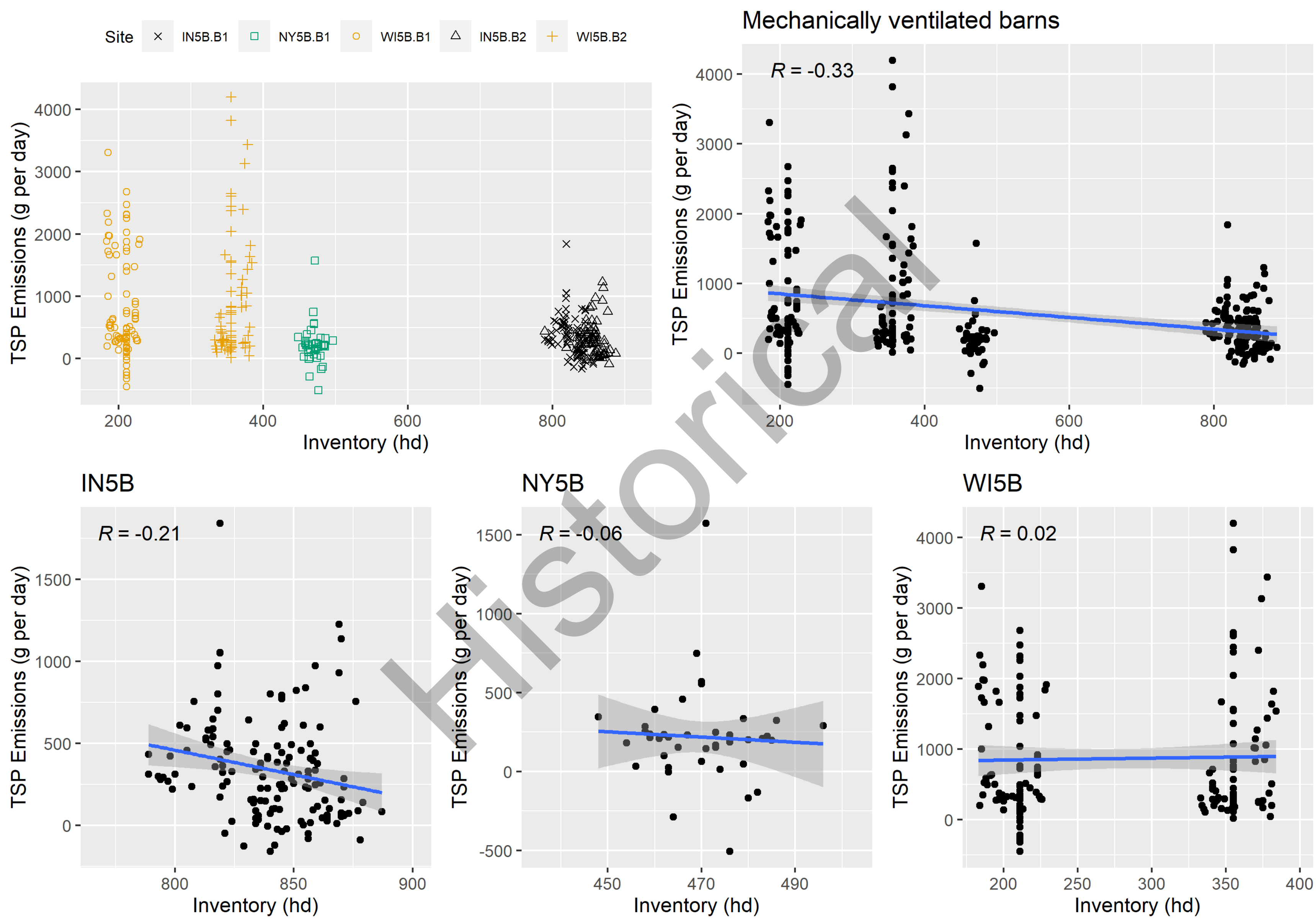


Figure F-5. Scatter plot of mechanically ventilated TSP emissions versus inventory and scatter plot with regression.

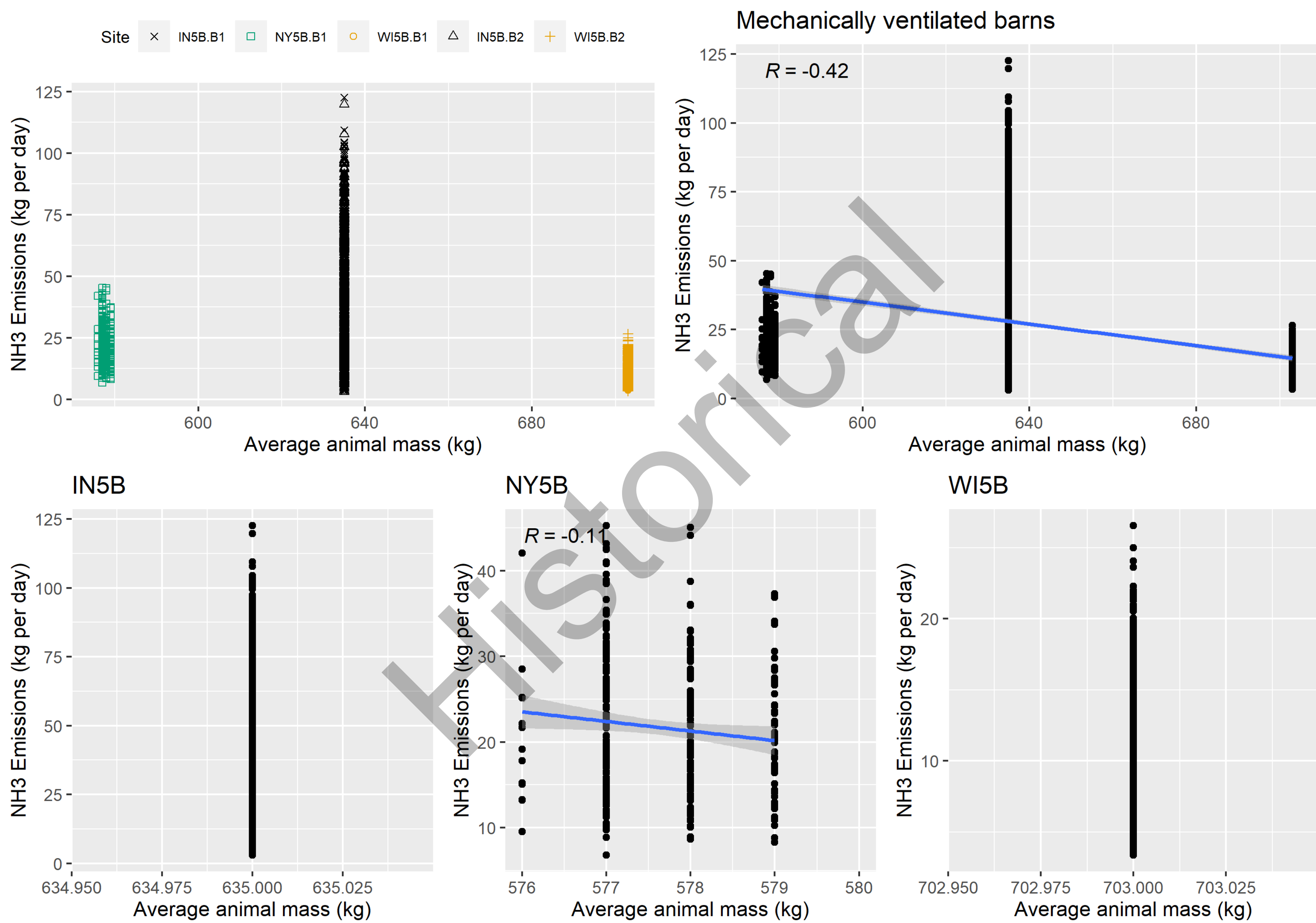


Figure F-6. Scatter plot of mechanically ventilated NH_3 emissions versus average animal mass and scatter plot with regression.

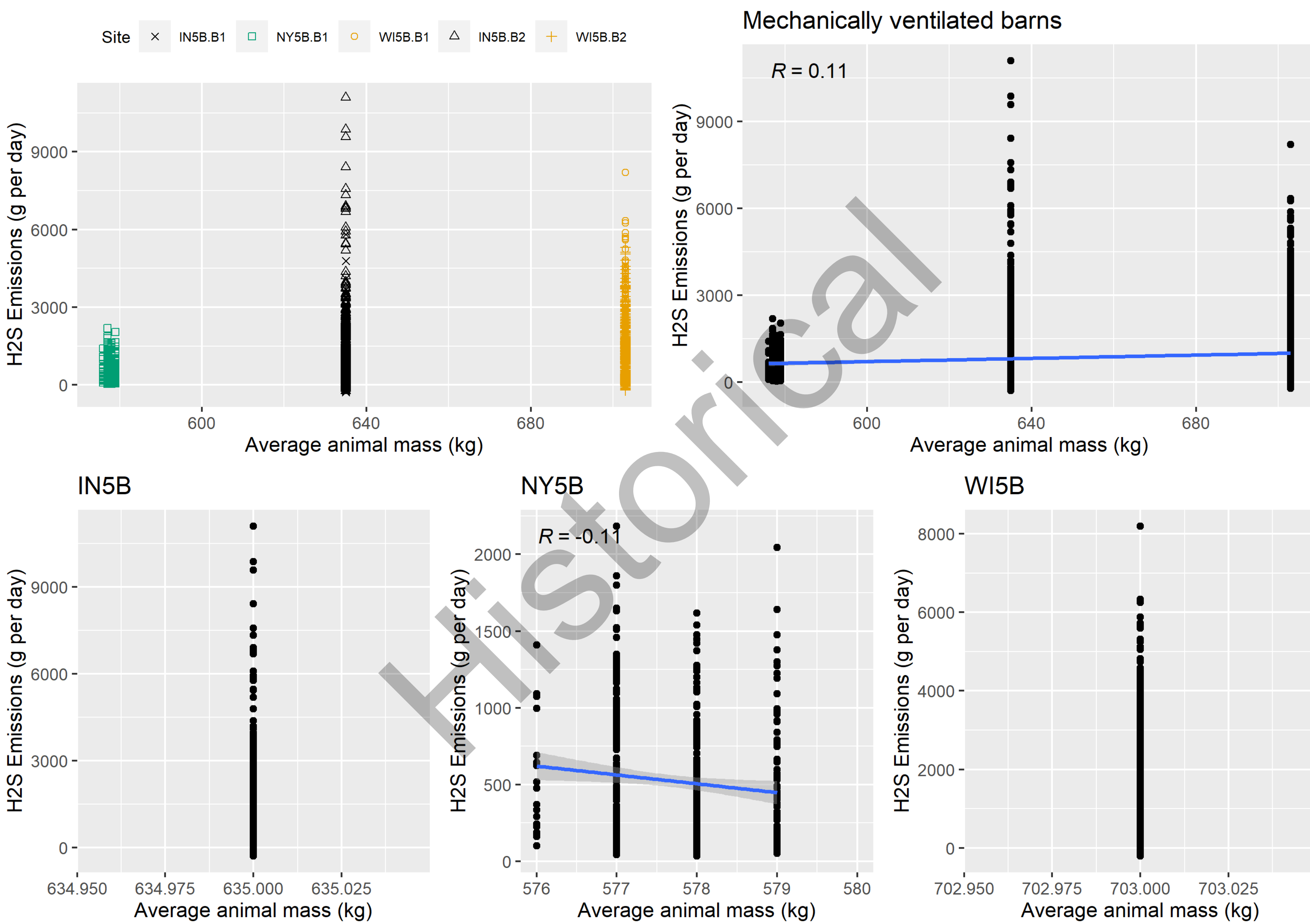


Figure F-7. Scatter plot of mechanically ventilated H_2S emissions versus average animal mass and scatter plot with regression.

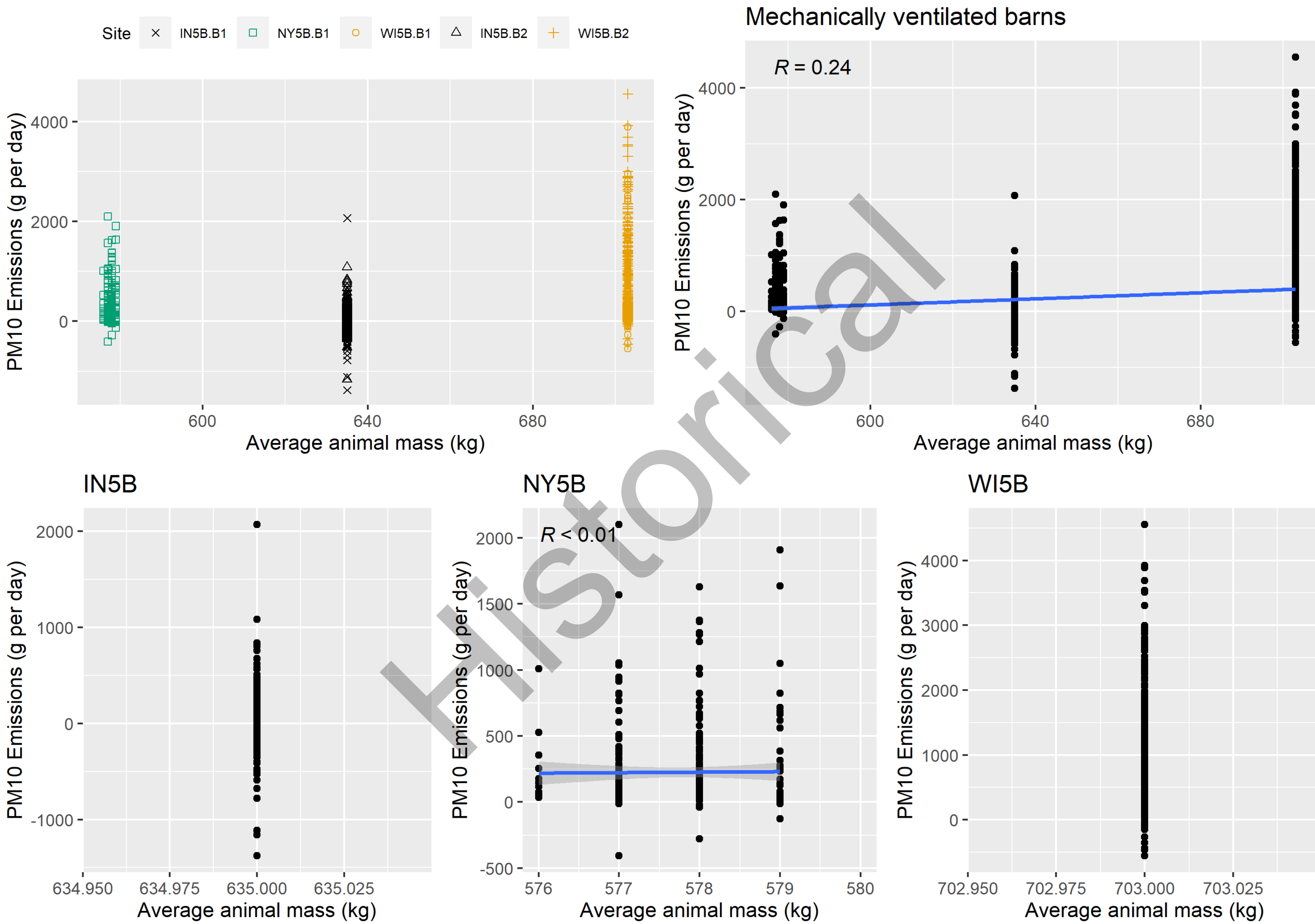


Figure F-8. Scatter plot of mechanically ventilated PM_{10} emissions versus average animal mass and scatter plot with regression.

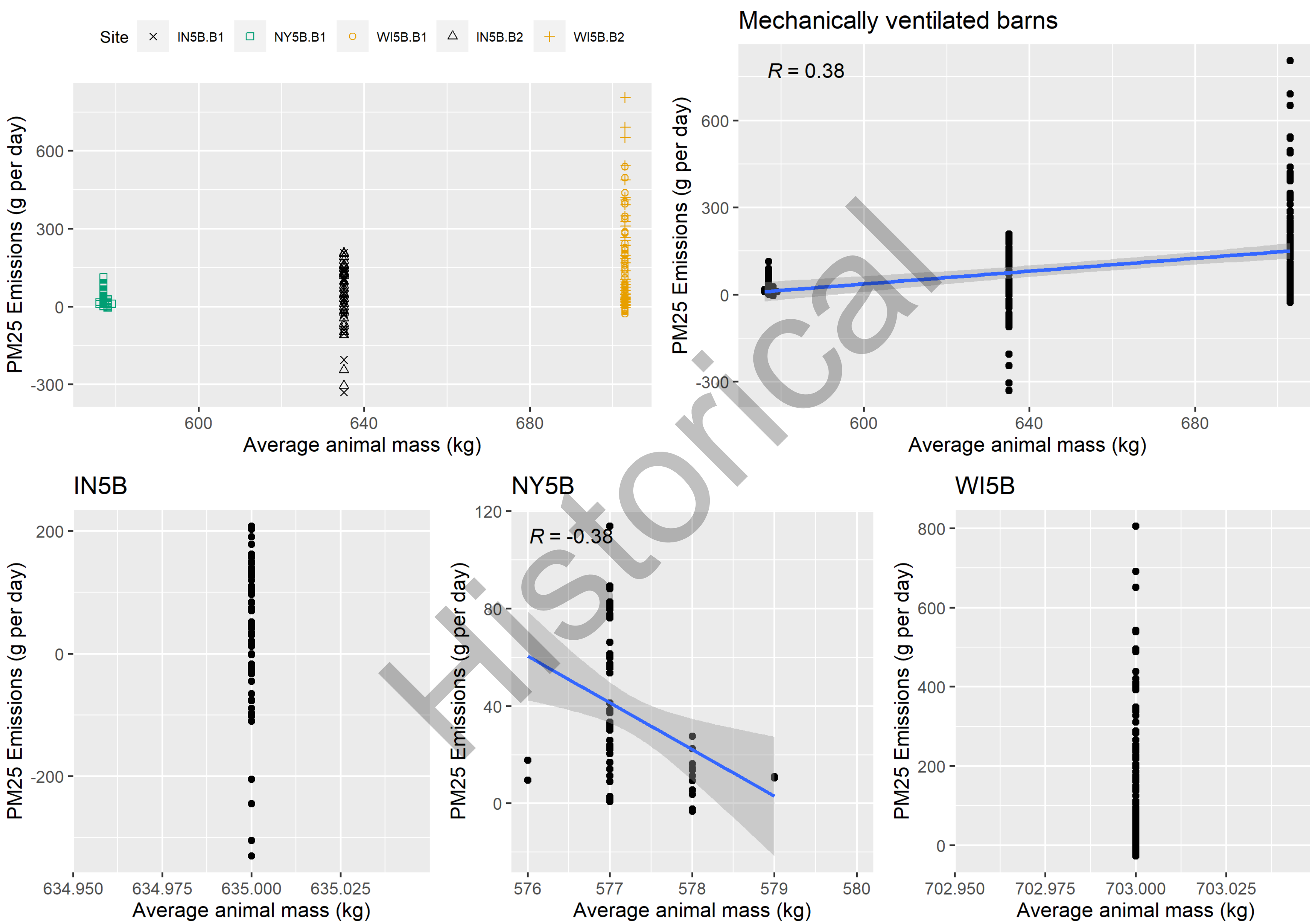


Figure F-9. Scatter plot of mechanically ventilated PM2.5 emissions versus average animal mass and scatter plot with regression.

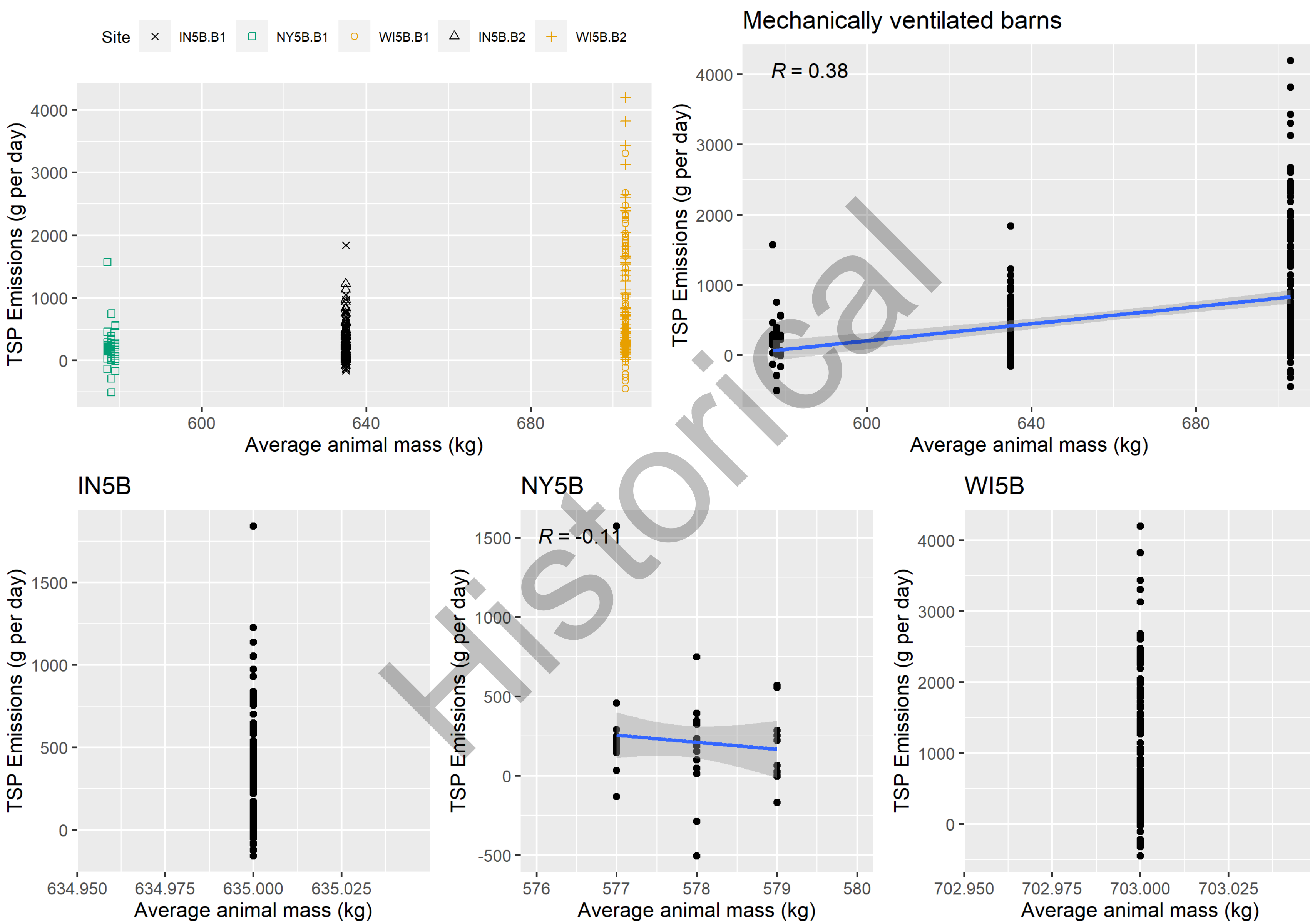


Figure F-10. Scatter plot of mechanically ventilated TSP emissions versus average animal mass and scatter plot with regression.

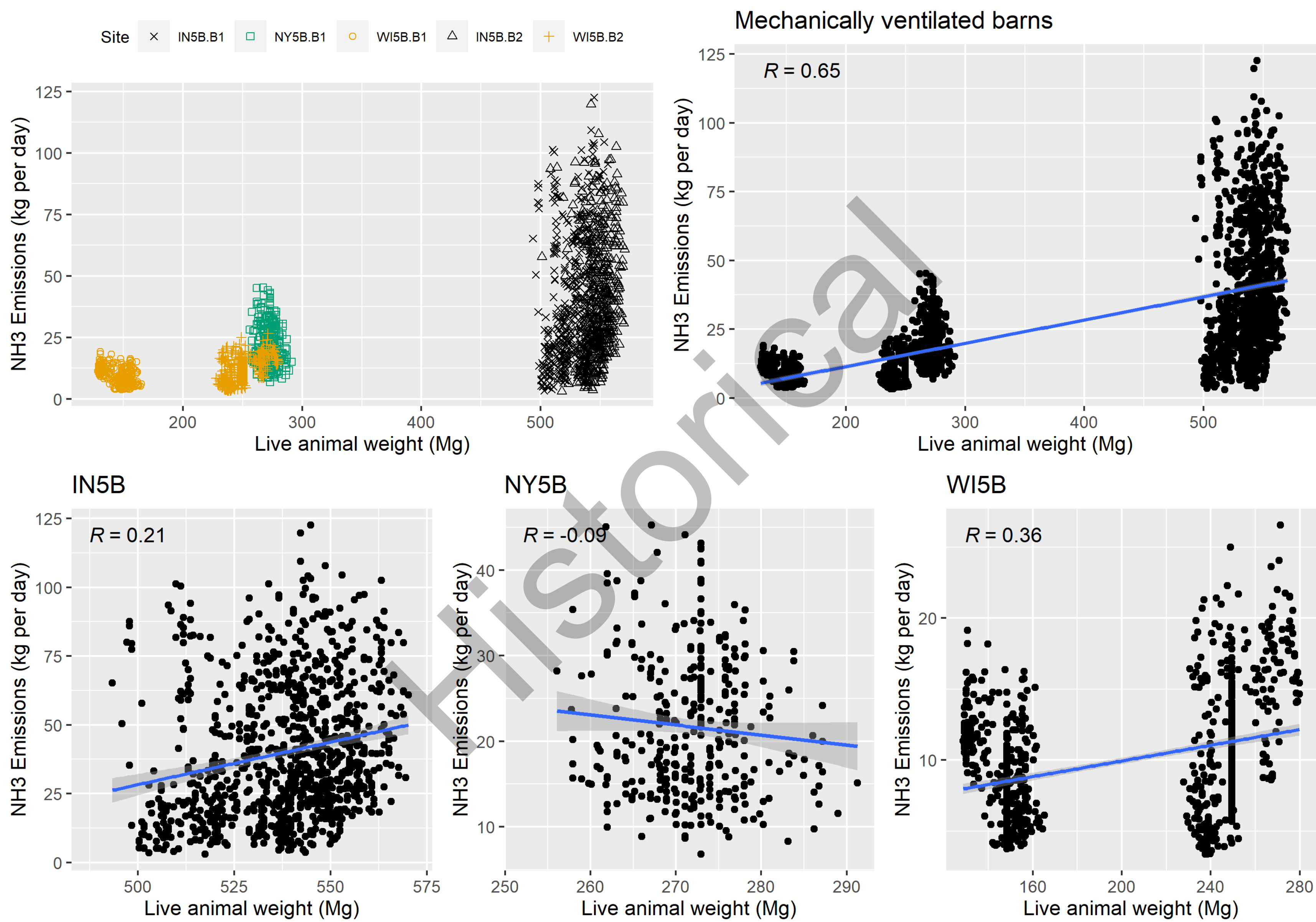


Figure F-11. Scatter plot of mechanically ventilated NH_3 emissions versus live animal weight and scatter plot with regression.

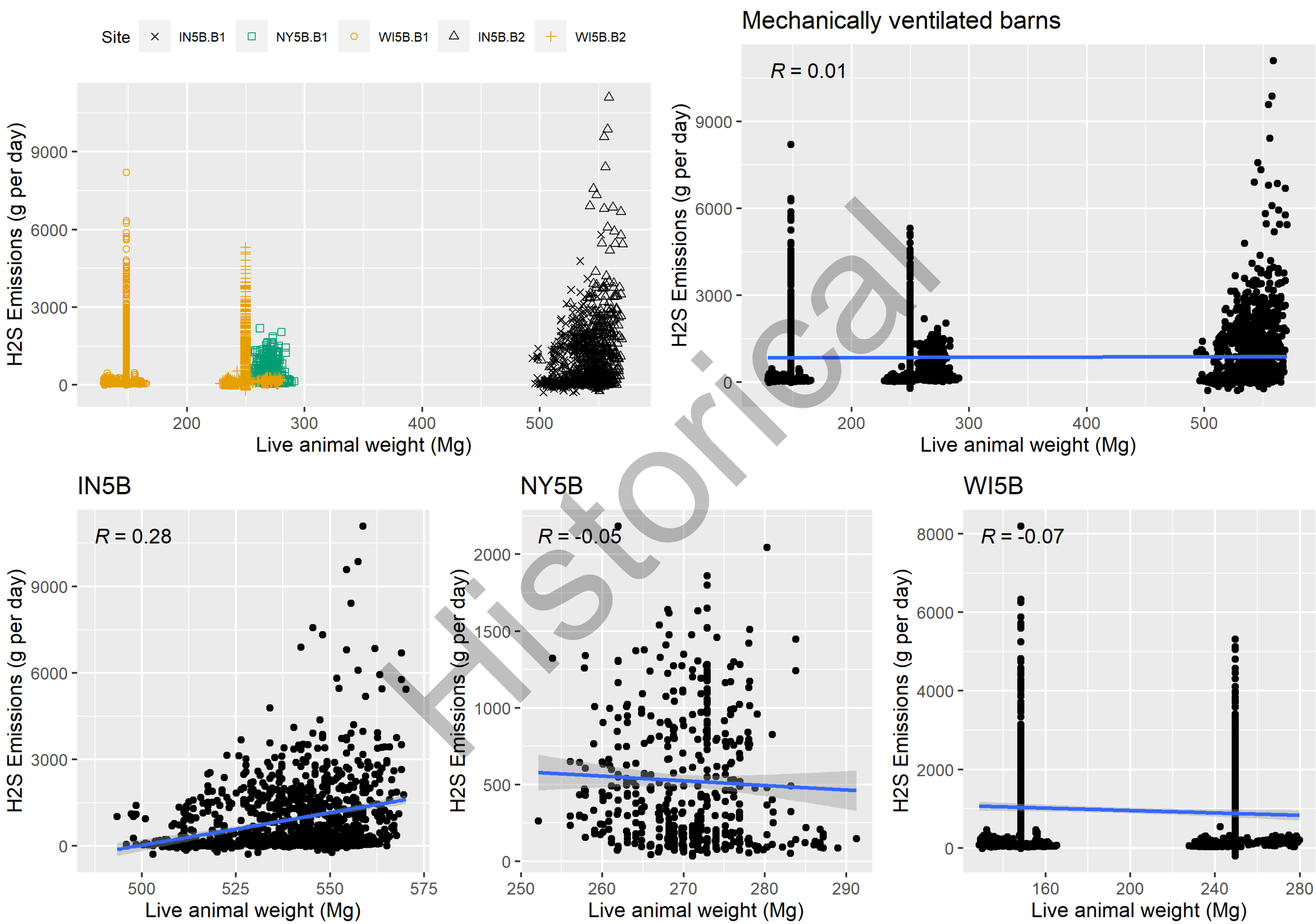


Figure F-12. Scatter plot of mechanically ventilated H_2S emissions versus live animal weight and scatter plot with regression.

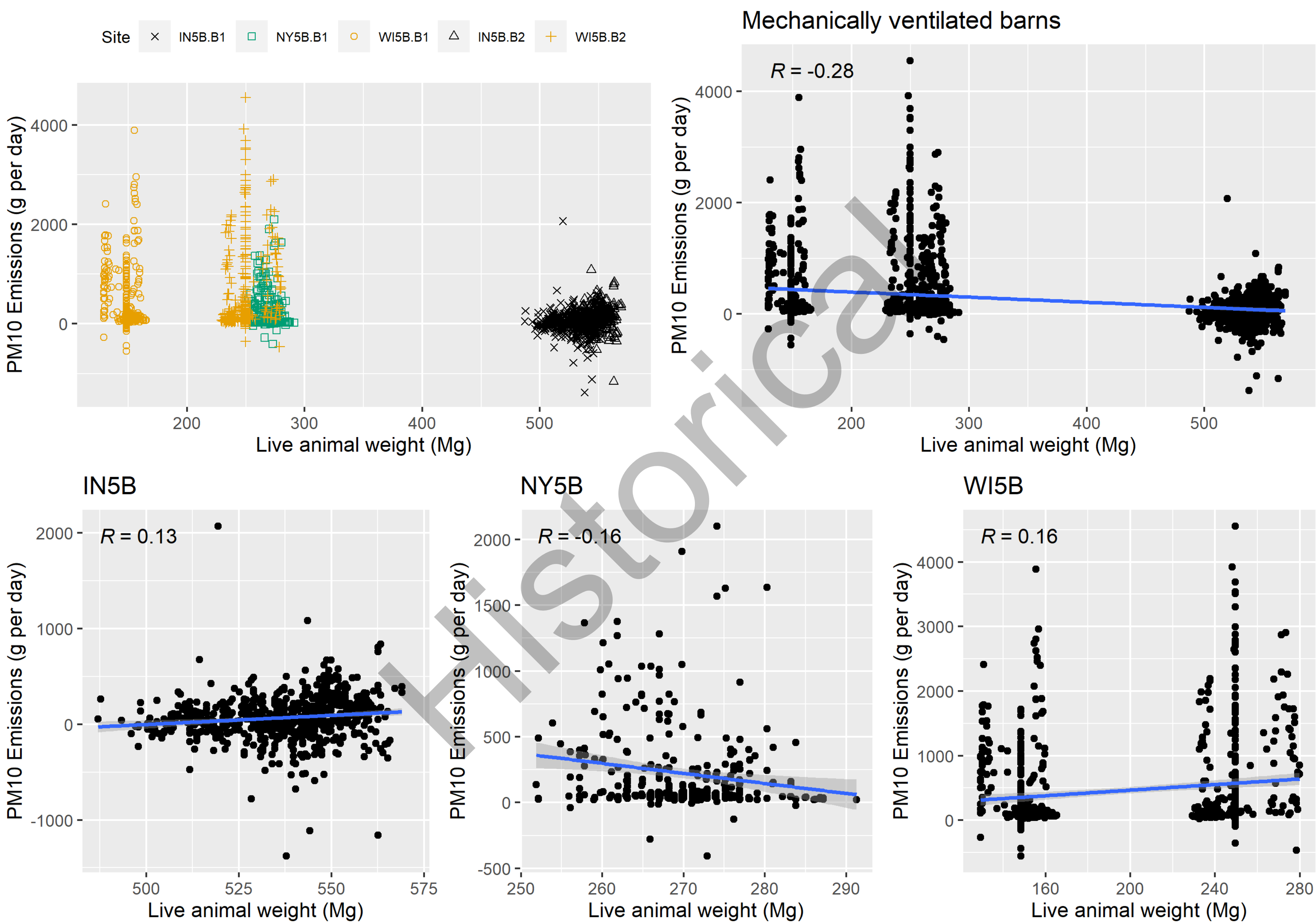


Figure F-13. Scatter plot of mechanically ventilated PM_{10} emissions versus live animal weight and scatter plot with regression.

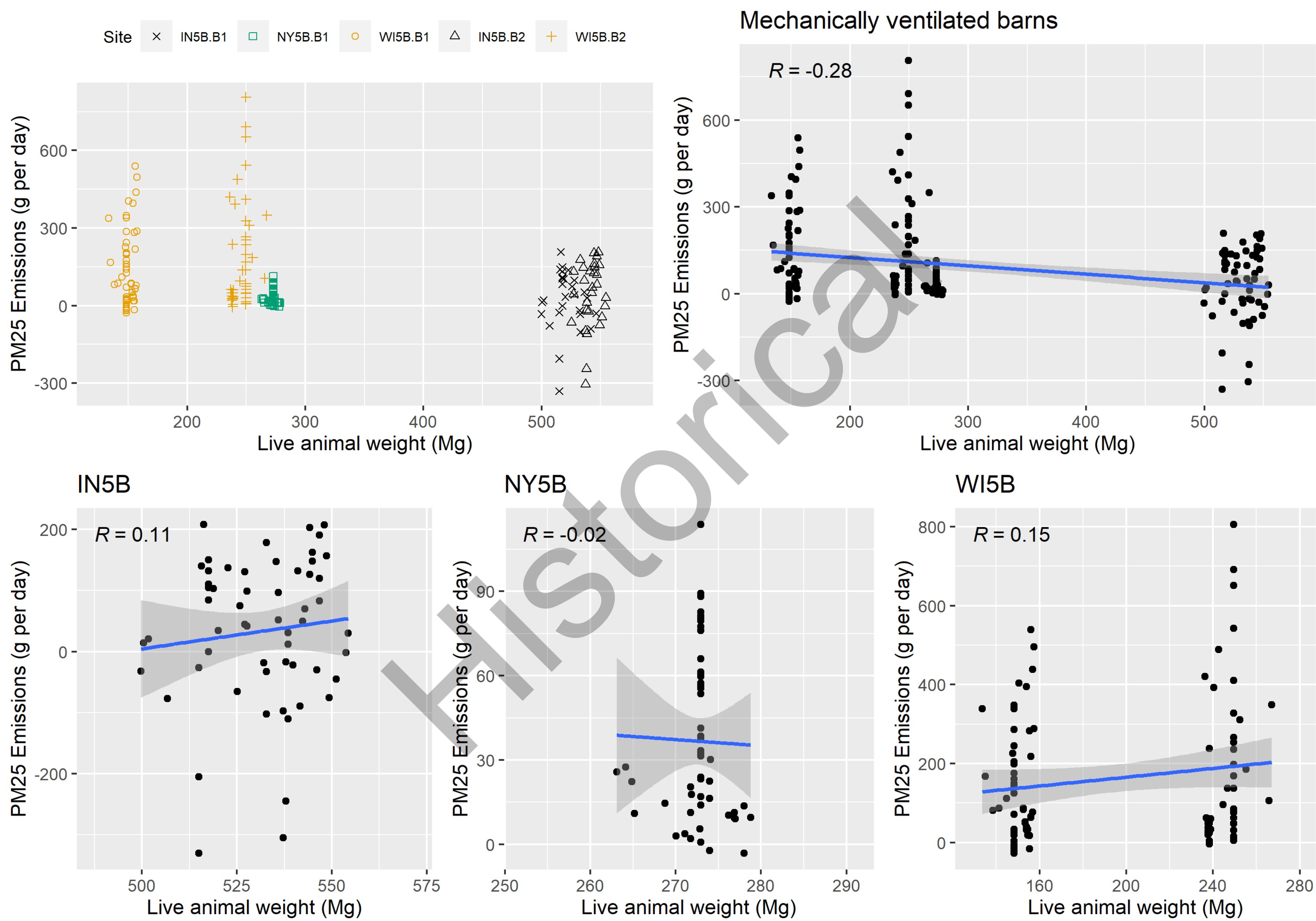


Figure F-14. Scatter plot of mechanically ventilated PM2.5 emissions versus live animal weight and scatter plot with regression.

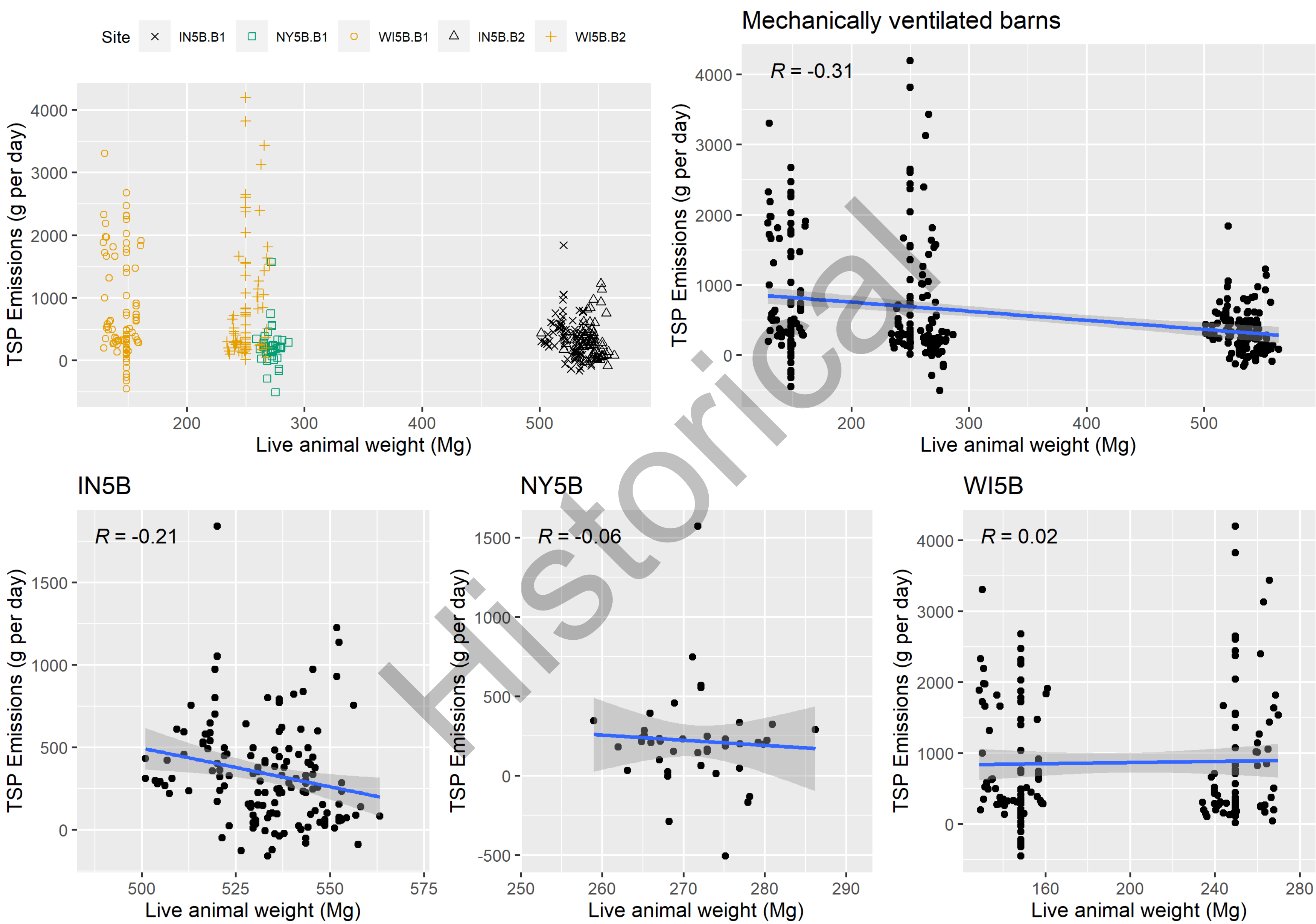


Figure F-15. Scatter plot of mechanically ventilated TSP emissions versus live animal weight and scatter plot with regression.

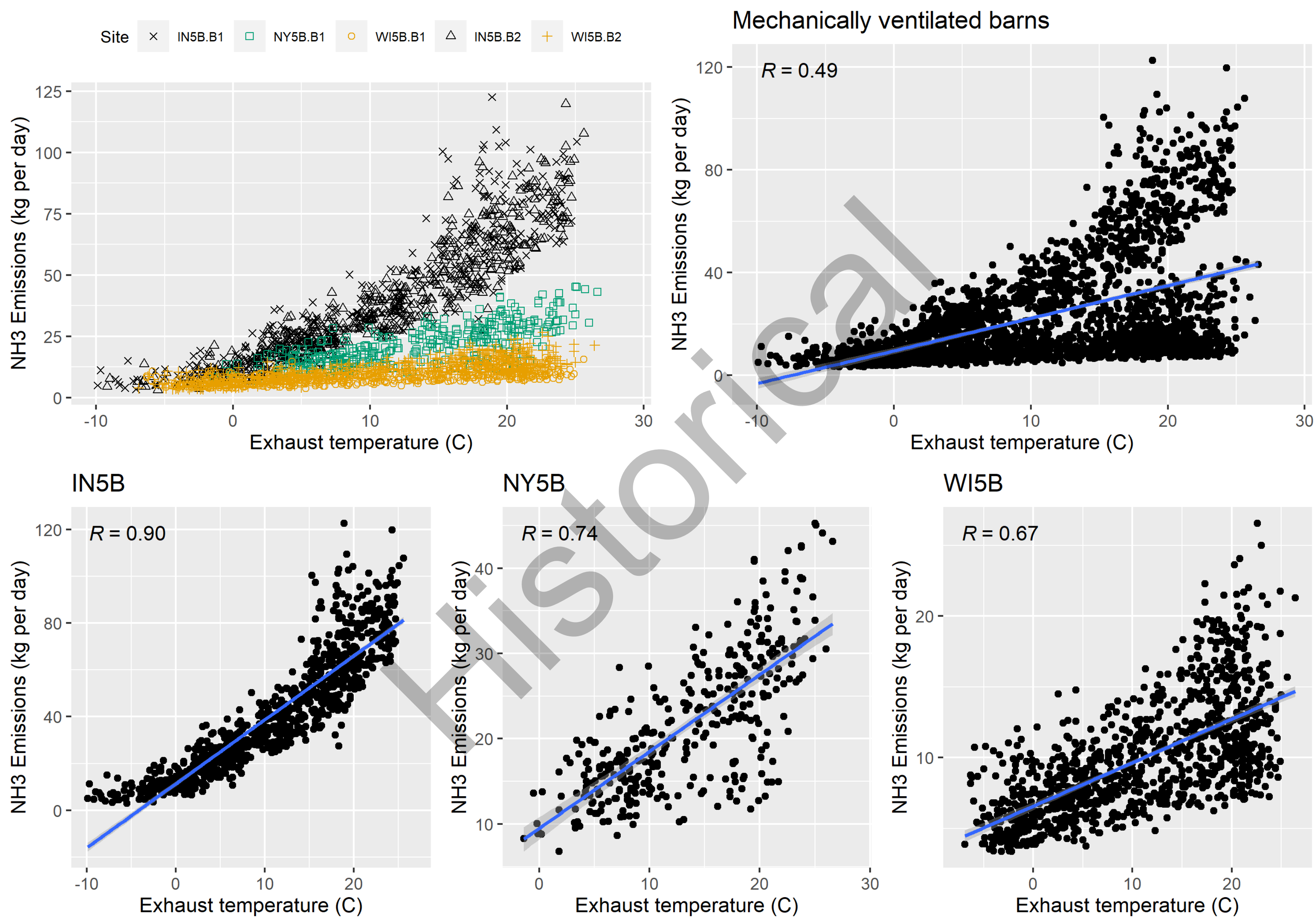


Figure F-16. Scatter plot of mechanically ventilated NH_3 emissions versus exhaust temperature and scatter plot with regression.

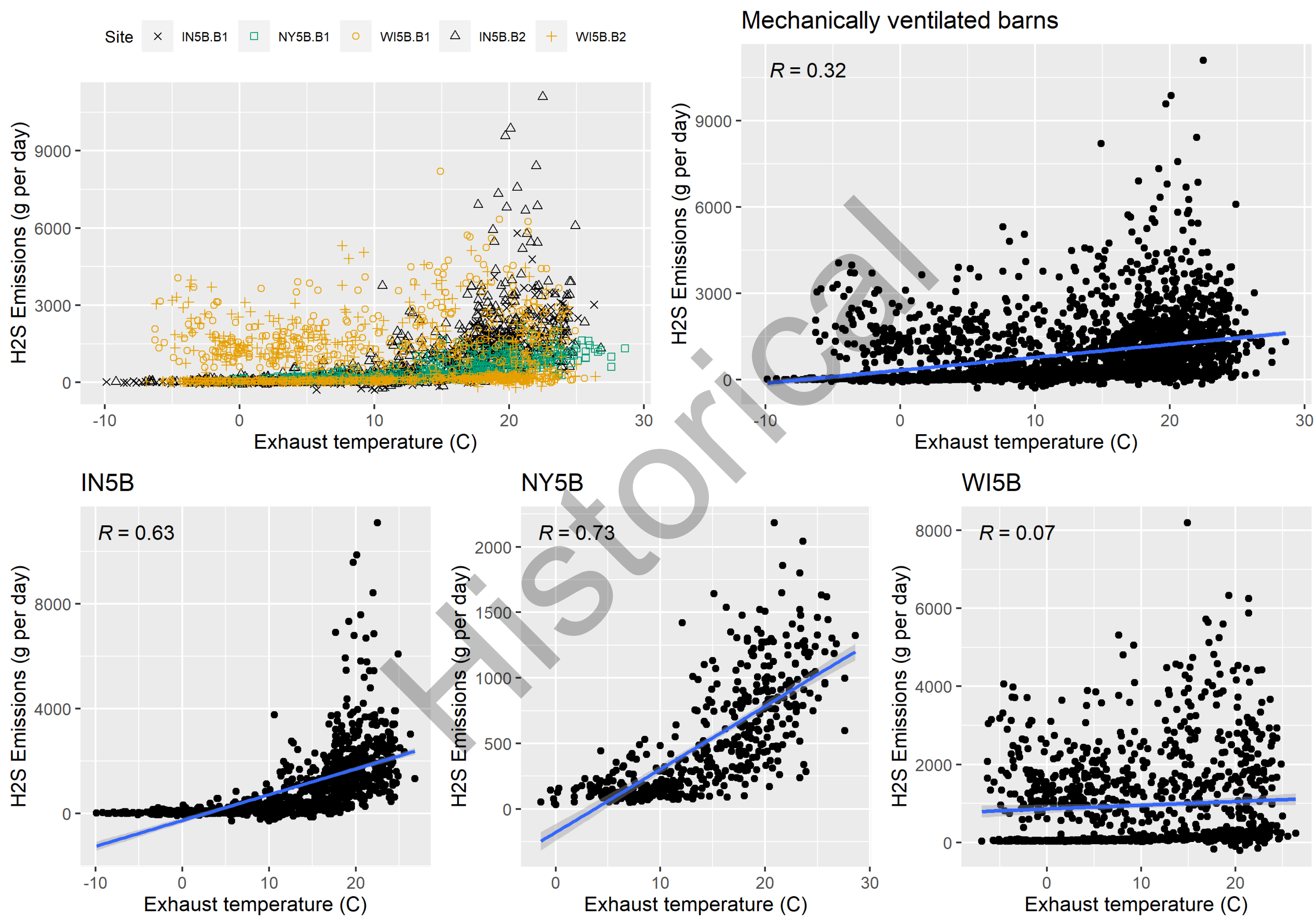


Figure F-17. Scatter plot of mechanically ventilated H_2S emissions versus exhaust temperature and scatter plot with regression.

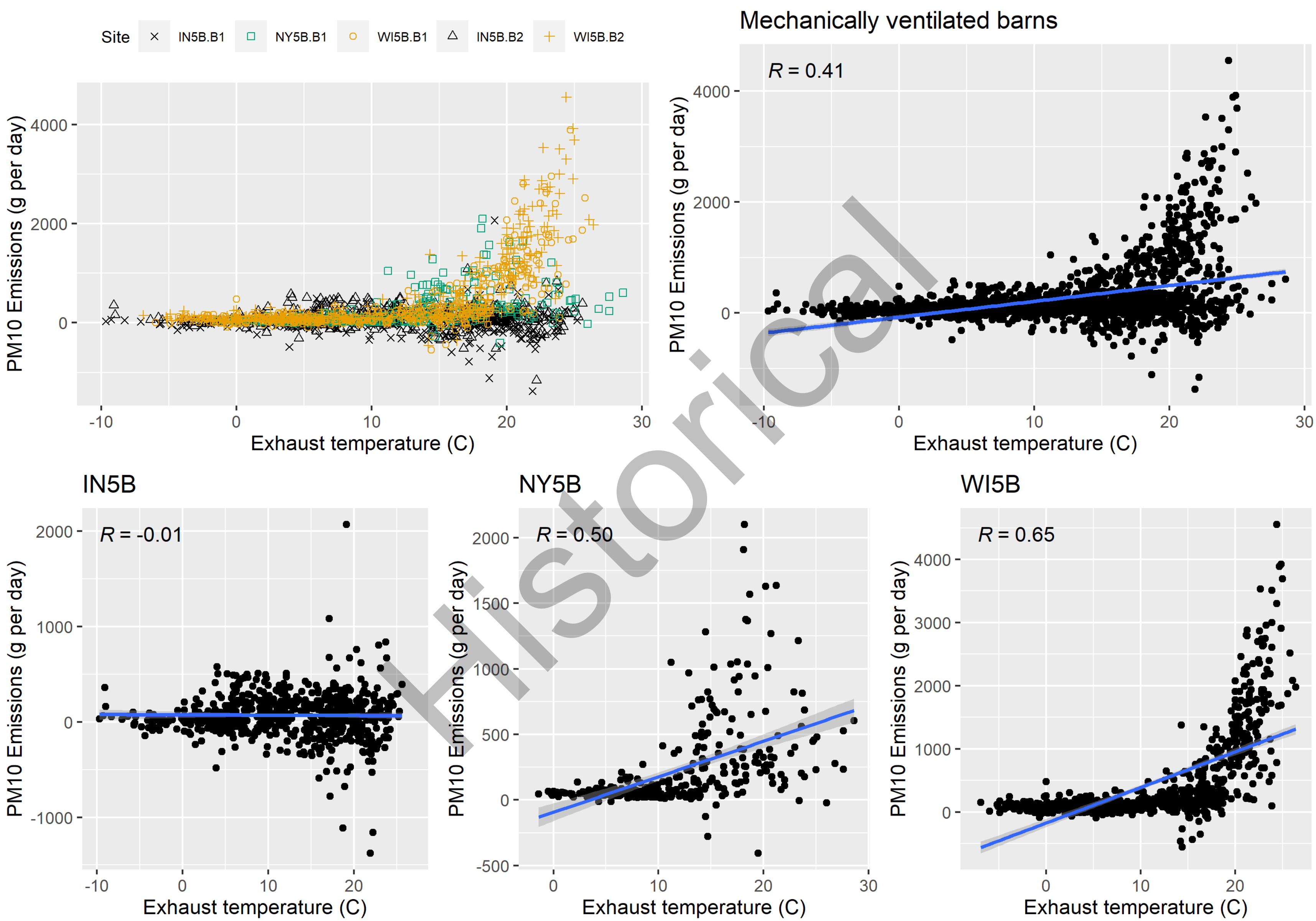


Figure F-18. Scatter plot of mechanically ventilated PM_{10} emissions versus exhaust temperature and scatter plot with regression.

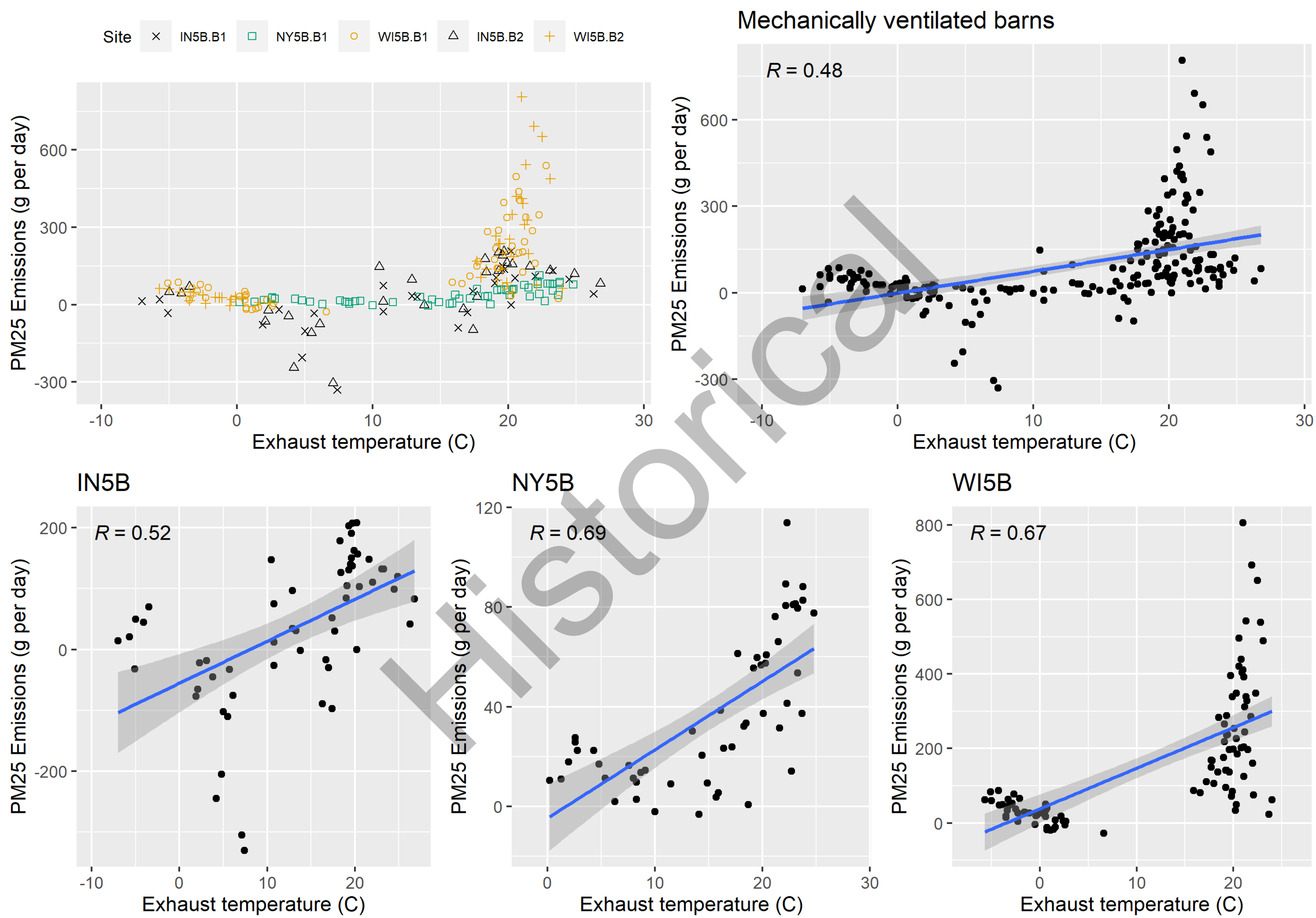


Figure F-19. Scatter plot of mechanically ventilated $PM_{2.5}$ emissions versus exhaust temperature and scatter plot with regression.

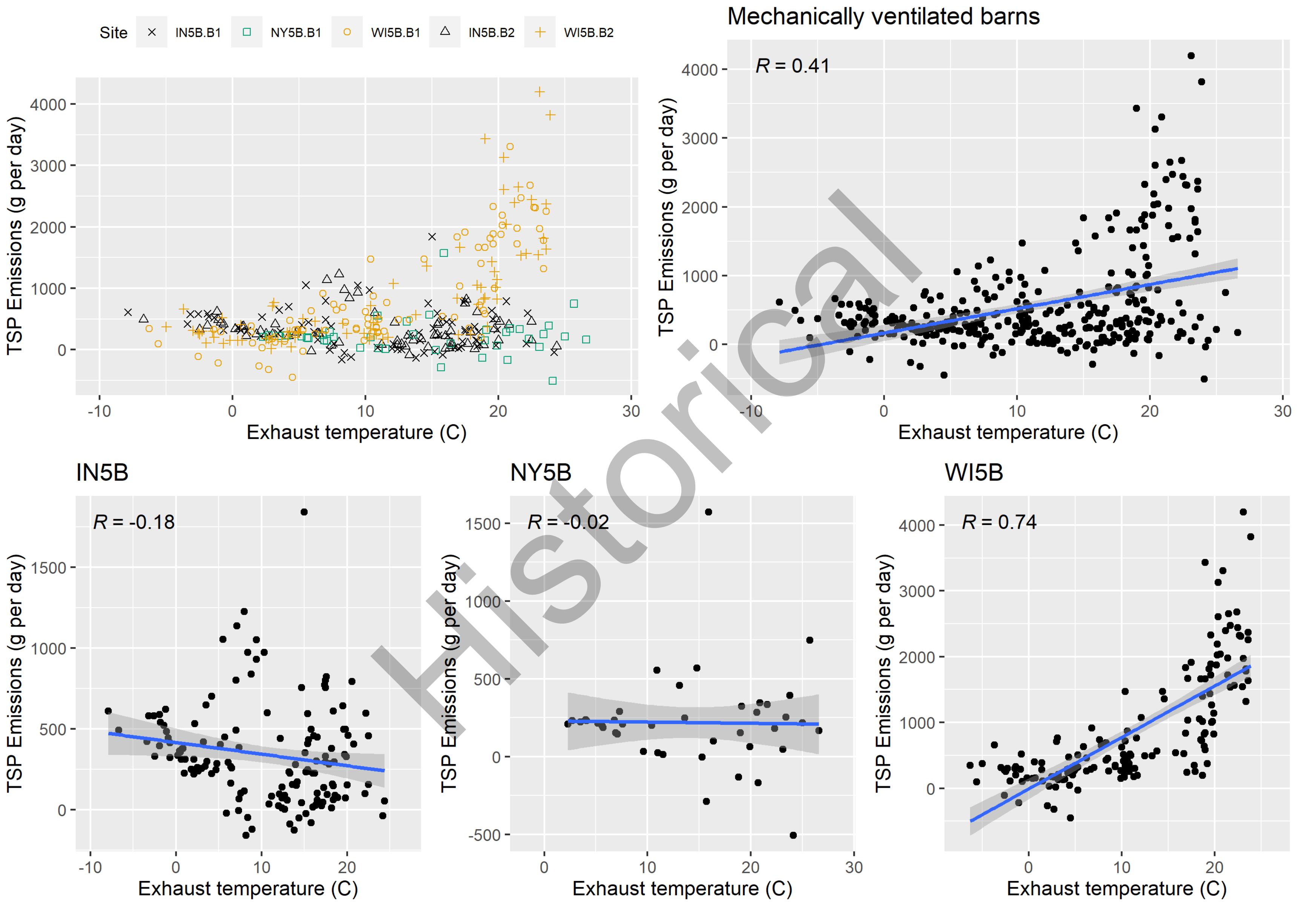


Figure F-20. Scatter plot of mechanically ventilated TSP emissions versus exhaust temperature and scatter plot with regression.

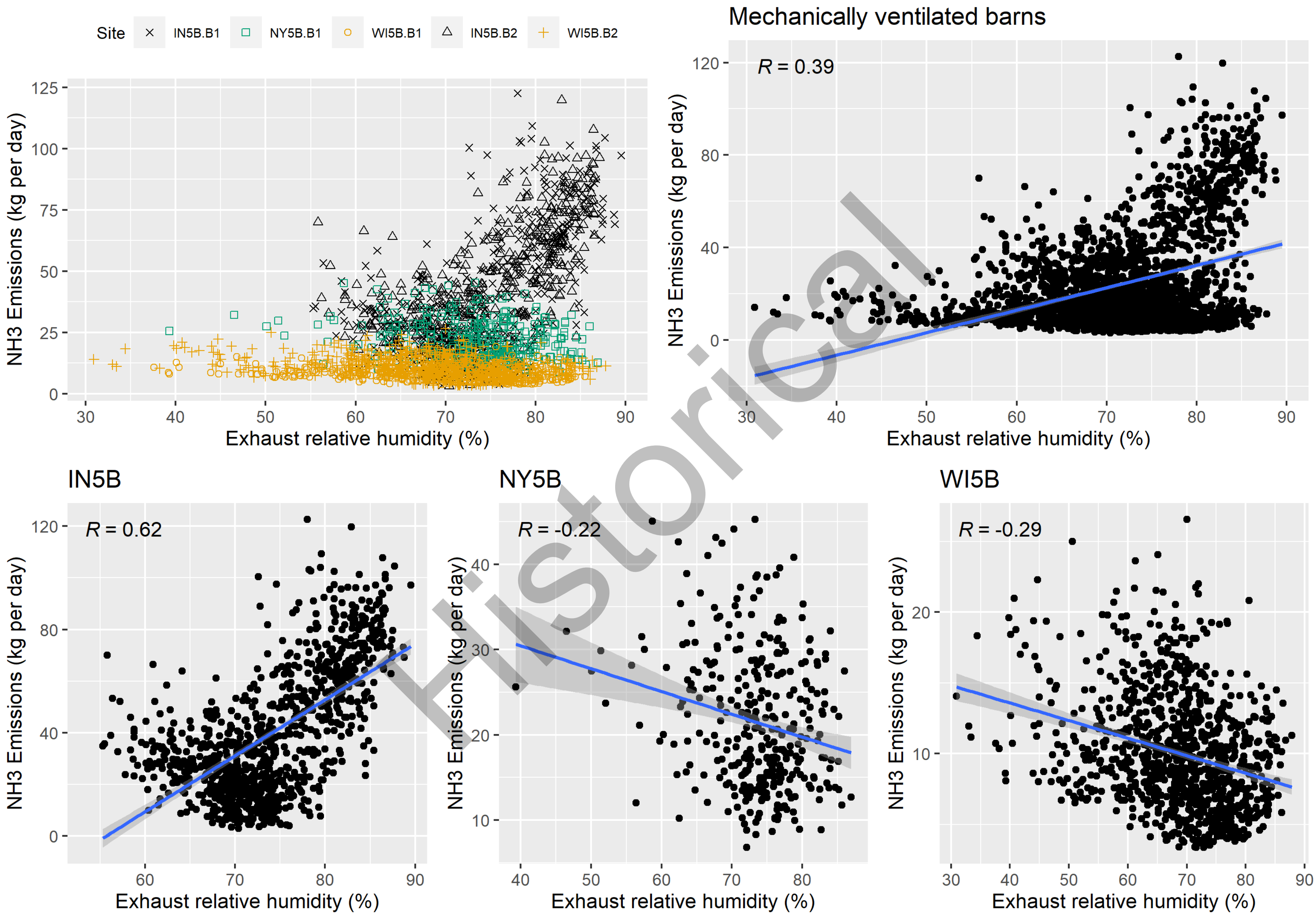


Figure F-21. Scatter plot of mechanically ventilated NH_3 emissions versus exhaust relative humidity and scatter plot with regression.

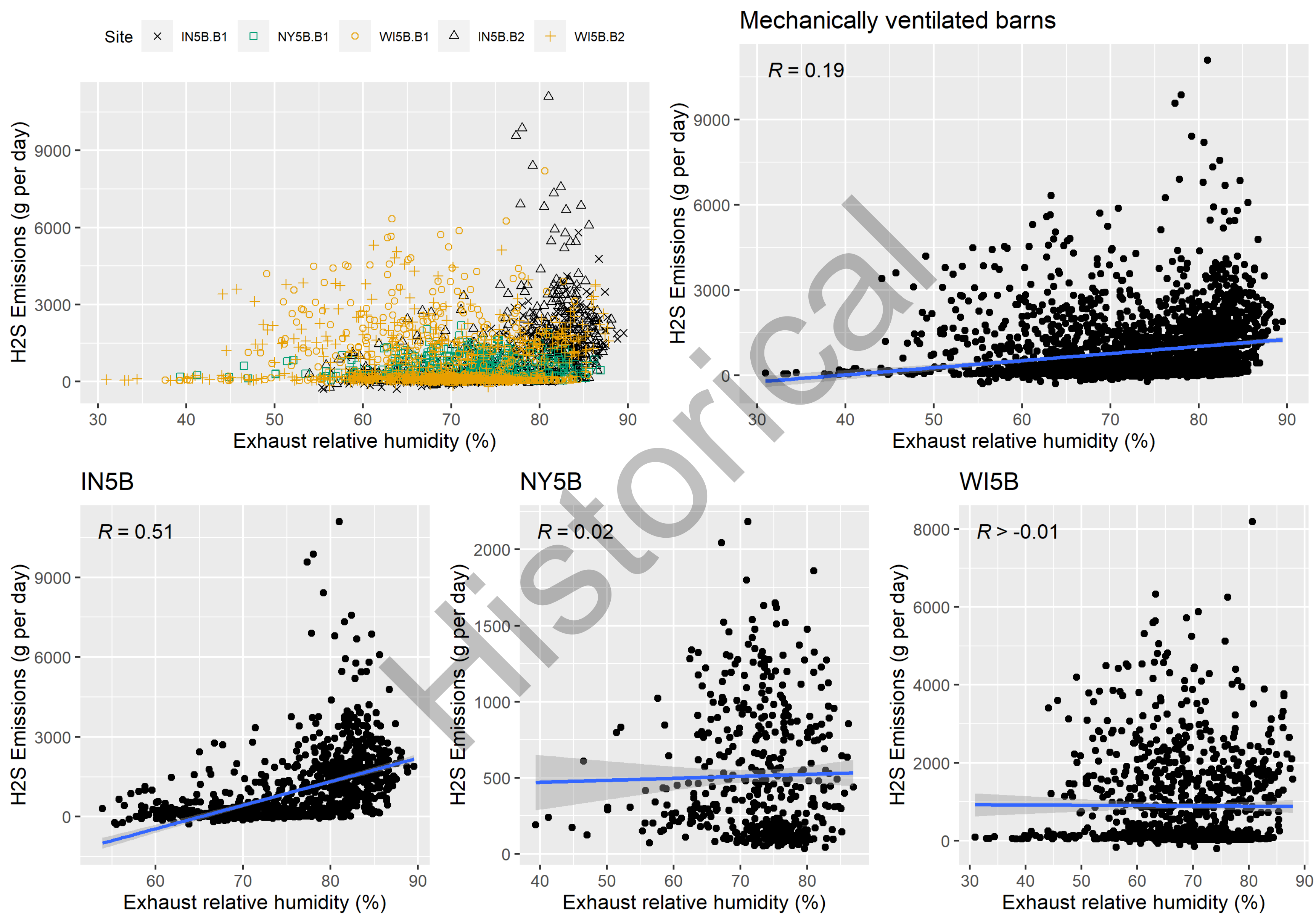


Figure F-22. Scatter plot of mechanically ventilated H_2S emissions versus exhaust relative humidity and scatter plot with regression.

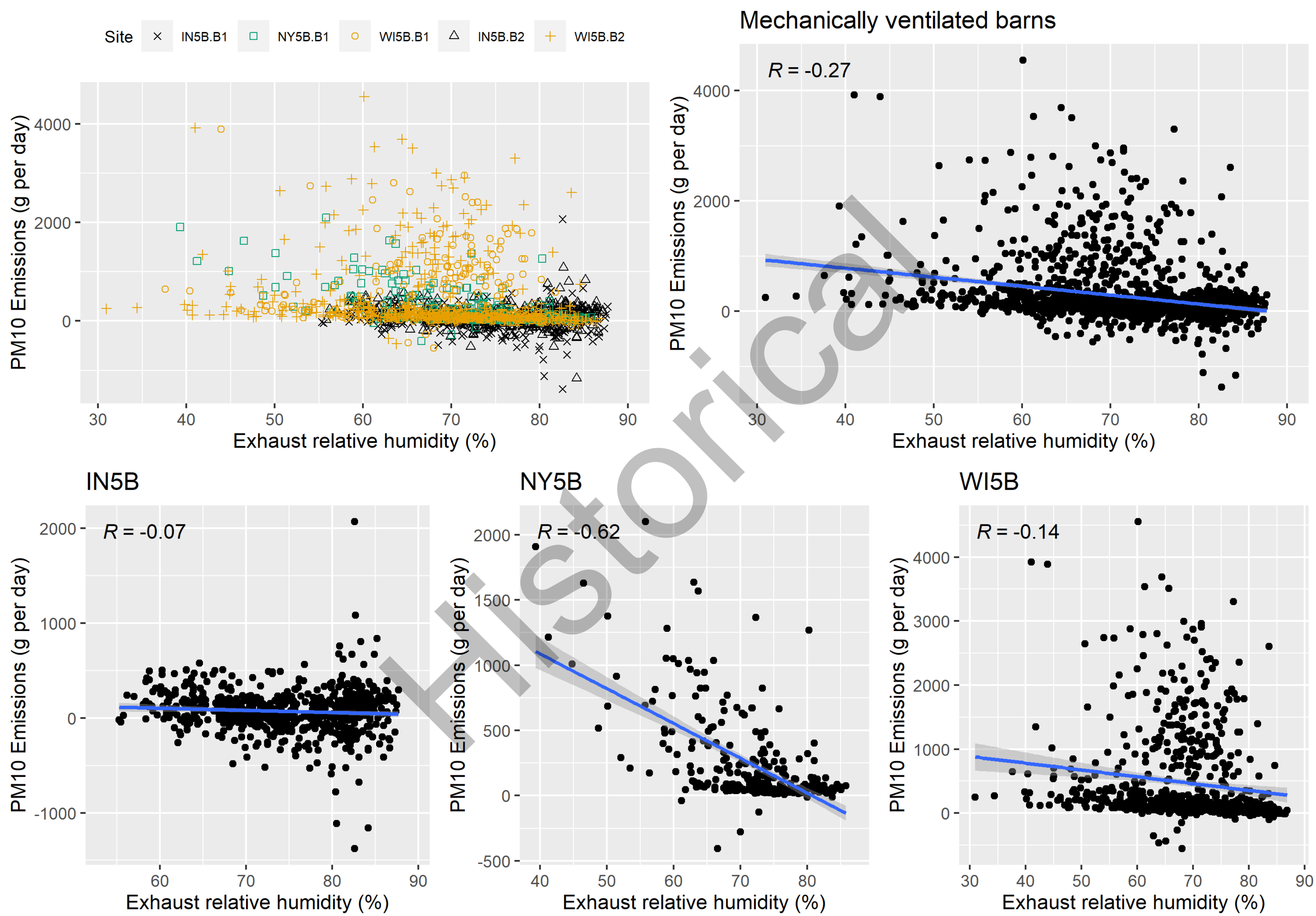


Figure F-23. Scatter plot of mechanically ventilated PM_{10} emissions versus exhaust relative humidity and scatter plot with regression.

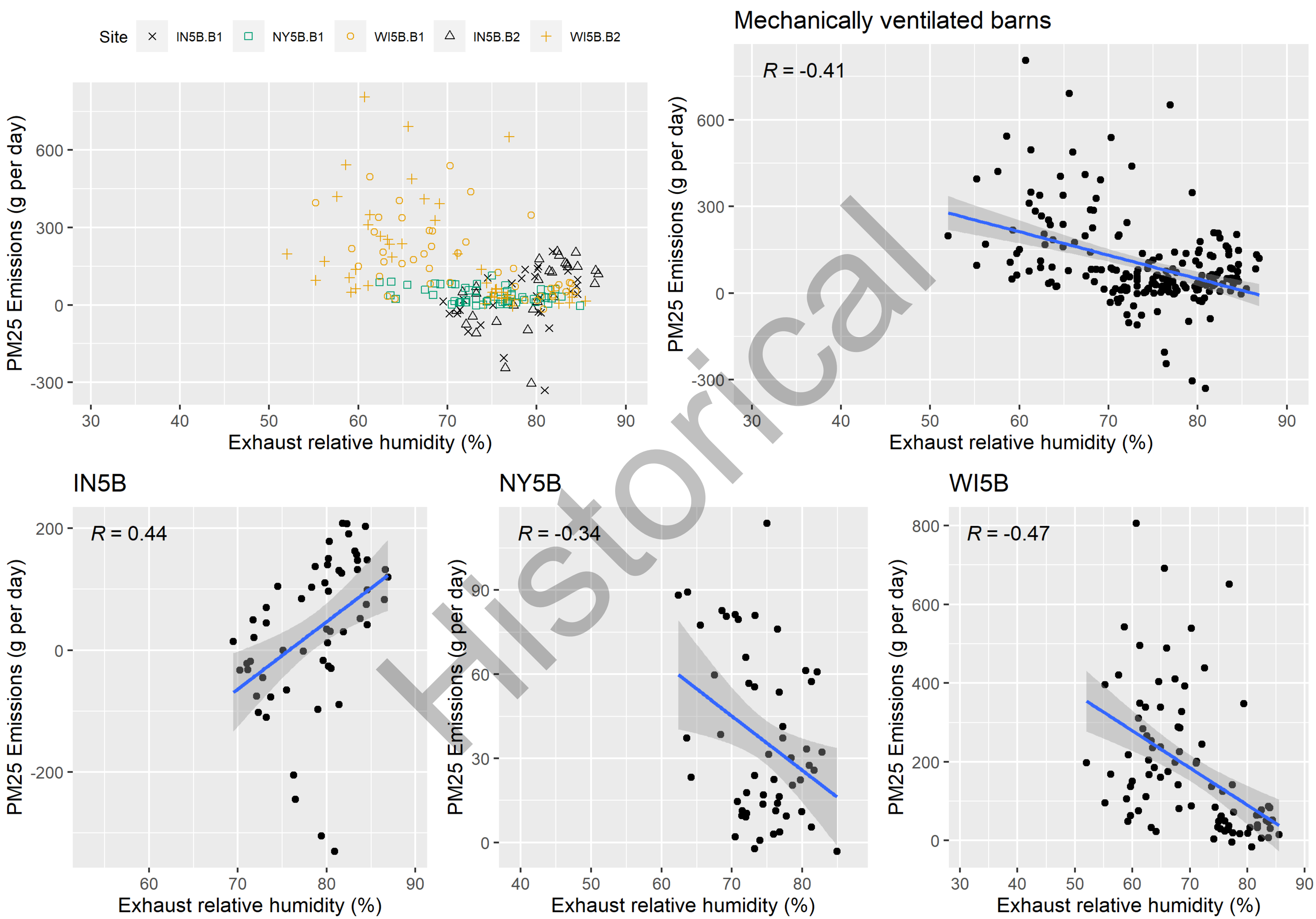


Figure F-24. Scatter plot of mechanically ventilated PM2.5 emissions versus exhaust relative humidity and scatter plot with regression.

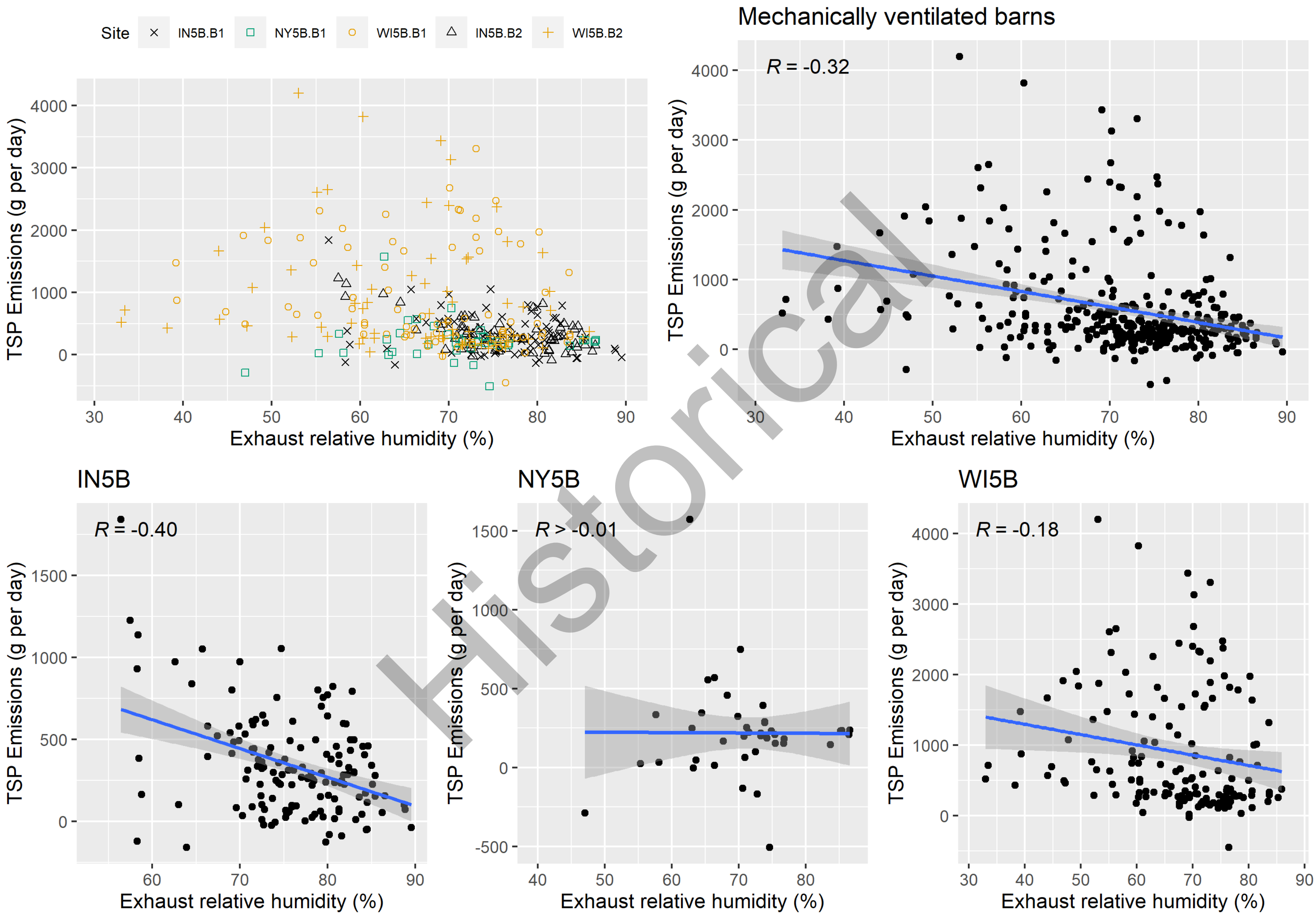


Figure F-25. Scatter plot of mechanically ventilated TSP emissions versus exhaust relative humidity and scatter plot with regression.

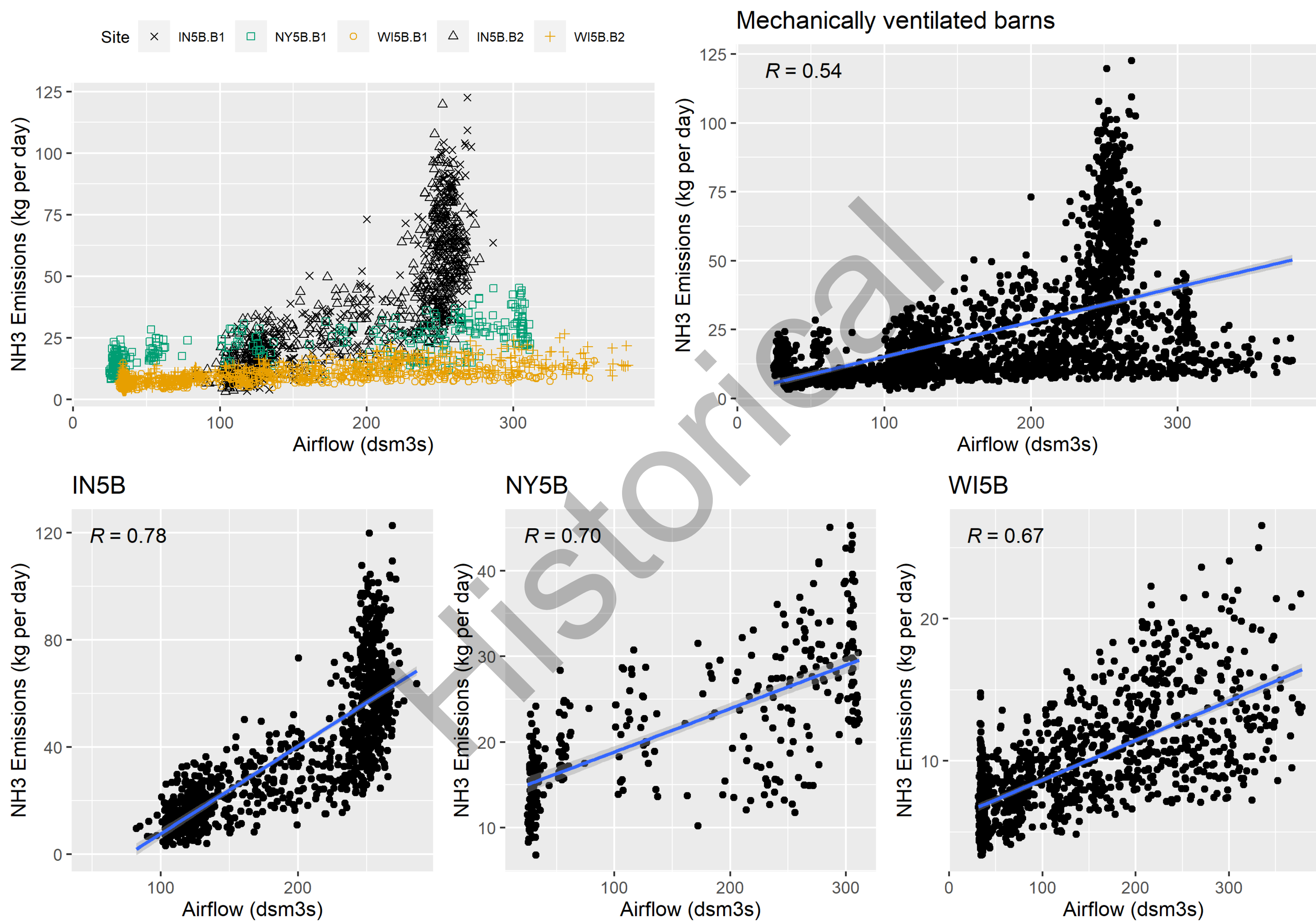


Figure F-26. Scatter plot of mechanically ventilated NH_3 emissions versus airflow and scatter plot with regression.

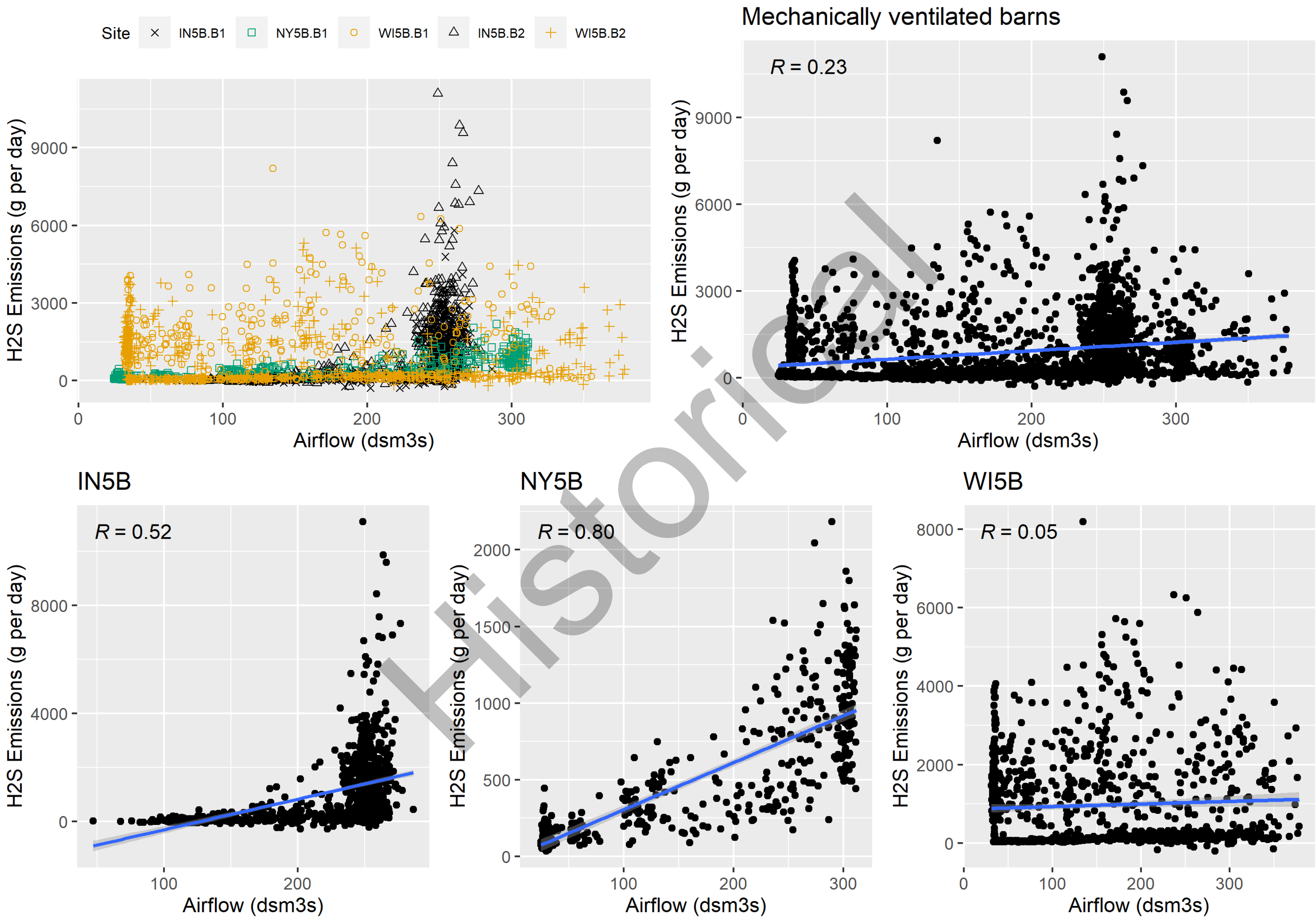


Figure F-27. Scatter plot of mechanically ventilated H_2S emissions versus airflow and scatter plot with regression.

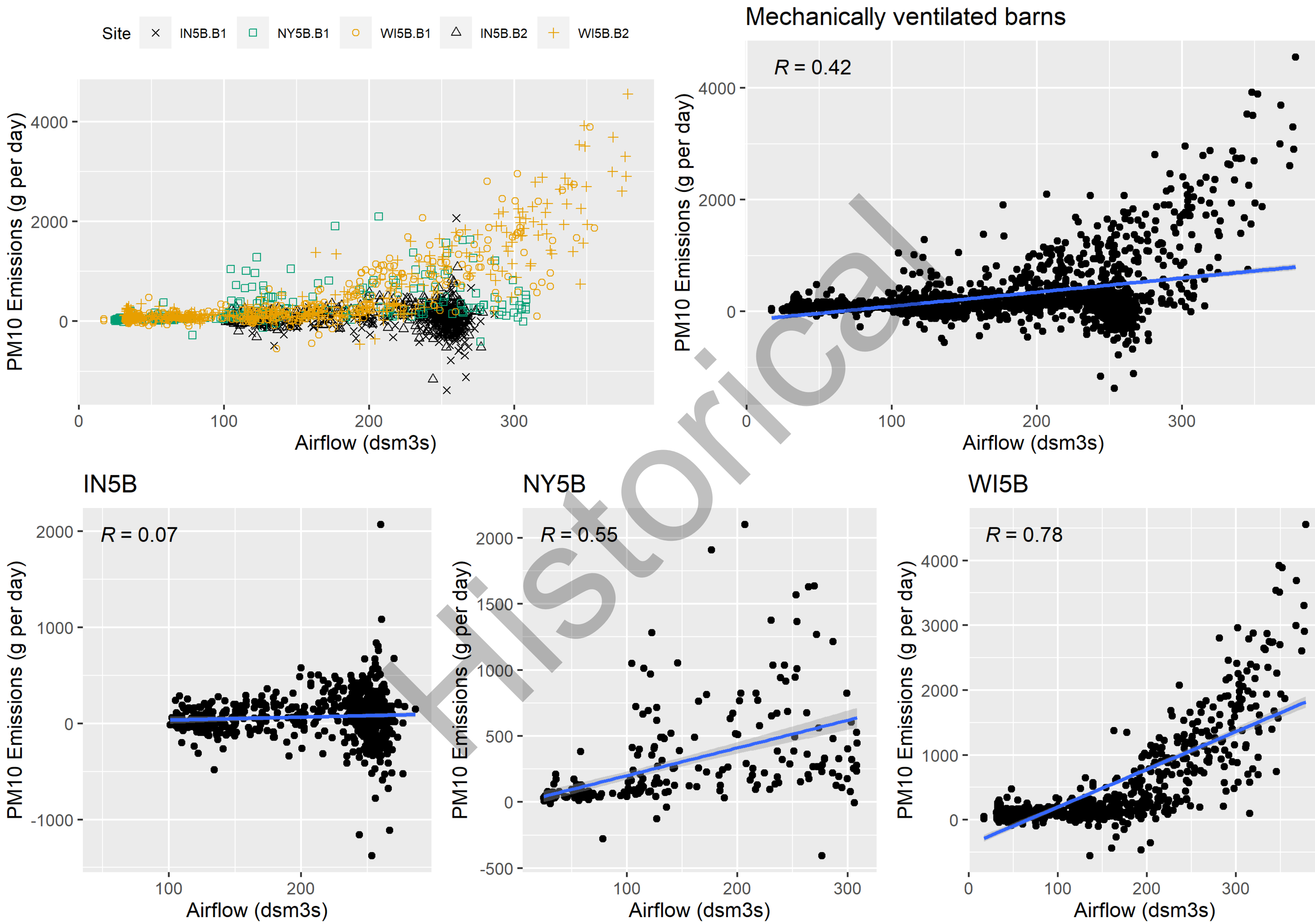


Figure F-28. Scatter plot of mechanically ventilated PM_{10} emissions versus airflow and scatter plot with regression.

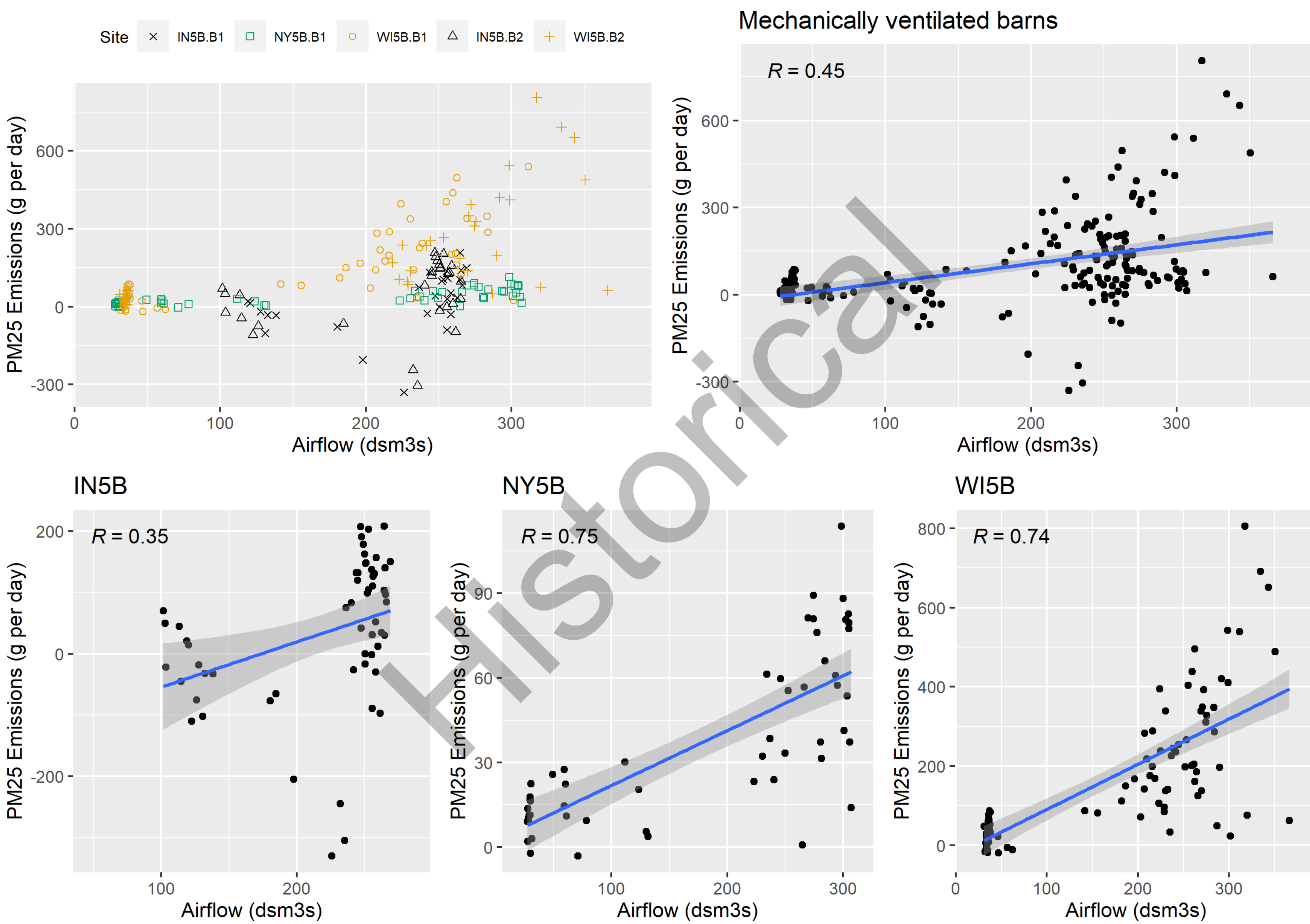


Figure F-29. Scatter plot of mechanically ventilated PM2.5 emissions versus airflow and scatter plot with regression.

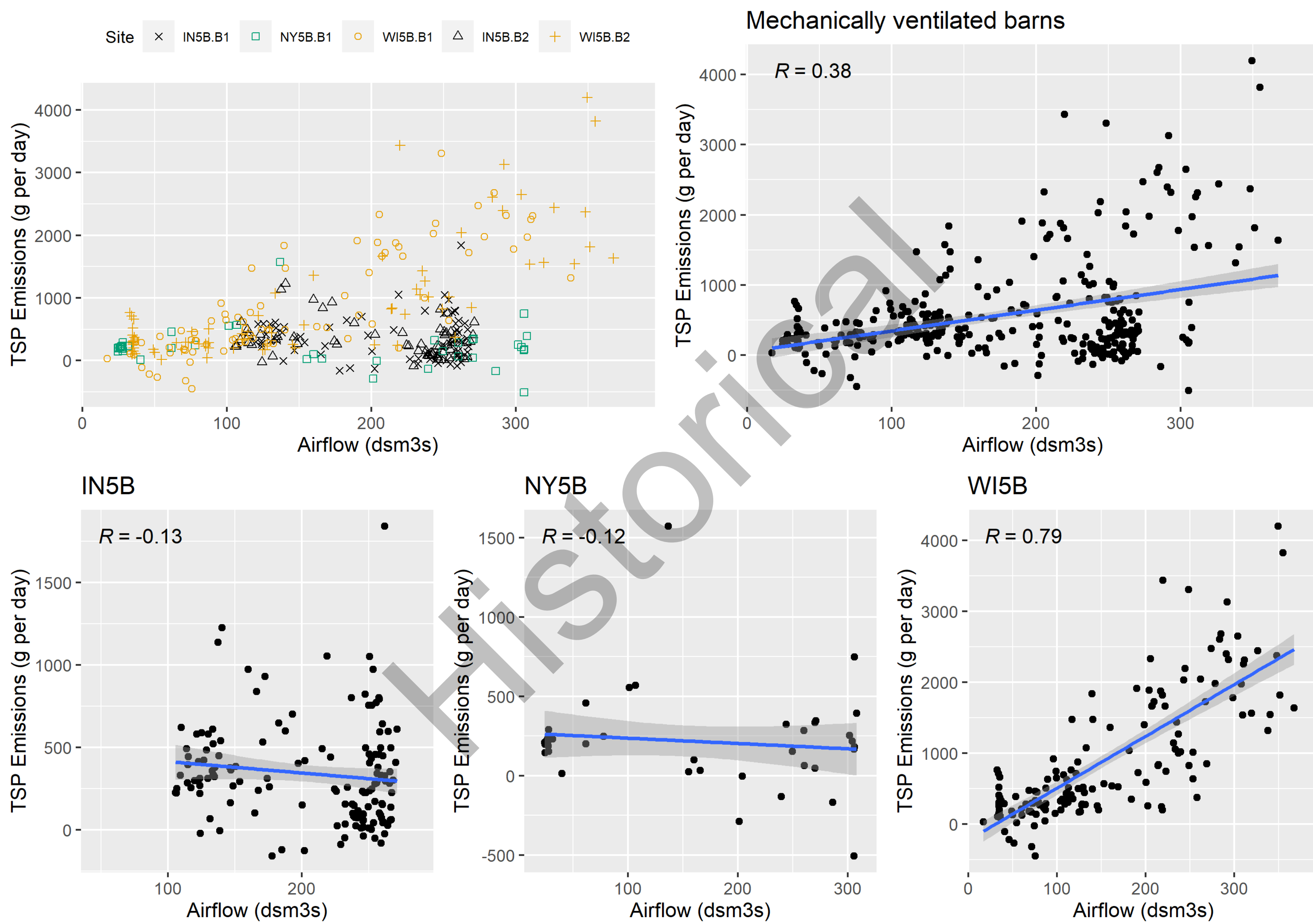


Figure F-30. Scatter plot of mechanically ventilated TSP emissions versus airflow and scatter plot with regression.

F.1.2 Ambient Parameters

Table F-3. Summary of mechanically ventilated barn R^2 values for ambient parameters.

Pollutant	Parameter	R	R^2	Strength	Figure
NH_3	Ambient temperature	0.537	0.289	modest	F-31
H_2S	Ambient temperature	0.257	0.066	slight or weak	F-32
PM_{10}	Ambient temperature	0.370	0.137	slight or weak	F-33
$PM_{2.5}$	Ambient temperature	0.398	0.159	slight or weak	F-34
TSP	Ambient temperature	0.348	0.121	slight or weak	F-35
NH_3	Ambient relative humidity	-0.110	0.012	slight or weak	F-36
H_2S	Ambient relative humidity	0.000	0.000	slight or weak	F-37
PM_{10}	Ambient relative humidity	-0.129	0.017	slight or weak	F-38
$PM_{2.5}$	Ambient relative humidity	-0.331	0.109	slight or weak	F-39
TSP	Ambient relative humidity	-0.155	0.024	slight or weak	F-40

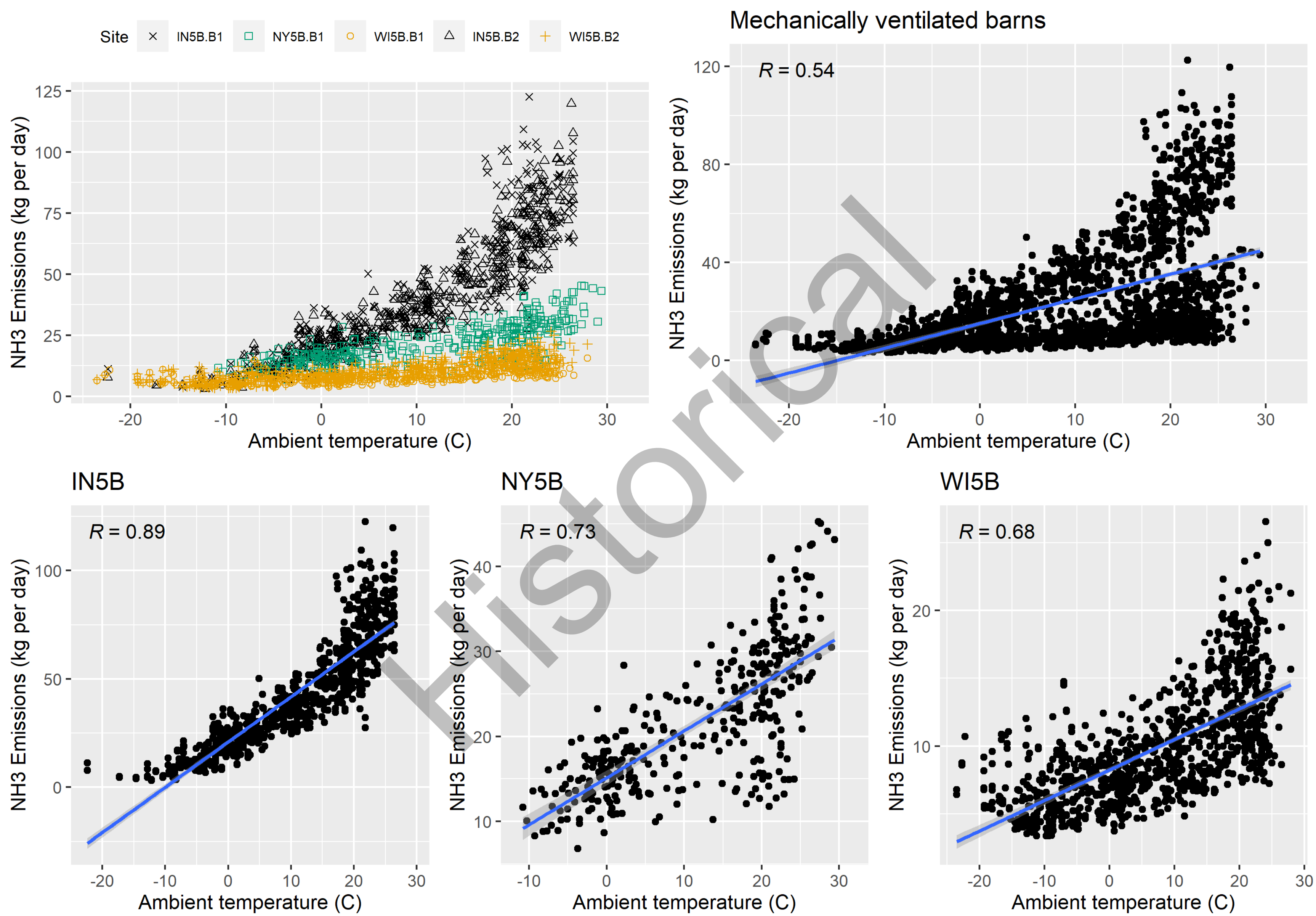


Figure F-31. Scatter plot of mechanically ventilated NH_3 emissions versus ambient temperature and scatter plot with regression.

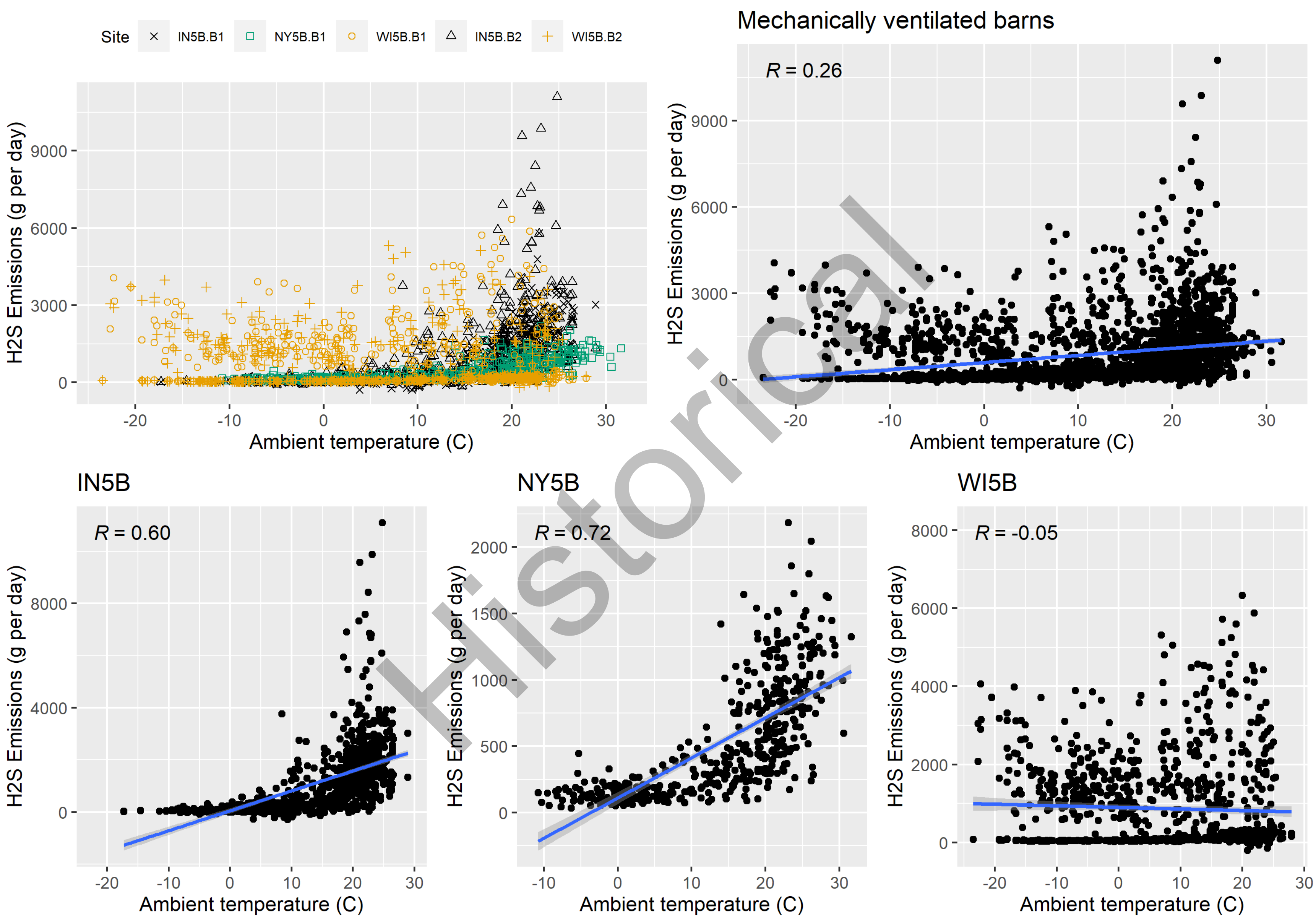


Figure F-32. Scatter plot of mechanically ventilated H_2S emissions versus ambient temperature and scatter plot with regression.

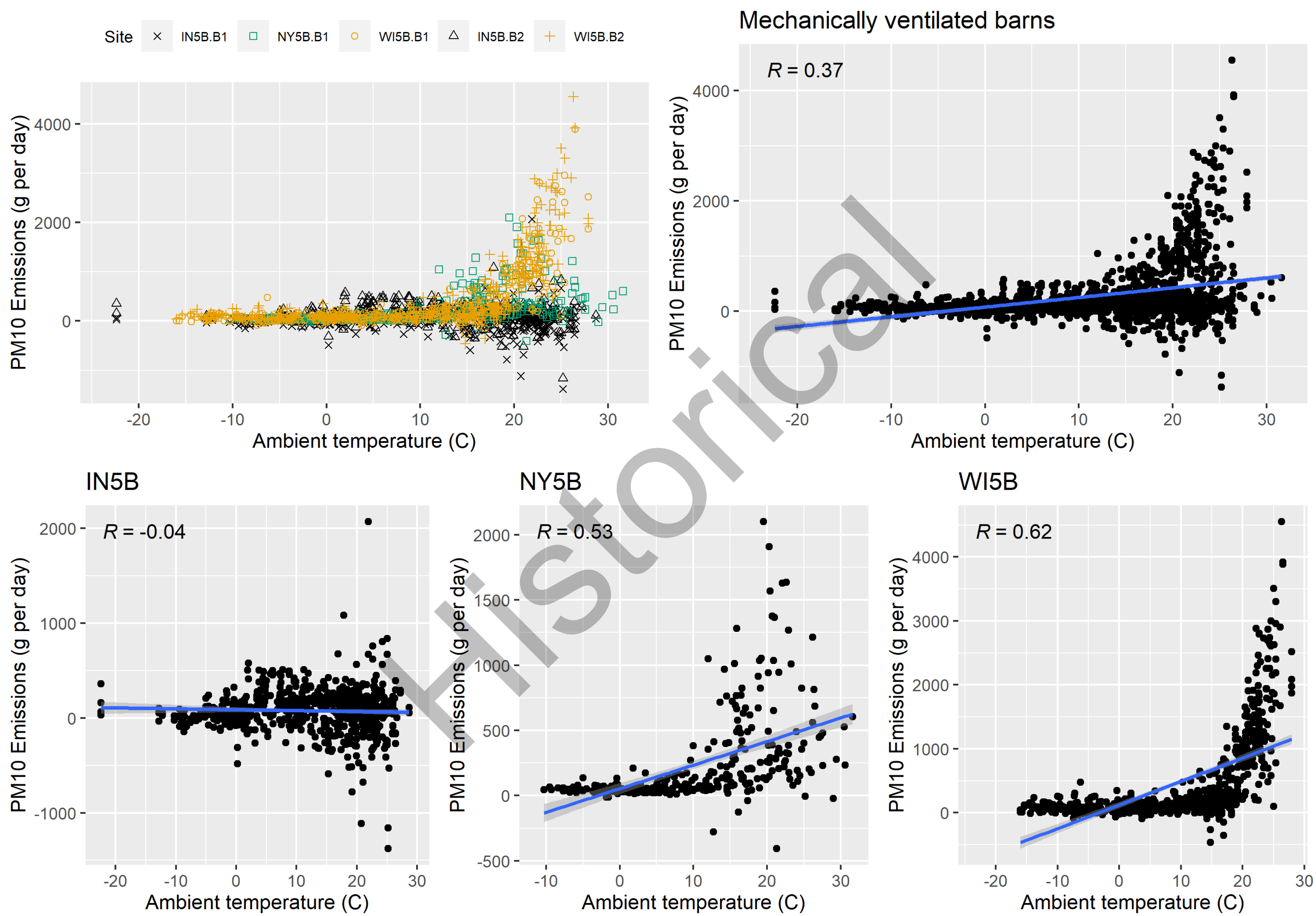


Figure F-33. Scatter plot of mechanically ventilated PM_{10} emissions versus ambient temperature and scatter plot with regression.

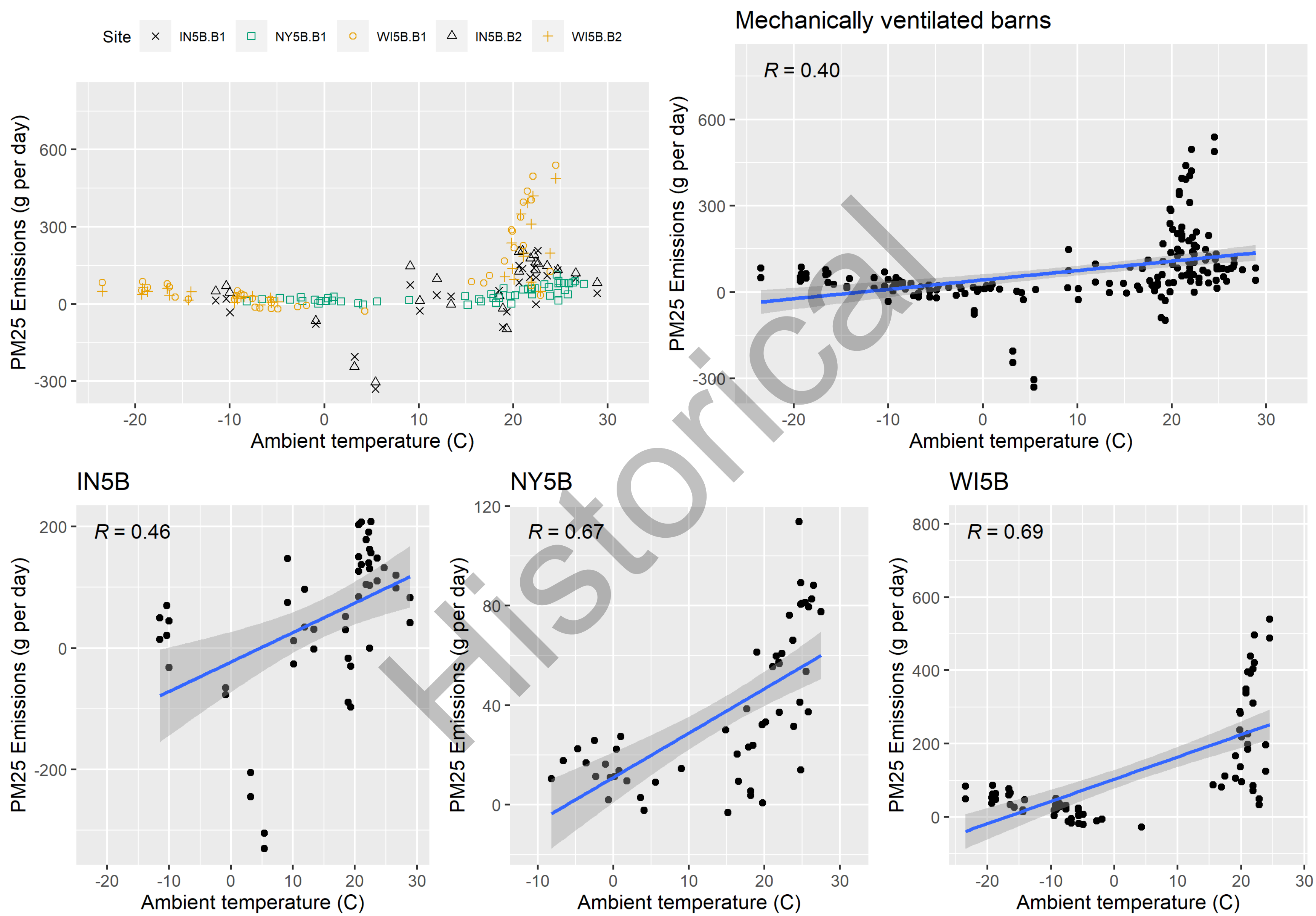


Figure F-34. Scatter plot of mechanically ventilated $PM_{2.5}$ emissions versus ambient temperature and scatter plot with regression.

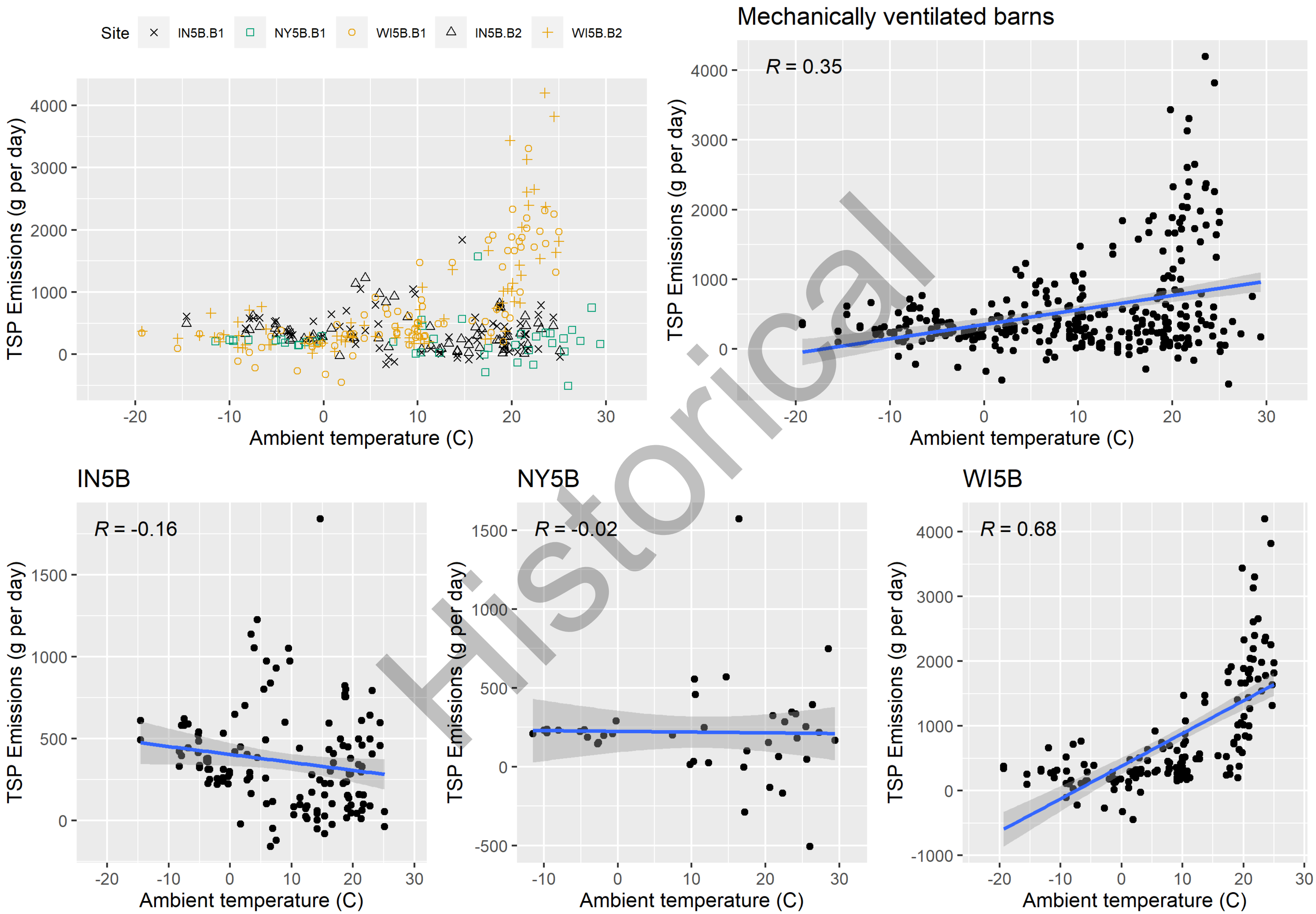


Figure F-35. Scatter plot of mechanically ventilated TSP emissions versus ambient temperature and scatter plot with regression.

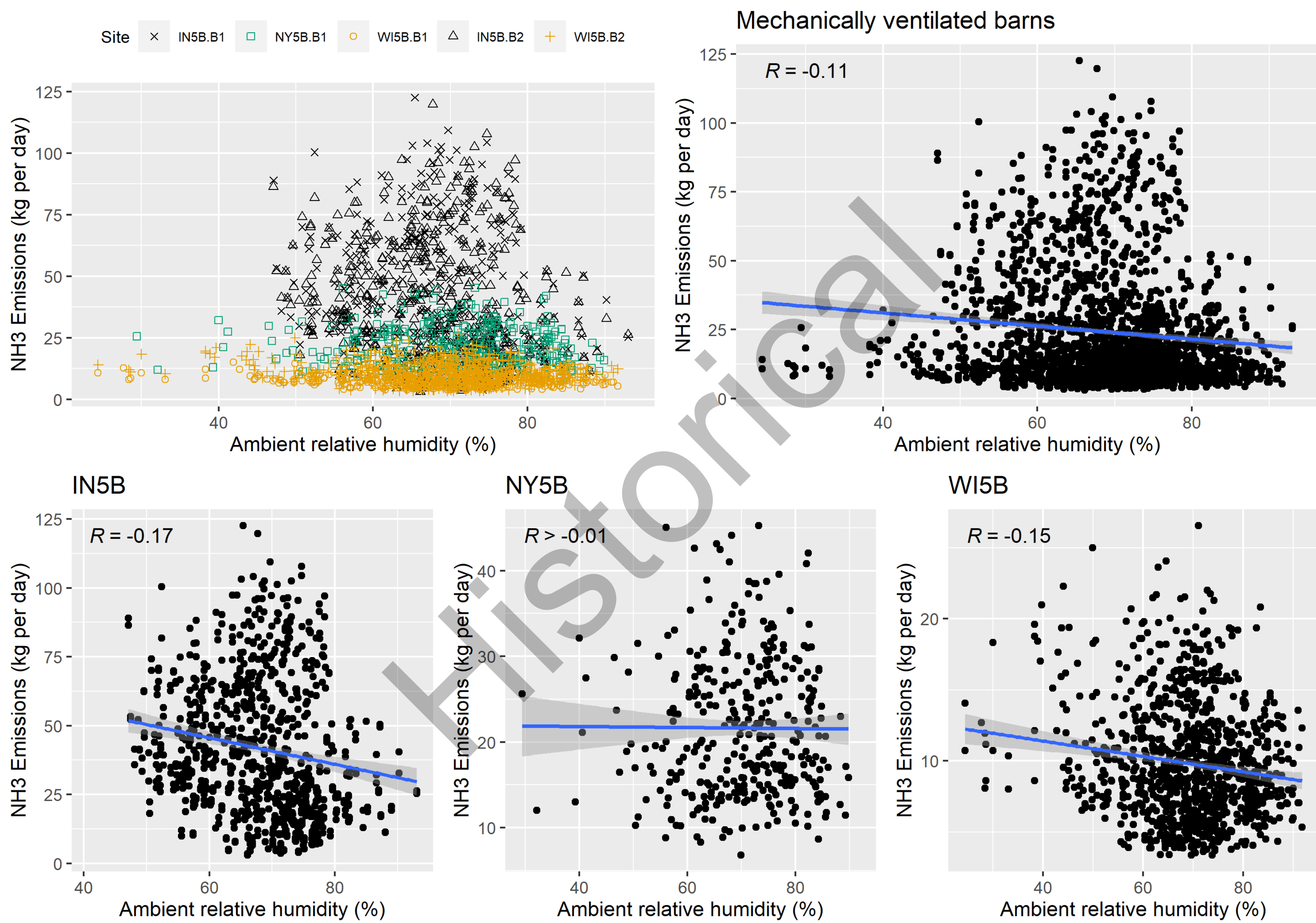


Figure F-36. Scatter plot of mechanically ventilated NH_3 emissions versus ambient relative humidity and scatter plot with regression.

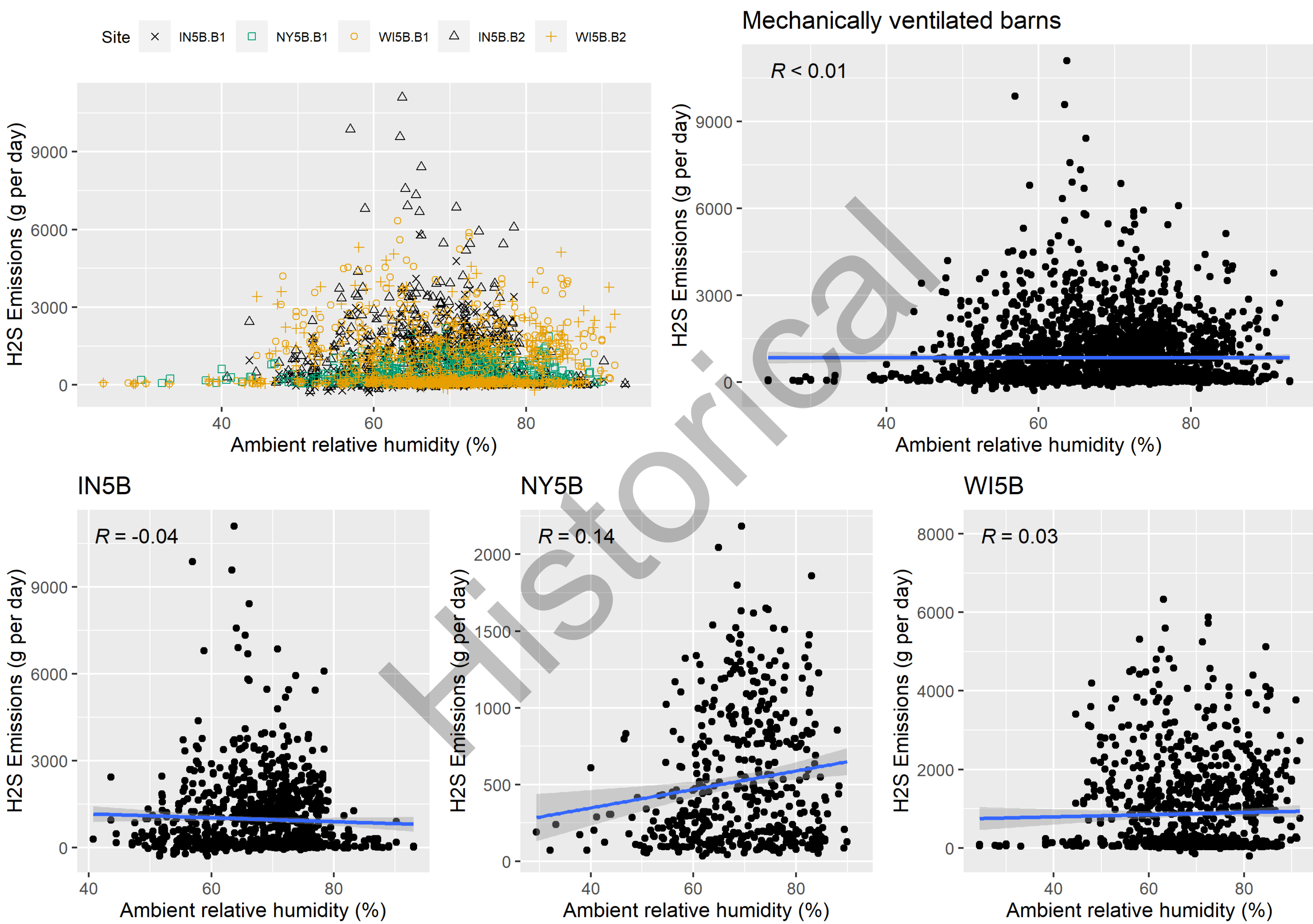


Figure F-37. Scatter plot of mechanically ventilated H_2S emissions versus ambient relative humidity and scatter plot with regression.

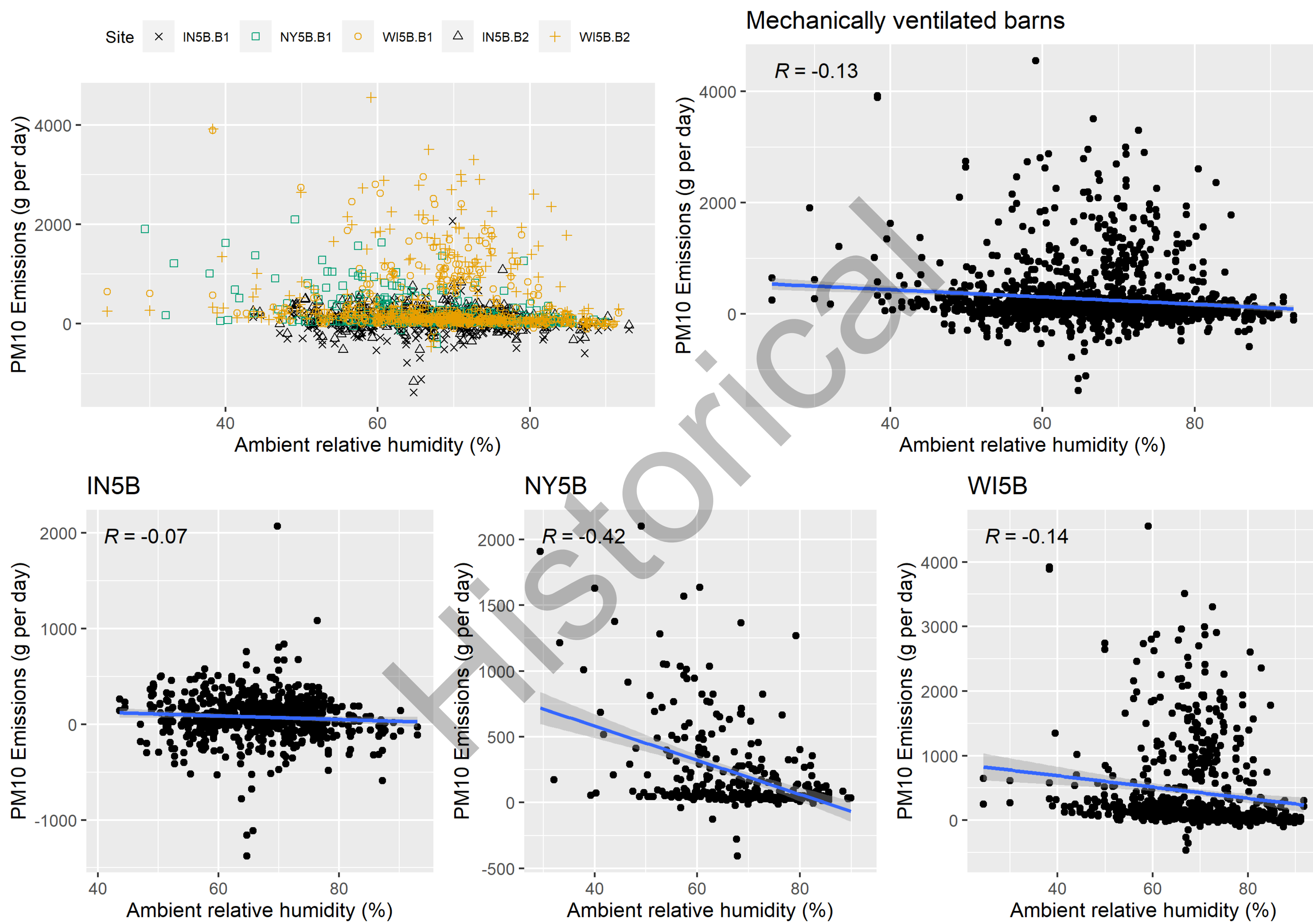


Figure F-38. Scatter plot of mechanically ventilated PM_{10} emissions versus ambient relative humidity and scatter plot with regression.

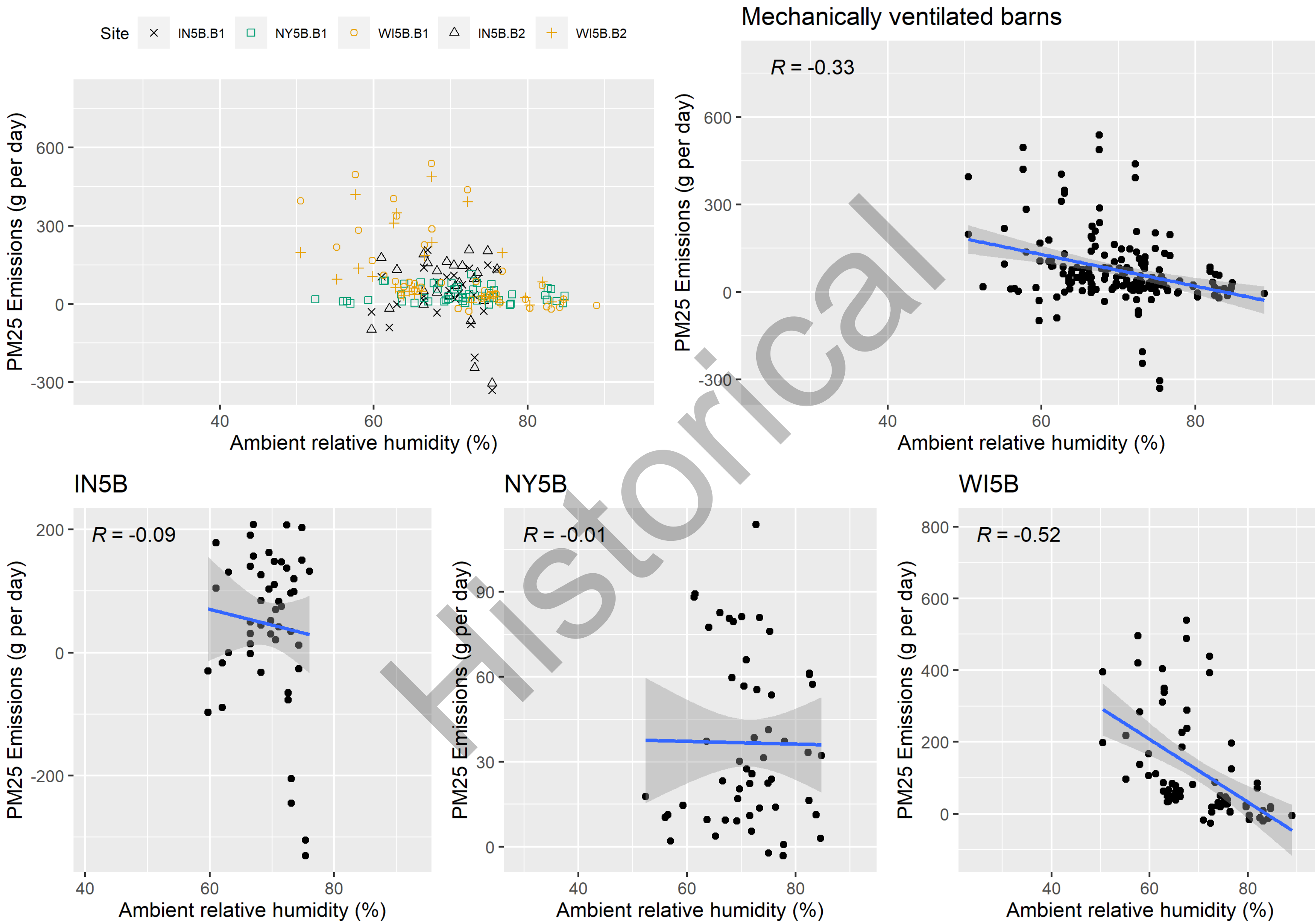


Figure F-39. Scatter plot of mechanically ventilated $PM_{2.5}$ emissions versus ambient relative humidity and scatter plot with regression.

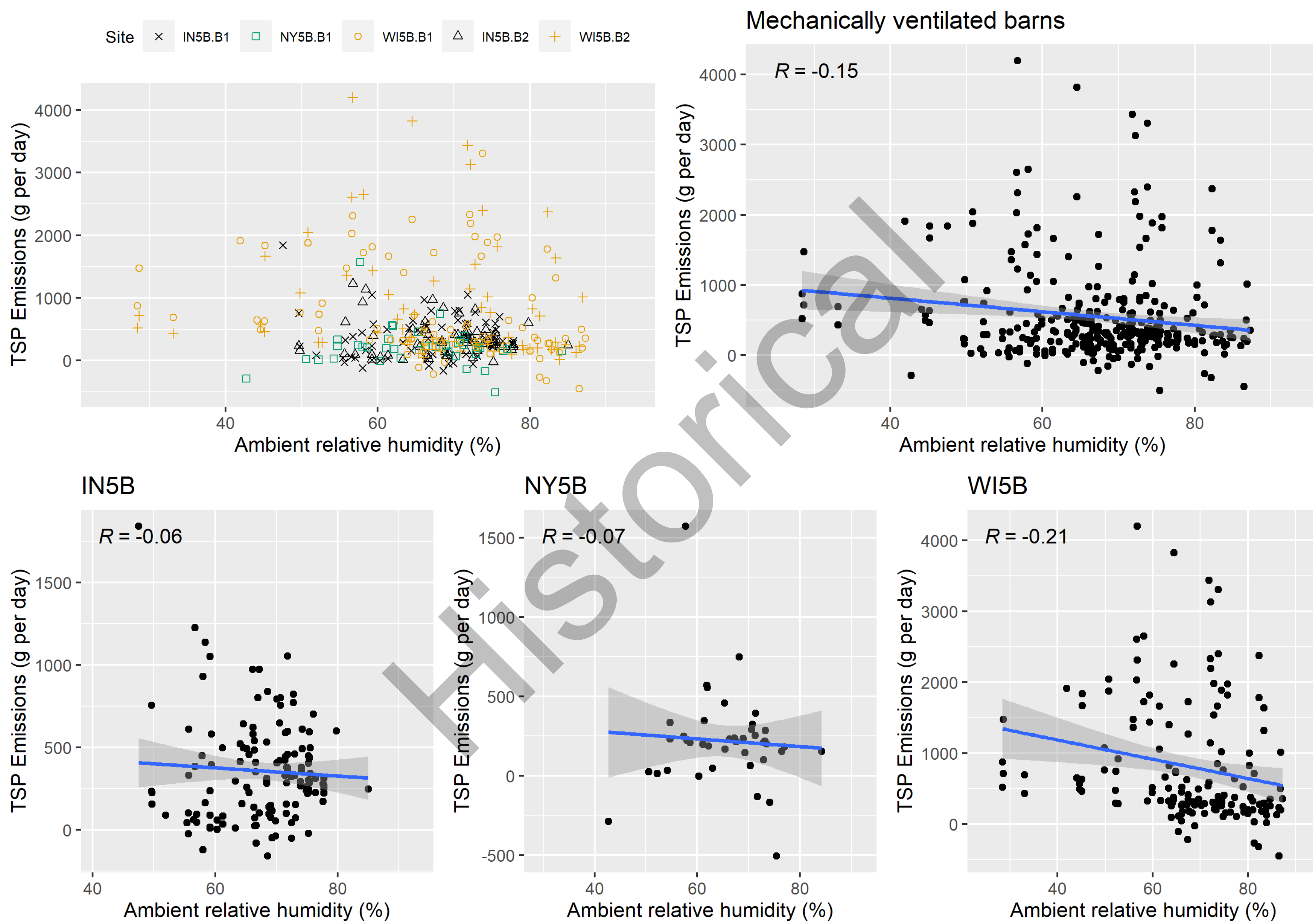


Figure F-40. Scatter plot of mechanically ventilated TSP emissions versus ambient relative humidity and scatter plot with regression.

F.2 Milking Centers

F.2.1 Environmental Parameters

Table F-4. Summary of milking center barn R^2 values for environmental parameters.

Pollutant	Parameter	R	R^2	Strength	Figure
NH_3	Inventory	0.279	0.078	slight or weak	F-41
H_2S	Inventory	0.360	0.130	slight or weak	F-42
PM_{10}	Inventory			None	F-43
$PM_{2.5}$	Inventory			None	F-44
TSP	Inventory			None	F-45
NH_3	Average animal weight	0.279	0.078	slight or weak	F-46
H_2S	Average animal weight	0.360	0.130	slight or weak	F-47
PM_{10}	Average animal weight	-0.005	0.000	slight or weak	F-48
$PM_{2.5}$	Average animal weight	-0.161	0.026	slight or weak	F-49
TSP	Average animal weight	0.154	0.024	slight or weak	F-50
NH_3	Live animal weight	0.279	0.078	slight or weak	F-51
H_2S	Live animal weight	0.360	0.130	slight or weak	F-52
PM_{10}	Live animal weight	-0.005	0.000	slight or weak	F-53
$PM_{2.5}$	Live animal weight	-0.161	0.026	slight or weak	F-54
TSP	Live animal weight	0.154	0.024	slight or weak	F-55
NH_3	Exhaust temperature	0.518	0.268	modest	F-56
H_2S	Exhaust temperature	0.322	0.104	slight or weak	F-57
PM_{10}	Exhaust temperature	0.550	0.303	modest	F-58
$PM_{2.5}$	Exhaust temperature	0.401	0.160	slight or weak	F-59
TSP	Exhaust temperature	0.348	0.121	slight or weak	F-60
NH_3	Exhaust relative humidity	-0.188	0.035	slight or weak	F-61
H_2S	Exhaust relative humidity	-0.378	0.143	slight or weak	F-62
PM_{10}	Exhaust relative humidity	-0.111	0.012	slight or weak	F-63
$PM_{2.5}$	Exhaust relative humidity	-0.241	0.058	slight or weak	F-64
TSP	Exhaust relative humidity	0.184	0.034	slight or weak	F-65
NH_3	Airflow	0.381	0.146	slight or weak	F-66
H_2S	Airflow	0.332	0.110	slight or weak	F-67
PM_{10}	Airflow	-0.458	0.210	modest	F-68
$PM_{2.5}$	Airflow	-0.009	0.000	slight or weak	F-69
TSP	Airflow	0.106	0.011	slight or weak	F-70

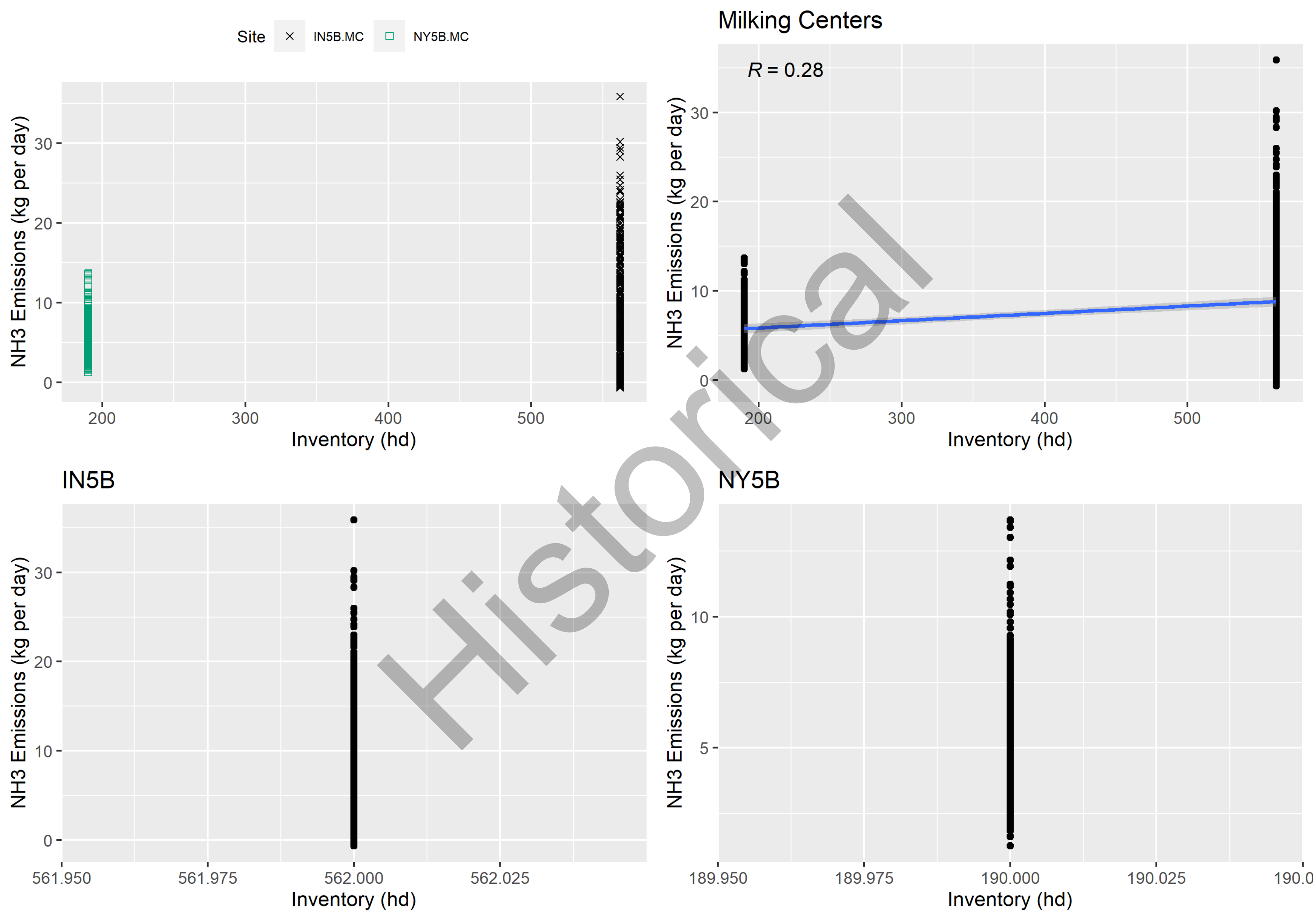


Figure F-41. Scatter plot of milking center NH_3 emissions versus inventory and scatter plot with regression.

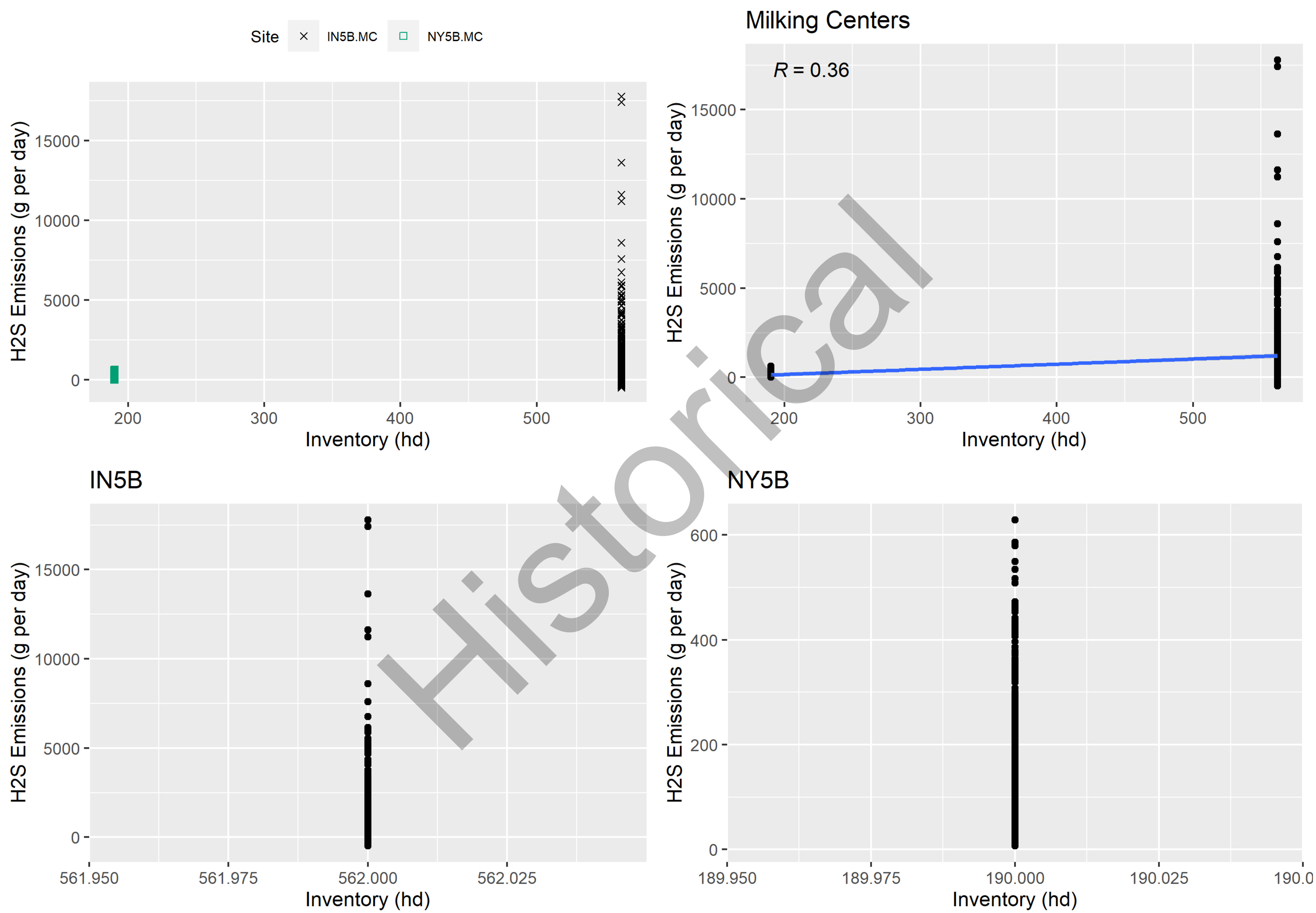


Figure F-42. Scatter plot of milking center H_2S emissions versus inventory and scatter plot with regression.

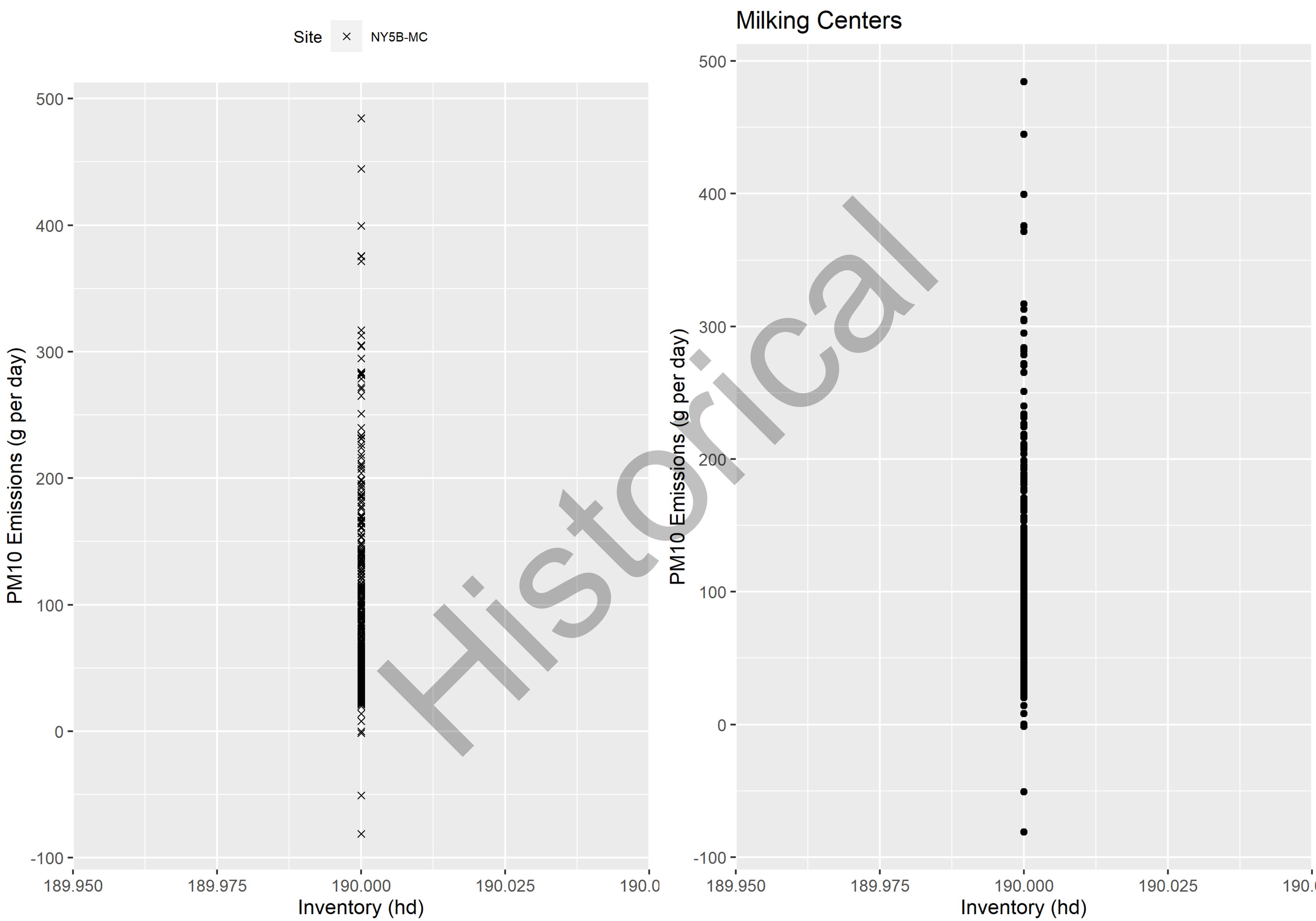


Figure F-43. Scatter plot of milking center PM_{10} emissions versus inventory and scatter plot with regression.

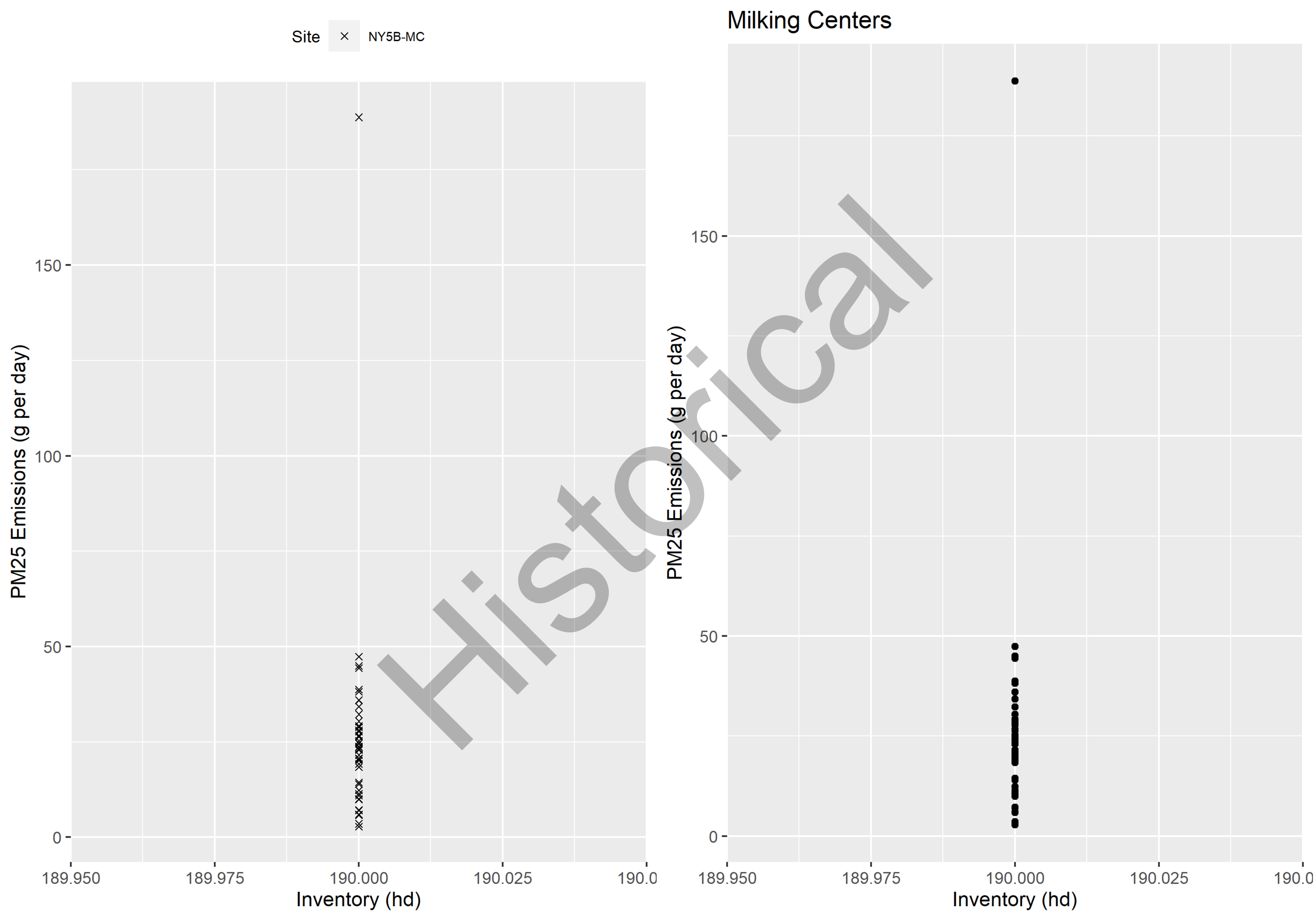


Figure F-44. Scatter plot of milking center $PM_{2.5}$ emissions versus inventory and scatter plot with regression.

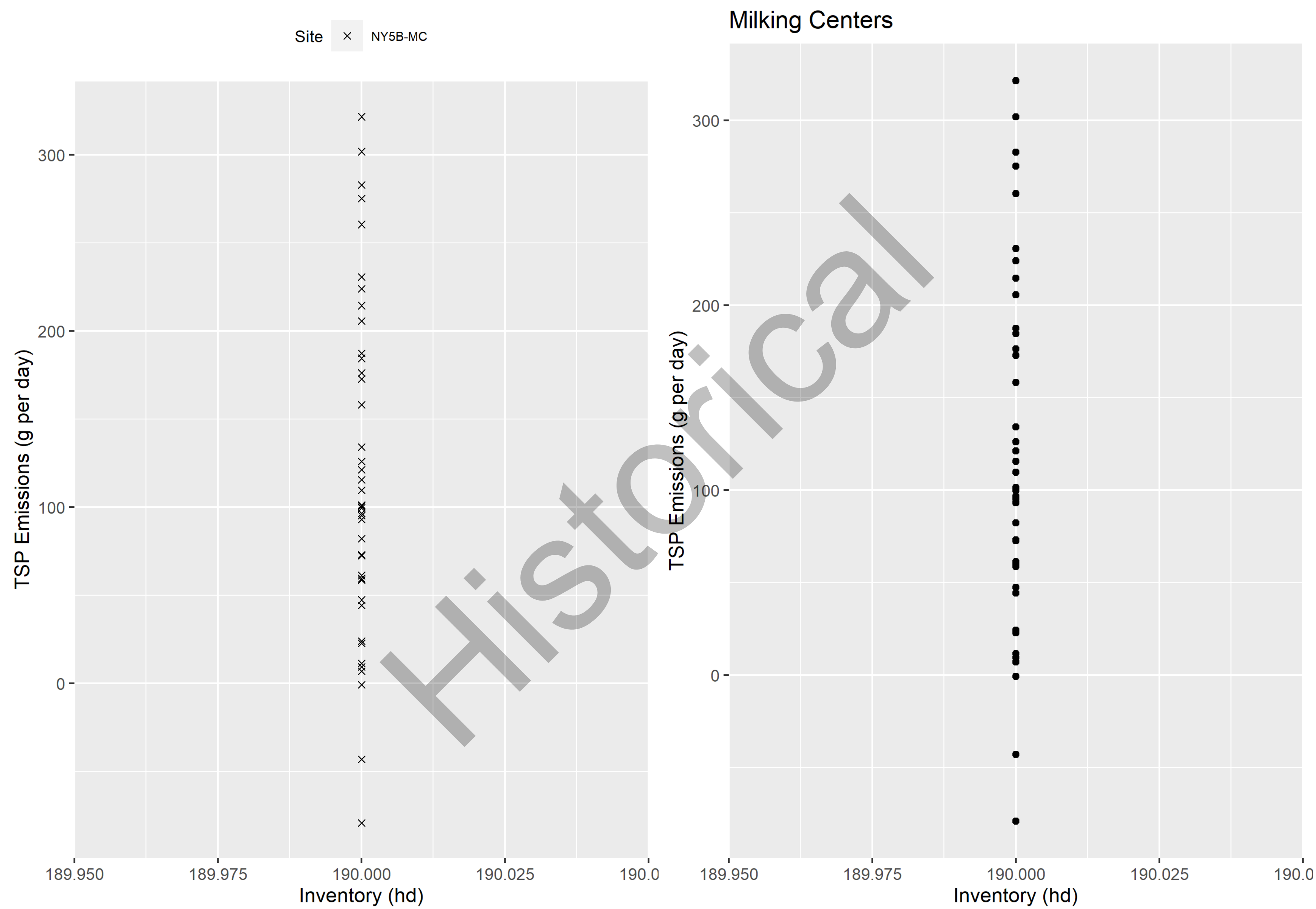


Figure F-45. Scatter plot of milking center TSP emissions versus inventory and scatter plot with regression.

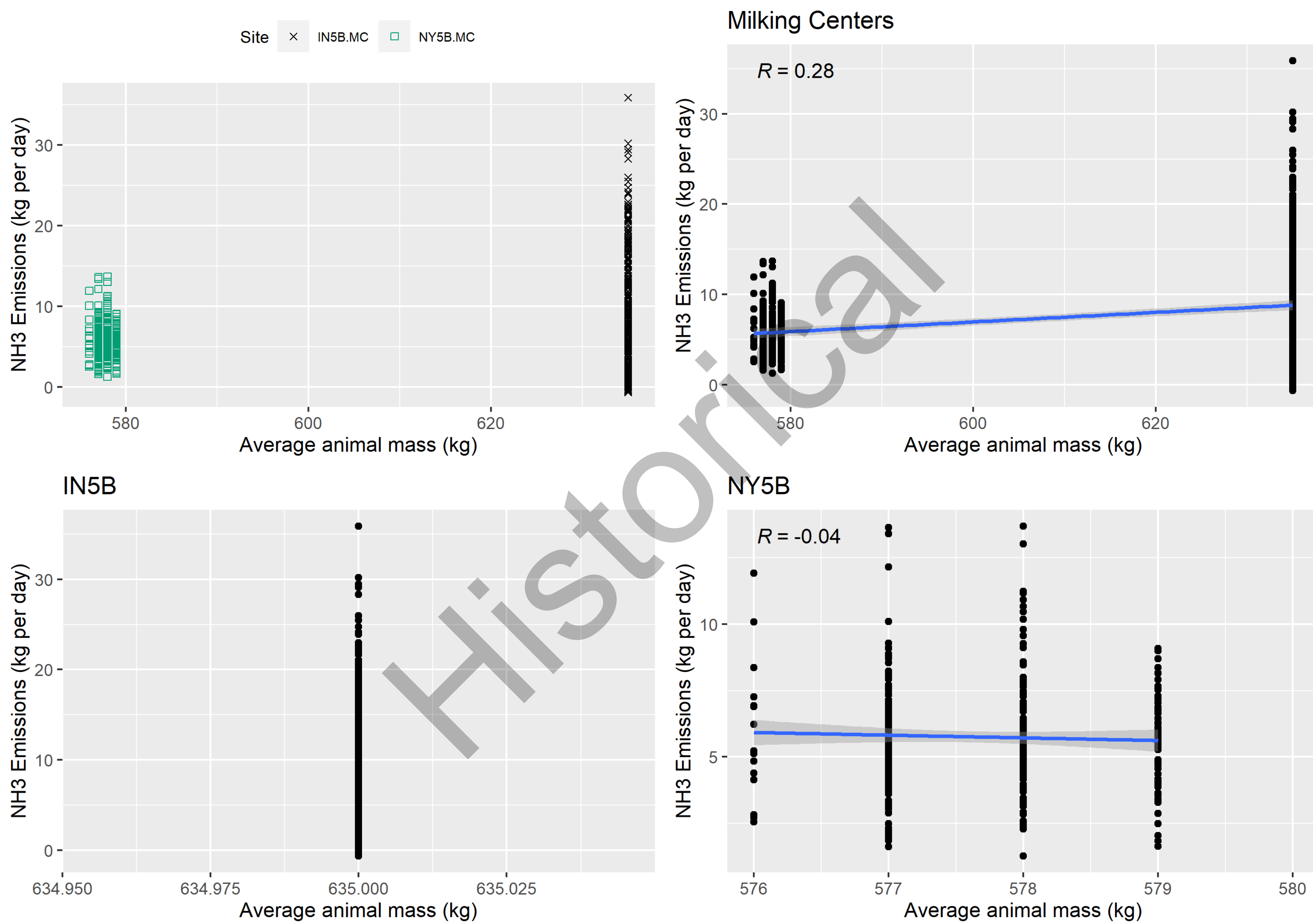


Figure F-46. Scatter plot of milking center NH_3 emissions versus average animal mass and scatter plot with regression.

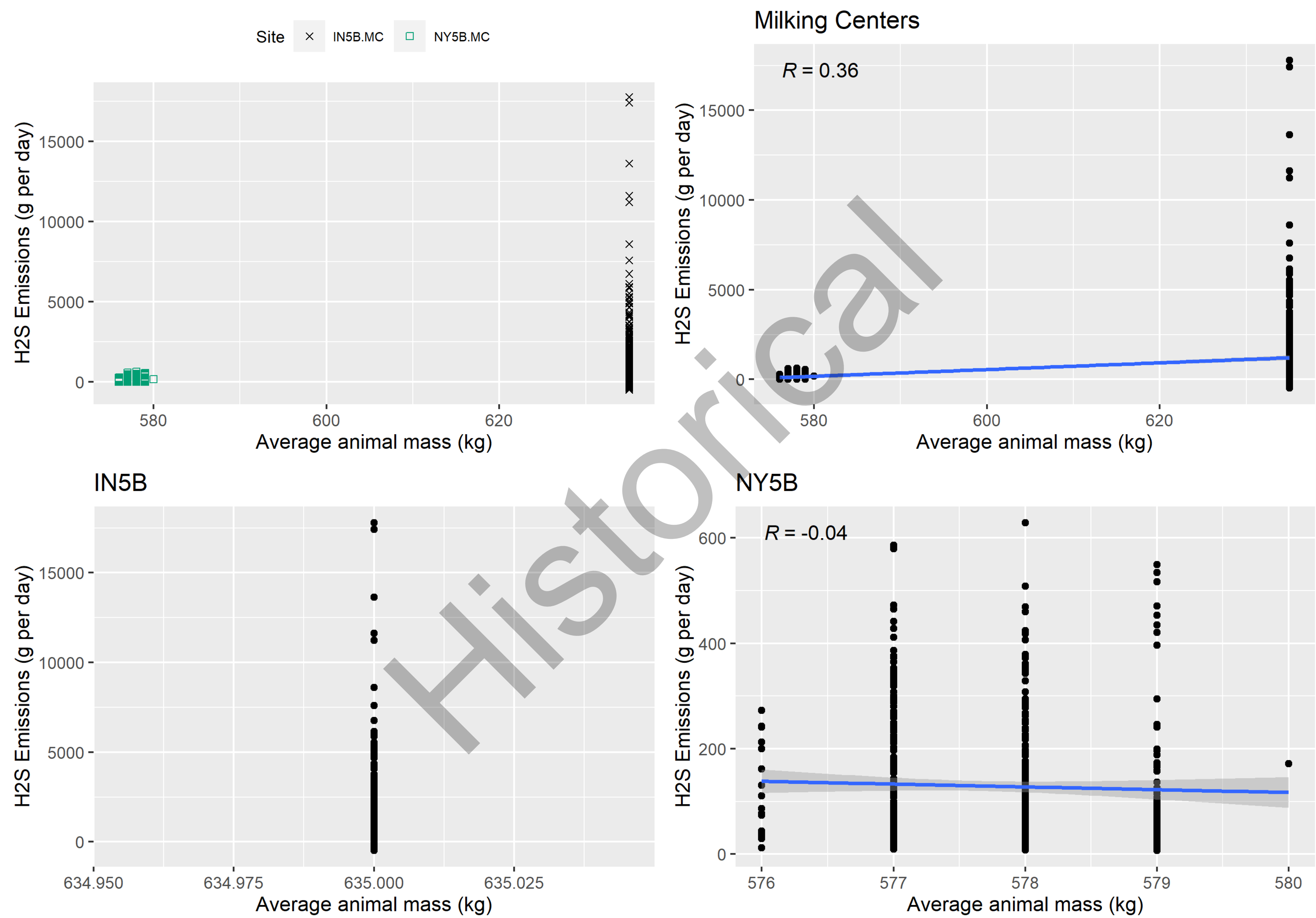


Figure F-47. Scatter plot of milking center H_2S emissions versus average animal mass and scatter plot with regression.

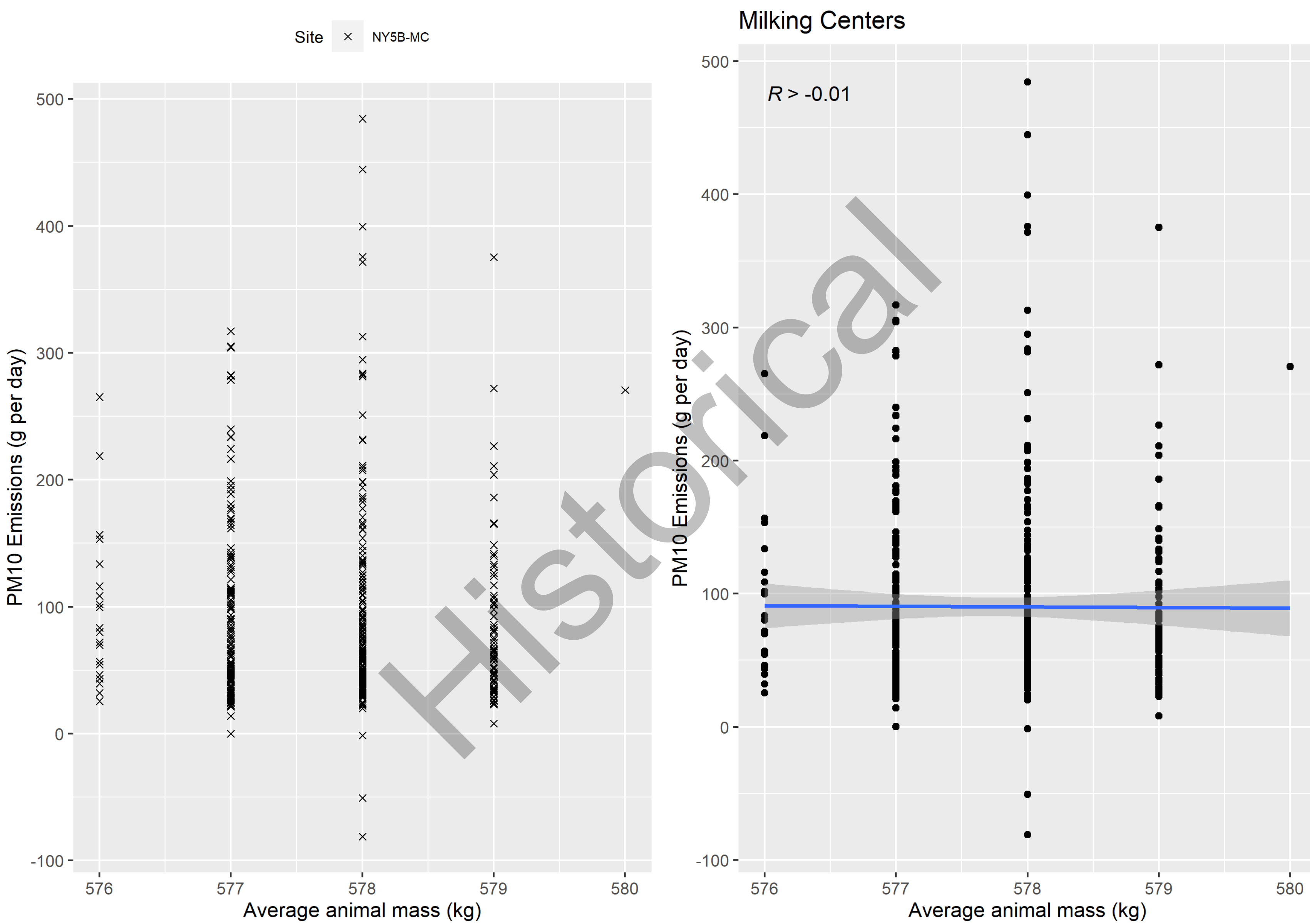


Figure F-48. Scatter plot of milking center PM_{10} emissions versus average animal mass and scatter plot with regression.

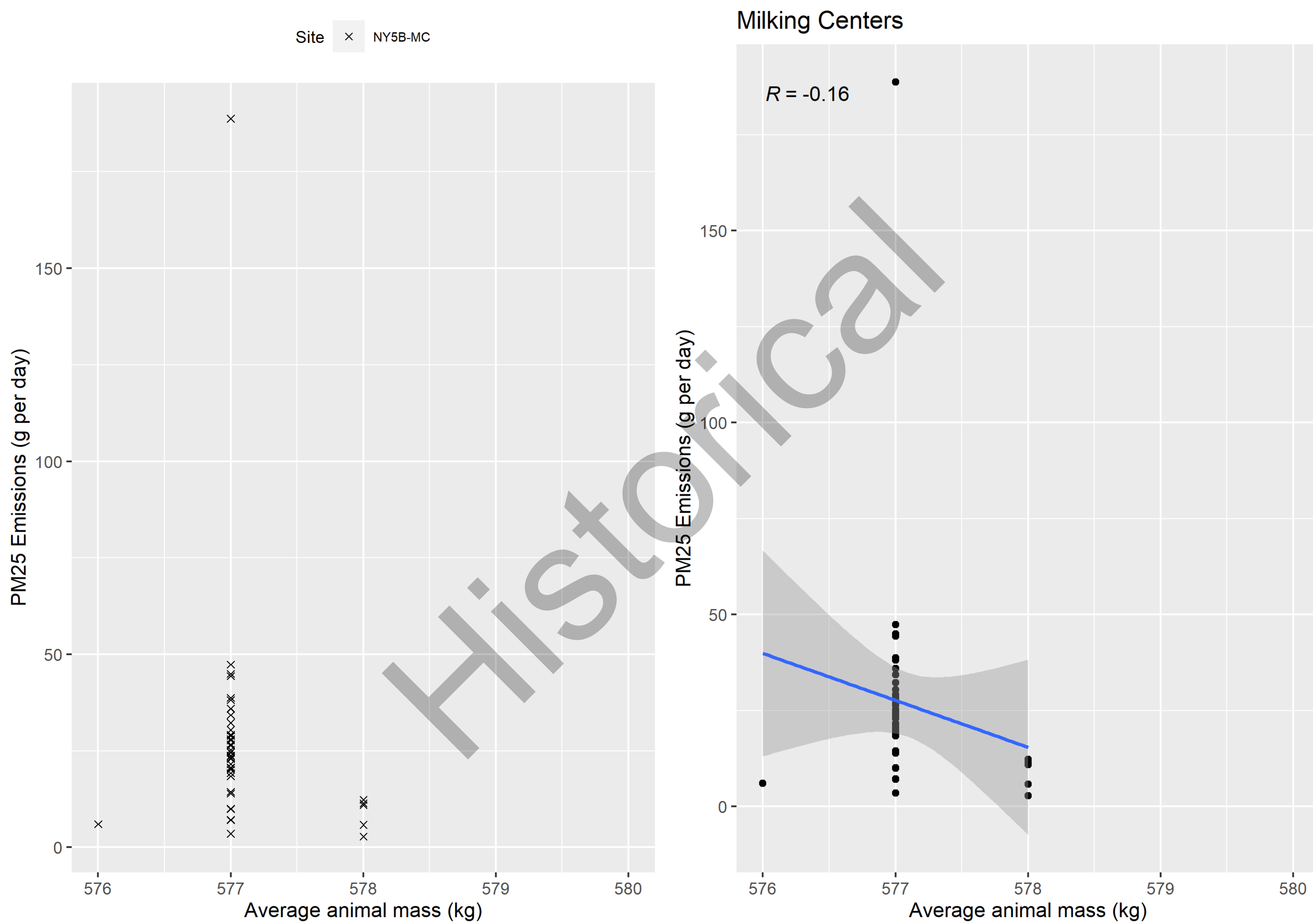


Figure F-49. Scatter plot of milking center $PM_{2.5}$ emissions versus average animal mass and scatter plot with regression.

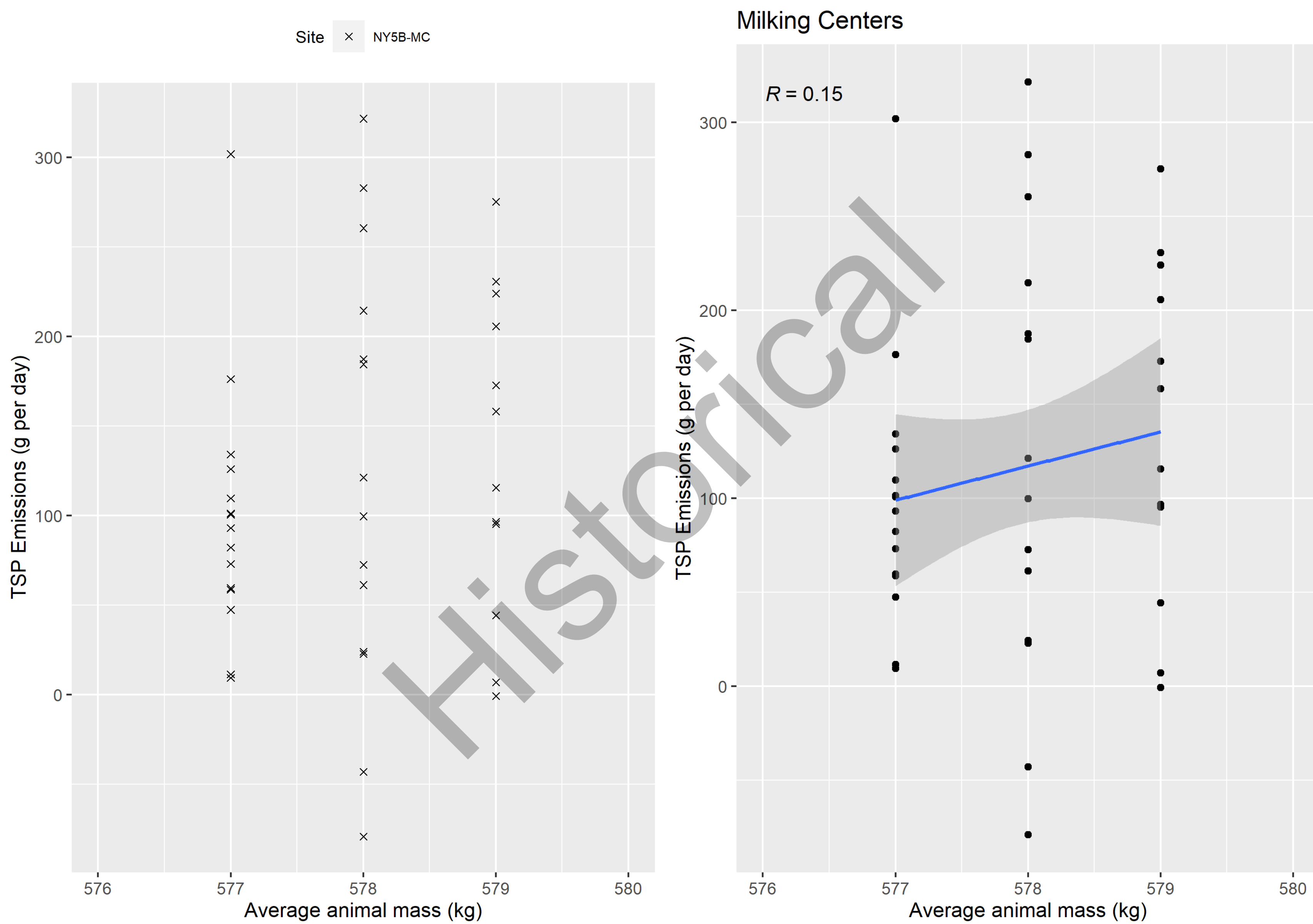


Figure F-50. Scatter plot of milking center TSP emissions versus average animal mass and scatter plot with regression.

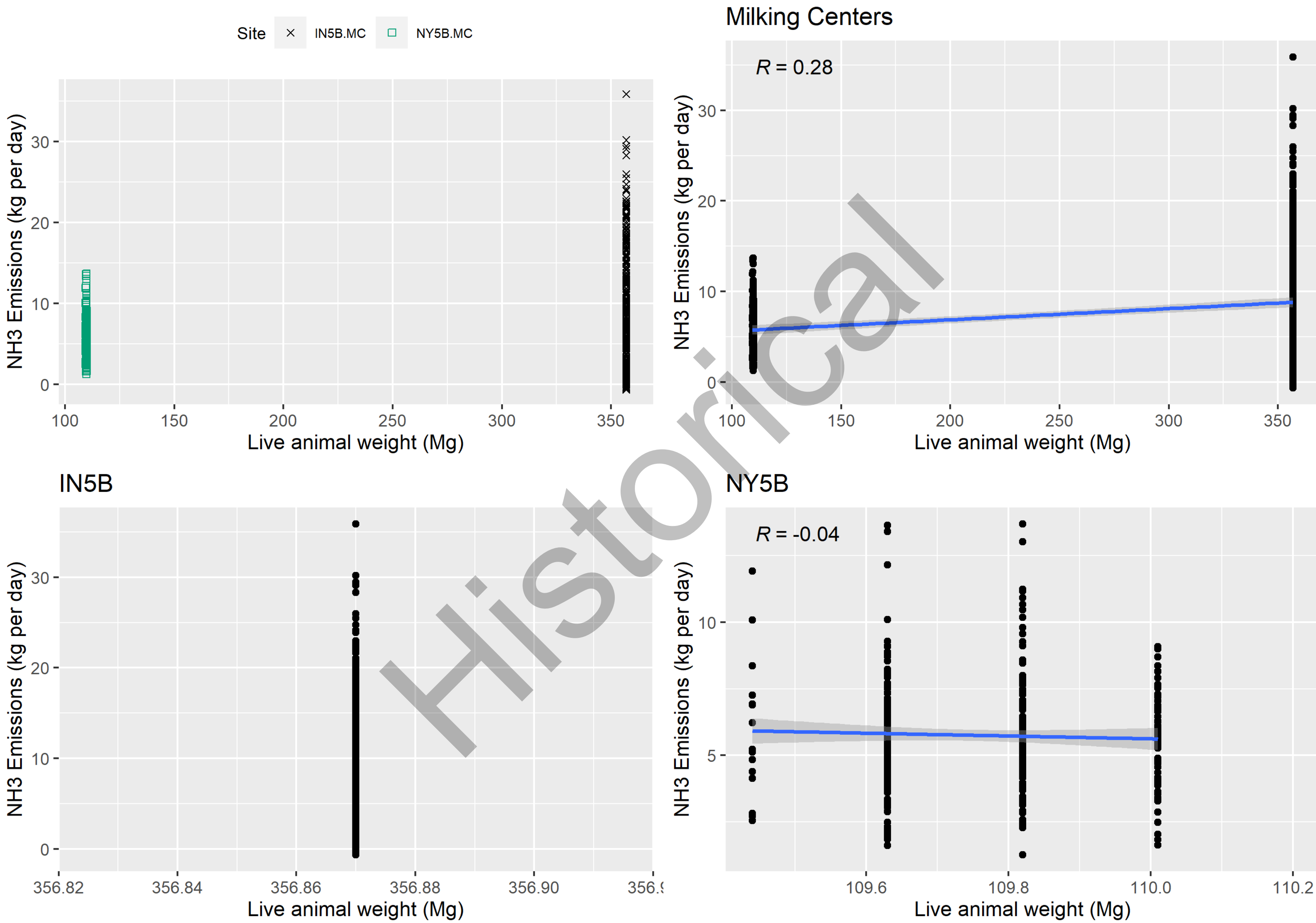


Figure F-51. Scatter plot of milking center NH_3 emissions versus live animal weight and scatter plot with regression.

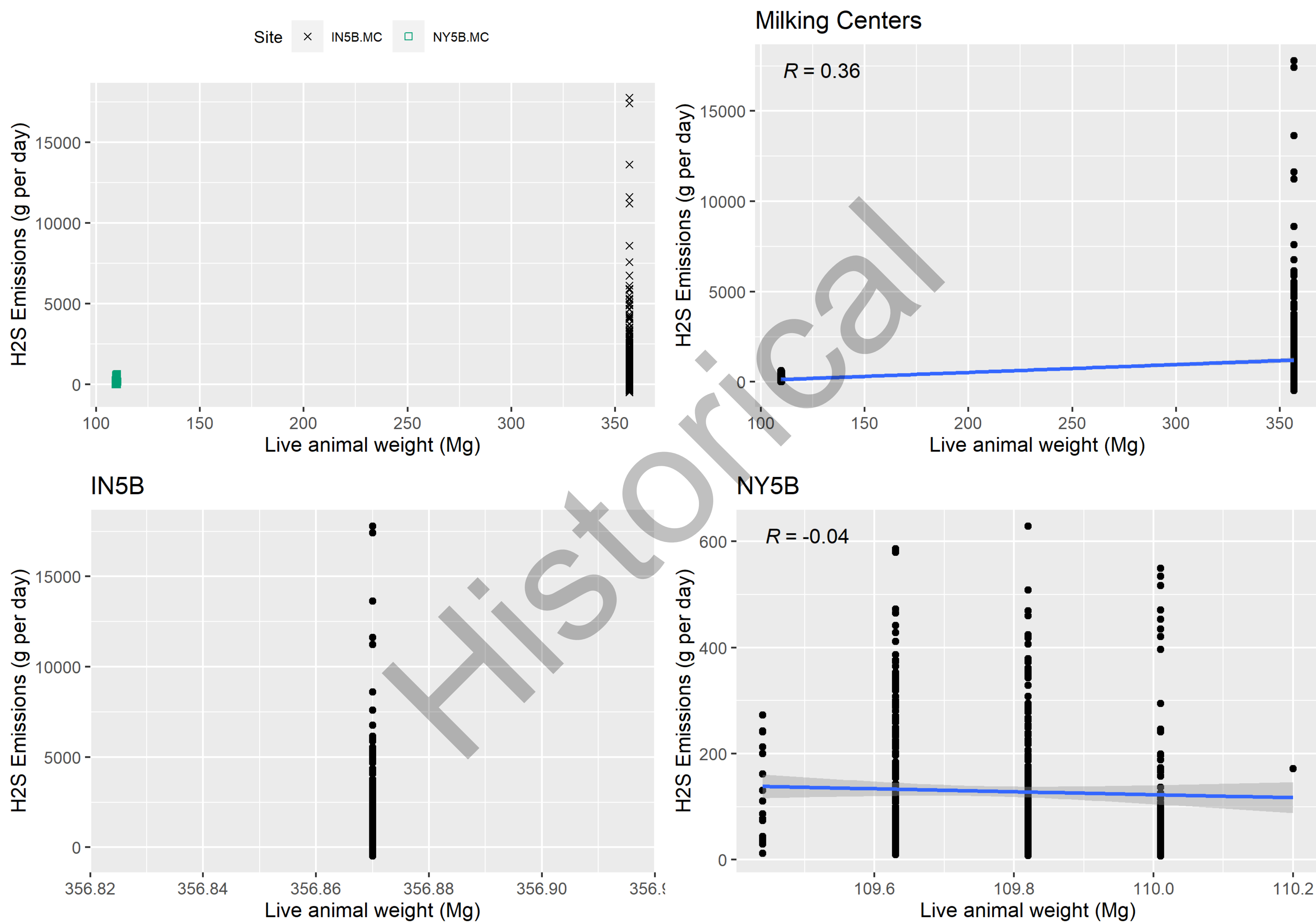


Figure F-52. Scatter plot of milking center H_2S emissions versus live animal weight and scatter plot with regression.

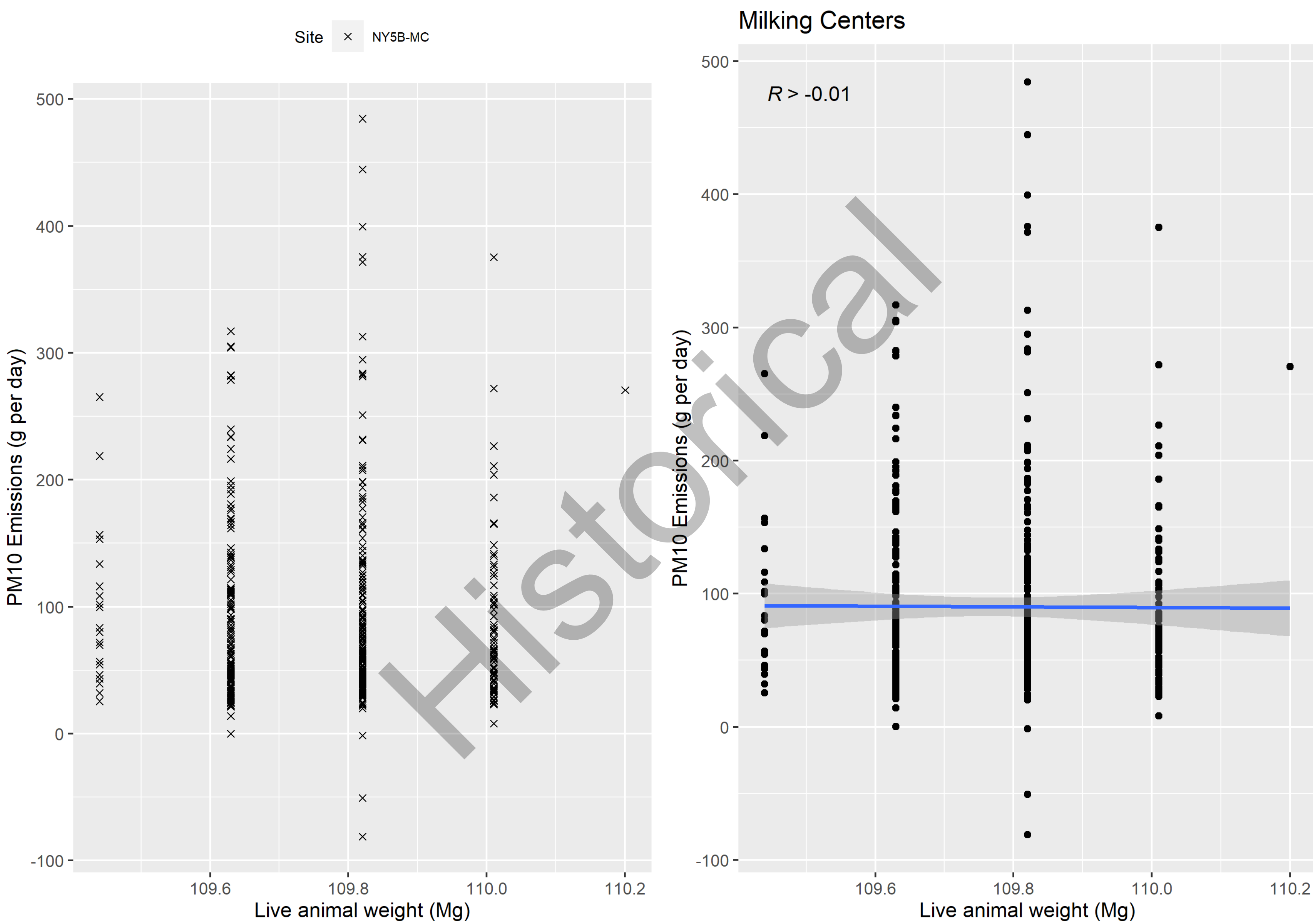


Figure F-53. Scatter plot of milking center PM_{10} emissions versus live animal weight and scatter plot with regression.

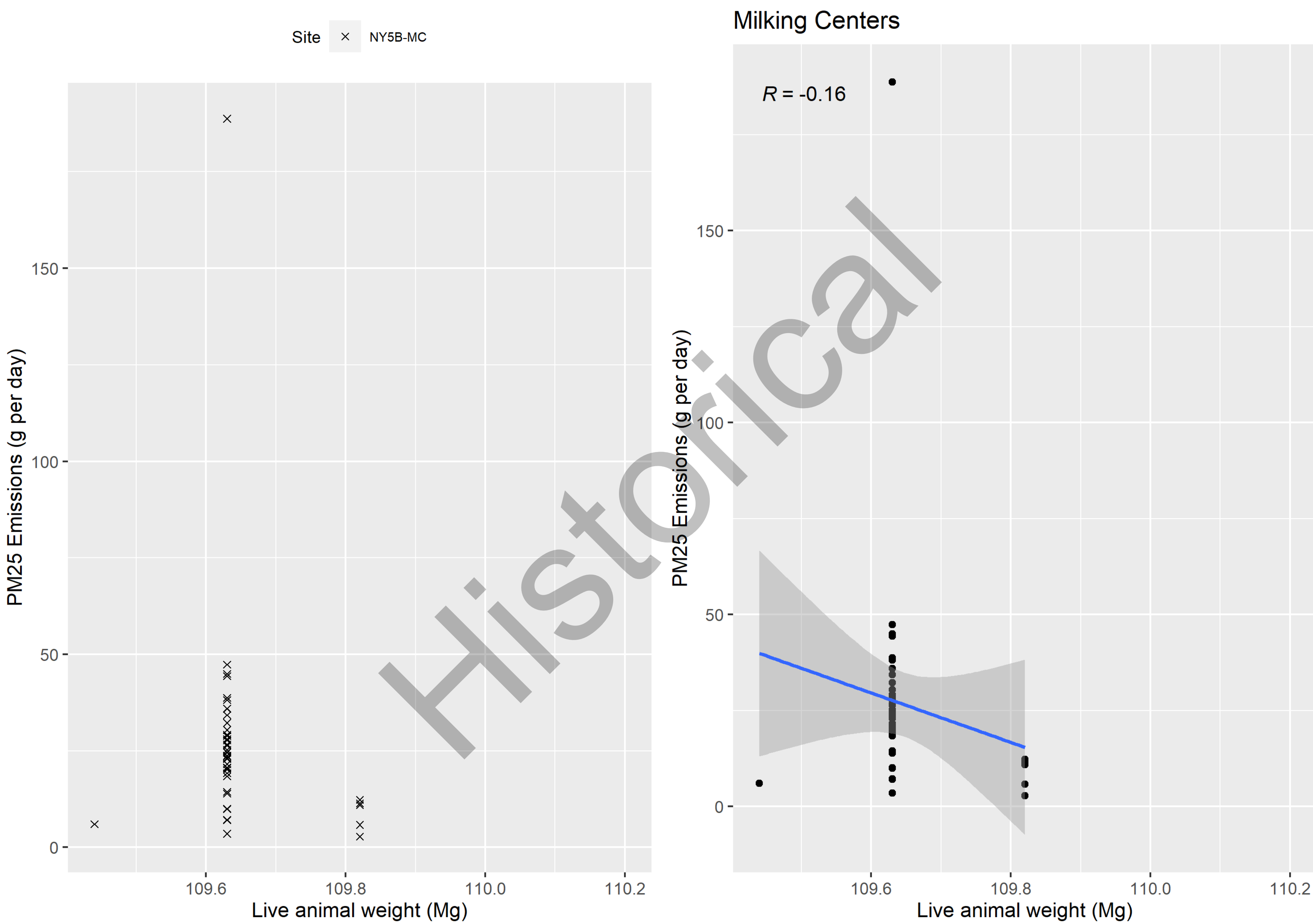


Figure F-54. Scatter plot of milking center $PM_{2.5}$ emissions versus live animal weight and scatter plot with regression.

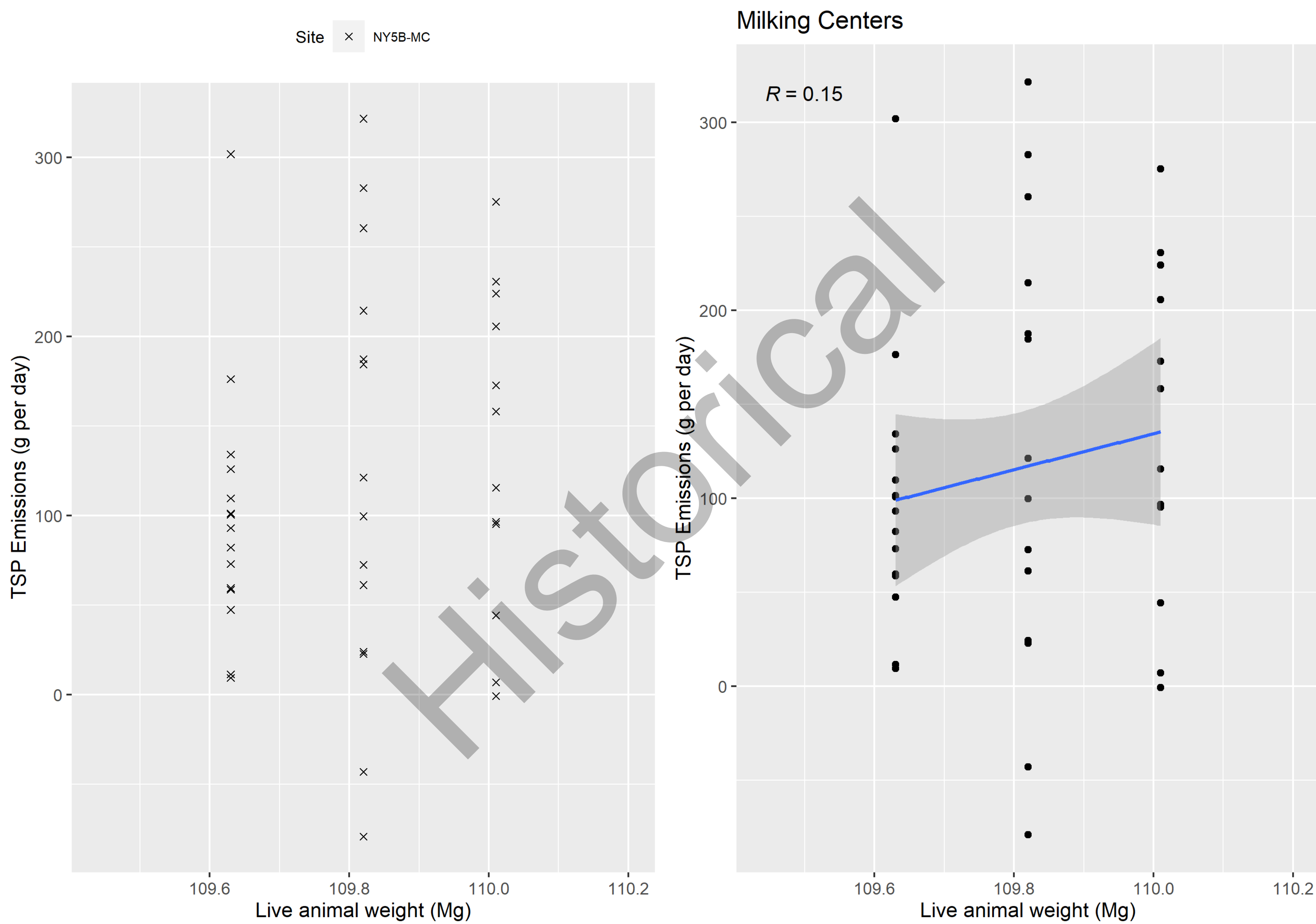


Figure F-55. Scatter plot of milking center TSP emissions versus live animal weight and scatter plot with regression.

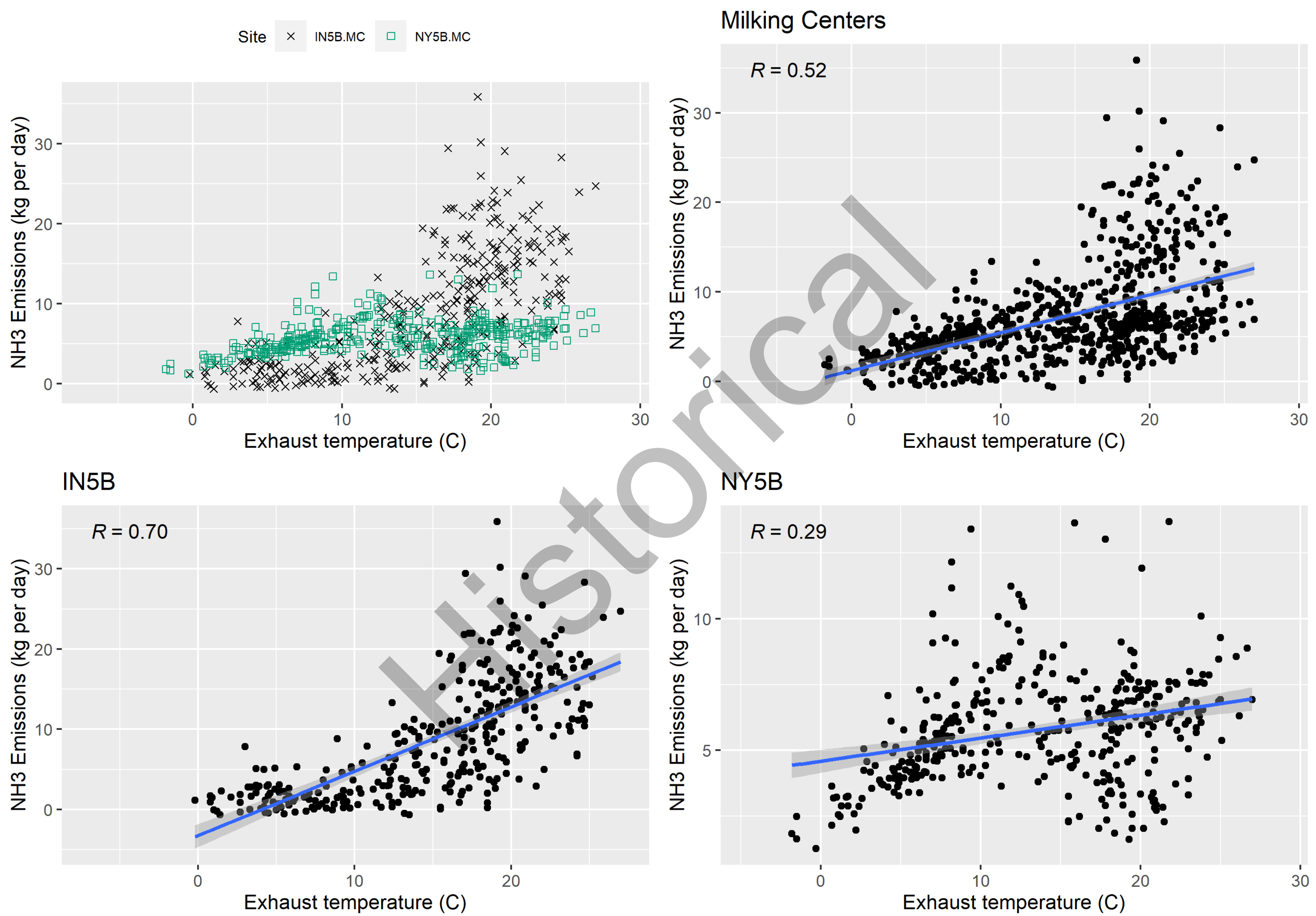


Figure F-56. Scatter plot of milking center NH_3 emissions versus exhaust temperature and scatter plot with regression.

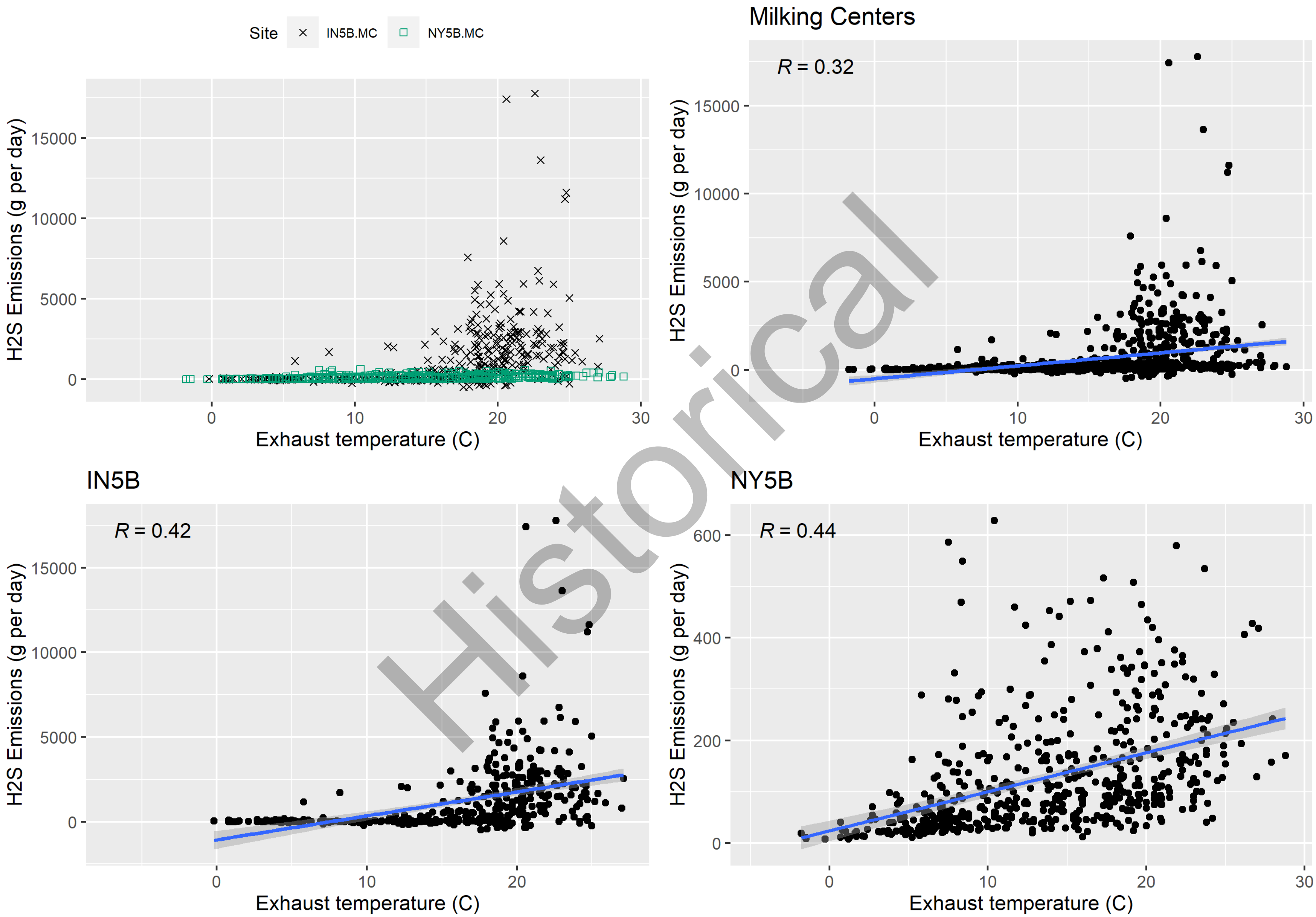


Figure F-57. Scatter plot of milking center H_2S emissions versus exhaust temperature and scatter plot with regression.

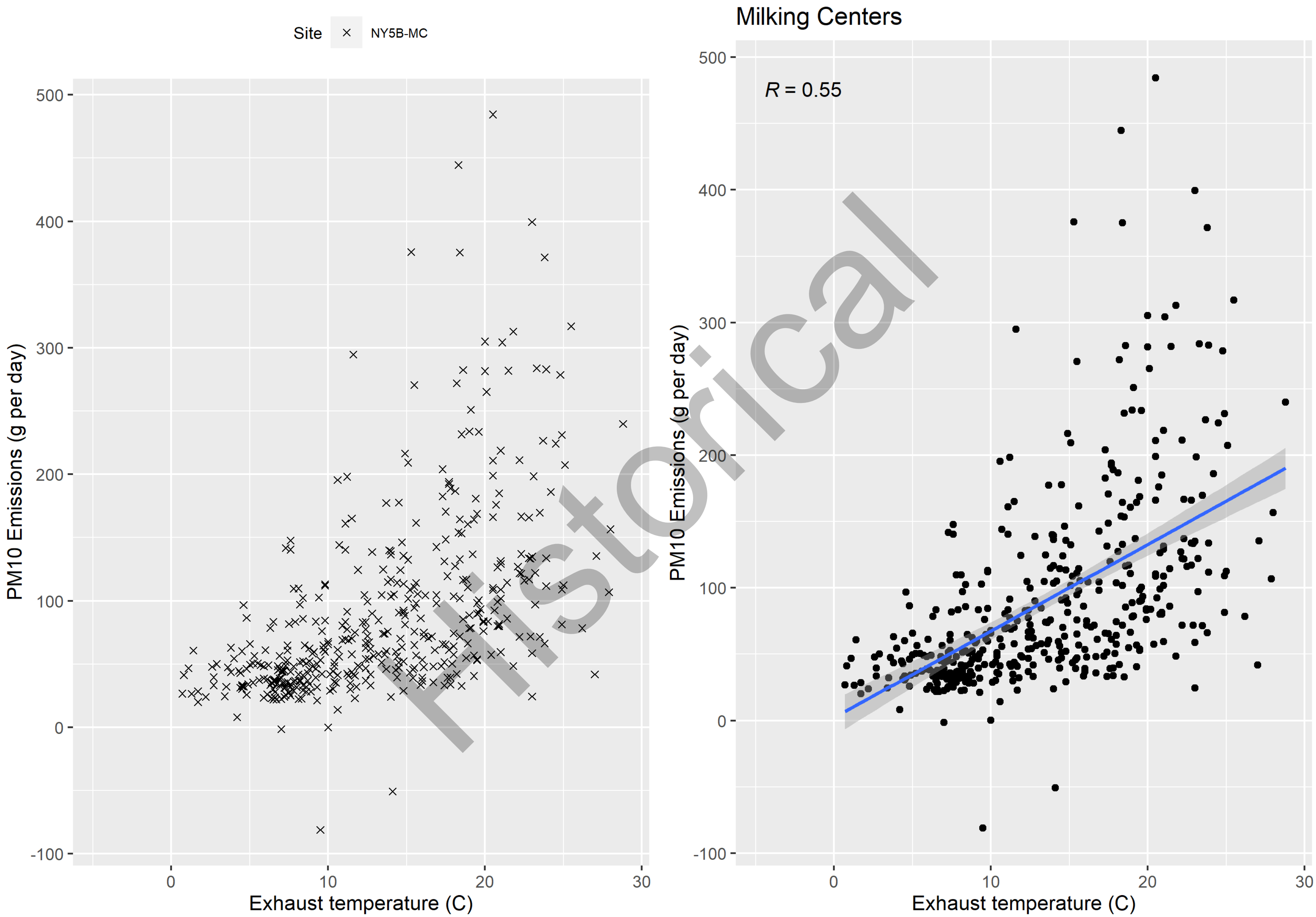


Figure F-58. Scatter plot of milking center PM_{10} emissions versus exhaust temperature and scatter plot with regression.

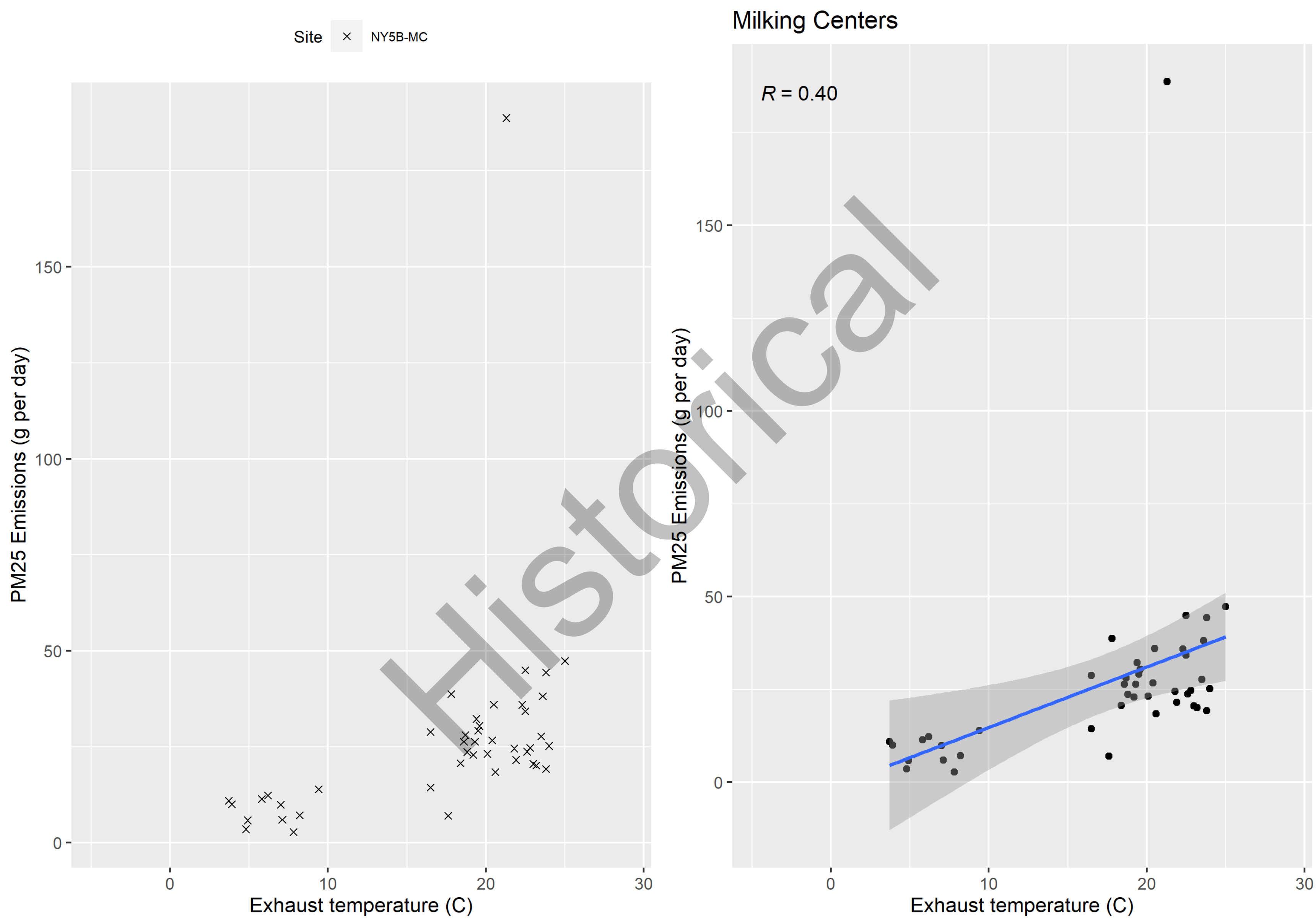


Figure F-59. Scatter plot of milking center $PM_{2.5}$ emissions versus exhaust temperature and scatter plot with regression.

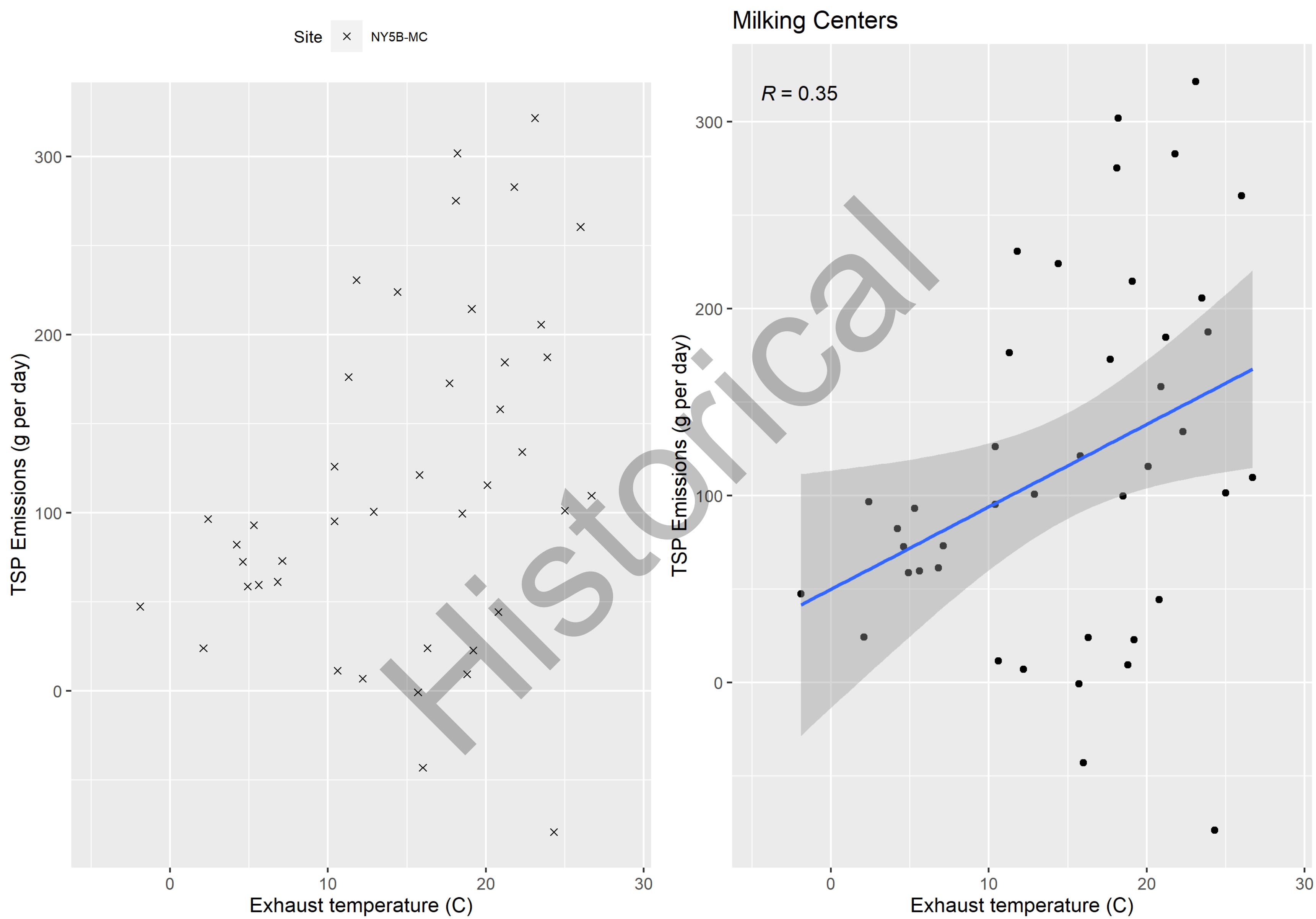


Figure F-60. Scatter plot of milking center TSP emissions versus exhaust temperature and scatter plot with regression.

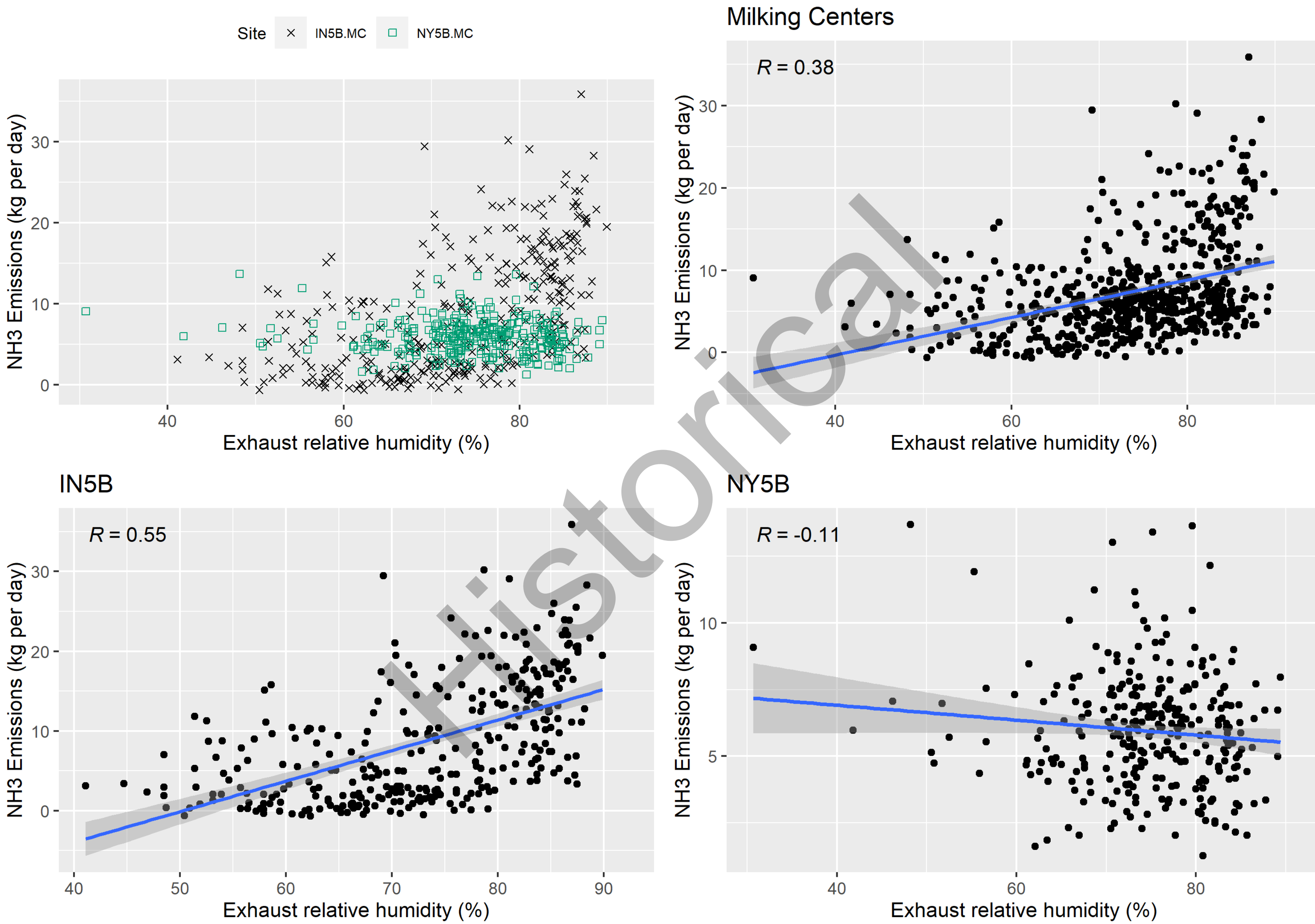


Figure F-61. Scatter plot of milking center NH_3 emissions versus exhaust relative humidity and scatter plot with regression.

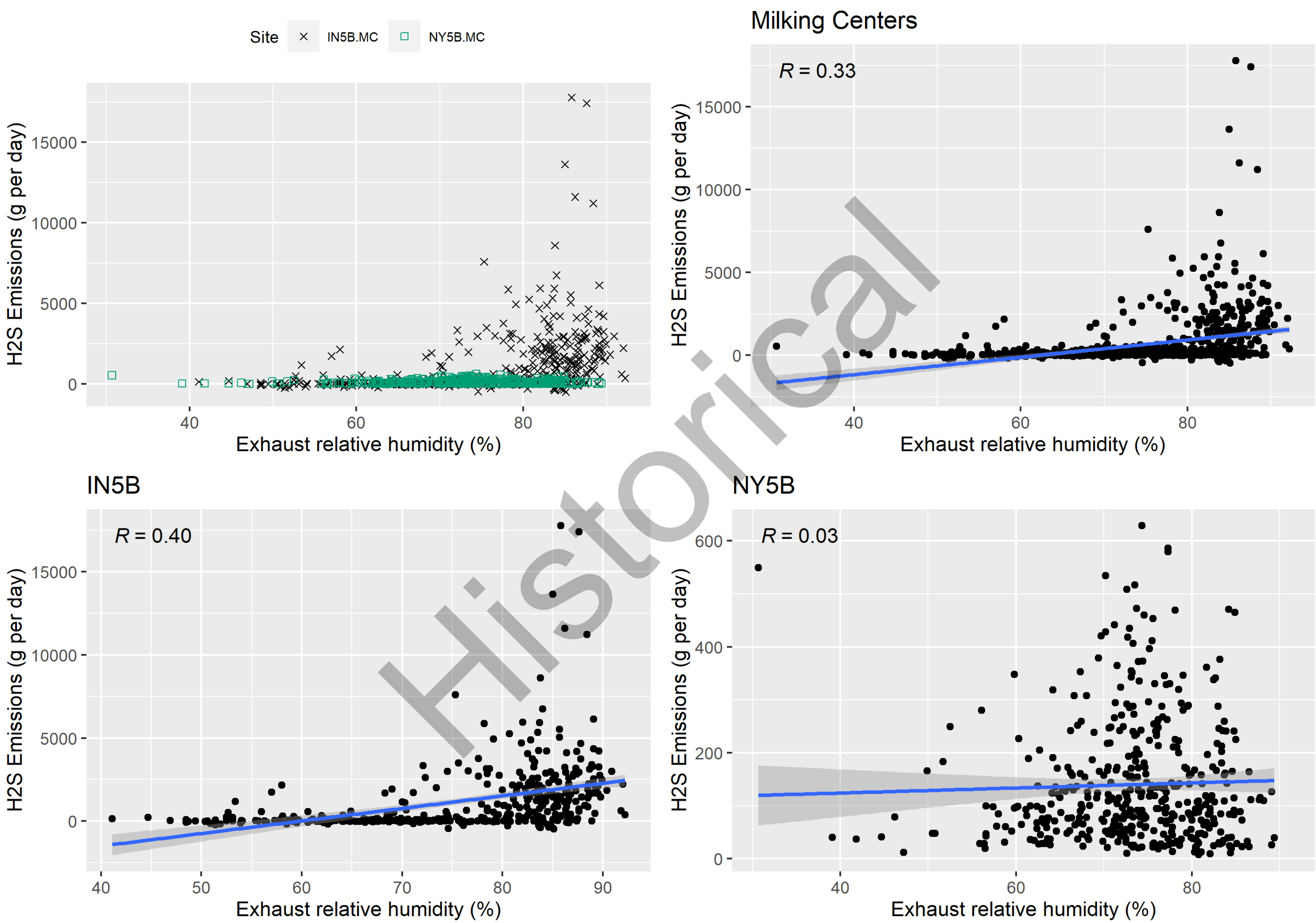


Figure F-62. Scatter plot of milking center H_2S emissions versus exhaust relative humidity and scatter plot with regression.

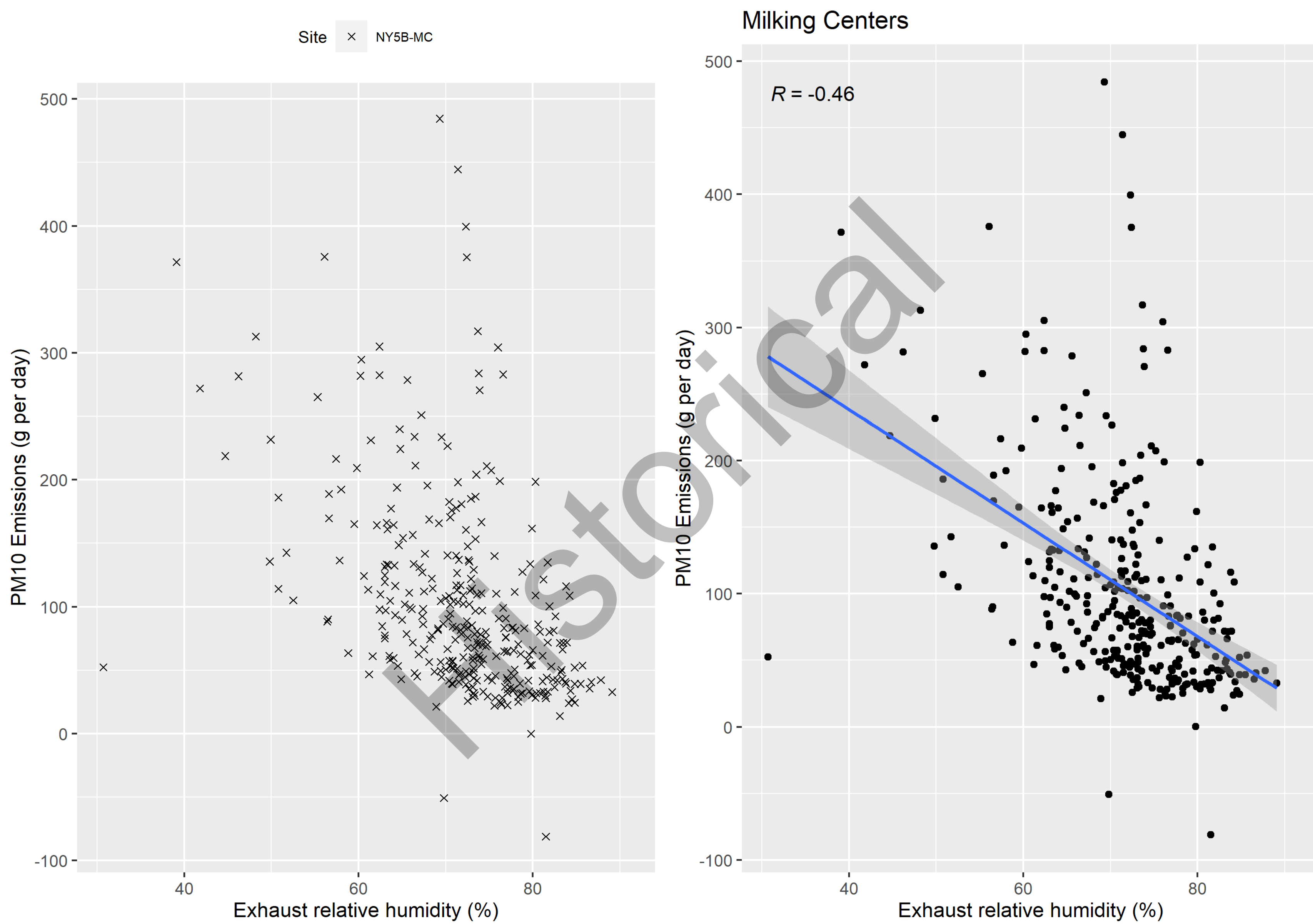


Figure F-63. Scatter plot of milking center PM_{10} emissions versus exhaust relative humidity and scatter plot with regression.

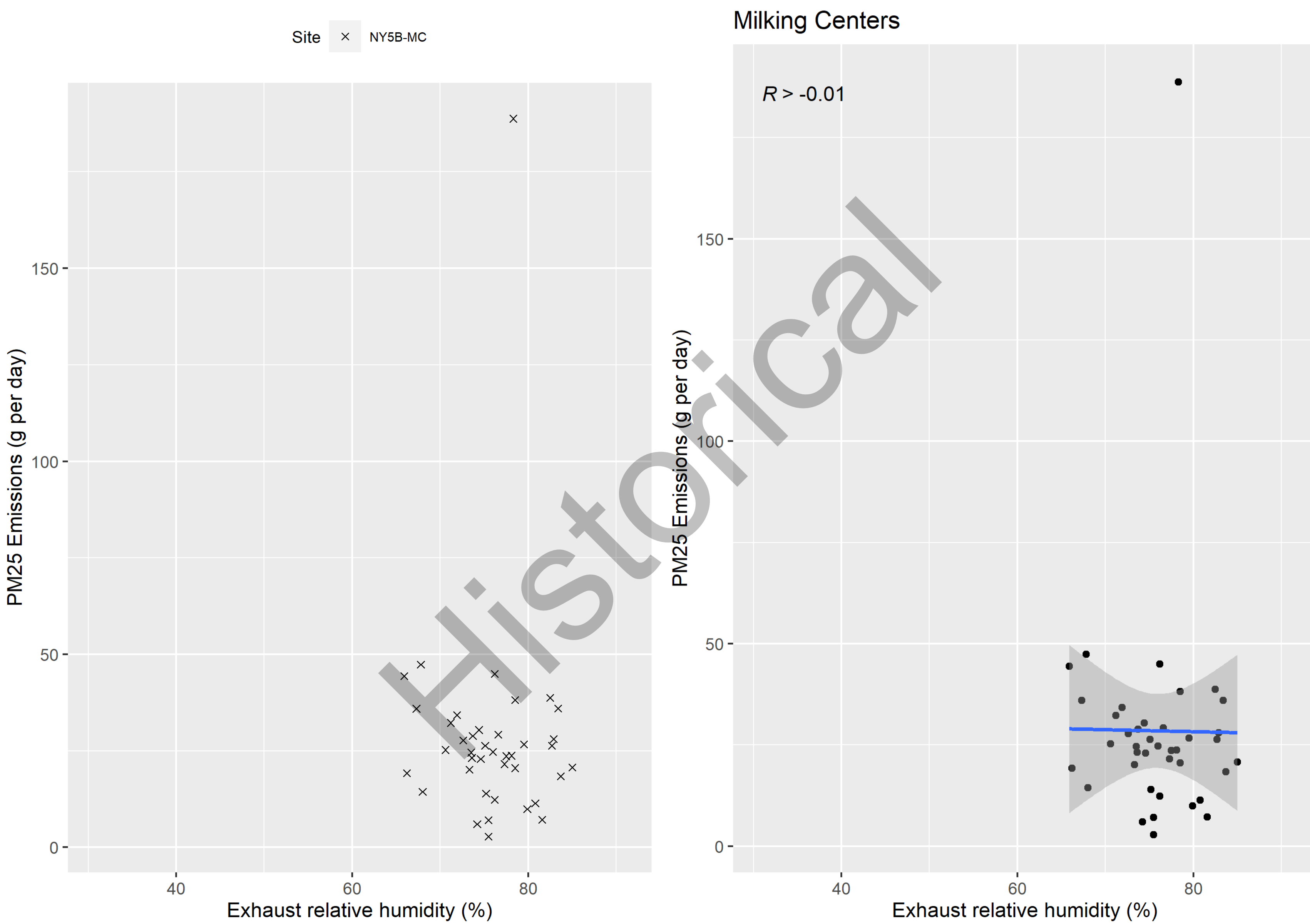


Figure F-64. Scatter plot of milking center $PM_{2.5}$ emissions versus exhaust relative humidity and scatter plot with regression.

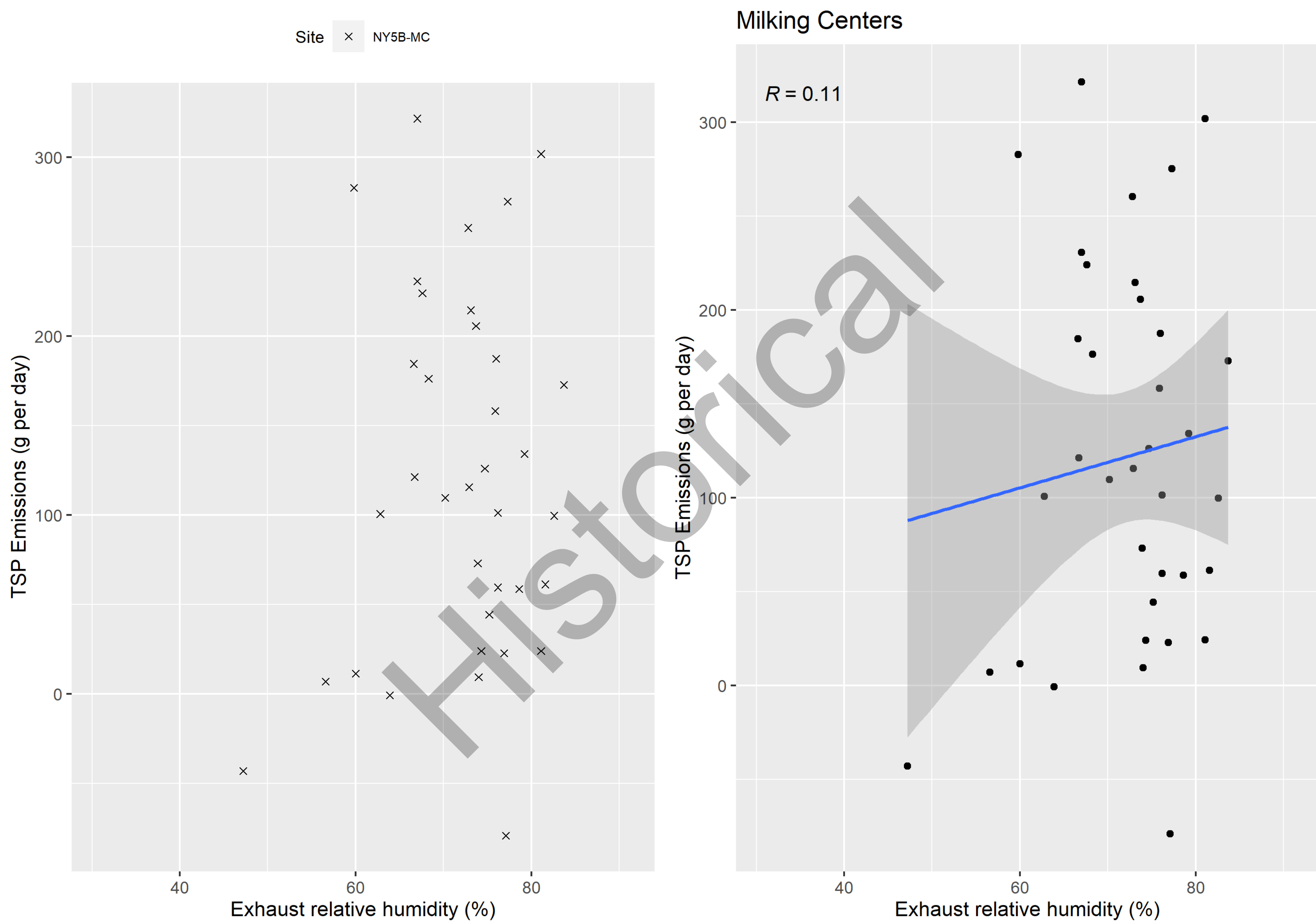


Figure F-65. Scatter plot of milking center TSP emissions versus exhaust relative humidity and scatter plot with regression.

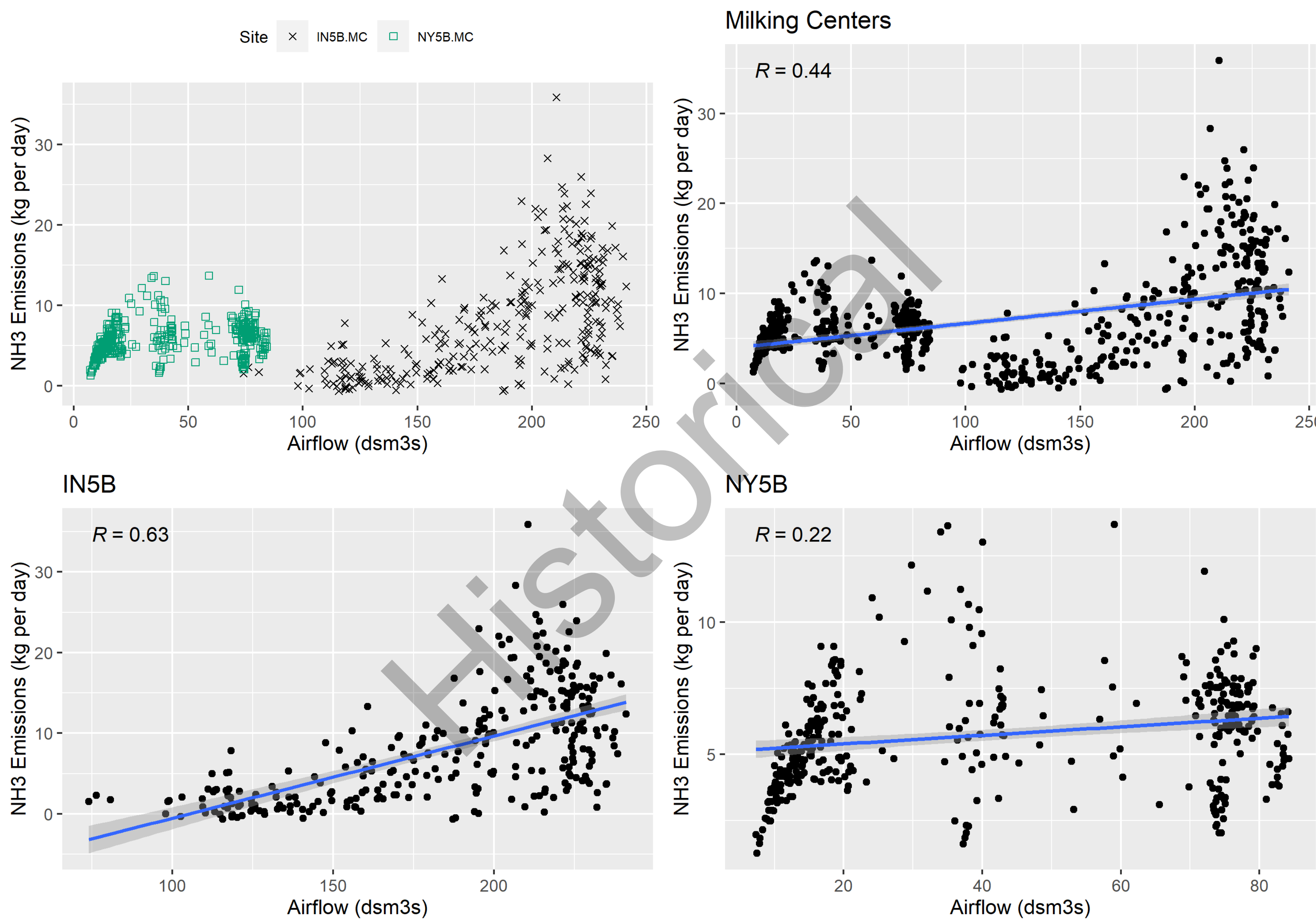


Figure F-66. Scatter plot of milking center NH_3 emissions versus airflow and scatter plot with regression.

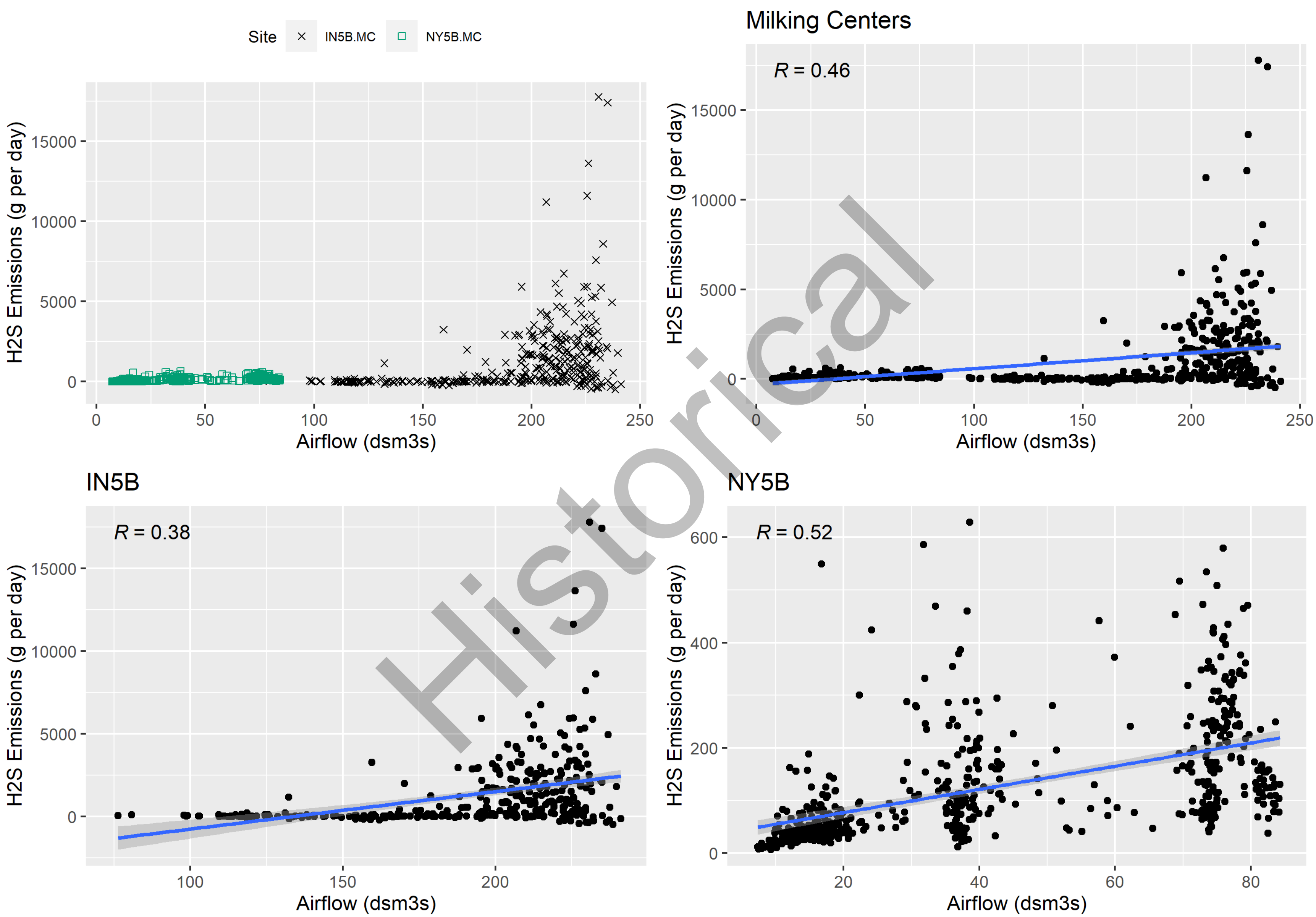


Figure F-67. Scatter plot of milking center H_2S emissions versus airflow and scatter plot with regression.

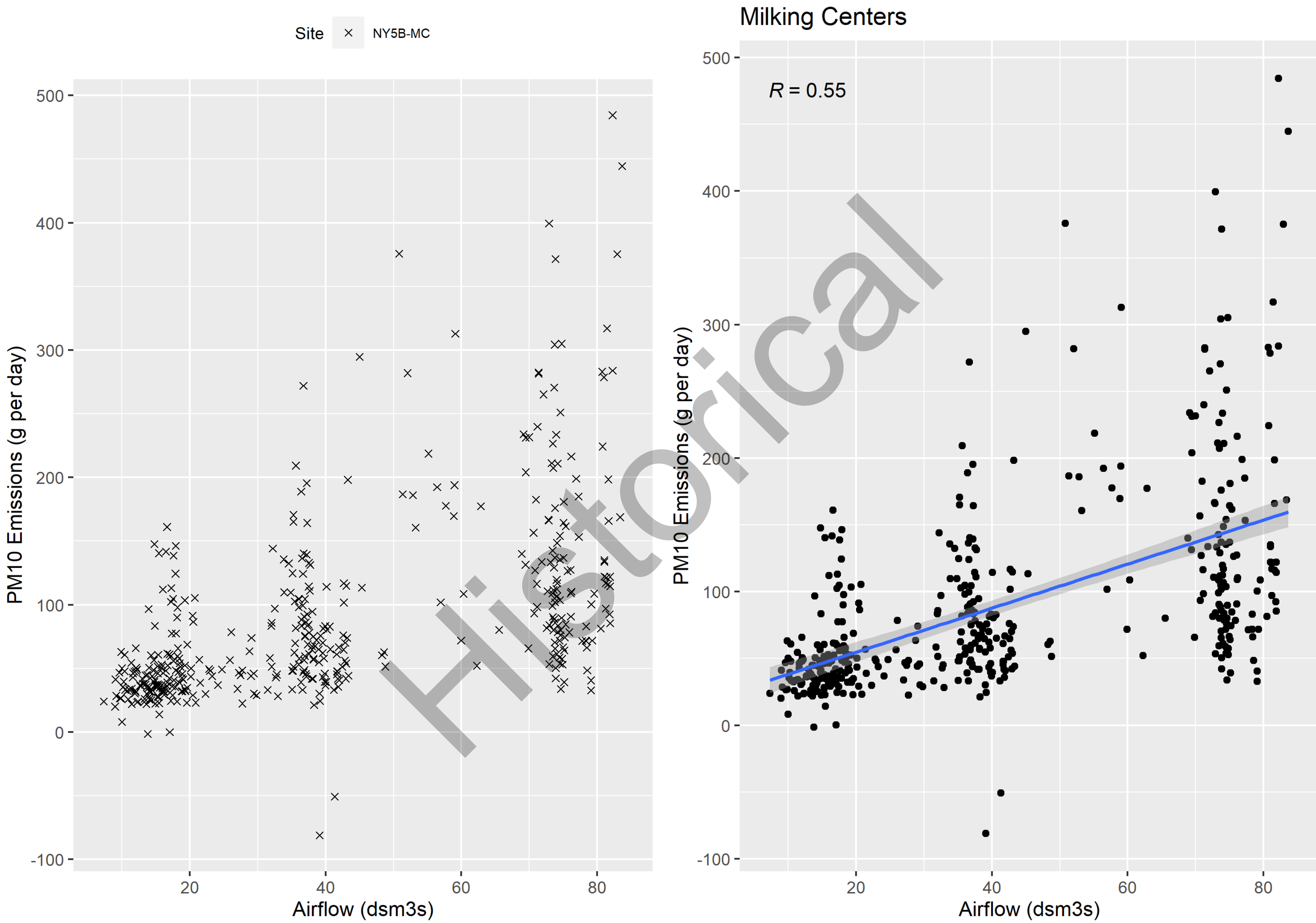


Figure F-68. Scatter plot of milking center PM_{10} emissions versus airflow and scatter plot with regression.

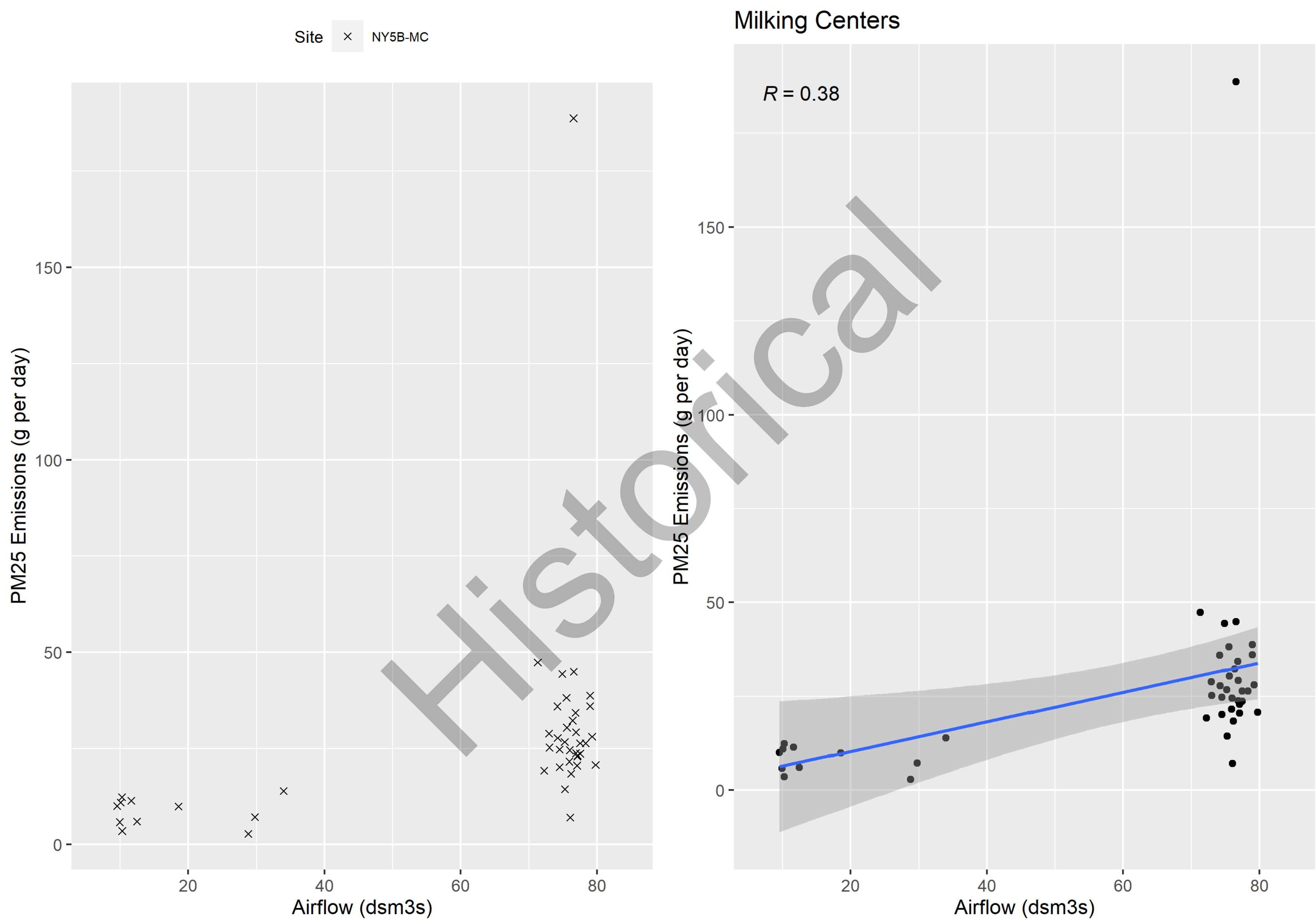


Figure F-69. Scatter plot of milking center $PM_{2.5}$ emissions versus airflow and scatter plot with regression.

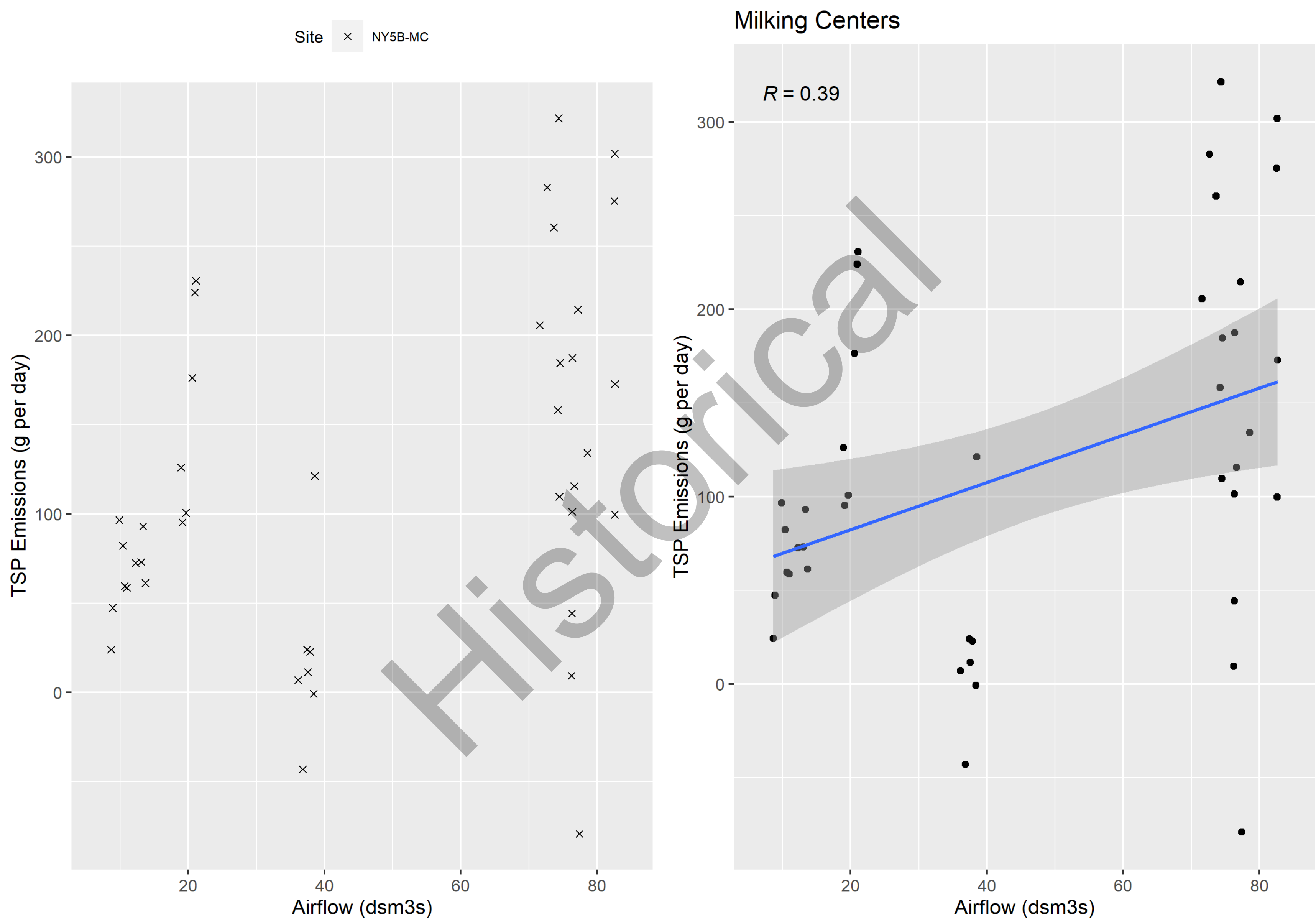


Figure F-70. Scatter plot of milking center TSP emissions versus airflow and scatter plot with regression.

F.2.2 Ambient Parameters

Table F-5. Summary of milking center barn R^2 values for ambient parameters.

Pollutant	Parameter	R	R^2	Strength	Figure
NH_3	Ambient temperature	0.495	0.245	modest	F-71
H_2S	Ambient temperature	0.296	0.088	slight or weak	F-72
PM_{10}	Ambient temperature	0.568	0.323	modest	F-73
$PM_{2.5}$	Ambient temperature	0.399	0.159	slight or weak	F-74
TSP	Ambient temperature	0.348	0.121	slight or weak	F-75
NH_3	Ambient relative humidity	-0.043	0.002	slight or weak	F-76
H_2S	Ambient relative humidity	0.039	0.002	slight or weak	F-77
PM_{10}	Ambient relative humidity	-0.421	0.178	slight or weak	F-78
$PM_{2.5}$	Ambient relative humidity	0.043	0.002	slight or weak	F-79
TSP	Ambient relative humidity	0.066	0.004	slight or weak	F-80

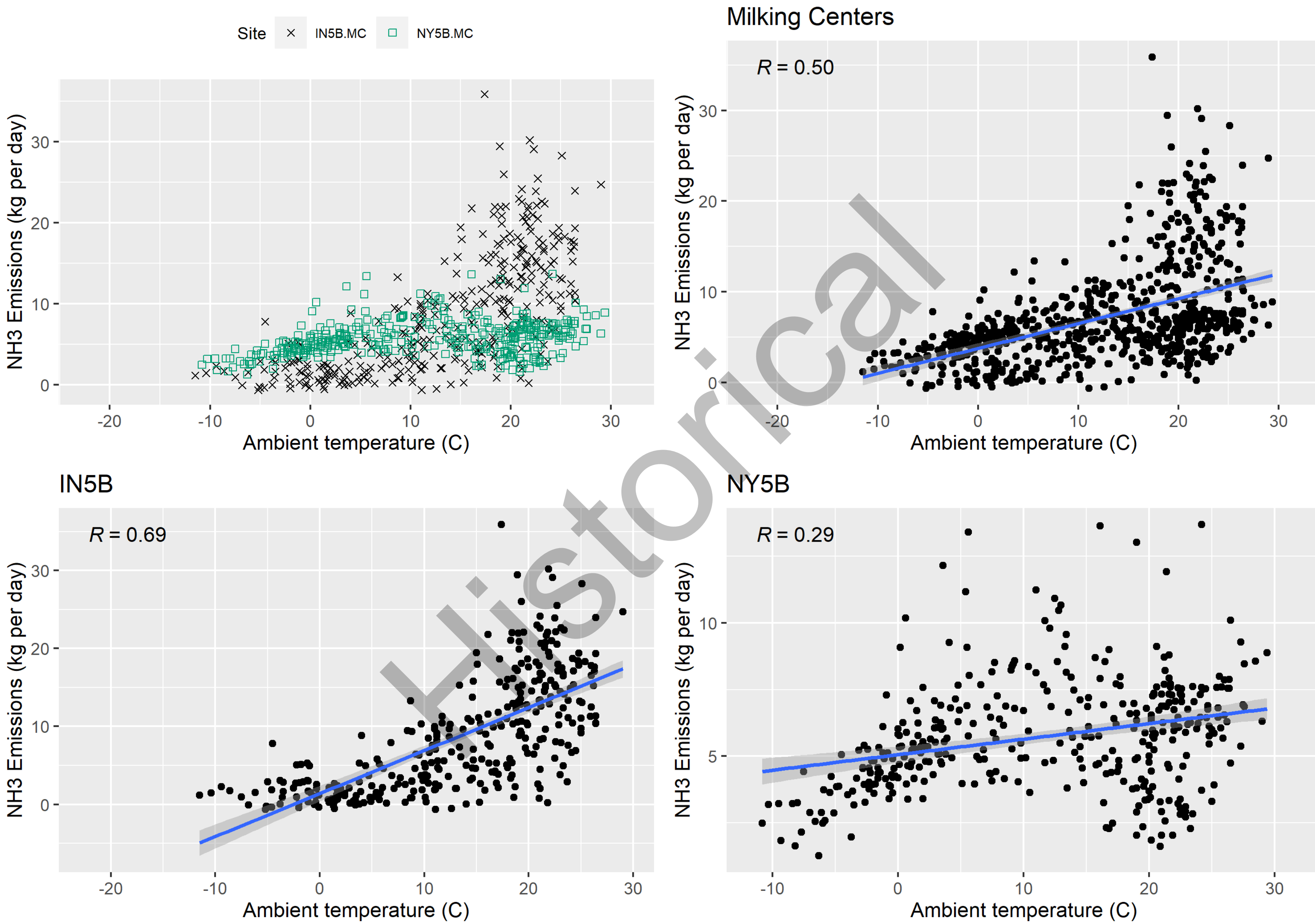


Figure F-71. Scatter plot of milking center NH_3 emissions versus ambient temperature and scatter plot with regression.

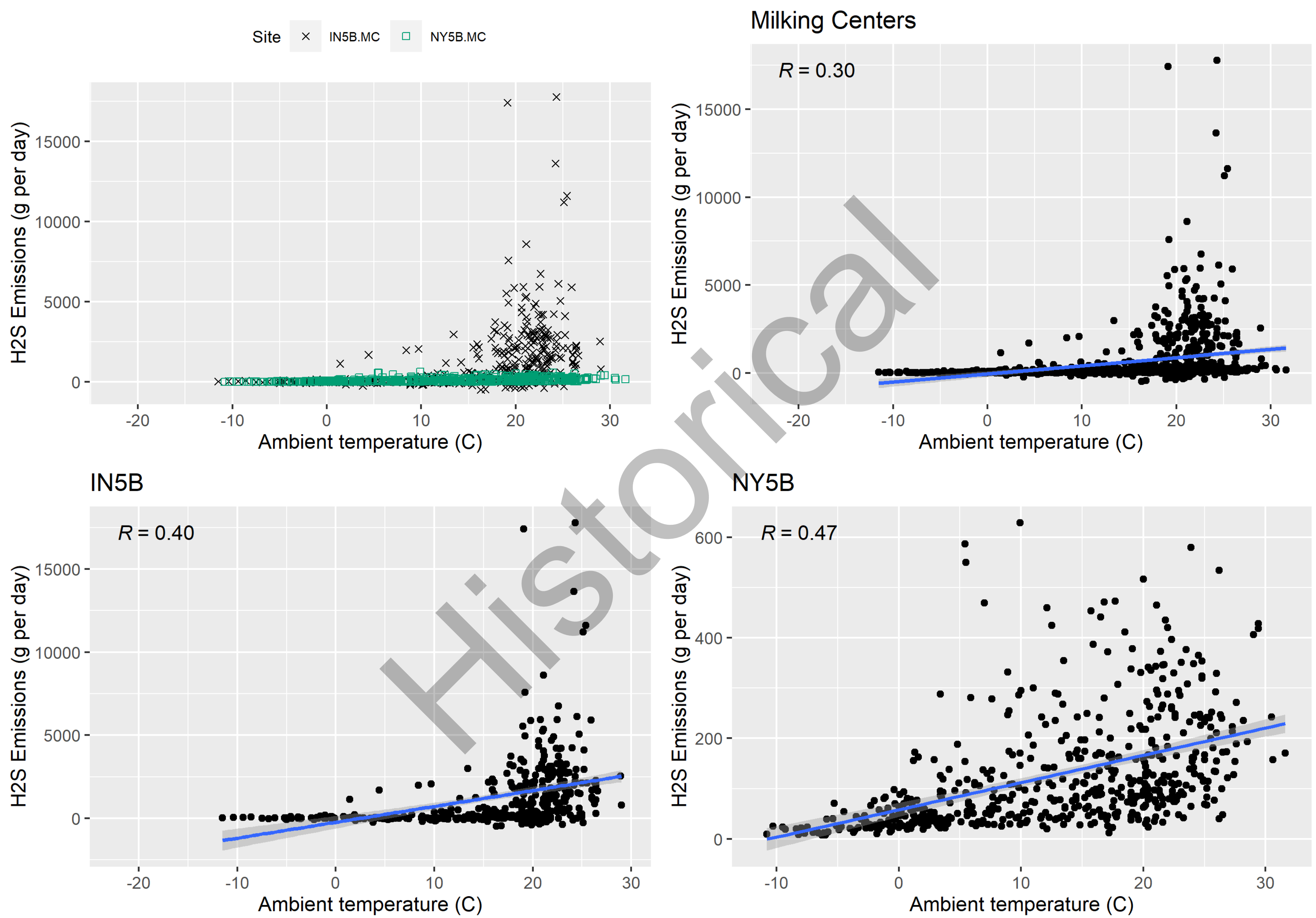


Figure F-72. Scatter plot of milking center H_2S emissions versus ambient temperature and scatter plot with regression.

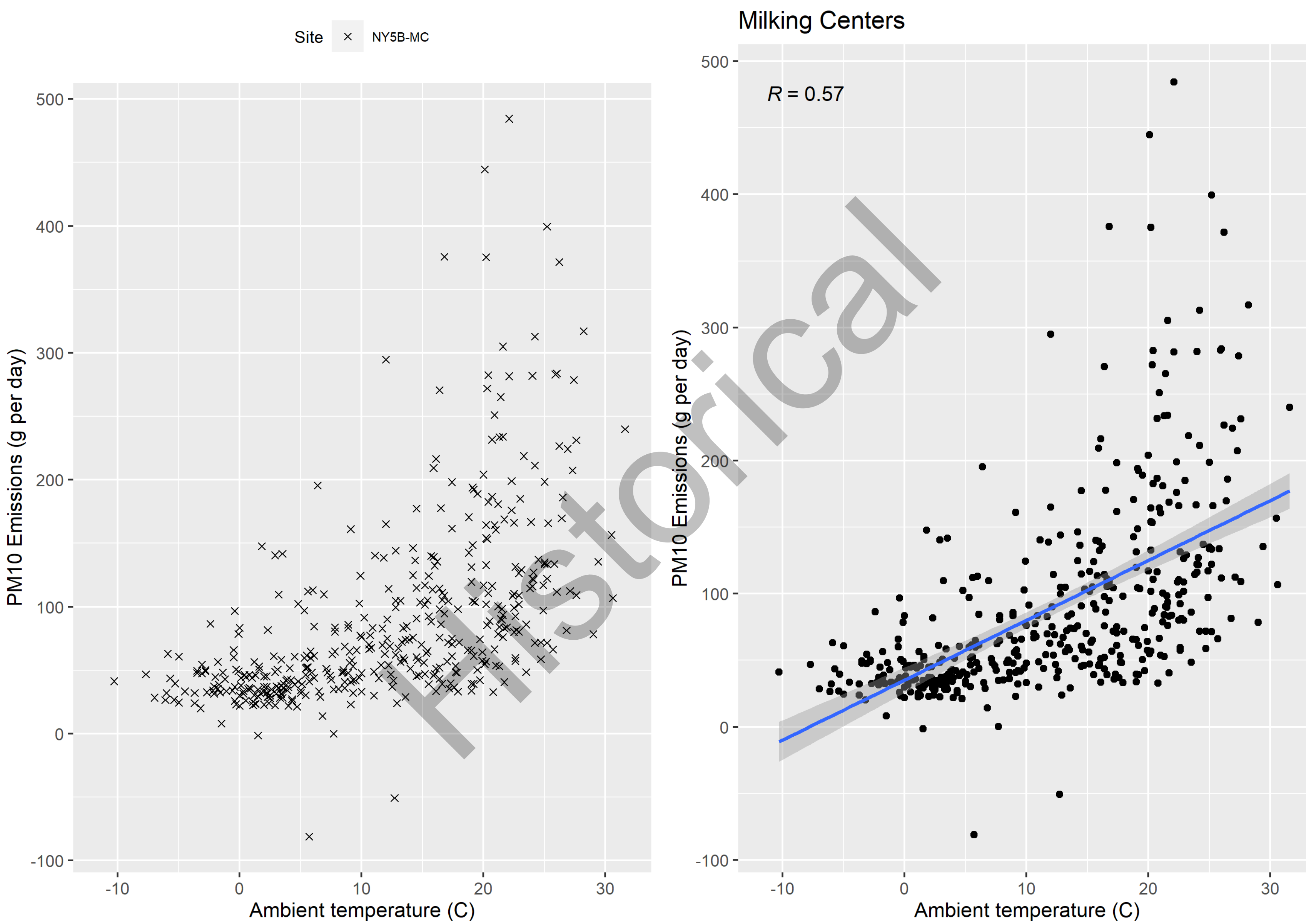


Figure F-73. Scatter plot of milking center PM_{10} emissions versus ambient temperature and scatter plot with regression.

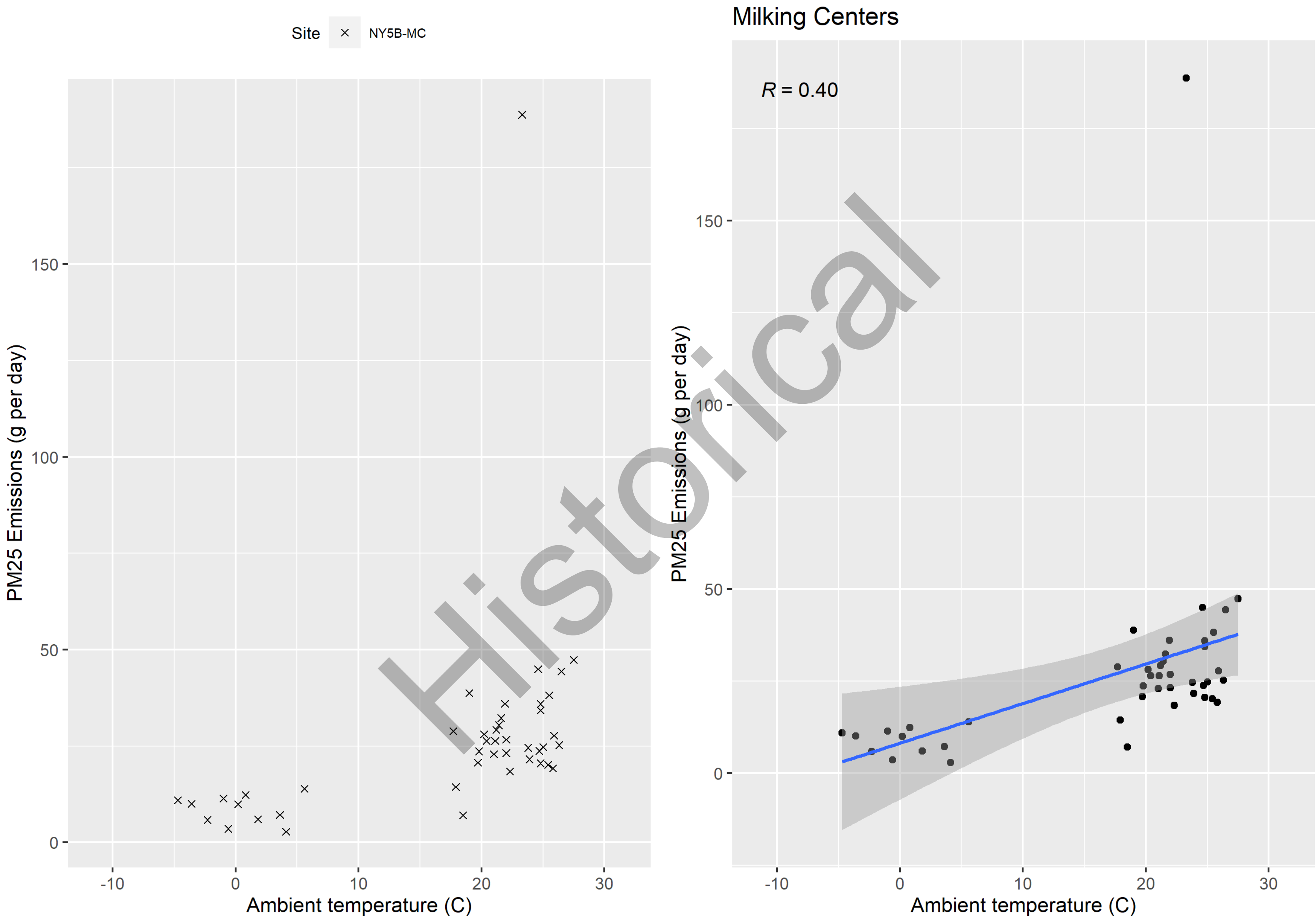


Figure F-74. Scatter plot of milking center $PM_{2.5}$ emissions versus ambient temperature and scatter plot with regression.

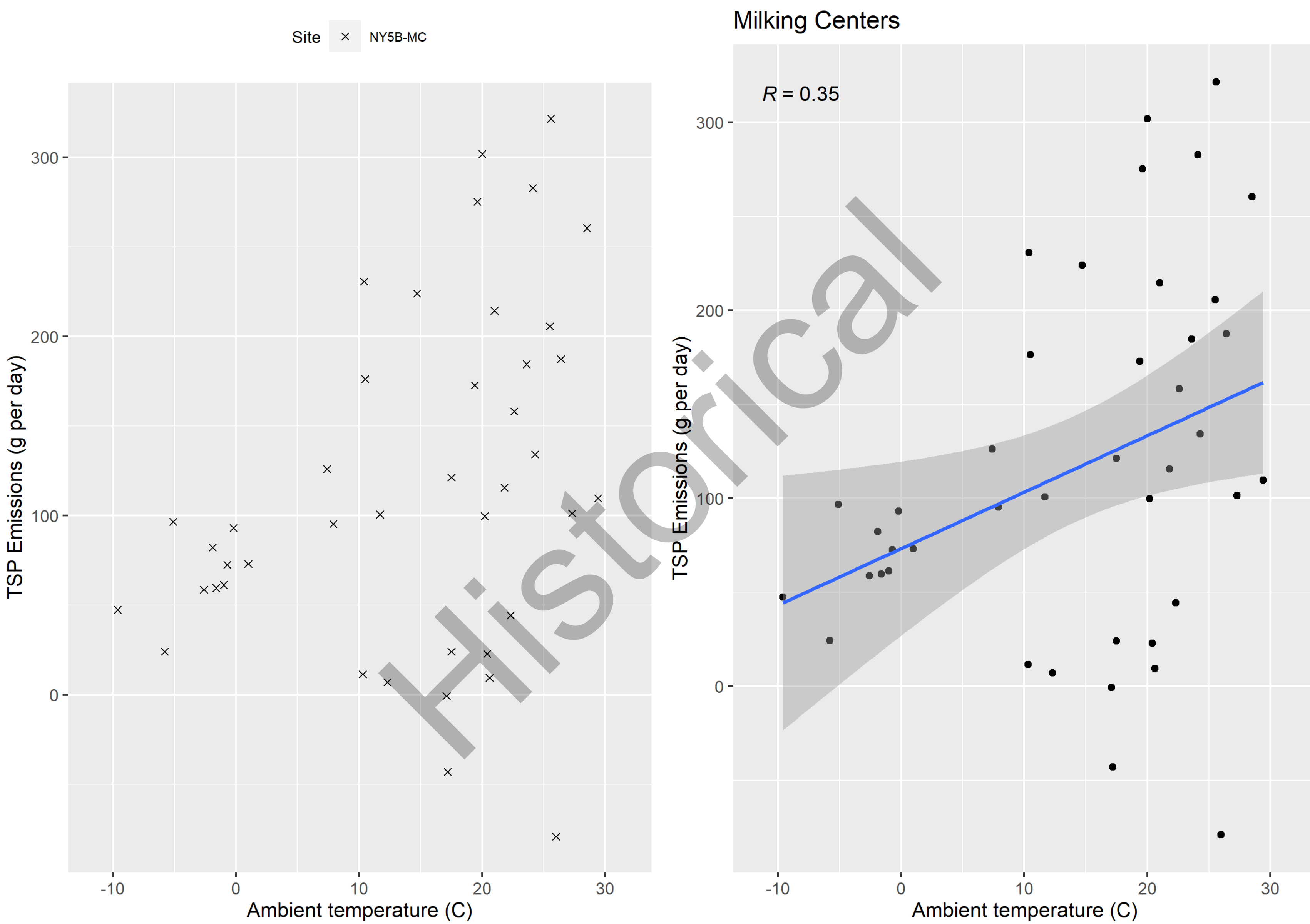


Figure F-75. Scatter plot of milking center TSP emissions versus ambient temperature and scatter plot with regression.

Figure F-76. Scatter plot of milking center NH_3 emissions versus ambient relative humidity and scatter plot with regression.

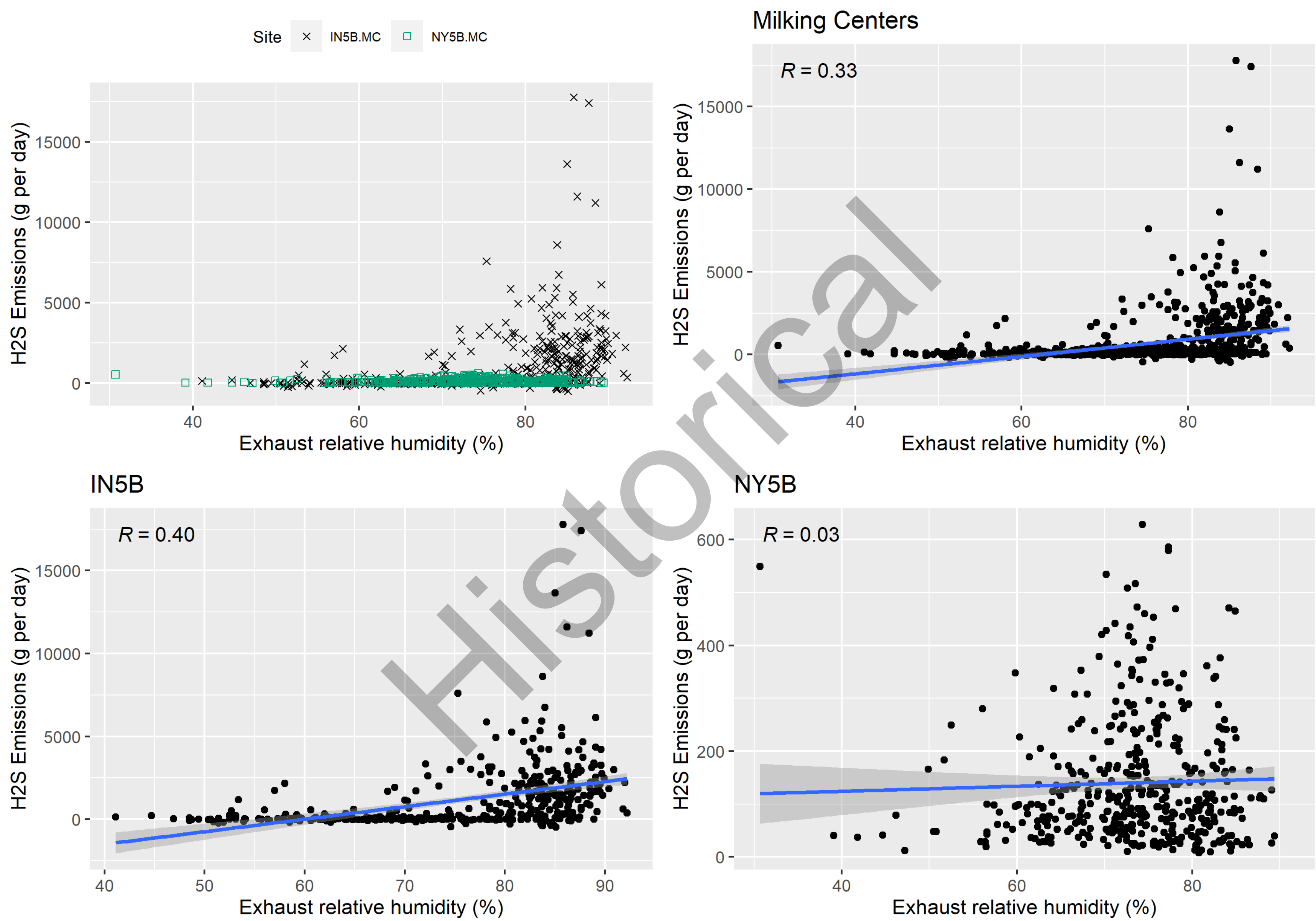


Figure F-77. Scatter plot of milking center H_2S emissions versus ambient relative humidity and scatter plot with regression.

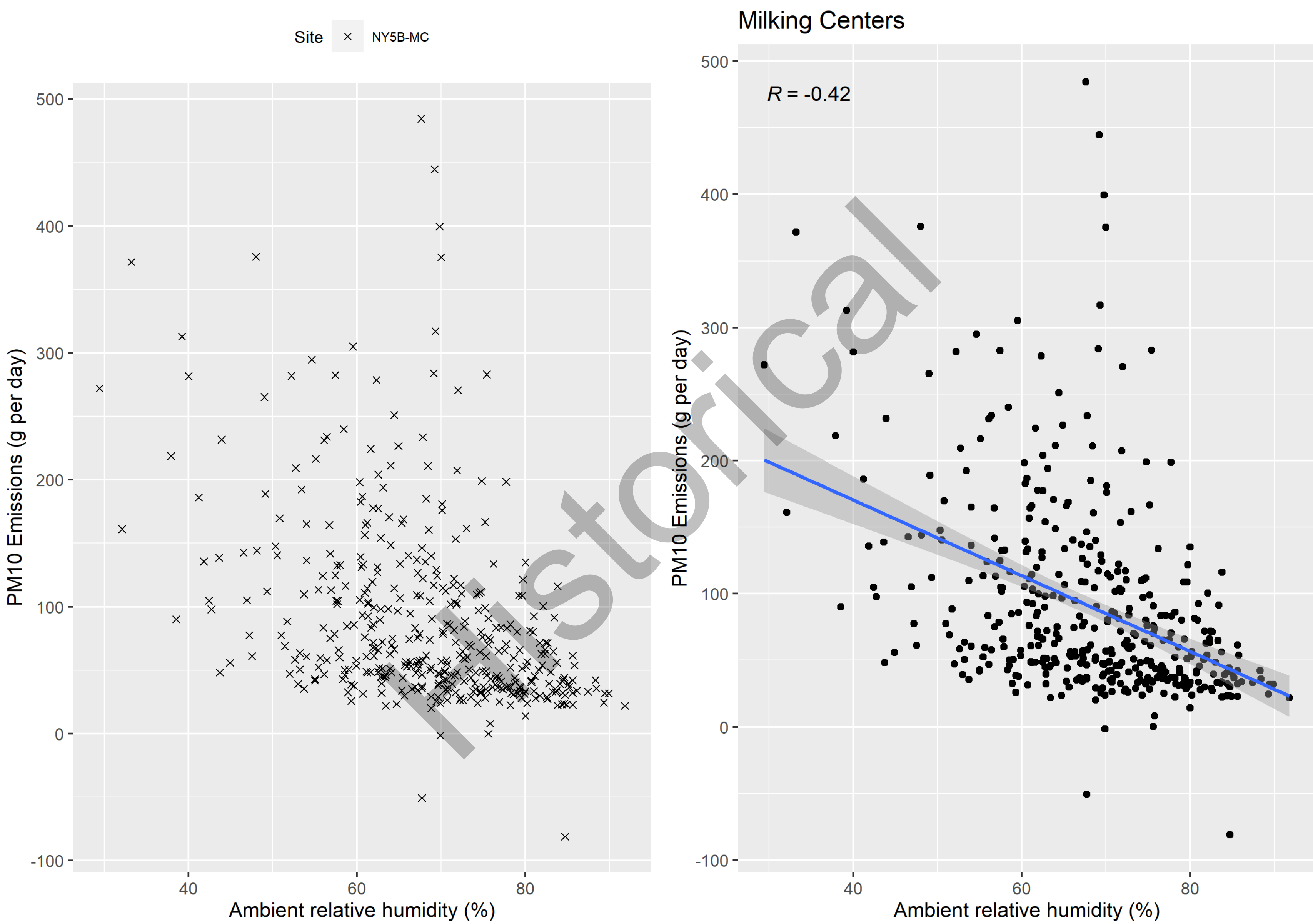


Figure F-78. Scatter plot of milking center PM_{10} emissions versus ambient relative humidity and scatter plot with regression.

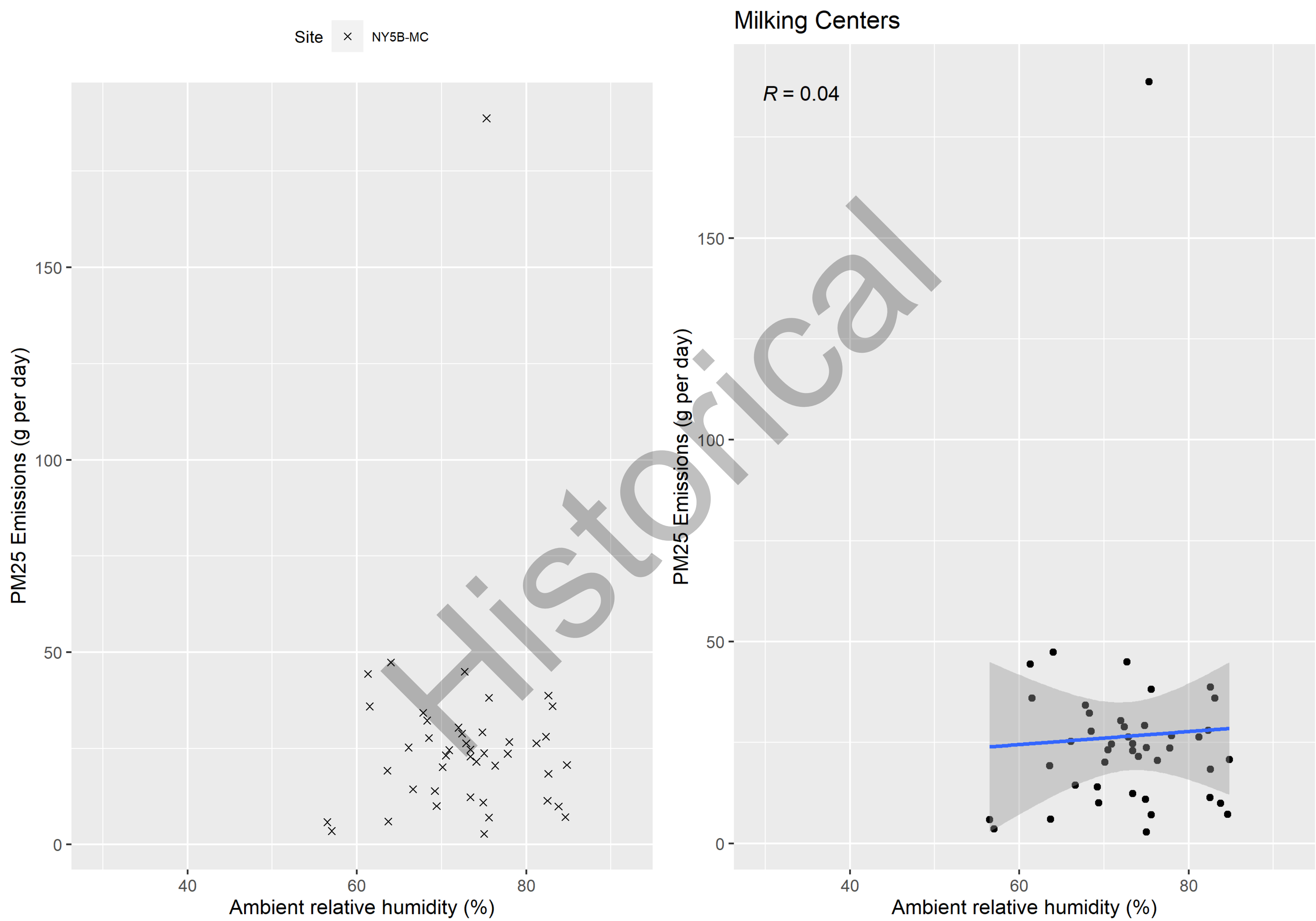


Figure F-79. Scatter plot of milking center $PM_{2.5}$ emissions versus ambient relative humidity and scatter plot with regression.

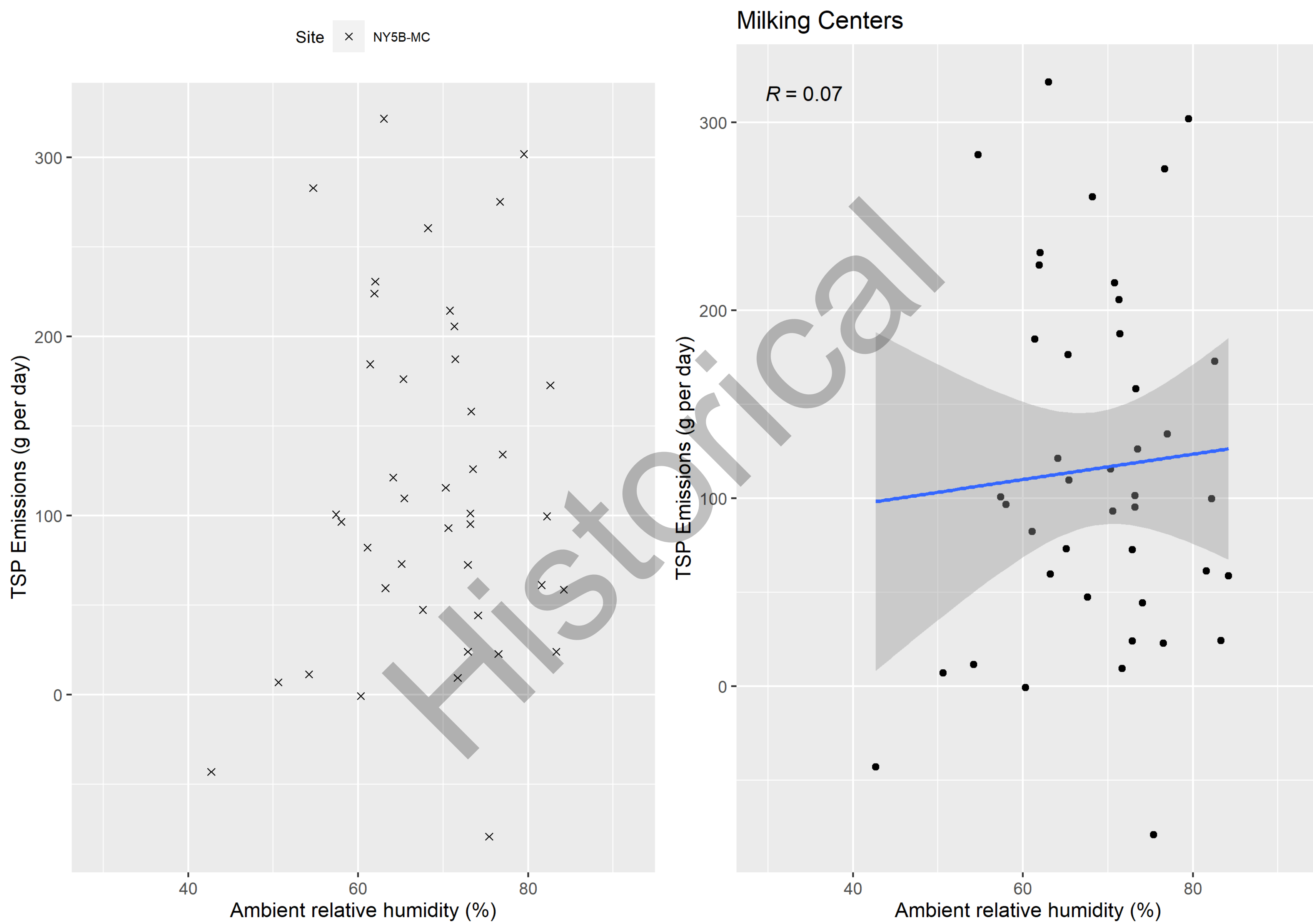


Figure F-80. Scatter plot of milking center TSP emissions versus ambient relative humidity and scatter plot with regression.

F.3 Naturally Ventilated Barns

F.3.1 Environmental Parameters

Table F-6. Summary of naturally ventilated barn R^2 values for environmental parameters.

Pollutant	Parameter	R	R^2	Strength	Figure
NH_3	Inventory	0.660	0.435	moderate	F-81
H_2S	Inventory	0.002	0.000	slight or weak	F-82
PM_{10}	Inventory	-0.292	0.085	slight or weak	F-83
$PM_{2.5}$	Inventory	-0.319	0.102	slight or weak	F-84
TSP	Inventory	-0.327	0.107	slight or weak	F-85
NH_3	Average animal weight	-0.423	0.179	slight or weak	F-86
H_2S	Average animal weight	0.114	0.013	slight or weak	F-87
PM_{10}	Average animal weight	0.240	0.058	slight or weak	F-88
$PM_{2.5}$	Average animal weight	0.384	0.148	slight or weak	F-89
TSP	Average animal weight	0.384	0.147	slight or weak	F-90
NH_3	Live animal weight	0.653	0.426	moderate	F-91
H_2S	Live animal weight	0.014	0.000	slight or weak	F-92
PM_{10}	Live animal weight	-0.278	0.077	slight or weak	F-93
$PM_{2.5}$	Live animal weight	-0.283	0.080	slight or weak	F-94
TSP	Live animal weight	-0.307	0.094	slight or weak	F-95
NH_3	Exhaust temperature	0.493	0.243	modest	F-96
H_2S	Exhaust temperature	0.323	0.104	slight or weak	F-97
PM_{10}	Exhaust temperature	0.410	0.168	slight or weak	F-98
$PM_{2.5}$	Exhaust temperature	0.484	0.234	modest	F-99
TSP	Exhaust temperature	0.406	0.165	slight or weak	F-100
NH_3	Exhaust relative humidity	0.390	0.152	slight or weak	F-101
H_2S	Exhaust relative humidity	0.193	0.037	slight or weak	F-102
PM_{10}	Exhaust relative humidity	-0.269	0.072	slight or weak	F-103
$PM_{2.5}$	Exhaust relative humidity	-0.414	0.171	slight or weak	F-104
TSP	Exhaust relative humidity	-0.322	0.104	slight or weak	F-105
NH_3	Airflow	0.536	0.287	modest	F-106
H_2S	Airflow	0.232	0.054	slight or weak	F-107
PM_{10}	Airflow	0.425	0.180	slight or weak	F-108
$PM_{2.5}$	Airflow	0.449	0.202	modest	F-109
TSP	Airflow	0.376	0.141	slight or weak	F-110

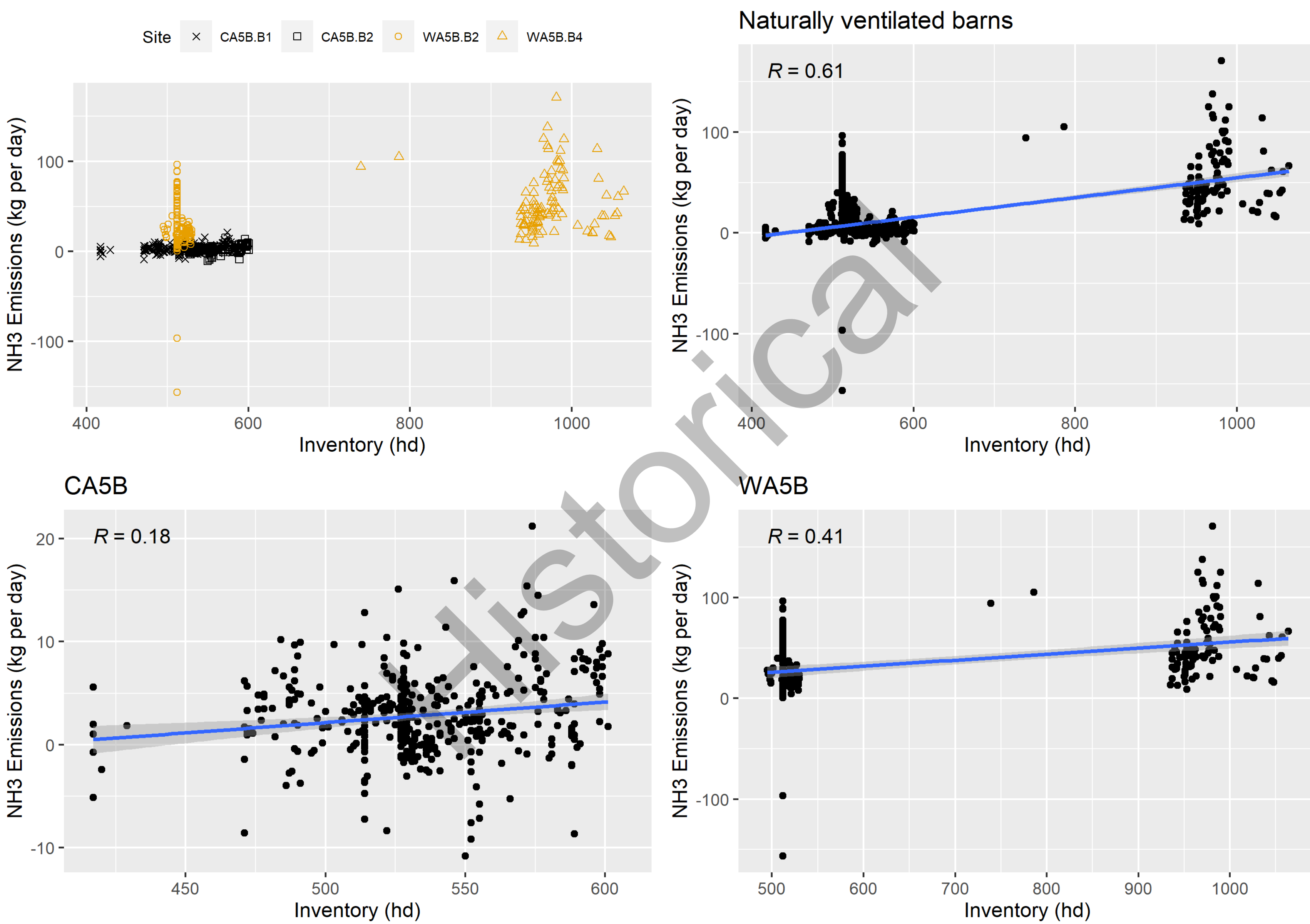


Figure F-81. Scatter plot of naturally ventilated barns NH_3 emissions versus inventory and scatter plot with regression.

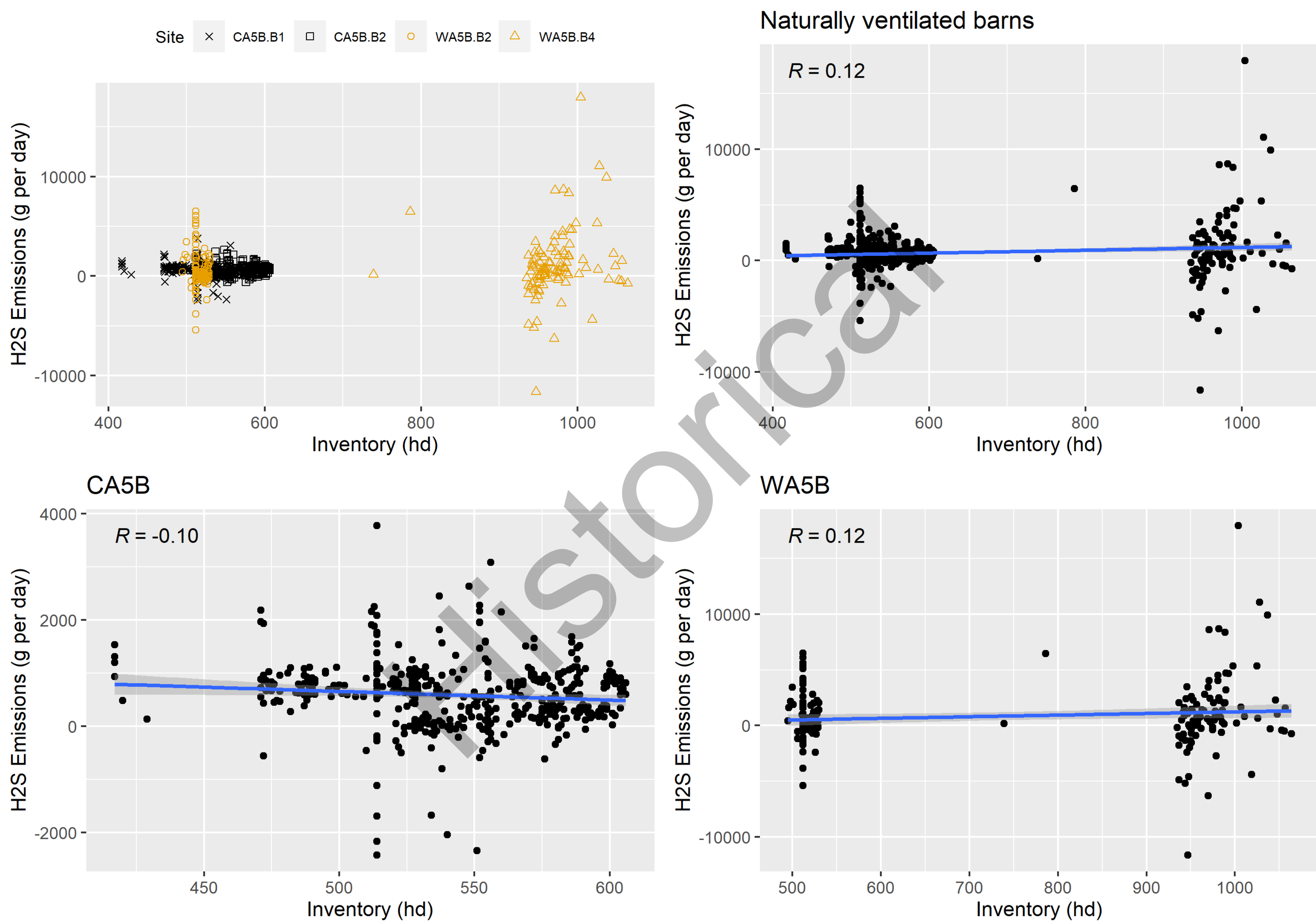


Figure F-82. Scatter plot of naturally ventilated barns H_2S emissions versus inventory and scatter plot with regression.

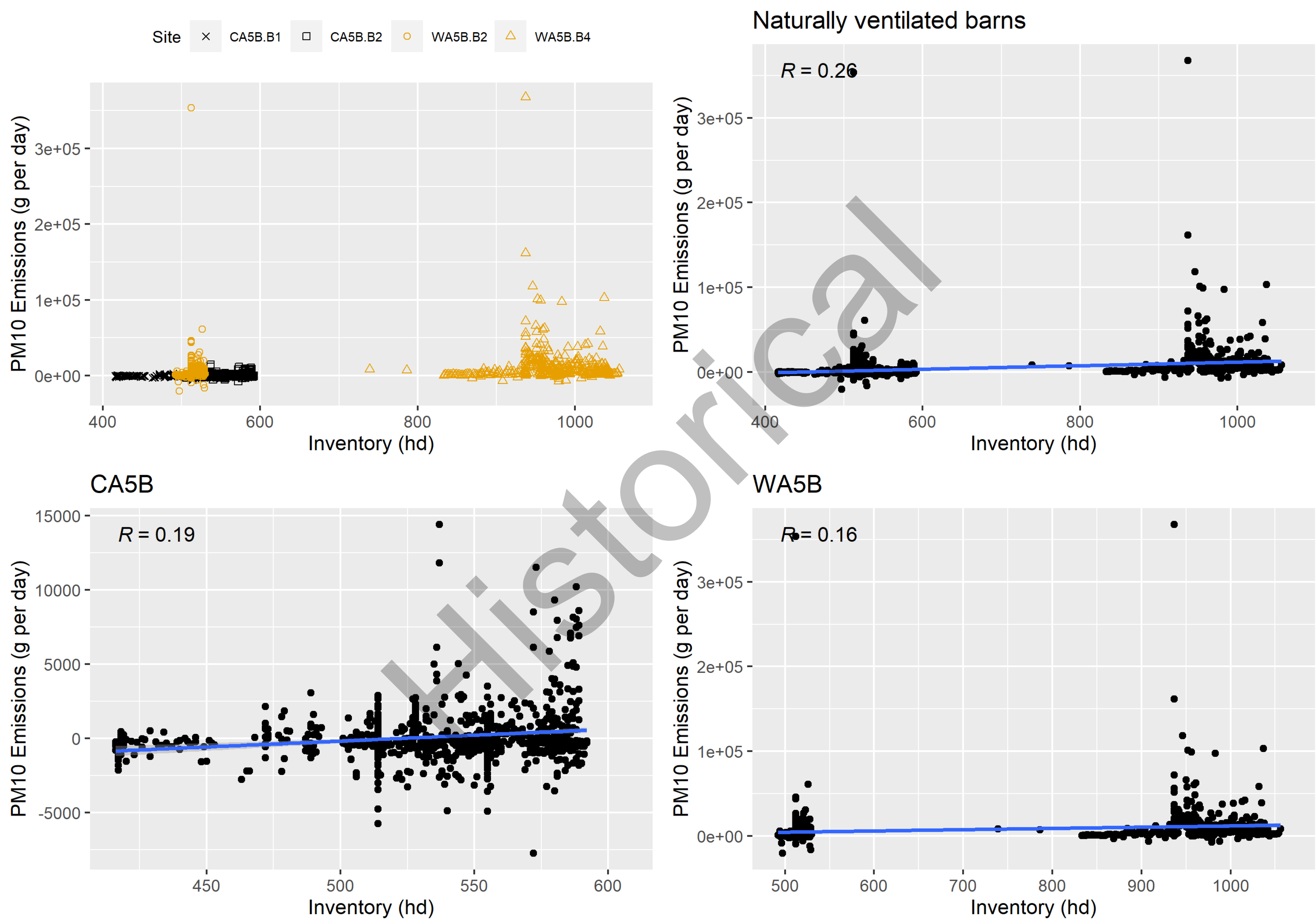


Figure F-83. Scatter plot of naturally ventilated barns PM_{10} emissions versus inventory and scatter plot with regression.

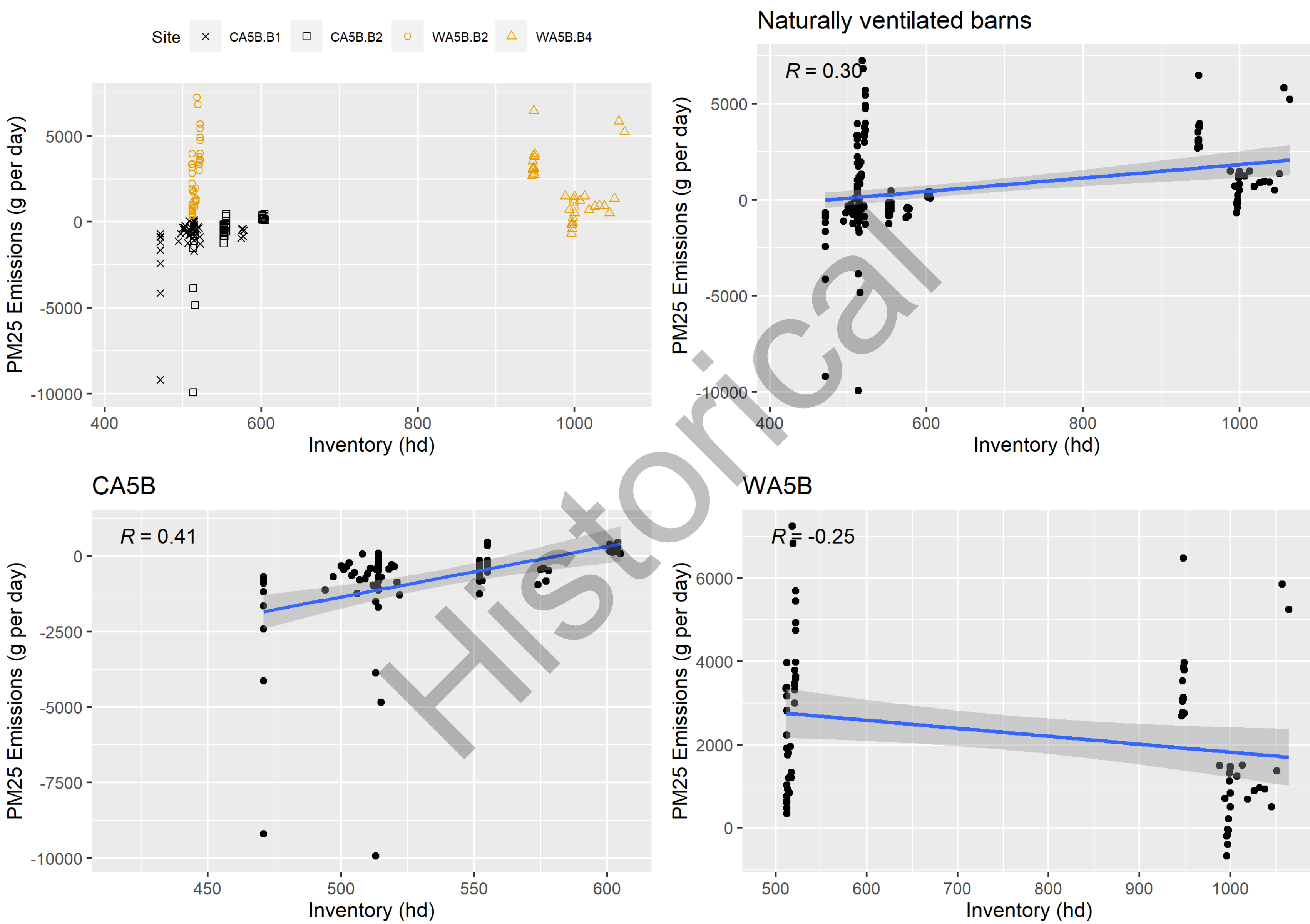


Figure F-84. Scatter plot of naturally ventilated barns $PM_{2.5}$ emissions versus inventory and scatter plot with regression.

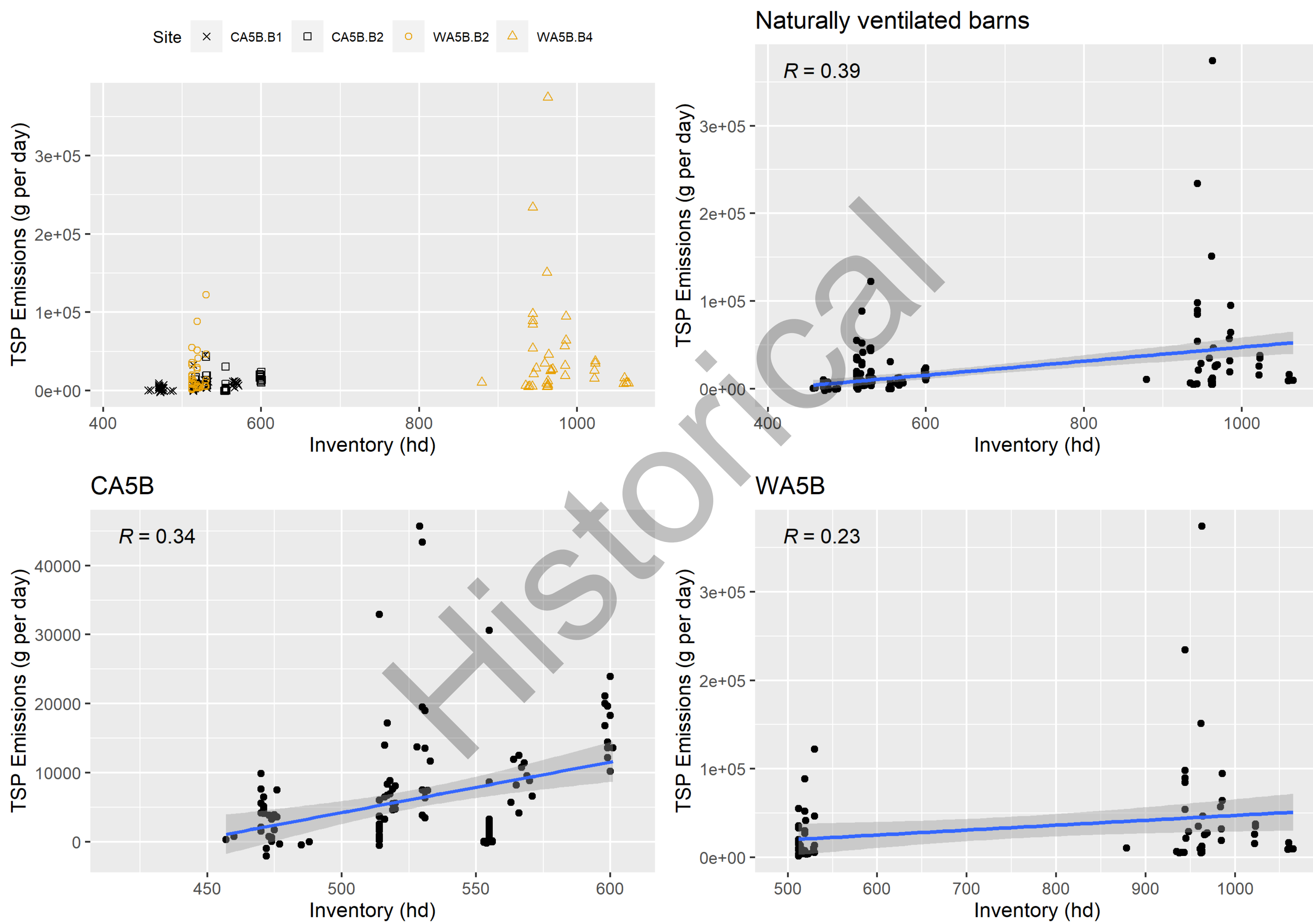


Figure F-85. Scatter plot of naturally ventilated barns TSP emissions versus inventory and scatter plot with regression.

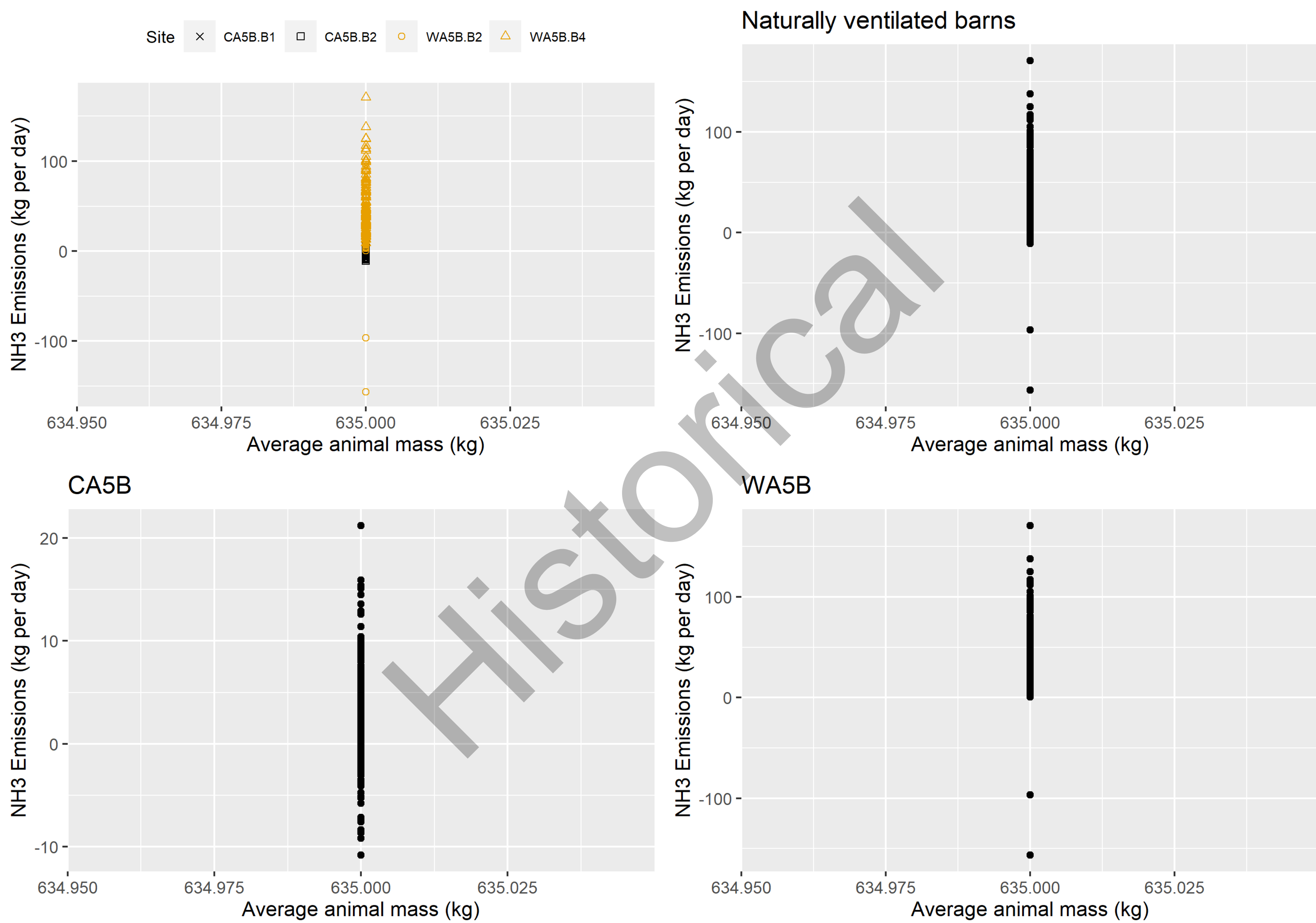


Figure F-86. Scatter plot of naturally ventilated barns NH_3 emissions versus average animal mass and scatter plot with regression.

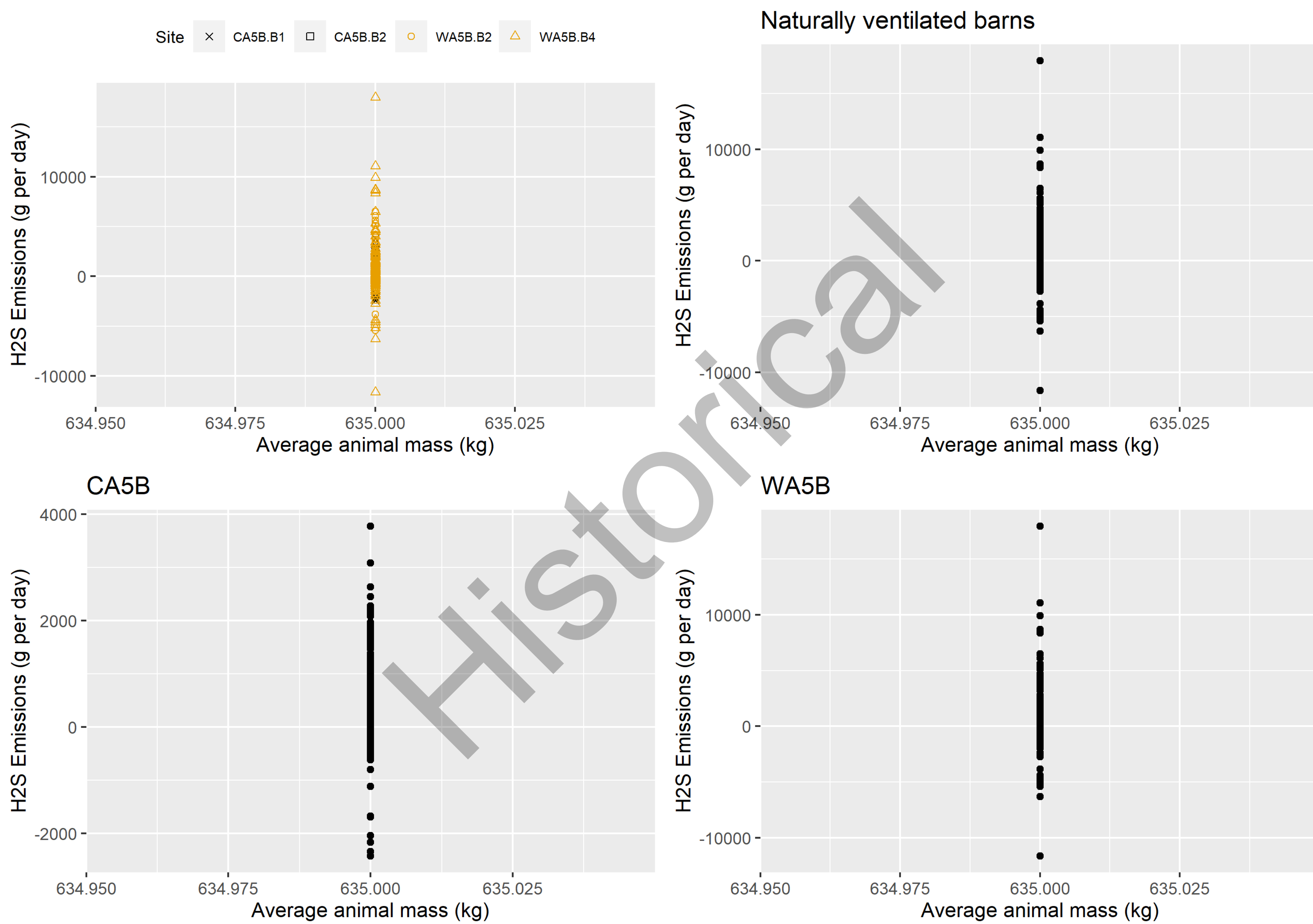


Figure F-87. Scatter plot of naturally ventilated barns H_2S emissions versus average animal mass and scatter plot with regression.

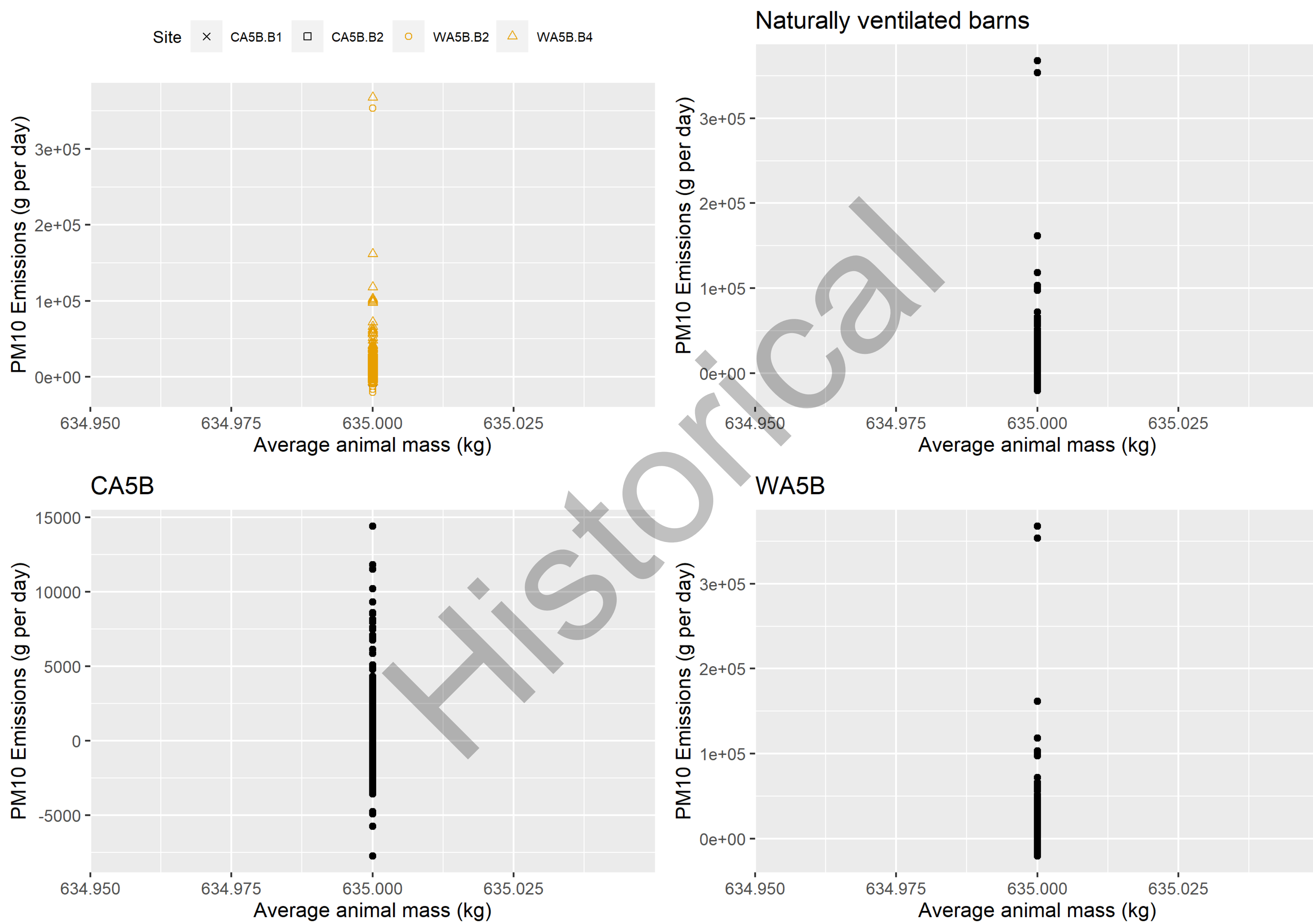


Figure F-88. Scatter plot of naturally ventilated barns PM_{10} emissions versus average animal mass and scatter plot with regression.

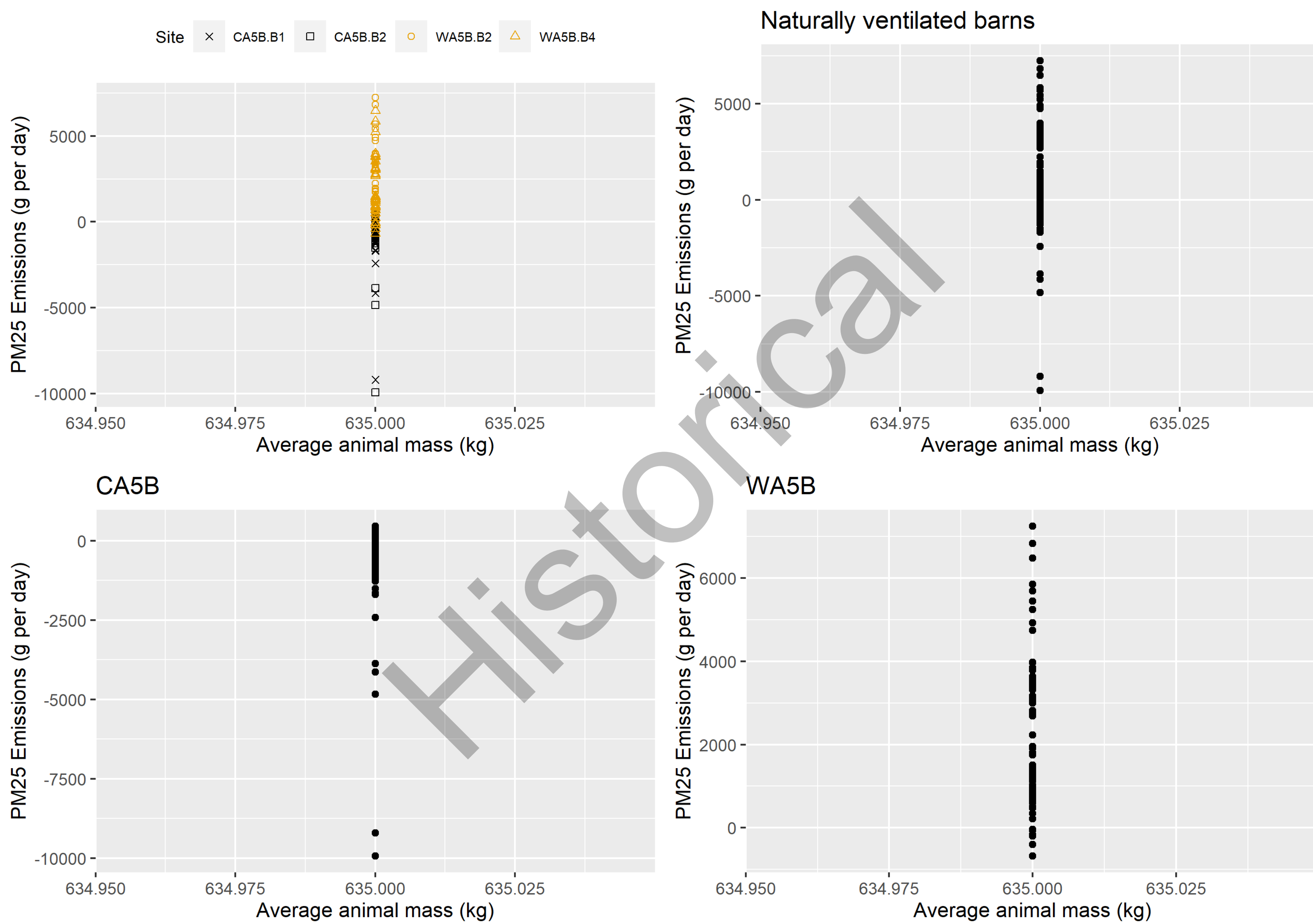


Figure F-89. Scatter plot of naturally ventilated barns $PM_{2.5}$ emissions versus average animal mass and scatter plot with regression.

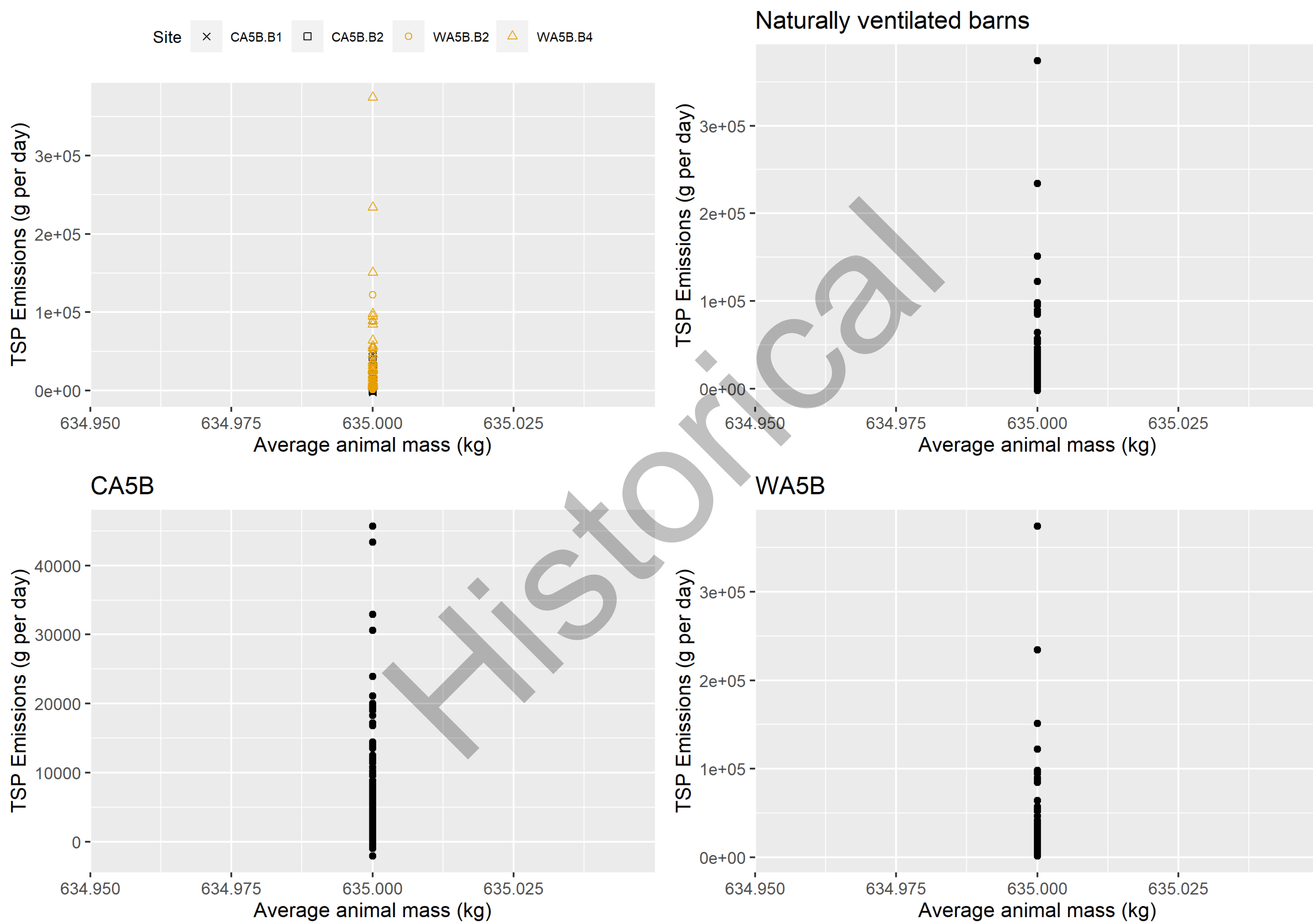


Figure F-90. Scatter plot of naturally ventilated barns TSP emissions versus average animal mass and scatter plot with regression.

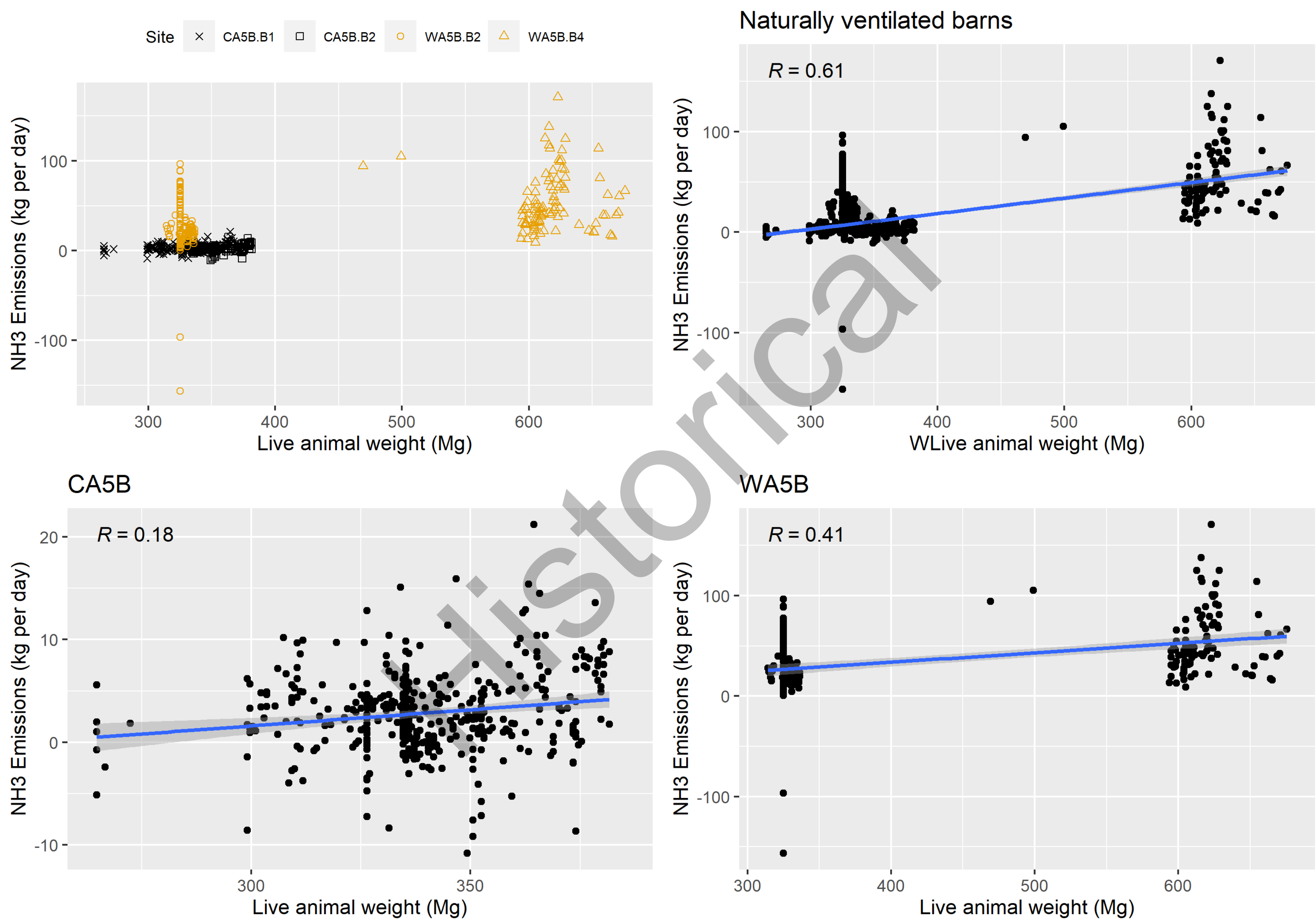


Figure F-91. Scatter plot of naturally ventilated barns NH_3 emissions versus live animal weight and scatter plot with regression.

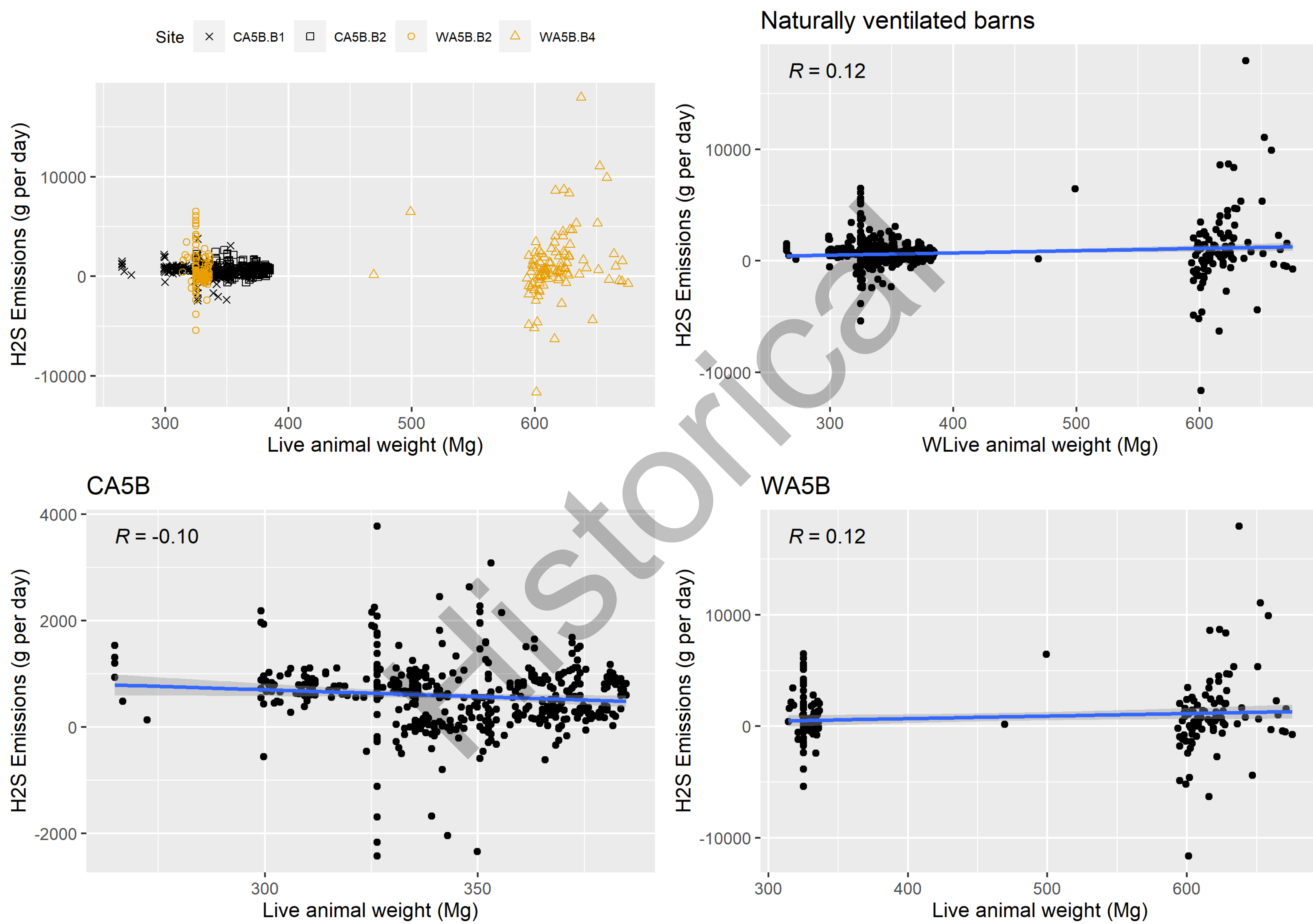


Figure F-92. Scatter plot of naturally ventilated barns H_2S emissions versus live animal weight and scatter plot with regression.

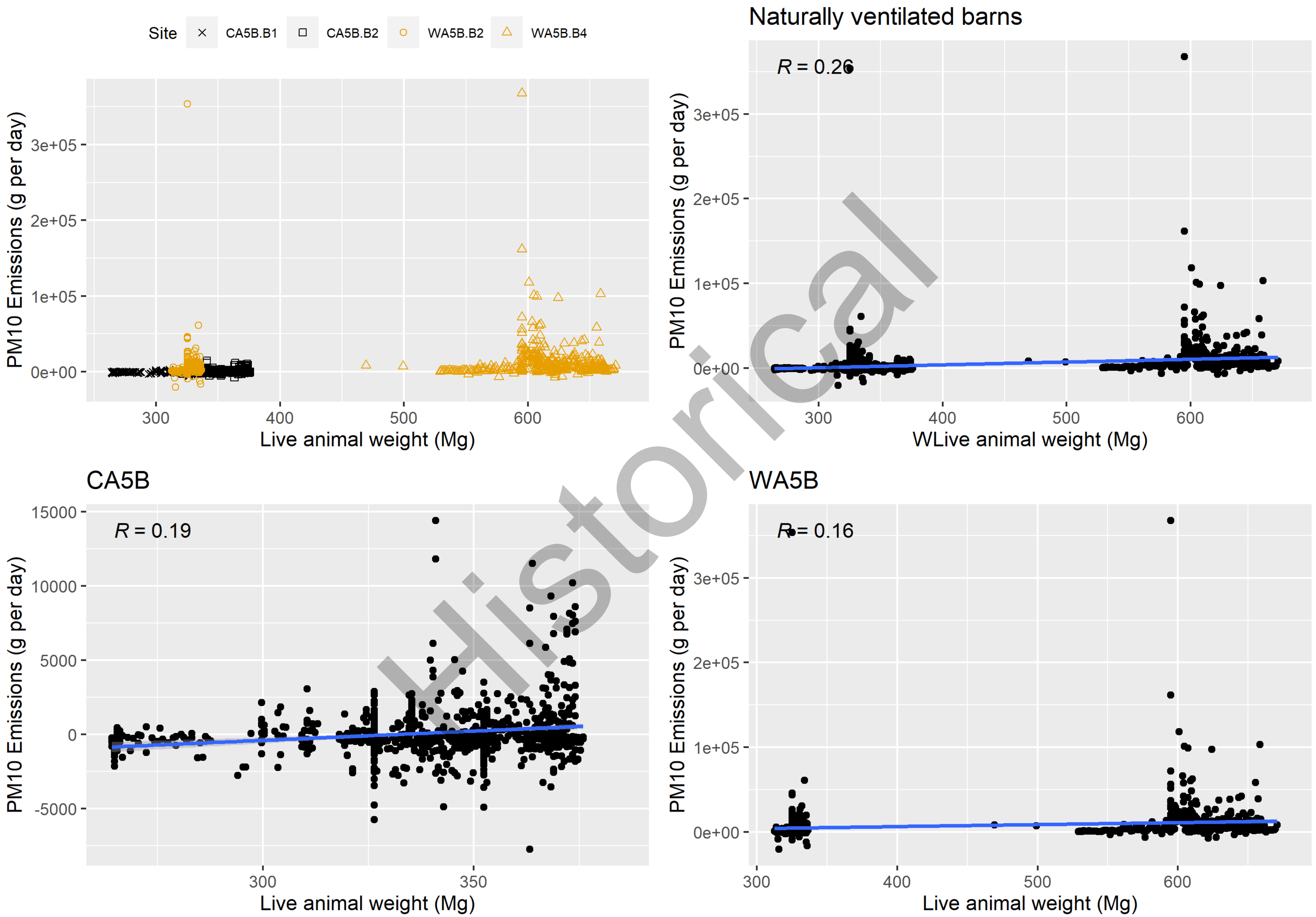


Figure F-93. Scatter plot of naturally ventilated barns PM_{10} emissions versus live animal weight and scatter plot with regression.

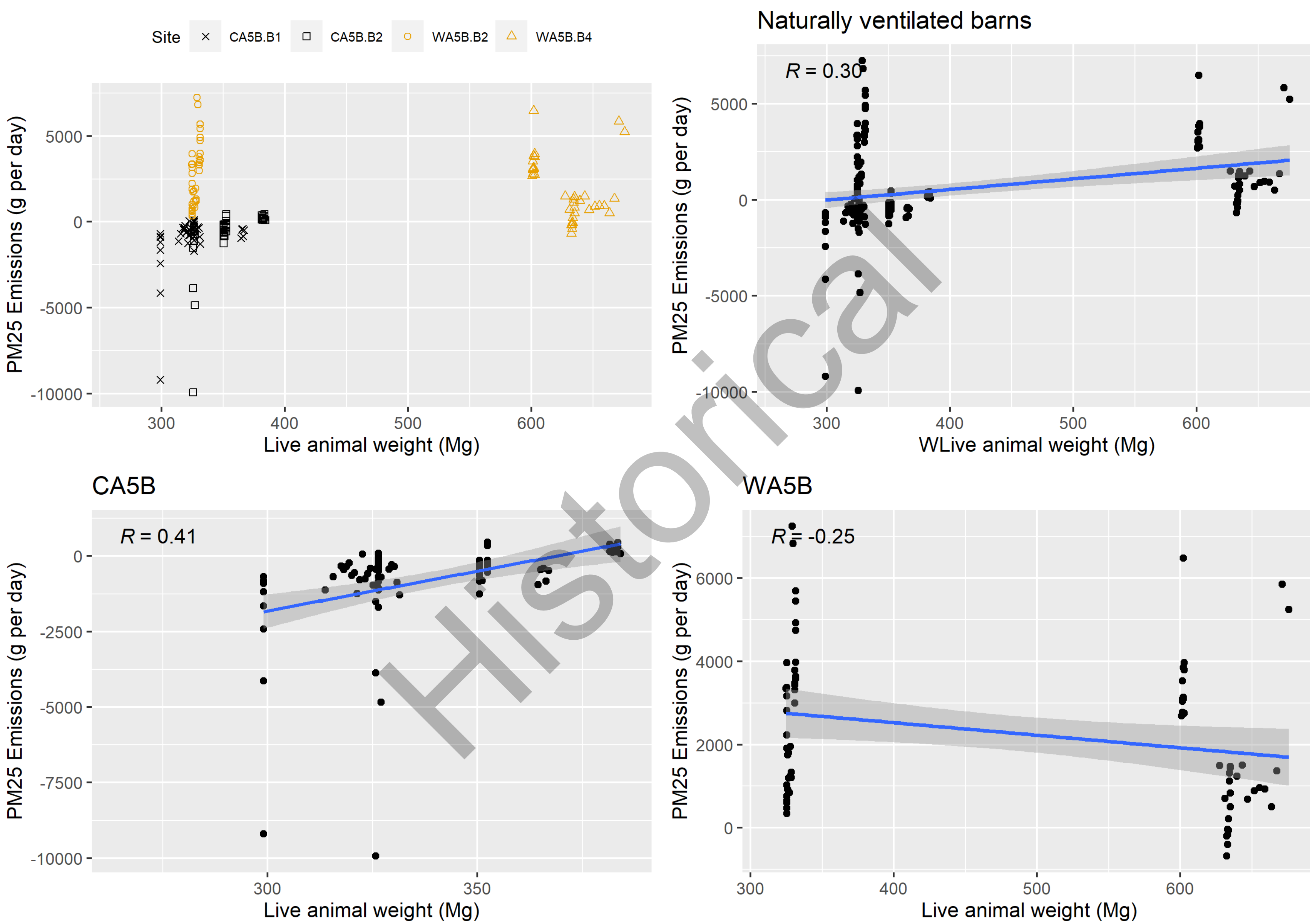


Figure F-94. Scatter plot of naturally ventilated barns $PM_{2.5}$ emissions versus live animal weight and scatter plot with regression.

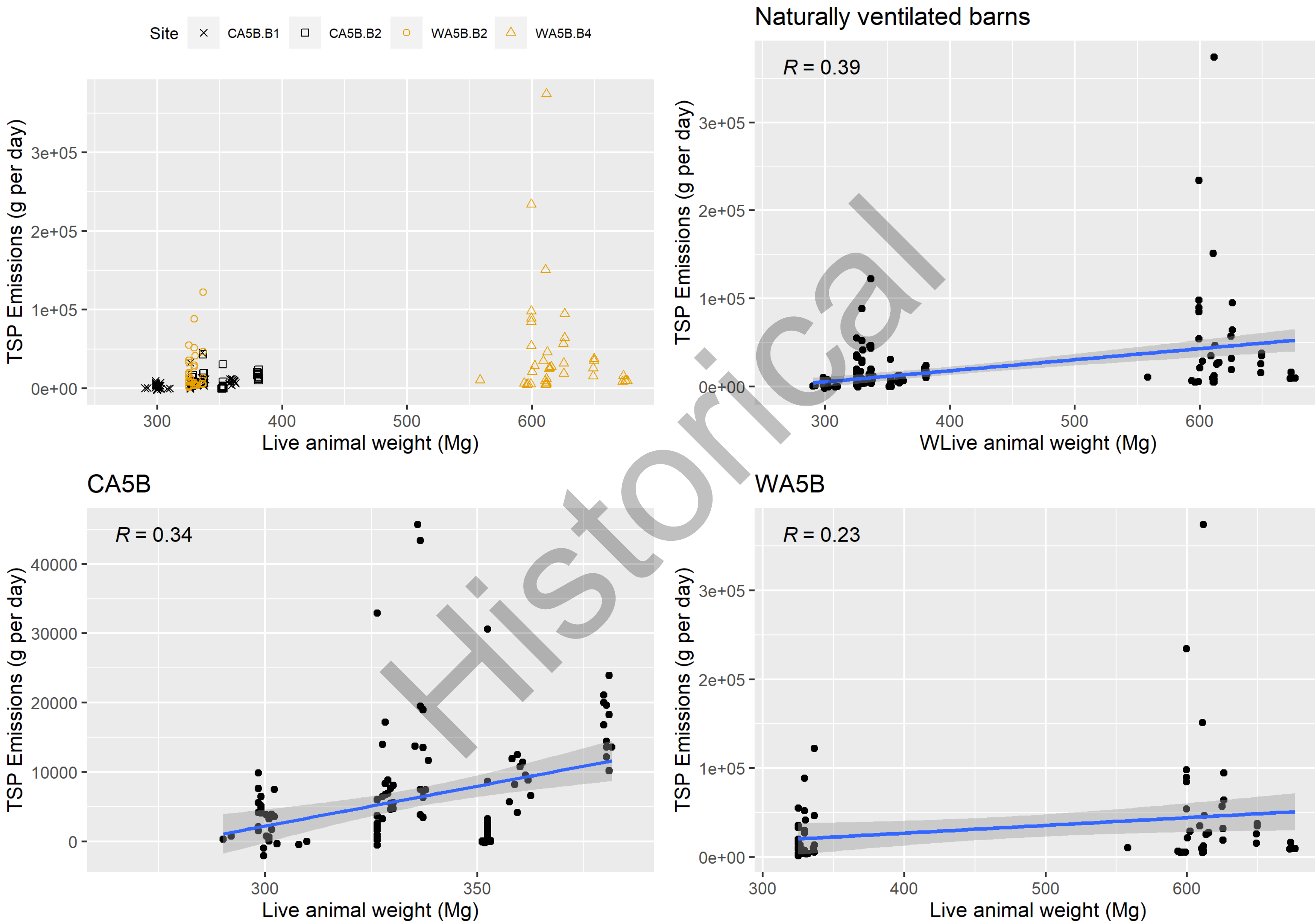


Figure F-95. Scatter plot of naturally ventilated barns TSP emissions versus live animal weight and scatter plot with regression.

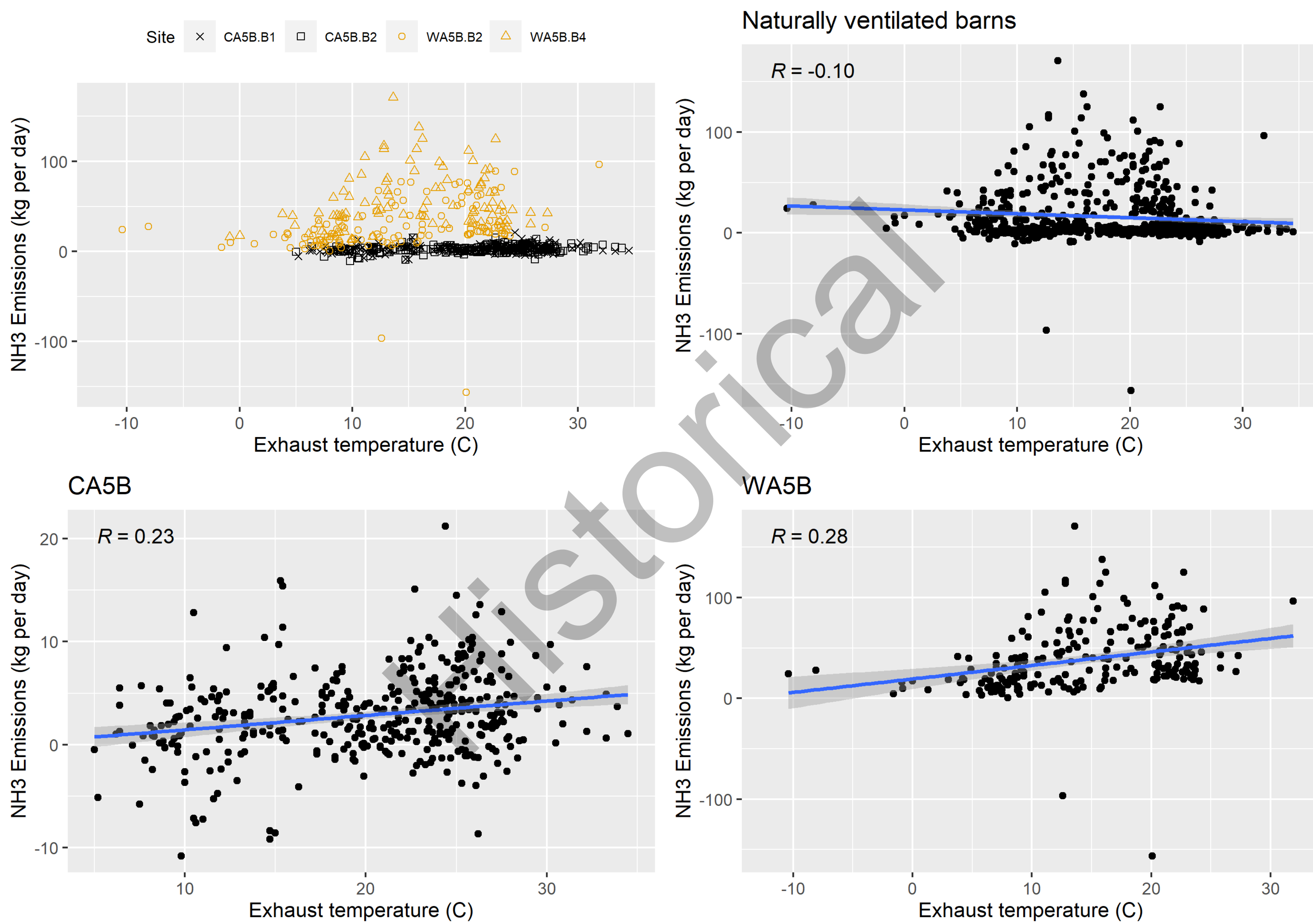


Figure F-96. Scatter plot of naturally ventilated barns NH_3 emissions versus exhaust temperature and scatter plot with regression.

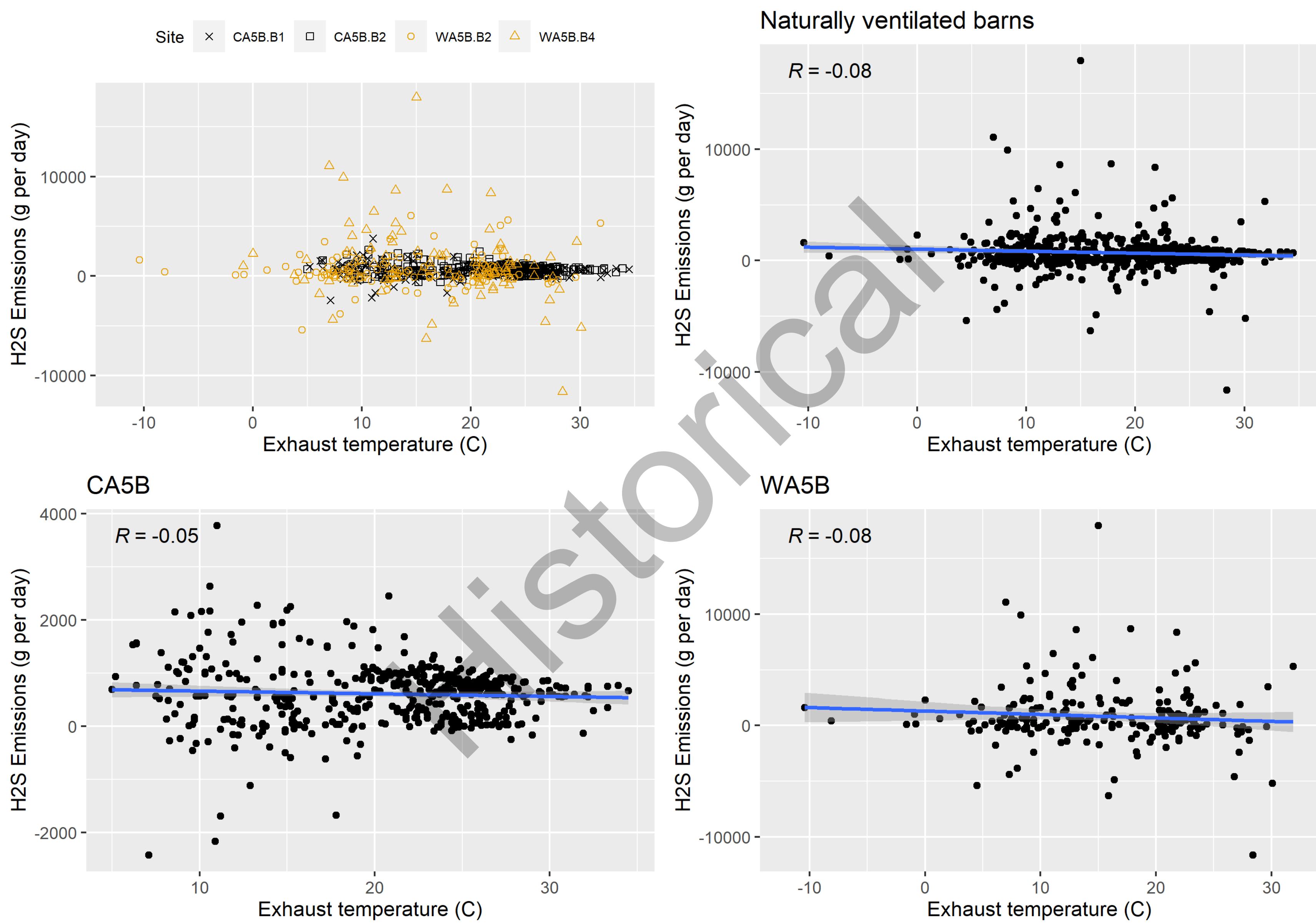


Figure F-97. Scatter plot of naturally ventilated barns H_2S emissions versus exhaust temperature and scatter plot with regression.

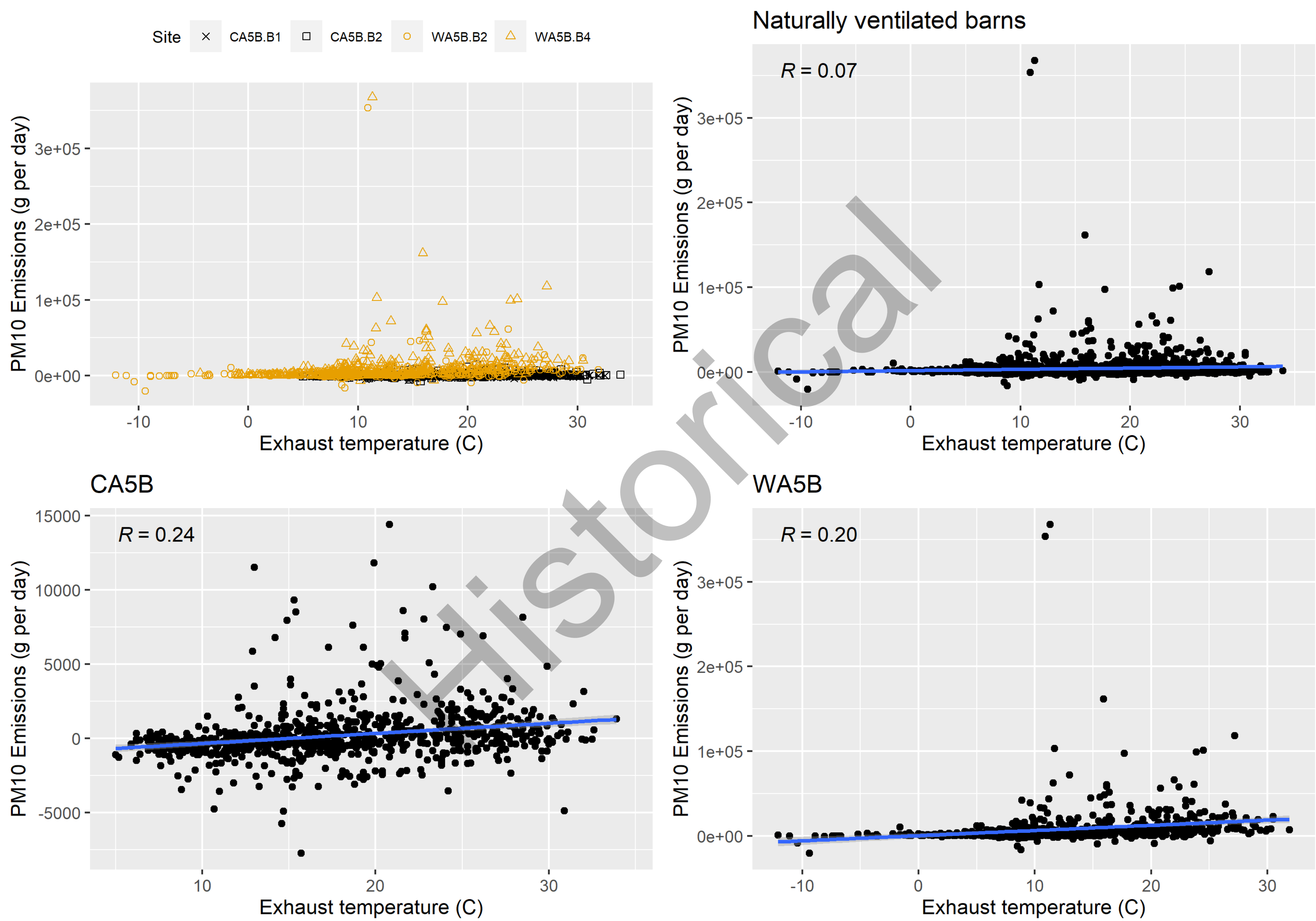


Figure F-98. Scatter plot of naturally ventilated barns PM_{10} emissions versus exhaust temperature and scatter plot with regression.

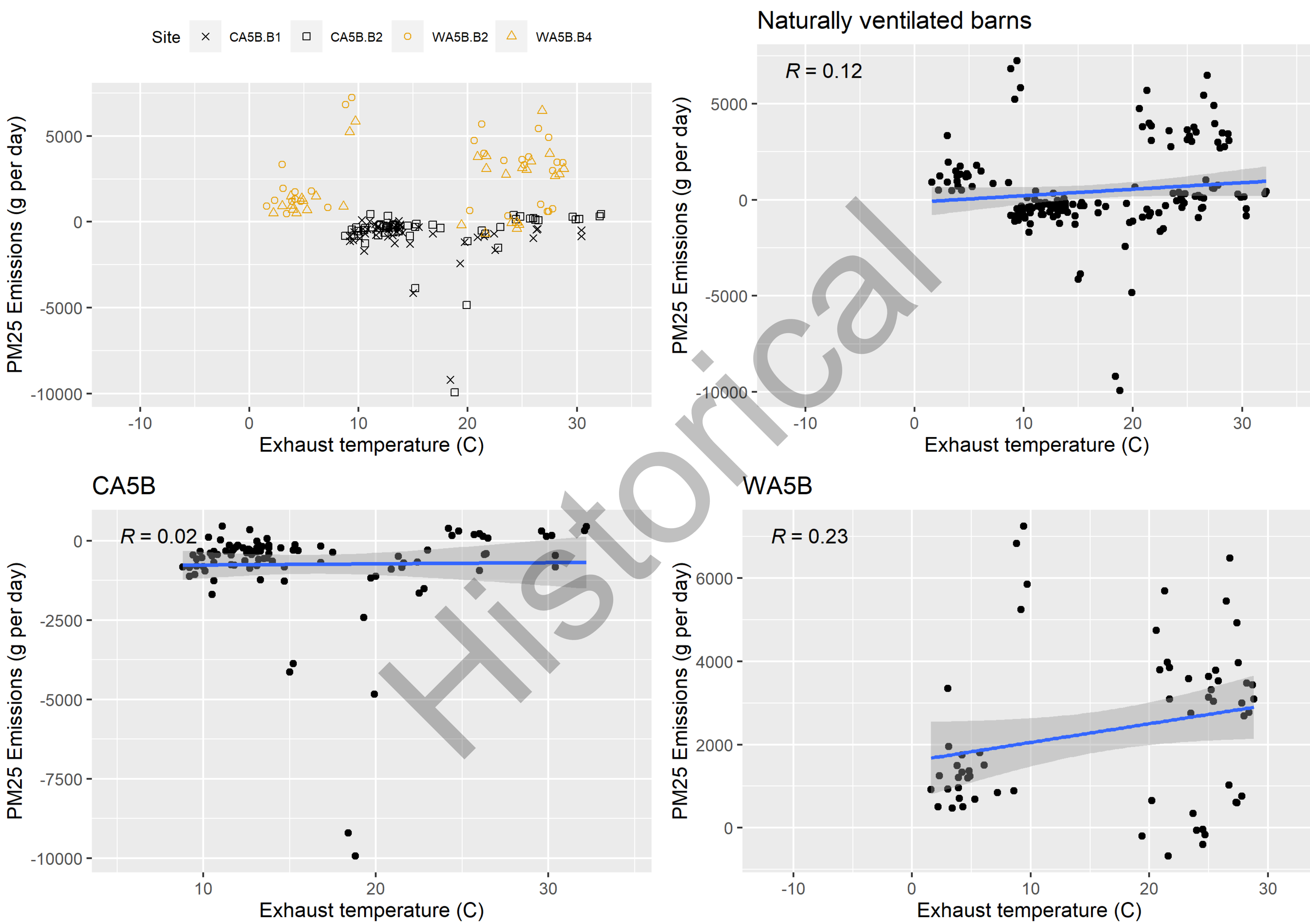


Figure F-99. Scatter plot of naturally ventilated barns $PM_{2.5}$ emissions versus exhaust temperature and scatter plot with regression.

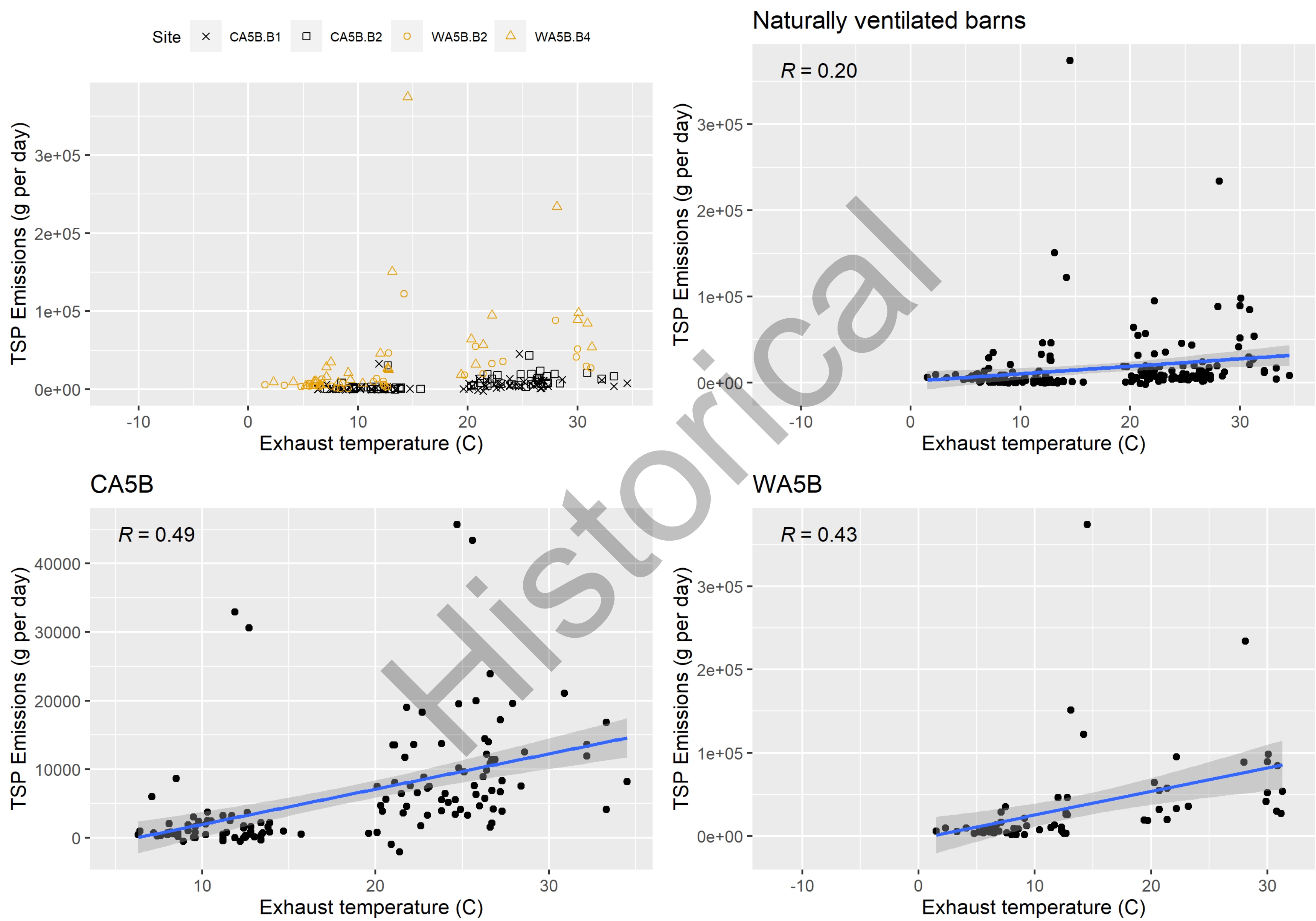


Figure F-100. Scatter plot of naturally ventilated barns TSP emissions versus exhaust temperature and scatter plot with regression.

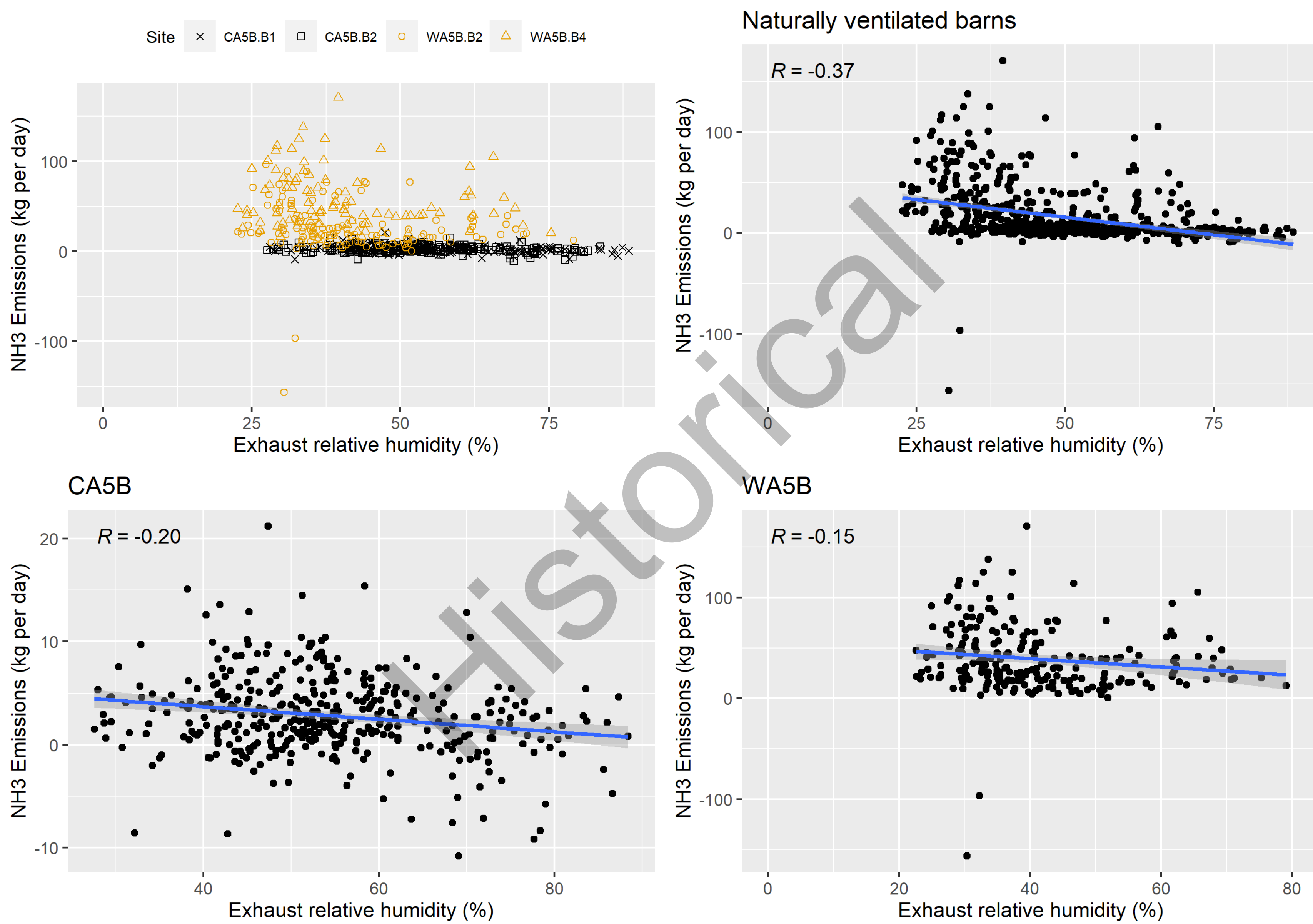


Figure F-101. Scatter plot of naturally ventilated barns NH_3 emissions versus exhaust relative humidity and scatter plot with regression.

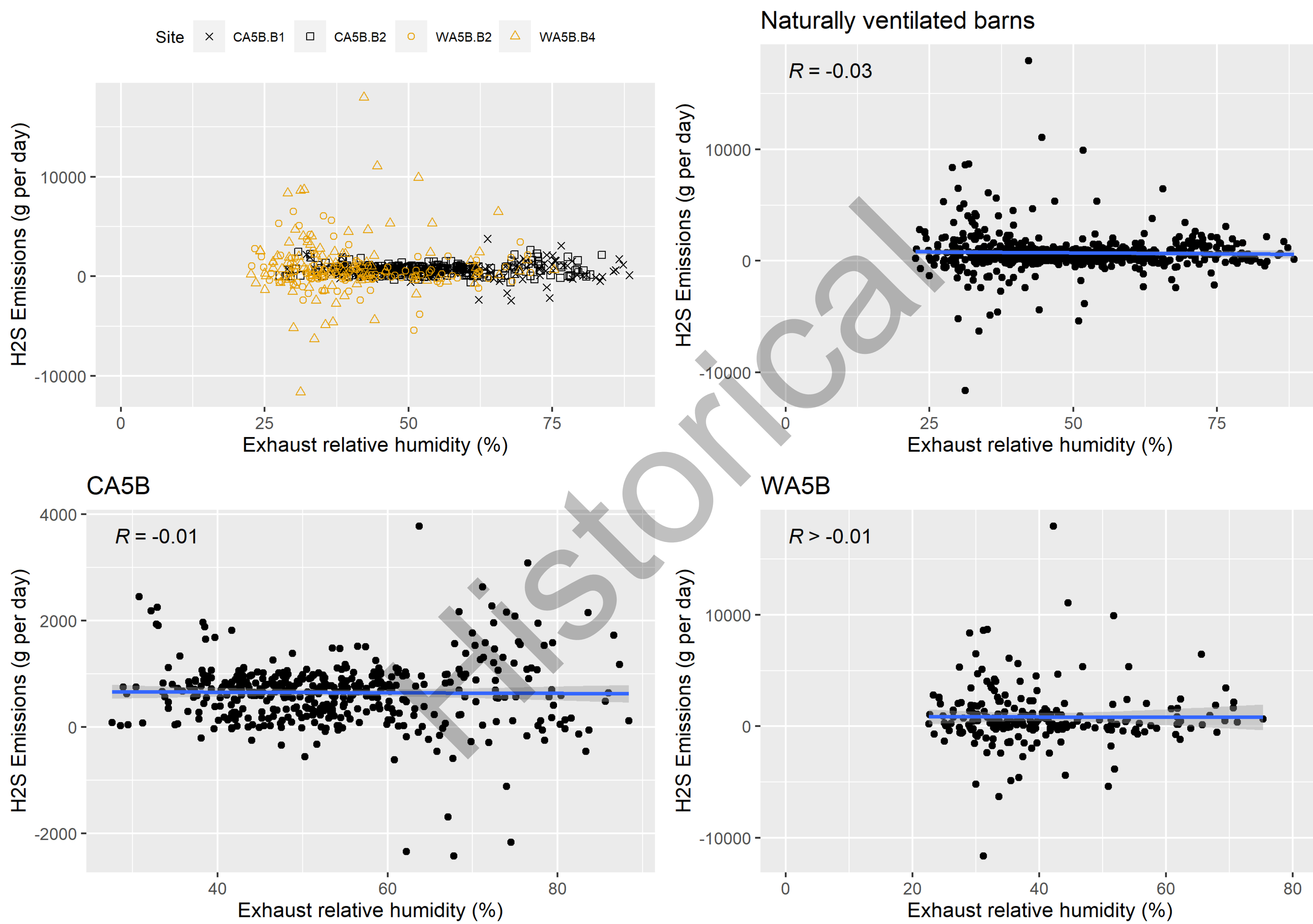


Figure F-102. Scatter plot of naturally ventilated barns H_2S emissions versus exhaust relative humidity and scatter plot with regression.

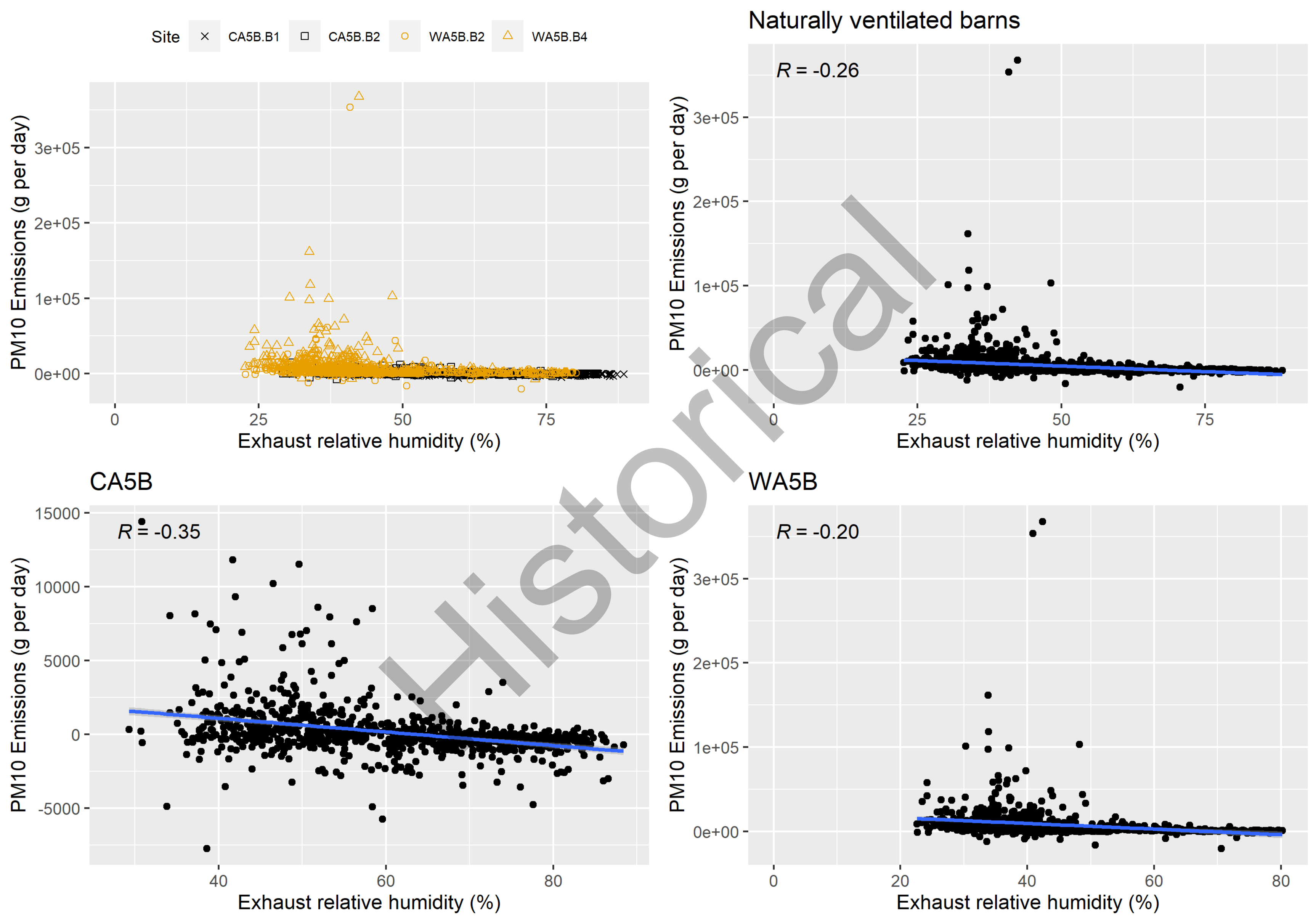


Figure F-103. Scatter plot of naturally ventilated barns PM_{10} emissions versus exhaust relative humidity and scatter plot with regression.

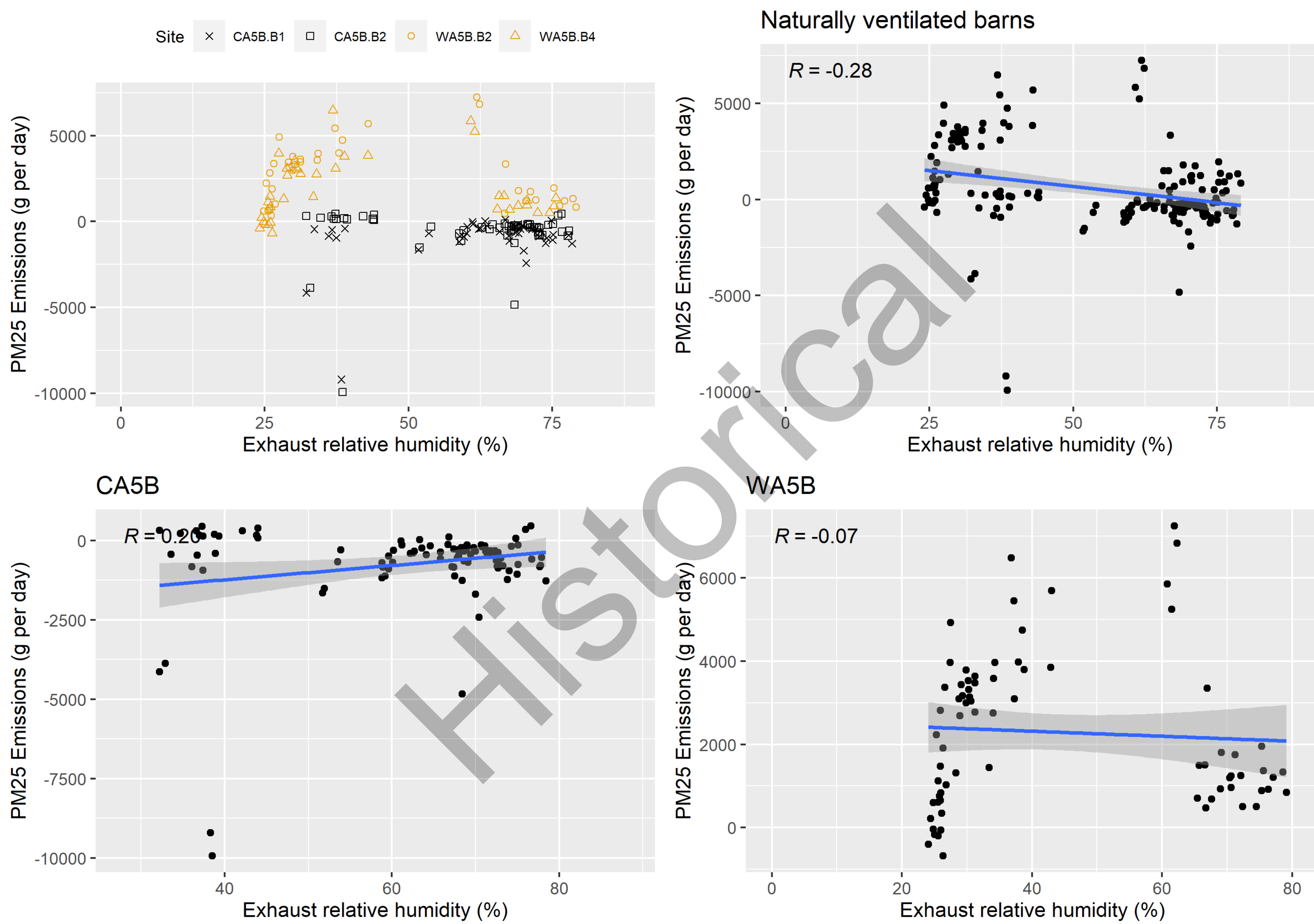


Figure F-104. Scatter plot of naturally ventilated barns $PM_{2.5}$ emissions versus exhaust relative humidity and scatter plot with regression.

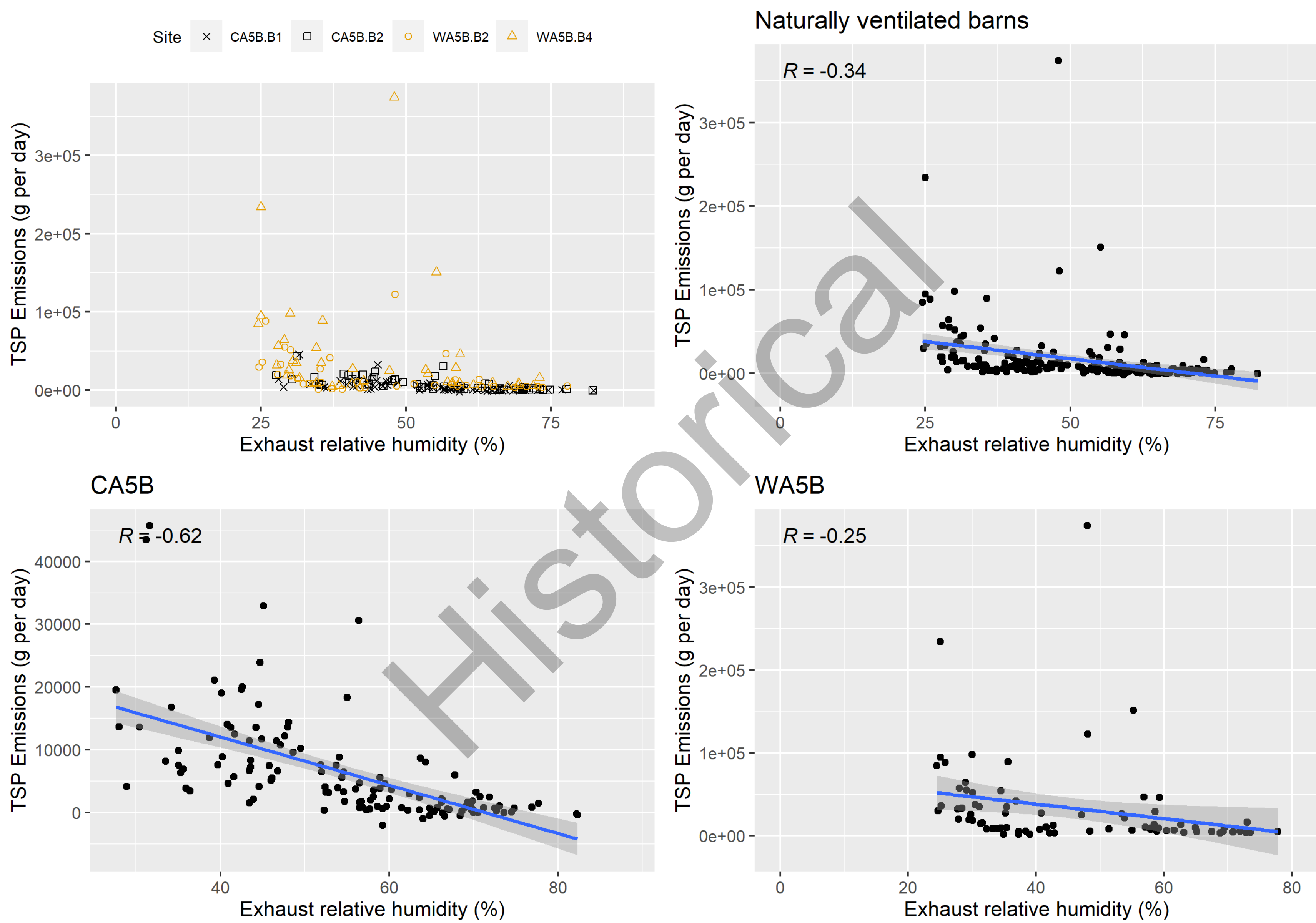


Figure F-105. Scatter plot of naturally ventilated barns TSP emissions versus exhaust relative humidity and scatter plot with regression.

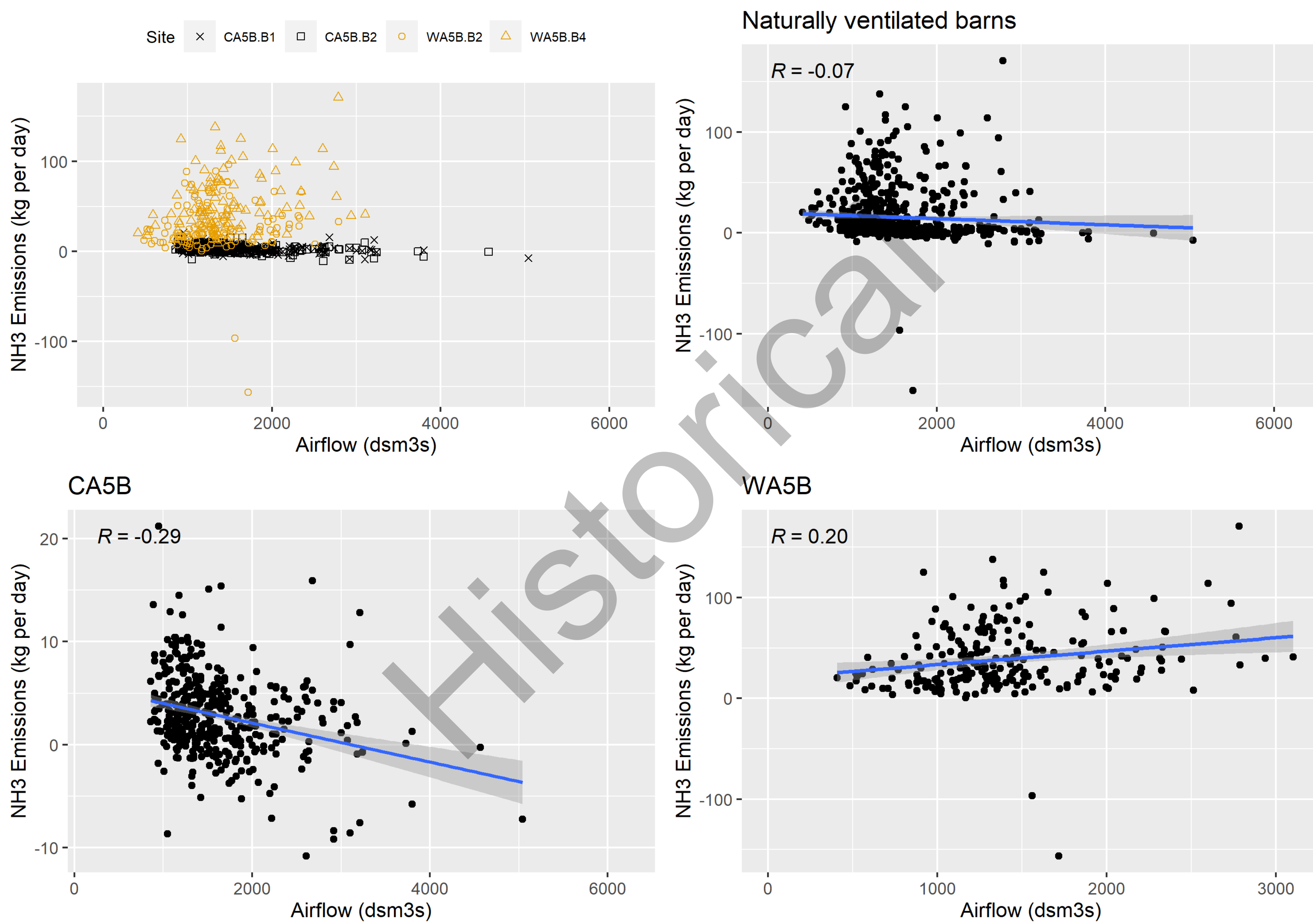


Figure F-106. Scatter plot of naturally ventilated barns NH_3 emissions versus airflow and scatter plot with regression.

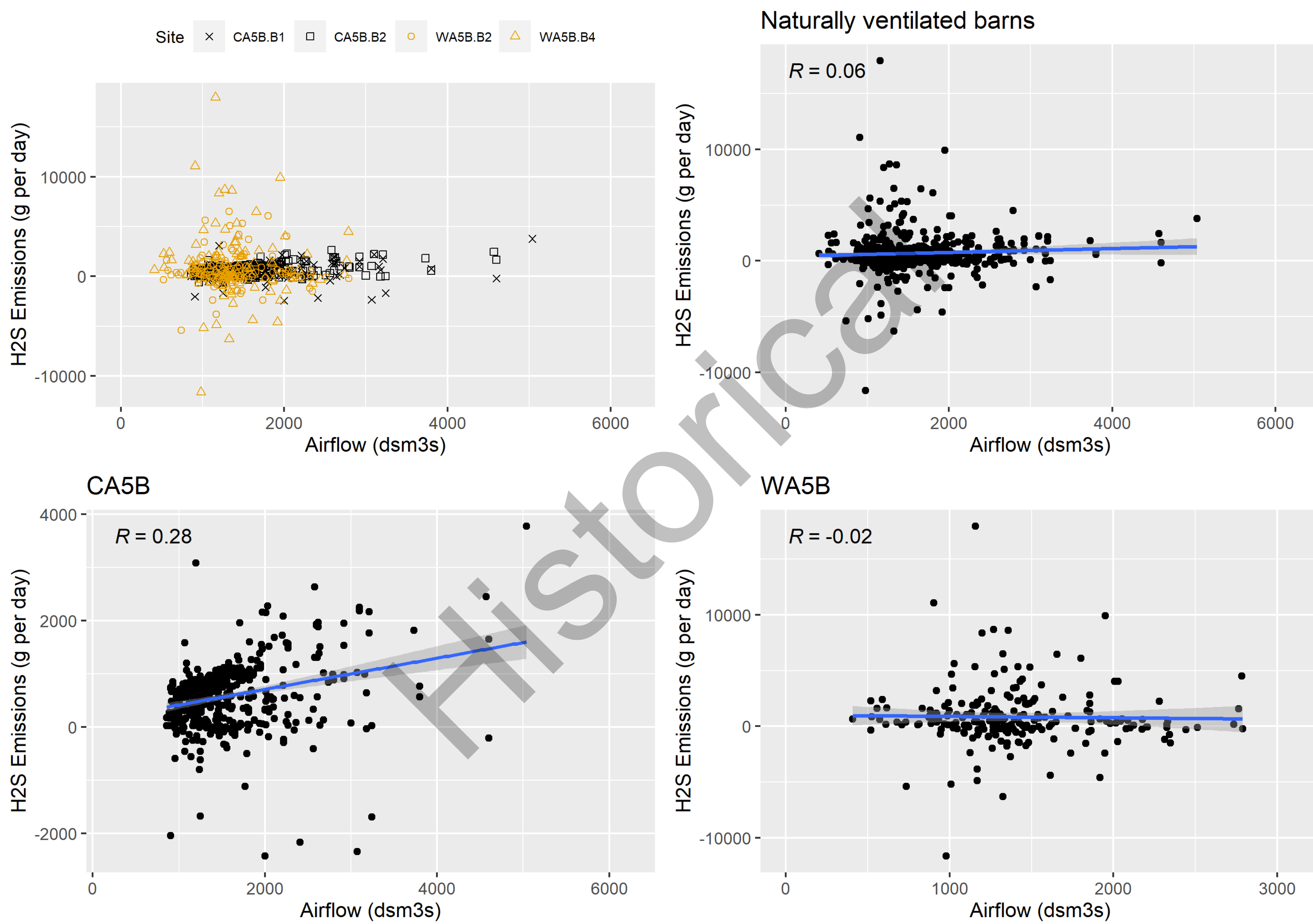


Figure F-107. Scatter plot of naturally ventilated barns H_2S emissions versus airflow and scatter plot with regression.

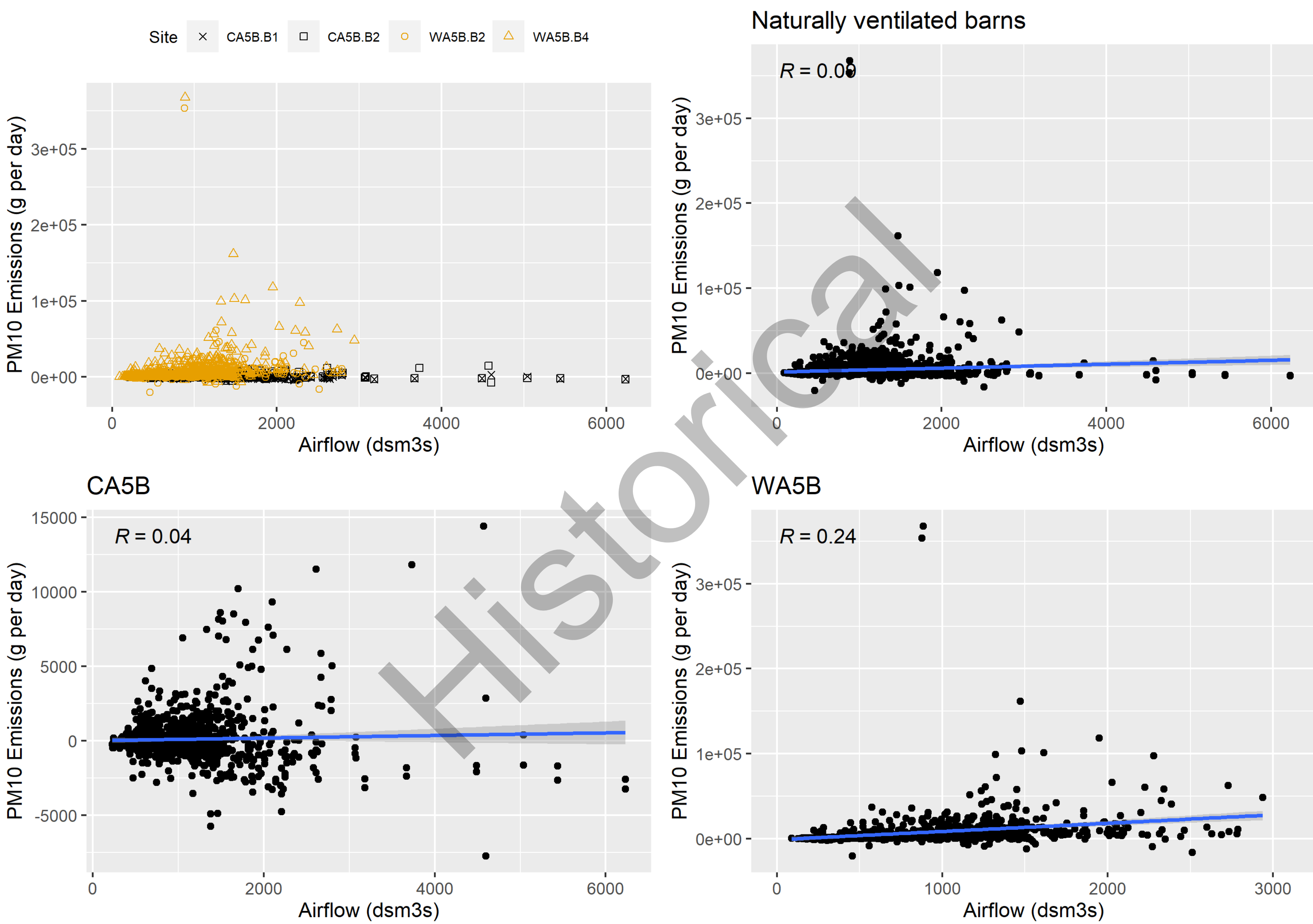


Figure F-108. Scatter plot of naturally ventilated barns PM_{10} emissions versus airflow and scatter plot with regression.

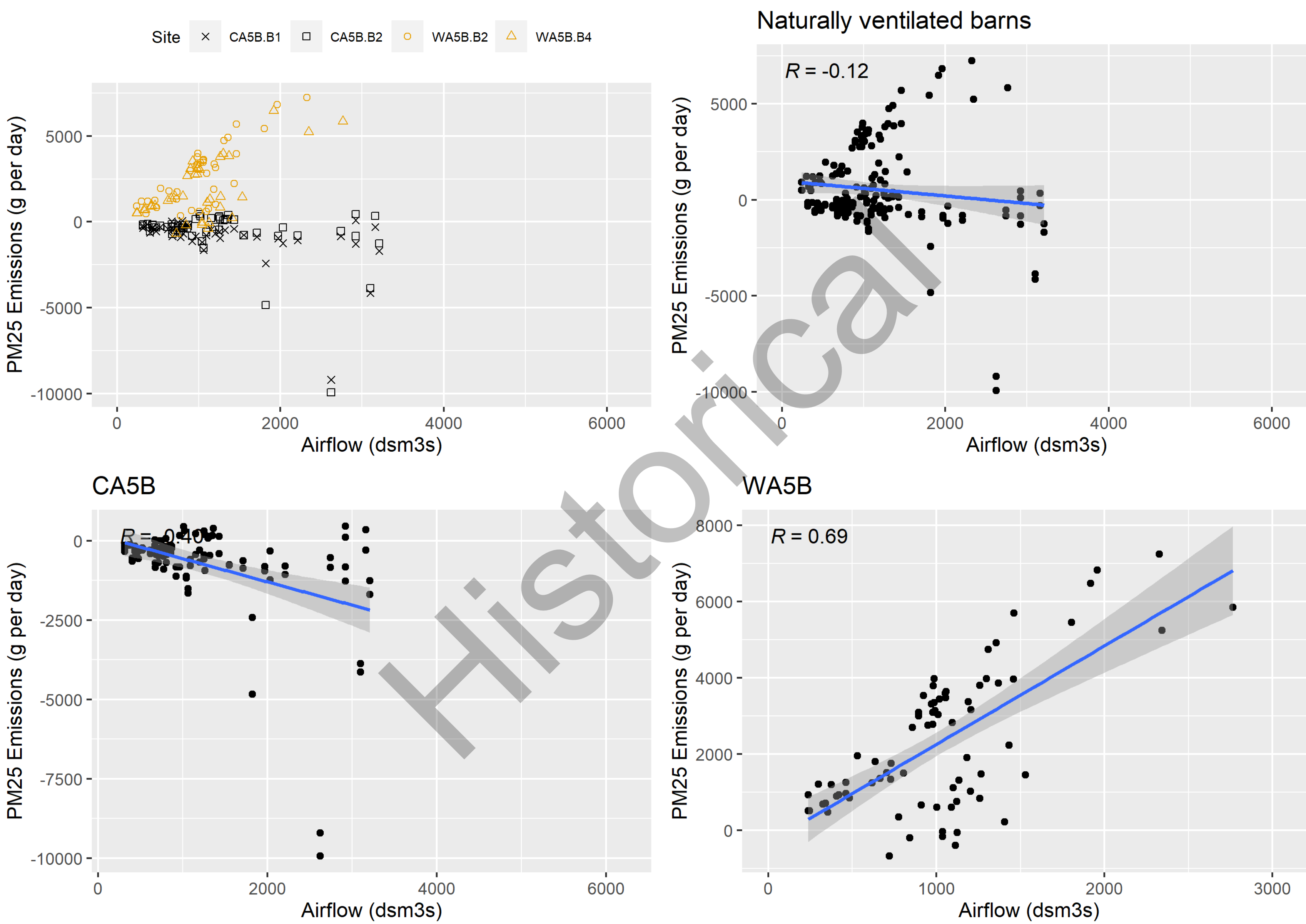


Figure F-109. Scatter plot of naturally ventilated barns $PM_{2.5}$ emissions versus airflow and scatter plot with regression.

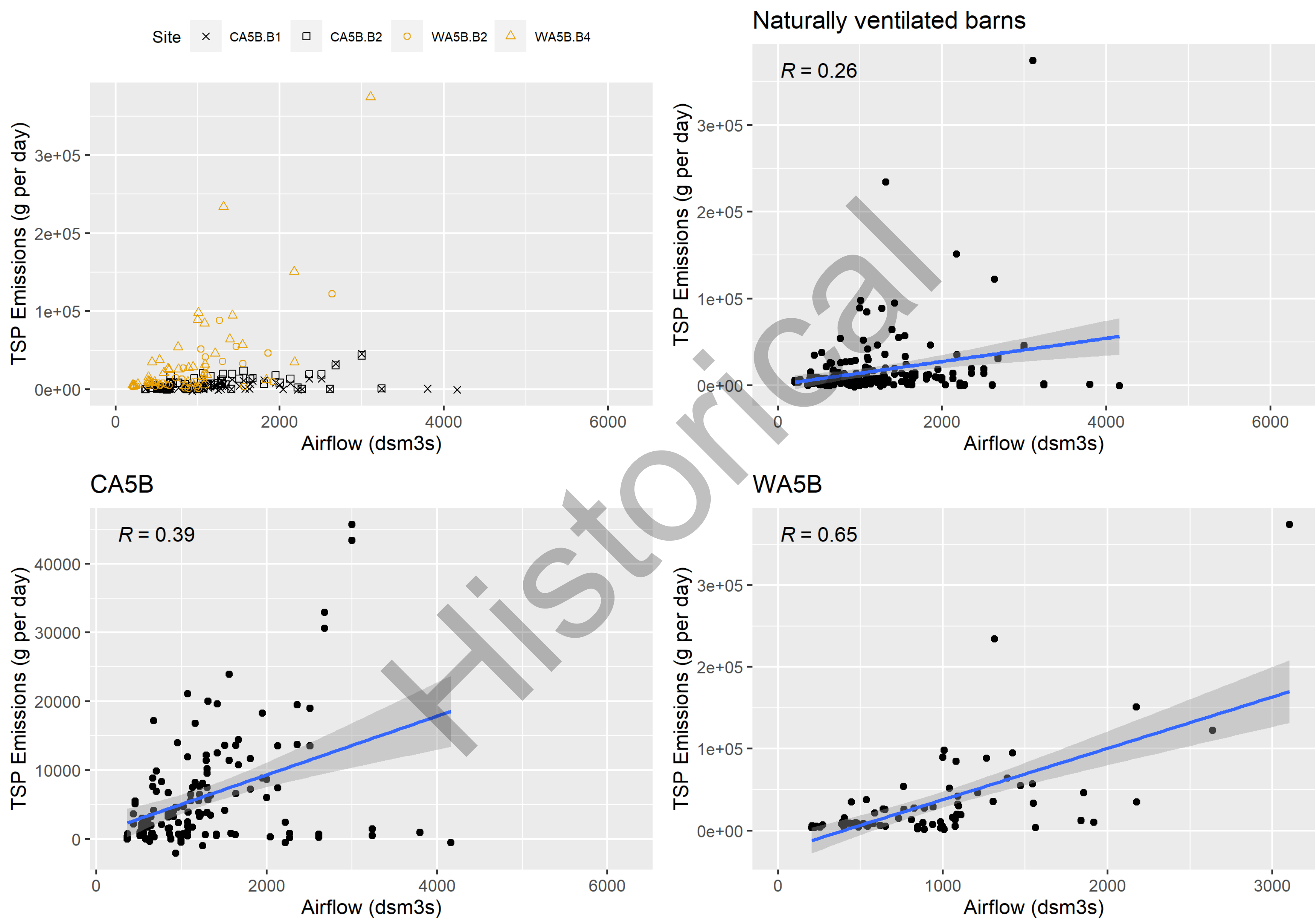


Figure F-110. Scatter plot of naturally ventilated barns TSP emissions versus airflow and scatter plot with regression.

F.3.2 Ambient Parameters

Table F-7. Summary of naturally ventilated barn R^2 values for ambient parameters.

Pollutant	Parameter	R	R^2	Strength	Figure
NH_3	Ambient temperature	0.537	0.289	modest	F-111
H_2S	Ambient temperature	0.257	0.066	slight or weak	F-112
PM_{10}	Ambient temperature	0.370	0.137	slight or weak	F-113
$PM_{2.5}$	Ambient temperature	0.398	0.159	slight or weak	F-114
TSP	Ambient temperature	0.348	0.121	slight or weak	F-115
NH_3	Ambient relative humidity	-0.110	0.012	slight or weak	F-116
H_2S	Ambient relative humidity	0.000	0.000	slight or weak	F-117
PM_{10}	Ambient relative humidity	-0.129	0.017	slight or weak	F-118
$PM_{2.5}$	Ambient relative humidity	-0.331	0.109	slight or weak	F-119
TSP	Ambient relative humidity	-0.155	0.024	slight or weak	F-120
NH_3	Wind speed	0.537	0.289	modest	F-121
H_2S	Wind speed	0.257	0.066	slight or weak	F-122
PM_{10}	Wind speed	0.370	0.137	slight or weak	F-123
$PM_{2.5}$	Wind speed	0.398	0.159	slight or weak	F-124
TSP	Wind speed	0.348	0.121	slight or weak	F-125

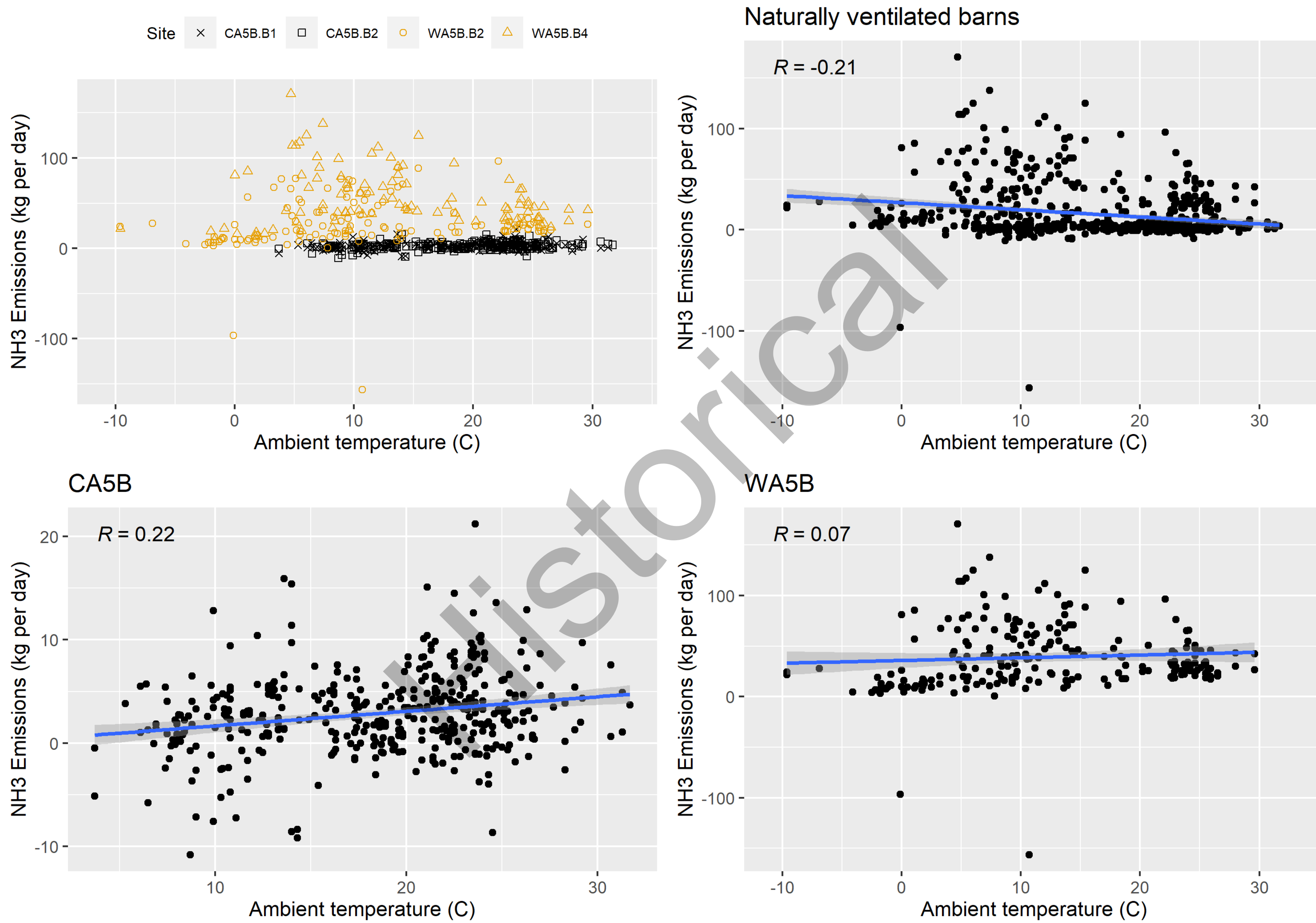


Figure F-111. Scatter plot of naturally ventilated barns NH_3 emissions versus ambient temperature and scatter plot with regression.

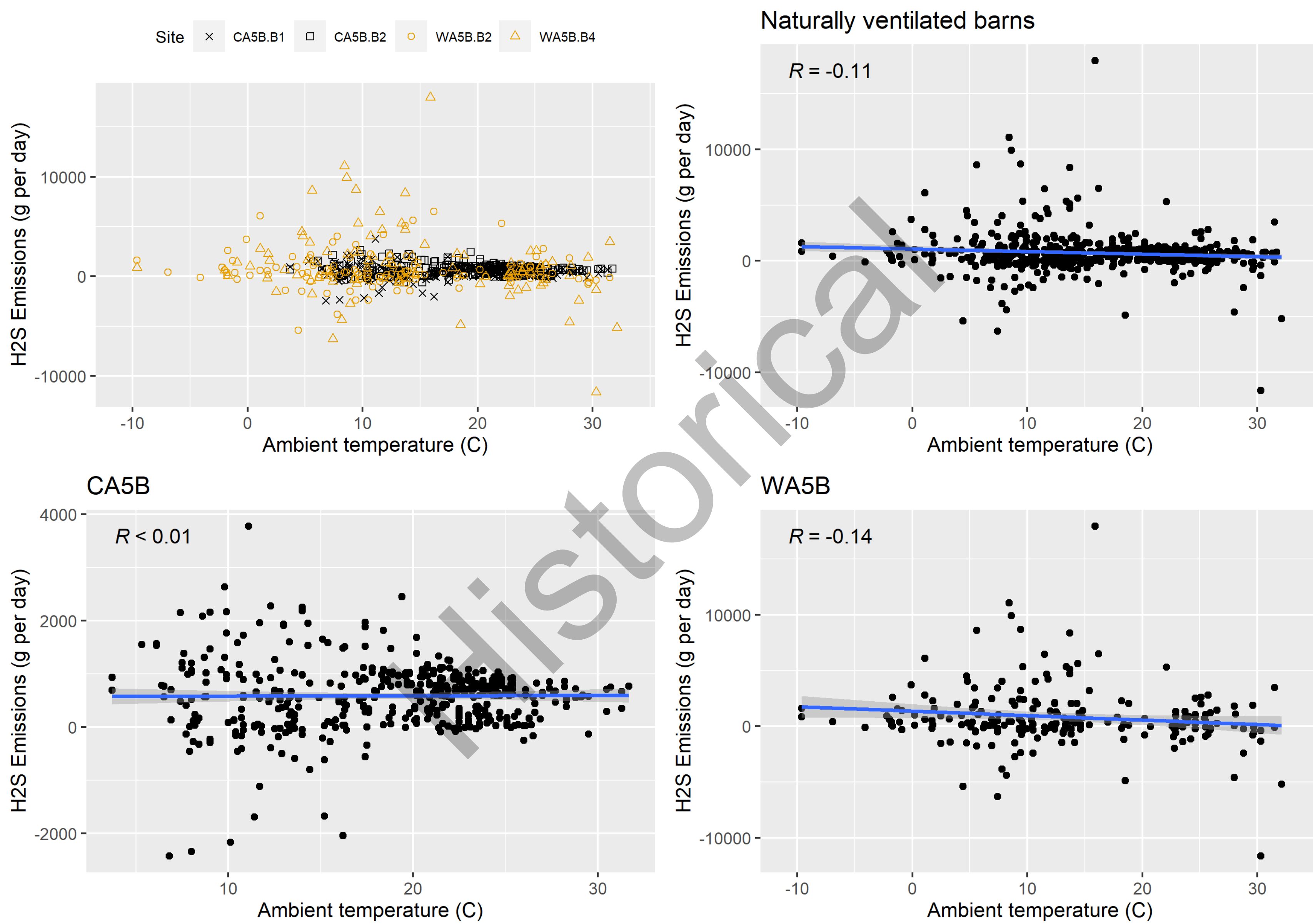


Figure F-112. Scatter plot of naturally ventilated barns H_2S emissions versus ambient temperature and scatter plot with regression.

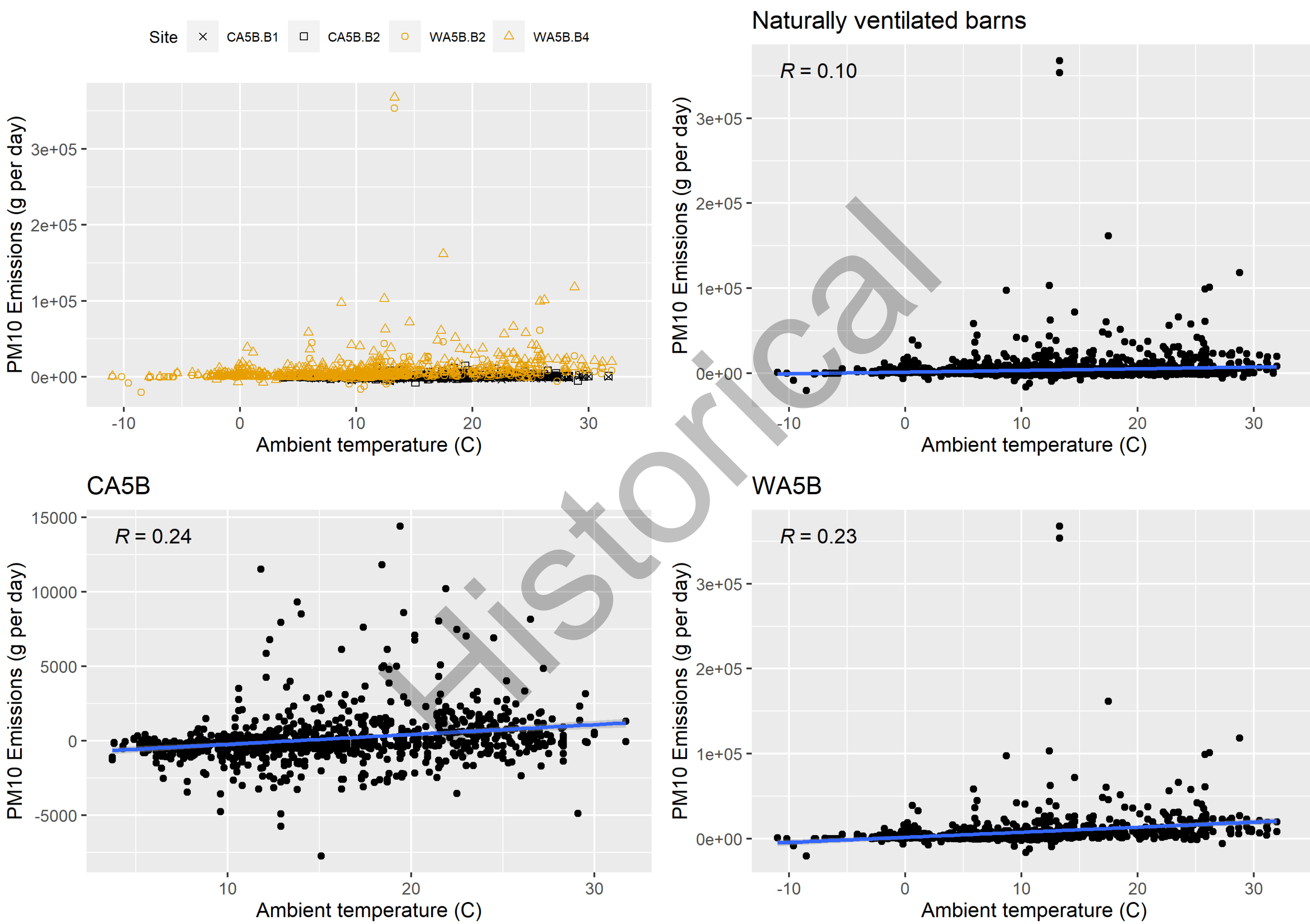


Figure F-113. Scatter plot of naturally ventilated barns PM_{10} emissions versus ambient temperature and scatter plot with regression.

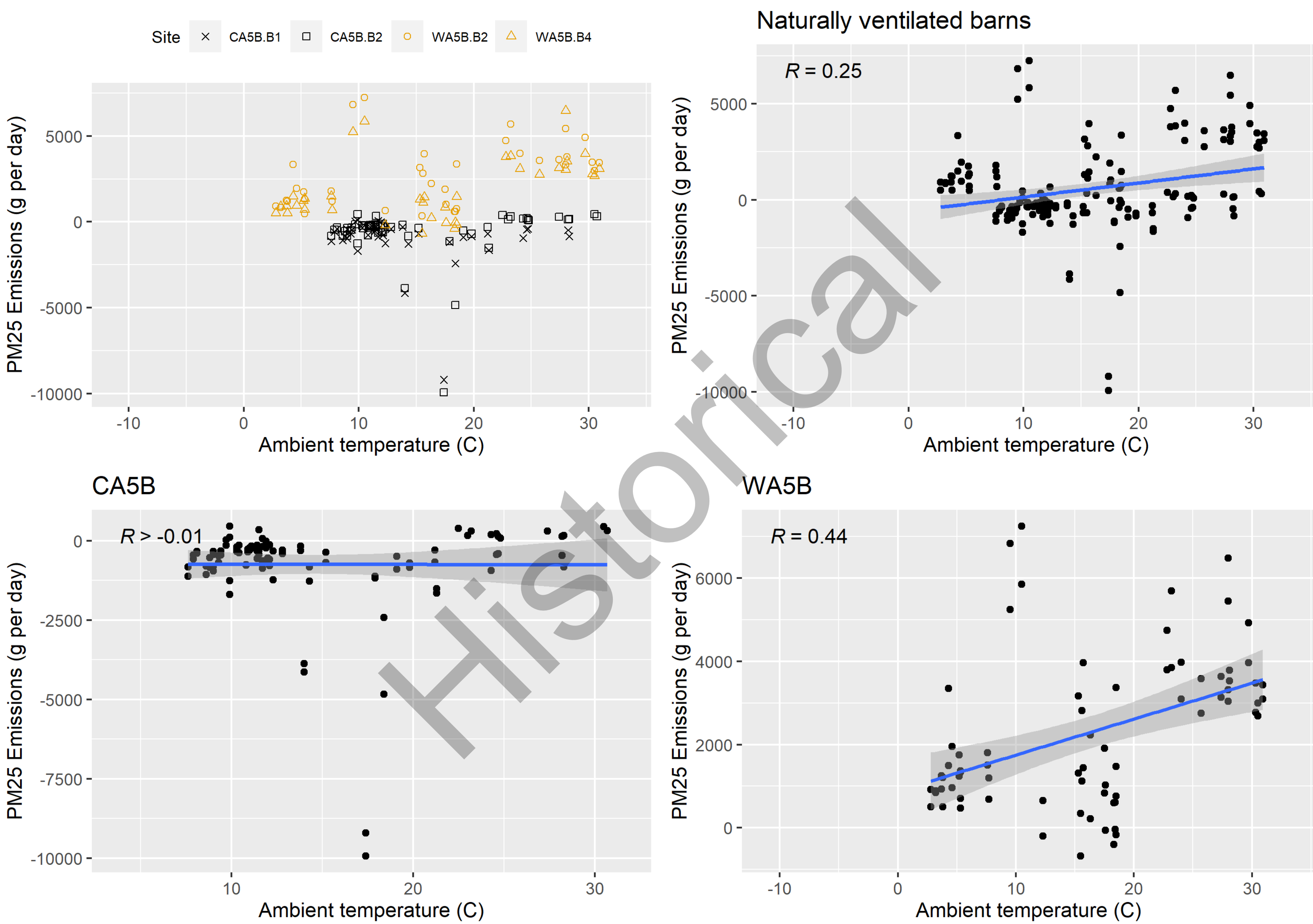


Figure F-114. Scatter plot of naturally ventilated barns $PM_{2.5}$ emissions versus ambient temperature and scatter plot with regression.

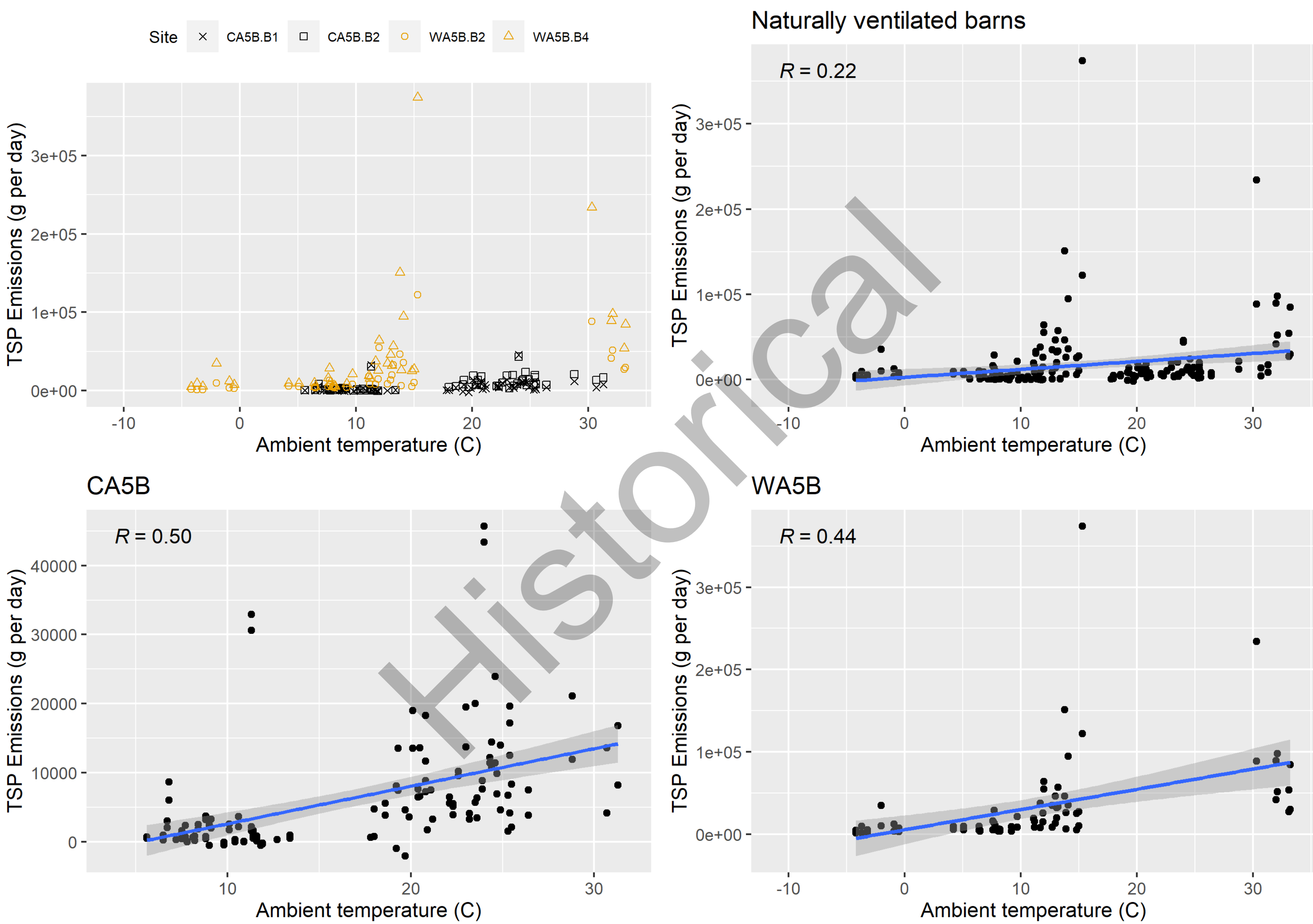


Figure F-115. Scatter plot of naturally ventilated barns TSP emissions versus ambient temperature and scatter plot with regression.

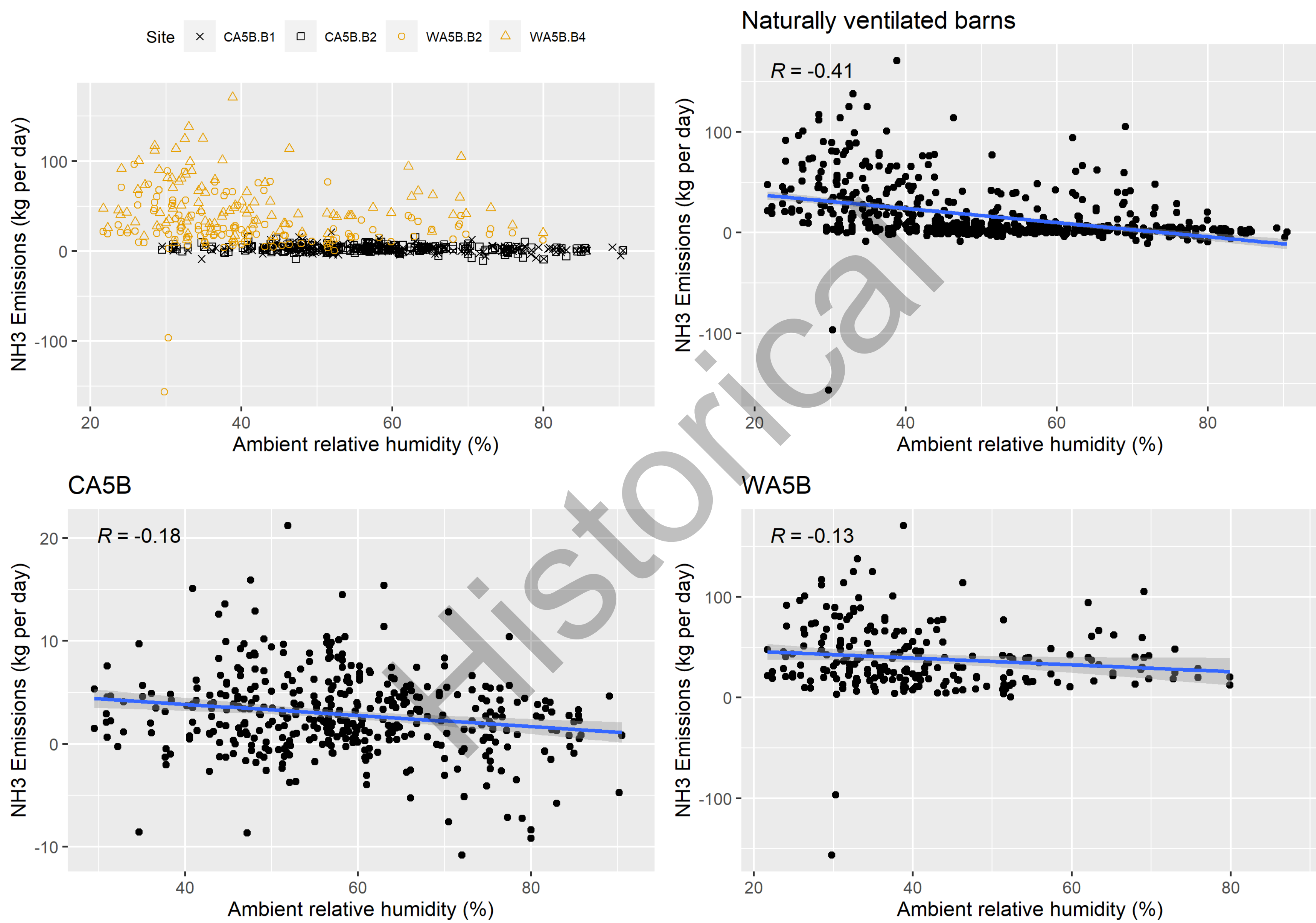


Figure F-116. Scatter plot of naturally ventilated barns NH_3 emissions versus ambient relative humidity and scatter plot with regression.

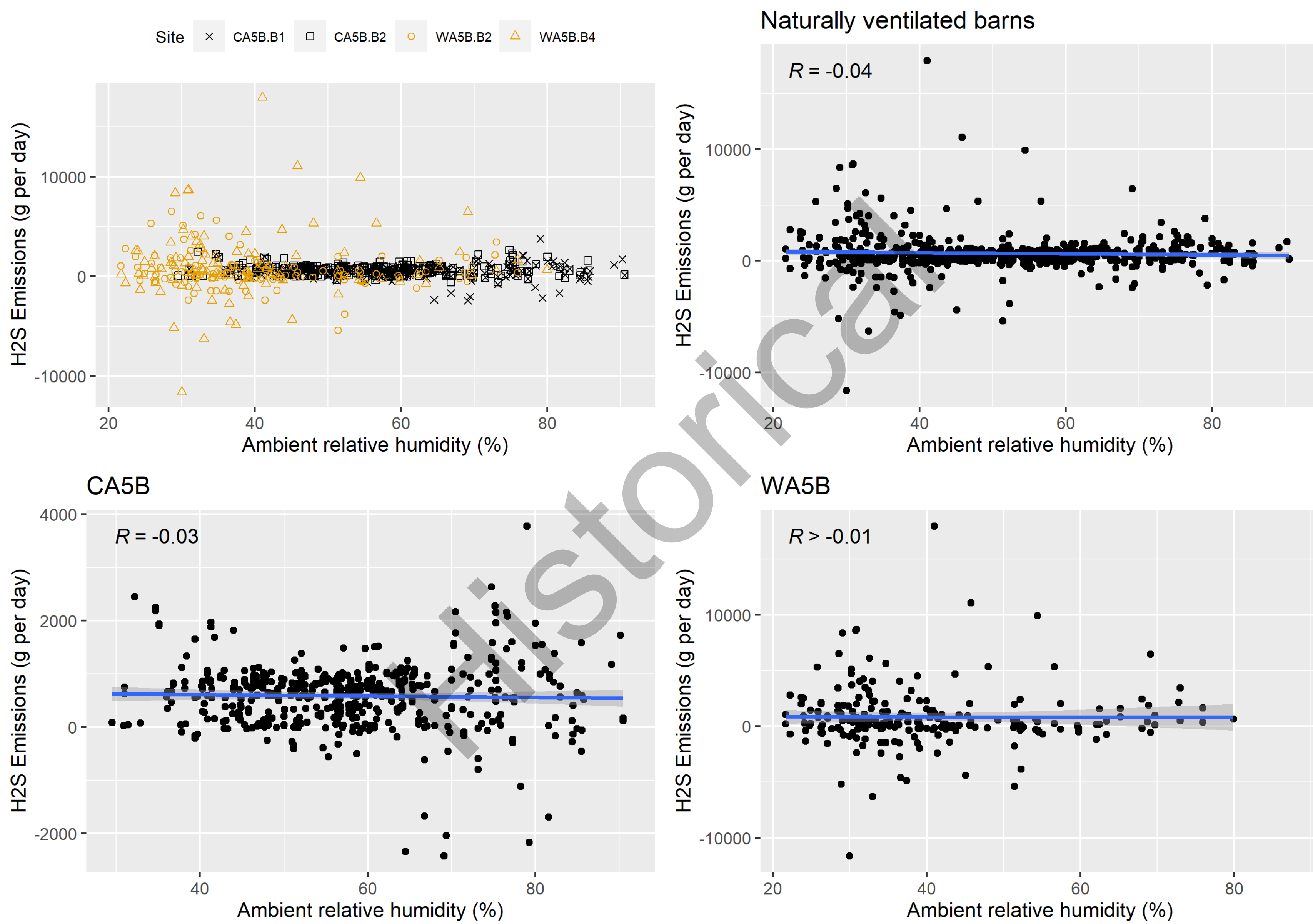


Figure F-117. Scatter plot of naturally ventilated barns H_2S emissions versus ambient relative humidity and scatter plot with regression.

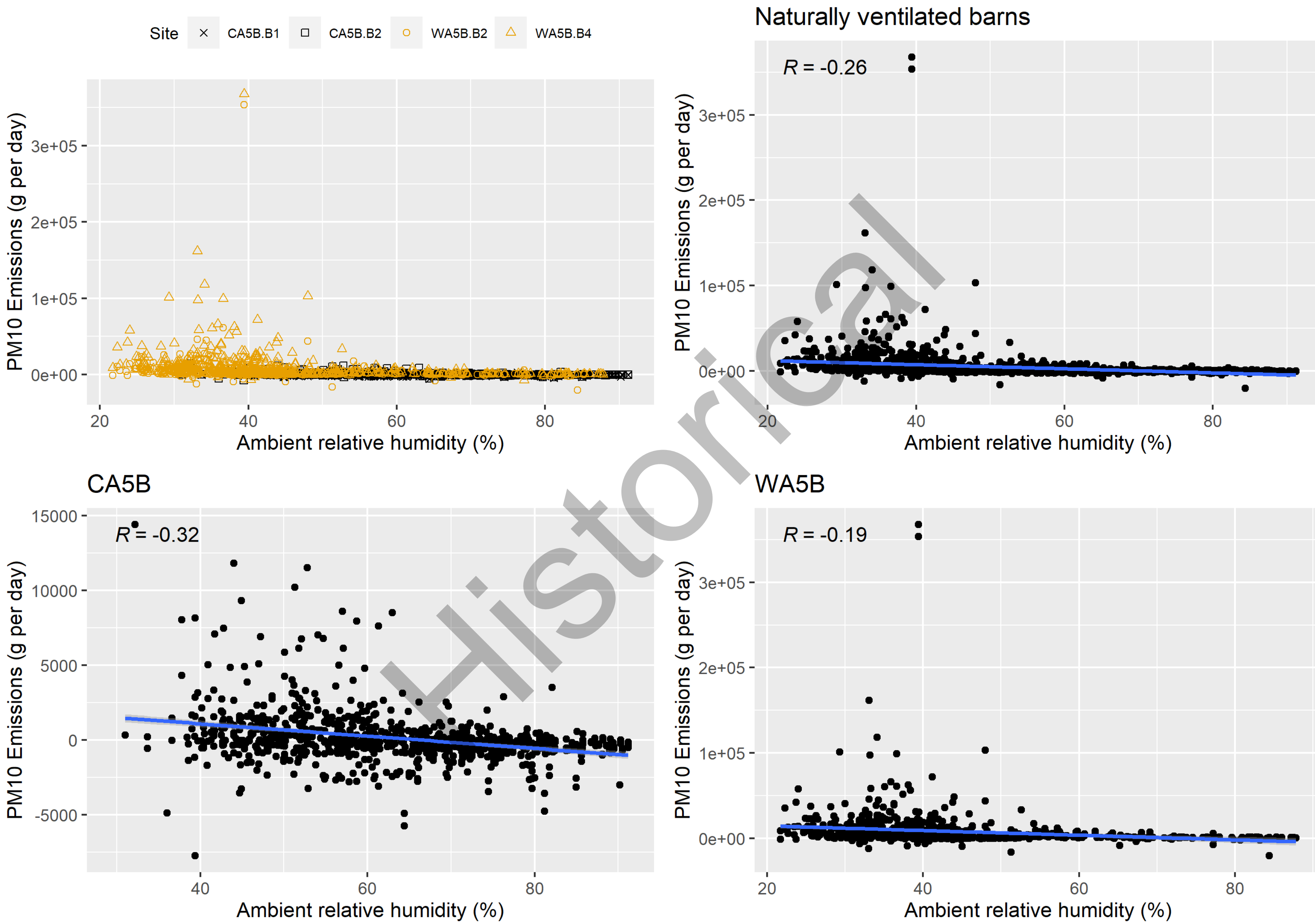
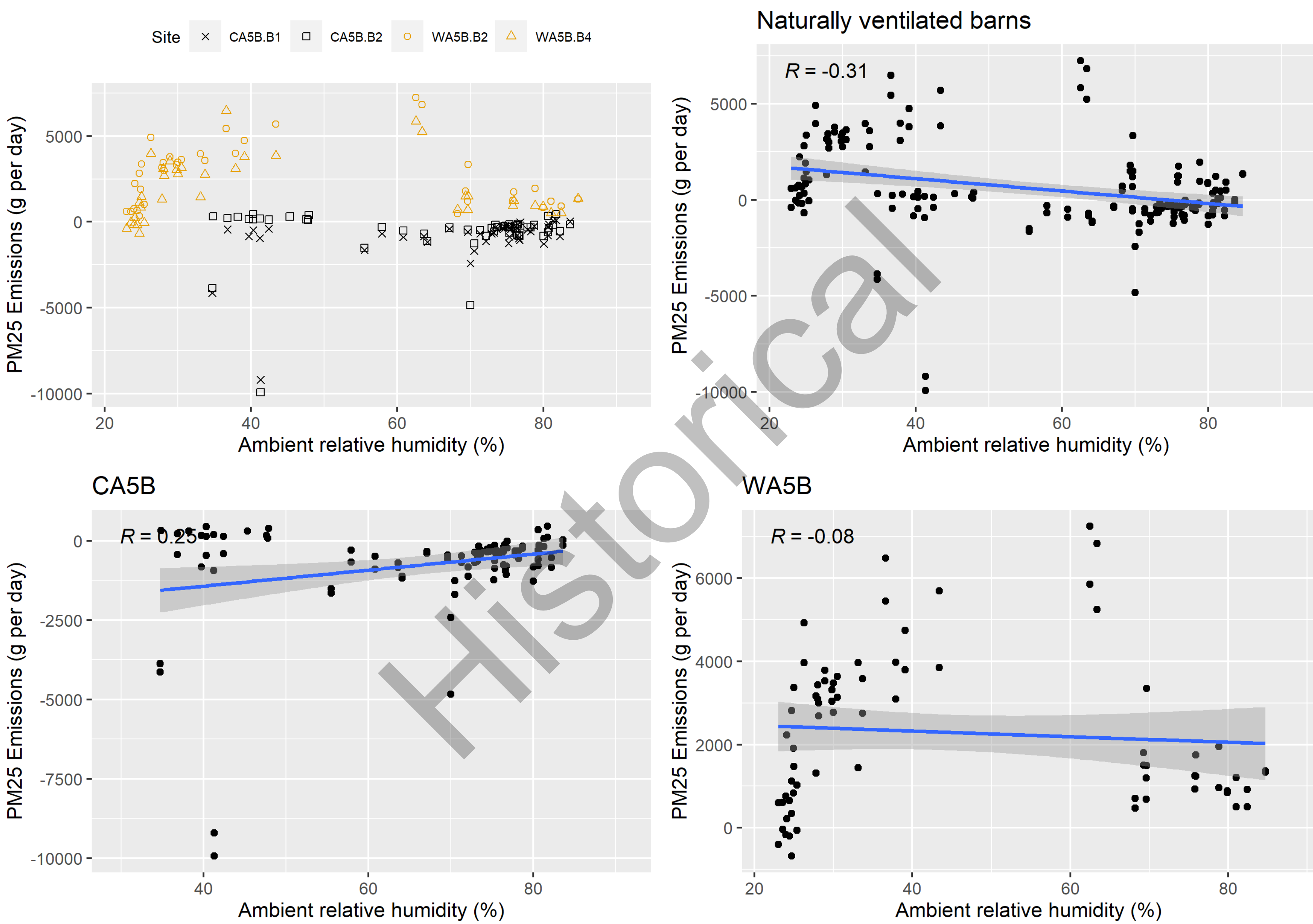


Figure F-118. Scatter plot of naturally ventilated barns PM_{10} emissions versus ambient relative humidity and scatter plot with regression.



Site
CA5B.B1
CA5B.B2
WA5B.B2
WA5B.B4
PM25 Emissions (g per day)
Ambient relative humidity (%)
Naturally ventilated barns
R = -0.31
CA5B
R = 0.25
WA5B
R = -0.08

Figure F-119. Scatter plot of naturally ventilated barns $PM_{2.5}$ emissions versus ambient relative humidity and scatter plot with regression.

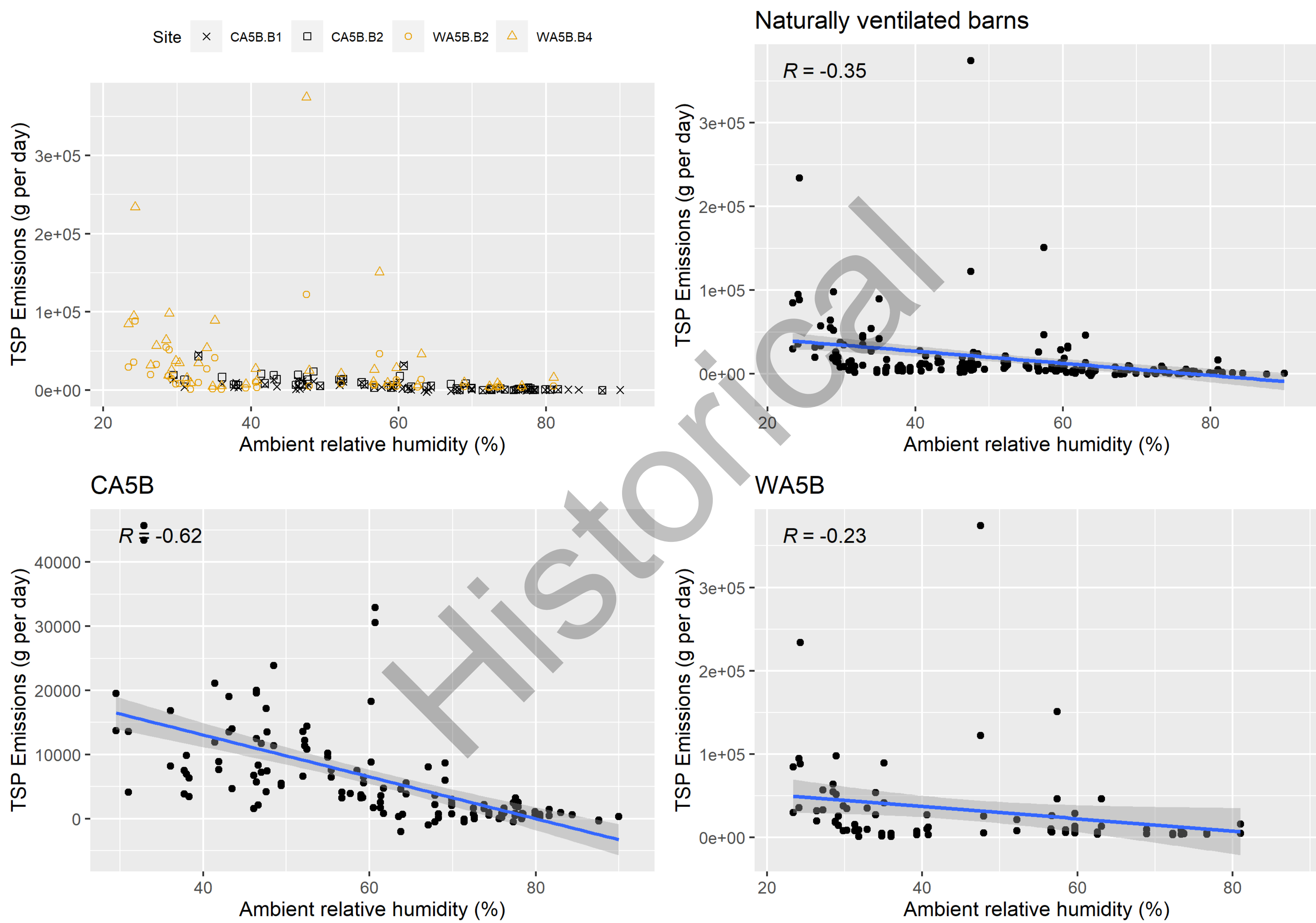


Figure F-120. Scatter plot of naturally ventilated barns TSP emissions versus ambient relative humidity and scatter plot with regression.

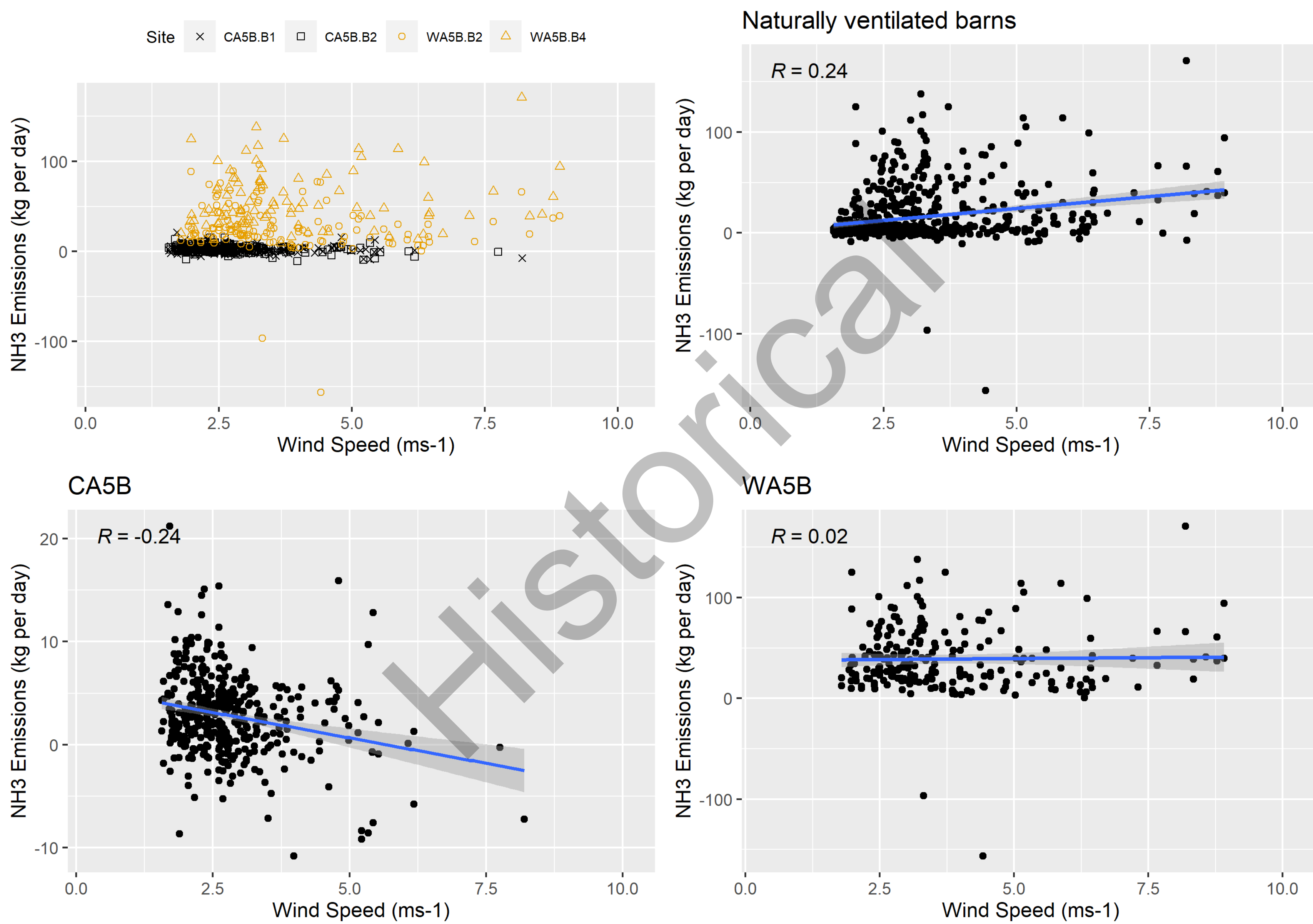


Figure F-121. Scatter plot of naturally ventilated barns NH_3 emissions versus wind speed and scatter plot with regression.

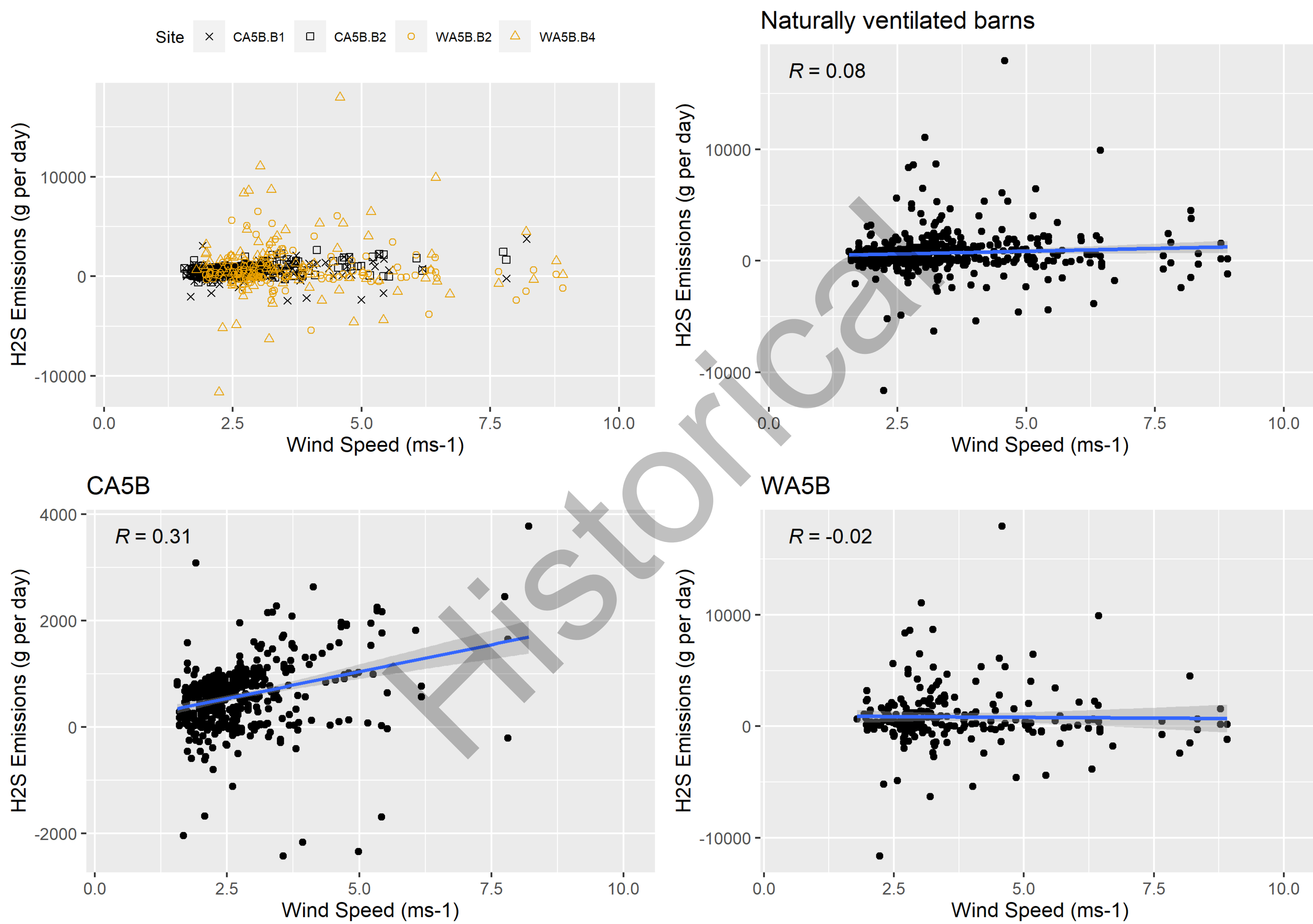


Figure F-122. Scatter plot of naturally ventilated barns H_2S emissions versus wind speed and scatter plot with regression.

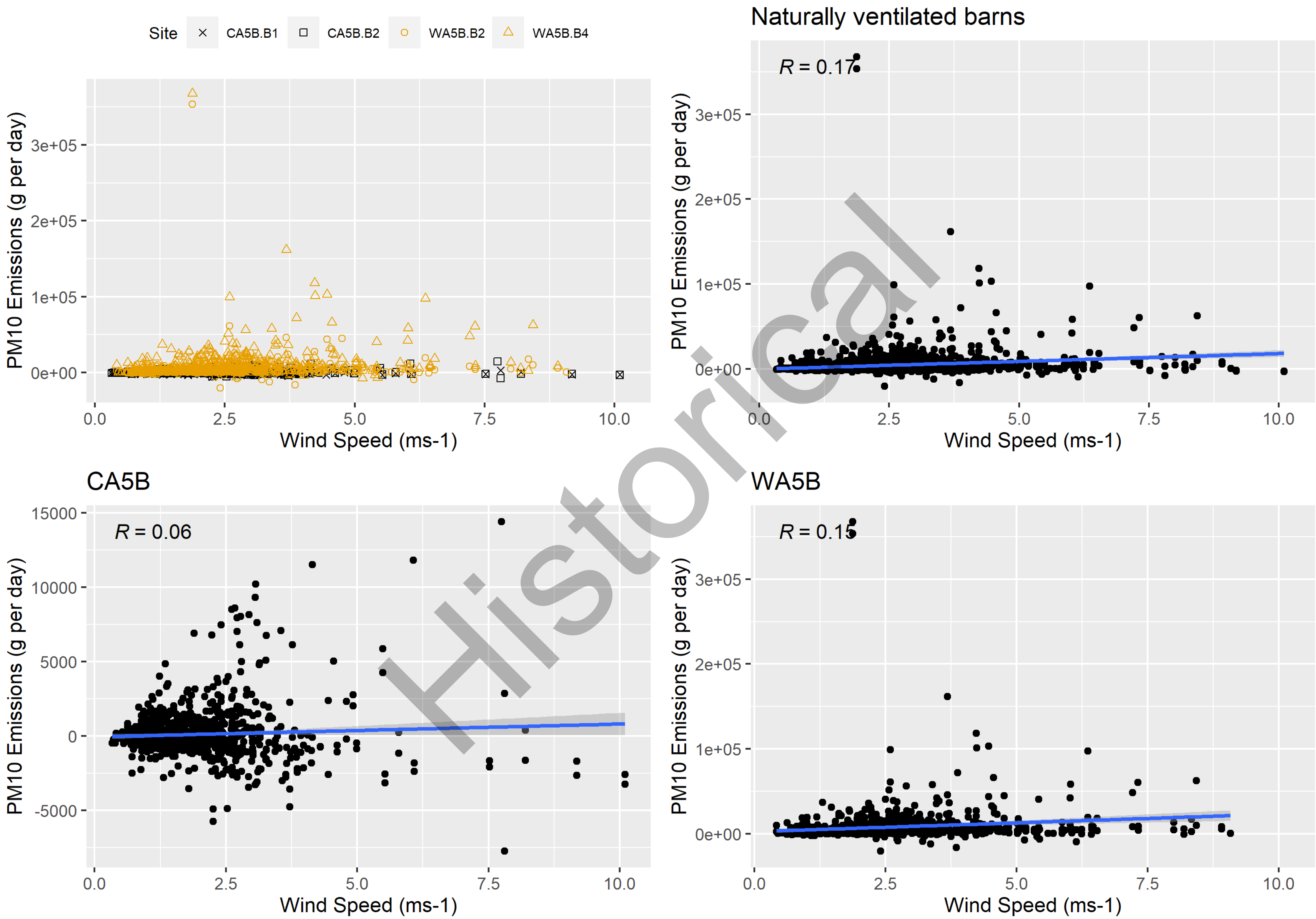


Figure F-123. Scatter plot of naturally ventilated barns PM_{10} emissions versus wind speed and scatter plot with regression.

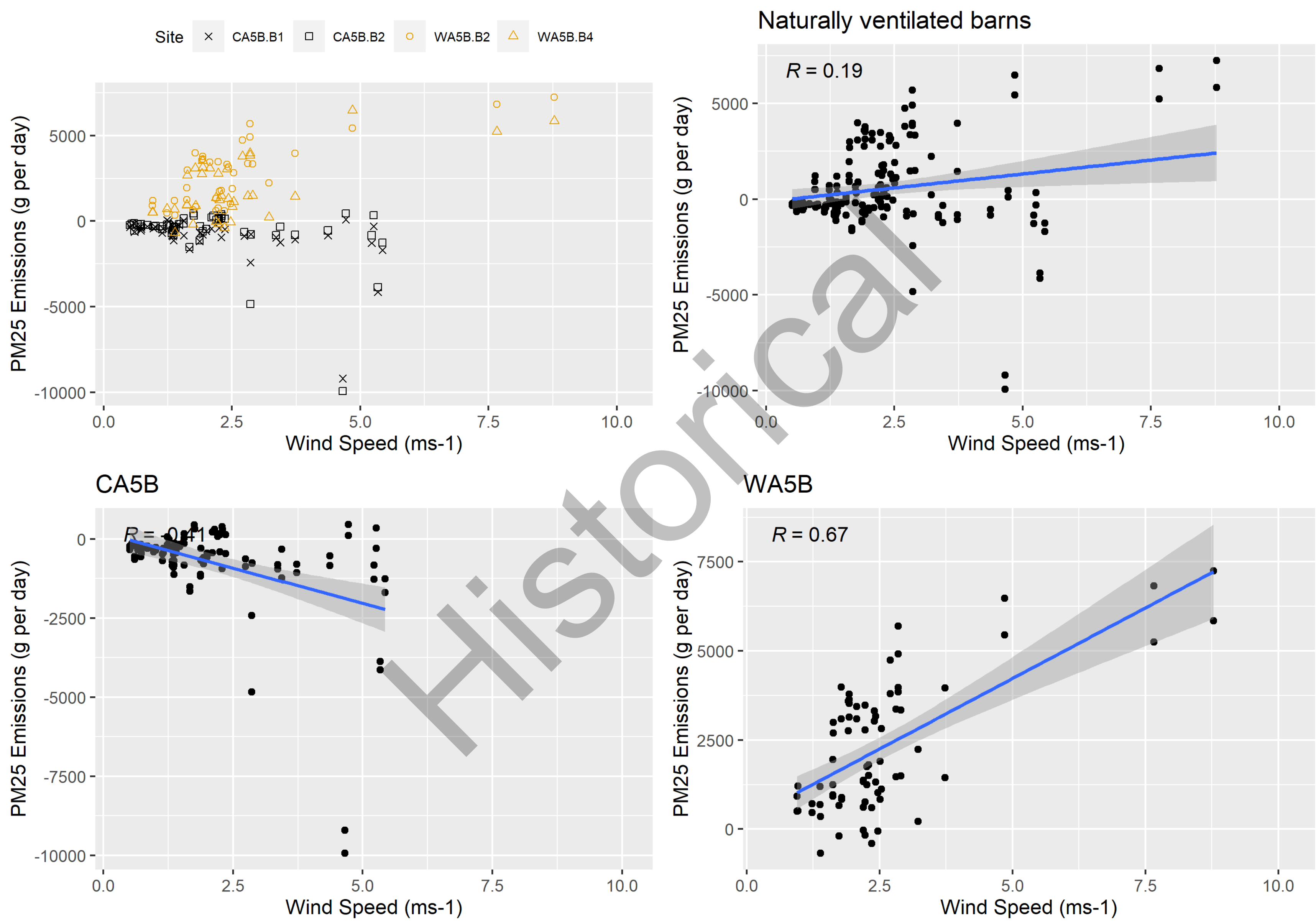


Figure F-124. Scatter plot of naturally ventilated barns $PM_{2.5}$ emissions versus wind speed and scatter plot with regression.

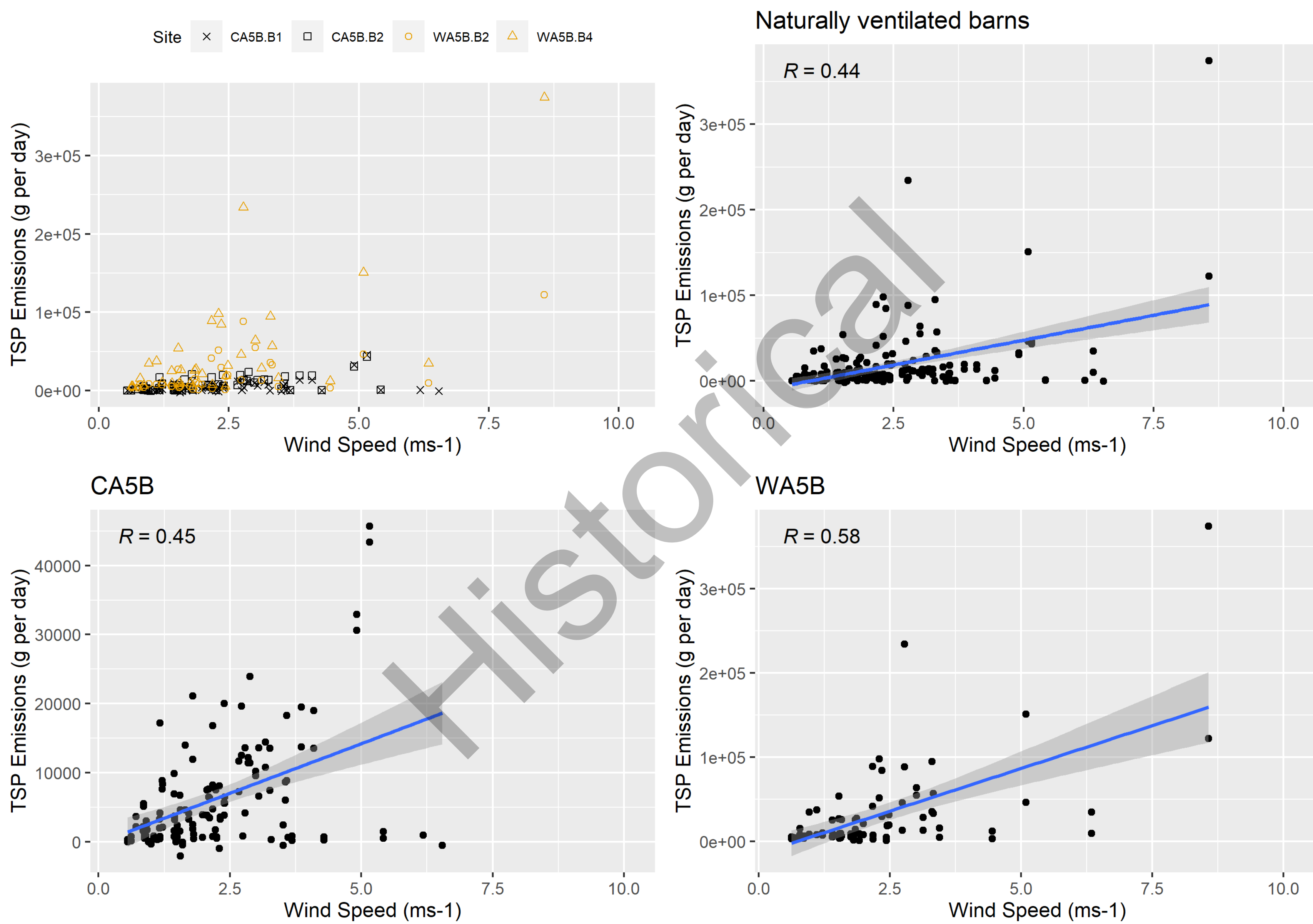


Figure F-125. Scatter plot of naturally ventilated barns TSP emissions versus wind speed and scatter plot with regression.

F.4 Lagoon/basin

F.4.1 Environmental Parameters

Table F-8. Summary of lagoons/basins R^2 values for environmental parameters.

Pollutant	Parameter	R	R^2	Strength	Figure
NH_3	Lagoon temperature	0.66	0.436	moderate	F-126
H_2S	Lagoon temperature	-0.68	0.462	moderate	F-127
NH_3	Lagoon pH	-0.2	0.040	slight or weak	F-128
H_2S	Lagoon pH	0.4	0.160	slight or weak	F-129

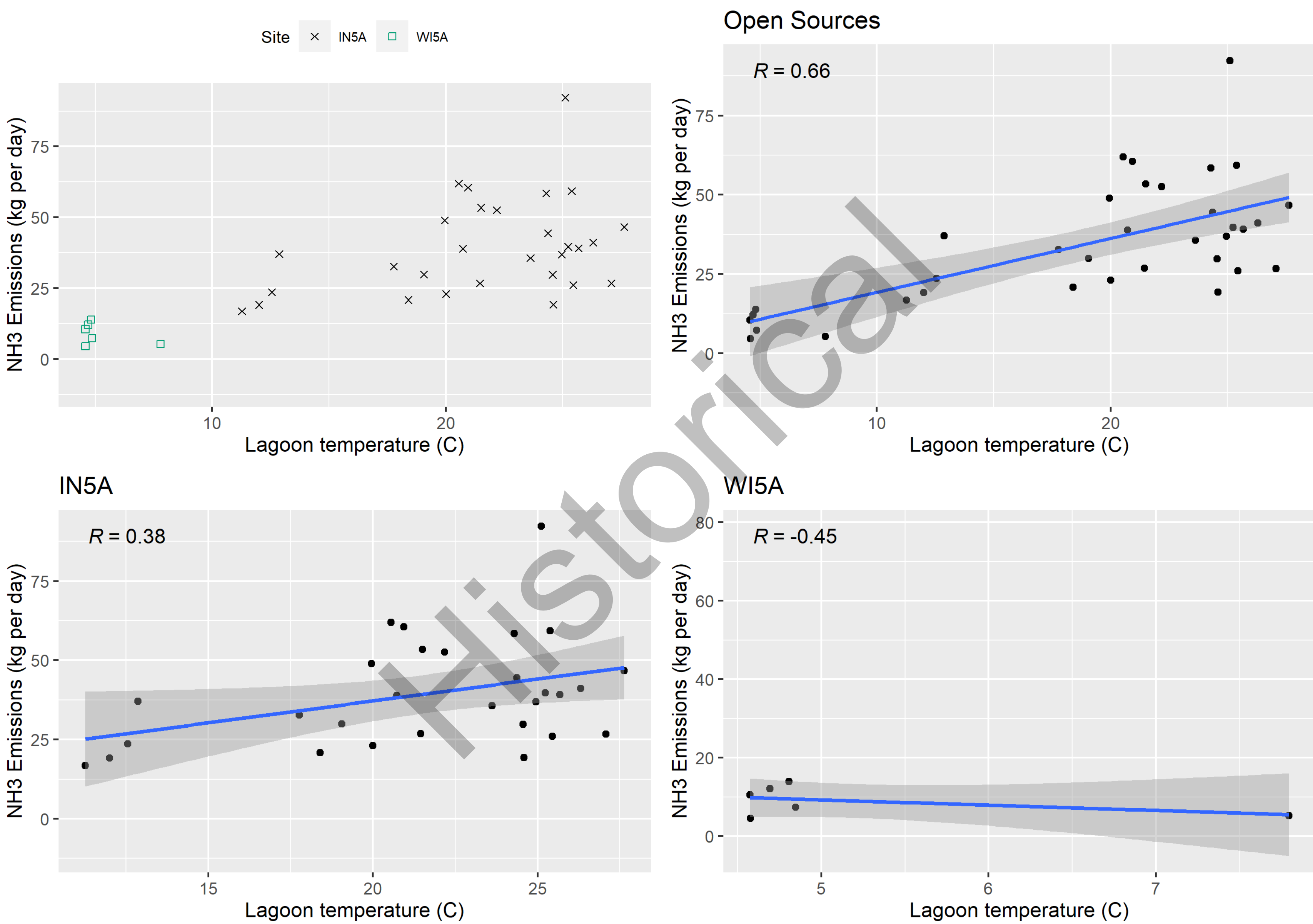


Figure F-126. Scatter plot of lagoon/basin NH_3 emissions versus lagoon temperature and scatter plot with regression.

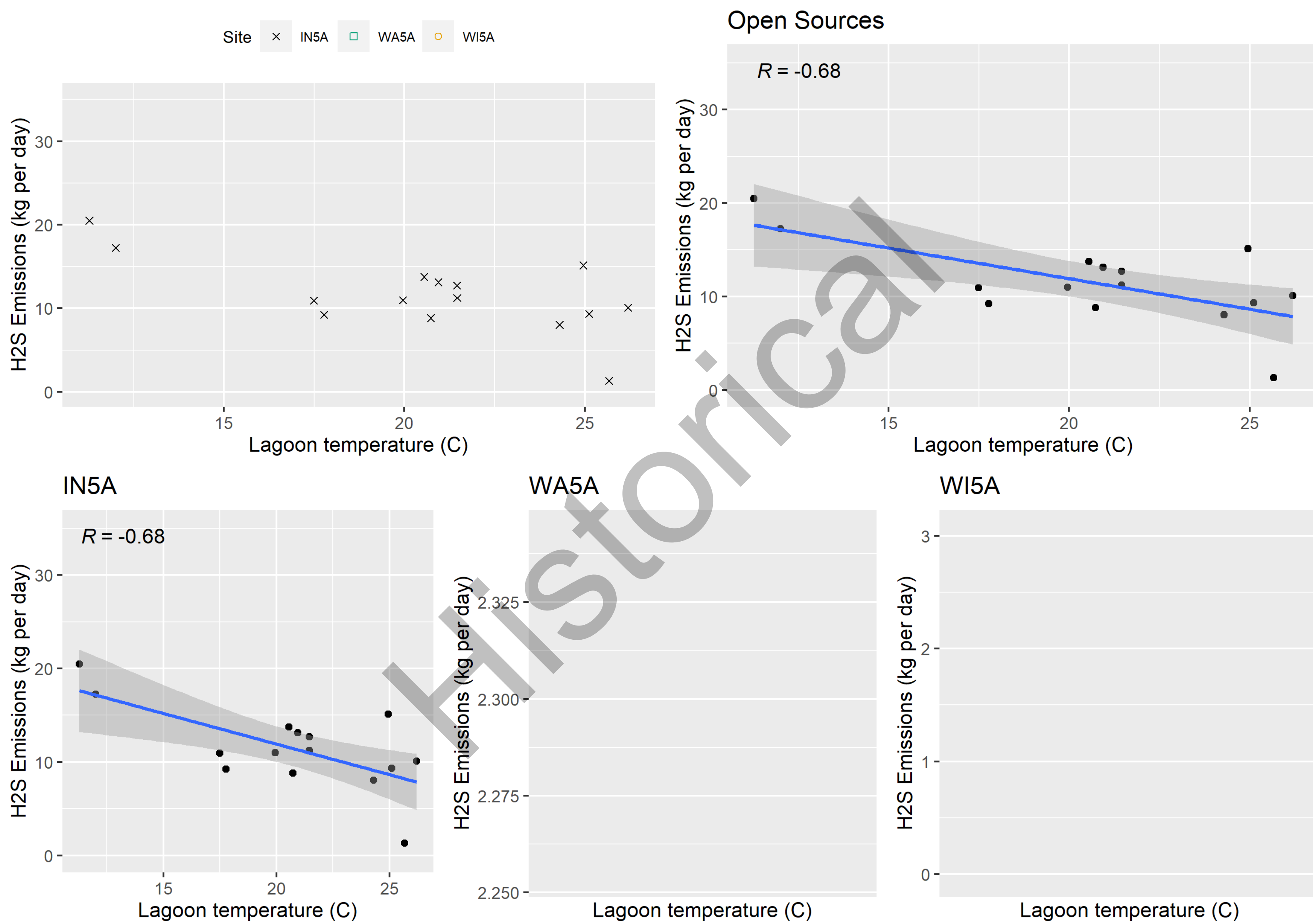


Figure F-127. Scatter plot of lagoon/basin H_2S emissions versus lagoon temperature and scatter plot with regression.

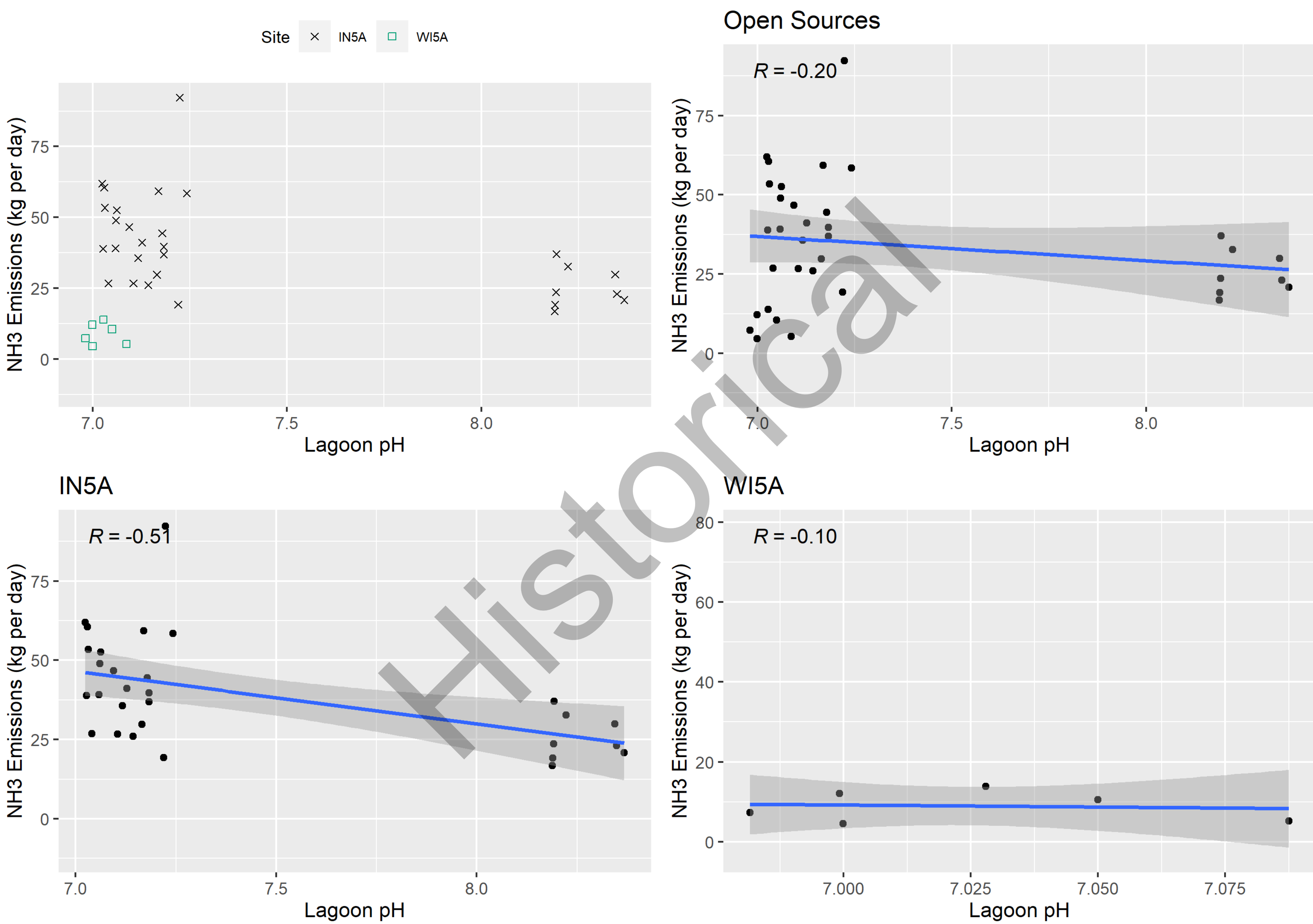


Figure F-128. Scatter plot of lagoon/basin NH_3 emissions versus lagoon pH and scatter plot with regression.

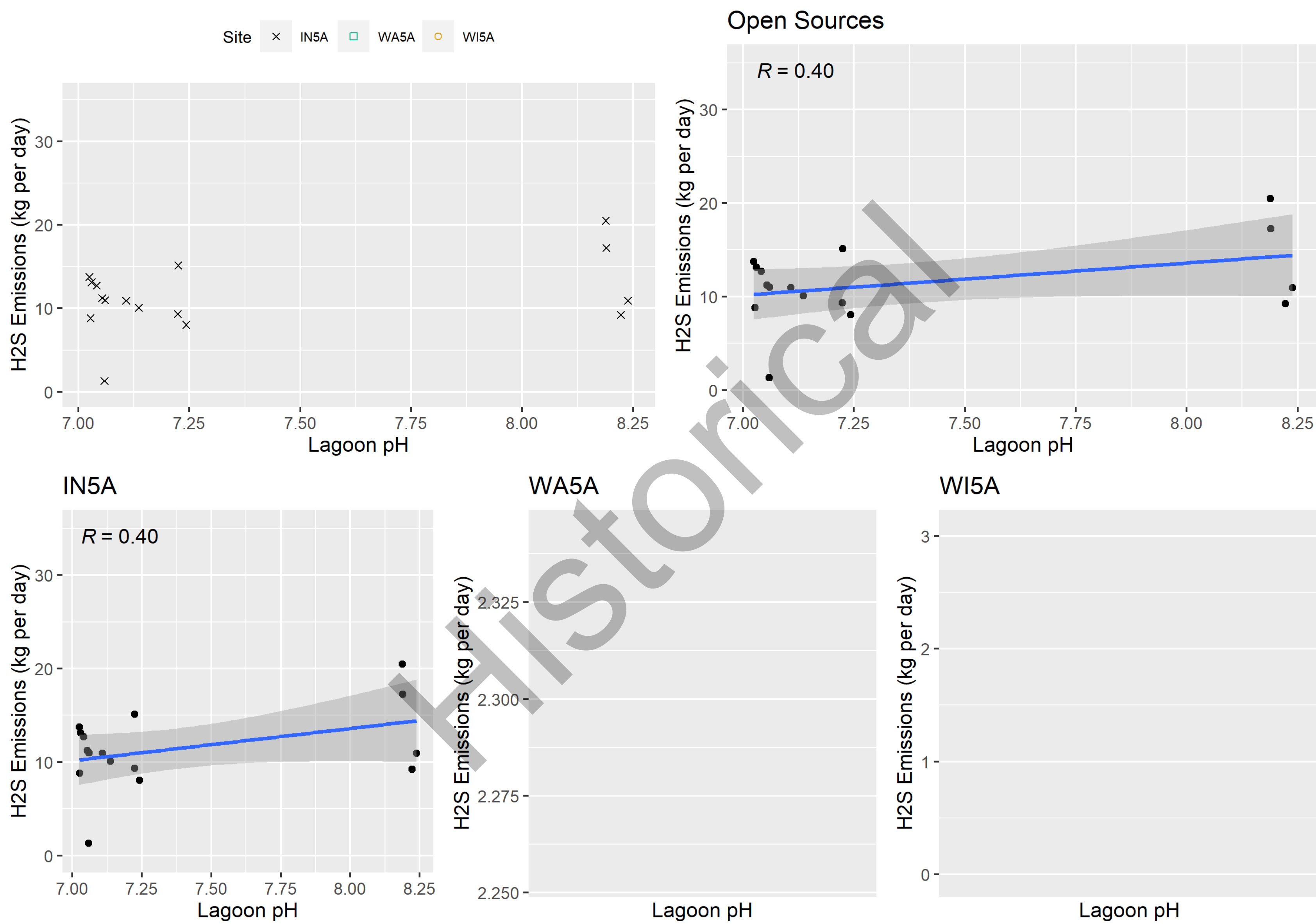


Figure F-129. Scatter plot of lagoon/basin H_2S emissions versus lagoon pH and scatter plot with regression.

F.4.2 Ambient Parameters

Table F-9. Summary of lagoons/basins R^2 values for ambient parameters.

Pollutant	Parameter	R	R^2	Strength	Figure
NH_3	Ambient temperature	0.84	0.706	moderately strong	F-130
H_2S	Ambient temperature	0.59	0.348	modest	F-131
NH_3	Ambient relative humidity	-0.34	0.116	slight or weak	F-132
H_2S	Ambient relative humidity	-0.18	0.032	slight or weak	F-133
NH_3	Wind speed	-0.25	0.063	slight or weak	F-134
H_2S	Wind speed	0.10	0.010	slight or weak	F-135

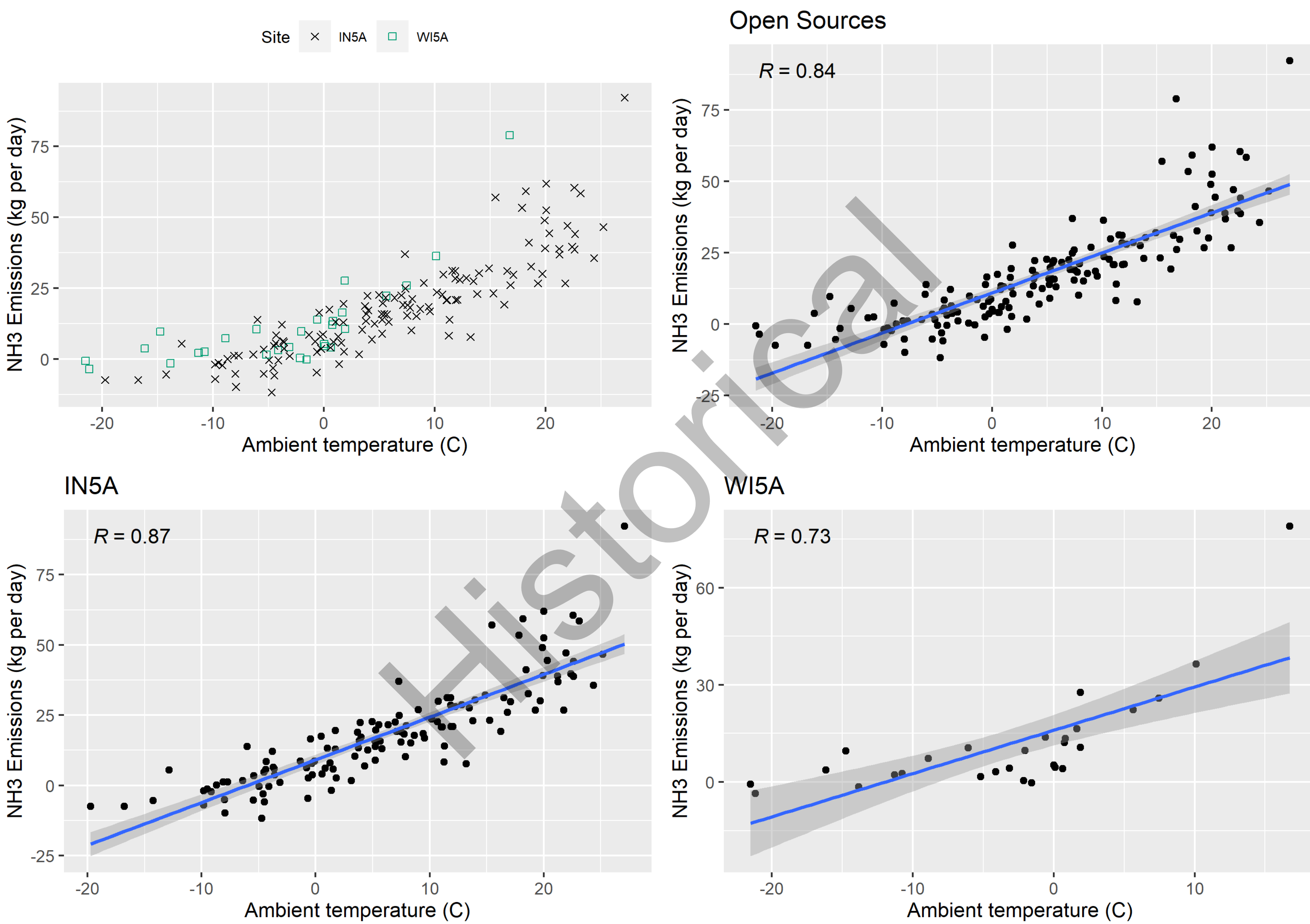


Figure F-130. Scatter plot of lagoon/basin NH_3 emissions versus ambient temperature and scatter plot with regression.

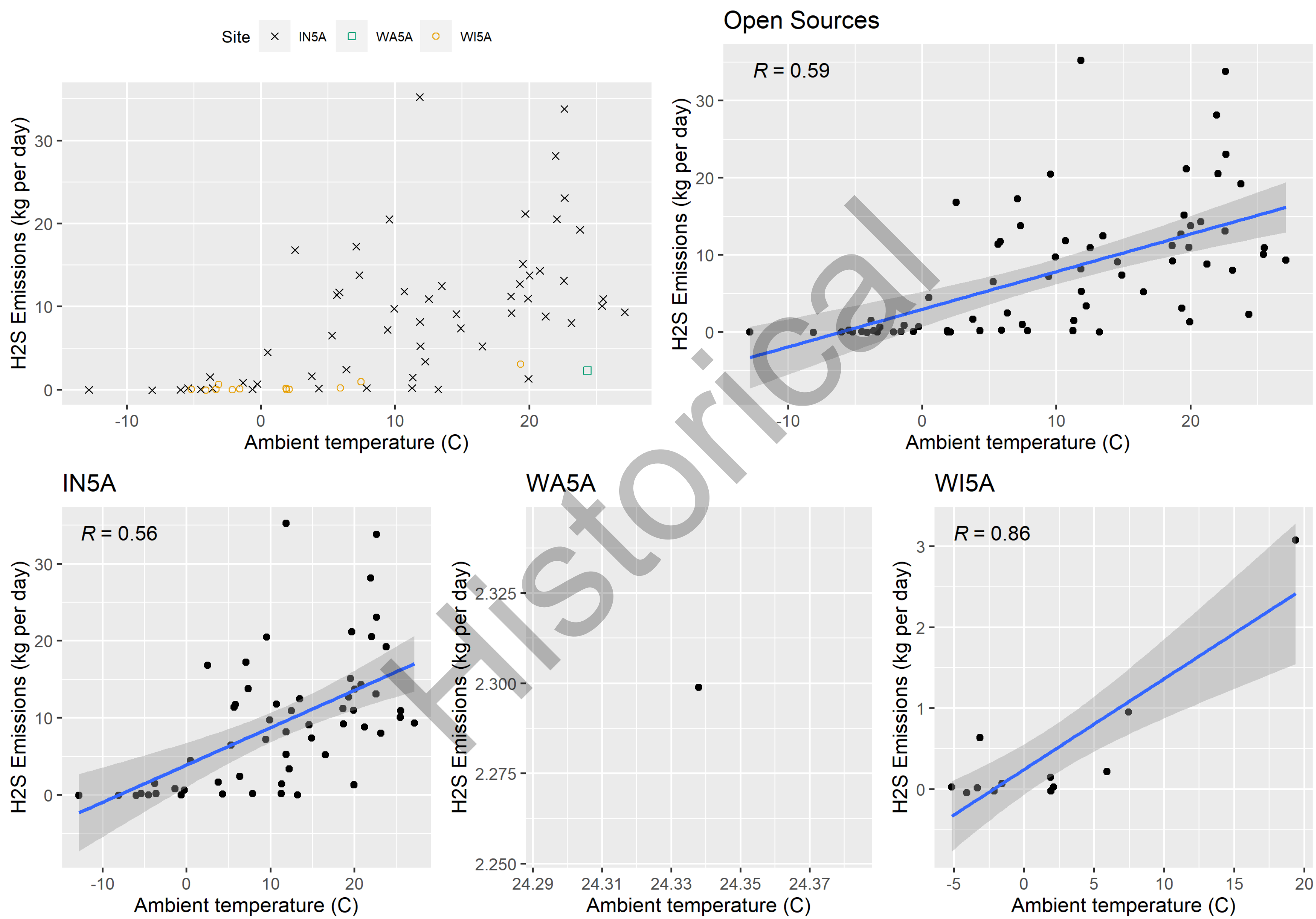


Figure F-131. Scatter plot of lagoon/basin H_2S emissions versus ambient temperature and scatter plot with regression.

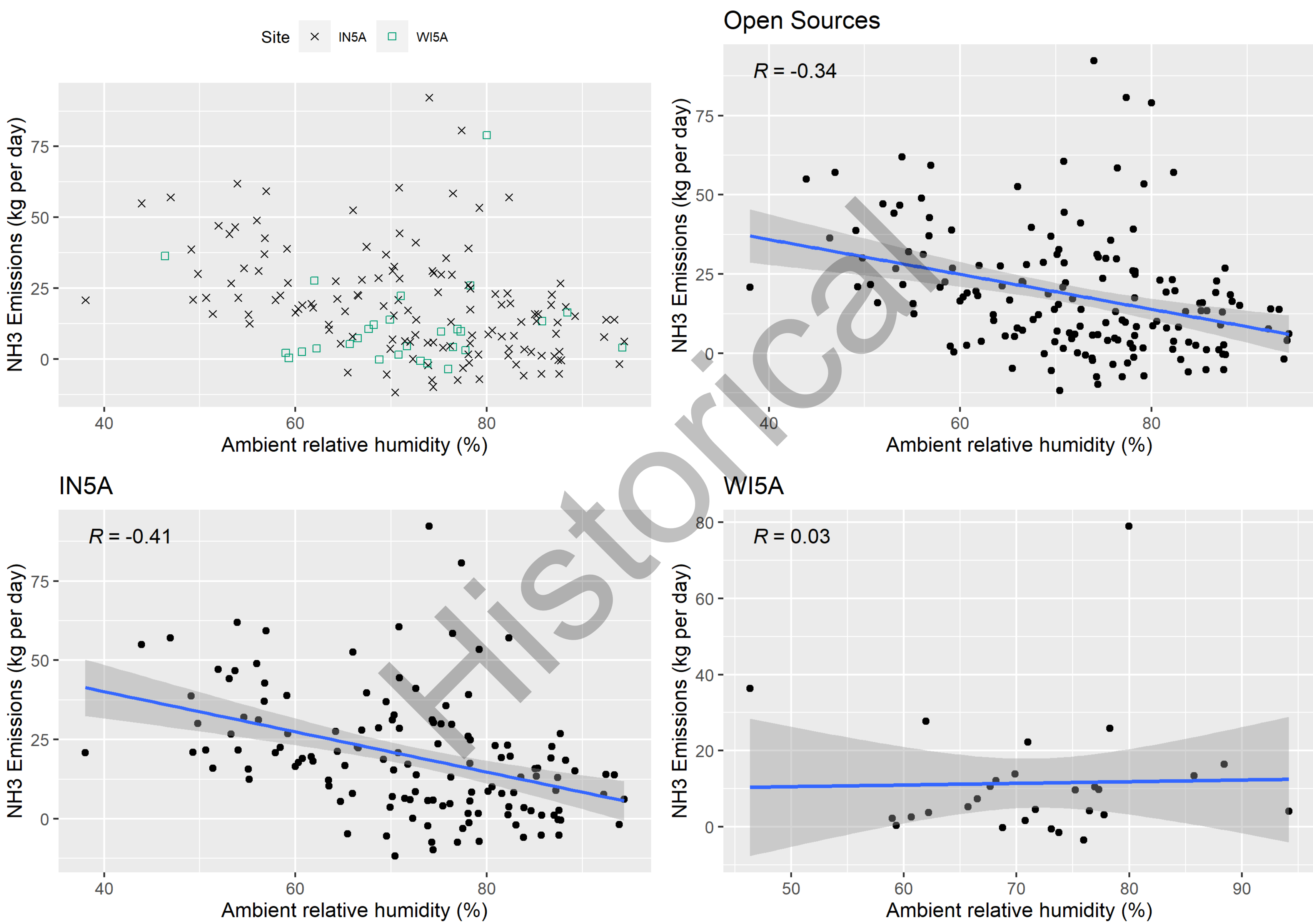


Figure F-132. Scatter plot of lagoon/basin NH_3 emissions versus ambient relative humidity and scatter plot with regression.

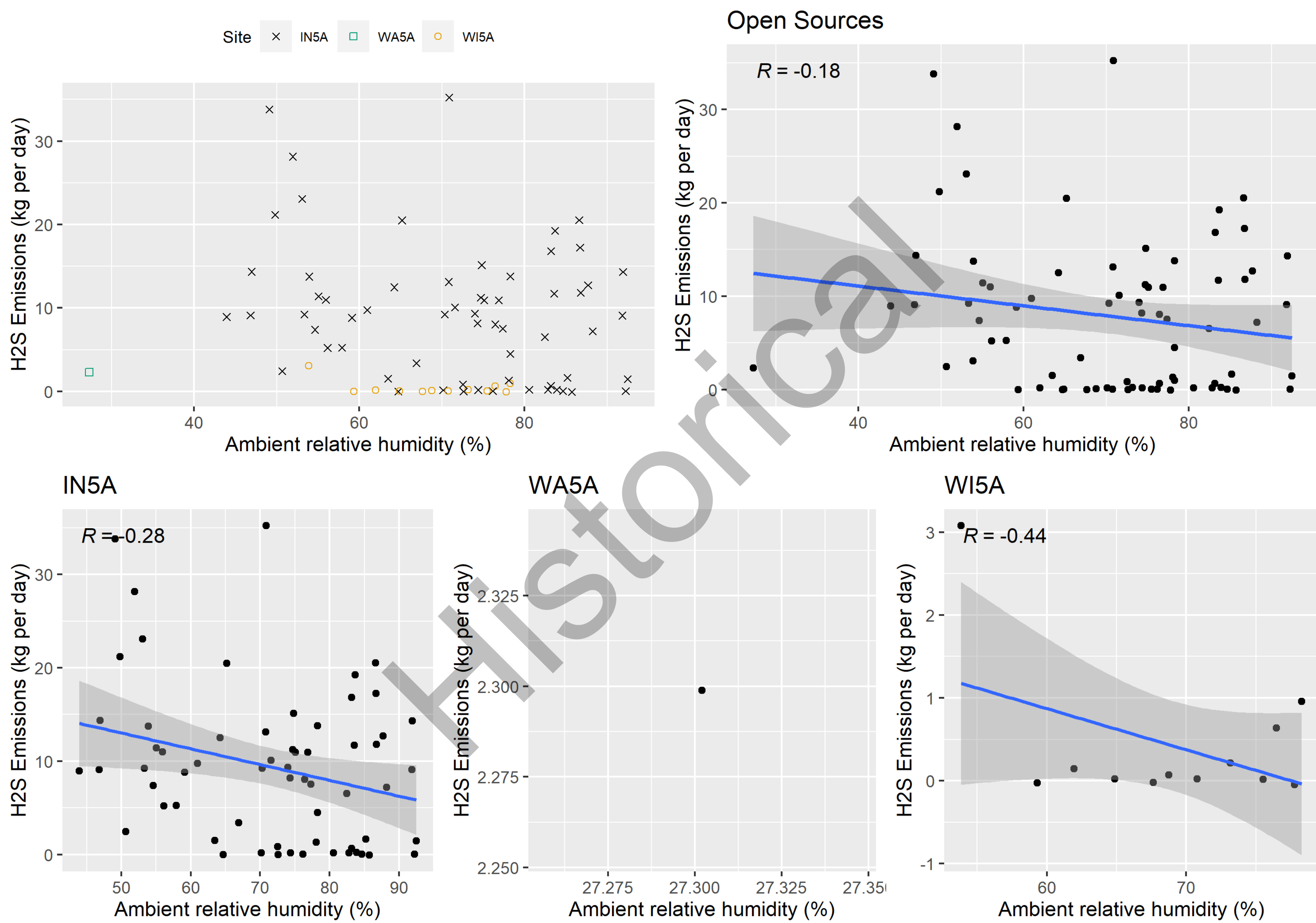


Figure F-133. Scatter plot of lagoon/basin H_2S emissions versus ambient relative humidity and scatter plot with regression.

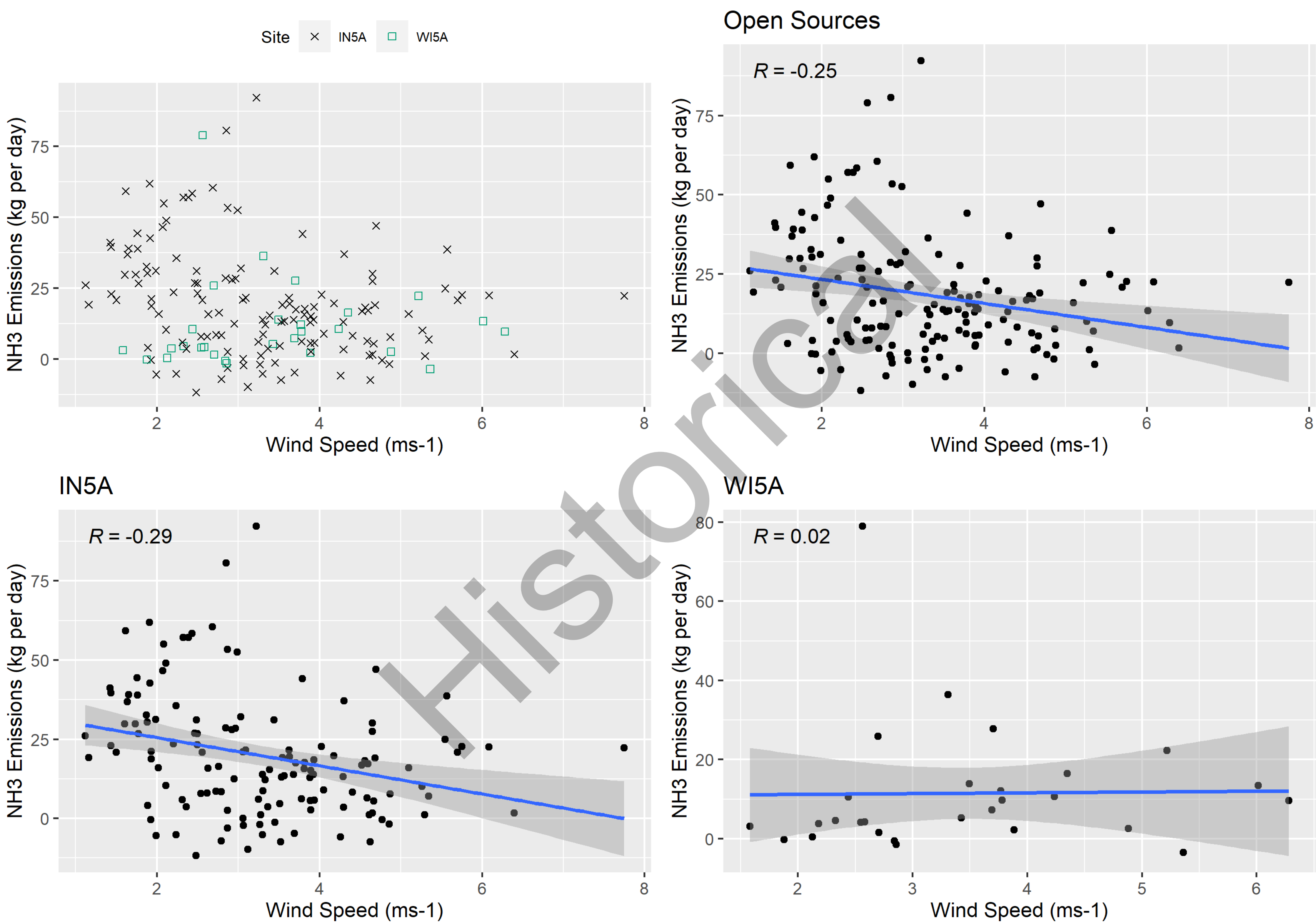


Figure F-134. Scatter plot of lagoon/basin NH_3 emissions versus wind speed and scatter plot with regression.

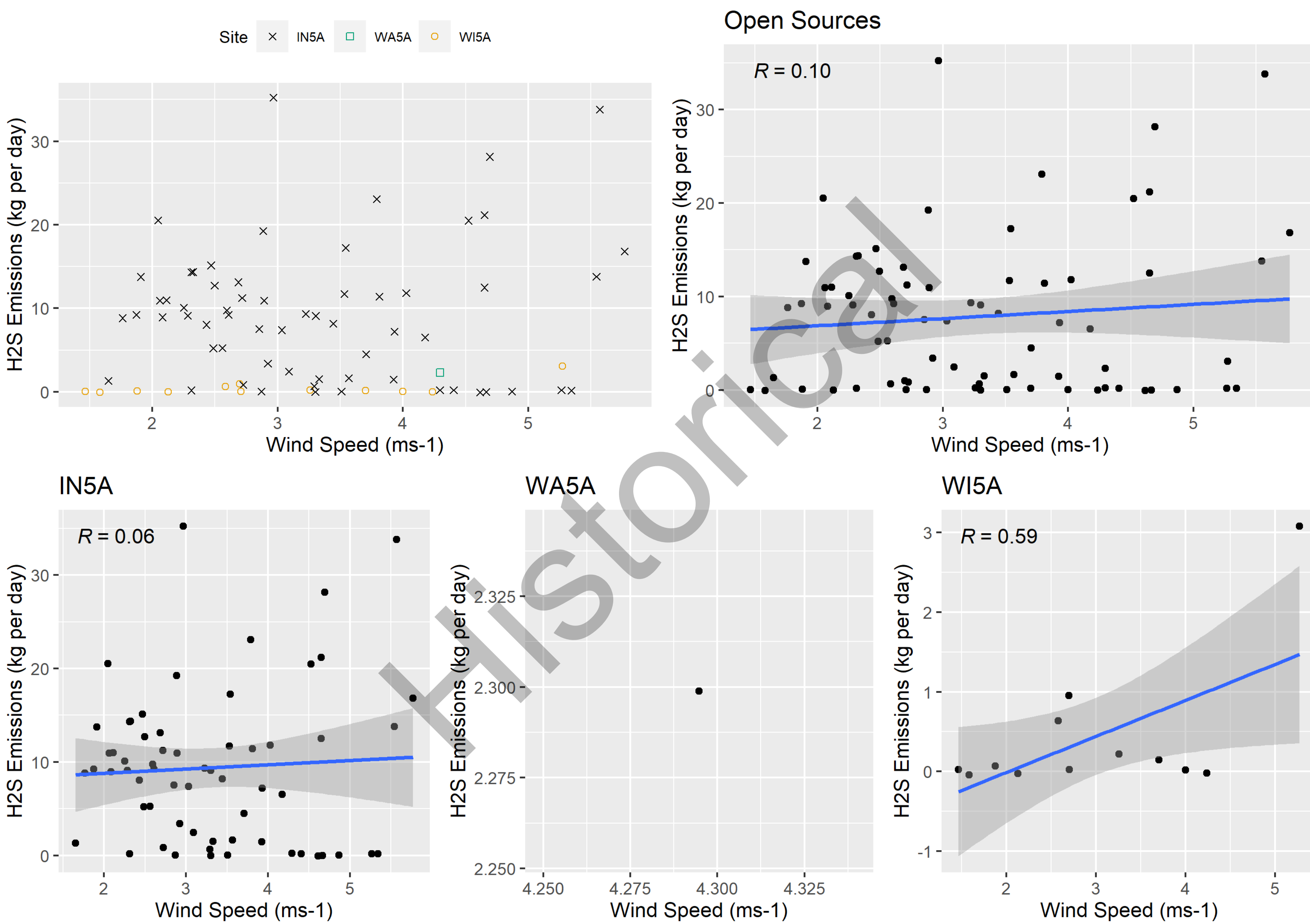


Figure F-135. Scatter plot of lagoon/basin H_2S emissions versus wind speed and scatter plot with regression.

F.5 Corral

F.5.1 Ambient Parameters

Table F-10. Summary of corral R^2 values for ambient parameters.

Pollutant	Parameter	R	R^2	Strength	Figure
NH_3	Ambient temperature	0.17	0.029	slight or weak	F-136
H_2S	Ambient temperature	0.003	0.000	slight or weak	F-137
NH_3	Ambient relative humidity	0.17	0.029	slight or weak	F-138
H_2S	Ambient relative humidity	0.15	0.023	slight or weak	F-139
NH_3	Wind speed	0.002	0.000	slight or weak	F-140
H_2S	Wind speed	0.003	0.000	slight or weak	F-141
NH_3	Water vapor deficit	0.32	0.102	slight or weak	F-142
H_2S	Water vapor deficit	-0.16	0.026	slight or weak	F-143

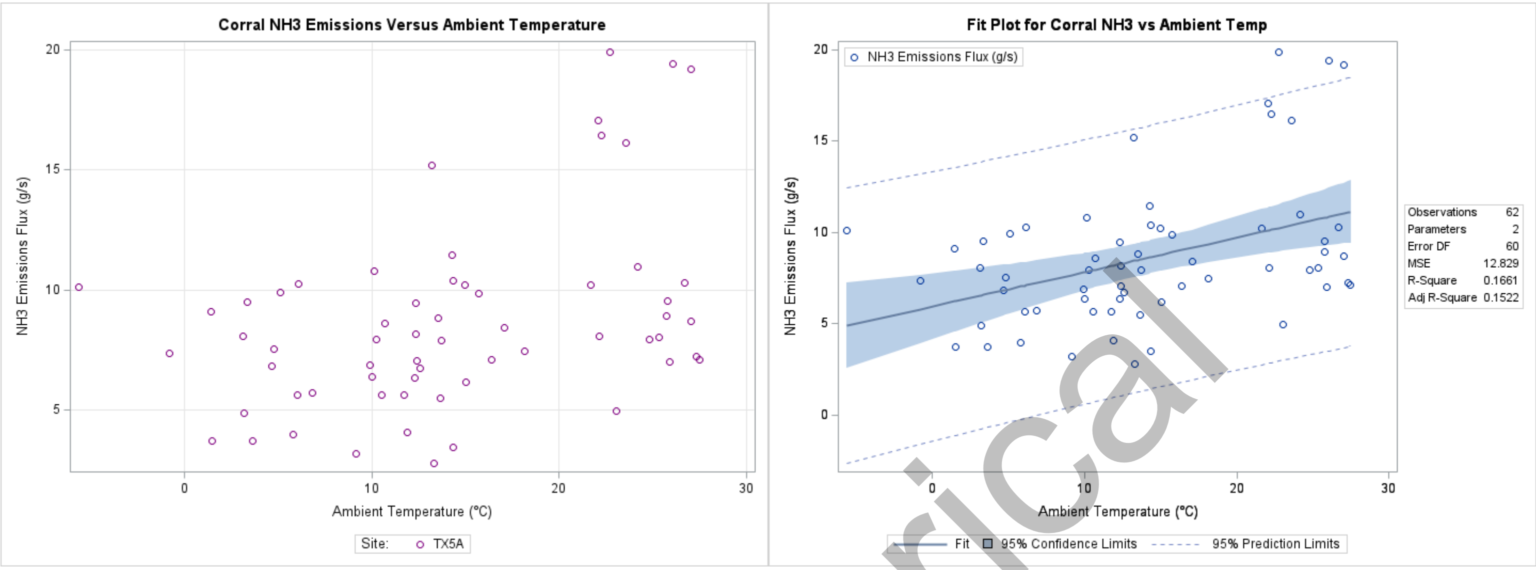


Figure F-136. Scatter plot of corral NH_3 emissions versus ambient temperature and scatter plot with regression.

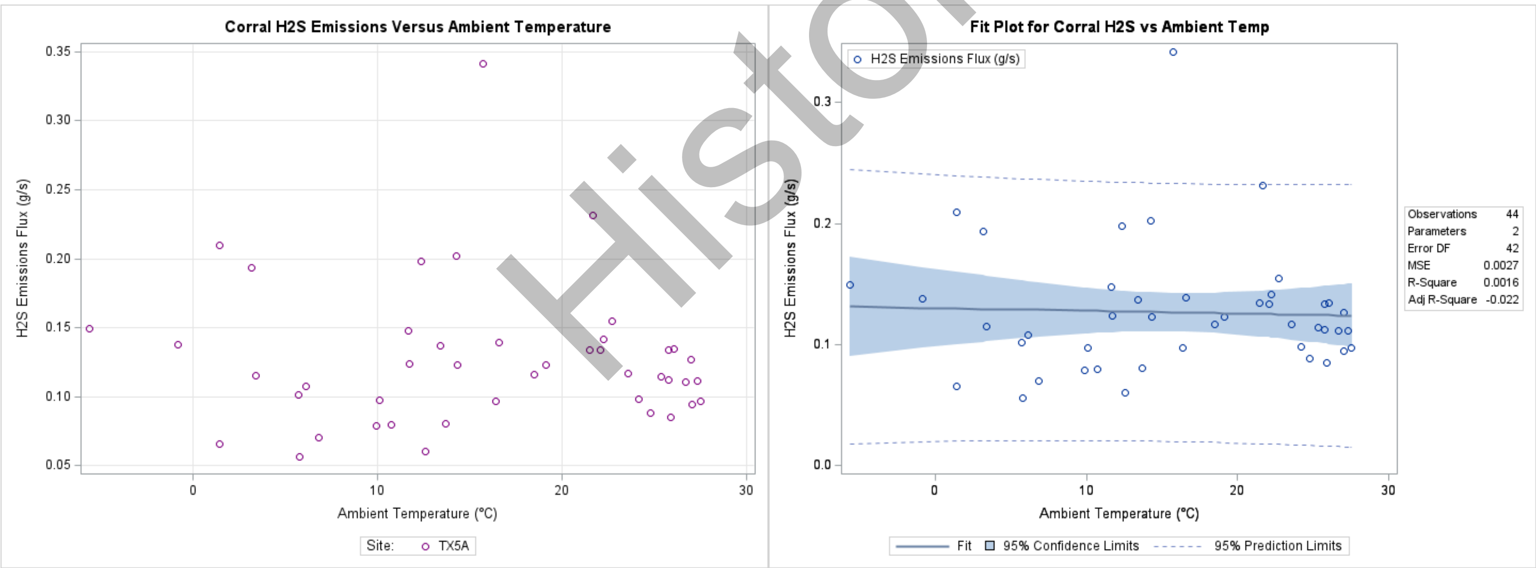


Figure F-137. Scatter plot of corral H_2S emissions versus ambient temperature and scatter plot with regression.

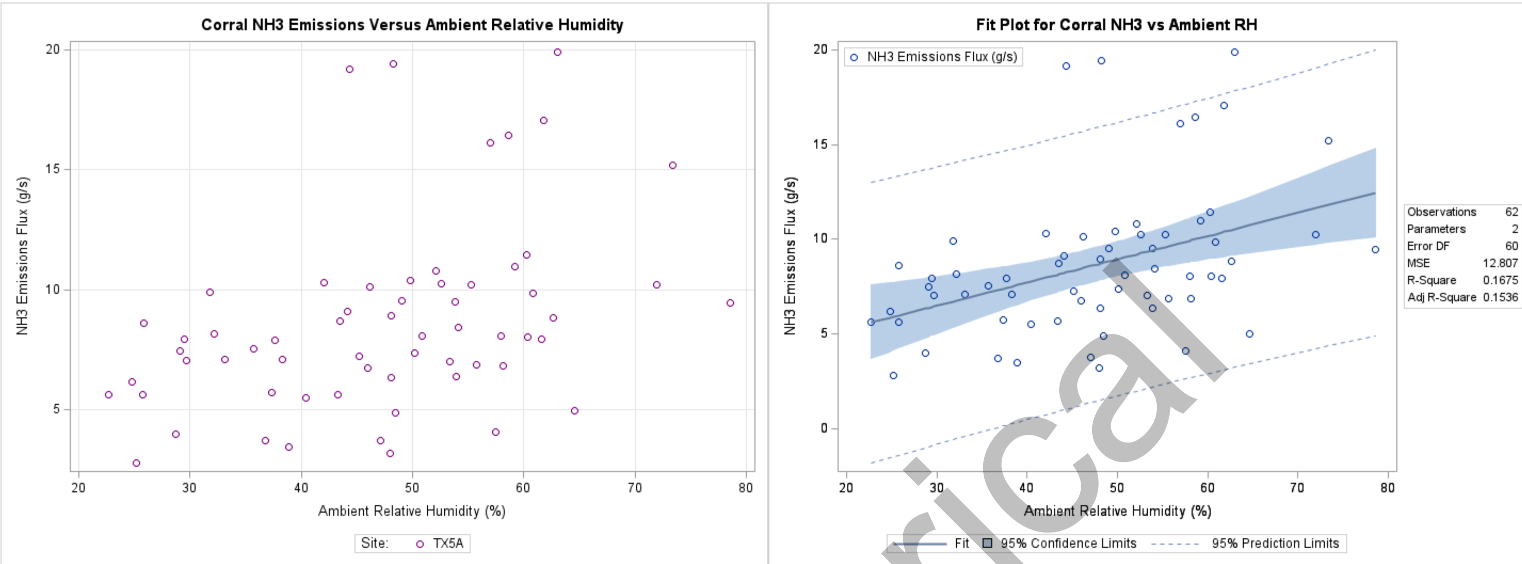


Figure F-138. Scatter plot of corral NH_3 emissions versus ambient relative humidity and scatter plot with regression.

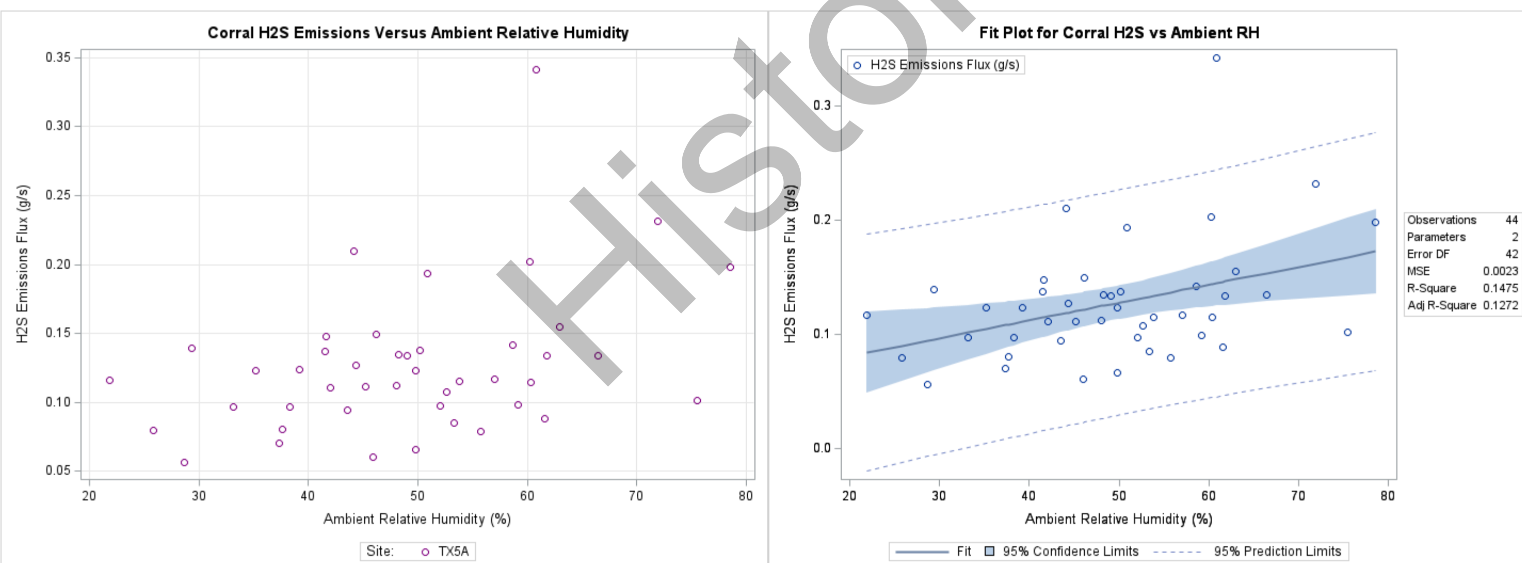


Figure F-139. Scatter plot of corral H_2S emissions versus ambient relative humidity and scatter plot with regression.

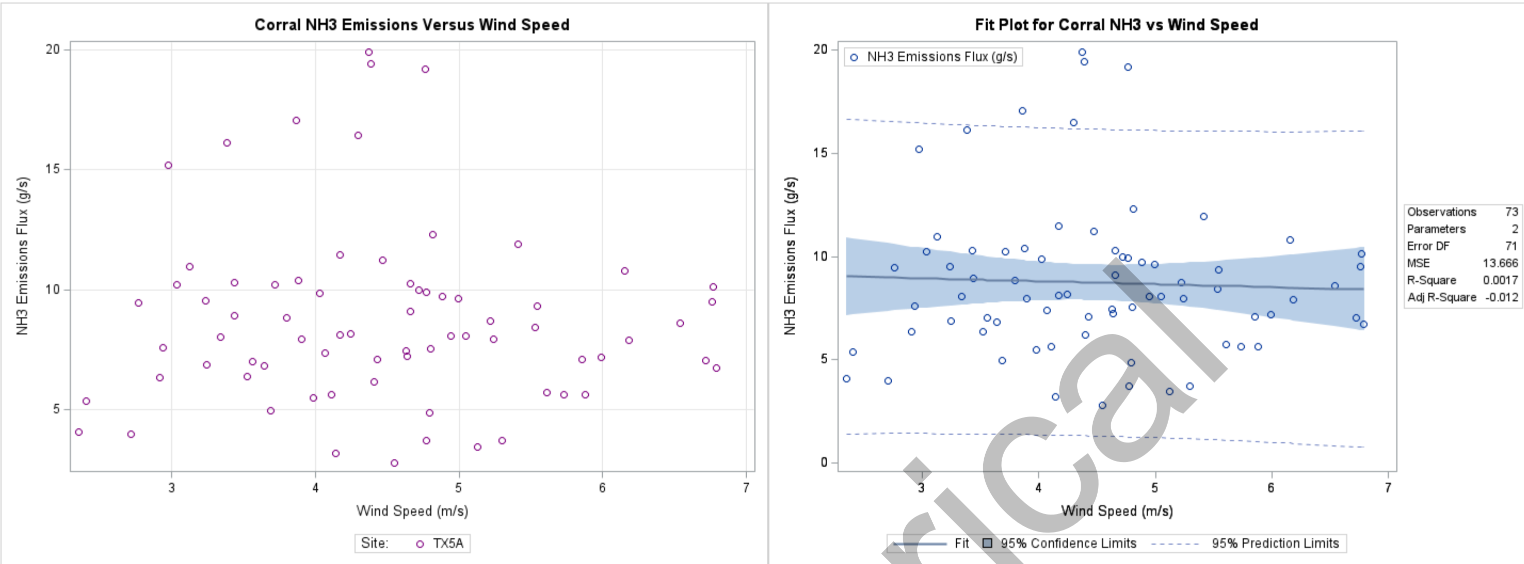


Figure F-140. Scatter plot of corral NH_3 emissions versus wind speed and scatter plot with regression.

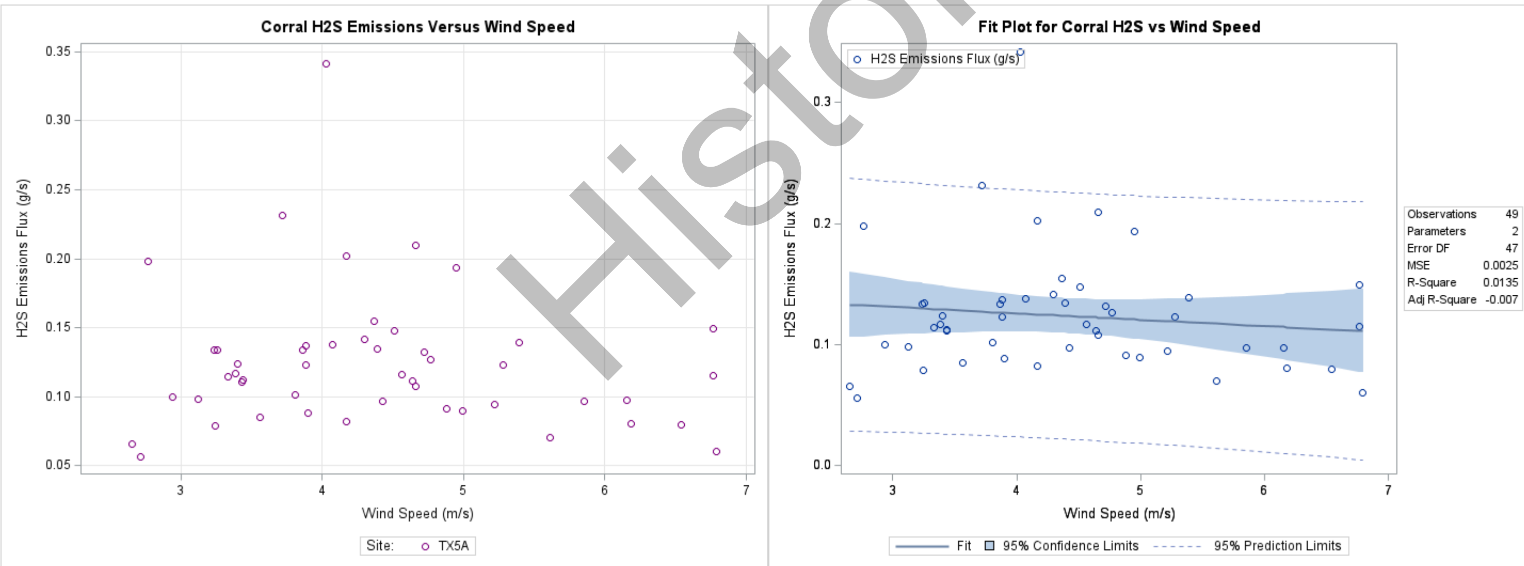


Figure F-141. Scatter plot of corral H_2S emissions versus wind speed and scatter plot with regression.

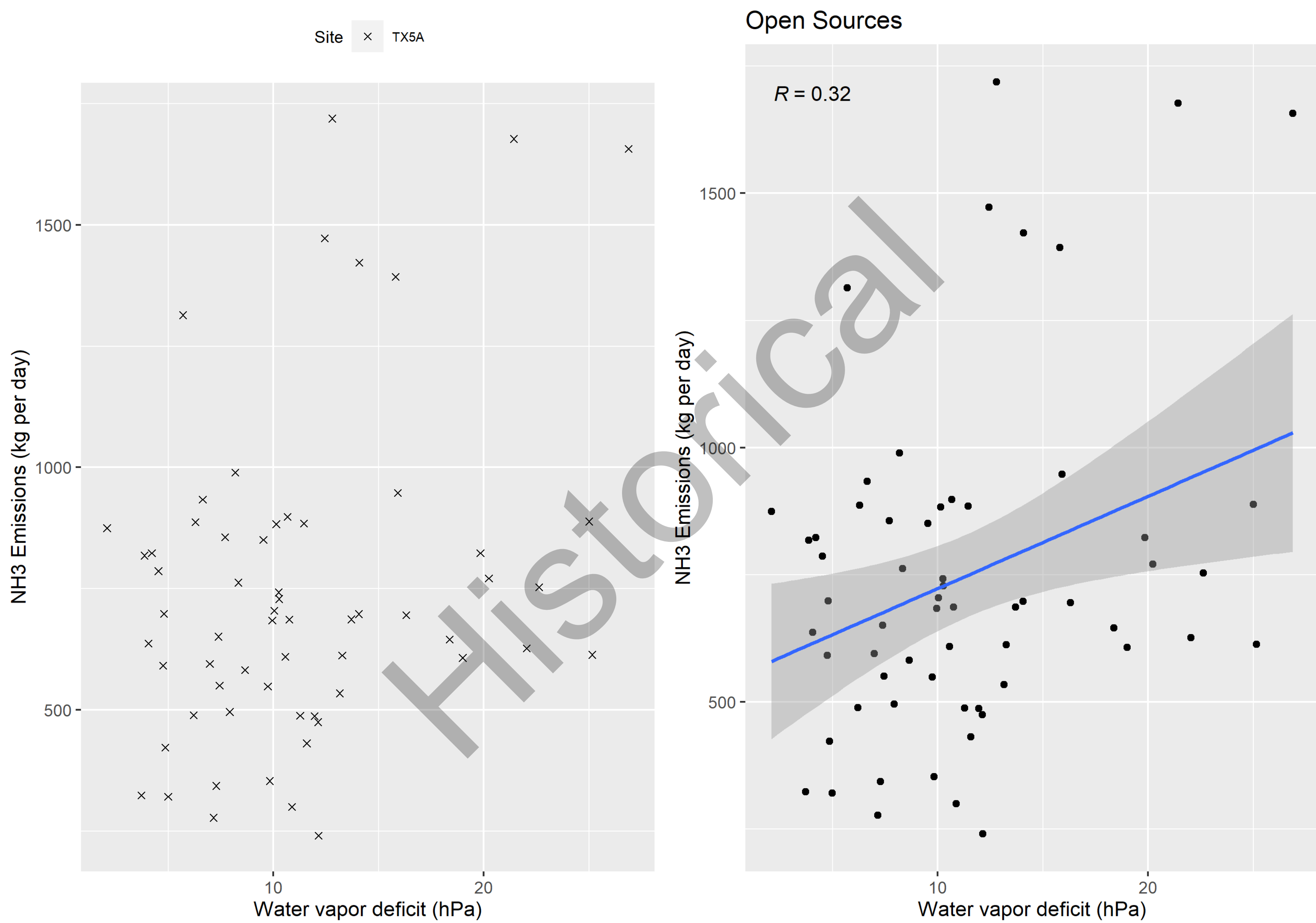


Figure F-142. Scatter plot of corral H_2S emissions versus water vapor deficit and scatter plot with regression.

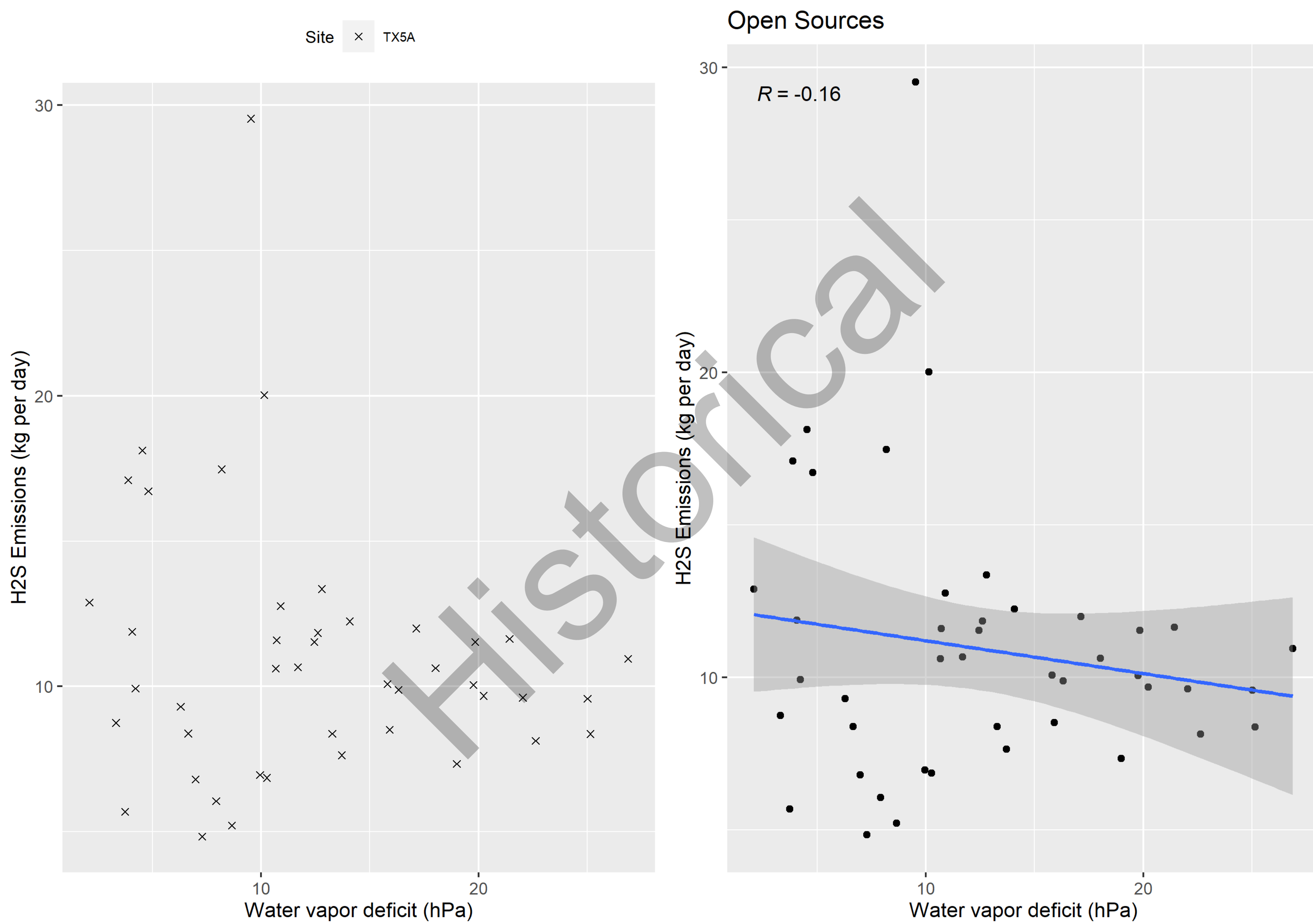


Figure F-143. Scatter plot of corral H_2S emissions versus water vapor deficit and scatter plot with regression.

Appendix G: Modeling Results

Table of Contents

List of Tables

List of Figures

G.1 Mechanically Ventilated Barns

Table G-1. Parameter combinations tested as models for NH_3 and H_2S emissions.

Model	Parameters
MV-G1	Inventory, manure management system (Flush, Scrape)
MV-G2	Inventory, Exhaust temperature, Exhaust relative humidity, manure management system (Flush, Scrape)
MV-G3	Inventory, Exhaust temperature, manure management system (Flush, Scrape)
MV-G4	Inventory, Exhaust relative humidity, manure management system (Flush, Scrape)
MV-G5	Inventory, Ambient relative humidity, Ambient temperature, manure management system (Flush, Scrape)
MV-G6	Inventory, Manure age, Ambient temperature, manure management system (Flush, Scrape)
MV-G7	Inventory, Ambient relative humidity, manure management system (Flush, Scrape)
MV-G8	Inventory, Ambient temperature, Exhaust relative humidity, manure management system (Flush, Scrape)
MV-G9	Inventory, Exhaust temperature, Ambient relative humidity, manure management system (Flush, Scrape)

Table G-2. Parameter combinations tested as models for PM_{10}, $PM_{2.5}$, and TSP emissions.

Model	Parameters
MV-P1	Intercept, Inventory
MV-P2	Intercept, Inventory, Exhaust temperature, Exhaust relative humidity
MV-P3	Intercept, Inventory, Exhaust temperature
MV-P4	Intercept, Inventory, Exhaust relative humidity
MV-P5	Intercept, Inventory, Ambient relative humidity, Ambient temperature
MV-P6	Intercept, Inventory, Manure age, Ambient temperature
MV-P7	Intercept, Inventory, Ambient relative humidity
MV-P8	Intercept, Inventory, Ambient temperature, Exhaust relative humidity
MV-P9	Intercept, Inventory, Exhaust temperature, Ambient relative humidity
MV-P10	Intercept, Exhaust temperature, Exhaust relative humidity (Emissions normalized by Inventory)
MV-P11	Intercept, Exhaust temperature (Emissions normalized by Inventory)
MV-P12	Intercept, Exhaust relative humidity (Emissions normalized by Inventory)
MV-P13	Intercept, Ambient temperature, Ambient relative humidity (Emissions normalized by Inventory)
MV-P14	Intercept, Ambient temperature (Emissions normalized by Inventory)
MV-P15	Intercept, Ambient relative humidity (Emissions normalized by Inventory)
MV-P16	Intercept, Ambient temperature, Exhaust relative humidity (Emissions normalized by Inventory)
MV-P17	Intercept, Ambient relative humidity, Exhaust temperature (Emissions normalized by Inventory)

G.1.1 Ammonia (NH_3)

Table G-3. Parameter and estimates NH_3 emission models for dairy mechanically ventilated barn.

Model	Parameter	Estimate	Standard Error	p-value
MV-G1	Inventory	1.747472	0.13368	<.0001
	FLUSH	1.968975	0.07724	<.0001
	SCRAPE	2.160489	0.0875	<.0001
MV-G2	Inventory	1.737001	0.05581	<.0001
	Exhaust temperature	0.048392	0.00111	<.0001
	Exhaust relative humidity	0.003011	0.00068	<.0001
	FLUSH	1.194081	0.05649	<.0001
	SCRAPE	1.396364	0.05863	<.0001
MV-G3	Inventory	1.752395	0.06206	<.0001
	Exhaust temperature	0.047056	0.00114	<.0001
	FLUSH	1.456887	0.03748	<.0001
	SCRAPE	1.619738	0.04267	<.0001
MV-G4	Inventory	1.709631	0.13396	<.0001
	Exhaust relative humidity	0.00436	0.00087	<.0001
	FLUSH	1.686656	0.0987	<.0001
	SCRAPE	1.868988	0.10501	<.0001
MV-G5	Inventory	1.773753	0.06478	<.0001
	Ambient temperature	0.029581	0.00088	<.0001
	Ambient relative humidity	-0.000242	0.00049	**0.6239**
	FLUSH	1.763365	0.05105	<.0001
	SCRAPE	1.881425	0.05421	<.0001
MV-G6	Inventory	1.773832	0.06477	<.0001
	Ambient temperature	0.029586	0.00088	<.0001
	FLUSH	1.746585	0.03789	<.0001
	SCRAPE	1.864935	0.04253	<.0001
MV-G7	Inventory	1.790687	0.13499	<.0001
	Ambient relative humidity	0.00001	0.00058	**0.9866**
	FLUSH	1.953638	0.08808	<.0001
	SCRAPE	2.144209	0.09609	<.0001
MV-G8	Inventory	1.731025	0.05731	<.0001
	Exhaust relative humidity	0.004884	0.00071	<.0001
	Ambient temperature	0.031826	0.00086	<.0001
	FLUSH	1.366088	0.05869	<.0001
	SCRAPE	1.515295	0.06027	<.0001
MV-G9	Inventory	1.775013	0.06212	<.0001
	Exhaust temperature	0.04585	0.00117	<.0001
	Ambient relative humidity	-0.00111	0.00047	*0.0183*
	FLUSH	1.564041	0.04971	<.0001
	SCRAPE	1.700058	0.05275	<.0001

Table G-4. Fit and evaluation statistics for dairy mechanically ventilated barn NH_3 models tested.

Model	2LogL	AIC	AICc	BIC	Corr.	LNME[a] (%)	NME[b] (%)	ME[b] (kg day^{-1})	MB[b] (kg day^{-1})	NMB[b] (%)
MV-G1	-156	-146	-146	-144	0.736	11.54	43.67	10.29	-0.625	-2.65
MV-G2	-1347	-1333	-1333	-1330	0.921	6.812	22.36	5.389	-0.566	-2.347
MV-G3	-1345	-1333	-1333	-1330	0.911	7.291	23.68	5.58	-0.434	-1.843
MV-G4	-125	-113	-113	-110	0.733	11.61	42.99	10.36	-0.685	-2.841
MV-G5	-1105	-1091	-1091	-1088	0.909	7.322	24.57	5.957	-0.579	-2.389
MV-G6	-1105	-1093	-1093	-1091	0.909	7.322	24.57	5.959	-0.583	-2.404
MV-G7	-255	-243	-243	-241	0.754	11.4	42.74	10.35	-0.784	-3.24
MV-G8	-1155	-1141	-1141	-1139	0.922	6.773	22.57	5.609	-0.628	-2.527
MV-G9	-1314	-1300	-1300	-1298	0.918	6.999	23	5.568	-0.45	-1.859

[a] Based on transformed data (i.e., ln(NH_3)).
[b] Based on back-transformed data.

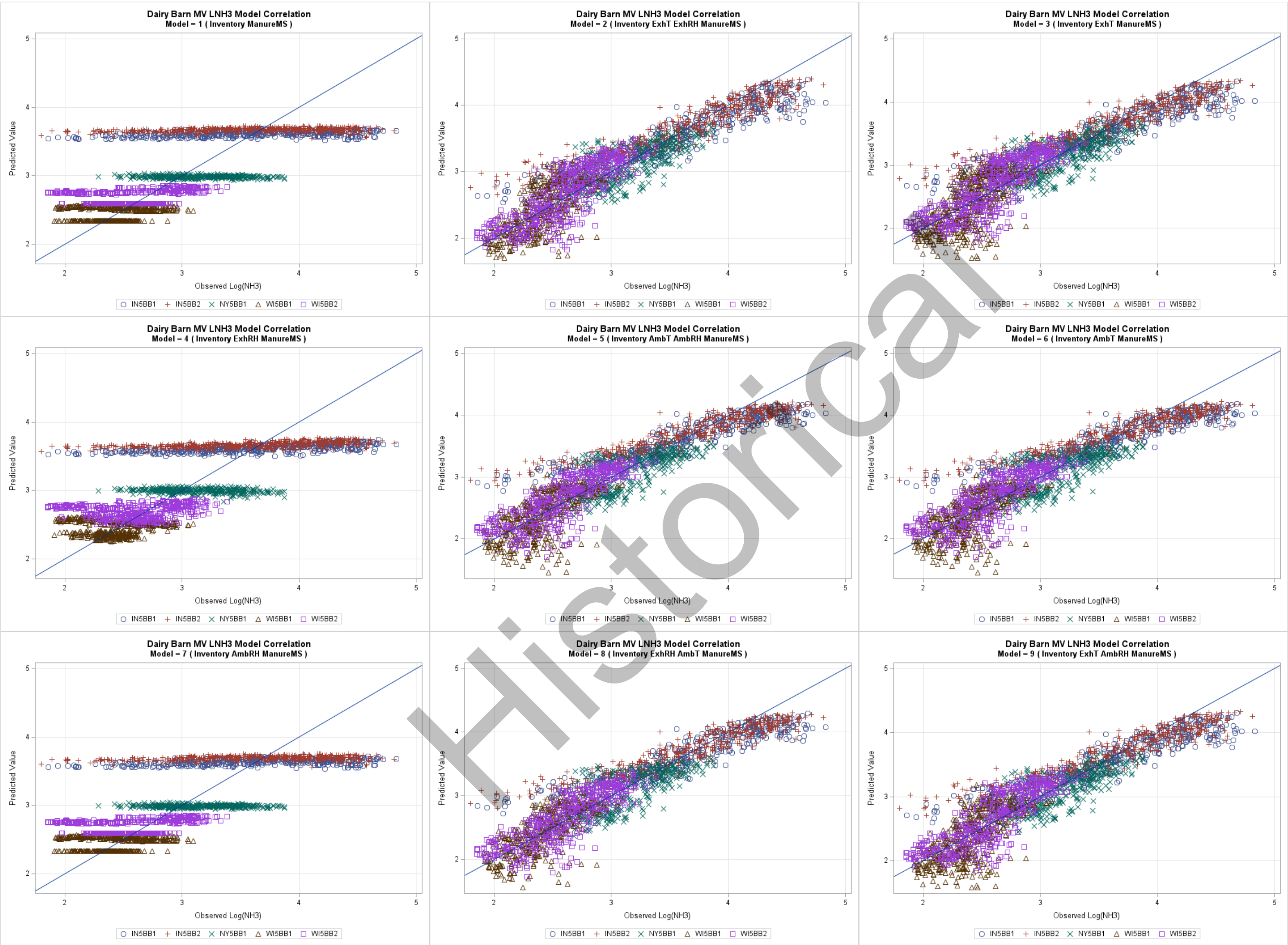


Figure G-1. Dairy mechanically ventilated barn NH_3 one-to-one plots models 1 through 9, log transformed.

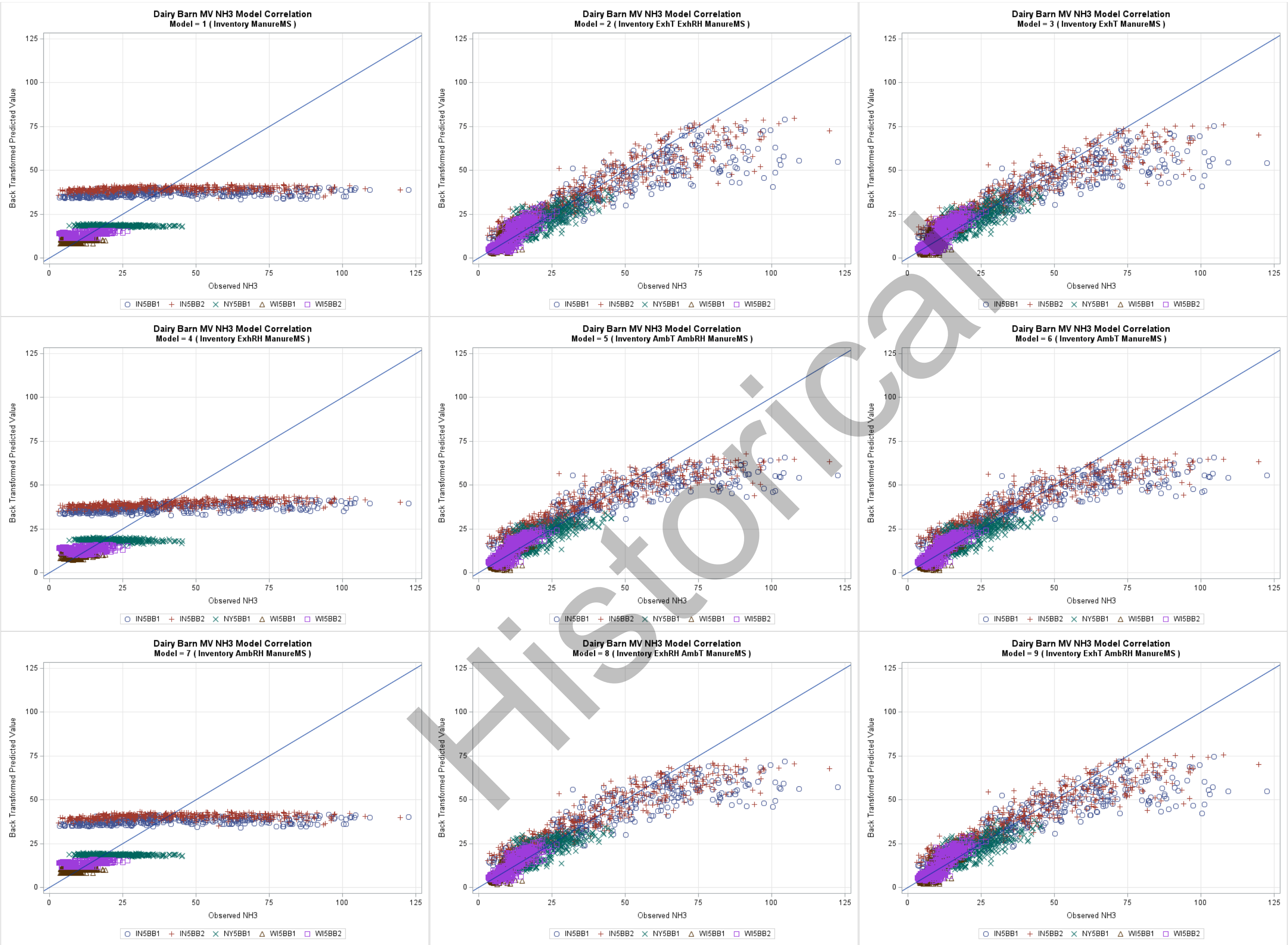


Figure G-2. Dairy mechanically ventilated barn NH_3 one-to-one plots models 1 through 9, back transformed.

G.1.2 Hydrogen Sulfide (H_2S)

Table G-5. Parameter and estimates H_2S emission models for dairy mechanically ventilated barn.

Model	Parameter	Estimate	Standard Error	p-value
MV-G1	Inventory	0.85197	0.10927	<.0001
	FLUSH	7.489765	0.0634	<.0001
	SCRAPE	6.409219	0.07174	<.0001
MV-G2	Inventory	0.749681	0.07466	<.0001
	Exhaust temperature	0.023646	0.00164	<.0001
	Exhaust relative humidity	0.003395	0.00106	0.0014
	FLUSH	7.001505	0.0838	<.0001
	SCRAPE	5.943562	0.08587	<.0001
MV-G3	Inventory	0.790491	0.07913	<.0001
	Exhaust temperature	0.021314	0.00166	<.0001
	FLUSH	7.272397	0.04871	<.0001
	SCRAPE	6.193112	0.05513	<.0001
MV-G4	Inventory	0.828413	0.10997	<.0001
	Exhaust relative humidity	0.002065	0.0011	**0.0598**
	FLUSH	7.362012	0.09788	<.0001
	SCRAPE	6.273489	0.10168	<.0001
MV-G5	Inventory	0.862257	0.08689	<.0001
	Ambient temperature	0.012718	0.00127	<.0001
	Ambient relative humidity	-0.00075	0.00072	**0.2988**
	FLUSH	7.459213	0.07186	<.0001
	SCRAPE	6.338222	0.07532	<.0001
MV-G6	Inventory	0.86173	0.08664	<.0001
	Ambient temperature	0.012786	0.00127	<.0001
	FLUSH	7.406887	0.05129	<.0001
	SCRAPE	6.287004	0.05691	<.0001
MV-G7	Inventory	0.921144	0.1135	<.0001
	Ambient relative humidity	-0.000989	0.00072	**0.167**
	FLUSH	7.551565	0.0833	<.0001
	SCRAPE	6.449859	0.08831	<.0001
MV-G8	Inventory	0.804201	0.08038	<.0001
	Exhaust relative humidity	0.003593	0.00105	0.0006
	Ambient temperature	0.015583	0.00126	<.0001
	FLUSH	7.13763	0.08504	<.0001
	SCRAPE	6.029703	0.08645	<.0001
MV-G9	Inventory	0.848409	0.0827	<.0001
	Exhaust temperature	0.020512	0.00171	<.0001
	Ambient relative humidity	-0.001261	0.00072	**0.0782**
	FLUSH	7.378145	0.071	<.0001
	SCRAPE	6.265544	0.07426	<.0001

Table G-6. Fit and evaluation statistics for H_2S emission models for dairy mechanically ventilated barn.

Model	2LogL	AIC	AICc	BIC	Corr.	LNME[a] (%)	NME[b] (%)	ME[b] (g day^{-1})	MB[b] (g day^{-1})	NMB[b] (%)
MV-G1	1234	1244	1244	1246	0.59	5.33	74.81	649.1	0.724	0.083
MV-G2	1035	1049	1049	1051	0.746	4.287	62.99	527	-46.27	-5.53
MV-G3	1122	1134	1134	1137	0.726	4.47	63.99	555.2	-38.55	-4.443
MV-G4	1163	1175	1176	1178	0.588	5.33	76.61	641	-4.608	-0.551
MV-G5	848	862	863	865	0.713	4.467	64.4	553.9	-38.24	-4.446
MV-G6	850	862	862	864	0.714	4.46	64.31	553.1	-38.66	-4.495
MV-G7	916	928	928	931	0.595	5.201	74.21	633.7	1	0.117
MV-G8	750	764	764	767	0.742	4.232	62.78	518.8	-47.85	-5.79
MV-G9	818	832	832	834	0.729	4.388	63.2	539.7	-42.24	-4.946

[a] Based on transformed data (i.e., ln(H_2S)).
[b] Based on back-transformed data.

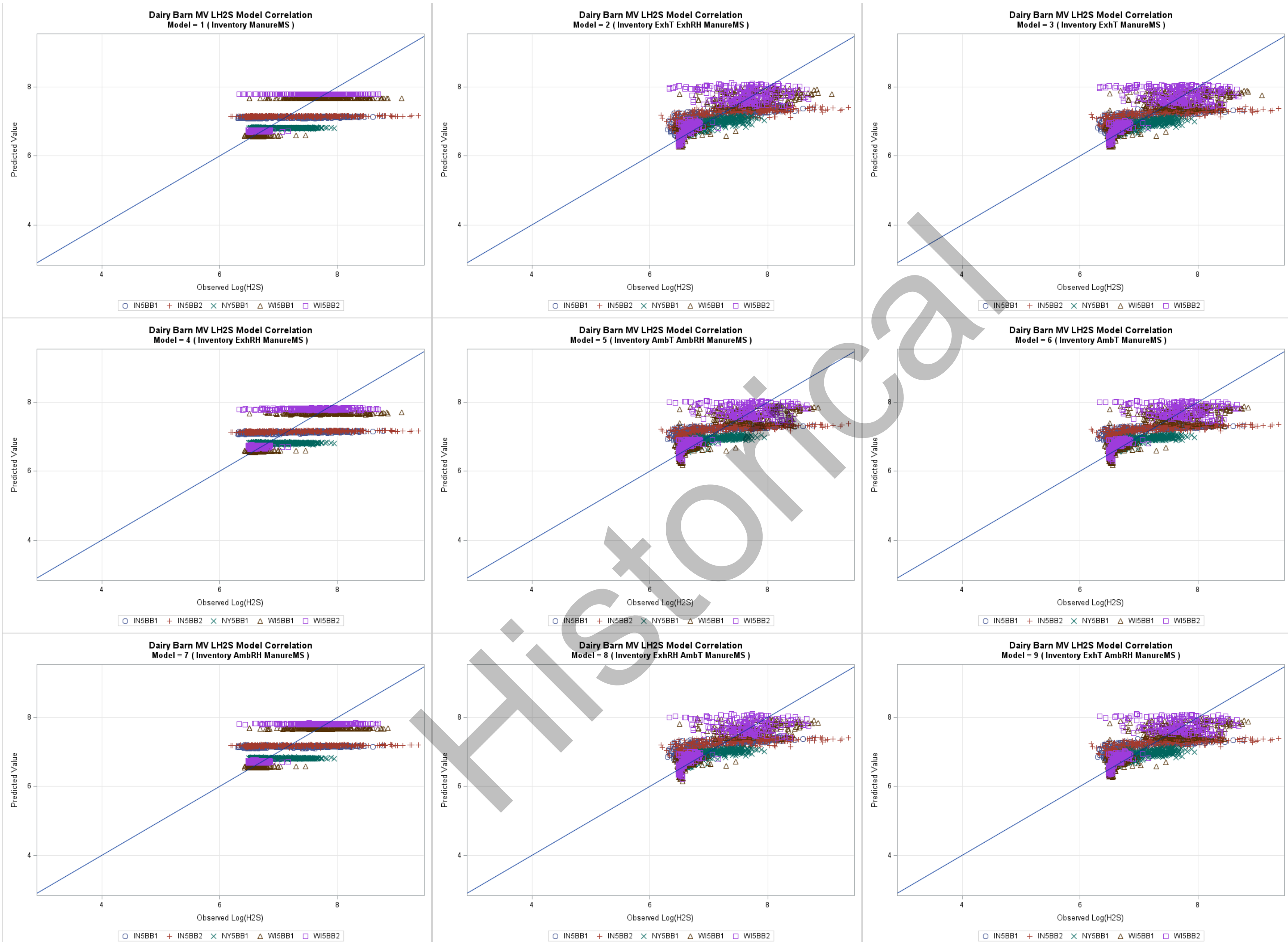


Figure G-3. Dairy mechanically ventilated barn H_2S one-to-one plots models 1 through 9, log transformed.

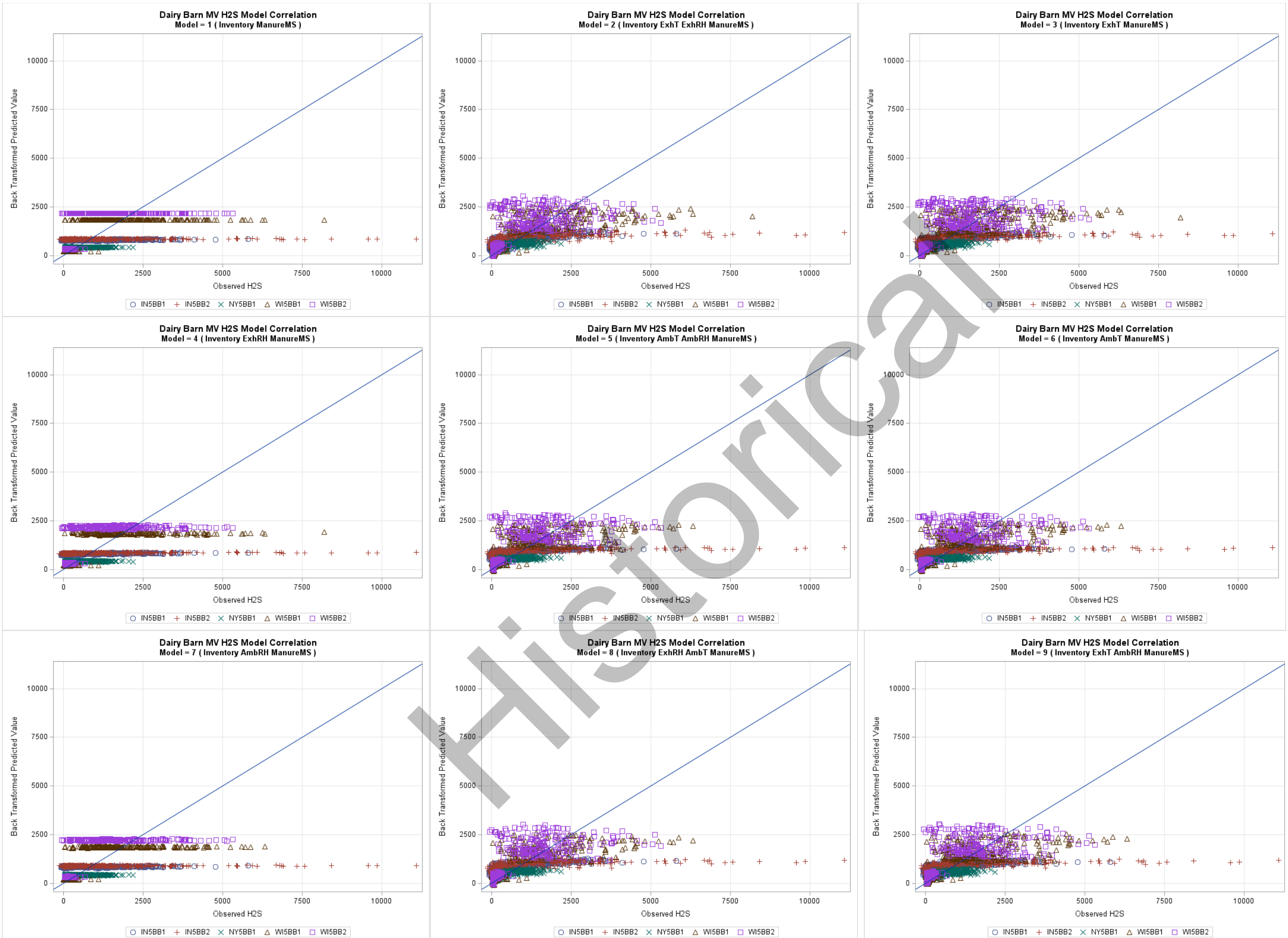


Figure G-4. Dairy mechanically ventilated barn H_2S one-to-one plots models 1 through 9, back transformed.

G.1.3 PM_{10}

Table G-7. Parameter and estimates PM_{10} emission models for dairy mechanically ventilated barn.

Model	Parameter	Estimate	Standard Error	p-value
MVP-1	Intercept	7.893278	0.02207	<.0001
	Inventory	-0.164739	0.03776	<.0001
MVP-2	Intercept	8.000154	0.0316	<.0001
	Inventory	-0.154561	0.02763	<.0001
	Exhaust temperature	0.009357	0.00069	<.0001
	Exhaust relative humidity	-0.003067	0.00039	<.0001
MVP-3	Intercept	7.792627	0.01763	<.0001
	Inventory	-0.176717	0.02764	<.0001
	Exhaust temperature	0.009331	0.00069	<.0001
MVP-4	Intercept	8.105856	0.03512	<.0001
	Inventory	-0.149821	0.03774	0.0001
	Exhaust relative humidity	-0.003063	0.00041	<.0001
MVP-5	Intercept	7.975044	0.02594	<.0001
	Inventory	-0.19122	0.02854	<.0001
	Ambient temperature	0.006017	0.00051	<.0001
	Ambient relative humidity	-0.001883	0.00029	<.0001
MVP-6	Intercept	7.843341	0.01664	<.0001
	Inventory	-0.186495	0.02844	<.0001
	Ambient temperature	0.006236	0.00051	<.0001
MVP-7	Intercept	8.029831	0.02952	<.0001
	Inventory	-0.16347	0.03753	<.0001
	Ambient relative humidity	-0.002031	0.00029	<.0001
MVP-8	Intercept	8.027481	0.03188	<.0001
	Inventory	-0.166792	0.02878	<.0001
	Exhaust relative humidity	-0.002682	0.00041	<.0001
	Ambient temperature	0.006001	0.00051	<.0001
MVP-9	Intercept	7.936865	0.02607	<.0001
	Inventory	-0.1827	0.02753	<.0001
	Exhaust temperature	0.009106	0.00069	<.0001
	Ambient relative humidity	-0.002059	0.00028	<.0001
MVP-10	Intercept	8.249507	0.06206	<.0001
	Exhaust temperature	0.018019	0.00156	<.0001
	Exhaust relative humidity	-0.007211	0.00078	<.0001
MVP-11	Intercept	7.737968	0.02793	<.0001
	Exhaust temperature	0.01796	0.00159	<.0001
MVP-12	Intercept	8.447248	0.06301	<.0001
	Exhaust relative humidity	-0.00706	0.00081	<.0001
MVP-13	Intercept	8.130759	0.04588	<.0001
	Ambient temperature	0.01083	0.00117	<.0001
	Ambient relative humidity	-0.004322	0.00056	<.0001

Model	Parameter	Estimate	Standard Error	p-value
MVP-14	Intercept	7.835482	0.0252	<.0001
	Ambient temperature	0.011268	0.00118	<.0001
MVP-15	Intercept	8.250004	0.04677	<.0001
	Ambient relative humidity	-0.004532	0.00057	<.0001
MVP-16	Intercept	8.301634	0.06314	<.0001
	Exhaust relative humidity	-0.006477	0.00081	<.0001
	Ambient temperature	0.010627	0.00117	<.0001
MVP-17	Intercept	8.05718	0.04675	<.0001
	Exhaust temperature	0.01731	0.00158	<.0001
	Ambient relative humidity	-0.004623	0.00056	<.0001

Table G-8. Fit and evaluation statistics for PM_{10} emission models for dairy mechanically ventilated barn.

Model	2LogL	AIC	AICc	BIC	Corr.	LNME[a] (%)	NME[b] (%)	ME[b] (g day^{-1})	MB[b] (kg day^{-1})	NMB[b] (%)
MVP-1	-2,874	-2,866	-2,866	-2,865	0.22	1.43	102.20	323.70	-0.50	-0.16
MVP-2	-2,986	-2,974	-2,974	-2,972	0.62	1.18	82.59	266.30	-7.22	-2.24
MVP-3	-3,017	-3,007	-3,007	-3,005	0.59	1.22	86.12	272.80	-6.68	-2.11
MVP-4	-2,843	-2,833	-2,833	-2,831	0.31	1.41	99.97	322.40	-1.31	-0.41
MVP-5	-2,897	-2,885	-2,885	-2,883	0.57	1.19	85.84	265.10	-5.69	-1.84
MVP-6	-2,887	-2,877	-2,877	-2,875	0.57	1.19	86.50	265.40	-5.77	-1.88
MVP-7	-2,801	-2,791	-2,791	-2,789	0.27	1.38	99.99	308.10	-0.86	-0.28
MVP-8	-2,840	-2,828	-2,828	-2,826	0.59	1.17	83.56	261.10	-6.28	-2.01
MVP-9	-2,939	-2,927	-2,927	-2,925	0.59	1.18	85.03	262.00	-5.83	-1.89
MVP-10	-818	-808	-808	-806	0.58	2.71	96.84	941.10	-70.93	-7.30
MVP-11	-724	-716	-716	-714	0.51	2.84	101.30	969.60	-58.71	-6.14
MVP-12	-700	-692	-692	-691	0.29	3.02	113.20	1,100.00	-14.42	-1.48
MVP-13	-730	-720	-720	-718	0.46	2.78	102.80	951.80	-45.14	-4.88
MVP-14	-688	-680	-680	-678	0.47	2.82	103.70	952.90	-47.53	-5.17
MVP-15	-657	-649	-649	-647	0.13	3.08	116.60	1,075.00	-1.75	-0.19
MVP-16	-764	-754	-754	-752	0.54	2.71	99.80	932.00	-58.17	-6.23
MVP-17	-766	-756	-755	-754	0.49	2.75	100.50	927.40	-51.05	-5.53

[a] Based on transformed data (i.e., $\ln(PM_{10})$).
[b] Based on back-transformed data.

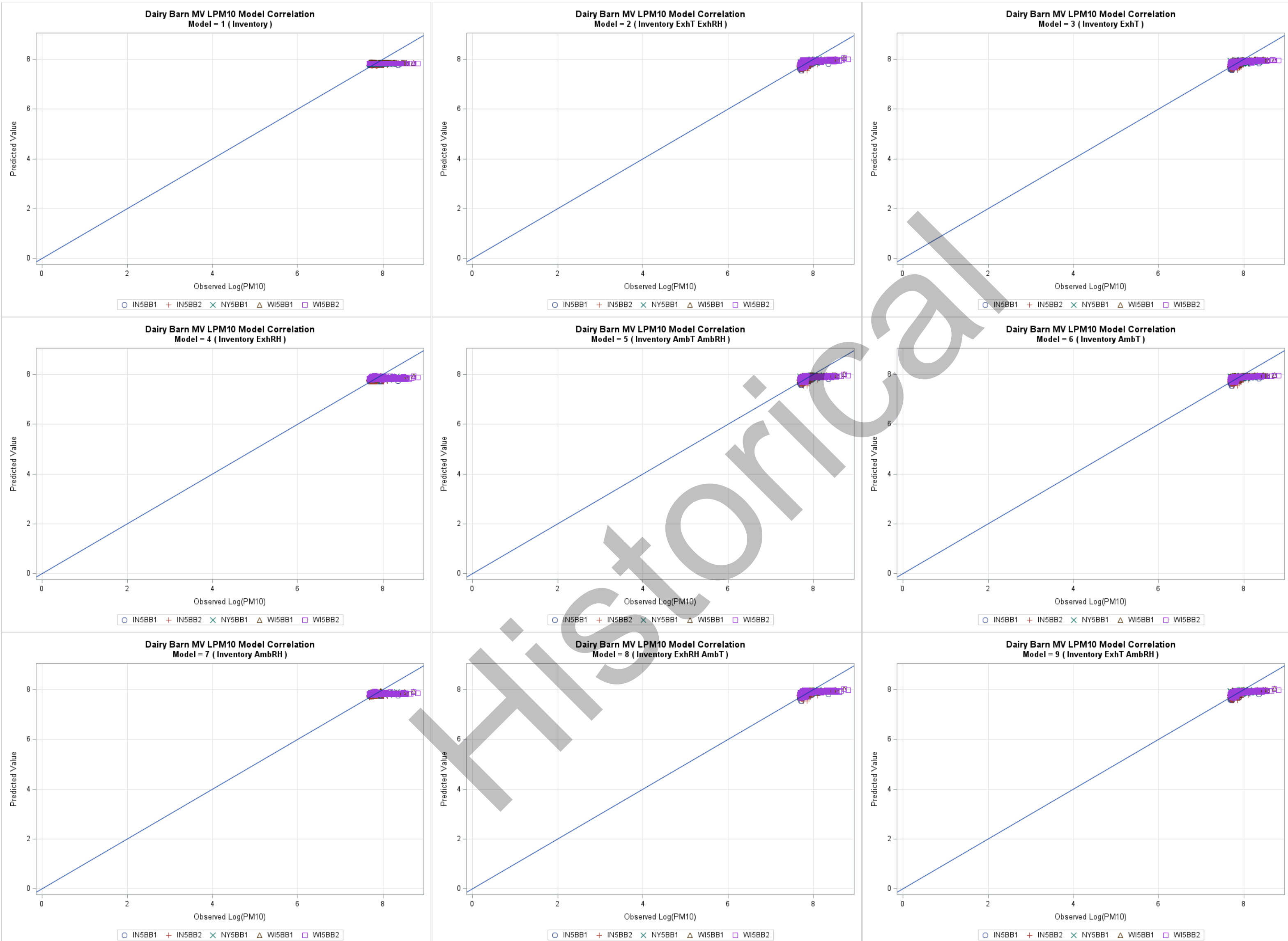


Figure G-5. Dairy mechanically ventilated barn PM_{10} one-to-one plots models 1 through 9, log transformed.

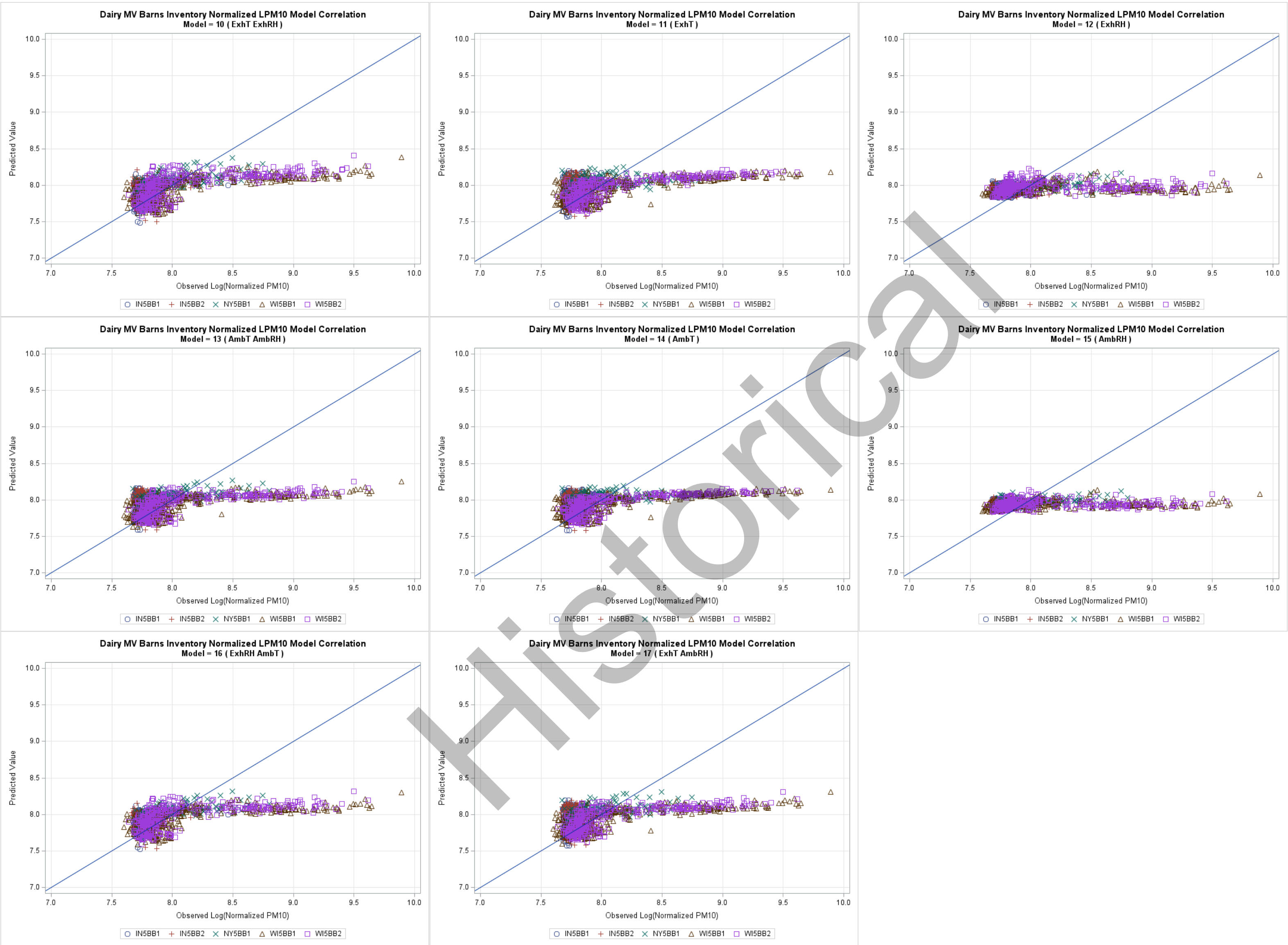


Figure G-6. Dairy mechanically ventilated barn PM_{10} one-to-one plots models 10 through 17, log transformed.

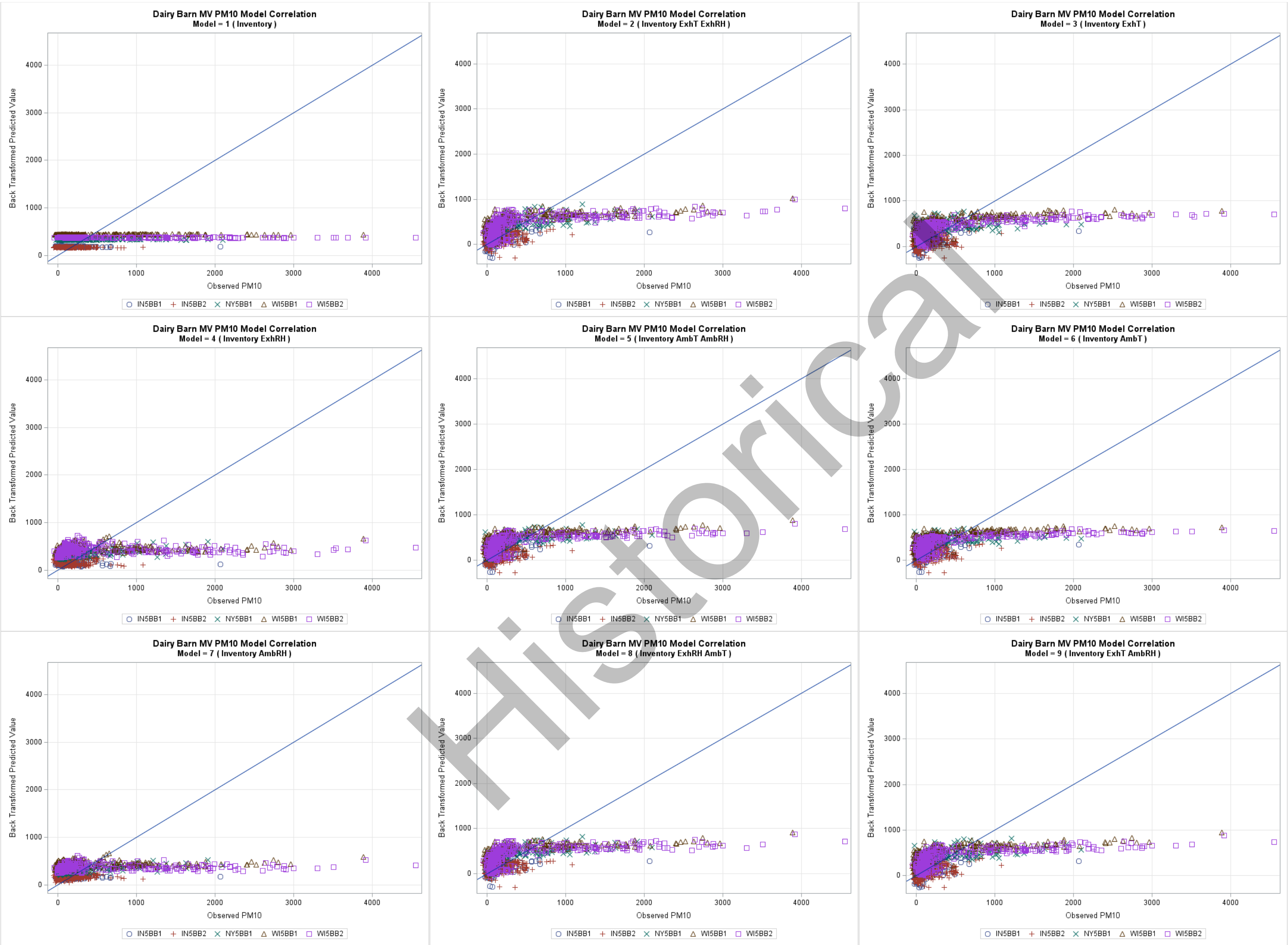


Figure G-7. Dairy mechanically ventilated barn PM_{10} one-to-one plots models 1 through 9, back transformed.

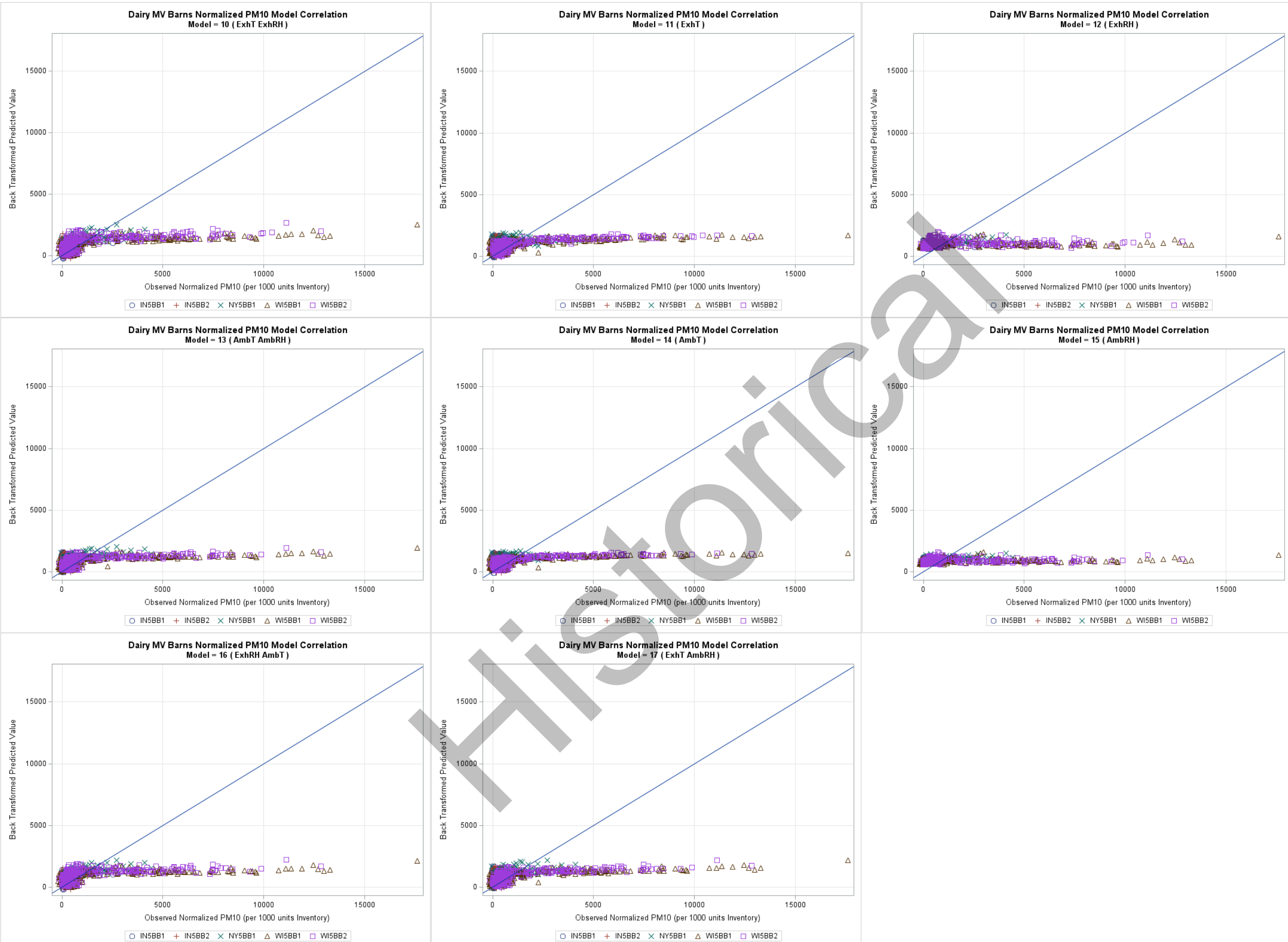


Figure G-8. Dairy mechanically ventilated barn PM_{10} one-to-one plots models 10 through 17, back transformed.

G.1.4 Fine particulate matter ($PM_{2.5}$)

Table G-9. Parameter and estimates $PM_{2.5}$ emission models for dairy mechanically ventilated barn.

Model	Parameter	Estimate	Standard Error	p-value
MVP-1	Intercept	6.723444	0.05214	<.0001
	Inventory	-0.162107	0.09504	**0.0991**
MVP-2	Intercept	6.705085	0.11364	<.0001
	Inventory	-0.223783	0.07902	0.0079
	Exhaust temperature	0.008378	0.00169	<.0001
	Exhaust relative humidity	-0.000595	0.0015	**0.6917**
MVP-3	Intercept	6.639886	0.04142	<.0001
	Inventory	-0.202089	0.07244	0.0088
	Exhaust temperature	0.008704	0.00159	<.0001
MVP-4	Intercept	6.838487	0.11859	<.0001
	Inventory	-0.206677	0.09595	*0.0406*
	Exhaust relative humidity	-0.001078	0.00159	**0.4986**
MVP-5	Intercept	6.697356	0.08085	<.0001
	Inventory	-0.150216	0.07109	*0.0449*
	Ambient temperature	0.00381	0.001	0.0004
	Ambient relative humidity	-0.000422	0.00101	**0.6764**
MVP-6	Intercept	6.667655	0.03747	<.0001
	Inventory	-0.149752	0.07223	*0.0477*
	Ambient temperature	0.003817	0.00101	0.0004
MVP-7	Intercept	6.672905	0.08644	<.0001
	Inventory	-0.076468	0.08704	**0.3894**
	Ambient relative humidity	-0.00009	0.00102	**0.9295**
MVP-8	Intercept	6.656394	0.10911	<.0001
	Inventory	-0.200477	0.08068	*0.0195*
	Exhaust relative humidity	0.000576	0.00147	**0.6967**
	Ambient temperature	0.003939	0.0011	0.0008
MVP-9	Intercept	6.65579	0.08022	<.0001
	Inventory	-0.149074	0.06841	*0.039*
	Exhaust temperature	0.006647	0.00145	<.0001
	Ambient relative humidity	-0.000437	0.00099	**0.6602**
MVP-10	Intercept	6.734071	0.2477	<.0001
	Exhaust temperature	0.018344	0.00461	0.0002
	Exhaust relative humidity	-0.001841	0.00313	**0.5567**
MVP-11	Intercept	6.607057	0.07549	<.0001
	Exhaust temperature	0.016971	0.00434	0.0002
MVP-12	Intercept	6.945997	0.25138	<.0001
	Exhaust relative humidity	-0.001699	0.00326	**0.603**
MVP-13	Intercept	6.76777	0.15722	<.0001
	Ambient temperature	0.00474	0.00273	**0.0872**
	Ambient relative humidity	-0.000547	0.00207	**0.7919**

Model	Parameter	Estimate	Standard Error	p-value
MVP-14	Intercept	6.72987	0.06275	<.0001
	Ambient temperature	0.004738	0.00274	**0.0878**
MVP-15	Intercept	6.803706	0.15669	<.0001
	Ambient relative humidity	-0.000454	0.00207	**0.8267**
MVP-16	Intercept	6.640063	0.24227	<.0001
	Exhaust relative humidity	0.001234	0.00305	**0.6865**
	Ambient temperature	0.005929	0.00301	**0.0528**
MVP-17	Intercept	6.689929	0.159	<.0001
	Exhaust temperature	0.01113	0.00397	0.0063
	Ambient relative humidity	-0.000642	0.00204	**0.7532**

Table G-10. Fit and evaluation statistics for $PM_{2.5}$ emission models for dairy mechanically ventilated barn.

Model	2LogL	AIC	AICc	BIC	Corr.	LNME[a] (%)	NME[b] (%)	ME[b] (g day^{-1})	MB[b] (kg day^{-1})	NMB[b] (%)
MVP-1	-338	-330	-330	-328	0.19	1.75	90.89	101.00	0.07	0.06
MVP-2	-340	-328	-328	-326	0.57	1.47	70.94	83.19	-0.25	-0.22
MVP-3	-363	-353	-353	-351	0.57	1.45	73.38	81.53	-0.51	-0.46
MVP-4	-318	-308	-307	-306	0.31	1.74	85.29	100.00	-0.10	-0.08
MVP-5	-369	-357	-356	-354	0.52	1.29	80.29	69.43	-0.70	-0.81
MVP-6	-369	-359	-358	-357	0.51	1.31	81.34	70.33	-0.62	-0.71
MVP-7	-357	-347	-346	-345	0.08	1.43	90.73	78.45	0.03	0.03
MVP-8	-343	-331	-331	-329	0.49	1.35	78.93	72.74	-0.36	-0.39
MVP-9	-375	-363	-362	-360	0.55	1.26	78.22	67.64	-0.54	-0.62
MVP-10	-60	-50	-50	-48	0.44	4.10	93.30	342.50	-5.74	-1.56
MVP-11	-65	-57	-56	-55	0.43	4.04	96.72	336.20	-7.30	-2.10
MVP-12	-44	-36	-36	-35	0.53	4.07	101.90	374.20	-3.30	-0.90
MVP-13	-109	-99	-98	-97	0.33	3.23	101.80	258.00	-4.87	-1.92
MVP-14	-109	-101	-100	-99	0.31	3.25	102.40	259.40	-4.33	-1.71
MVP-15	-106	-98	-97	-96	0.39	3.24	104.60	265.20	-0.52	-0.21
MVP-16	-102	-92	-92	-90	0.23	3.44	102.00	275.80	-1.57	-0.58
MVP-17	-114	-104	-103	-102	0.37	3.25	100.70	255.10	-4.98	-1.96

[a] Based on transformed data (i.e., ln($PM_{2.5}$)).
[b] Based on back-transformed data.

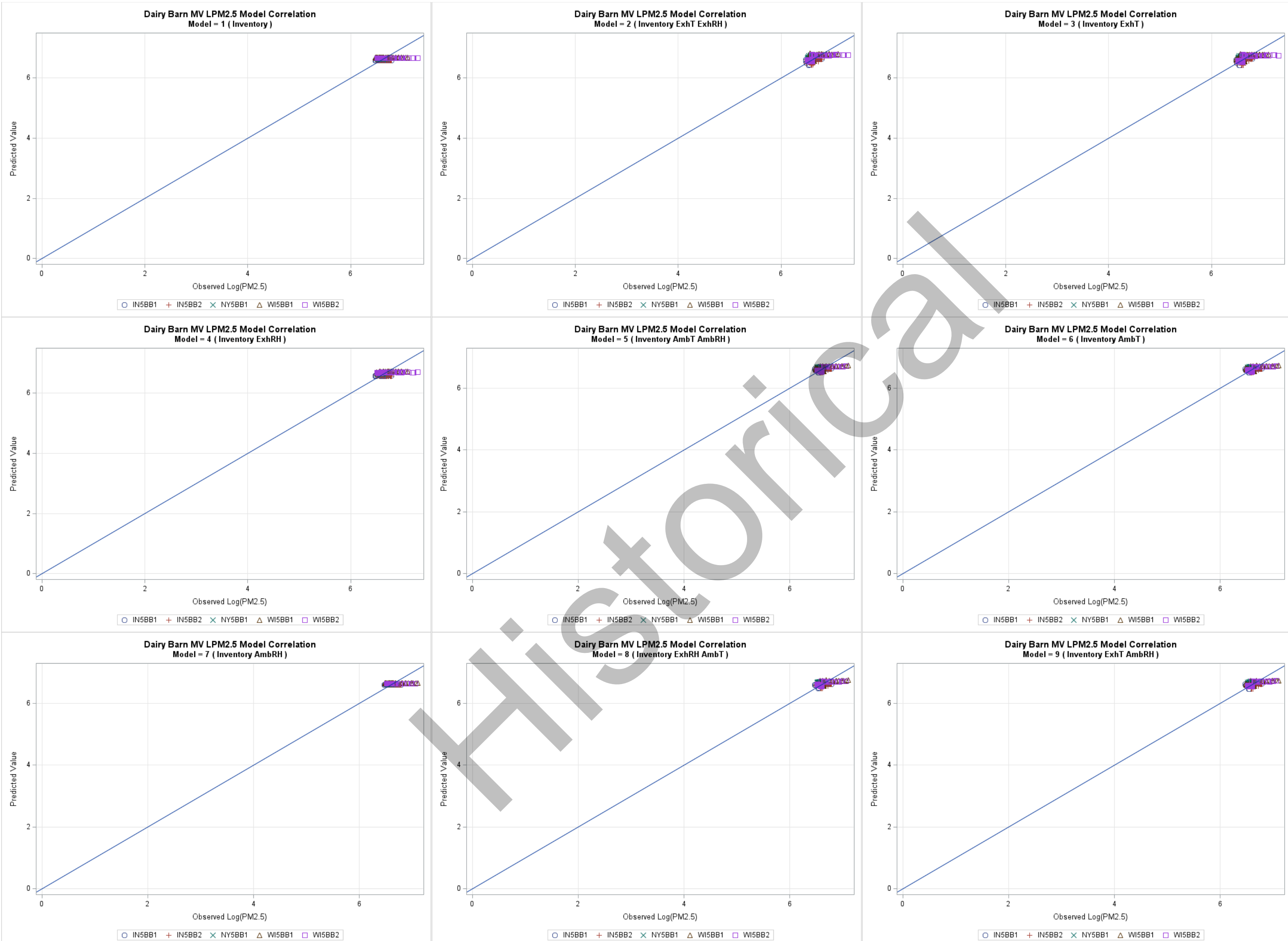


Figure G-9. Dairy mechanically ventilated barn $PM_{2.5}$ one-to-one plots models 1 through 9, log transformed.

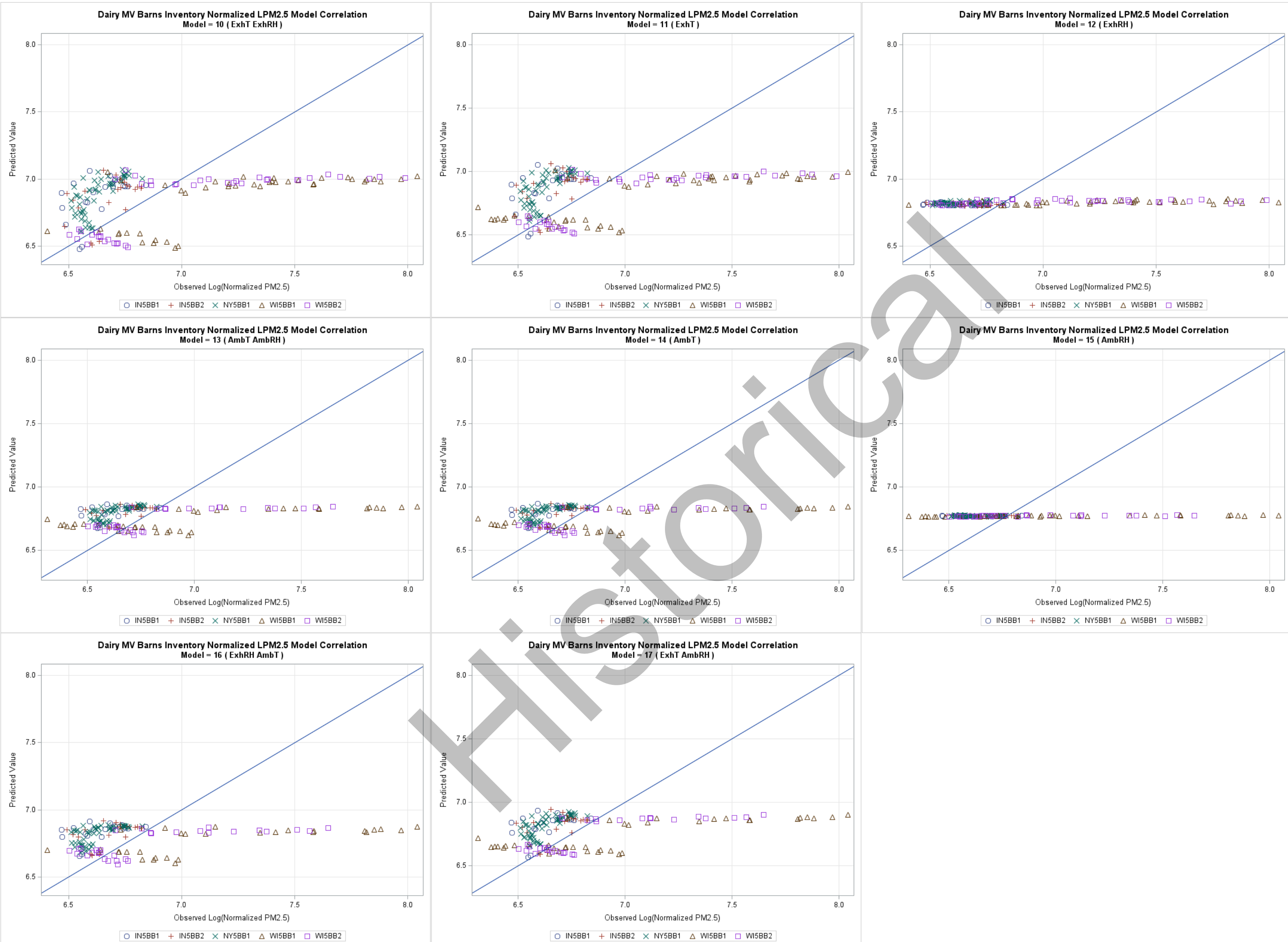


Figure G-10. Dairy mechanically ventilated barn $PM_{2.5}$ one-to-one plots models 10 through 17, log transformed.

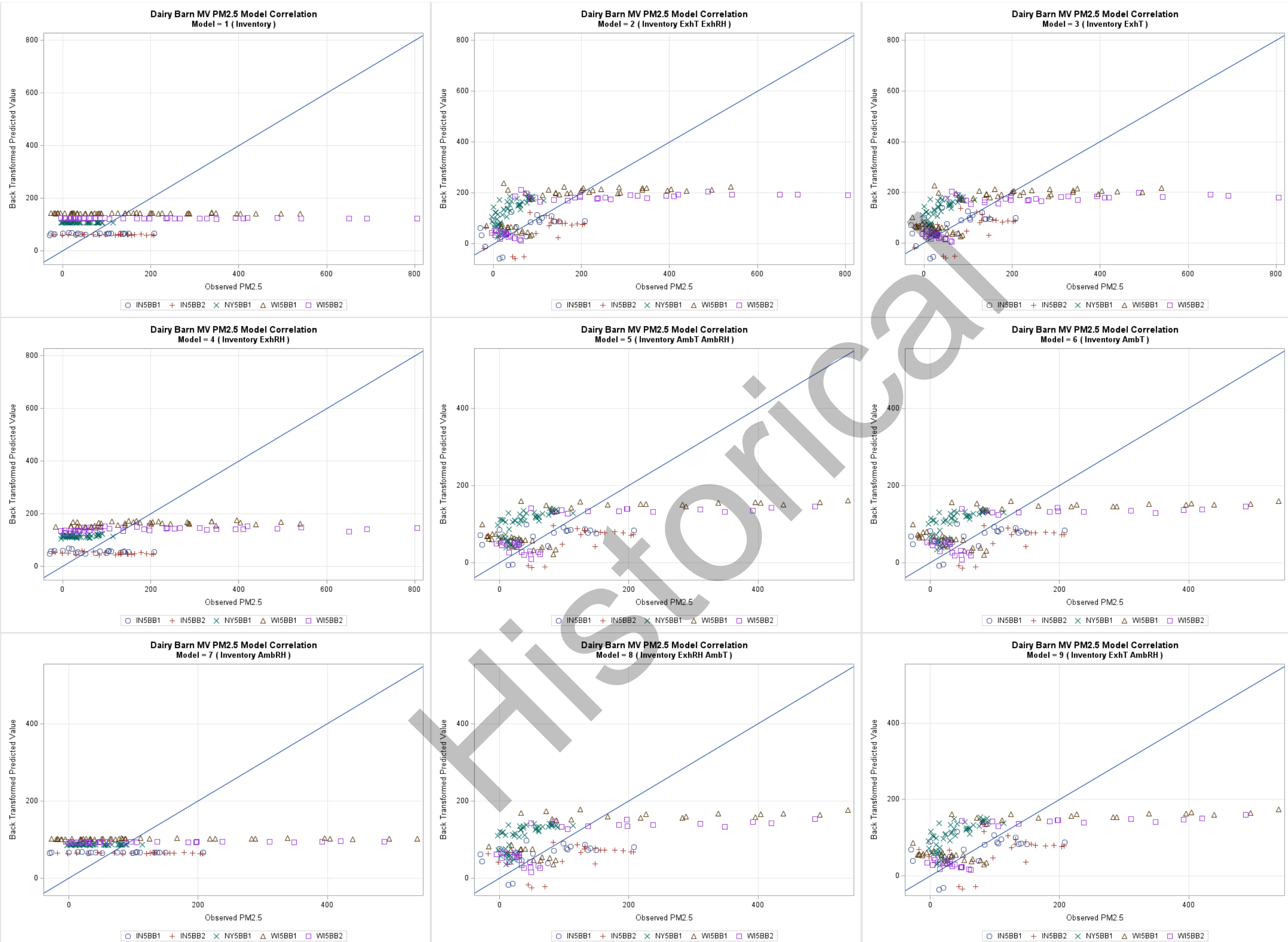


Figure G-11. Dairy mechanically ventilated barn $PM_{2.5}$ one-to-one plots models 1 through 9, back transformed.

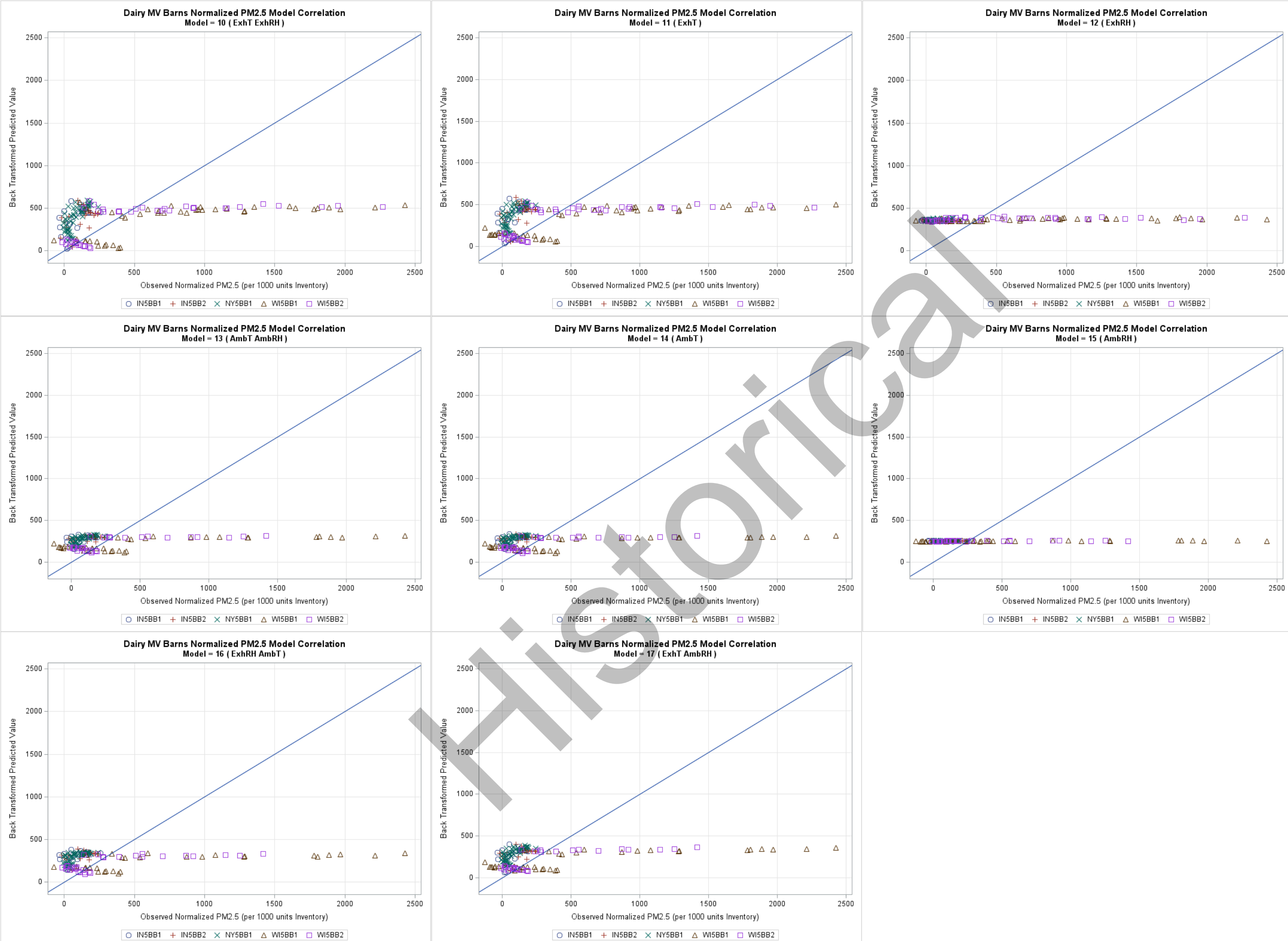


Figure G-12. Dairy mechanically ventilated barn $PM_{2.5}$ one-to-one plots models 10 through 17, back transformed.

G.1.5 Total Suspended Particulates (TSP)

Table G-11. Parameter and estimates TSP emission models for dairy mechanically ventilated barn.

Model	Parameter	Estimate	Standard Error	p-value
MVP-1	Intercept	7.506149	0.07383	<.0001
	Inventory	-0.426276	0.12654	0.0013
MVP-2	Intercept	8.080847	0.12835	<.0001
	Inventory	-0.266376	0.10963	*0.0178*
	Exhaust temperature	0.015445	0.00297	<.0001
	Exhaust relative humidity	-0.011664	0.00178	<.0001
MVP-3	Intercept	7.358078	0.07017	<.0001
	Inventory	-0.436108	0.10746	0.0001
	Exhaust temperature	0.014361	0.00303	<.0001
MVP-4	Intercept	8.210417	0.13518	<.0001
	Inventory	-0.278826	0.12623	*0.0308*
	Exhaust relative humidity	-0.011042	0.00185	<.0001
MVP-5	Intercept	7.857034	0.11335	<.0001
	Inventory	-0.389323	0.1128	0.001
	Ambient temperature	0.008795	0.00219	<.0001
	Ambient relative humidity	-0.006738	0.00139	<.0001
MVP-6	Intercept	7.409806	0.06478	<.0001
	Inventory	-0.404463	0.10961	0.0005
	Ambient temperature	0.009577	0.00219	<.0001
MVP-7	Intercept	7.939351	0.11744	<.0001
	Inventory	-0.352971	0.1263	0.0071
	Ambient relative humidity	-0.007146	0.00141	<.0001
MVP-8	Intercept	8.090359	0.12981	<.0001
	Inventory	-0.254138	0.11268	*0.0276*
	Exhaust relative humidity	-0.010719	0.0018	<.0001
	Ambient temperature	0.009293	0.00217	<.0001
MVP-9	Intercept	7.796195	0.11451	<.0001
	Inventory	-0.368408	0.11077	0.0015
	Exhaust temperature	0.014024	0.00303	<.0001
	Ambient relative humidity	-0.007089	0.00138	<.0001
MVP-10	Intercept	8.975691	0.21501	<.0001
	Exhaust temperature	0.027785	0.0056	<.0001
	Exhaust relative humidity	-0.023121	0.00293	<.0001
MVP-11	Intercept	7.431124	0.09737	<.0001
	Exhaust temperature	0.020482	0.00614	0.001
MVP-12	Intercept	9.111458	0.22141	<.0001
	Exhaust relative humidity	-0.020799	0.00299	<.0001
MVP-13	Intercept	8.434953	0.17254	<.0001
	Ambient temperature	0.01277	0.00439	0.004
	Ambient relative humidity	-0.013417	0.0023	<.0001

Model	Parameter	Estimate	Standard Error	p-value
MVP-14	Intercept	7.539927	0.08173	<.0001
	Ambient temperature	0.013471	0.00453	0.0033
MVP-15	Intercept	8.546104	0.1713	<.0001
	Ambient relative humidity	-0.0135	0.00231	<.0001
MVP-16	Intercept	9.009825	0.21894	<.0001
	Exhaust relative humidity	-0.021338	0.00297	<.0001
	Ambient temperature	0.016536	0.00418	0.0001
MVP-17	Intercept	8.338173	0.17488	<.0001
	Exhaust temperature	0.023054	0.00598	0.0001
	Ambient relative humidity	-0.014012	0.00228	<.0001

Table G-12. Fit and evaluation statistics for TSP emission models for dairy mechanically ventilated barn.

Model	2LogL	AIC	AICc	BIC	Corr.	LNME[a] (%)	NME[b] (%)	ME[b] (g day^{-1})	MB[b] (kg day^{-1})	NMB[b] (%)
MVP-1	-39	-31	-31	-30	0.36	3.43	76.20	452.20	-7.27	-1.23
MVP-2	-100	-88	-88	-85	0.58	3.12	65.73	392.90	-10.15	-1.70
MVP-3	-59	-49	-49	-47	0.52	3.29	69.78	414.10	-13.38	-2.25
MVP-4	-75	-65	-65	-63	0.45	3.21	72.38	432.70	-5.15	-0.86
MVP-5	-74	-62	-62	-60	0.48	3.20	70.42	403.60	-7.64	-1.33
MVP-6	-52	-42	-42	-40	0.48	3.20	70.09	401.70	-10.53	-1.84
MVP-7	-60	-50	-49	-48	0.35	3.28	74.49	426.90	-3.09	-0.54
MVP-8	-87	-75	-74	-72	0.54	3.07	66.61	384.80	-8.25	-1.43
MVP-9	-79	-67	-67	-65	0.49	3.20	70.07	401.60	-7.09	-1.24
MVP-10	236	246	246	248	0.57	5.76	80.77	1,507.00	-161.40	-8.65
MVP-11	310	318	318	320	0.37	6.77	93.60	1,735.00	-119.00	-6.42
MVP-12	260	268	268	269	0.42	6.12	93.23	1,740.00	-54.94	-2.94
MVP-13	270	280	281	282	0.31	6.41	92.68	1,628.00	-66.13	-3.77
MVP-14	303	311	311	312	0.31	6.63	94.21	1,655.00	-86.80	-4.94
MVP-15	279	287	287	288	0.15	6.57	99.61	1,749.00	13.17	0.75
MVP-16	237	247	247	249	0.52	5.73	82.91	1,466.00	-125.10	-7.08
MVP-17	264	274	274	276	0.36	6.36	90.45	1,589.00	-85.82	-4.89

[a] Based on transformed data (i.e., ln(TSP)).
[b] Based on back-transformed data.

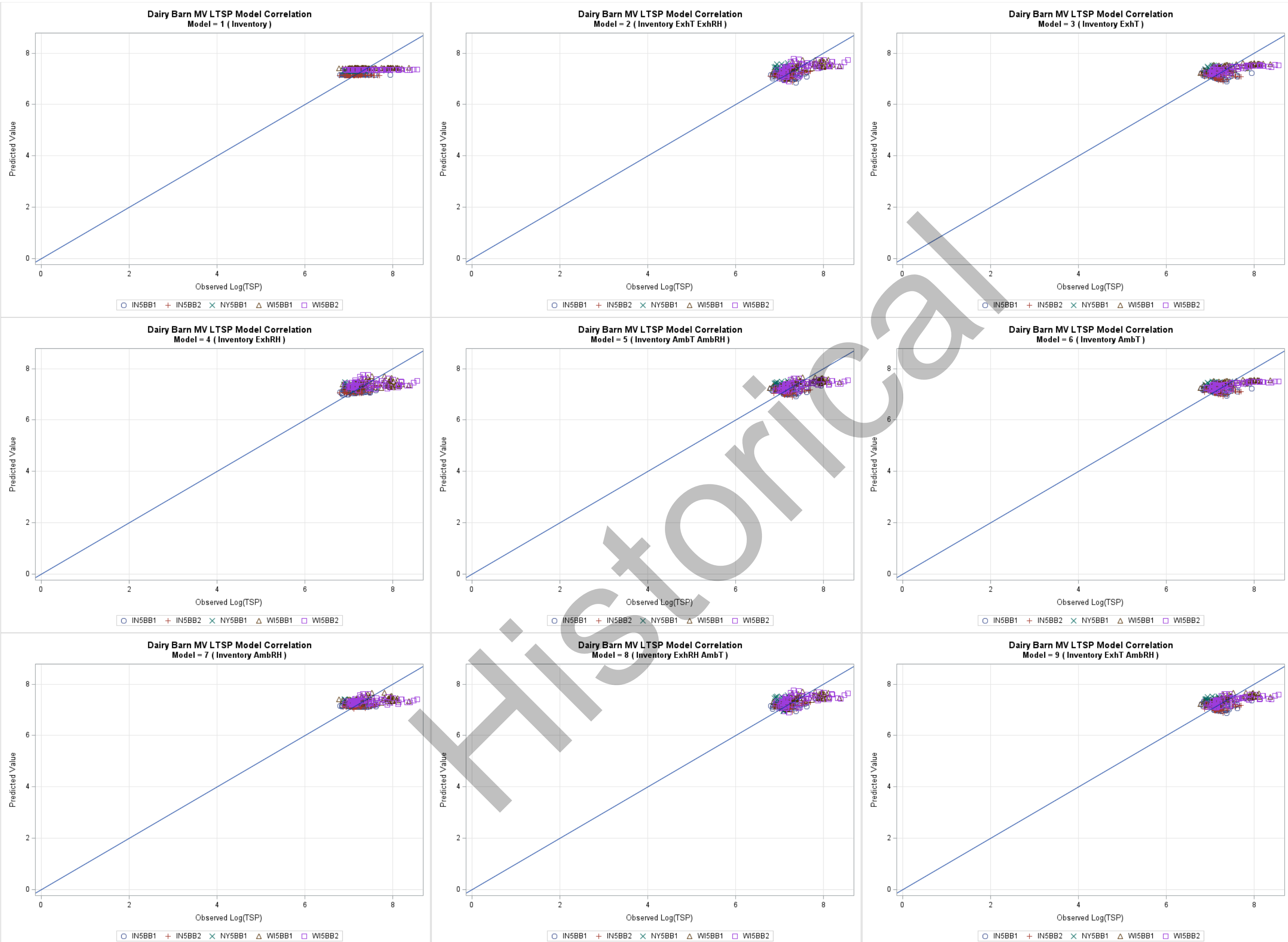


Figure G-13. Dairy mechanically ventilated barn TSP one-to-one plots models 1 through 9, log transformed.

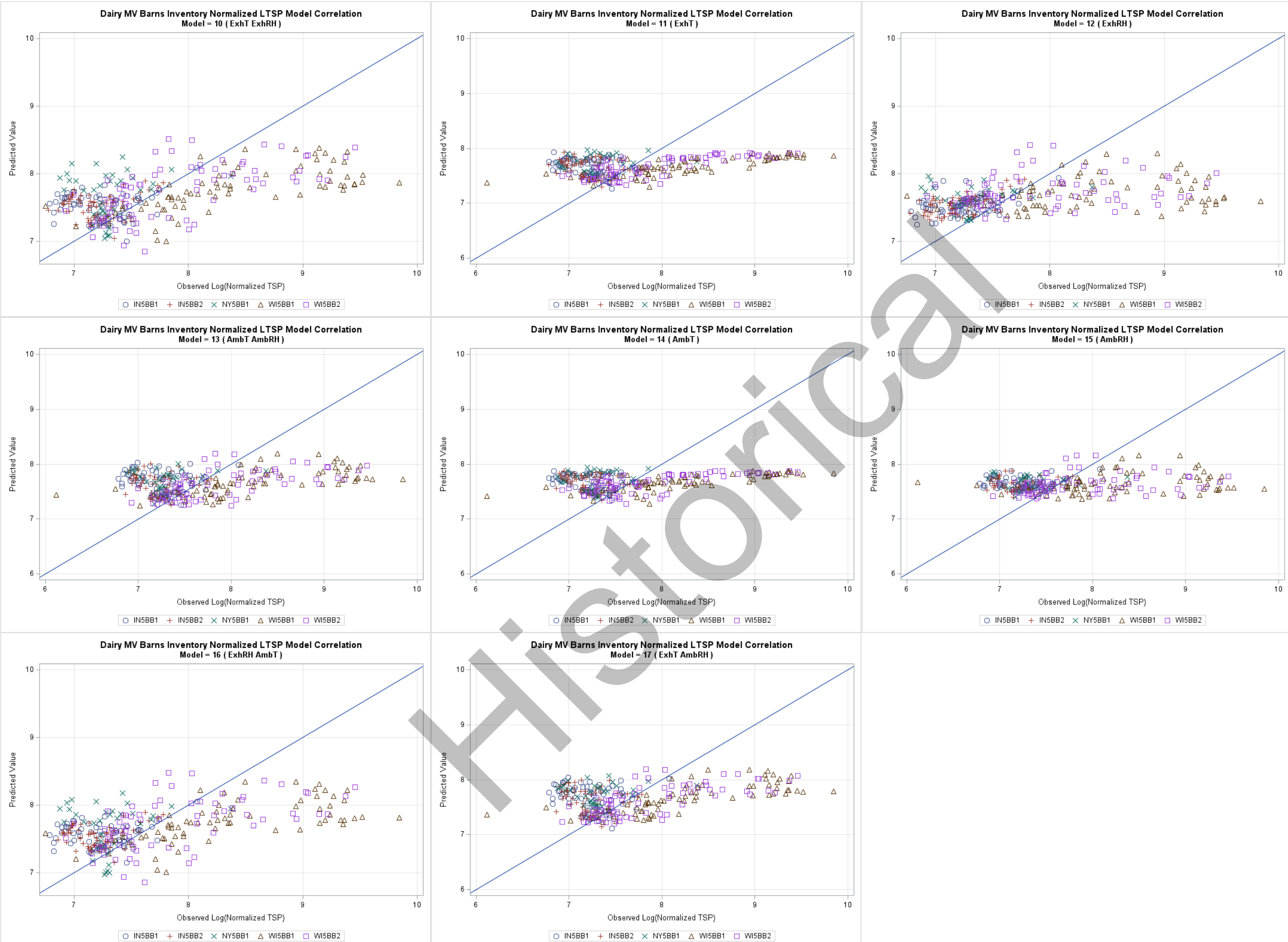


Figure G-14. Dairy mechanically ventilated barn TSP one-to-one plots models 10 through 17, log transformed.

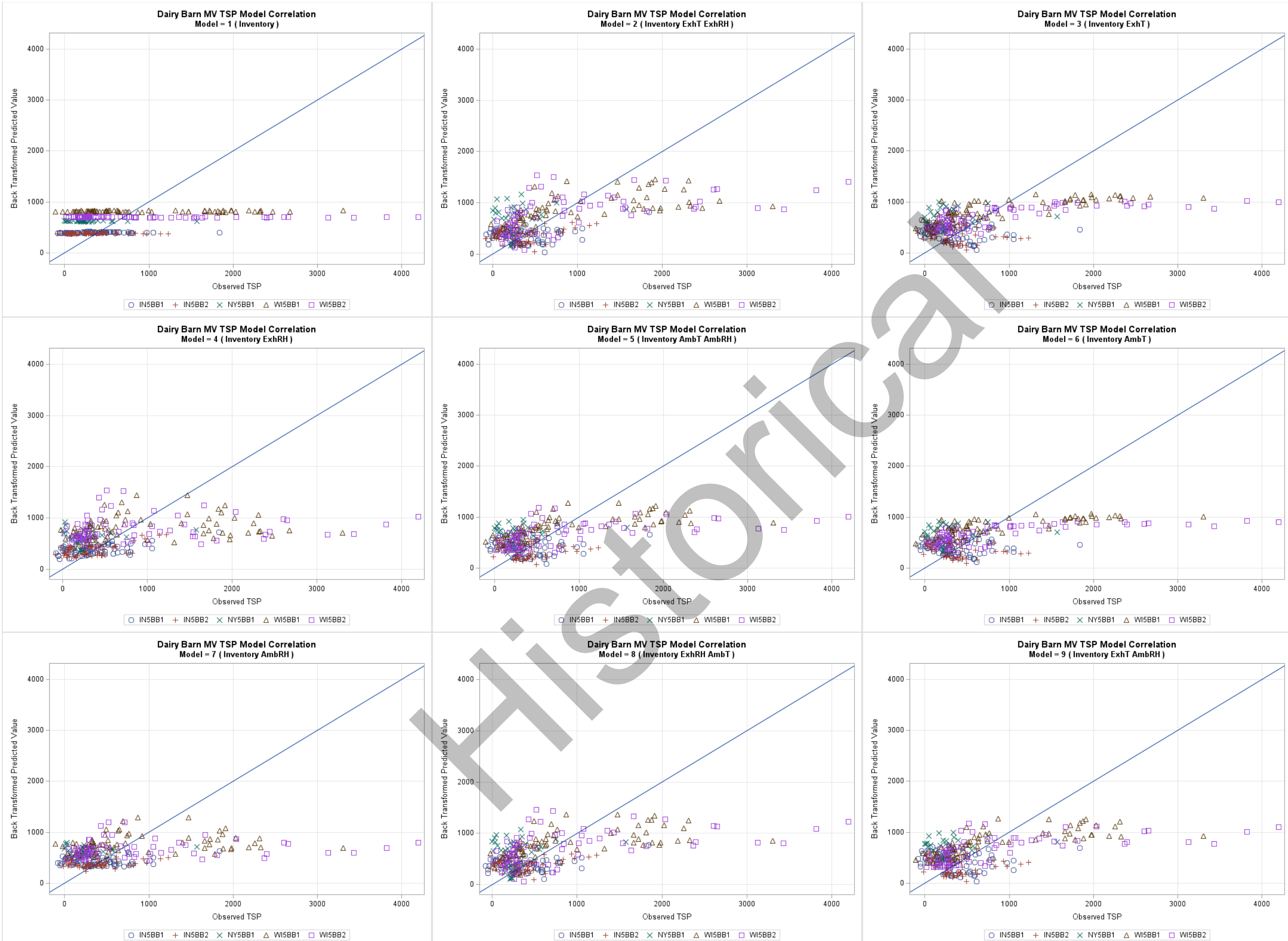


Figure G-15. Dairy mechanically ventilated barn TSP one-to-one plots models 1 through 9, back transformed.

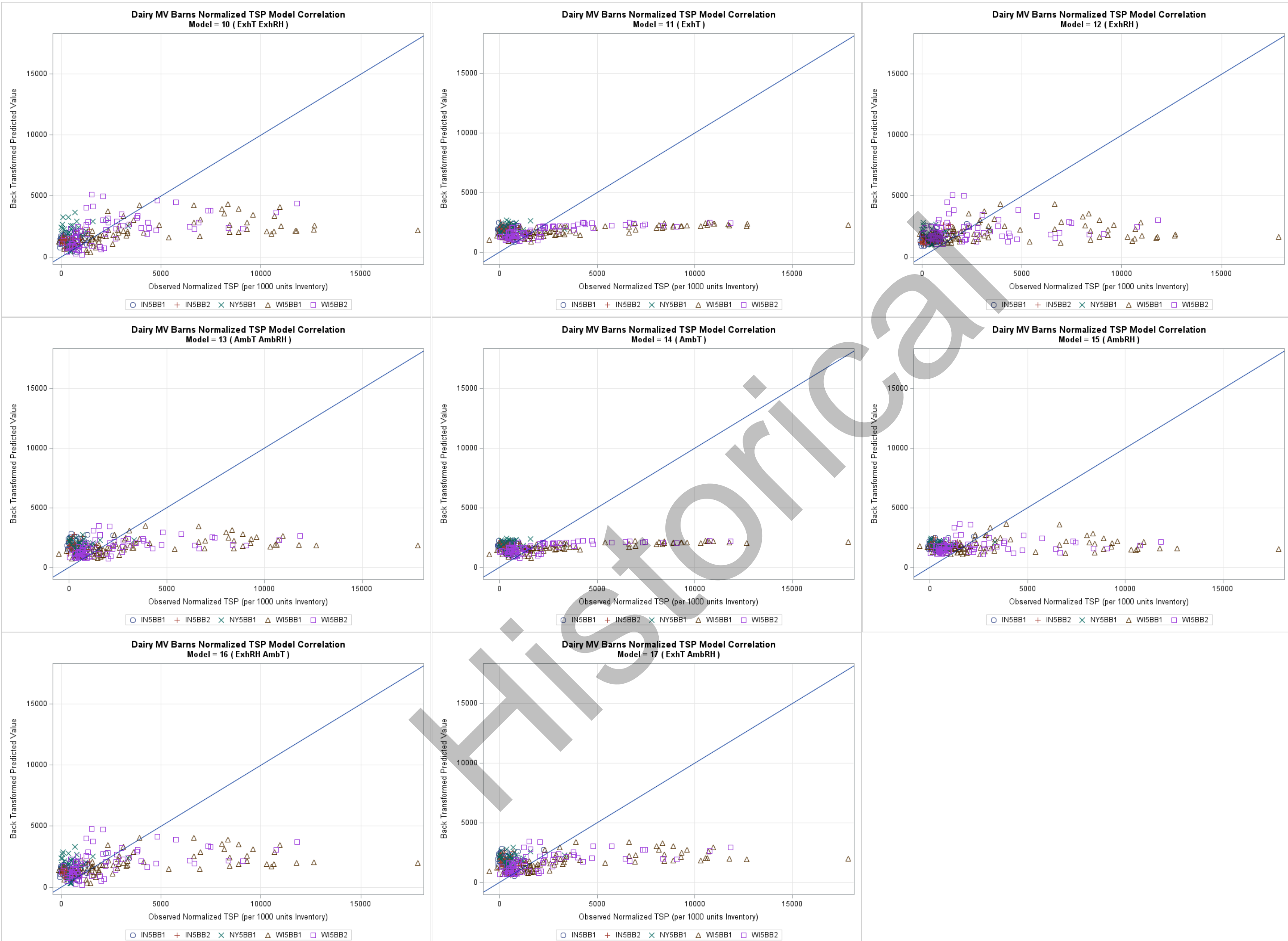


Figure G-16. Dairy mechanically ventilated barn TSP one-to-one plots models 1 through 9, back transformed.

G.2 Milking Centers

G.2.1 Ammonia (NH_3)

Table G-13. Parameter and estimates NH_3 emission models for dairy milking centers.

Model	Parameter	Estimate	Standard Error	p-value
MC-1	Intercept	1.208525	0.8987	**0.1802**
	Inventory	0	.	.
	Milk Production	0.017805	0.02543	**0.4848**
	Exhaust temperature	0.0238	0.00339	<.0001
	Exhaust relative humidity	0.000102	0.00144	**0.9434**
MC-2	Intercept	0.897337	0.76585	**0.2424**
	Inventory	0	.	.
	Milk Production	0.024322	0.02166	**0.2626**
	Exhaust temperature	0.030704	0.00286	<.0001
MC-3	Intercept	1.652131	0.89508	**0.0669**
	Inventory	0	.	.
	Milk Production	0.018111	0.02522	**0.4739**
	Exhaust relative humidity	-0.00155	0.00155	**0.3188**
MC-4	Intercept	0.838636	0.80156	**0.2965**
	Inventory	0	.	.
	Milk Production	0.028606	0.02269	**0.2087**
	Ambient temperature	0.019551	0.00209	<.0001
	Ambient relative humidity	0.001192	0.00087	**0.1697**
MC-5	Intercept	0.829125	0.80015	**0.3012**
	Inventory	0	.	.
	Milk Production	0.031273	0.02257	**0.1674**
	Ambient temperature	0.019256	0.00208	<.0001
MC-6	Intercept	1.548428	0.80445	**0.056**
	Inventory	0	.	.
	Milk Production	0.015087	0.02273	**0.5079**
	Ambient relative humidity	0.000923	0.00099	**0.3531**
MC-7	Intercept	1.120794	0.94412	**0.2367**
	Inventory	0	.	.
	Milk Production	0.022857	0.02672	**0.3935**
	Exhaust relative humidity	0.000694	0.00152	**0.6489**
	Ambient temperature	0.015329	0.00252	<.0001
MC-8	Intercept	0.774798	0.79271	**0.3292**
	Inventory	0	.	.
	Milk Production	0.025147	0.02248	**0.2642**
	Exhaust temperature	0.032583	0.00296	<.0001
	Ambient relative humidity	0.001034	0.00083	**0.2133**
MC-9	Intercept	0.804663	0.15646	<.0001
	Inventory	0.18583	0.25045	**0.4624**

Model	Parameter	Estimate	Standard Error	p-value
	Exhaust temperature	0.051146	0.00368	<.0001
	Exhaust relative humidity	0.008179	0.00146	<.0001
MC-10	Intercept	1.433197	0.11131	<.0001
	Inventory	0.088677	0.25075	**0.7254**
	Exhaust temperature	0.053704	0.00331	<.0001
MC-11	Intercept	1.346365	0.17597	<.0001
	Inventory	0.263579	0.29536	**0.3772**
	Exhaust relative humidity	0.010509	0.00166	<.0001
MC-12	Intercept	1.406205	0.13211	<.0001
	Inventory	0.210045	0.25239	**0.41**
	Ambient temperature	0.035077	0.00241	<.0001
	Ambient relative humidity	0.00438	0.00107	<.0001
MC-13	Intercept	1.718316	0.10593	<.0001
	Inventory	0.191352	0.24706	**0.4428**
	Ambient temperature	0.034376	0.00242	<.0001
MC-14	Intercept	1.823354	0.15017	<.0001
	Inventory	0.409915	0.29689	**0.1744**
	Ambient relative humidity	0.003493	0.00122	0.0043
MC-15	Intercept	1.004861	0.15587	<.0001
	Inventory	0.272607	0.24764	**0.2771**
	Exhaust relative humidity	0.009201	0.00152	<.0001
	Ambient temperature	0.032845	0.00267	<.0001
MC-16	Intercept	1.197532	0.13428	<.0001
	Inventory	0.090108	0.25633	**0.727**
	Exhaust temperature	0.054912	0.00335	<.0001
	Ambient relative humidity	0.003251	0.00104	0.0018
MC-17	Intercept	1.208525	0.8987	**0.1802**
	Milk Production	0.017805	0.02543	**0.4848**
	Exhaust temperature	0.0238	0.00339	<.0001
	Exhaust relative humidity	0.000102	0.00144	**0.9434**
MC-18	Intercept	0.897337	0.76585	**0.2424**
	Milk Production	0.024322	0.02166	**0.2626**
	Exhaust temperature	0.030704	0.00286	<.0001
MC-19	Intercept	1.652131	0.89508	**0.0669**
	Milk Production	0.018111	0.02522	**0.4739**
	Exhaust relative humidity	-0.00155	0.00155	**0.3188**
MC-20	Intercept	0.838636	0.80156	**0.2965**
	Milk Production	0.028606	0.02269	**0.2087**
	Ambient temperature	0.019551	0.00209	<.0001
	Ambient relative humidity	0.001192	0.00087	**0.1697**
MC-21	Intercept	0.829125	0.80015	**0.3012**
	Milk Production	0.031273	0.02257	**0.1674**
	Ambient temperature	0.019256	0.00208	<.0001

Model	Parameter	Estimate	Standard Error	p-value
MC-22	Intercept	1.548428	0.80445	**0.056**
	Milk Production	0.015087	0.02273	**0.5079**
	Ambient relative humidity	0.000923	0.00099	**0.3531**
MC-23	Intercept	1.120794	0.94412	**0.2367**
	Milk Production	0.022857	0.02672	**0.3935**
	Exhaust relative humidity	0.000694	0.00152	**0.6489**
	Ambient temperature	0.015329	0.00252	<.0001
MC-24	Intercept	0.774798	0.79271	**0.3292**
	Milk Production	0.025147	0.02248	**0.2642**
	Exhaust temperature	0.032583	0.00296	<.0001
	Ambient relative humidity	0.001034	0.00083	**0.2133**
MC-25	Intercept	1.397358	0.17941	<.0001
	Exhaust temperature	0.068193	0.00507	<.0001
	Exhaust relative humidity	0.009331	0.00191	<.0001
MC-26	Intercept	2.077434	0.11748	<.0001
	Exhaust temperature	0.072495	0.00453	<.0001
MC-27	Intercept	2.153227	0.18617	<.0001
	Exhaust relative humidity	0.012156	0.00217	<.0001
MC-28	Intercept	2.12093	0.14039	<.0001
	Ambient temperature	0.047334	0.00332	<.0001
	Ambient relative humidity	0.00551	0.00139	<.0001
MC-29	Intercept	2.505637	0.10119	<.0001
	Ambient temperature	0.046434	0.00335	<.0001
MC-30	Intercept	2.774069	0.14027	<.0001
	Ambient relative humidity	0.004302	0.00159	0.0069
MC-31	Intercept	1.700751	0.17521	<.0001
	Exhaust relative humidity	0.010613	0.00199	<.0001
	Ambient temperature	0.043973	0.00371	<.0001
MC-32	Intercept	1.78757	0.14904	<.0001
	Exhaust temperature	0.074156	0.00458	<.0001
	Ambient relative humidity	0.003945	0.00134	0.0032

Table G-14. Fit and evaluation statistics for NH_3 emission models for dairy milking centers.

Model	2LogL	AIC	AICc	BIC	Corr.	LNME[a] (%)	NME[b] (%)	ME[b] (kg day^{-1})	MB[b] (kg day^{-1})	NMB[b] (%)
MC-1	-266	-256	-256	-238	0.209	8.607	27.94	1.684	0.139	2.31
MC-2	-366	-358	-358	-342	0.318	9.035	30.29	1.759	0.224	3.861
MC-3	-224	-216	-216	-201	-0.024	8.906	28.11	1.695	0.004	0.062
MC-4	-335	-325	-325	-306	0.316	9.015	29.85	1.729	0.201	3.471
MC-5	-333	-325	-325	-310	0.316	8.912	29.47	1.707	0.188	3.24
MC-6	-261	-253	-253	-238	-0.127	9.095	29.09	1.685	0.007	0.118
MC-7	-243	-233	-233	-215	0.208	8.636	27.84	1.675	0.125	2.077
MC-8	-356	-346	-346	-327	0.315	9.509	32.04	1.855	0.267	4.609
MC-9	16	28	29	31	0.614	15.49	47.52	3.521	0.086	1.159
MC-10	-24	-14	-14	-12	0.558	15.93	49.43	3.55	0.226	3.147
MC-11	187	197	197	199	0.412	17.2	52.4	3.883	-0.157	-2.112
MC-12	14	26	26	28	0.537	16.38	50.44	3.619	0.21	2.926
MC-13	30	40	40	42	0.541	16.16	49.76	3.57	0.168	2.34
MC-14	202	212	212	214	0.104	17.21	53.21	3.818	-0.045	-0.62
MC-15	55	67	67	69	0.607	15.66	47.7	3.532	0.034	0.46
MC-16	-29	-17	-17	-14	0.557	16.16	50.06	3.592	0.266	3.709
MC-17	-266	-254	-254	-232	0.209	8.607	27.94	1.684	0.139	2.31
MC-18	-366	-356	-356	-337	0.318	9.035	30.29	1.759	0.224	3.861
MC-19	-224	-214	-214	-196	-0.024	8.906	28.11	1.695	0.004	0.062
MC-20	-335	-323	-323	-300	0.316	9.015	29.85	1.729	0.201	3.471
MC-21	-333	-323	-323	-304	0.316	8.912	29.47	1.707	0.188	3.24
MC-22	-261	-251	-251	-232	-0.127	9.095	29.09	1.685	0.007	0.118
MC-23	-243	-231	-231	-210	0.208	8.636	27.84	1.675	0.125	2.077
MC-24	-356	-344	-344	-321	0.315	9.509	32.04	1.855	0.267	4.609
MC-25	382	392	392	394	0.514	17.68	52.09	12.03	2.2	9.522
MC-26	390	398	398	400	0.384	18.81	58.25	13.66	3.717	15.85
MC-27	541	549	550	551	0.373	19.48	49.75	11.49	-0.169	-0.732
MC-28	423	433	433	435	0.401	18.31	55.01	12.82	3.194	13.7
MC-29	438	446	446	448	0.394	18.25	54.18	12.63	3.017	12.94
MC-30	601	609	609	611	0.079	18.92	48.9	11.4	0.006	0.025
MC-31	412	422	423	424	0.529	17.31	49.26	11.29	1.719	7.5
MC-32	381	391	391	393	0.386	19.1	60.13	14.02	3.985	17.1

[a] Based on transformed data (i.e., ln(NH_3)).
[b] Based on back-transformed data.

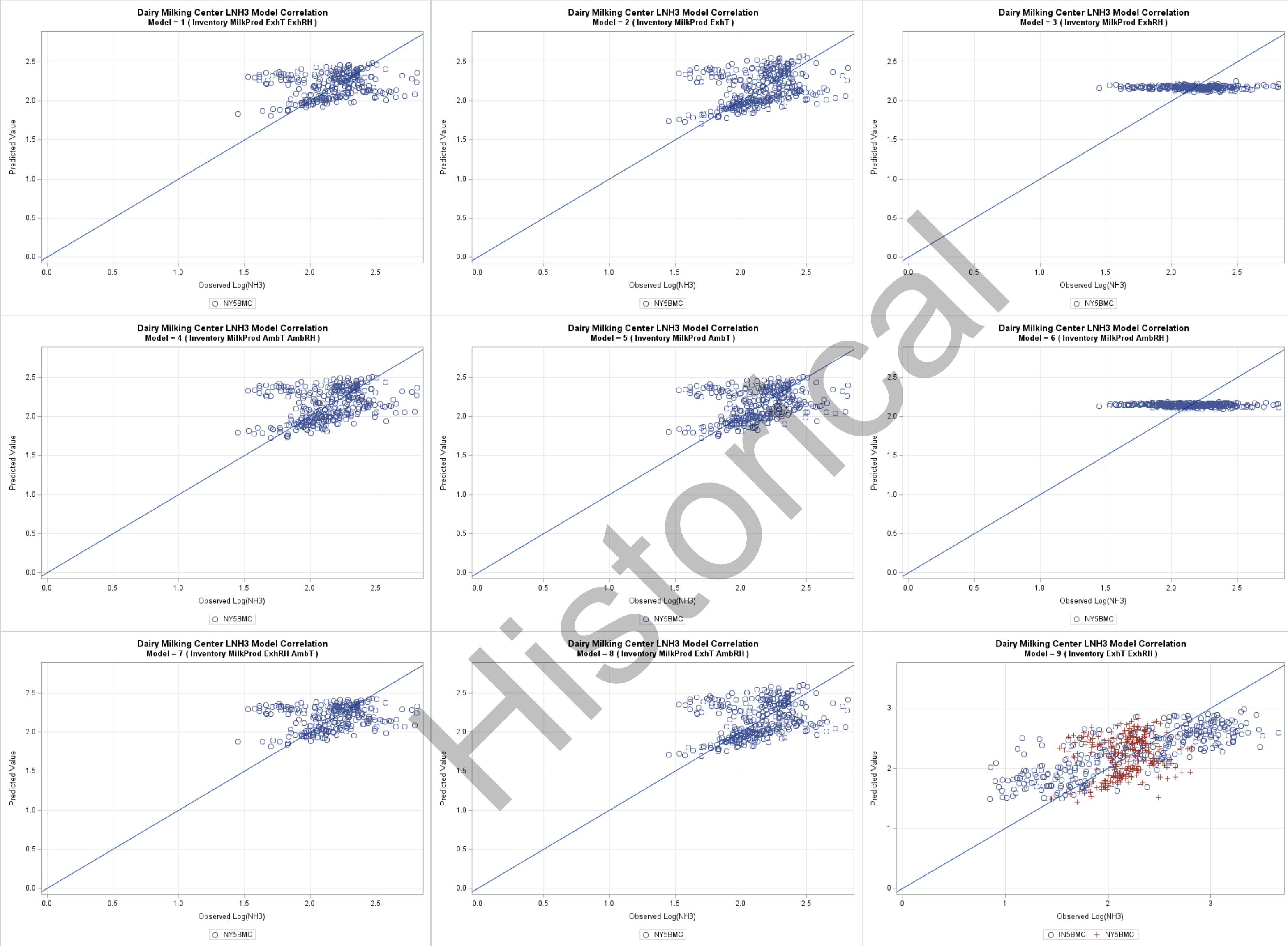


Figure G-17. Dairy milking center NH_3 one-to-one plots models 1 through 9, log transformed.

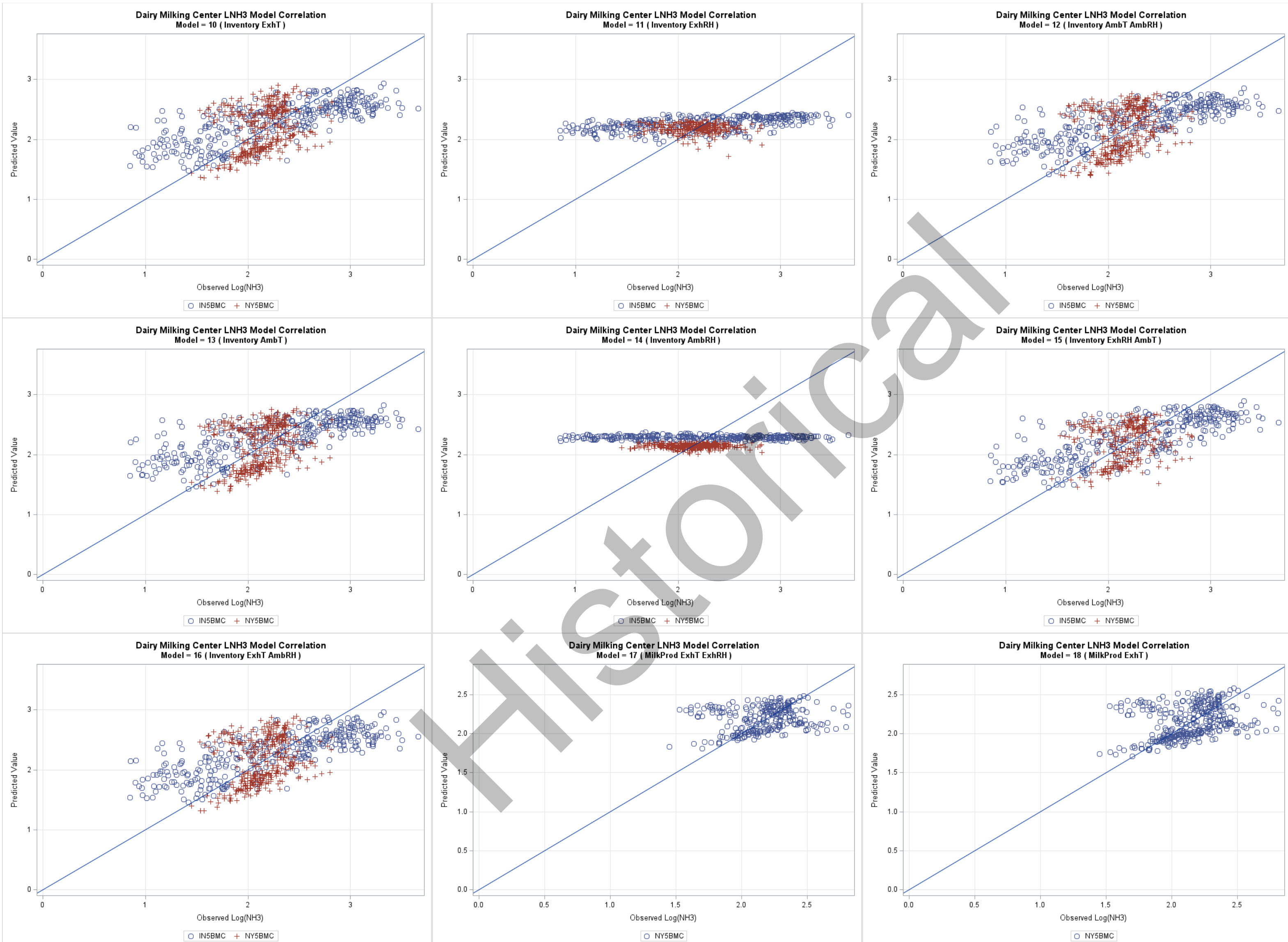


Figure G-18. Dairy milking center NH_3 one-to-one plots models 10 through 18, log transformed.

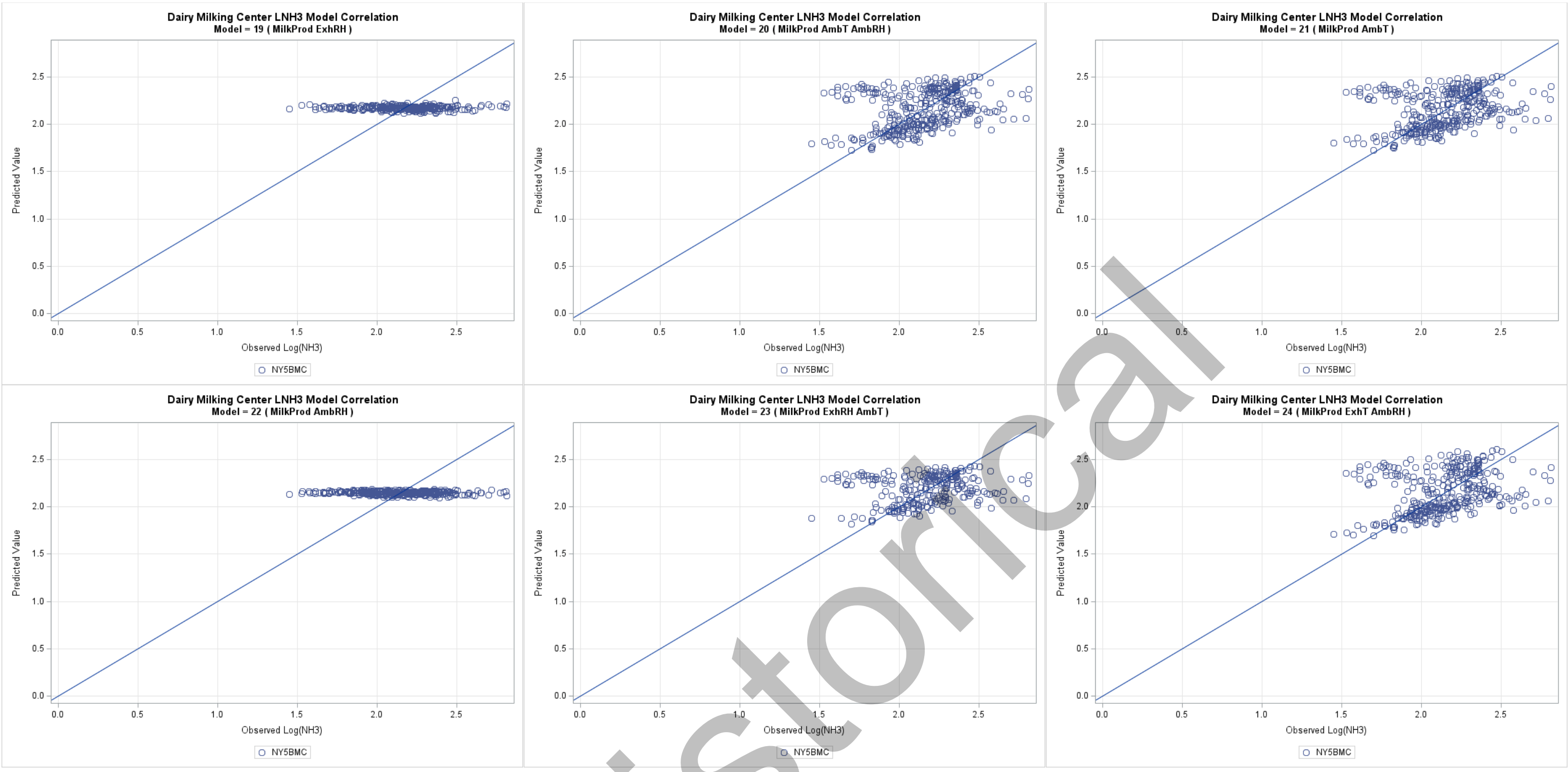


Figure G-19. Dairy milking center NH_3 one-to-one plots models 19 through 24, log transformed.

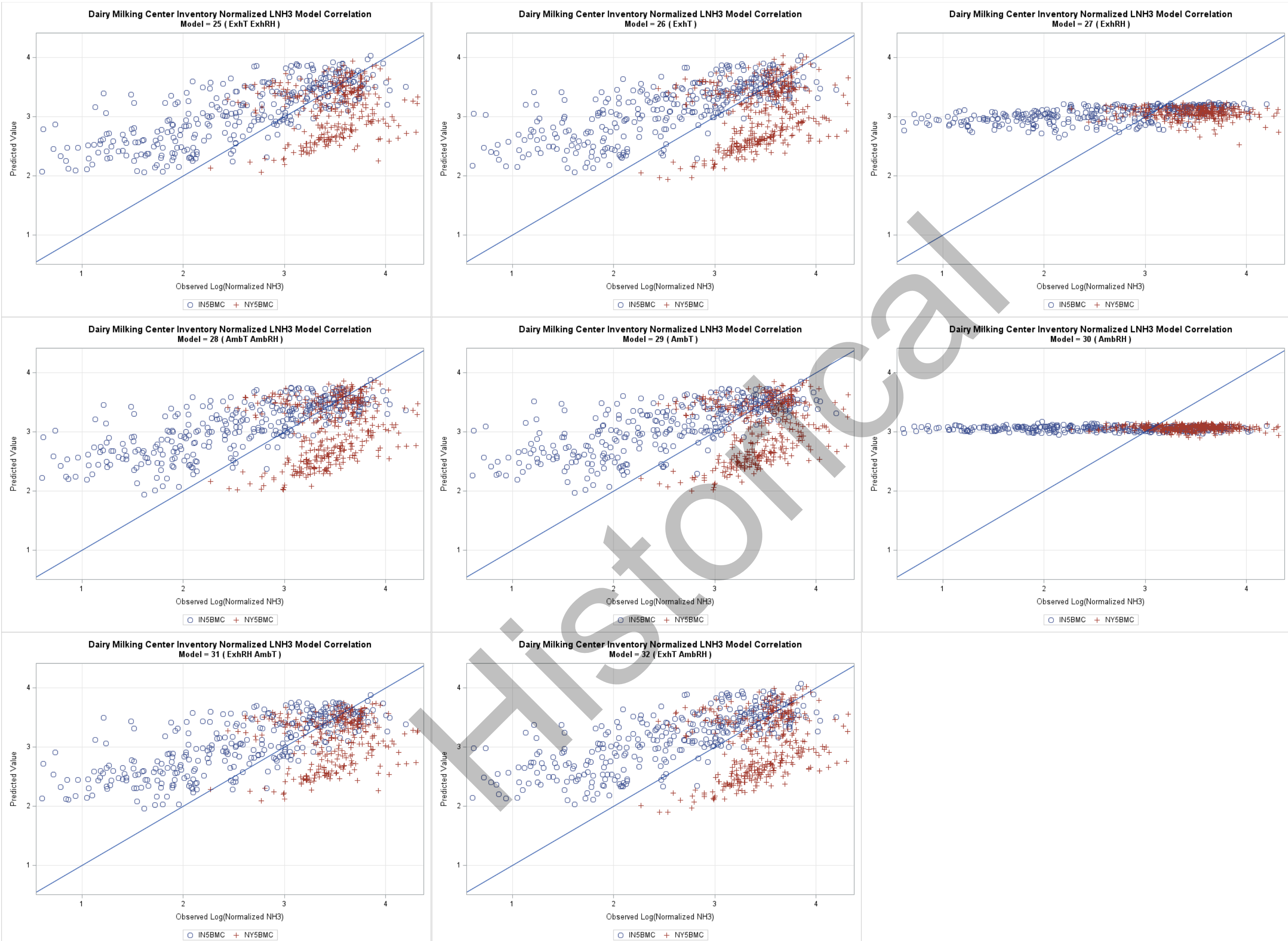


Figure G-20. Dairy milking center NH_3 one-to-one plots models 25 through 32, log transformed.

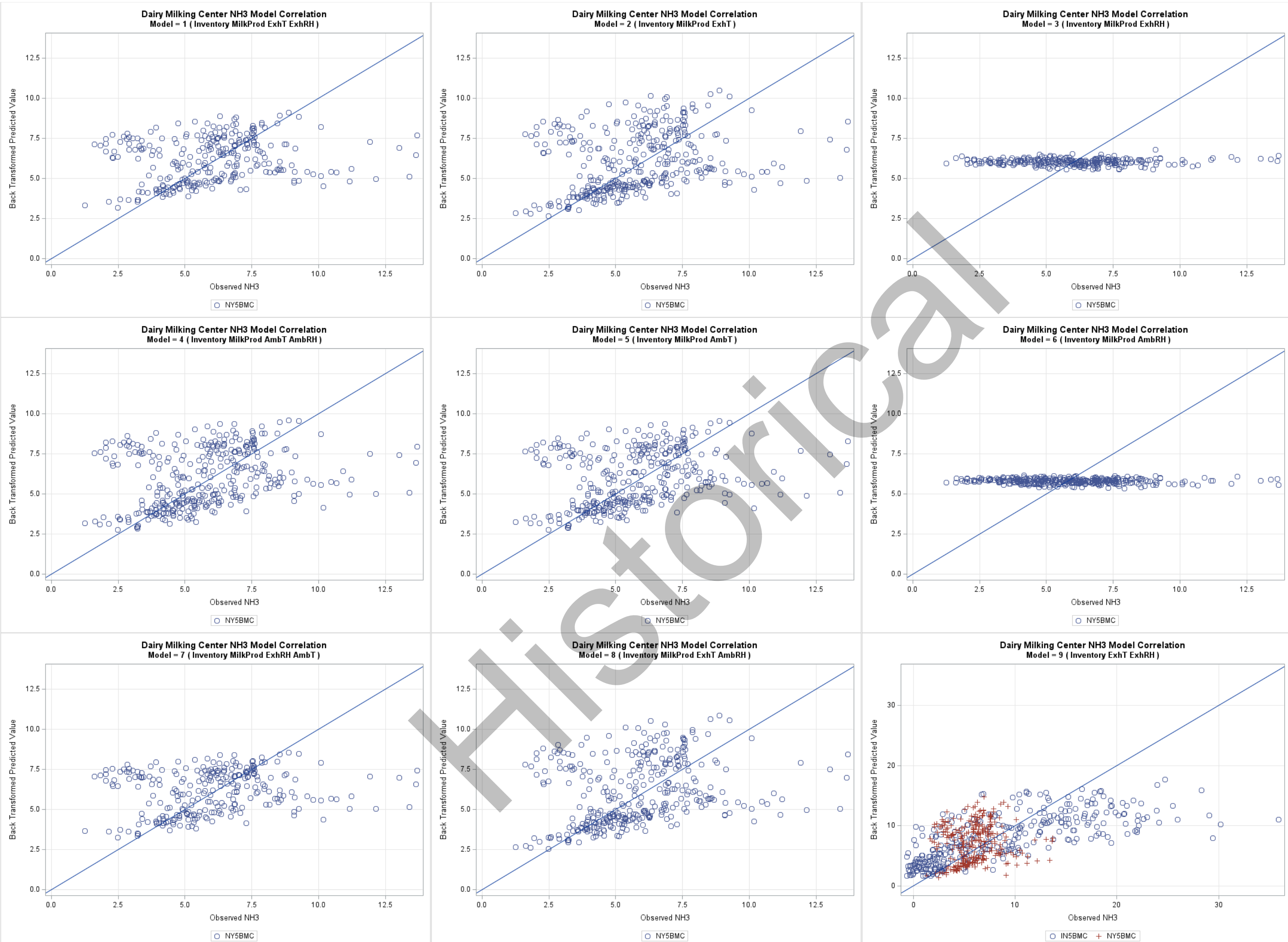


Figure G-21 Dairy milking center NH_3 one-to-one plots models 1 through 9, back transformed.

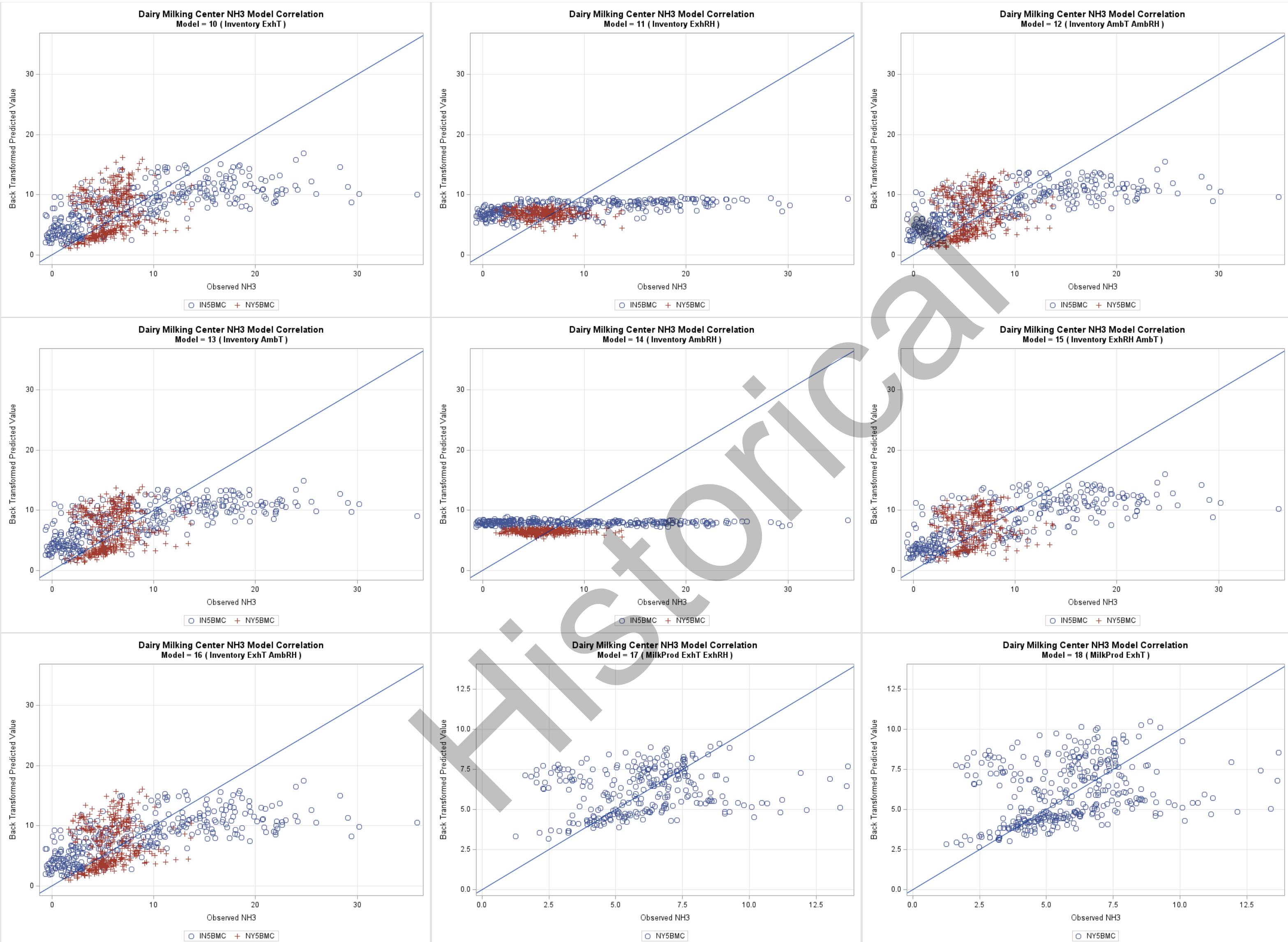


Figure G-22 Dairy milking center NH_3 one-to-one plots models 10 through 18, back transformed.

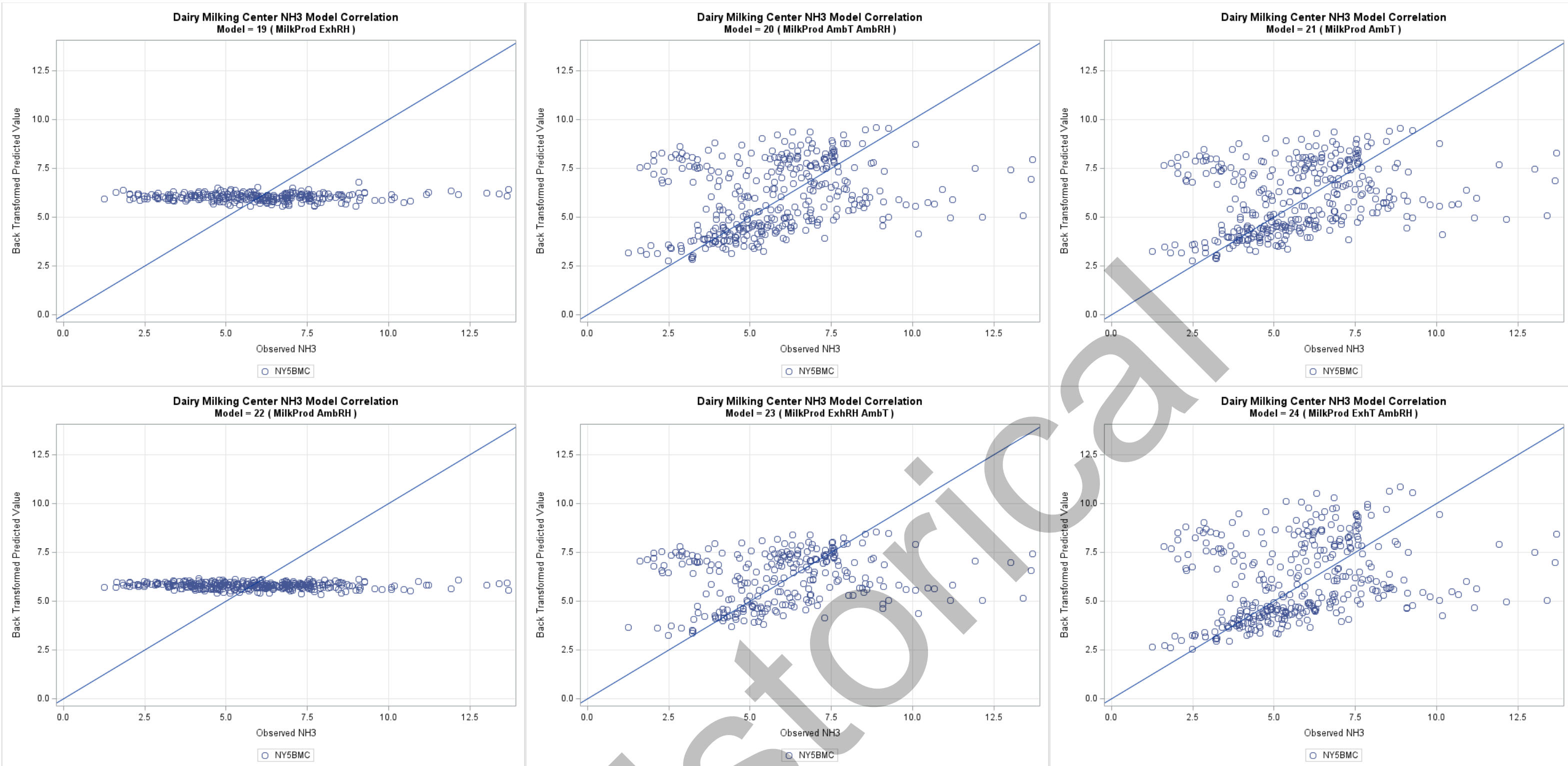


Figure G-23 Dairy milking center NH_3 one-to-one plots models 19 through 24, back transformed.

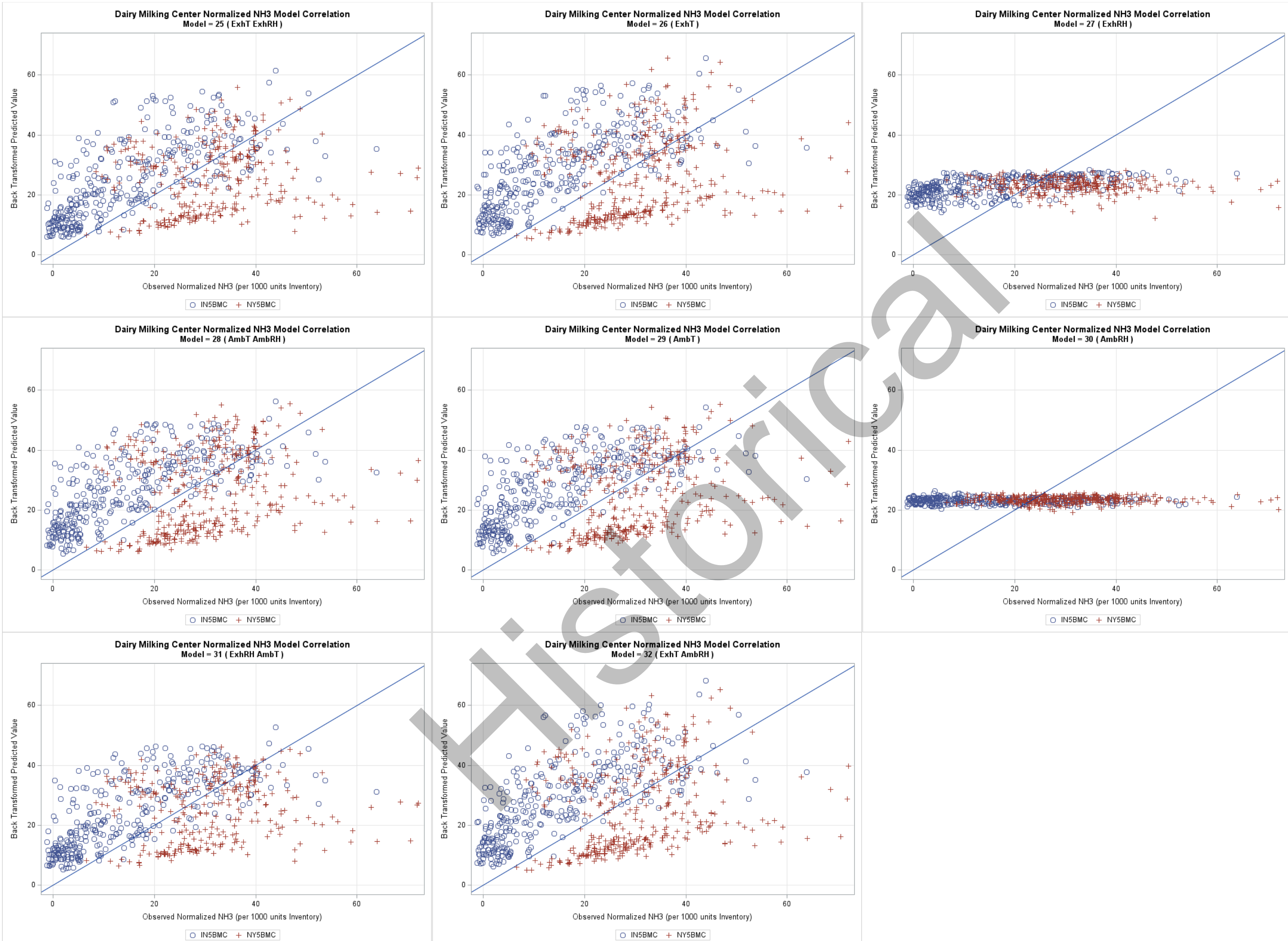


Figure G-24 Dairy milking center NH_3 one-to-one plots models 25 through 32, back transformed.

G.2.2 Hydrogen Sulfide (H_2S)

Table G-15. Parameter and estimates H_2S emission models for dairy milking centers.

Model	Parameter	Estimate	Standard Error	p-value
MC-1	Intercept	7.893109	0.43963	<.0001
	Inventory	0	.	.
	Milk Production	-0.035798	0.01243	0.0043
	Exhaust temperature	-0.000485	0.00156	**0.7567**
	Exhaust relative humidity	0.000179	0.00066	**0.7859**
MC-2	Intercept	7.717017	0.35514	<.0001
	Inventory	0	.	.
	Milk Production	-0.032225	0.00999	0.0014
	Exhaust temperature	0.003142	0.00125	*0.0128*
MC-3	Intercept	7.898421	0.43608	<.0001
	Inventory	0	.	.
	Milk Production	-0.036205	0.01229	0.0035
	Exhaust relative humidity	0.000204	0.00065	**0.7547**
MC-4	Intercept	7.531657	0.35782	<.0001
	Inventory	0	.	.
	Milk Production	-0.028082	0.01007	0.0057
	Ambient temperature	0.002876	0.00088	0.0013
	Ambient relative humidity	0.000661	0.00042	**0.115**
MC-5	Intercept	7.543277	0.36085	<.0001
	Inventory	0	.	.
	Milk Production	-0.02709	0.01015	0.0082
	Ambient temperature	0.002689	0.00089	0.0029
MC-6	Intercept	7.501342	0.37715	<.0001
	Inventory	0	.	.
	Milk Production	-0.025945	0.01065	*0.0154*
	Ambient relative humidity	0.000501	0.00041	**0.2271**
MC-7	Intercept	7.66922	0.45352	<.0001
	Inventory	0	.	.
	Milk Production	-0.029811	0.01283	*0.021*
	Exhaust relative humidity	0.000297	0.00067	**0.6574**
	Ambient temperature	-0.000295	0.00117	**0.8018**
MC-8	Intercept	7.522973	0.36263	<.0001
	Inventory	0	.	.
	Milk Production	-0.028004	0.0102	0.0065
	Exhaust temperature	0.003377	0.00126	0.008
	Ambient relative humidity	0.000596	0.00042	**0.1536**
MC-9	Intercept	5.509849	0.16201	<.0001
	Inventory	1.31127	0.18731	<.0001
	Exhaust temperature	0.024987	0.00417	<.0001
	Exhaust relative humidity	0.006798	0.00191	0.0004
MC-10	Intercept	6.049	0.09117	<.0001
	Inventory	1.355319	0.19579	<.0001
	Exhaust temperature	0.022625	0.0038	<.0001
MC-11	Intercept	5.942188	0.16899	<.0001
	Inventory	1.351143	0.23652	<.0001

Model	Parameter	Estimate	Standard Error	p-value
	Exhaust relative humidity	0.00596	0.00194	0.0022
MC-12	Intercept	6.034746	0.12697	<.0001
	Inventory	1.40603	0.1962	<.0001
	Ambient temperature	0.016109	0.00273	<.0001
	Ambient relative humidity	0.001621	0.00136	**0.2333**
MC-13	Intercept	6.149091	0.08507	<.0001
	Inventory	1.405751	0.19795	<.0001
	Ambient temperature	0.015731	0.00274	<.0001
MC-14	Intercept	6.281146	0.13305	<.0001
	Inventory	1.493207	0.24053	<.0001
	Ambient relative humidity	0.000723	0.00135	**0.5928**
MC-15	Intercept	5.570392	0.16012	<.0001
	Inventory	1.359386	0.18838	<.0001
	Exhaust relative humidity	0.007425	0.00193	0.0001
	Ambient temperature	0.017816	0.00297	<.0001
MC-16	Intercept	5.971123	0.13014	<.0001
	Inventory	1.358924	0.1965	<.0001
	Exhaust temperature	0.023044	0.00384	<.0001
	Ambient relative humidity	0.001053	0.00135	**0.4366**
MC-17	Intercept	7.893109	0.43963	<.0001
	Milk Production	-0.035798	0.01243	0.0043
	Exhaust temperature	-0.000485	0.00156	**0.7567**
	Exhaust relative humidity	0.000179	0.00066	**0.7859**
MC-18	Intercept	7.717017	0.35514	<.0001
	Milk Production	-0.032225	0.00999	0.0014
	Exhaust temperature	0.003142	0.00125	*0.0128*
MC-19	Intercept	7.898421	0.43608	<.0001
	Milk Production	-0.036205	0.01229	0.0035
	Exhaust relative humidity	0.000204	0.00065	**0.7547**
MC-20	Intercept	7.531657	0.35782	<.0001
	Milk Production	-0.028082	0.01007	0.0057
	Ambient temperature	0.002876	0.00088	0.0013
	Ambient relative humidity	0.000661	0.00042	**0.115**
MC-21	Intercept	7.543277	0.36085	<.0001
	Milk Production	-0.02709	0.01015	0.0082
	Ambient temperature	0.002689	0.00089	0.0029
MC-22	Intercept	7.501342	0.37715	<.0001
	Milk Production	-0.025945	0.01065	*0.0154*
	Ambient relative humidity	0.000501	0.00041	**0.2271**
MC-23	Intercept	7.66922	0.45352	<.0001
	Milk Production	-0.029811	0.01283	*0.021*
	Exhaust relative humidity	0.000297	0.00067	**0.6574**
	Ambient temperature	-0.000295	0.00117	**0.8018**
MC-24	Intercept	7.522973	0.36263	<.0001
	Milk Production	-0.028004	0.0102	0.0065
	Exhaust temperature	0.003377	0.00126	0.008
	Ambient relative humidity	0.000596	0.00042	**0.1536**
MC-25	Intercept	6.121627	0.19903	<.0001
	Exhaust temperature	0.0332	0.00556	<.0001

Model	Parameter	Estimate	Standard Error	p-value
	Exhaust relative humidity	0.008349	0.00245	0.0007
MC-26	Intercept	6.727295	0.08868	<.0001
	Exhaust temperature	0.033995	0.00499	<.0001
MC-27	Intercept	6.719077	0.19516	<.0001
	Exhaust relative humidity	0.007161	0.00248	0.004
MC28	Intercept	6.712936	0.14037	<.0001
	Ambient temperature	0.024797	0.00361	<.0001
	Ambient relative humidity	0.002601	0.00174	0.1357
MC-29	Intercept	6.898188	0.07052	<.0001
	Ambient temperature	0.024053	0.00361	<.0001
MC-30	Intercept	7.141095	0.13417	<.0001
	Ambient relative humidity	0.001169	0.00173	0.4985
MC-31	Intercept	6.21485	0.19461	<.0001
	Exhaust relative humidity	0.009244	0.00247	0.0002
	Ambient temperature	0.02404	0.00398	<.0001
MC-32	Intercept	6.596762	0.14782	<.0001
	Exhaust temperature	0.034941	0.00504	<.0001
	Ambient relative humidity	0.001726	0.00173	0.3196

Table G-16. Fit and evaluation statistics for H_2S emission models for dairy milking centers.

Model	2LogL	AIC	AICc	BIC	Corr.	LNME[a] (%)	NME[b] (%)	ME[b] (g day^{-1})	MB[b] (g day^{-1})	NMB[b] (%)
MC-1	-836	-826	-826	-806	0.237	1.655	62.34	88.63	-0.125	-0.088
MC-2	-1077	-1069	-1069	-1052	0.487	1.458	59.63	77.93	-0.889	-0.681
MC-3	-836	-828	-828	-812	0.279	1.639	61.71	87.73	-0.247	-0.174
MC-4	-1062	-1052	-1051	-1030	0.532	1.402	58.25	75.04	-1.048	-0.813
MC-5	-1059	-1051	-1051	-1034	0.518	1.425	59.07	76.1	-1.01	-0.784
MC-6	-1057	-1049	-1049	-1032	0.344	1.557	64.53	83.19	-0.449	-0.348
MC-7	-816	-806	-806	-786	0.205	1.663	63.38	88.8	-0.123	-0.088
MC-8	-1062	-1052	-1052	-1031	0.504	1.438	59.67	76.92	-0.952	-0.739
MC-9	671	683	683	685	0.648	4.686	90.64	589.1	-100.4	-15.44
MC-10	667	677	677	679	0.598	4.648	94.71	563	-82.11	-13.81
MC-11	698	708	708	710	0.512	5.28	101.5	659.4	-76.1	-11.71
MC-12	669	681	681	683	0.6	4.707	94.81	567.1	-82.69	-13.82
MC-13	670	680	680	682	0.596	4.721	95.1	568.9	-81.9	-13.69
MC-14	696	706	706	708	0.464	5.108	105.1	628.3	-59.23	-9.91
MC-15	670	682	683	685	0.651	4.725	90.48	592.8	-101.3	-15.47
MC-16	668	680	680	682	0.6	4.671	94.87	567.1	-83.35	-13.94
MC-17	-836	-824	-824	-800	0.237	1.655	62.34	88.63	-0.125	-0.088
MC-18	-1077	-1067	-1067	-1046	0.487	1.458	59.63	77.93	-0.889	-0.681
MC-19	-836	-826	-826	-806	0.279	1.639	61.71	87.73	-0.247	-0.174
MC-20	-1062	-1050	-1049	-1024	0.532	1.402	58.25	75.04	-1.048	-0.813
MC-21	-1059	-1049	-1049	-1028	0.518	1.425	59.07	76.1	-1.01	-0.784
MC-22	-1057	-1047	-1047	-1026	0.344	1.557	64.53	83.19	-0.449	-0.348
MC-23	-816	-804	-804	-780	0.205	1.663	63.38	88.8	-0.123	-0.088
MC-24	-1062	-1050	-1050	-1025	0.504	1.438	59.67	76.92	-0.952	-0.739
MC-25	1080	1090	1090	1092	0.613	6.679	87.05	1235	-153.9	-10.84
MC-26	1147	1155	1155	1156	0.547	6.632	89.96	1190	-118.3	-8.949
MC-27	1105	1113	1113	1115	0.454	7.858	99.39	1410	-54.77	-3.86
MC-28	1139	1149	1149	1151	0.551	6.556	90.52	1198	-116.2	-8.777
MC-29	1141	1149	1149	1150	0.542	6.611	90.97	1204	-113.5	-8.571
MC-30	1173	1181	1181	1183	0.099	7.907	105.2	1392	-1.373	-0.104
MC-31	1071	1081	1081	1083	0.614	6.634	87.47	1244	-154.3	-10.85
MC-32	1138	1148	1148	1150	0.554	6.612	90.08	1192	-122.5	-9.259

[a] Based on transformed data (i.e., $\ln(H_2S)$).
[b] Based on back-transformed data.

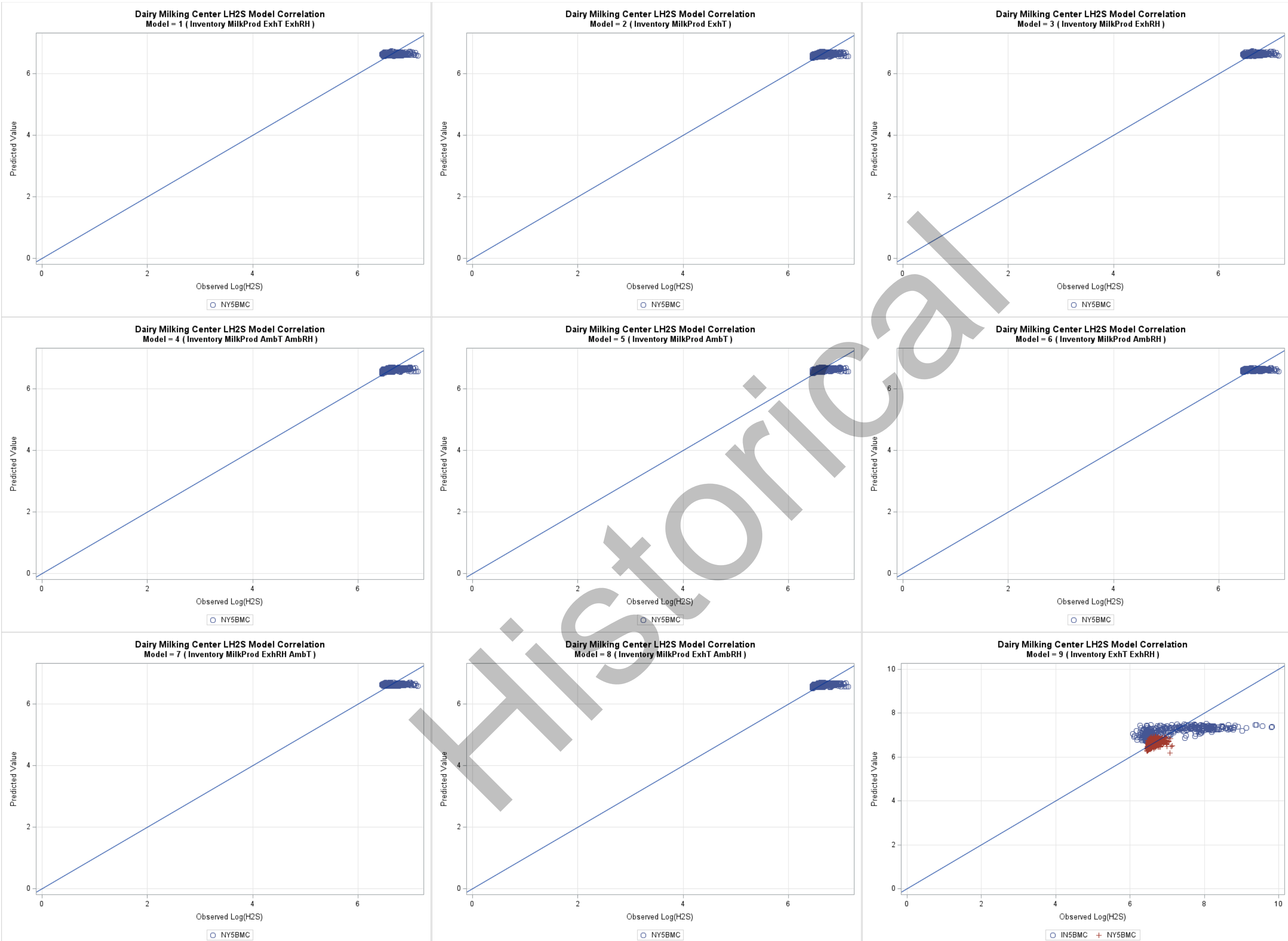


Figure G-25. Dairy milking center H_2S one-to-one plots models 1 through 9, log transformed.

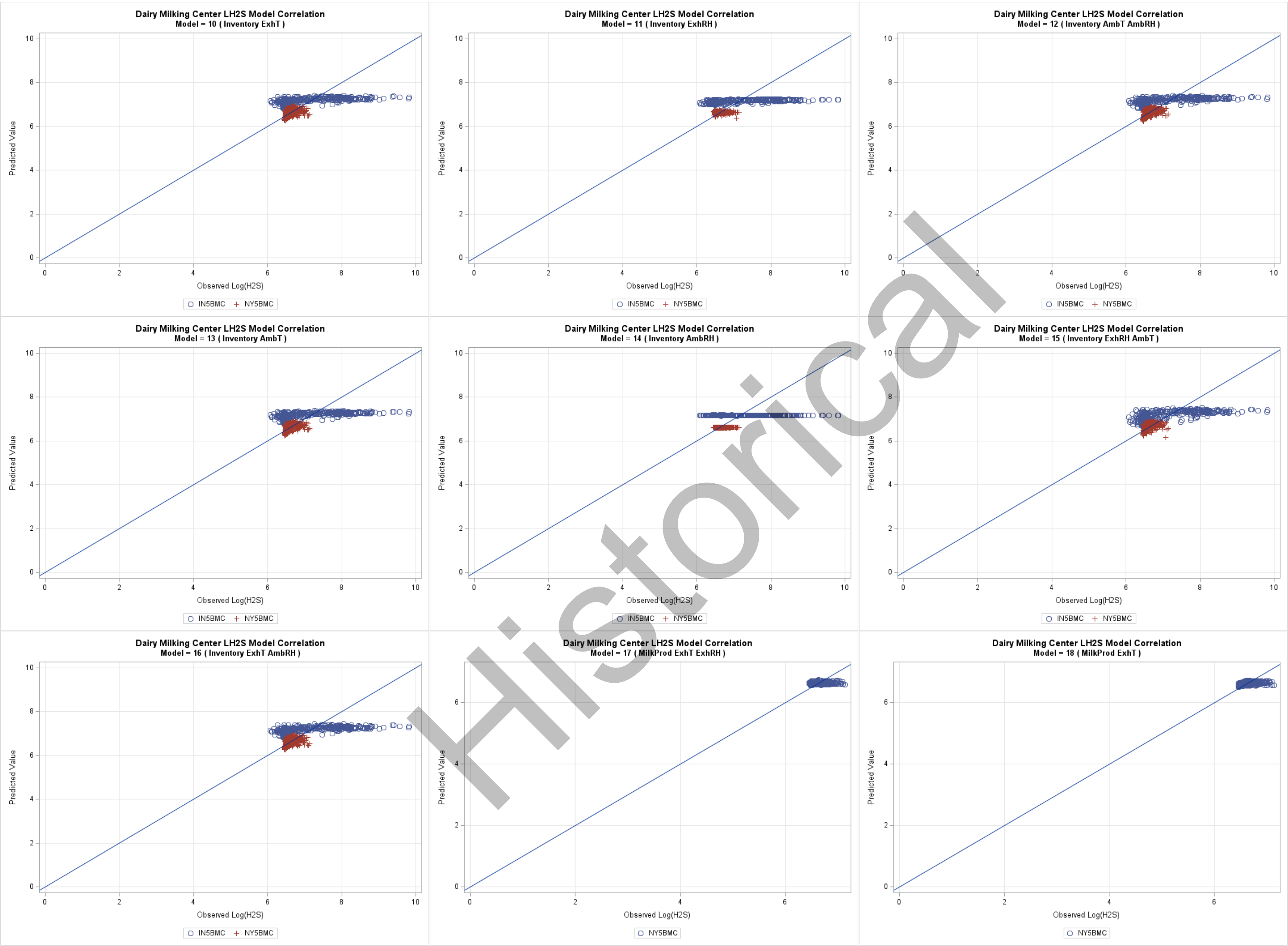


Figure G-26. Dairy milking center H_2S one-to-one plots models 10 through 18, log transformed.

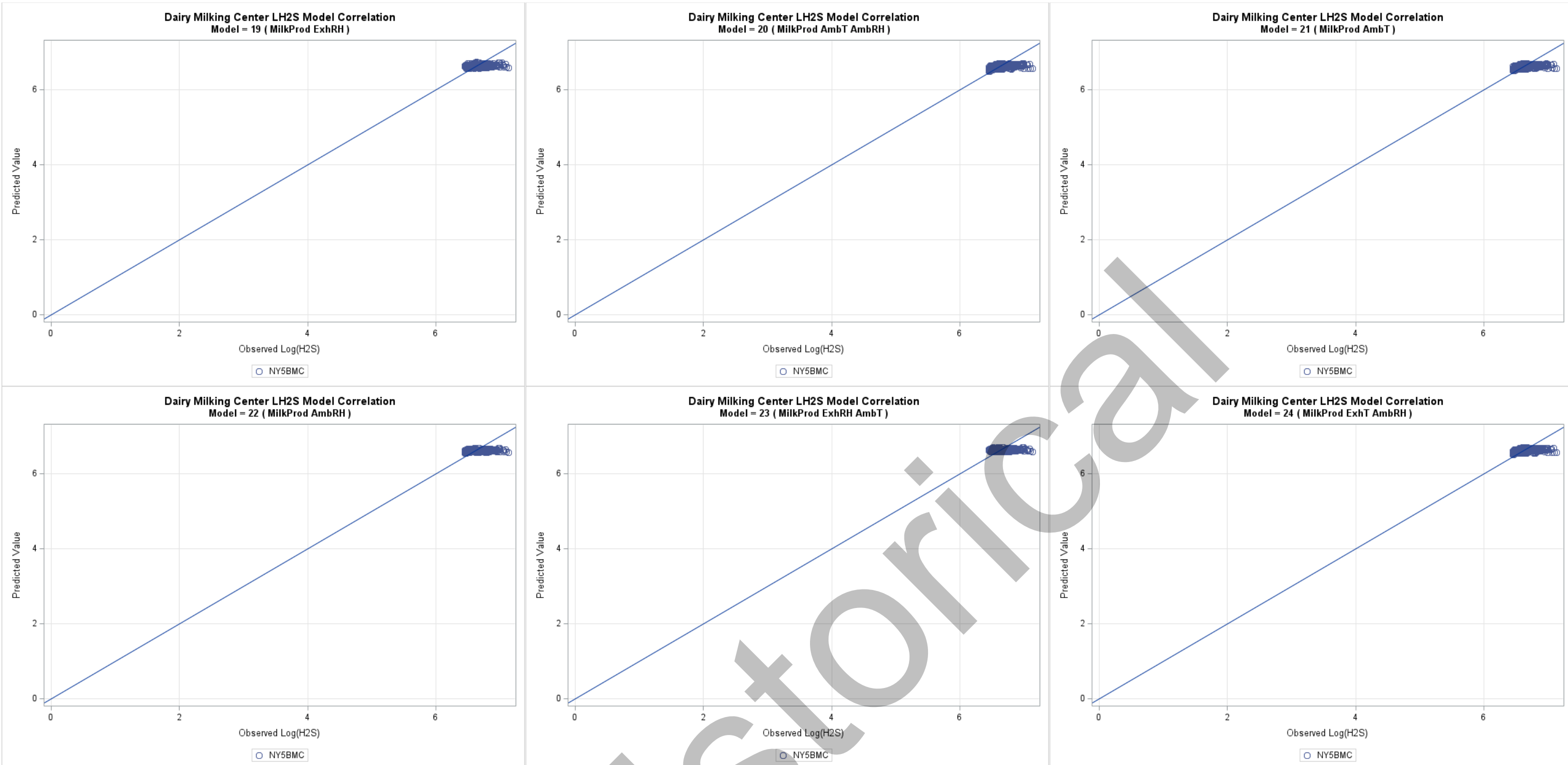


Figure G-27. Dairy milking center H_2S one-to-one plots models 19 through 24, log transformed.

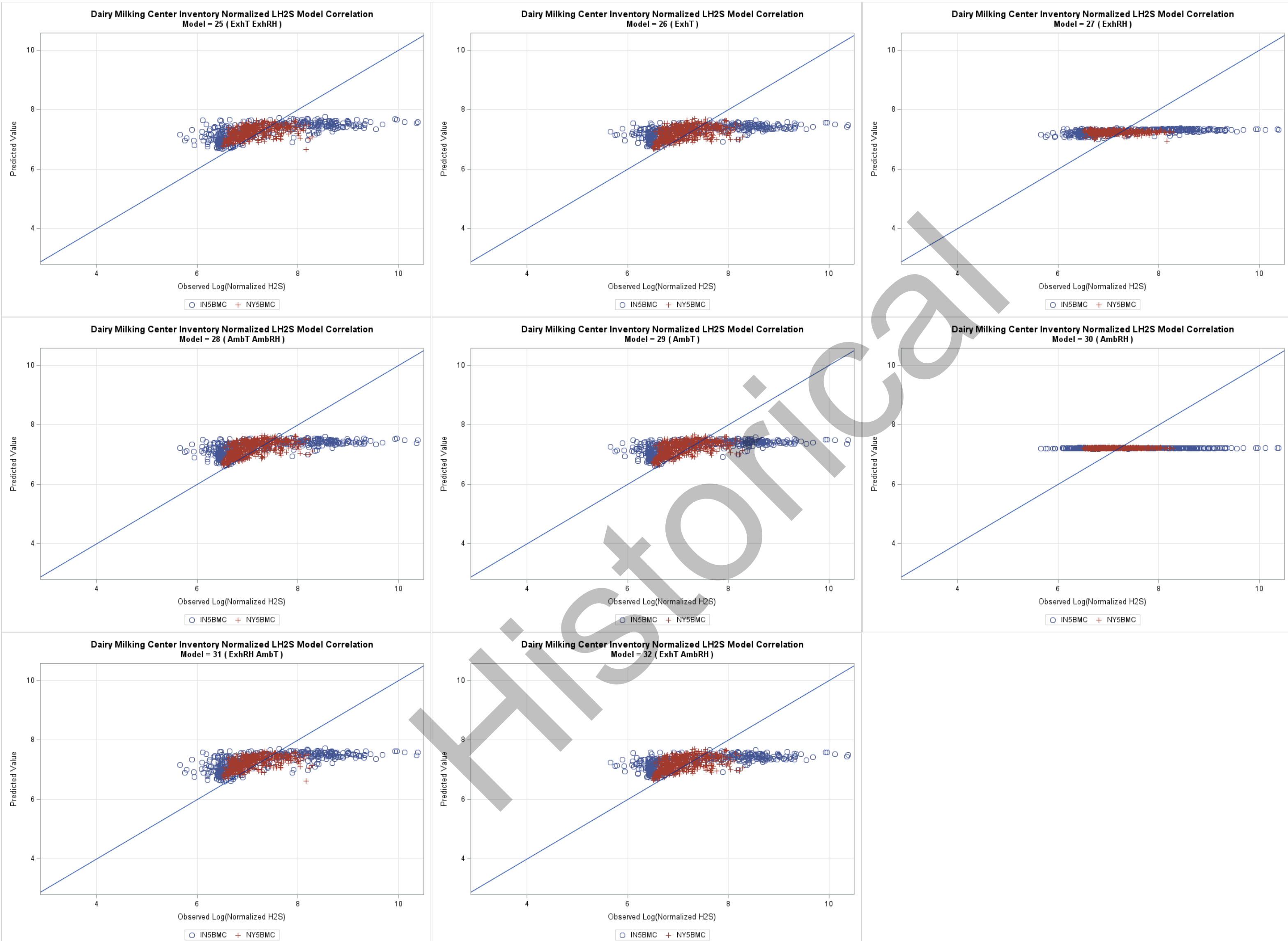


Figure G-28. Dairy milking center H_2S one-to-one plots models 25 through 32, log transformed.

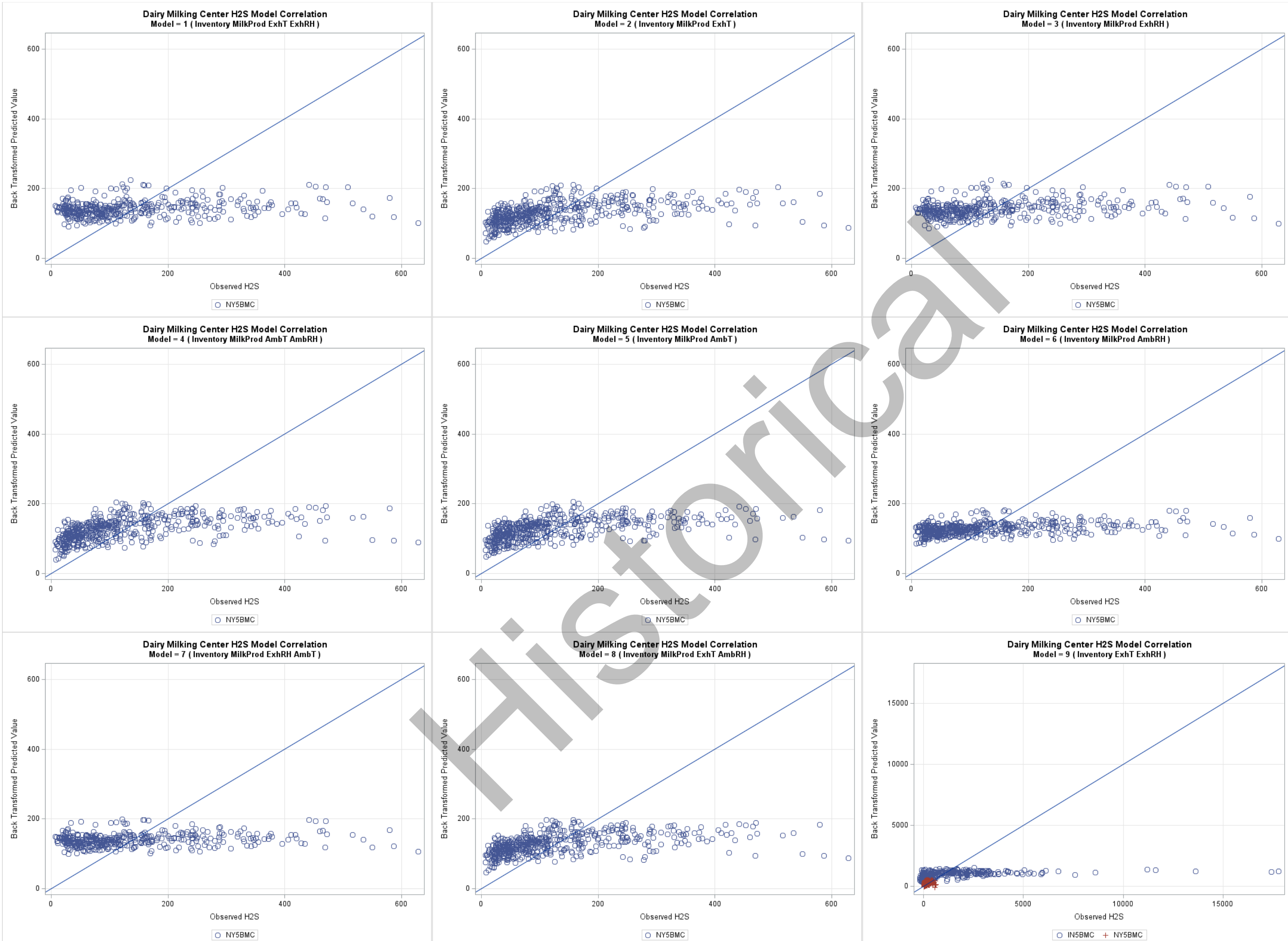


Figure G-29. Dairy milking center H_2S one-to-one plots models 1 through 9, back transformed.

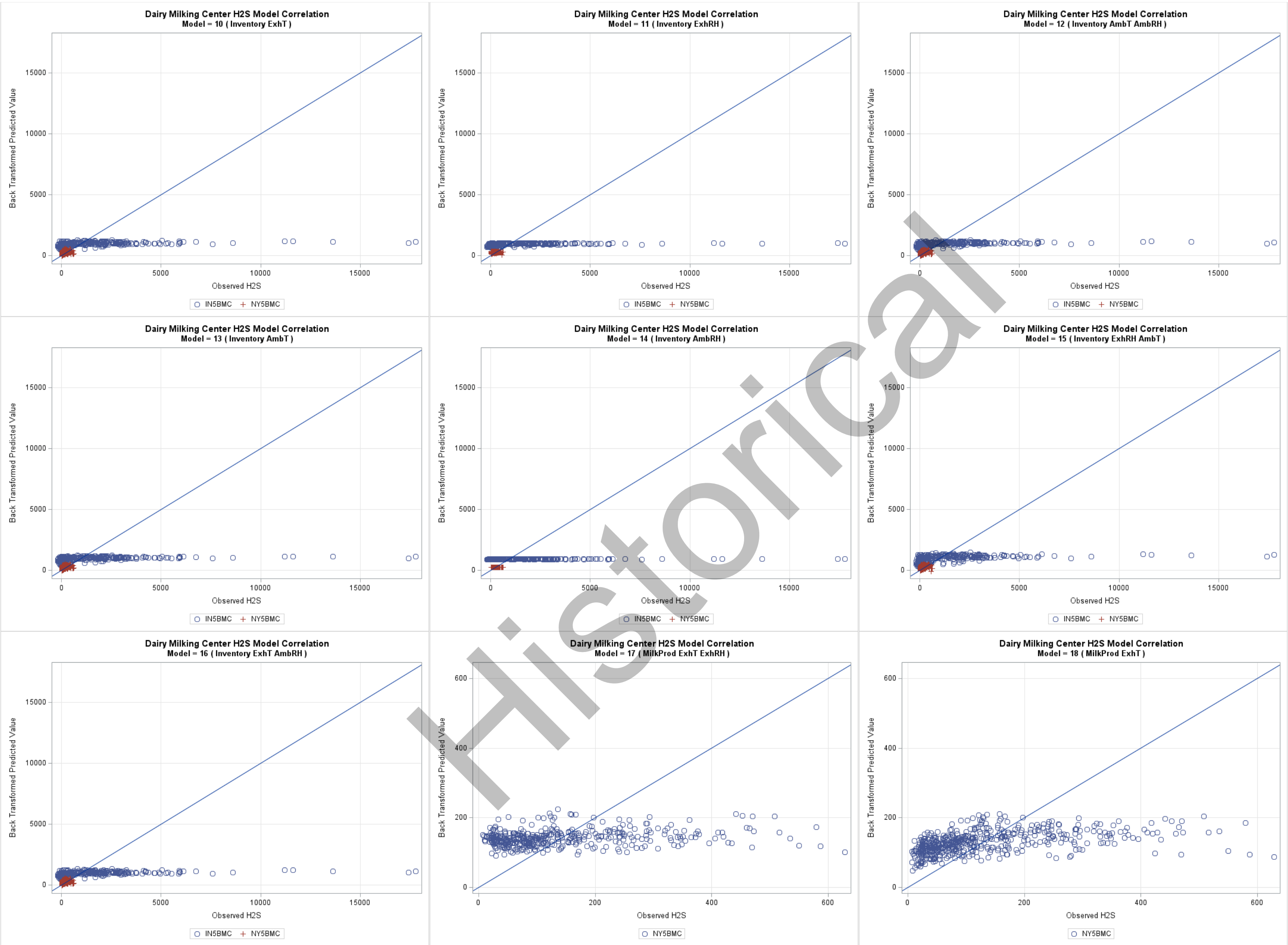


Figure G-30. Dairy milking center H_2S one-to-one plots models 10 through 18, back transformed.

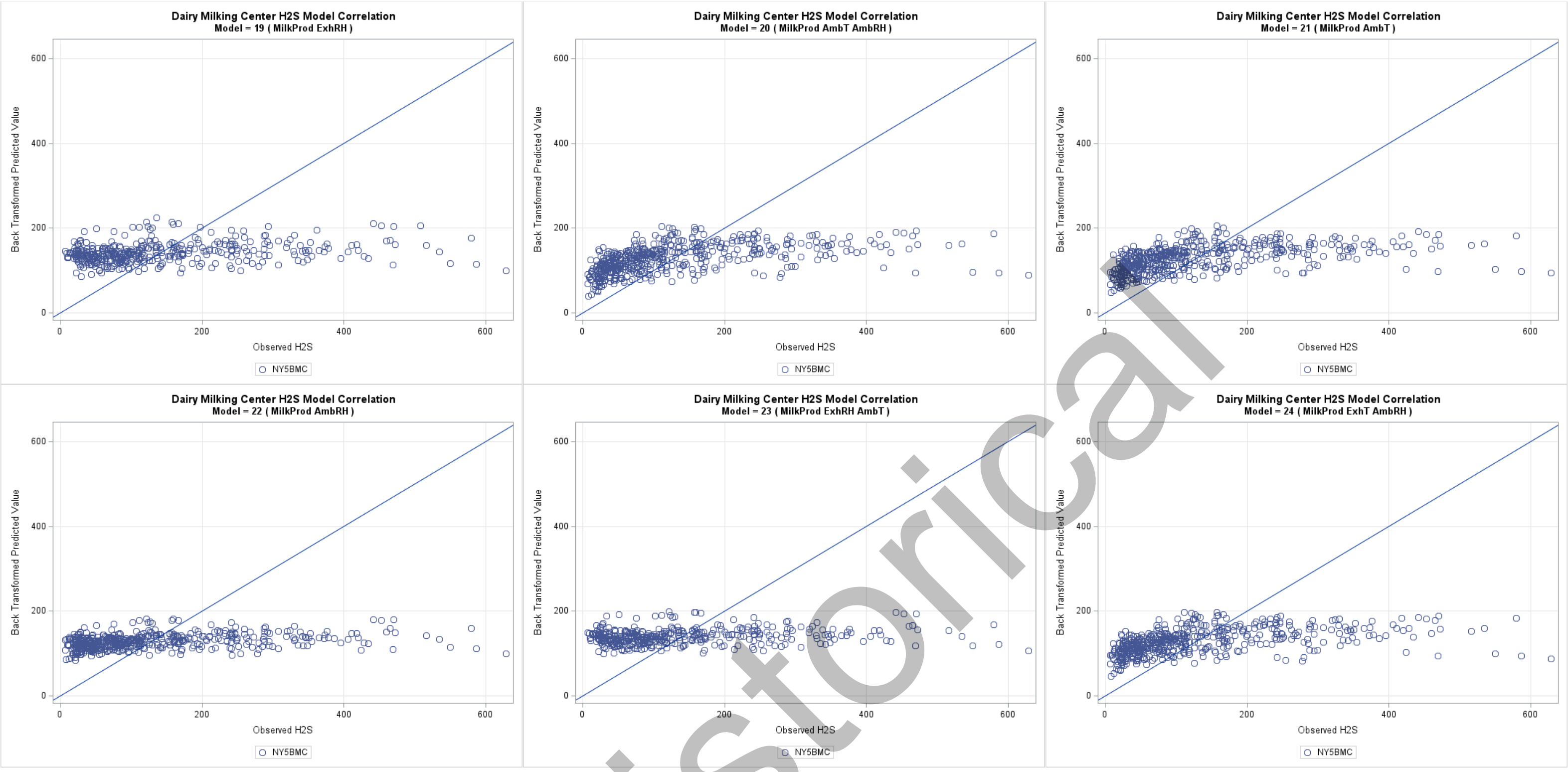


Figure G-31. Dairy milking center H_2S one-to-one plots models 19 through 24, back transformed.

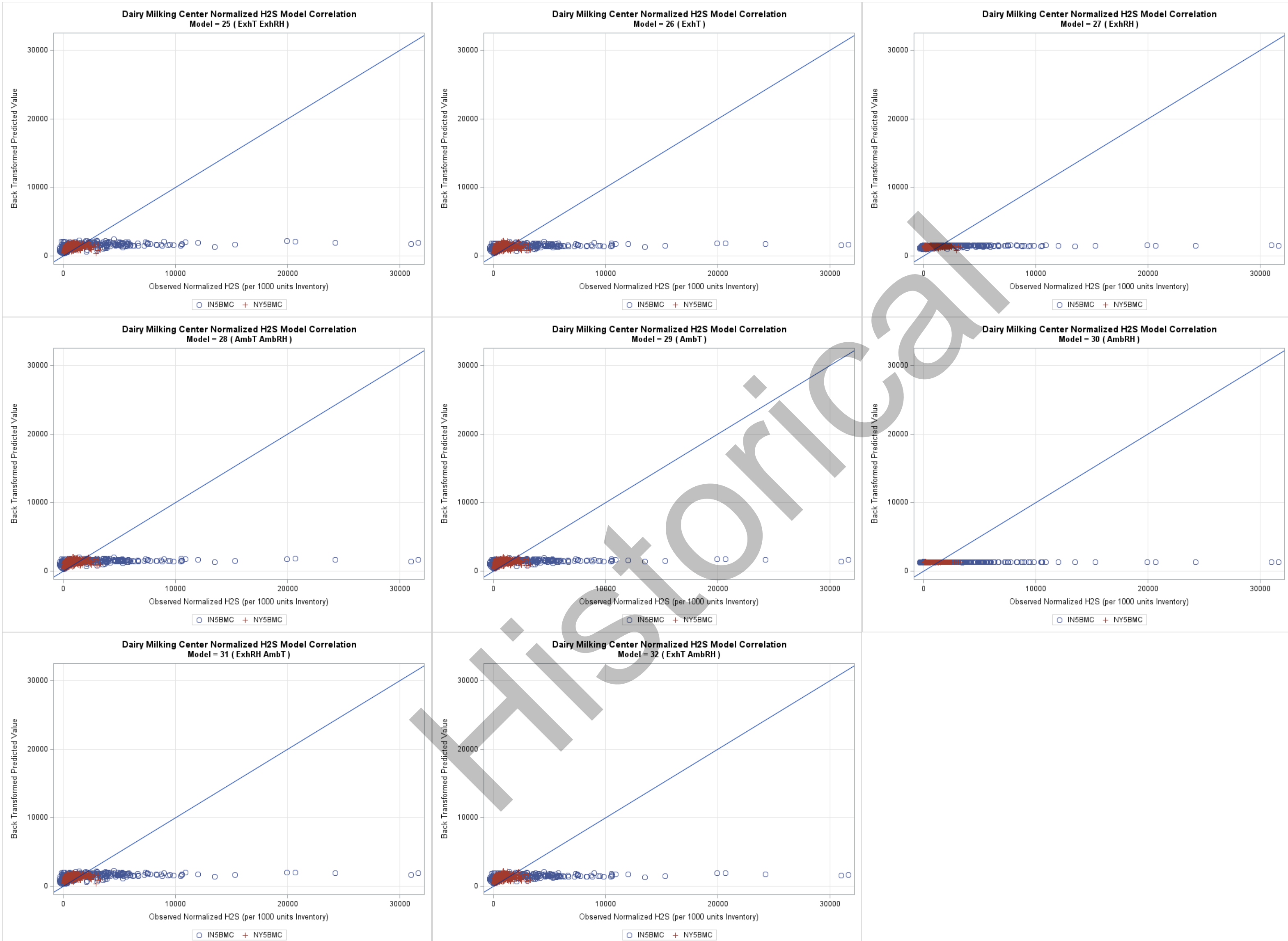


Figure G-32. Dairy milking center H_2S one-to-one plots models 25 through 32, back transformed.

G.2.3 PM_{10}

Table G-17. Parameter and estimates PM_{10} emission models for dairy milking centers.

Model	Parameter	Estimate	Standard Error	p-value
MC-1	Intercept	7.910105	0.09756	<.0001
	Inventory	0	.	.
	Milk Production	-0.003003	0.00272	**0.2724**
	Exhaust temperature	0.00227	0.00035	<.0001
	Exhaust relative humidity	-0.001367	0.00018	<.0001
MC-2	Intercept	7.818453	0.08025	<.0001
	Inventory	0	.	.
	Milk Production	-0.0032	0.00224	**0.156**
	Exhaust temperature	0.002308	0.0003	<.0001
MC-3	Intercept	7.939436	0.11836	<.0001
	Inventory	0	.	.
	Milk Production	-0.002741	0.00333	**0.4125**
	Exhaust relative humidity	-0.001433	0.00019	<.0001
MC-4	Intercept	7.905604	0.07678	<.0001
	Inventory	0	.	.
	Milk Production	-0.003753	0.00215	**0.0824**
	Ambient temperature	0.001506	0.00019	<.0001
	Ambient relative humidity	-0.000804	0.00011	<.0001
MC-5	Intercept	7.839738	0.08147	<.0001
	Inventory	0	.	.
	Milk Production	-0.003497	0.00228	**0.1277**
	Ambient temperature	0.001685	0.00021	<.0001
MC-6	Intercept	8.009566	0.09414	<.0001
	Inventory	0	.	.
	Milk Production	-0.006083	0.00266	*0.0236*
	Ambient relative humidity	-0.000848	0.00011	<.0001
MC-7	Intercept	7.930999	0.10033	<.0001
	Inventory	0	.	.
	Milk Production	-0.003376	0.00281	**0.2322**
	Exhaust relative humidity	-0.001333	0.00018	<.0001
	Ambient temperature	0.00166	0.00024	<.0001
MC-8	Intercept	7.912341	0.07564	<.0001
	Inventory	0	.	.
	Milk Production	-0.004203	0.00211	*0.0482*
	Exhaust temperature	0.002259	0.00027	<.0001
	Ambient relative humidity	-0.000841	0.00011	<.0001
MC-9	Intercept	7.803527	0.01421	<.0001
	Inventory	0	.	.
	Exhaust temperature	0.002284	0.00035	<.0001
	Exhaust relative humidity	-0.001359	0.00018	<.0001
MC-10	Intercept	7.704265	0.0045	<.0001
	Inventory	0	.	.
	Exhaust temperature	0.002354	0.00029	<.0001
MC-11	Intercept	7.841781	0.01365	<.0001
	Inventory	0	.	.

Model	Parameter	Estimate	Standard Error	p-value
	Exhaust relative humidity	-0.001416	0.00019	<.0001
MC-12	Intercept	7.772467	0.00806	<.0001
	Inventory	0	.	.
	Ambient temperature	0.001574	0.00018	<.0001
	Ambient relative humidity	-0.000817	0.00011	<.0001
MC-13	Intercept	7.715019	0.00322	<.0001
	Inventory	0	.	.
	Ambient temperature	0.001725	0.0002	<.0001
MC-14	Intercept	7.79443	0.00809	<.0001
	Inventory	0	.	.
	Ambient relative humidity	-0.000855	0.00011	<.0001
MC-15	Intercept	7.811649	0.01366	<.0001
	Inventory	0	.	.
	Exhaust relative humidity	-0.001331	0.00018	<.0001
	Ambient temperature	0.001667	0.00024	<.0001
MC-16	Intercept	7.762946	0.00846	<.0001
	Inventory	0	.	.
	Exhaust temperature	0.002356	0.00026	<.0001
	Ambient relative humidity	-0.000857	0.00011	<.0001
MC-17	Intercept	7.910105	0.09756	<.0001
	Milk Production	-0.003003	0.00272	**0.2724**
	Exhaust temperature	0.00227	0.00035	<.0001
	Exhaust relative humidity	-0.001367	0.00018	<.0001
MC-18	Intercept	7.818453	0.08025	<.0001
	Milk Production	-0.0032	0.00224	**0.156**
	Exhaust temperature	0.002308	0.0003	<.0001
MC-19	Intercept	7.939436	0.11836	<.0001
	Milk Production	-0.002741	0.00333	**0.4125**
	Exhaust relative humidity	-0.001433	0.00019	<.0001
MC-20	Intercept	7.905604	0.07678	<.0001
	Milk Production	-0.003753	0.00215	**0.0824**
	Ambient temperature	0.001506	0.00019	<.0001
	Ambient relative humidity	-0.000804	0.00011	<.0001
MC-21	Intercept	7.839738	0.08147	<.0001
	Milk Production	-0.003497	0.00228	**0.1277**
	Ambient temperature	0.001685	0.00021	<.0001
MC-22	Intercept	8.009566	0.09414	<.0001
	Milk Production	-0.006083	0.00266	*0.0236*
	Ambient relative humidity	-0.000848	0.00011	<.0001
MC-23	Intercept	7.930999	0.10033	<.0001
	Milk Production	-0.003376	0.00281	**0.2322**
	Exhaust relative humidity	-0.001333	0.00018	<.0001
	Ambient temperature	0.00166	0.00024	<.0001
MC-24	Intercept	7.912341	0.07564	<.0001
	Milk Production	-0.004203	0.00211	*0.0482*
	Exhaust temperature	0.002259	0.00027	<.0001
	Ambient relative humidity	-0.000841	0.00011	<.0001
MC-25	Intercept	8.173978	0.05729	<.0001
	Exhaust temperature	0.009635	0.00139	<.0001

Model	Parameter	Estimate	Standard Error	p-value
	Exhaust relative humidity	-0.005808	0.00071	<.0001
MC-26	Intercept	7.747757	0.01852	<.0001
	Exhaust temperature	0.010041	0.0012	<.0001
MC-27	Intercept	8.335064	0.0552	<.0001
	Exhaust relative humidity	-0.006048	0.00075	<.0001
MC-28	Intercept	8.042215	0.03257	<.0001
	Ambient temperature	0.006791	0.00074	<.0001
	Ambient relative humidity	-0.003552	0.00043	<.0001
MC-29	Intercept	7.792856	0.01316	<.0001
	Ambient temperature	0.007429	0.00082	<.0001
MC-30	Intercept	8.135768	0.03298	<.0001
	Ambient relative humidity	-0.003695	0.00044	<.0001
MC-31	Intercept	8.206537	0.05486	<.0001
	Exhaust relative humidity	-0.005681	0.00071	<.0001
	Ambient temperature	0.007121	0.00096	<.0001
MC-32	Intercept	8.001735	0.03418	<.0001
	Exhaust temperature	0.010115	0.00107	<.0001
	Ambient relative humidity	-0.003722	0.00043	<.0001

Table G-18. Fit and evaluation statistics for PM_{10} emission models for dairy milking centers.

Model	2LogL	AIC	AICc	BIC	Corr.	LNME[a] (%)	NME[b] (%)	ME[b] (g day^{-1})	MB[b] (g day^{-1})	NMB[b] (%)
MC-1	-1524	-1514	-1513	-1495	0.648	0.222	38.98	41.04	-0.143	-0.136
MC-2	-2084	-2076	-2076	-2060	0.565	0.228	45.4	41.34	-0.083	-0.091
MC-3	-1492	-1484	-1483	-1469	0.472	0.269	47.36	49.85	-0.103	-0.098
MC-4	-2013	-2003	-2003	-1983	0.678	0.2	39.68	36.21	-0.109	-0.119
MC-5	-2039	-2031	-2031	-2015	0.587	0.223	44.5	40.29	-0.062	-0.068
MC-6	-1972	-1964	-1964	-1948	0.486	0.255	50.22	45.99	-0.113	-0.123
MC-7	-1476	-1466	-1465	-1447	0.662	0.22	38.5	40.44	-0.114	-0.109
MC-8	-2022	-2012	-2012	-1992	0.687	0.198	39.14	35.83	-0.122	-0.134
MC-9	-1573	-1565	-1565	-1563	0.648	0.22	39.02	40.71	-0.143	-0.137
MC-10	-2131	-2125	-2125	-2124	0.561	0.228	45.61	41.36	-0.099	-0.109
MC-11	-1540	-1534	-1534	-1532	0.464	0.266	47.15	49.2	-0.095	-0.091
MC-12	-2061	-2053	-2053	-2052	0.677	0.2	39.83	36.19	-0.126	-0.138
MC-13	-2086	-2080	-2080	-2078	0.58	0.223	44.74	40.34	-0.077	-0.085
MC-14	-2017	-2011	-2011	-2010	0.425	0.262	51.9	47.3	-0.086	-0.095
MC-15	-1524	-1516	-1516	-1515	0.659	0.218	38.61	40.2	-0.115	-0.11
MC-16	-2070	-2062	-2062	-2060	0.685	0.197	39.23	35.75	-0.141	-0.155
MC-17	-1524	-1512	-1511	-1489	0.648	0.222	38.98	41.04	-0.143	-0.136
MC-18	-2084	-2074	-2074	-2054	0.565	0.228	45.4	41.34	-0.083	-0.091
MC-19	-1492	-1482	-1481	-1463	0.472	0.269	47.36	49.85	-0.103	-0.098
MC-20	-2013	-2001	-2001	-1977	0.678	0.2	39.68	36.21	-0.109	-0.119
MC-21	-2039	-2029	-2029	-2009	0.587	0.223	44.5	40.29	-0.062	-0.068
MC-22	-1972	-1962	-1962	-1942	0.486	0.255	50.22	45.99	-0.113	-0.123
MC-23	-1476	-1464	-1463	-1441	0.662	0.22	38.5	40.44	-0.114	-0.109
MC-24	-2022	-2010	-2010	-1986	0.687	0.198	39.14	35.83	-0.122	-0.134
MC-25	-664	-654	-654	-652	0.67	0.898	38.92	213.7	-3.632	-0.661
MC-26	-901	-893	-893	-891	0.581	0.954	45.54	217.4	-2.747	-0.575
MC-27	-630	-622	-622	-620	0.478	1.108	47.15	258.9	-2.222	-0.405
MC-28	-919	-909	-908	-907	0.704	0.822	39.14	187.1	-3.441	-0.72
MC-29	-888	-880	-879	-878	0.603	0.929	44.43	210.8	-2.322	-0.489
MC-30	-868	-860	-860	-859	0.44	1.11	51.95	249.2	-2.087	-0.435
MC-31	-648	-638	-638	-636	0.684	0.885	38.2	209.4	-3.064	-0.559
MC-32	-924	-914	-914	-912	0.711	0.814	38.74	185.8	-3.748	-0.781

[a] Based on transformed data (i.e., $\ln(PM_{10})$).
[b] Based on back-transformed data.

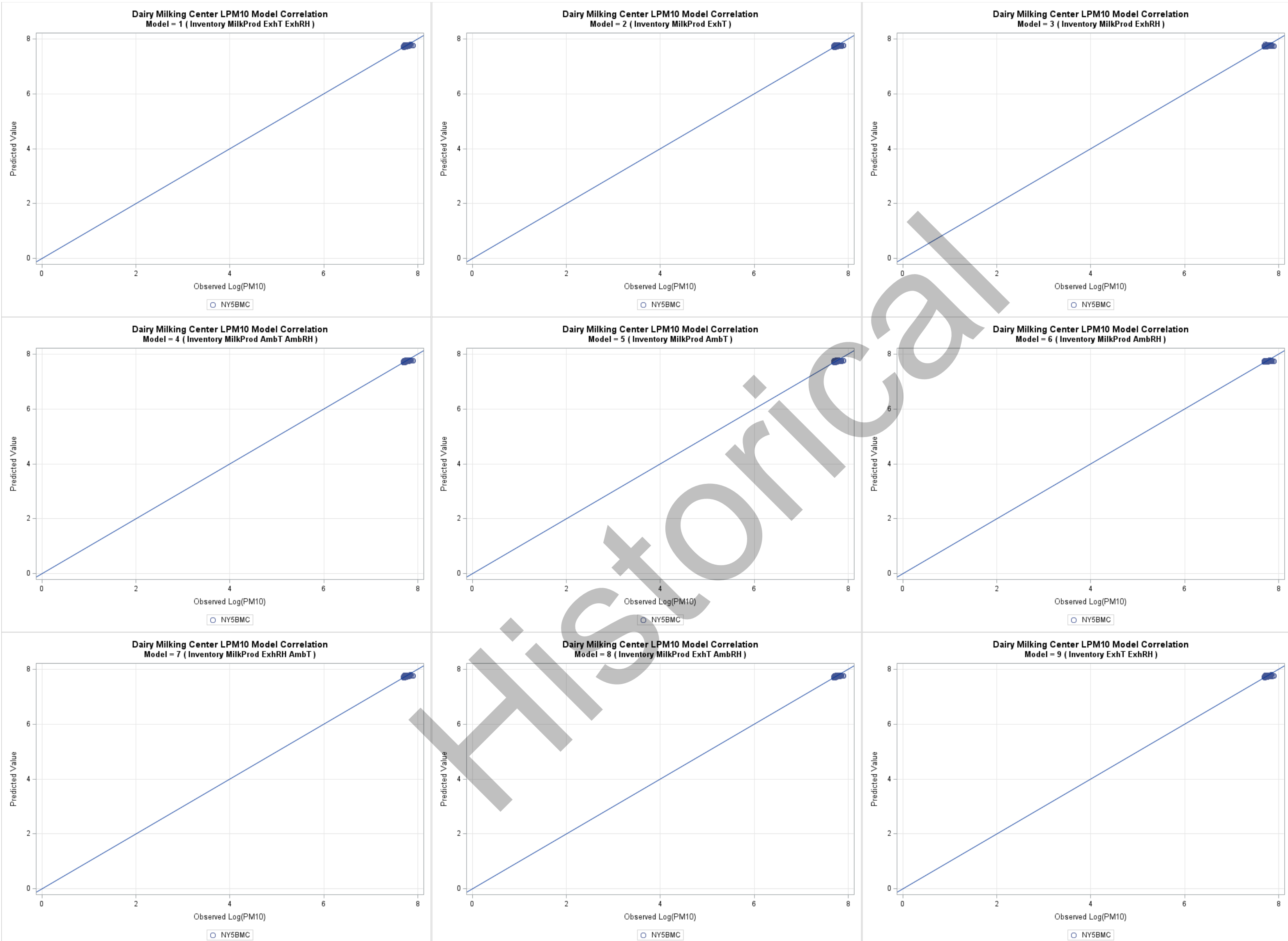


Figure G-33. Dairy milking center PM_{10} one-to-one plots models 1 through 9, log transformed.

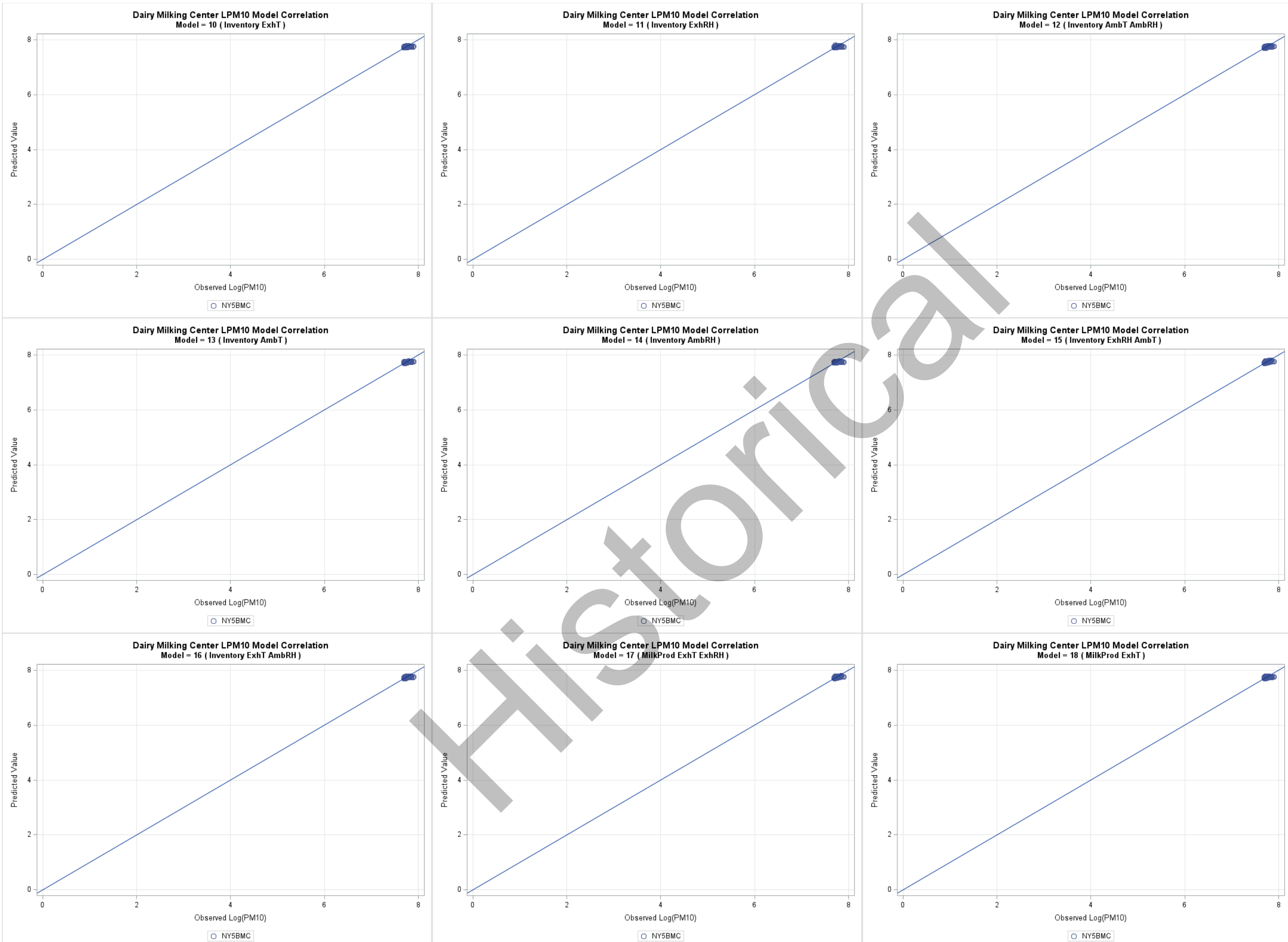


Figure G-34. Dairy milking center PM_{10} one-to-one plots models 10 through 18, log transformed.

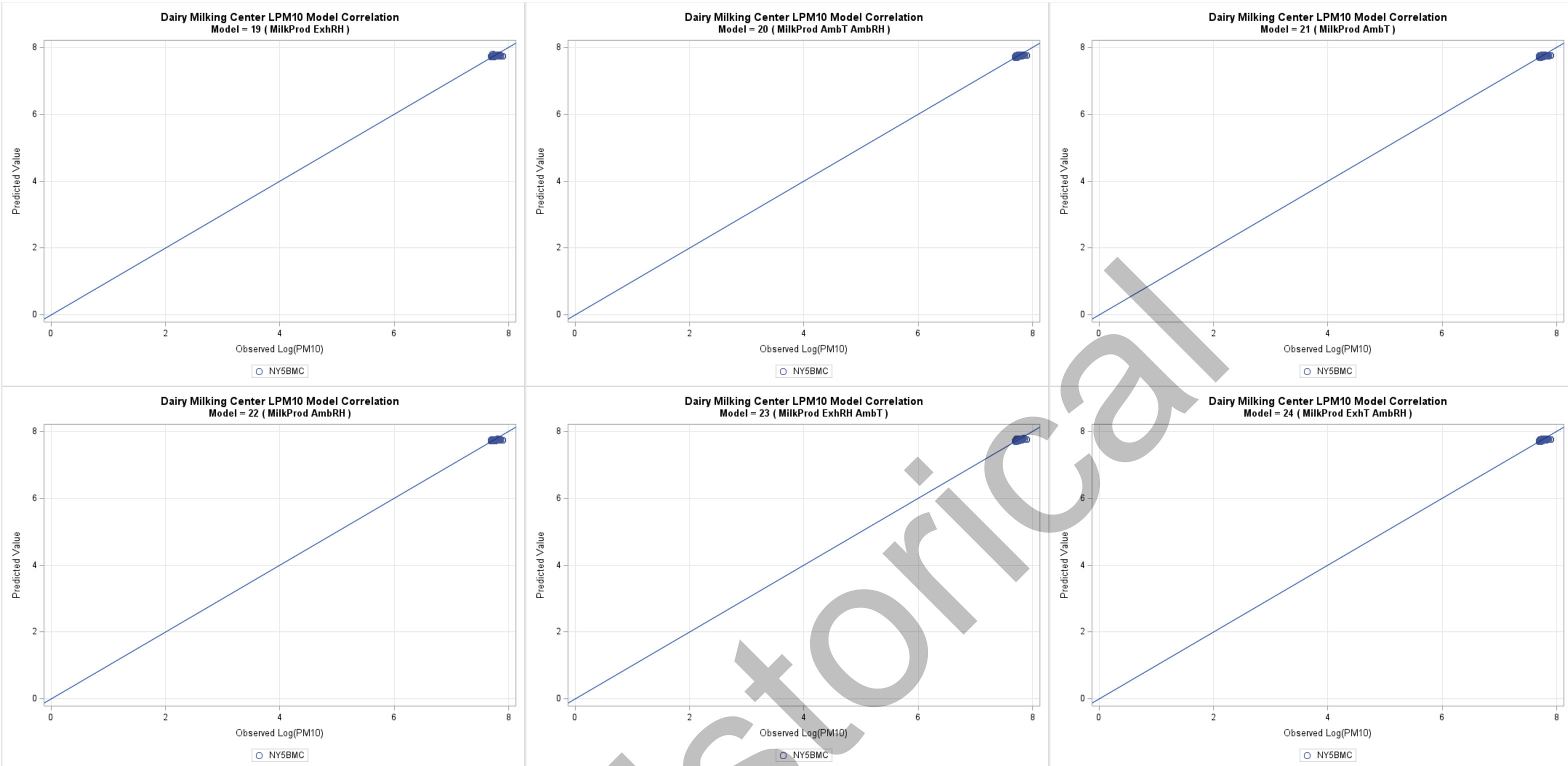


Figure G-35. Dairy milking center PM_{10} one-to-one plots models 19 through 24, log transformed.

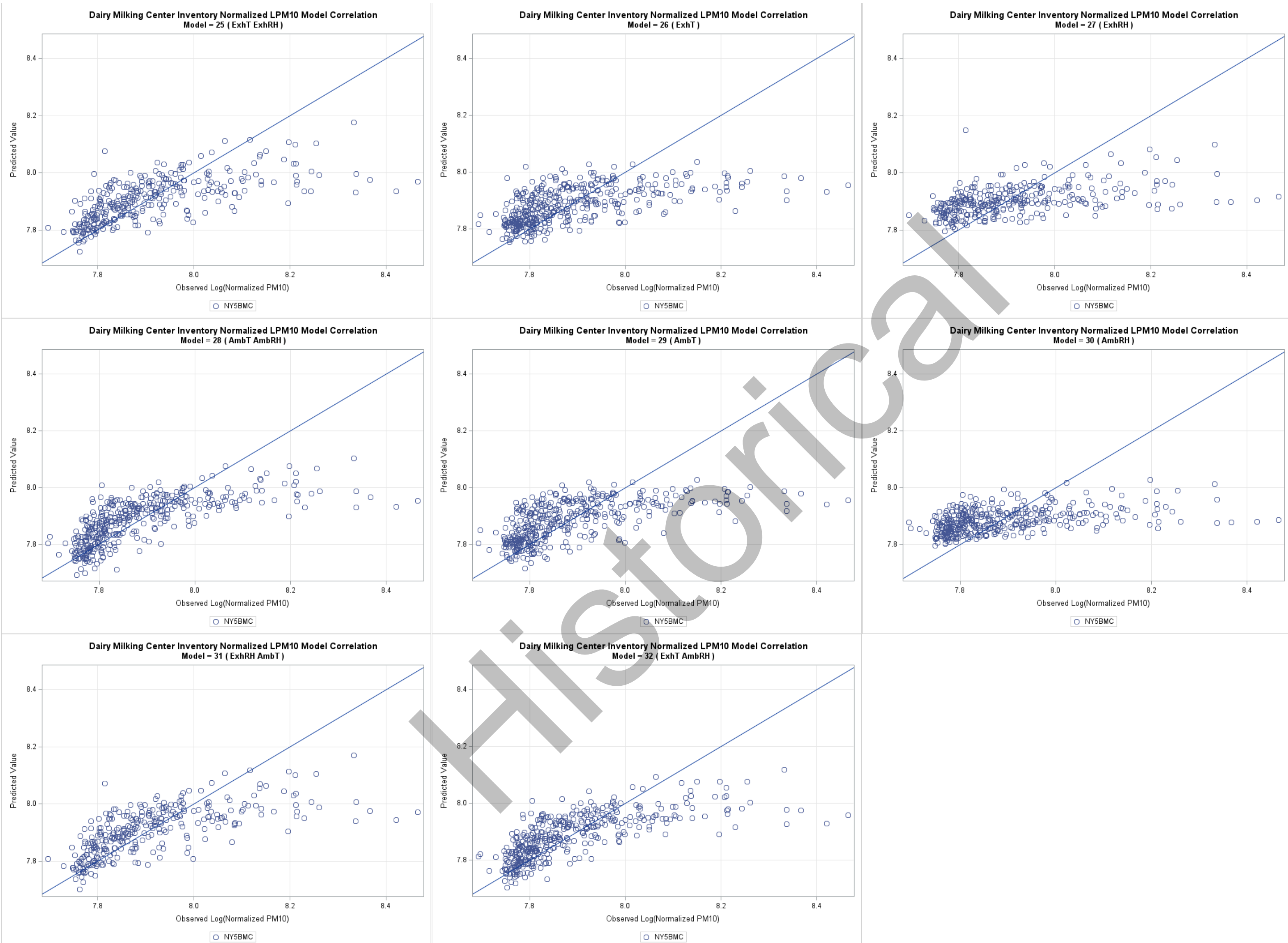


Figure G-36. Dairy milking center PM_{10} one-to-one plots models 25 through 32, log transformed.

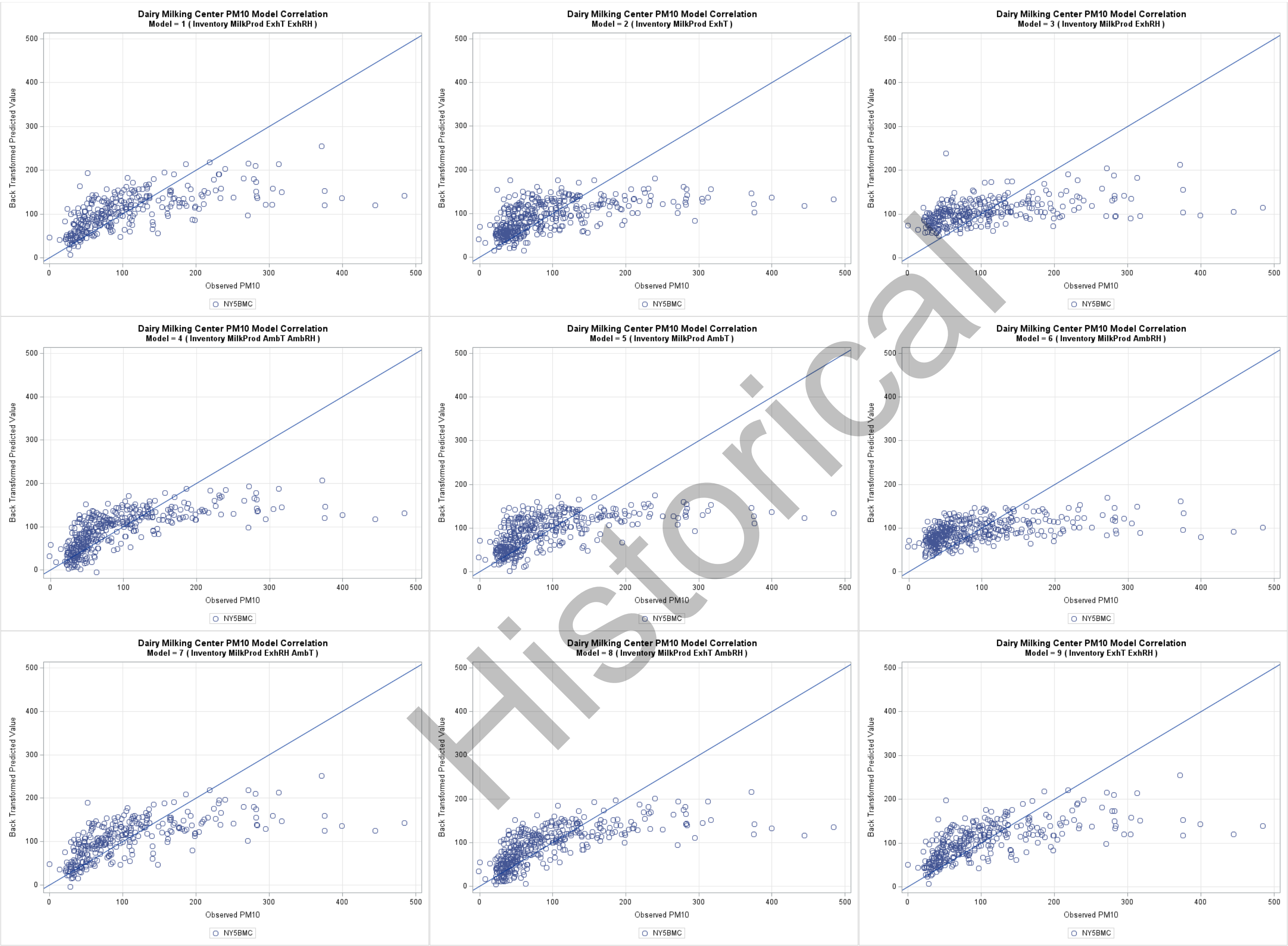


Figure G-37. Dairy milking center PM_{10} one-to-one plots models 1 through 9, back transformed.

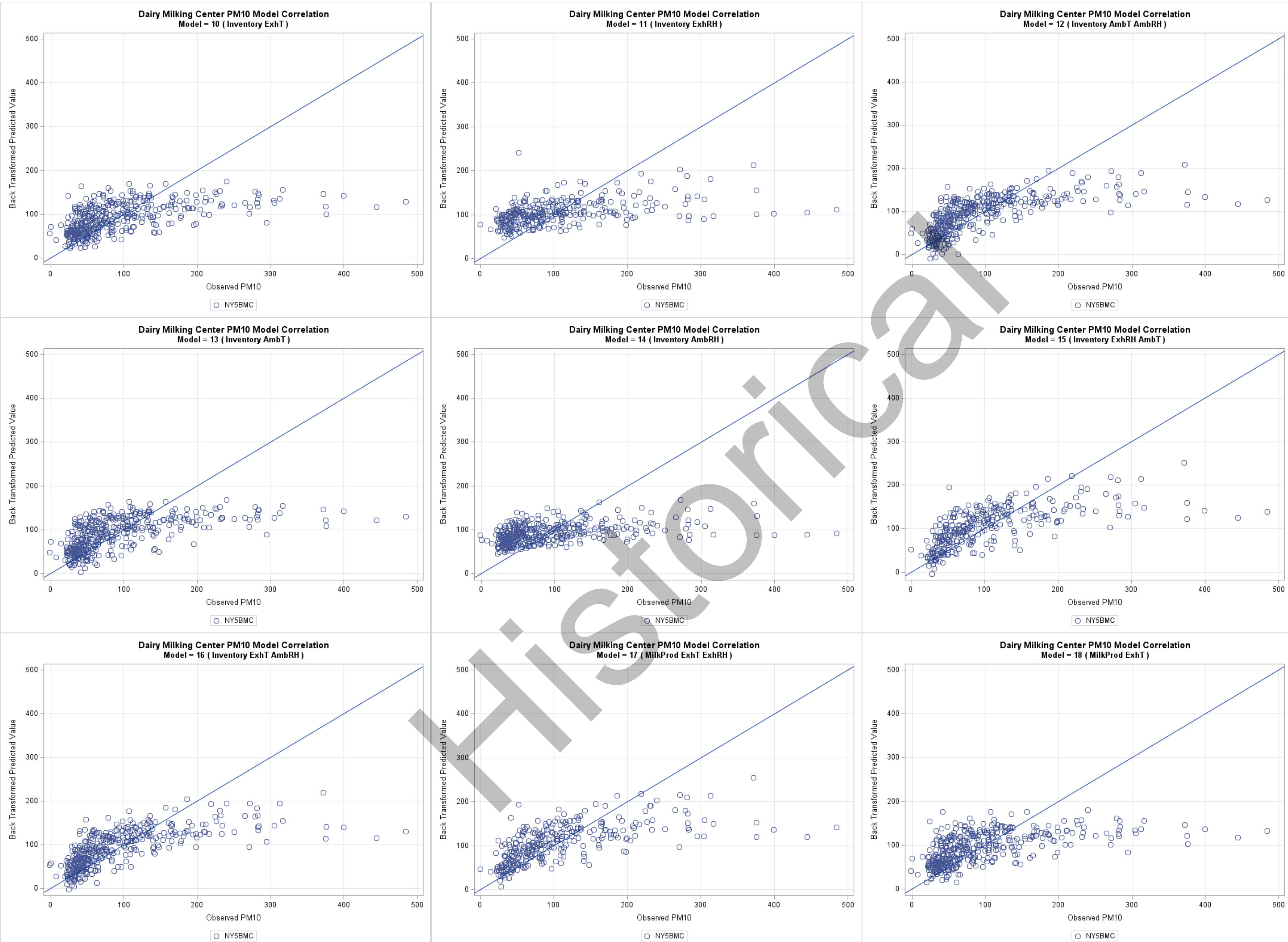


Figure G-38. Dairy milking center PM_{10} one-to-one plots models 10 through 18, back transformed.

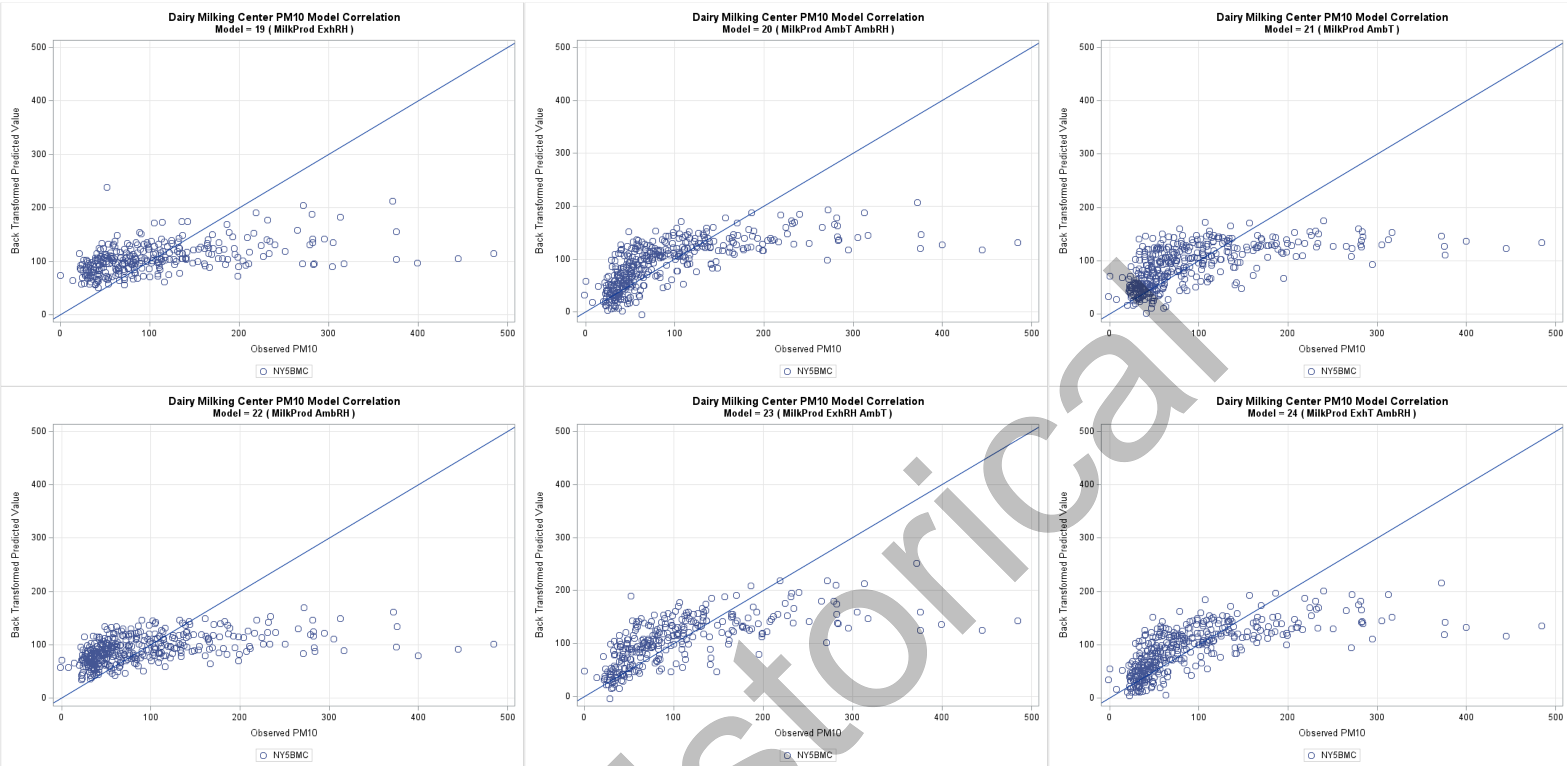


Figure G-39. Dairy milking center PM$_{10}$ one-to-one plots models 19 through 24, back transformed.

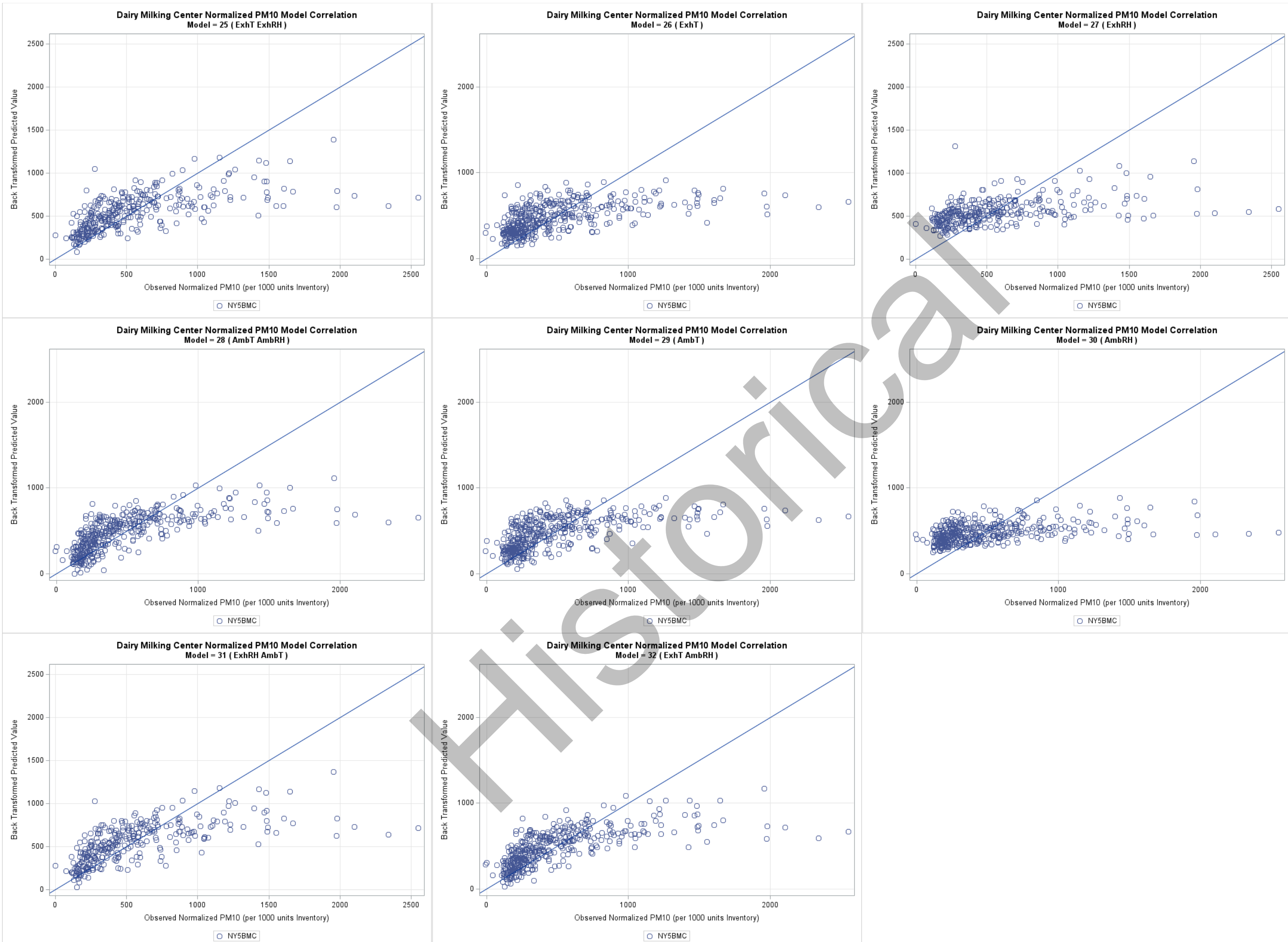


Figure G-40. Dairy milking center PM_{10} one-to-one plots models 25 through 32, back transformed.

G.2.4 Fine particulate matter ($PM_{2.5}$)

Table G-19. Parameter and estimates $PM_{2.5}$ emission models for dairy milking centers.

Model	Parameter	Estimate	Standard Error	p-value
MC-1	Intercept	5.782857	0.45714	<.0001
	Inventory	0	.	.
	Milk Production	0.017245	0.01151	**0.1455**
	Exhaust temperature	0.005228	0.00197	*0.013*
	Exhaust relative humidity	0.001056	0.00107	**0.3348**
MC-2	Intercept	5.994771	0.41089	<.0001
	Inventory	0	.	.
	Milk Production	0.013925	0.01087	**0.2098**
	Exhaust temperature	0.004385	0.00178	*0.0196*
MC-3	Intercept	6.882941	0.21318	<.0001
	Inventory	0	.	.
	Milk Production	-0.009611	0.00604	**0.13**
	Exhaust relative humidity	0.000201	0.00118	**0.8663**
MC-4	Intercept	5.779762	0.4562	<.0001
	Inventory	0	.	.
	Milk Production	0.019436	0.01196	**0.1146**
	Ambient temperature	0.003482	0.00129	*0.0116*
	Ambient relative humidity	0.000509	0.00066	**0.4459**
MC-5	Intercept	5.910604	0.43144	<.0001
	Inventory	0	.	.
	Milk Production	0.016897	0.01169	**0.1583**
	Ambient temperature	0.003223	0.00127	*0.0164*
MC-6	Intercept	6.931659	0.17526	<.0001
	Inventory	0	.	.
	Milk Production	-0.010649	0.0046	*0.0321*
	Ambient relative humidity	0.000032	0.00072	**0.9644**
MC-7	Intercept	5.644267	0.48097	<.0001
	Inventory	0	.	.
	Milk Production	0.021724	0.01243	**0.0917**
	Exhaust relative humidity	0.001082	0.00106	**0.3177**
	Ambient temperature	0.004016	0.00143	0.0091
MC-8	Intercept	5.864775	0.43643	<.0001
	Inventory	0	.	.
	Milk Production	0.016373	0.01114	**0.152**
	Exhaust temperature	0.004763	0.00182	*0.0136*
	Ambient relative humidity	0.000513	0.00066	**0.4447**
MC-9	Intercept	6.456241	0.09142	<.0001
	Inventory	0	.	.
	Exhaust temperature	0.002601	0.00093	*0.0121*
	Exhaust relative humidity	0.000764	0.00111	**0.4987**
MC-10	Intercept	6.520602	0.01278	<.0001
	Inventory	0	.	.
	Exhaust temperature	0.002273	0.00069	0.0036

Model	Parameter	Estimate	Standard Error	p-value
MC-11	Intercept	6.571678	0.09482	<.0001
	Inventory	0	.	.
	Exhaust relative humidity	-0.000124	0.00125	**0.9216**
MC-12	Intercept	6.518691	0.04956	<.0001
	Inventory	0	.	.
	Ambient temperature	0.001502	0.00046	0.0037
	Ambient relative humidity	0.00021	0.00067	**0.7554**
MC-13	Intercept	6.533998	0.00916	<.0001
	Inventory	0	.	.
	Ambient temperature	0.001502	0.00046	0.0038
MC-14	Intercept	6.546912	0.05823	<.0001
	Inventory	0	.	.
	Ambient relative humidity	0.000172	0.0008	**0.83**
MC-15	Intercept	6.473366	0.08908	<.0001
	Inventory	0	.	.
	Exhaust relative humidity	0.000733	0.00112	**0.5168**
	Ambient temperature	0.001747	0.00063	*0.0128*
MC-16	Intercept	6.503502	0.05028	<.0001
	Inventory	0	.	.
	Exhaust temperature	0.002275	0.00069	0.0034
	Ambient relative humidity	0.000234	0.00067	**0.7276**
MC-17	Intercept	5.782857	0.45714	<.0001
	Milk Production	0.017245	0.01151	**0.1455**
	Exhaust temperature	0.005228	0.00197	*0.013*
	Exhaust relative humidity	0.001056	0.00107	**0.3348**
MC-18	Intercept	5.994771	0.41089	<.0001
	Milk Production	0.013925	0.01087	**0.2098**
	Exhaust temperature	0.004385	0.00178	*0.0196*
MC-19	Intercept	6.882941	0.21318	<.0001
	Milk Production	-0.009611	0.00604	**0.13**
	Exhaust relative humidity	0.000201	0.00118	**0.8663**
MC-20	Intercept	5.779762	0.4562	<.0001
	Milk Production	0.019436	0.01196	**0.1146**
	Ambient temperature	0.003482	0.00129	*0.0116*
	Ambient relative humidity	0.000509	0.00066	**0.4459**
MC-21	Intercept	5.910604	0.43144	<.0001
	Milk Production	0.016897	0.01169	**0.1583**
	Ambient temperature	0.003223	0.00127	*0.0164*
MC-22	Intercept	6.931659	0.17526	<.0001
	Milk Production	-0.010649	0.0046	*0.0321*
	Ambient relative humidity	0.000032	0.00072	**0.9644**
MC-23	Intercept	5.644267	0.48097	<.0001
	Milk Production	0.021724	0.01243	**0.0917**
	Exhaust relative humidity	0.001082	0.00106	**0.3177**
	Ambient temperature	0.004016	0.00143	0.0091
MC-24	Intercept	5.864775	0.43643	<.0001
	Milk Production	0.016373	0.01114	**0.152**
	Exhaust temperature	0.004763	0.00182	*0.0136*

Model	Parameter	Estimate	Standard Error	p-value
	Ambient relative humidity	0.000513	0.00066	**0.4447**
MC-25	Intercept	6.289348	0.32603	<.0001
	Exhaust temperature	0.011374	0.00333	0.003
	Exhaust relative humidity	0.002775	0.00397	**0.4911**
MC-26	Intercept	6.524119	0.04565	<.0001
	Exhaust temperature	0.010128	0.00246	0.0005
MC-27	Intercept	6.7872	0.35897	<.0001
	Exhaust relative humidity	-0.001024	0.00472	**0.83**
MC28	Intercept	6.525115	0.17709	<.0001
	Ambient temperature	0.006696	0.00163	0.0006
	Ambient relative humidity	0.000805	0.00239	**0.7383**
MC-29	Intercept	6.58377	0.03273	<.0001
	Ambient temperature	0.006698	0.00164	0.0006
MC-30	Intercept	6.653836	0.22324	<.0001
	Ambient relative humidity	0.000586	0.00306	**0.8492**
MC-31	Intercept	6.363494	0.31761	<.0001
	Exhaust relative humidity	0.002645	0.00398	**0.5118**
	Ambient temperature	0.007648	0.00225	0.0032
MC-32	Intercept	6.457625	0.17955	<.0001
	Exhaust temperature	0.010136	0.00245	0.0005
	Ambient relative humidity	0.00091	0.00238	**0.7045**

Table G-20. Fit and evaluation statistics for $PM_{2.5}$ emission models for dairy milking centers.

Model	2LogL	AIC	AICc	BIC	Corr.	LNME[a] (%)	NME[b] (%)	ME[b] (g day^{-1})	MB[b] (g day^{-1})	NMB[b] (%)
MC-1	-161	-151	-149	-142	0.432	0.242	41.4	11.78	-0.004	-0.013
MC-2	-180	-172	-171	-165	0.459	0.213	38.83	10.31	-0.004	-0.014
MC-3	-155	-147	-146	-140	0.244	0.244	41.87	11.91		
MC-4	-181	-171	-169	-162	0.476	0.229	41.72	11.08	-0.005	-0.018
MC-5	-180	-172	-171	-165	0.466	0.223	40.57	10.78	-0.005	-0.017
MC-6	-174	-166	-165	-159	0.331	0.223	40.89	10.86	-0.001	-0.003
MC-7	-162	-152	-150	-143	0.448	0.248	42.25	12.02	-0.006	-0.019
MC-8	-180	-170	-169	-161	0.469	0.222	40.67	10.8	-0.004	-0.014
MC-9	-159	-151	-150	-149	0.383	0.229	39.22	11.16	-0.003	-0.012
MC-10	-178	-172	-171	-171	0.429	0.208	38.02	10.1	-0.003	-0.012
MC-11	-152	-146	-146	-145	0.017	0.266	45.31	12.89		
MC-12	-178	-170	-169	-168	0.429	0.214	39	10.36	-0.003	-0.013
MC-13	-178	-172	-171	-171	0.427	0.211	38.69	10.28	-0.003	-0.013
MC-14	-170	-164	-163	-162	0.043	0.272	49.27	13.09		-0.001
MC-15	-159	-151	-150	-149	0.382	0.232	39.5	11.24	-0.004	-0.013
MC-16	-178	-170	-169	-169	0.431	0.211	38.51	10.23	-0.003	-0.012
MC-17	-161	-149	-146	-139	0.432	0.242	41.4	11.78	-0.004	-0.013
MC-18	-180	-170	-168	-161	0.459	0.213	38.83	10.31	-0.004	-0.014
MC-19	-155	-145	-143	-136	0.244	0.244	41.87	11.91		
MC-20	-181	-169	-166	-158	0.476	0.229	41.72	11.08	-0.005	-0.018
MC-21	-180	-170	-168	-161	0.466	0.223	40.57	10.78	-0.005	-0.017
MC-22	-174	-164	-163	-155	0.331	0.223	40.89	10.86	-0.001	-0.003
MC-23	-162	-150	-147	-139	0.448	0.248	42.25	12.02	-0.006	-0.019
MC-24	-180	-168	-166	-158	0.469	0.222	40.67	10.8	-0.004	-0.014
MC-25	-57	-47	-45	-45	0.455	0.9	38.63	57.85	-0.245	-0.163
MC-26	-66	-58	-57	-56	0.509	0.832	37.75	52.77	-0.242	-0.173
MC-27	-48	-40	-39	-39	0.040	1.079	45.16	67.63	0.015	0.010
MC-28	-66	-56	-54	-54	0.509	0.85	38.41	53.69	-0.260	-0.186
MC-29	-66	-58	-57	-56	0.507	0.842	38.2	53.4	-0.248	-0.177
MC-30	-54	-46	-45	-45	0.044	1.131	49.22	68.8	-0.011	-0.008
MC-31	-57	-47	-45	-45	0.454	0.912	38.91	58.27	-0.254	-0.170
MC-32	-66	-56	-55	-54	0.512	0.839	37.97	53.08	-0.255	-0.183

[a] Based on transformed data (i.e., ln($PM_{2.5}$)).
[b] Based on back-transformed data.

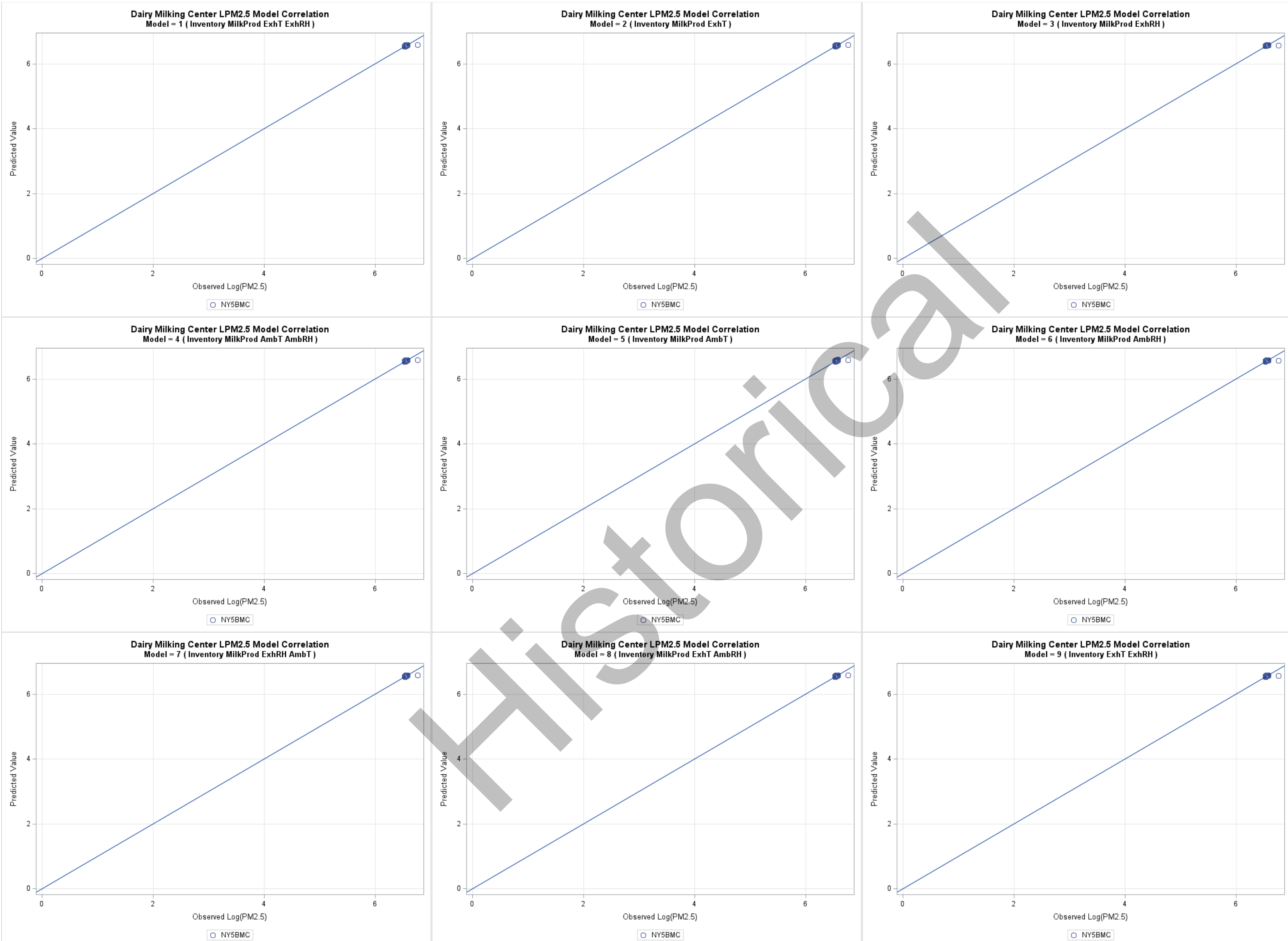


Figure G-41. Dairy milking center $PM_{2.5}$ one-to-one plots models 1 through 9, log transformed.

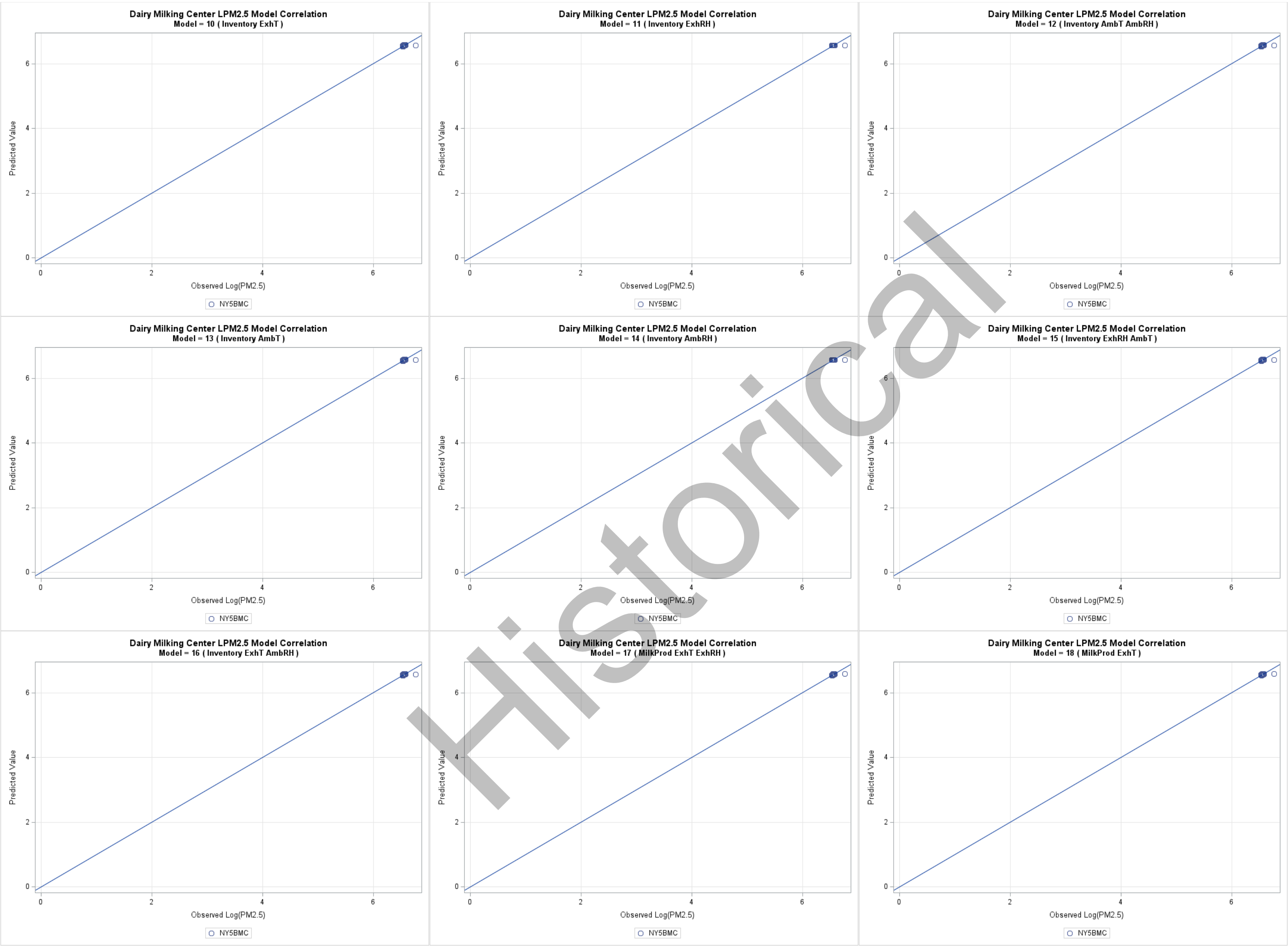


Figure G-42. Dairy milking center $PM_{2.5}$ one-to-one plots models 10 through 18, log transformed.

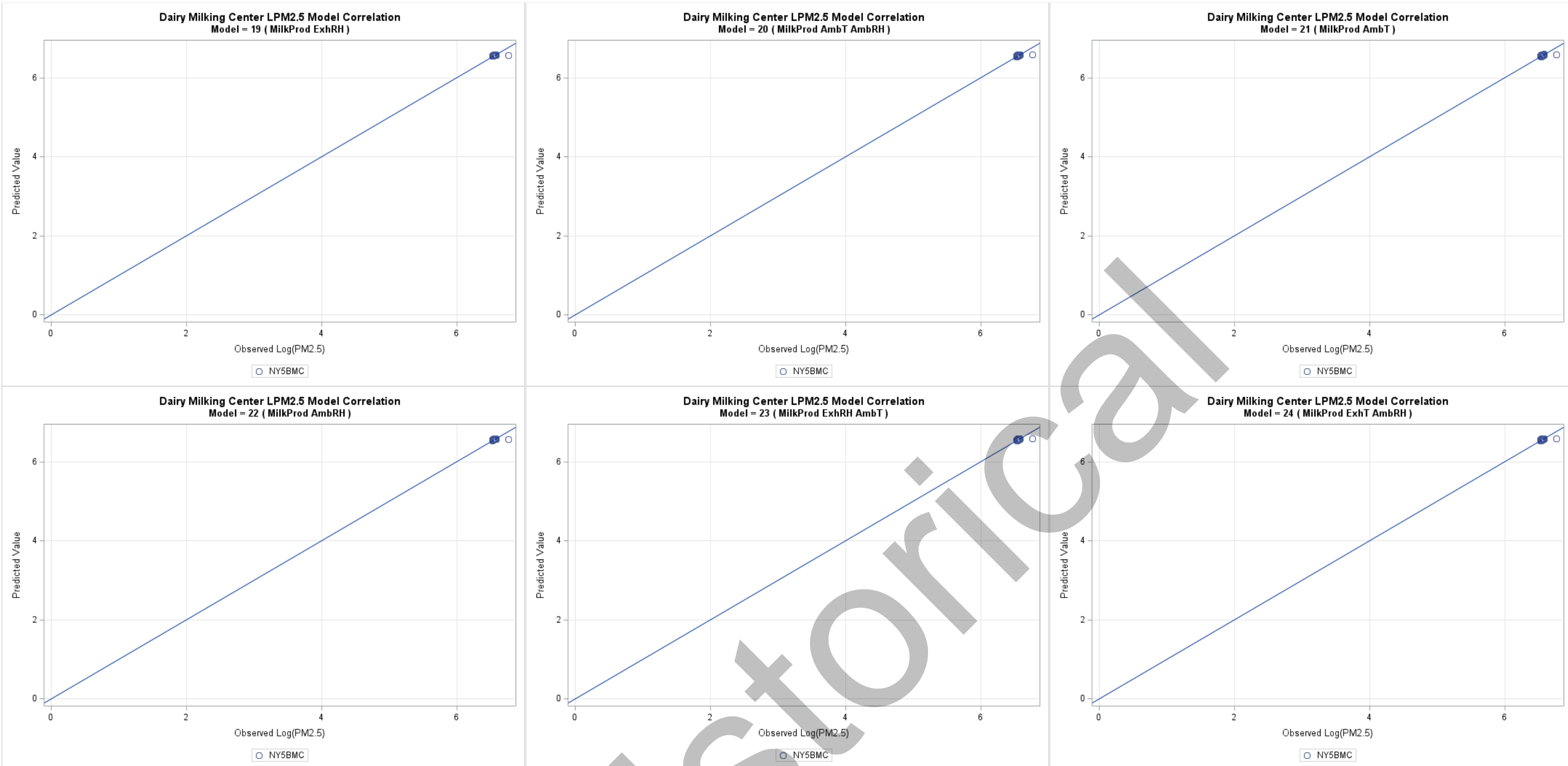


Figure G-43. Dairy milking center $PM_{2.5}$ one-to-one plots models 19 through 24, log transformed.

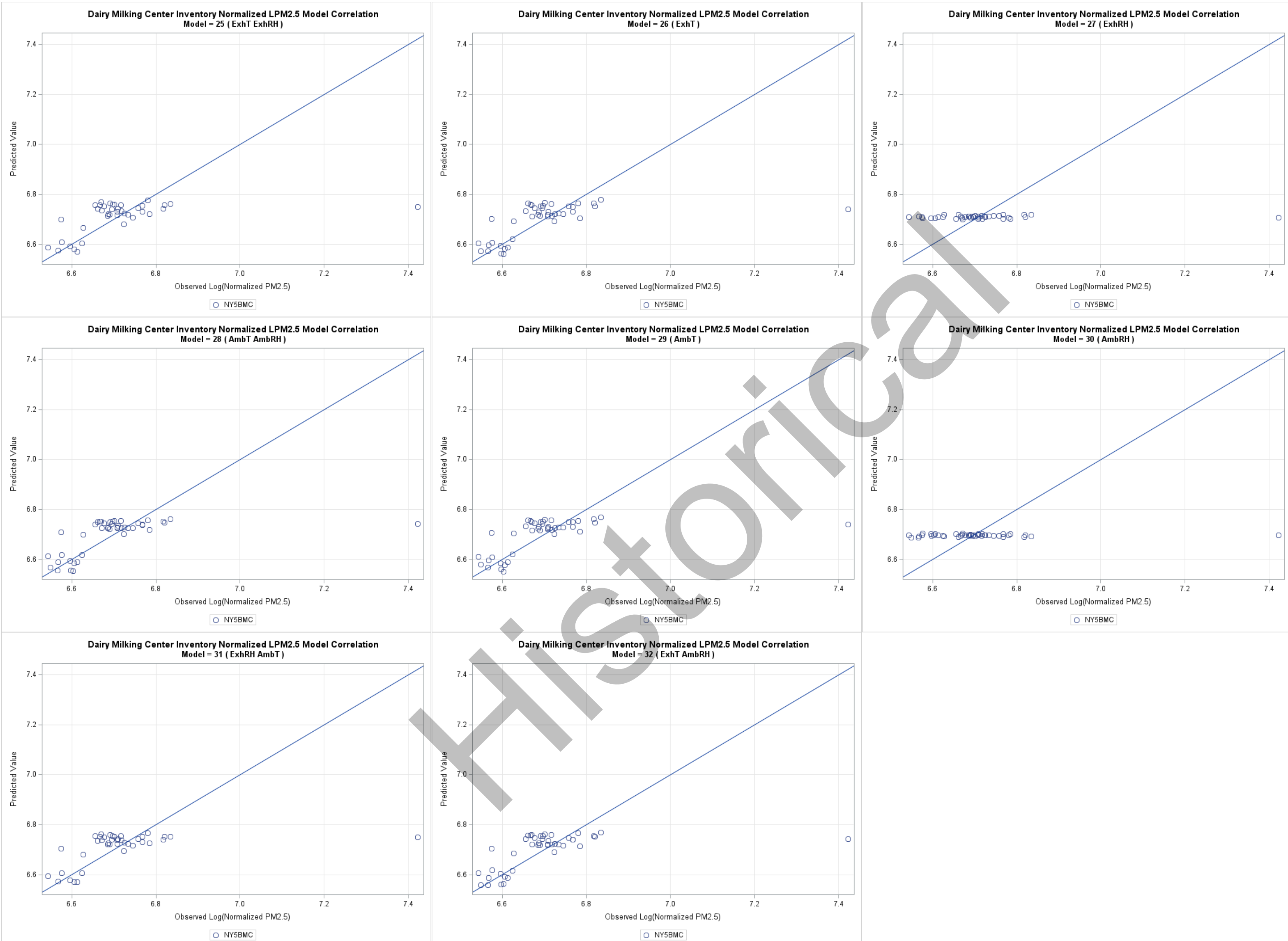


Figure G-44. Dairy milking center $PM_{2.5}$ one-to-one plots models 25 through 32, log transformed.

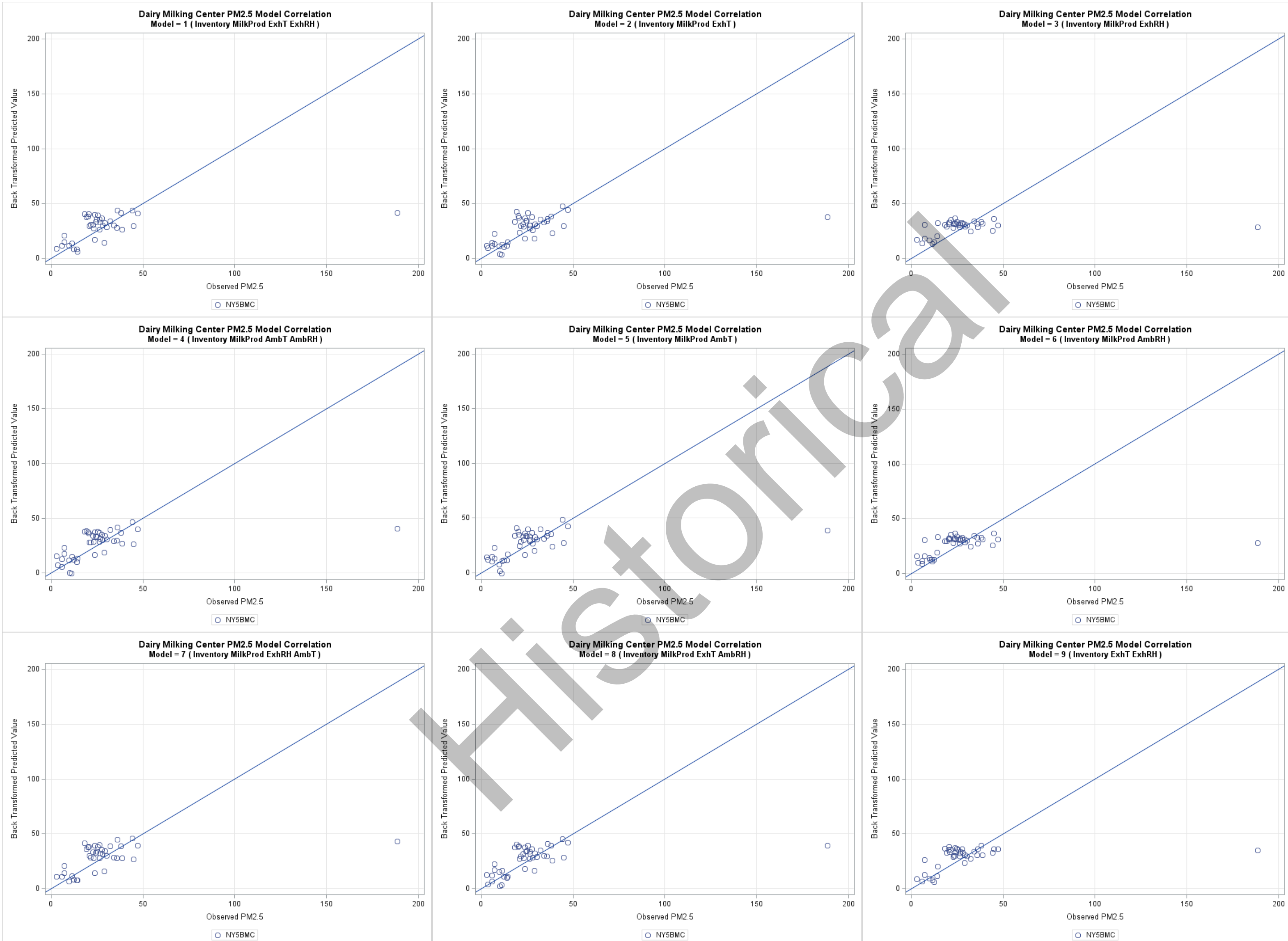


Figure G-45. Dairy milking center $PM_{2.5}$ one-to-one plots models 1 through 9, back transformed.

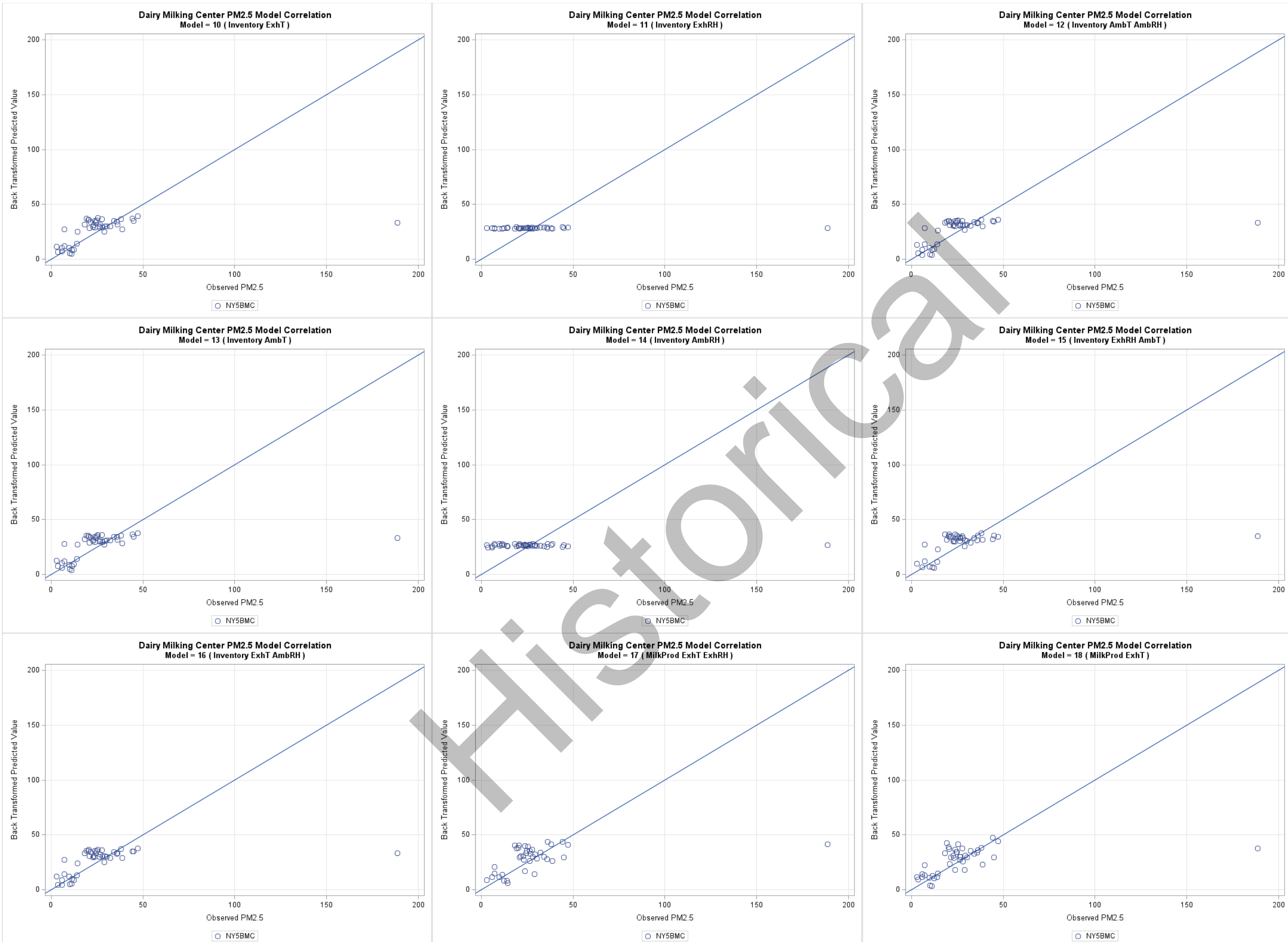


Figure G-46. Dairy milking center $PM_{2.5}$ one-to-one plots models 10 through 18, back transformed.

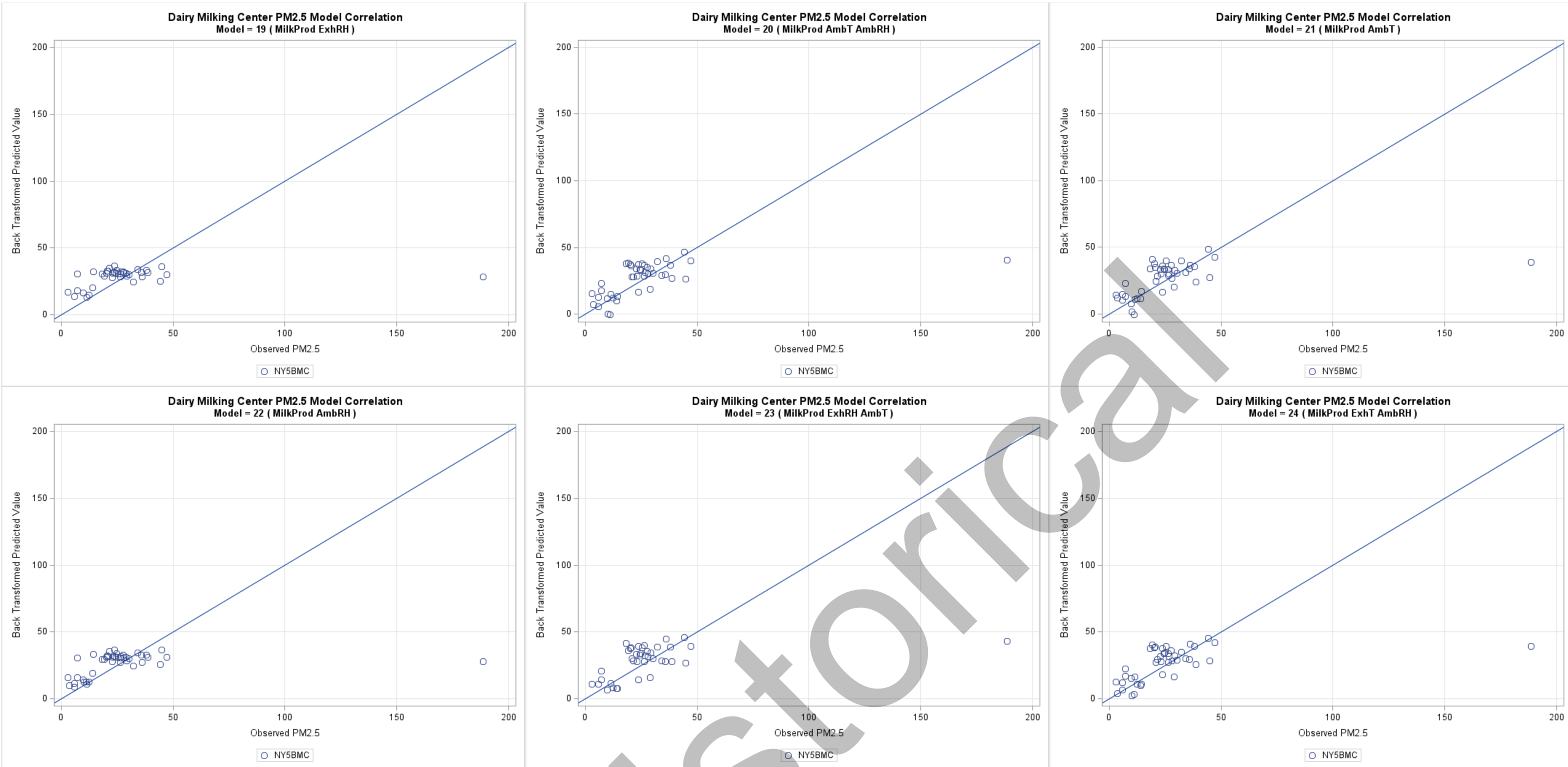


Figure G-47. Dairy milking center $PM_{2.5}$ one-to-one plots models 19 through 24, back transformed.

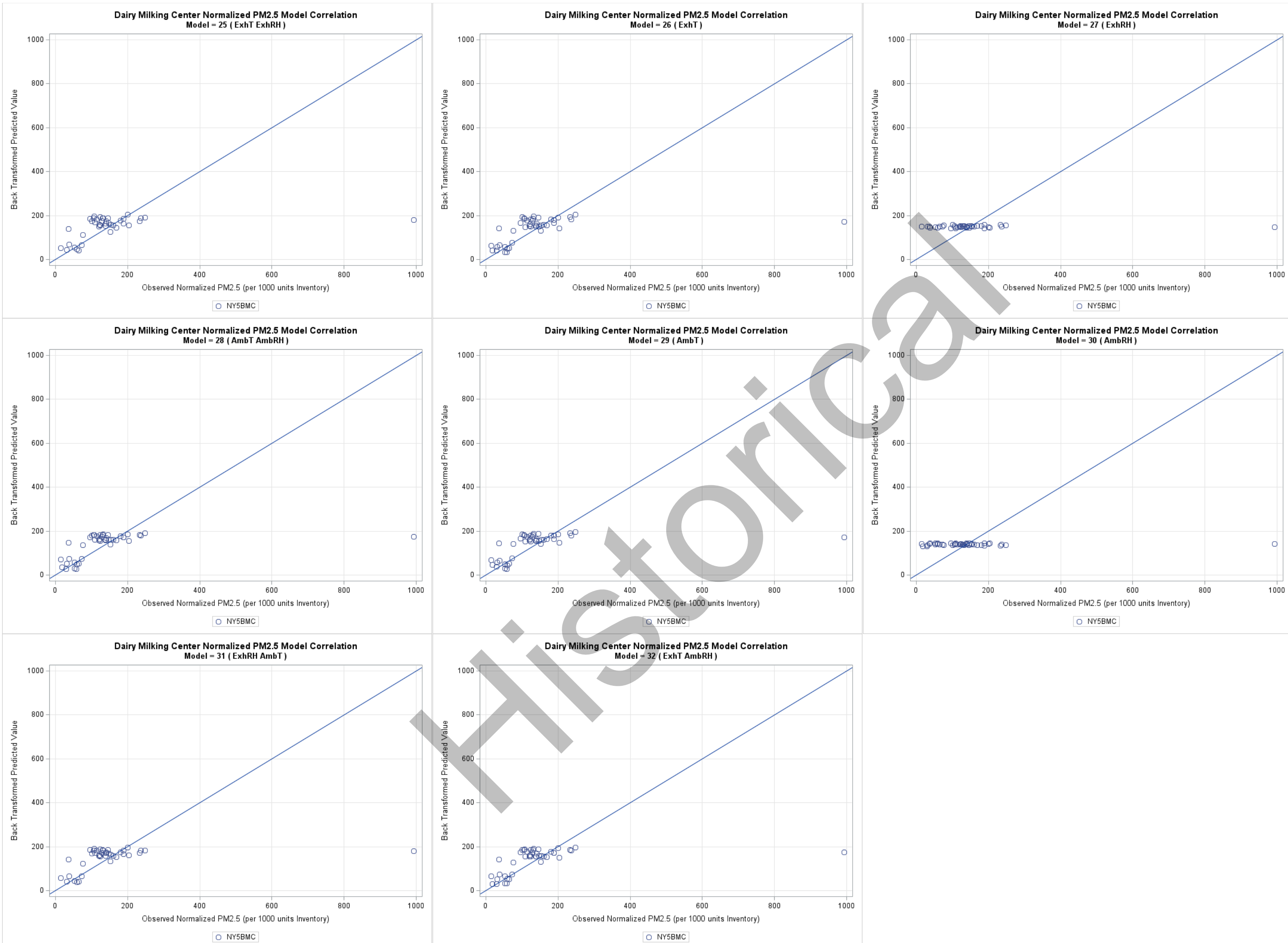


Figure G-48. Dairy milking center $PM_{2.5}$ one-to-one plots models 25 through 32, back transformed.

G.2.5 Total Suspended Particulates (TSP)

Table G-21. Parameter and estimates TSP emission models for dairy milking centers.

Model	Parameter	Estimate	Standard Error	p-value
MC-1	Intercept	7.417305	1.47685	<.0001
	Inventory	0	.	.
	Milk Production	-0.009841	0.04316	**0.8215**
	Exhaust temperature	0.005685	0.00354	**0.1232**
	Exhaust relative humidity	-0.002283	0.00192	**0.2463**
MC-2	Intercept	6.873533	0.80906	<.0001
	Inventory	0	.	.
	Milk Production	0.001702	0.02286	**0.9415**
	Exhaust temperature	0.004185	0.00187	*0.041*
MC-3	Intercept	6.155982	1.33907	0.0004
	Inventory	0	.	.
	Milk Production	0.029139	0.03836	**0.4599**
	Exhaust relative humidity	-0.002728	0.00197	**0.1788**
MC-4	Intercept	6.805037	0.83171	<.0001
	Inventory	0	.	.
	Milk Production	0.007334	0.02365	**0.7602**
	Ambient temperature	0.002678	0.00133	**0.0636**
	Ambient relative humidity	-0.001591	0.00124	**0.2091**
MC-5	Intercept	6.849108	0.81895	<.0001
	Inventory	0	.	.
	Milk Production	0.003034	0.02308	**0.8969**
	Ambient temperature	0.0028	0.0013	*0.0488*
MC-6	Intercept	6.582306	0.93037	<.0001
	Inventory	0	.	.
	Milk Production	0.014791	0.02636	**0.5815**
	Ambient relative humidity	-0.001797	0.00126	**0.1649**
MC-7	Intercept	7.24242	1.50524	<.0001
	Inventory	0	.	.
	Milk Production	-0.004363	0.04392	**0.9217**
	Exhaust relative humidity	-0.002037	0.00195	**0.3085**
	Ambient temperature	0.003466	0.0025	**0.1813**
MC-8	Intercept	6.836392	0.81838	<.0001
	Inventory	0	.	.
	Milk Production	0.00605	0.0233	**0.7982**
	Exhaust temperature	0.004136	0.0019	*0.0462*
	Ambient relative humidity	-0.001729	0.00123	**0.1707**
MC-9	Intercept	7.050905	0.1357	<.0001
	Inventory	0	.	.
	Exhaust temperature	0.005687	0.00299	**0.08**
	Exhaust relative humidity	-0.001897	0.00179	**0.2974**
MC-10	Intercept	6.934518	0.02998	<.0001
	Inventory	0	.	.
	Exhaust temperature	0.004622	0.0019	*0.0256*
MC-11	Intercept	7.141007	0.13383	<.0001
	Inventory	0	.	.

Model	Parameter	Estimate	Standard Error	p-value
	Exhaust relative humidity	-0.001912	0.00184	**0.3067**
MC-12	Intercept	7.040962	0.08412	<.0001
	Inventory	0	.	.
	Ambient temperature	0.003156	0.00135	*0.0331*
	Ambient relative humidity	-0.001202	0.00118	**0.3164**
MC-13	Intercept	6.958684	0.02208	<.0001
	Inventory	0	.	.
	Ambient temperature	0.003141	0.0013	*0.0277*
MC-14	Intercept	7.087242	0.08557	<.0001
	Inventory	0	.	.
	Ambient relative humidity	-0.00134	0.00122	**0.279**
MC-15	Intercept	7.058876	0.13559	<.0001
	Inventory	0	.	.
	Exhaust relative humidity	-0.001574	0.0018	**0.3881**
	Ambient temperature	0.003772	0.00205	**0.0925**
MC-16	Intercept	7.025749	0.08501	<.0001
	Inventory	0	.	.
	Exhaust temperature	0.004751	0.00197	*0.0277*
	Ambient relative humidity	-0.001355	0.00118	**0.2587**
MC-17	Intercept	7.417305	1.47685	<.0001
	Milk Production	-0.009841	0.04316	**0.8215**
	Exhaust temperature	0.005685	0.00354	**0.1232**
	Exhaust relative humidity	-0.002283	0.00192	**0.2463**
MC-18	Intercept	6.873533	0.80906	<.0001
	Milk Production	0.001702	0.02286	**0.9415**
	Exhaust temperature	0.004185	0.00187	*0.041*
MC-19	Intercept	6.155982	1.33907	0.0004
	Milk Production	0.029139	0.03836	**0.4599**
	Exhaust relative humidity	-0.002728	0.00197	**0.1788**
MC-20	Intercept	6.805037	0.83171	<.0001
	Milk Production	0.007334	0.02365	**0.7602**
	Ambient temperature	0.002678	0.00133	**0.0636**
	Ambient relative humidity	-0.001591	0.00124	**0.2091**
MC-21	Intercept	6.849108	0.81895	<.0001
	Milk Production	0.003034	0.02308	**0.8969**
	Ambient temperature	0.0028	0.0013	*0.0488*
MC-22	Intercept	6.582306	0.93037	<.0001
	Milk Production	0.014791	0.02636	**0.5815**
	Ambient relative humidity	-0.001797	0.00126	**0.1649**
MC-23	Intercept	7.24242	1.50524	<.0001
	Milk Production	-0.004363	0.04392	**0.9217**
	Exhaust relative humidity	-0.002037	0.00195	**0.3085**
	Ambient temperature	0.003466	0.0025	**0.1813**
MC-24	Intercept	6.836392	0.81838	<.0001
	Milk Production	0.00605	0.0233	**0.7982**
	Exhaust temperature	0.004136	0.0019	*0.0462*
	Ambient relative humidity	-0.001729	0.00123	**0.1707**
MC-25	Intercept	7.439891	0.46903	<.0001
	Exhaust temperature	0.020743	0.01092	**0.0789**

Model	Parameter	Estimate	Standard Error	p-value
	Exhaust relative humidity	-0.005608	0.00618	**0.3709**
MC-26	Intercept	7.123716	0.10967	<.0001
	Exhaust temperature	0.016156	0.00699	*0.0327*
MC-27	Intercept	7.748619	0.46313	<.0001
	Exhaust relative humidity	-0.005395	0.00636	**0.4029**
MC28	Intercept	7.457268	0.2912	<.0001
	Ambient temperature	0.010997	0.00497	*0.0417*
	Ambient relative humidity	-0.003639	0.00409	**0.3791**
MC-29	Intercept	7.209101	0.08119	<.0001
	Ambient temperature	0.010892	0.00482	*0.0372*
MC-30	Intercept	7.604712	0.29594	<.0001
	Ambient relative humidity	-0.003934	0.00421	**0.3562**
MC-31	Intercept	7.472509	0.46839	<.0001
	Exhaust relative humidity	-0.004474	0.0062	**0.4758**
	Ambient temperature	0.013728	0.00753	**0.0941**
MC-32	Intercept	7.402084	0.29449	<.0001
	Exhaust temperature	0.016685	0.00723	*0.0336*
	Ambient relative humidity	-0.004162	0.00407	**0.3139**

Table G-22. Fit and evaluation statistics for TSP emission models for dairy milking centers.

Model	2LogL	AIC	AICc	BIC	Corr.	LNME[a] (%)	NME[b] (%)	ME[b] (g day^{-1})	MB[b] (g day^{-1})	NMB[b] (%)
MC-1	-75	-65	-63	-58	0.475	0.872	54.48	66.33	-0.004	-0.004
MC-2	-95	-87	-85	-80	0.469	0.746	50.28	57.72	-0.115	-0.1
MC-3	-73	-65	-63	-59	0.302	0.904	58.22	70.87	-0.109	-0.09
MC-4	-96	-86	-84	-78	0.475	0.726	48.79	56	-0.076	-0.066
MC-5	-94	-86	-85	-80	0.454	0.739	49.96	57.35	-0.094	-0.082
MC-6	-92	-84	-83	-78	0.232	0.855	59.18	67.94	-0.044	-0.038
MC-7	-75	-65	-62	-58	0.441	0.882	55.02	66.98	0.041	0.034
MC-8	-96	-86	-84	-79	0.497	0.726	48.66	55.86	-0.091	-0.08
MC-9	-87	-79	-78	-78	0.412	0.869	50.89	67.38	0.164	0.124
MC-10	-107	-101	-100	-100	0.468	0.774	48.47	60.45	-0.117	-0.093
MC-11	-84	-78	-77	-76	0.001	1.006	59.85	79.23	0.172	0.13
MC-12	-108	-100	-99	-98	0.448	0.767	47.73	59.53	-0.008	-0.007
MC-13	-107	-101	-100	-100	0.462	0.768	48.2	60.11	-0.102	-0.081
MC-14	-103	-97	-96	-96	0.013	0.923	58.99	73.58	0.121	0.097
MC-15	-87	-79	-77	-77	0.405	0.883	51.7	68.45	0.149	0.112
MC-16	-108	-100	-99	-99	0.456	0.765	47.66	59.44		
MC-17	-75	-63	-59	-55	0.475	0.872	54.48	66.33	-0.004	-0.004
MC-18	-95	-85	-82	-77	0.469	0.746	50.28	57.72	-0.115	-0.1
MC-19	-73	-63	-60	-56	0.302	0.904	58.22	70.87	-0.109	-0.09
MC-20	-96	-84	-81	-75	0.475	0.726	48.79	56	-0.076	-0.066
MC-21	-94	-84	-82	-76	0.454	0.739	49.96	57.35	-0.094	-0.082
MC-22	-92	-82	-80	-74	0.232	0.855	59.18	67.94	-0.044	-0.038
MC-23	-75	-63	-59	-54	0.441	0.882	55.02	66.98	0.041	0.034
MC-24	-96	-84	-81	-75	0.497	0.726	48.66	55.86	-0.091	-0.08
MC-25	-2	8	10	10	0.412	2.939	50.43	351.4	2.215	0.318
MC-26	-7	1	2	3	0.454	2.636	48.44	318	-3.004	-0.458
MC-27	2	10	11	11	-0.031	3.415	59.87	417.2	1.988	0.285
MC-28	-7	3	4	5	0.43	2.618	47.65	312.8	-1.787	-0.272
MC-29	-7	1	2	3	0.444	2.609	48.38	317.6	-3.03	-0.462
MC-30	-3	5	6	7	-0.008	3.139	58.97	387.1	1.453	0.221
MC-31	-2	8	10	10	0.402	2.991	51.18	356.7	1.494	0.214
MC-32	-8	2	4	4	0.441	2.612	47.48	311.7	-1.317	-0.201

[a] Based on transformed data (i.e., ln(TSP)).
[b] Based on back-transformed data.

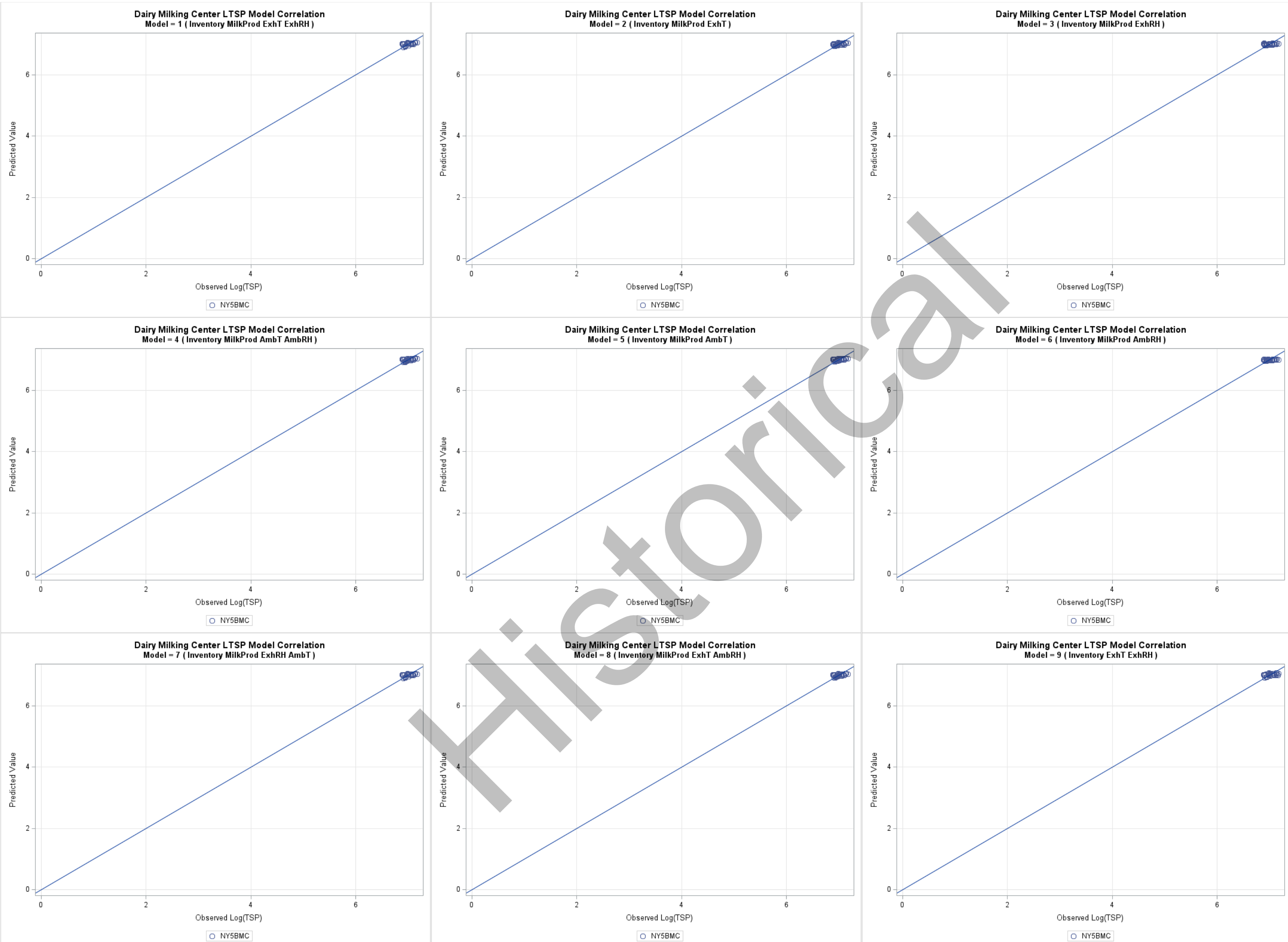


Figure G-49. Dairy milking center TSP one-to-one plots models 1 through 9, log transformed.

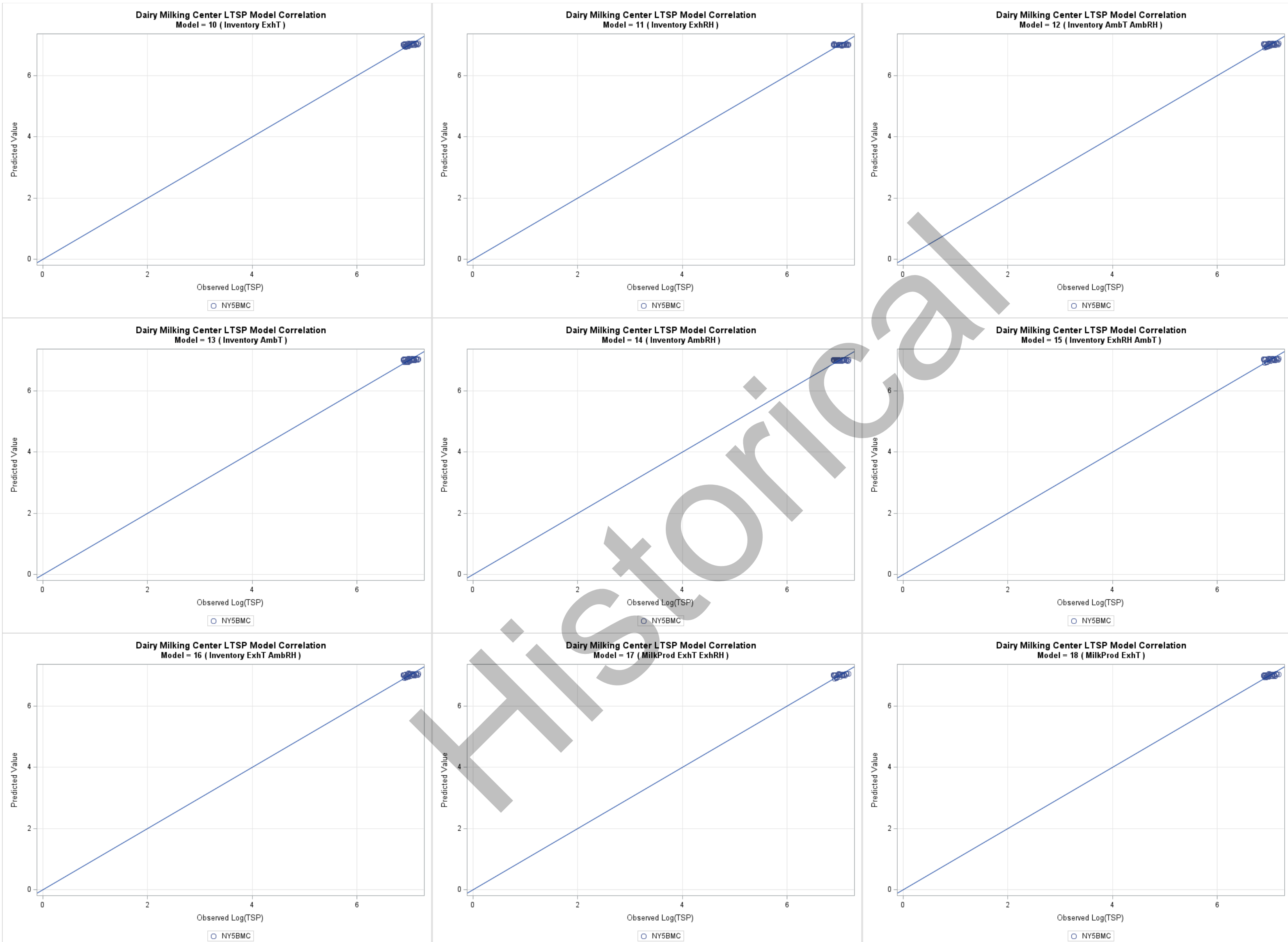


Figure G-50. Dairy milking center TSP one-to-one plots models 10 through 18, log transformed.

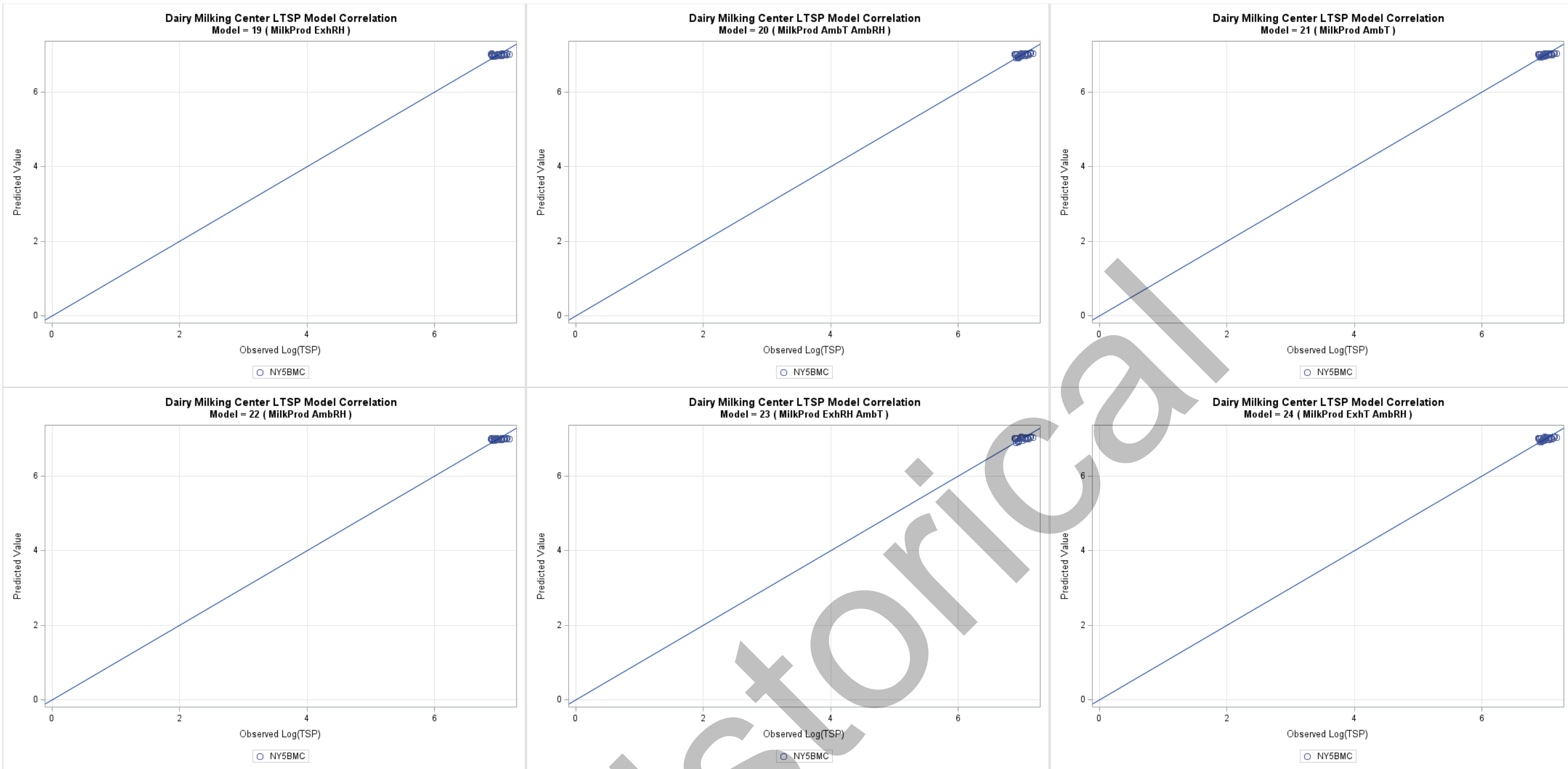


Figure G-51. Dairy milking center TSP one-to-one plots models 19 through 24, log transformed.

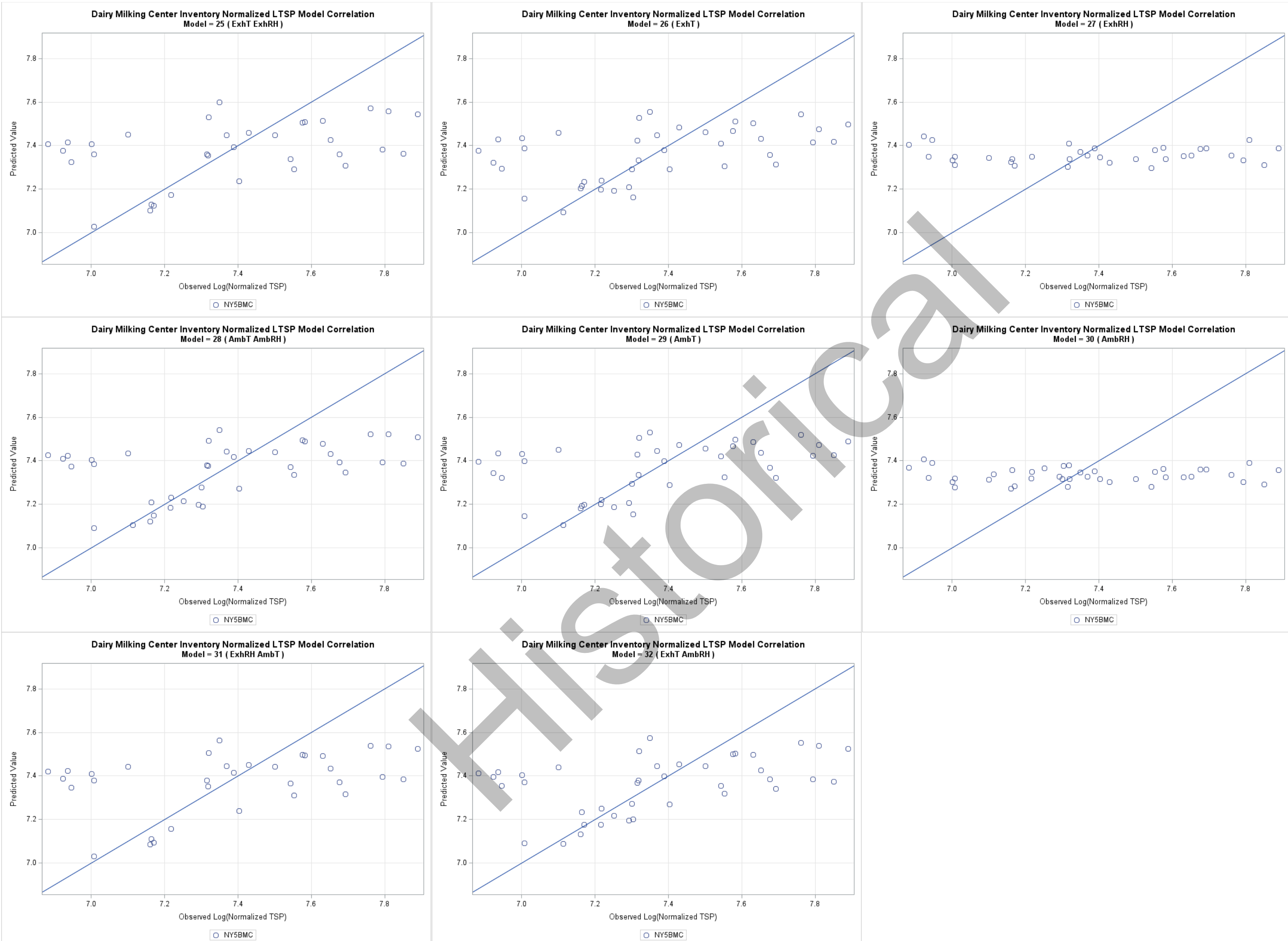


Figure G-52. Dairy milking center TSP one-to-one plots models 25 through 32, log transformed.

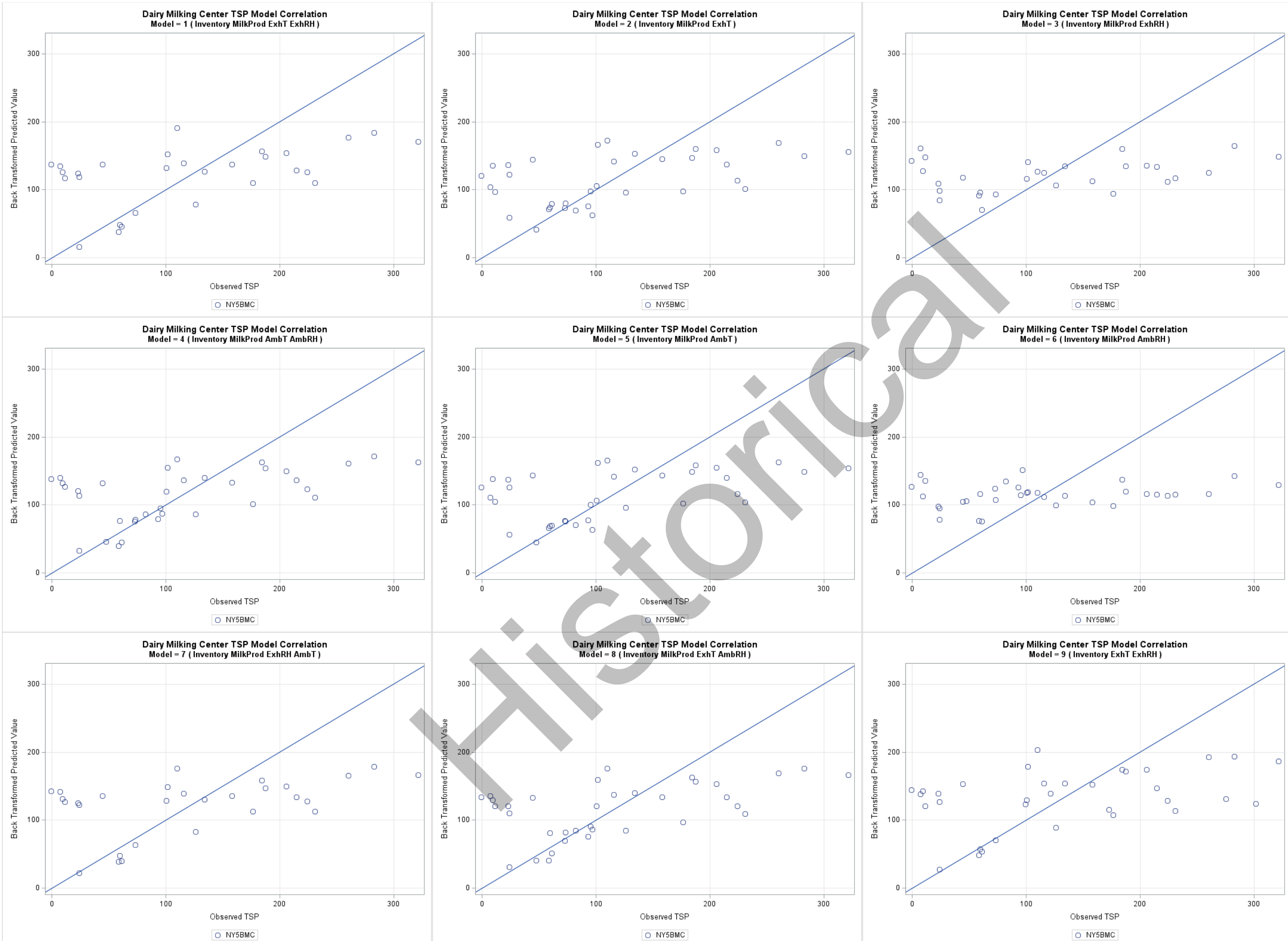


Figure G-53. Dairy milking center TSP one-to-one plots models 1 through 9, back transformed.

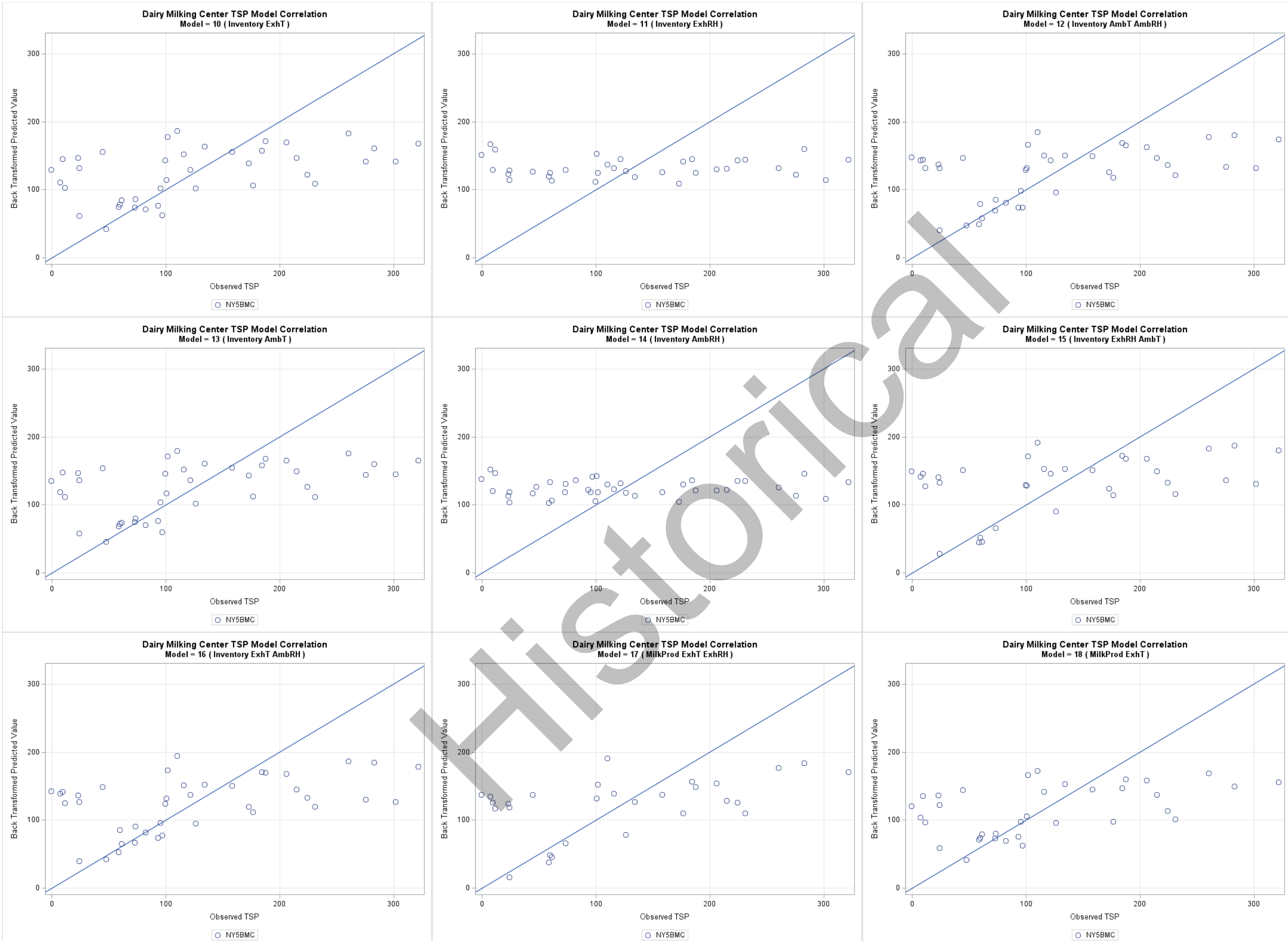


Figure G-54. Dairy milking center TSP one-to-one plots models 10 through 18, back transformed.

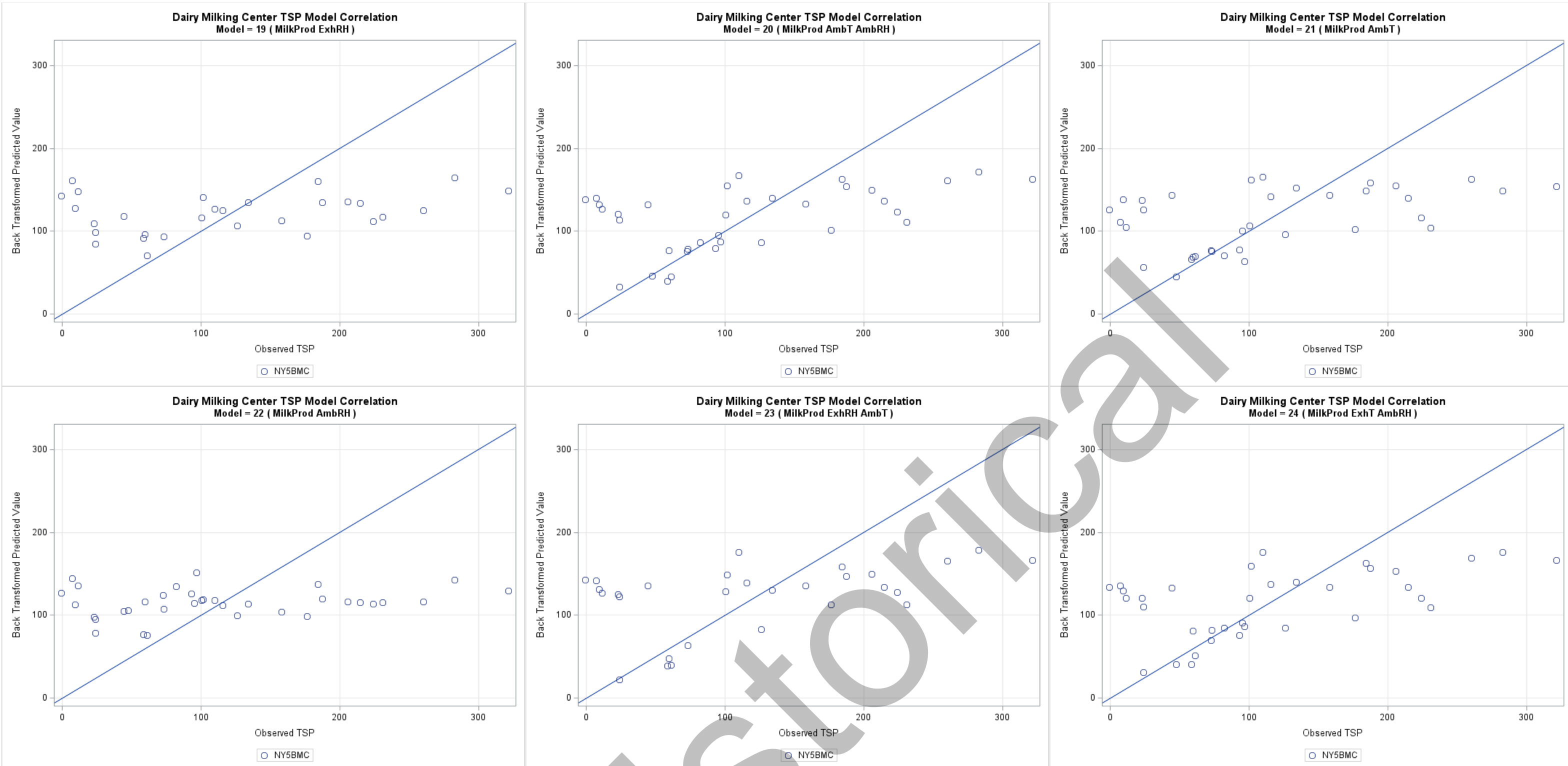


Figure G-55. Dairy milking center TSP one-to-one plots models 19 through 24, back transformed.

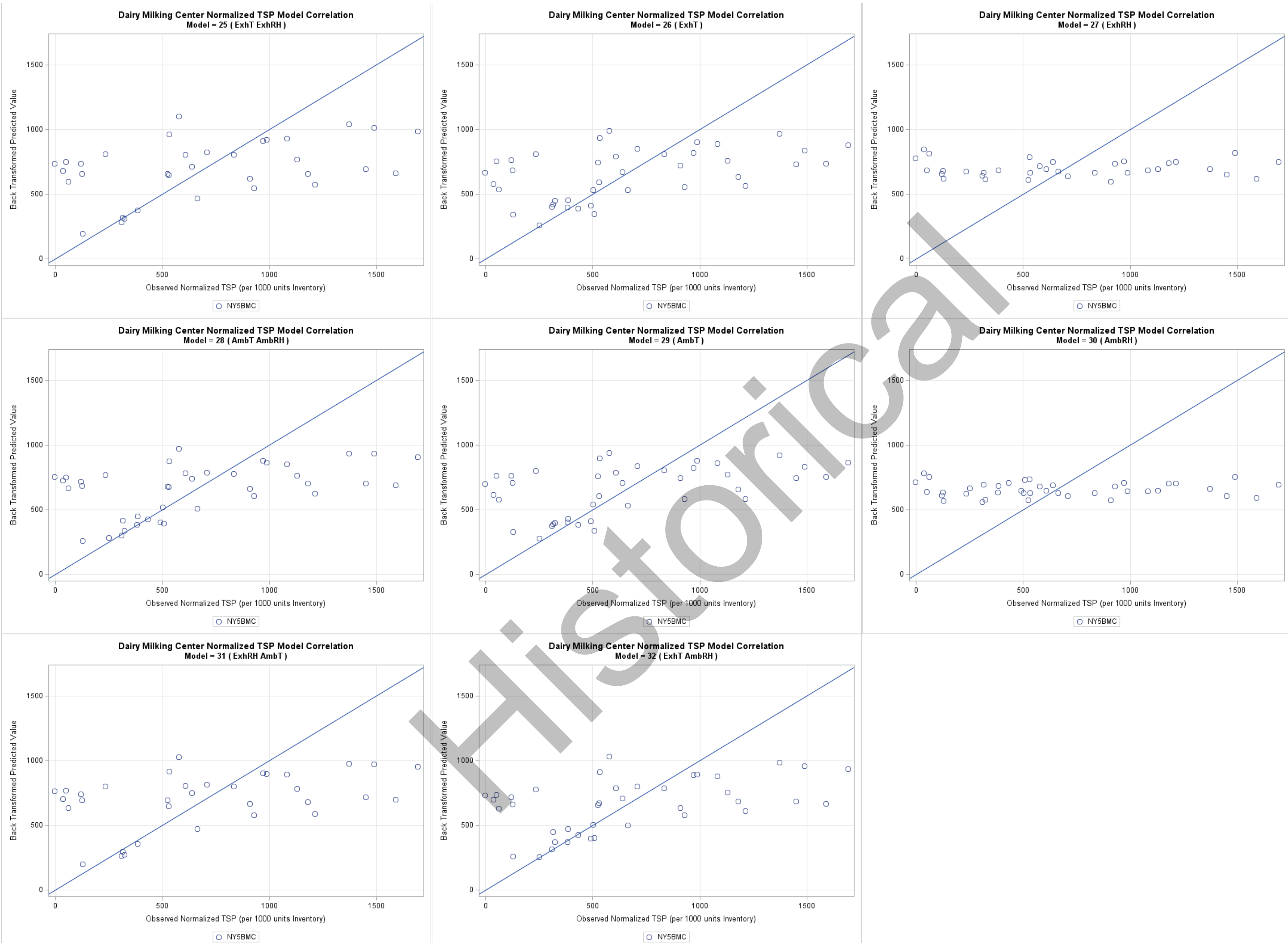


Figure G-56. Dairy milking center TSP one-to-one plots models 25 through 32, back transformed.

G.3 Naturally Ventilated Barns

Table G-23. Parameter combinations tested as naturally ventilated barns models.

Model	Parameters
NV-1	Intercept, Inventory
NV-2	Intercept, Inventory, Ambient temperature, Ambient relative humidity, Wind Speed
NV-3	Intercept, Inventory, Ambient temperature
NV-4	Intercept, Inventory, Ambient relative humidity
NV-5	Intercept, Inventory, Wind Speed
NV-6	Intercept, Inventory, Ambient temperature, Ambient relative humidity
NV-7	Intercept, Inventory, Ambient relative humidity, Wind Speed
NV-8	Intercept, Inventory Ambient temperature, Wind Speed

G.3.1 Ammonia (NH_3)

Table G-24. Parameter and estimates NH_3 emission models for dairy mechanically ventilated barn.

Model	Parameter	Estimate	Standard Error	p-value
NV-1	Intercept	0.302928	0.26899	**0.2638**
	Inventory	3.525901	0.41679	<.0001
NV-2	Intercept	1.564251	0.33361	<.0001
	Inventory	2.979164	0.33977	<.0001
	Ambient temperature	-0.01665	0.00637	0.0096
	Ambient relative humidity	-0.01548	0.00269	<.0001
	Wind Speed	0.046414	0.01877	*0.0137*
NV-3	Intercept	0.387363	0.29177	**0.1878**
	Inventory	3.492633	0.41432	<.0001
	Ambient temperature	-0.004143	0.00665	**0.5341**
NV-4	Intercept	1.121109	0.29364	0.0002
	Inventory	3.245651	0.36468	<.0001
	Ambient relative humidity	-0.01182	0.00261	<.0001
NV-5	Intercept	0.188357	0.2678	**0.484**
	Inventory	3.451939	0.4106	<.0001
	Wind Speed	0.048153	0.01837	0.009
NV-6	Intercept	1.726964	0.32917	<.0001
	Inventory	3.038111	0.34221	<.0001
	Ambient temperature	-0.019085	0.00633	0.0029
	Ambient relative humidity	-0.015666	0.00271	<.0001
NV-7	Intercept	1.02681	0.29008	0.0006
	Inventory	3.15081	0.35633	<.0001
	Ambient relative humidity	-0.012222	0.00258	<.0001
	Wind Speed	0.052342	0.01849	0.0048
NV-8	Intercept	0.238892	0.29441	**0.4192**
	Inventory	3.433342	0.41004	<.0001
	Ambient temperature	-0.002104	0.00665	**0.7521**
	Wind Speed	0.046827	0.01856	*0.0119*

Table G-25. Fit and evaluation statistics for NH_3 emission models for dairy mechanically ventilated barn.

Model	2LogL	AIC	AICc	BIC	Corr.	LNME[a] (%)	NME[b] (%)	ME[b] (kg day^{-1})	MB[b] (kg day^{-1})	NMB[b] (%)
NV-1	998	1,006	1,007	1,008	0.601	27.52	76.2	12.98	0.969	5.686
NV-2	964	978	978	981	0.719	24.21	62.92	10.76	-0.583	-3.41
NV-3	995	1,005	1,005	1,007	0.609	27.2	74.93	12.81	0.824	4.821
NV-4	978	988	988	990	0.671	25.61	68.15	11.65	0.019	0.113
NV-5	992	1,002	1,002	1,004	0.615	27.08	75.23	12.82	0.828	4.862
NV-6	970	982	982	984	0.715	24.36	63.4	10.84	-0.491	-2.87
NV-7	970	982	982	985	0.686	25.18	66.73	11.41	-0.21	-1.23
NV-8	988	1,000	1,001	1,003	0.618	26.92	74.61	12.75	0.765	4.476

[a] Based on transformed data (i.e., $\ln(NH_3)$).
[b] Based on back-transformed data.

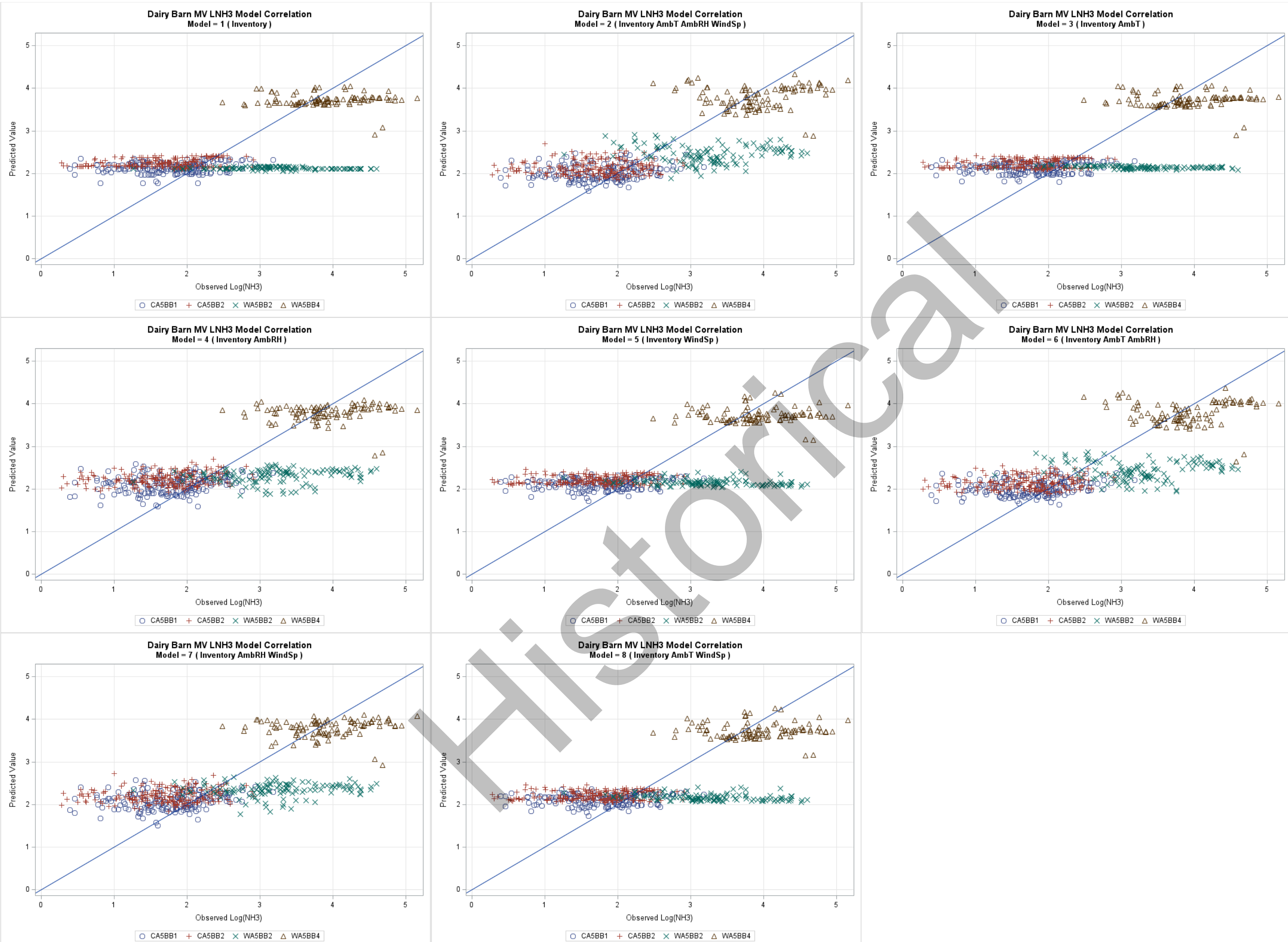


Figure G-57. Dairy naturally ventilated barn NH_3 one-to-one plots models 1 through 8, log transformed.

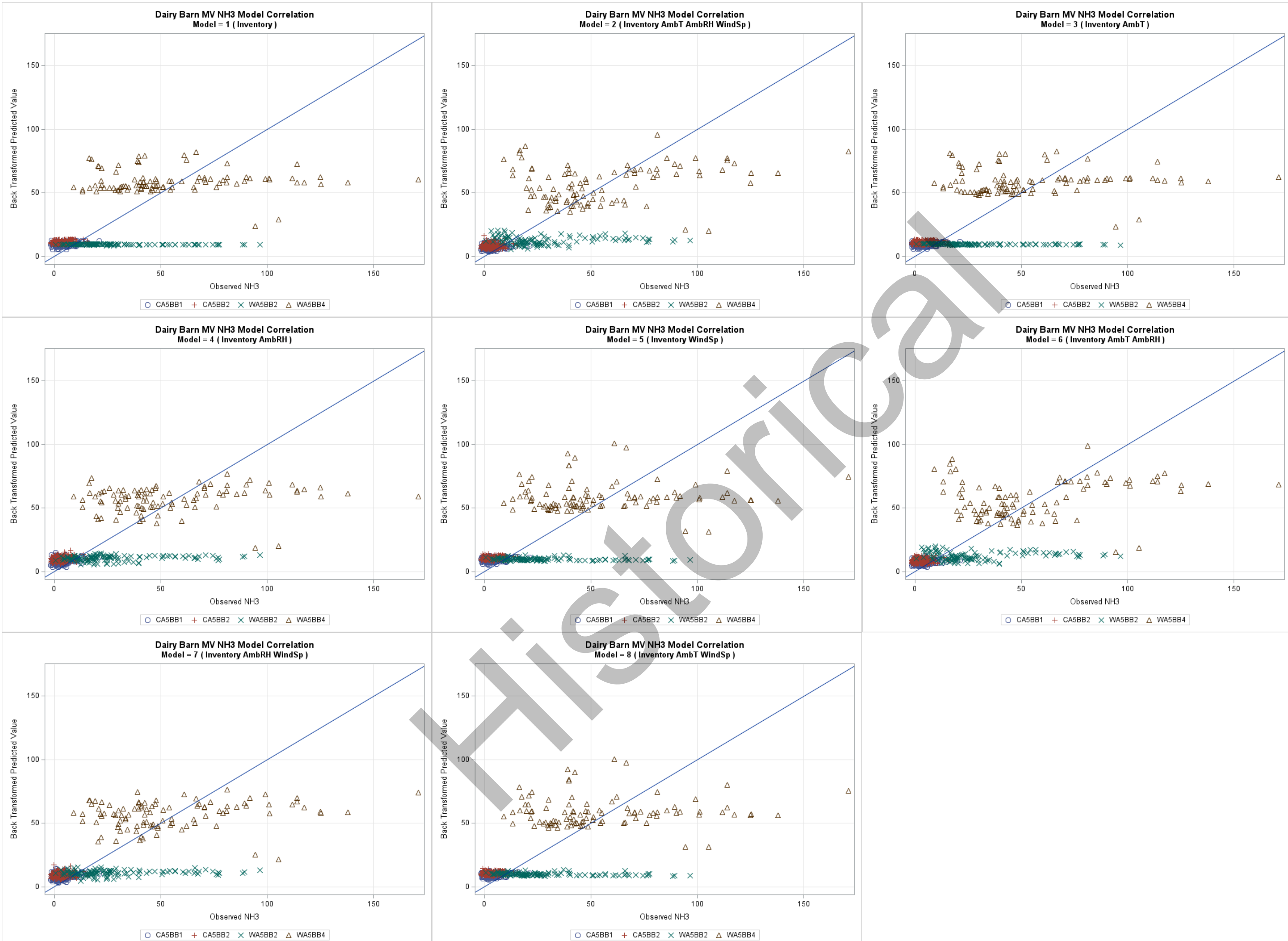


Figure G-58. Dairy naturally ventilated barn NH_3 one-to-one plots models 1 through 8, back transformed.

G.3.2 Hydrogen Sulfide (H_2S)

Table G-26. Parameter and estimates H_2S emission models for dairy naturally ventilated barn.

Model	Parameter	Estimate	Standard Error	p-value
NV-1	Intercept	6.68466	0.1356	<.0001
	Inventory	0.67609	0.21735	0.0022
NV-2	Intercept	6.675321	0.26174	<.0001
	Inventory	0.54958	0.23161	*0.0186*
	Ambient temperature	-0.003921	0.00477	**0.4118**
	Ambient relative humidity	-0.000765	0.00225	**0.734**
	Wind Speed	0.059704	0.02329	*0.0106*
NV-3	Intercept	6.824733	0.15921	<.0001
	Inventory	0.633119	0.21924	0.0043
	Ambient temperature	-0.007224	0.00424	**0.0895**
NV-4	Intercept	6.663477	0.20081	<.0001
	Inventory	0.686017	0.22535	0.0027
	Ambient relative humidity	0.000289	0.00212	**0.8919**
NV-5	Intercept	6.541057	0.14434	<.0001
	Inventory	0.587702	0.21921	0.008
	Wind Speed	0.062678	0.02193	0.0044
NV-6	Intercept	6.911144	0.24515	<.0001
	Inventory	0.599883	0.23054	*0.01*
	Ambient temperature	-0.007924	0.0045	**0.0794**
	Ambient relative humidity	-0.001042	0.00225	**0.6435**
NV-7	Intercept	6.541762	0.20441	<.0001
	Inventory	0.581809	0.22794	*0.0114*
	Ambient relative humidity	-0.000151	0.00212	**0.9432**
	Wind Speed	0.065974	0.02198	0.0028
NV-8	Intercept	6.610517	0.17959	<.0001
	Inventory	0.573546	0.2207	*0.0101*
	Ambient temperature	-0.003381	0.0045	**0.453**
	Wind Speed	0.060086	0.02327	*0.01*

Table G-27. Fit and evaluation statistics for H_2S emission models for dairy naturally ventilated barn.

Model	2LogL	AIC	AICc	BIC	Corr.	LNME[a] (%)	NME[b] (%)	ME[b] (g day^{-1})	MB[b] (g day^{-1})	NMB[b] (%)
NV-1	1182	1190	1190	1192	0.143	6.468	78.57	690.4	-22.89	-2.605
NV-2	1156	1170	1171	1173	0.185	6.477	76.7	675.5	-31.35	-3.56
NV-3	1163	1173	1173	1175	0.158	6.517	77.5	682.5	-27.48	-3.12
NV-4	1166	1176	1176	1178	0.143	6.43	78.11	687.9	-22.82	-2.591
NV-5	1174	1184	1184	1186	0.182	6.461	77.09	677.5	-29.02	-3.302
NV-6	1163	1175	1175	1177	0.16	6.525	77.45	682.1	-28.85	-3.276
NV-7	1157	1169	1169	1171	0.183	6.427	76.57	674.3	-29.47	-3.346
NV-8	1157	1169	1169	1171	0.184	6.474	76.72	675.7	-30.34	-3.445

[a] Based on transformed data (i.e., ln(H_2S)).
[b] Based on back-transformed data.

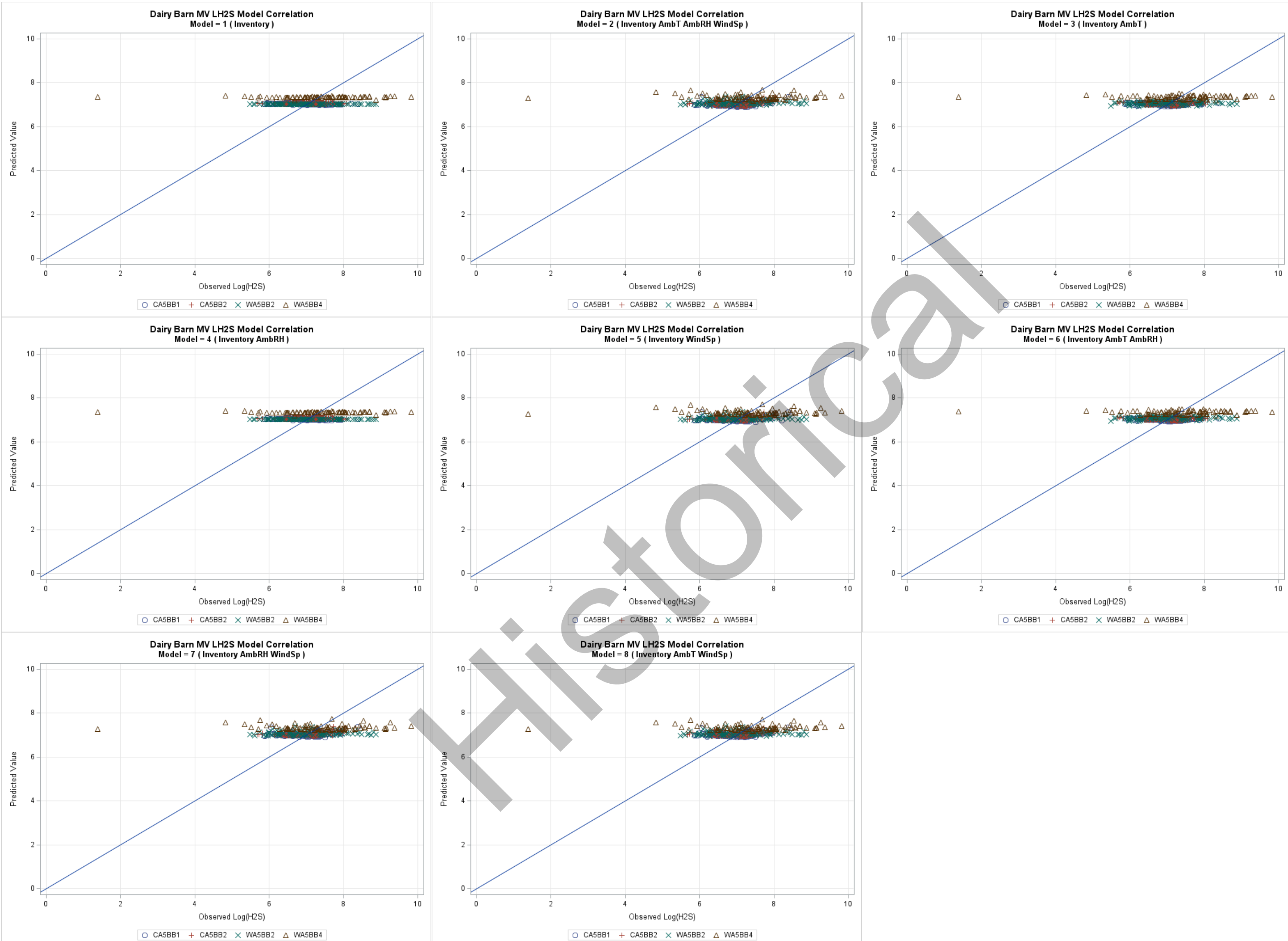


Figure G-59. Dairy naturally ventilated barn H_2S one-to-one plots models 1 through 8, log transformed.

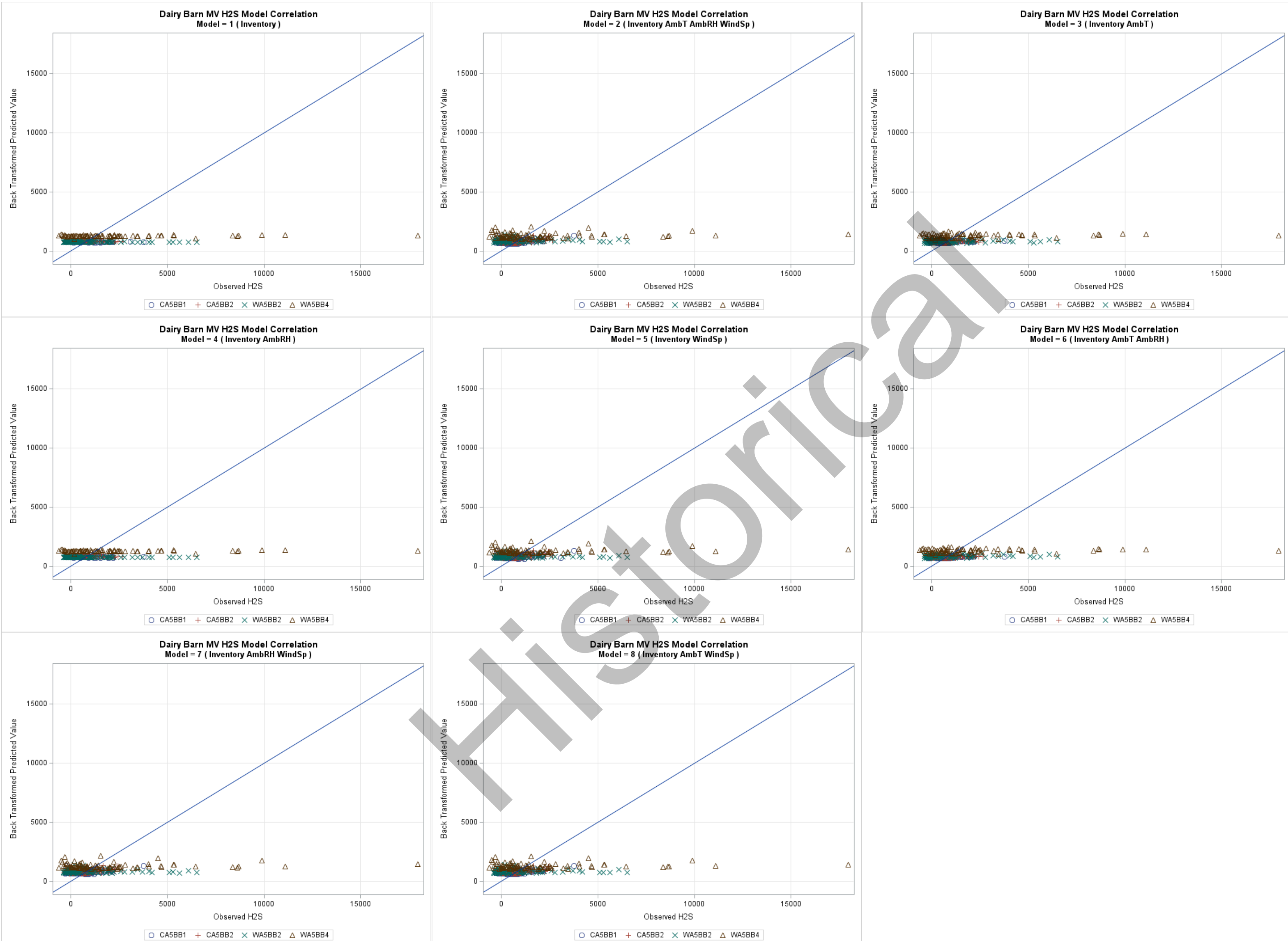


Figure G-60. Dairy naturally ventilated barn H_2S one-to-one plots models 1 through 8, back transformed.

G.3.3 PM_{10}

Table G-28. Parameter and estimates PM_{10} emission models for dairy naturally ventilated barn.

Model	Parameter	Estimate	Standard Error	p-value
NV-1	Intercept	7.009063	0.13722	<.0001
	Inventory	2.082987	0.20542	<.0001
NV-2	Intercept	7.64258	0.16783	<.0001
	Inventory	1.525009	0.14917	<.0001
	Ambient temperature	0.011864	0.00333	0.0004
	Ambient relative humidity	-0.01521	0.00154	<.0001
	Wind Speed	0.173698	0.01064	<.0001
NV-3	Intercept	6.65764	0.14302	<.0001
	Inventory	2.180088	0.19022	<.0001
	Ambient temperature	0.022242	0.00401	<.0001
NV-4	Intercept	8.55389	0.14514	<.0001
	Inventory	1.471936	0.1528	<.0001
	Ambient relative humidity	-0.021771	0.00153	<.0001
NV-5	Intercept	6.731818	0.12658	<.0001
	Inventory	1.87902	0.18847	<.0001
	Wind Speed	0.189893	0.01051	<.0001
NV-6	Intercept	8.30515	0.16936	<.0001
	Inventory	1.553859	0.15268	<.0001
	Ambient temperature	0.00977	0.00345	0.0049
	Ambient relative humidity	-0.020486	0.00159	<.0001
NV-7	Intercept	7.94231	0.14612	<.0001
	Inventory	1.430049	0.15197	<.0001
	Ambient relative humidity	-0.016713	0.00149	<.0001
	Wind Speed	0.172251	0.01063	<.0001
NV-8	Intercept	6.399407	0.12982	<.0001
	Inventory	1.970209	0.17197	<.0001
	Ambient temperature	0.02085	0.00363	<.0001
	Wind Speed	0.190344	0.01057	<.0001

Table G-29. Fit and evaluation statistics for PM_{10} emission models for dairy naturally ventilated barn.

Model	2LogL	AIC	AICc	BIC	Corr.	LNME[a] (%)	NME[b] (%)	ME[b] (g day^{-1})	MB[b] (g day^{-1})	NMB[b] (%)
NV-1	2520	2528	2528	2529	0.455	6.512	106.8	5382	-189.6	-3.764
NV-2	2103	2117	2117	2120	0.707	4.896	82.58	4196	-668.8	-13.16
NV-3	2480	2490	2490	2492	0.512	6.325	100	5082	-293.4	-5.775
NV-4	2354	2364	2364	2366	0.645	5.427	90.28	4588	-633.1	-12.46
NV-5	2225	2235	2235	2237	0.59	5.713	96.61	4867	-350.2	-6.951
NV-6	2346	2358	2358	2361	0.654	5.374	88.54	4499	-648.2	-12.76
NV-7	2115	2127	2127	2129	0.693	4.995	85.47	4343	-623.2	-12.26
NV-8	2187	2199	2199	2201	0.637	5.52	89.53	4550	-487.1	-9.586

[a] Based on transformed data (i.e., ln(PM_{10})).
[b] Based on back-transformed data.

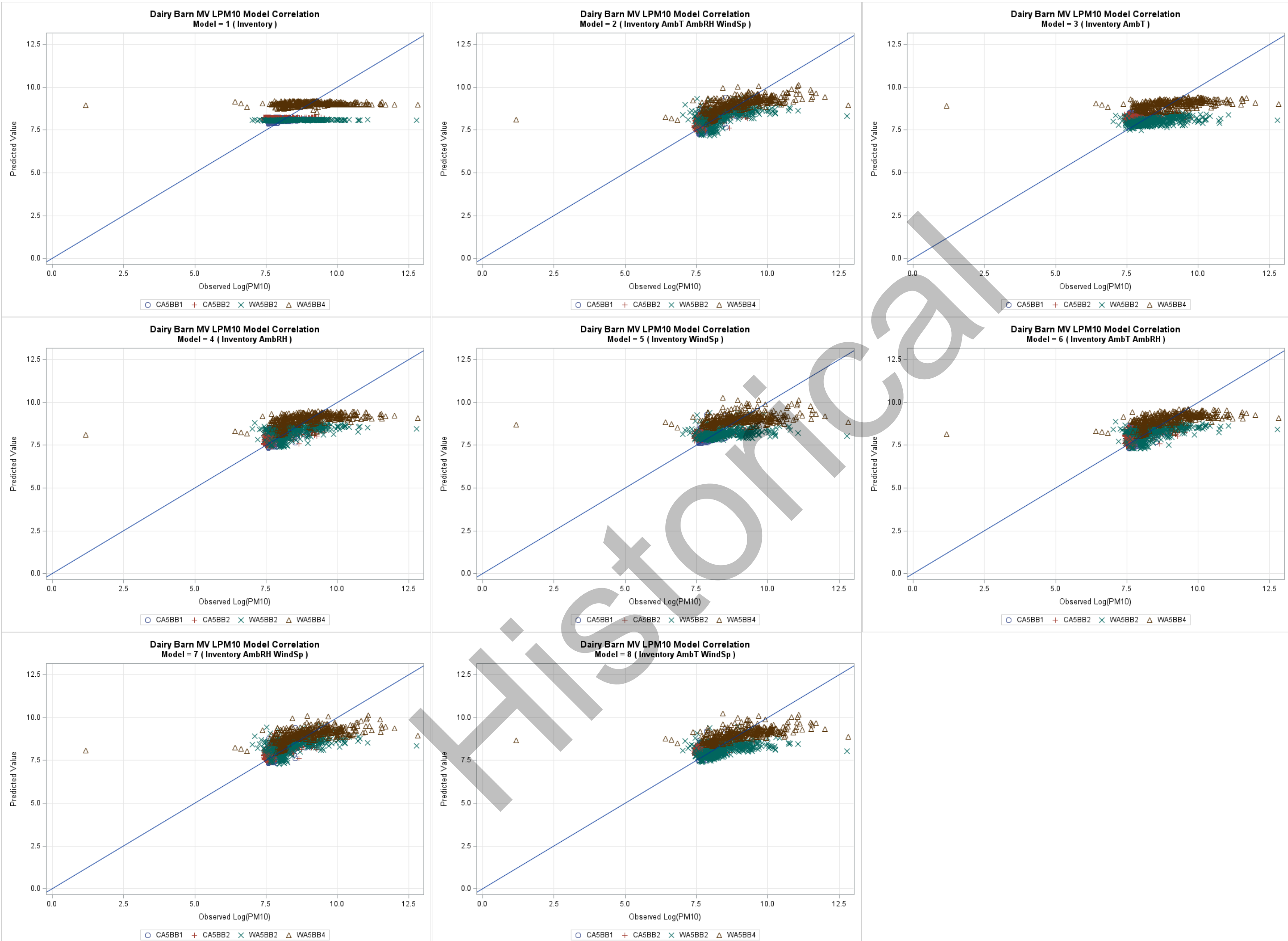


Figure G-61. Dairy naturally ventilated barn PM_{10} one-to-one plots models 1 through 8, log transformed.

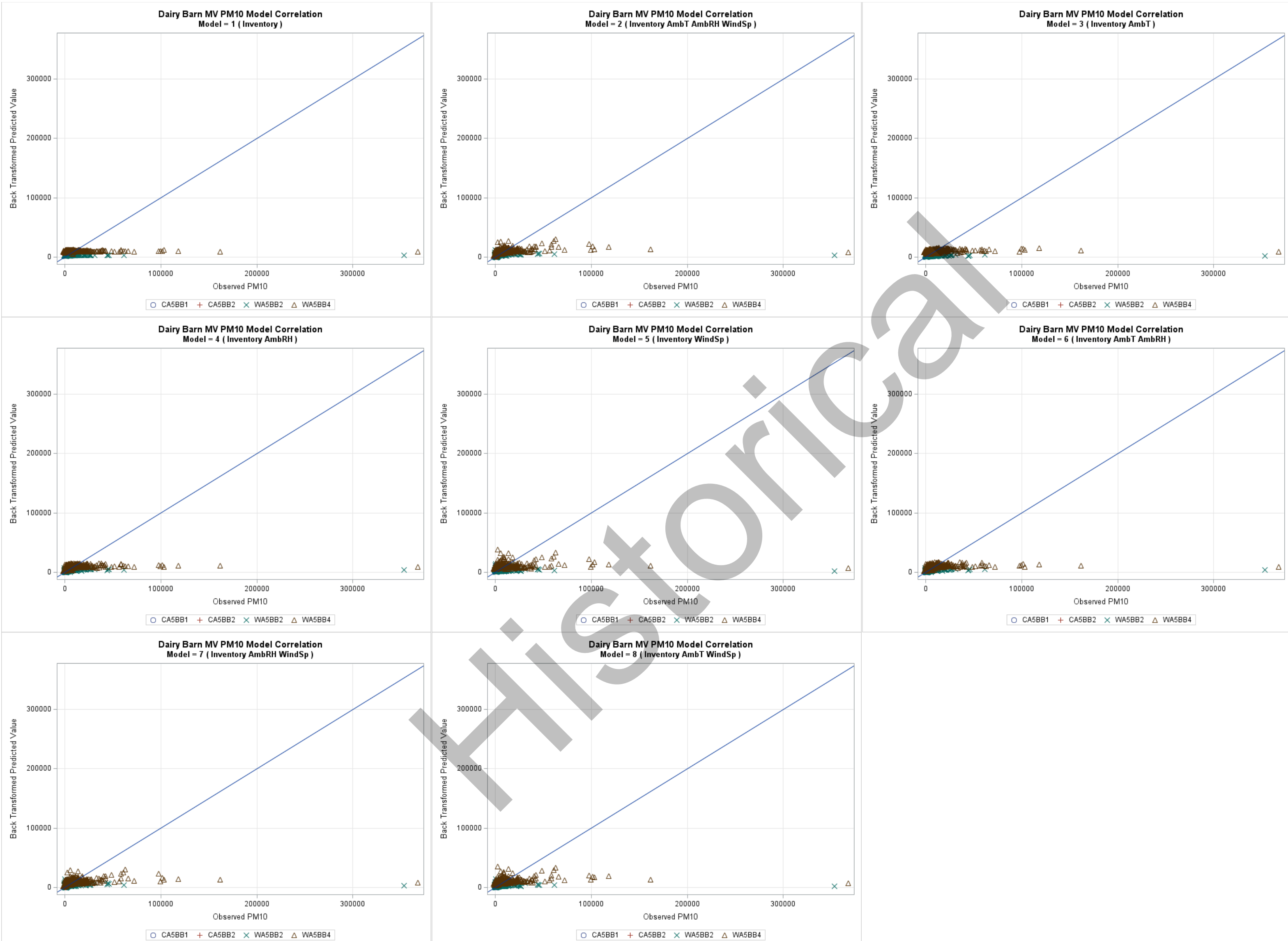


Figure G-62. Dairy naturally ventilated barn PM_{10} one-to-one plots models 1 through 8, back transformed.

G.3.4 Fine particulate matter ($PM_{2.5}$)

Table G-30. Parameter and estimates $PM_{2.5}$ emission models for dairy naturally ventilated barn.

Model	Parameter	Estimate	Standard Error	p-value
NV-1	Intercept	7.538178	0.60541	<.0001
	Inventory	-0.062898	0.82412	**0.9401**
NV-2	Intercept	7.068797	1.15954	<.0001
	Inventory	-0.220453	0.75959	**0.7753**
	Ambient temperature	0.01121	0.02585	**0.6681**
	Ambient relative humidity	-0.003808	0.01023	**0.7125**
	Wind Speed	0.218968	0.0563	0.0002
NV-3	Intercept	7.191914	0.67544	<.0001
	Inventory	-0.048643	0.8011	**0.9523**
	Ambient temperature	0.020077	0.01867	**0.2929**
NV-4	Intercept	8.102164	0.75989	<.0001
	Inventory	-0.210004	0.83321	**0.8043**
	Ambient relative humidity	-0.009286	0.00755	**0.2293**
NV-5	Intercept	7.017716	0.57907	<.0001
	Inventory	-0.162197	0.76824	**0.8354**
	Wind Speed	0.22186	0.05644	0.0002
NV-6	Intercept	7.884815	1.26347	<.0001
	Inventory	-0.175865	0.84208	**0.8374**
	Ambient temperature	0.006056	0.02852	**0.8336**
	Ambient relative humidity	-0.007434	0.01126	**0.5147**
NV-7	Intercept	7.468014	0.70982	<.0001
	Inventory	-0.2821	0.75884	**0.7147**
	Ambient relative humidity	-0.007141	0.0069	**0.3095**
	Wind Speed	0.217628	0.05624	0.0002
NV-8	Intercept	6.707074	0.63045	<.0001
	Inventory	-0.153913	0.73284	**0.8362**
	Ambient temperature	0.018488	0.01708	**0.2895**
	Wind Speed	0.22074	0.05621	0.0002

Table G-31. Fit and evaluation statistics for $PM_{2.5}$ emission models for dairy naturally ventilated barn.

Model	2LogL	AIC	AICc	BIC	Corr.	LNME[a] (%)	NME[b] (%)	ME[b] (g day^{-1})	MB[b] (g day^{-1})	NMB[b] (%)
NV-1	213	221	221	223	0.115	9.415	83.02	1547	-1.112	-0.06
NV-2	197	211	212	214	0.405	8.789	62.65	1167	-19.48	-1.046
NV-3	212	222	222	224	0.185	9.218	73.49	1369	-4.909	-0.264
NV-4	211	221	222	223	0.075	9.331	77.47	1443	33.14	1.779
NV-5	198	208	209	210	0.383	8.499	68.51	1276	32.93	1.768
NV-6	211	223	224	226	0.106	9.295	75.78	1412	25.66	1.378
NV-7	197	209	210	212	0.376	8.814	64.72	1206	-3.53	-0.189
NV-8	197	209	210	212	0.425	8.719	61.74	1150	-23.56	-1.265

a Based on transformed data (i.e., ln(PM2.5)).
b Based on back-transformed data.

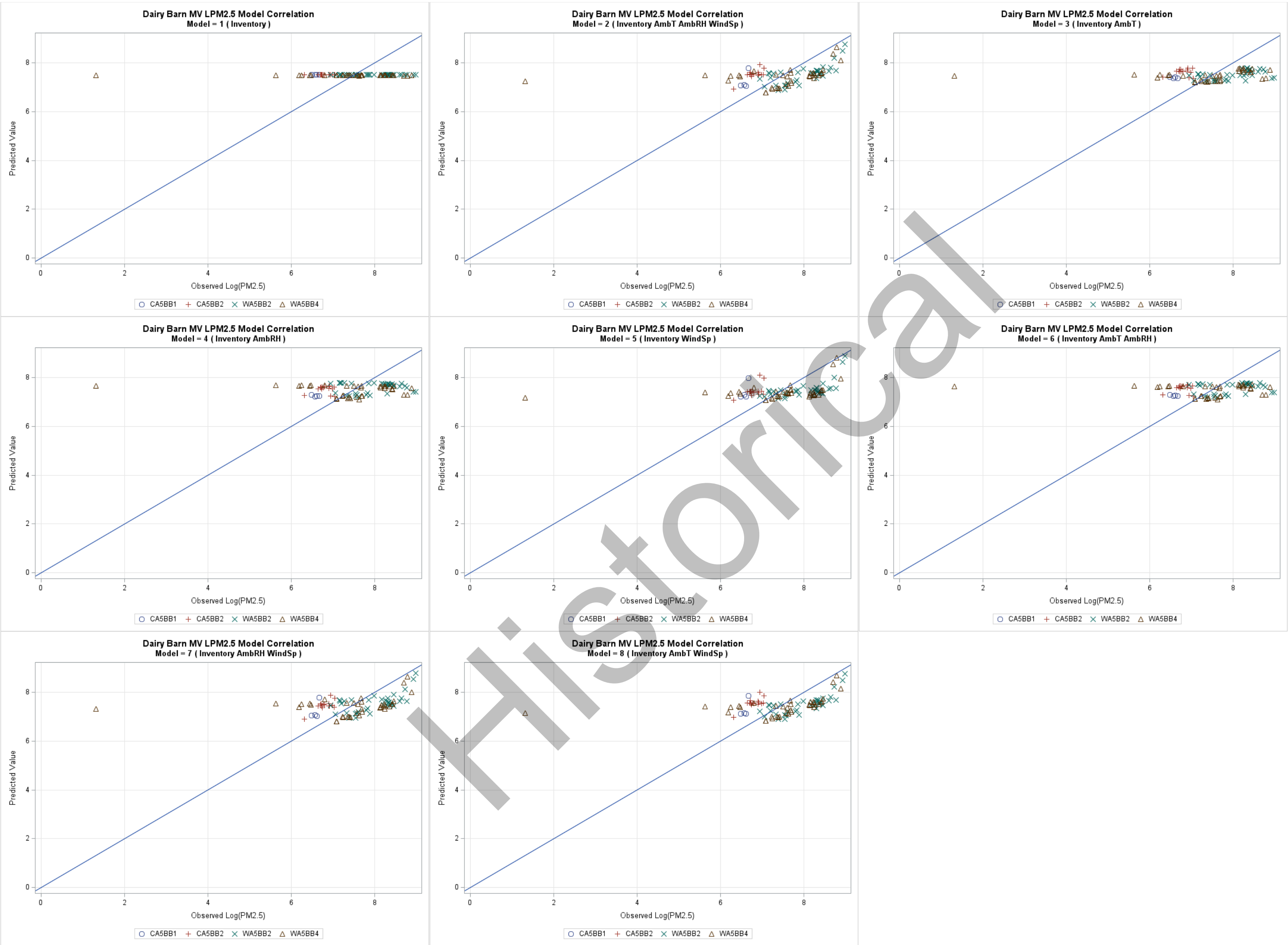


Figure G-63. Dairy naturally ventilated barn $PM_{2.5}$ one-to-one plots models 1 through 8, log transformed.

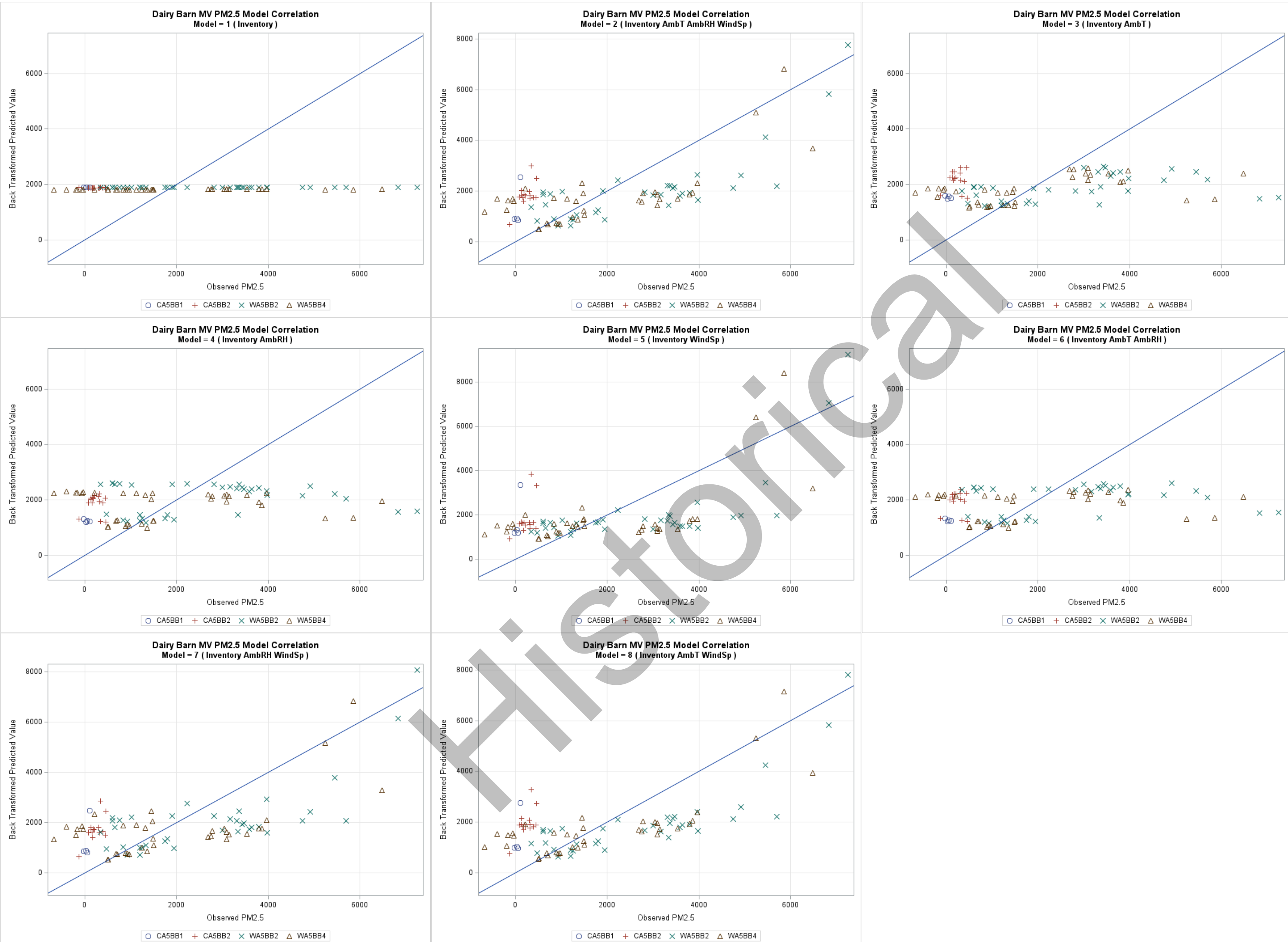


Figure G-64. Dairy naturally ventilated barn $PM_{2.5}$ one-to-one plots models 1 through 8, back transformed.

G.3.5 Total Suspended Particulates (TSP)

Table G-32. Parameter and estimates TSP emission models for dairy naturally ventilated barn.

Model	Parameter	Estimate	Standard Error	p-value
NV-1	Intercept	6.716276	0.54312	<.0001
	Inventory	3.65659	0.8364	<.0001
NV-2	Intercept	7.868847	0.58294	<.0001
	Inventory	2.953893	0.48928	<.0001
	Ambient temperature	0.034508	0.01069	0.0021
	Ambient relative humidity	-0.033997	0.00508	<.0001
	Wind Speed	0.248191	0.04211	<.0001
NV-3	Intercept	5.452192	0.49718	<.0001
	Inventory	4.164233	0.6622	<.0001
	Ambient temperature	0.063139	0.01381	<.0001
NV-4	Intercept	9.787872	0.4929	<.0001
	Inventory	2.537642	0.53949	<.0001
	Ambient relative humidity	-0.04473	0.00513	<.0001
NV-5	Intercept	6.174486	0.51843	<.0001
	Inventory	3.474803	0.78627	<.0001
	Wind Speed	0.280443	0.04518	<.0001
NV-6	Intercept	8.765746	0.59397	<.0001
	Inventory	2.928583	0.51502	<.0001
	Ambient temperature	0.030747	0.01123	0.0083
	Ambient relative humidity	-0.038657	0.00531	<.0001
NV-7	Intercept	9.015472	0.4949	<.0001
	Inventory	2.516121	0.5246	<.0001
	Ambient relative humidity	-0.040582	0.00498	<.0001
	Wind Speed	0.242434	0.04269	<.0001
NV-8	Intercept	4.87915	0.4634	<.0001
	Inventory	4.001109	0.60616	<.0001
	Ambient temperature	0.063391	0.01263	<.0001
	Wind Speed	0.288347	0.04483	<.0001

Table G-33. Fit and evaluation statistics for TSP emission models for dairy naturally ventilated barn.

Model	2LogL	AIC	AICc	BIC	Corr.	LNME[a] (%)	NME[b] (%)	ME[b] (g day^{-1})	MB[b] (g day^{-1})	NMB[b] (%)
NV-1	555	563	563	564	0.473	10.32	95.26	15590	731.5	4.469
NV-2	465	479	480	482	0.799	6.07	52.78	8640	-492.6	-3.009
NV-3	540	550	550	552	0.649	8.187	79.69	13040	1027	6.277
NV-4	504	514	514	516	0.738	7.035	77.22	12640	724.9	4.428
NV-5	519	529	530	531	0.562	9.458	74.7	12230	-481.8	-2.943
NV-6	498	510	510	512	0.765	6.577	70.74	11580	1087	6.638
NV-7	474	486	486	488	0.769	6.741	63.73	10430	-732.5	-4.475
NV-8	502	514	514	516	0.712	7.348	53.6	8773	-517.8	-3.164

[a] Based on transformed data (i.e., ln(TSP)).

[b] Based on back-transformed data.

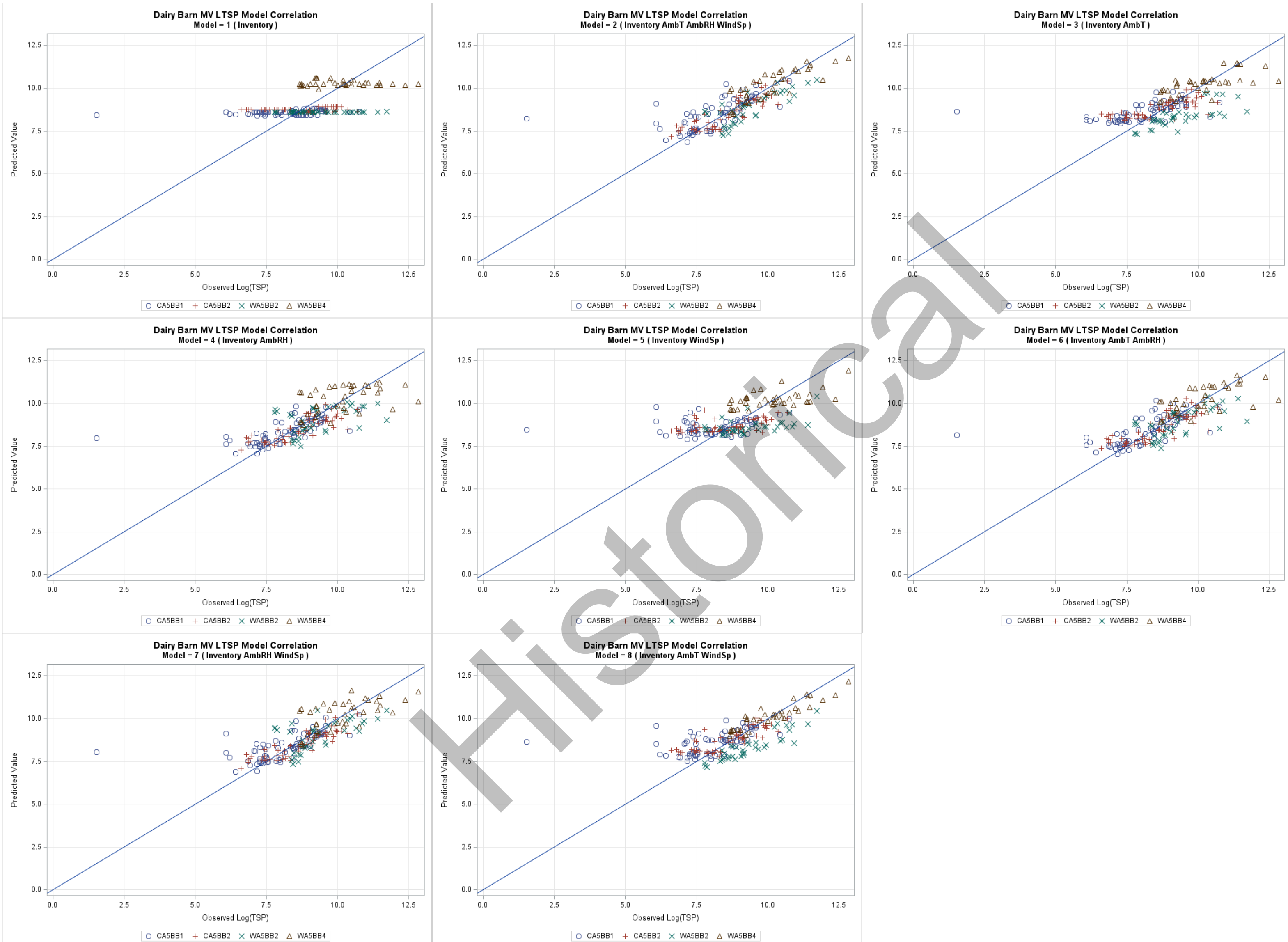


Figure G-65. Dairy naturally ventilated barn TSP one-to-one plots models 1 through 8, log transformed.

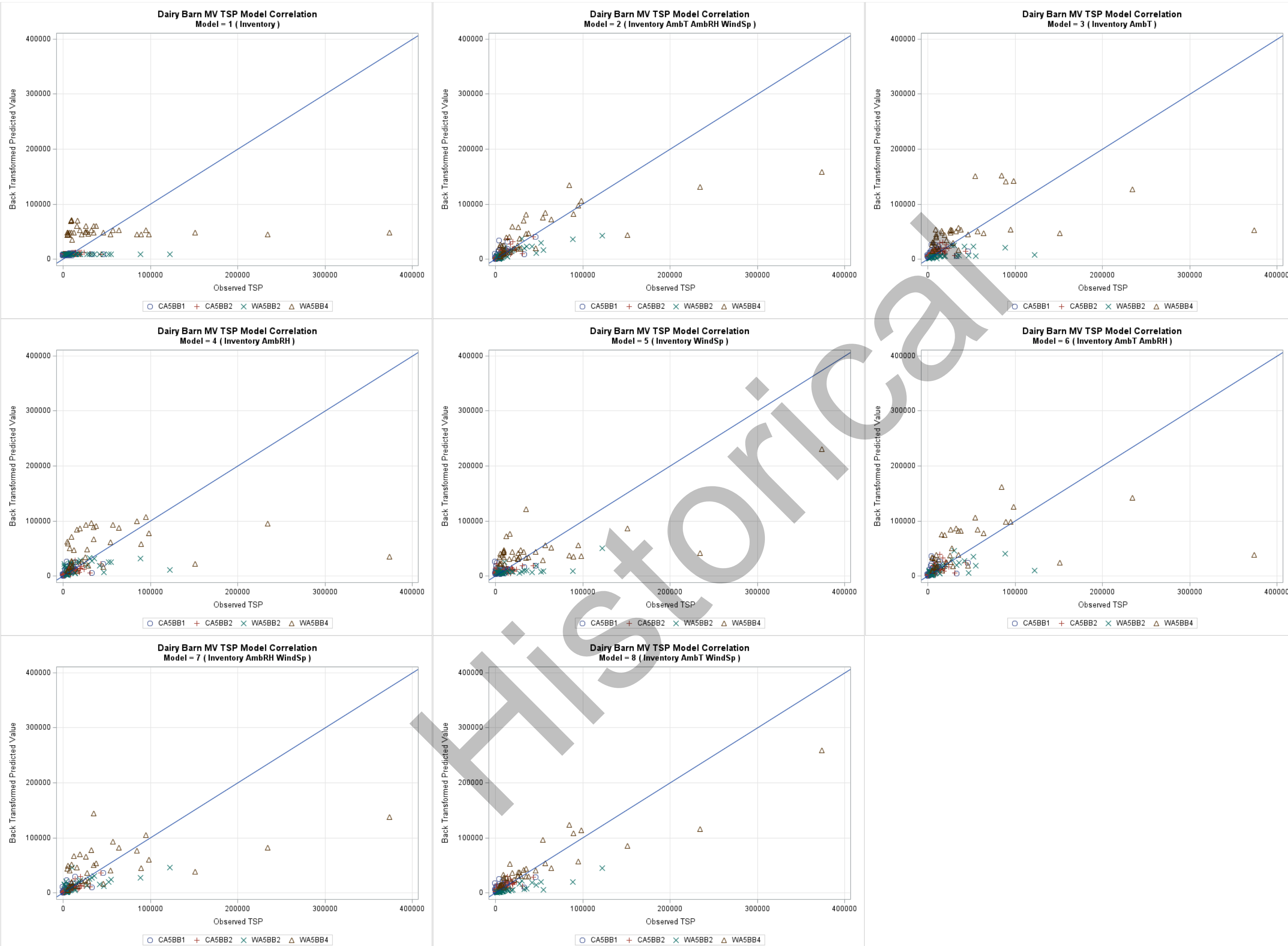


Figure G-66. Dairy naturally ventilated barn TSP one-to-one plots models 1 through 8, back transformed.

G.4 Lagoons

G.4.1 Ammonia (NH_3)

Table G-34. Parameter and estimates NH_3 emission models for dairy lagoons.

Model	Parameter	Estimate	Standard Error	p-value
1	Intercept	1.722568	0.6531	*0.0199*
	pH	-0.053724	0.08502	**0.5378**
	Lagoon temperature	0.027232	0.00574	0.0005
2	Intercept	2.591012	1.01478	*0.0295*
	pH	-0.102478	0.13732	**0.473**
3	Intercept	1.314921	0.11852	<.0001
	Lagoon temperature	0.027883	0.00579	0.0004
4	Intercept	1.371991	0.0478	<.0001
	Ambient temperature	0.027336	0.00196	<.0001
	Wind speed	0.007476	0.01235	**0.546**
5	Intercept	1.396734	0.0248	<.0001
	Ambient temperature	0.027201	0.00195	<.0001
6	Intercept	1.502677	0.09895	<.0001
	Wind speed	0.023567	0.01151	*0.0426*
7	Intercept	1.608092	0.43955	0.0048
	pH	-0.055494	0.0508	**0.305**
	Lagoon temperature	0.003169	0.0121	**0.7953**
	Ambient temperature	0.025656	0.00858	0.0055
	Wind speed	0.087207	0.04508	**0.0613**
8	Intercept	1.932937	0.34647	<.0001
	pH	-0.045789	0.04532	**0.3291**
	Lagoon temperature	-0.014509	0.00847	**0.1031**
	Ambient temperature	0.035315	0.00719	<.0001
9	Intercept	1.163616	0.61297	**0.0794**
	pH	-0.046984	0.07586	**0.547**
	Lagoon temperature	0.037778	0.00618	<.0001
	Wind speed	0.130956	0.04347	0.005
10	Intercept	1.653065	0.39038	0.0011
	pH	-0.054928	0.05035	**0.2967**
	Ambient temperature	0.027696	0.0032	<.0001
	Wind speed	0.07906	0.03441	*0.0295*
11	Intercept	1.169318	0.22158	<.0001
	Lagoon temperature	0.00492	0.01259	**0.6987**
	Ambient temperature	0.024875	0.00893	0.0092
	Wind speed	0.090877	0.04651	**0.0591**
12	Intercept	1.852817	0.3957	0.0006
	pH	-0.049413	0.05252	**0.3659**
	Ambient temperature	0.023893	0.00288	<.0001
13	Intercept	2.318938	1.30318	**0.1328**
	pH	-0.098184	0.17512	**0.598**
	Wind speed	0.093085	0.04437	*0.0451*
14	Intercept	1.590048	0.07475	<.0001
	Lagoon temperature	-0.014419	0.00859	**0.1094**
	Ambient temperature	0.035571	0.00728	<.0001
15	Intercept	0.804363	0.19861	0.0003
	Lagoon temperature	0.038432	0.00622	<.0001
	Wind speed	0.131343	0.0434	0.0048

Table G-35. Fit and evaluation statistics for NH_3 emission models for dairy lagoons.

Model	2LogL	AIC	AICc	BIC	Corr.	LNME[a] (%)	NME[b] (%)	ME[b] (kg $day^{-1}m^{-2}$)	MB[b] (kg day^{-1} m^{-2})	NMB[b] (%)
1	-18	-8	-6	-14	0.708	8.598	31	1.09	0.01	0.275
2	-4	4	5	-1	0.195	11.94	39.73	1.397	-0.006	-0.164
3	-17	-9	-8	-14	0.701	8.806	31.62	1.112	0.01	0.295
4	-84	-74	-73	-78	0.845	9.664	38.59	0.708	-0.036	-1.947
5	-83	-75	-75	-79	0.844	9.709	38.77	0.712	-0.034	-1.859
6	-26	-18	-17	-21	-0.21	20.38	79.01	1.531	0.017	0.901
7	-33	-19	-15	-28	0.837	6.727	23.31	0.819	-0.01	-0.291
8	-30	-18	-15	-25	0.811	7.504	26.16	0.92	-0.001	-0.035
9	-27	-15	-12	-22	0.783	7.857	27.49	0.966	0.005	0.133
10	-33	-21	-18	-28	0.837	6.772	23.42	0.823	-0.01	-0.284
11	-32	20	17	27	-0.83	6.828	23.86	0.839	-0.012	-0.341
12	-27	-17	-15	-24	0.805	7.521	26.6	0.935	-0.01	-0.285
13	-7	3	5	-4	-0.08	13.16	43.55	1.531	0.052	1.472
14	-29	-19	-17	-25	0.805	7.781	26.94	0.947	-0.002	-0.044
15	-26	-16	-14	-23	0.777	7.921	27.62	0.971	0.006	0.165

[a] Based on transformed data (i.e., ln(NH_3)).
[b] Based on back-transformed data.

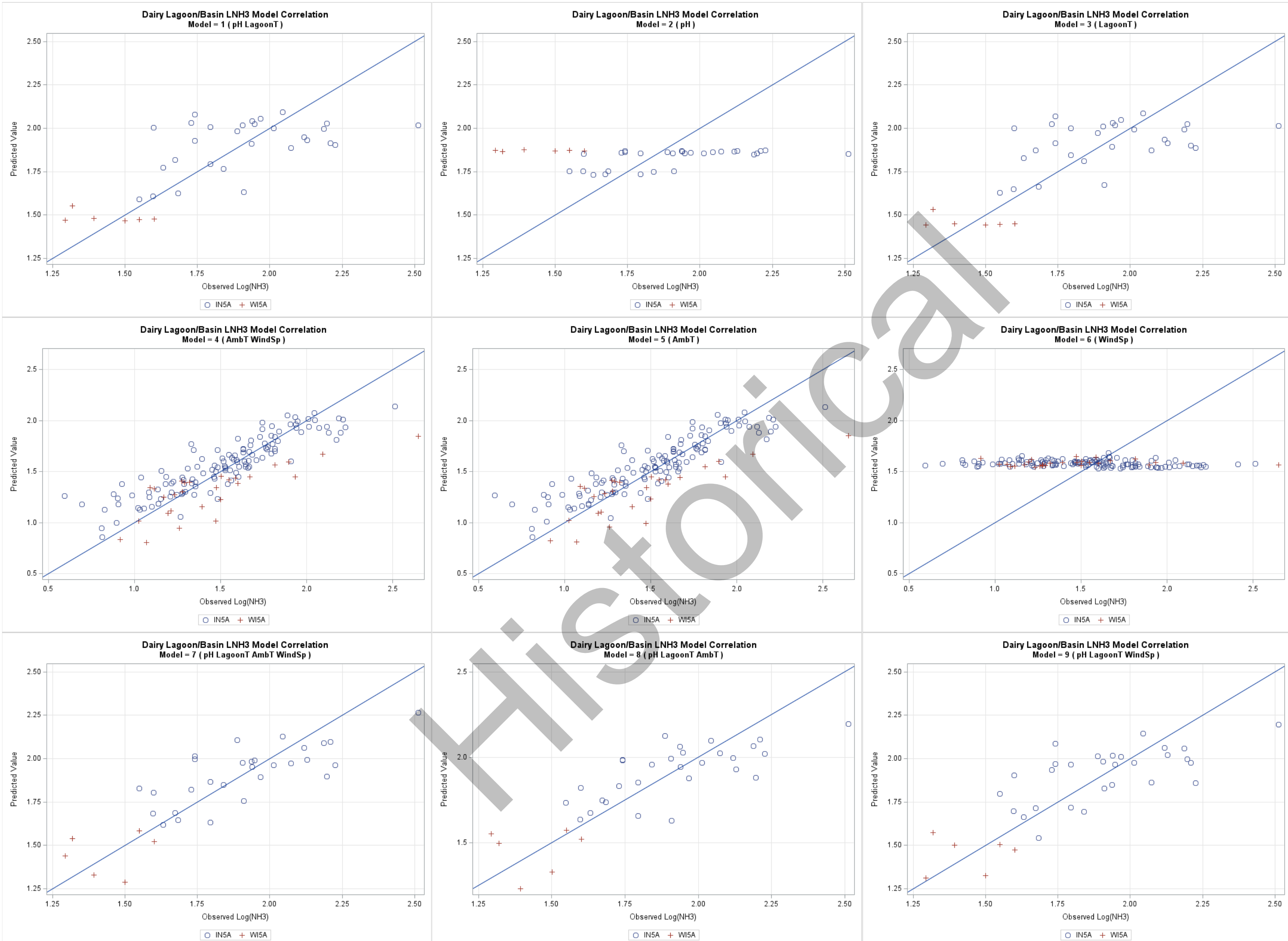


Figure G-67. Dairy lagoon NH_3 one-to-one plots models 1 through 9, log transformed.

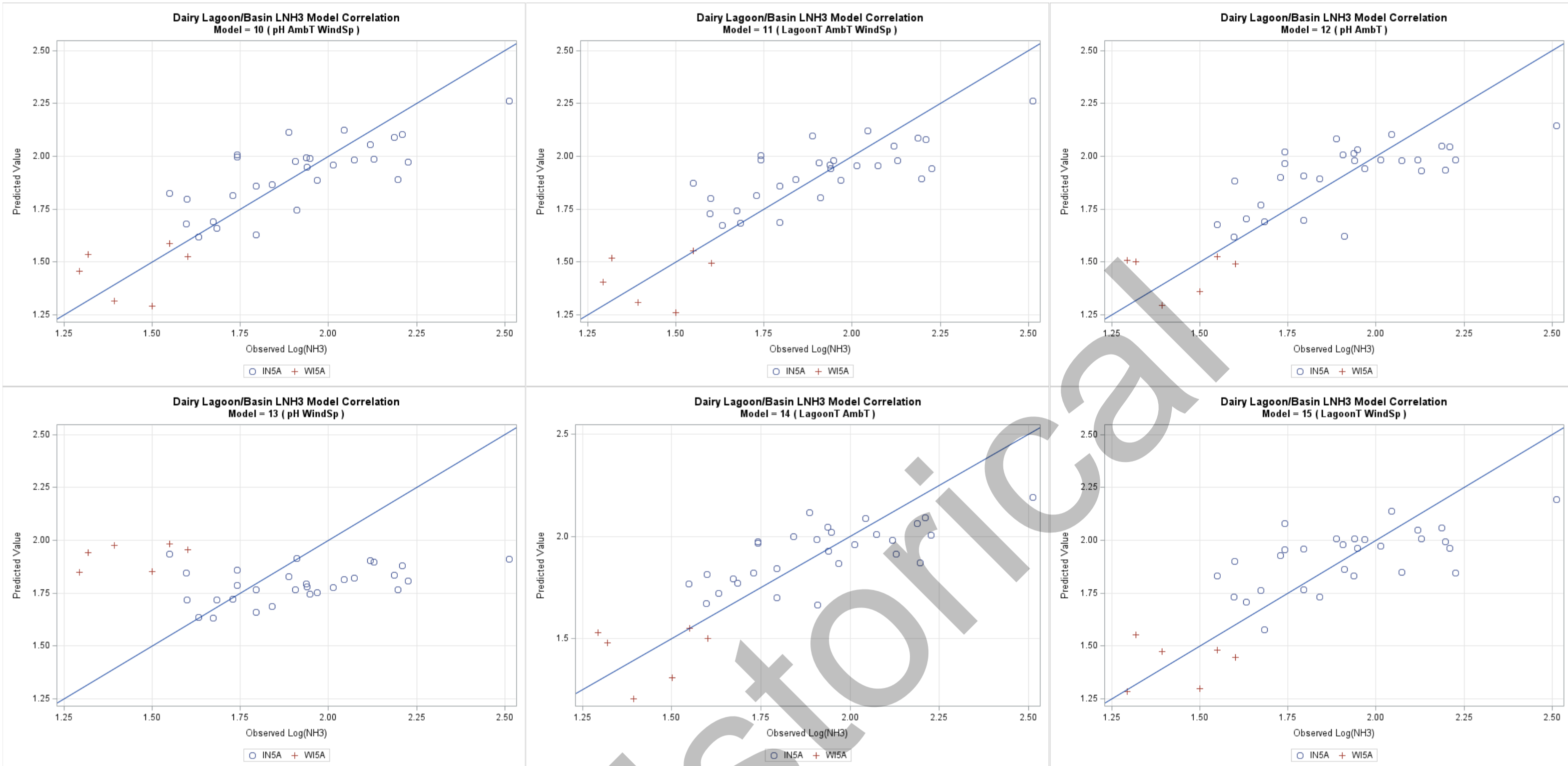


Figure G-68. Dairy lagoon NH_3 one-to-one plots models 10 through 15, log transformed.

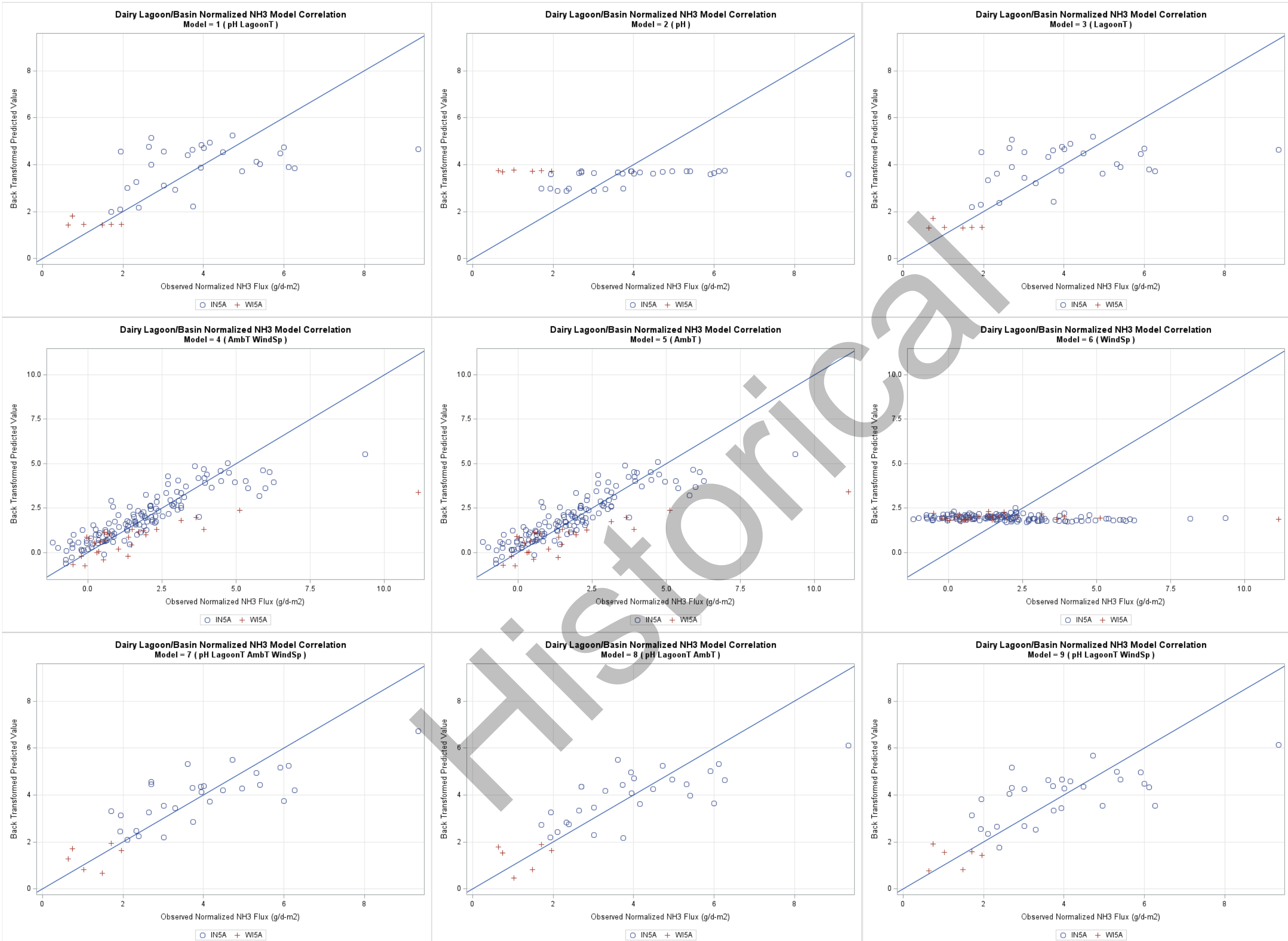


Figure G-69. Dairy lagoon NH_3 one-to-one plots models 1 through 9, back transformed.

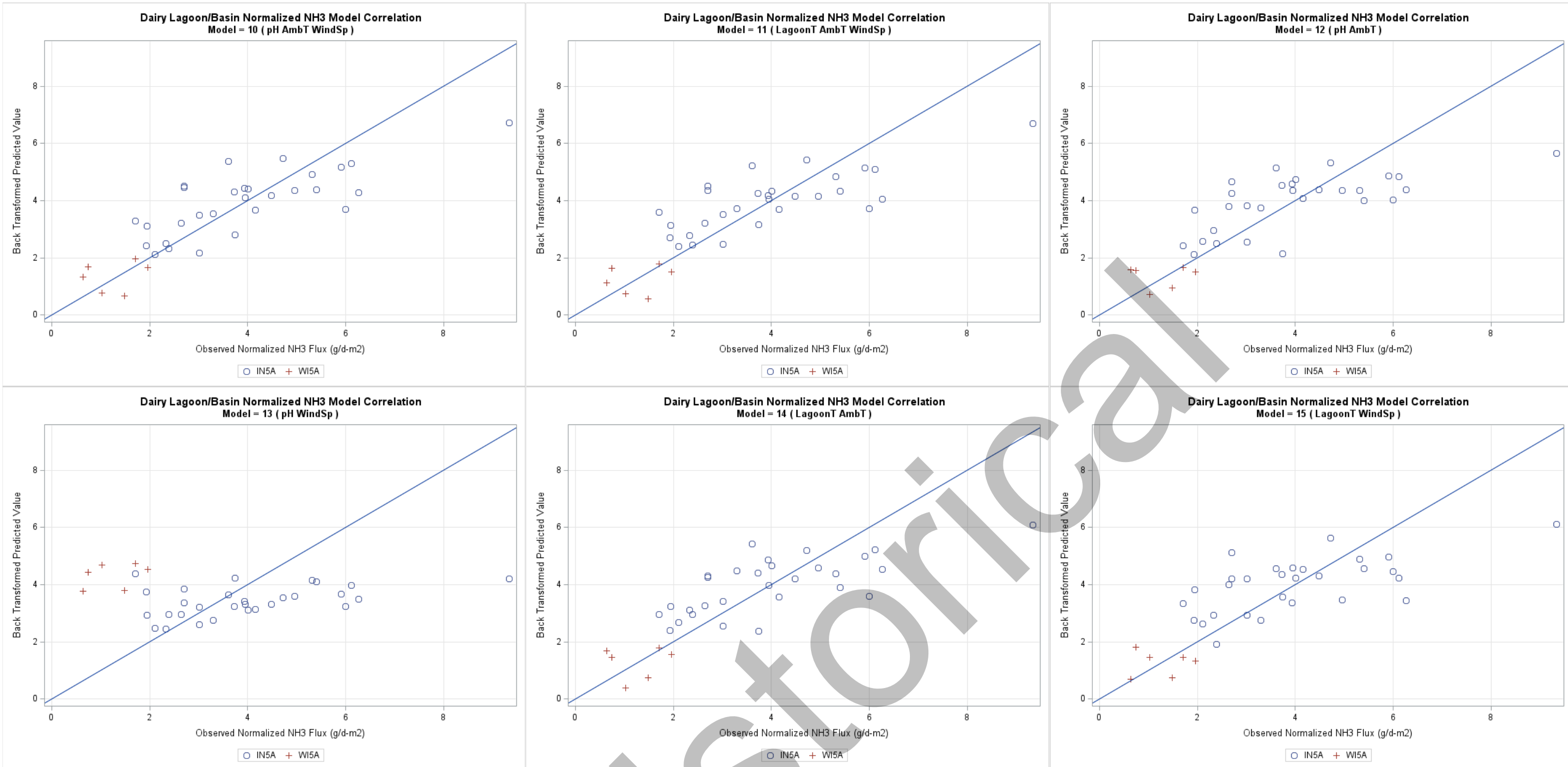


Figure G-70. Dairy lagoon NH_3 one-to-one plots models 10 through 15, back transformed.

G.4.2 Hydrogen Sulfide (H_2S)

Table G-36. Parameter and estimates H_2S emission models for dairy lagoons.

Model	Parameter	Estimate	Standard Error	p-value
1	Intercept	2.025152	0.48925	0.0015
	pH	-0.02631	0.05394	**0.6347**
	Lagoon temperature	-0.019651	0.00545	0.0042
2	Intercept	0.835524	0.4355	**0.0939**
	pH	0.07913	0.05889	**0.2177**
3	Intercept	1.788655	0.06241	<.0001
	Lagoon temperature	-0.017479	0.00301	0.0003
4	Intercept	1.097897	0.06192	<.0001
	Ambient temperature	0.010035	0.00221	<.0001
	Wind speed	0.028266	0.01635	**0.0883**
5	Intercept	1.189272	0.03163	<.0001
	Ambient temperature	0.010557	0.0022	<.0001
6	Intercept	1.096039	0.06837	<.0001
	Wind speed	0.050923	0.01682	0.0035
7	Intercept	2.238441	0.45542	0.0002
	pH	-0.078948	0.05614	**0.1808**
	Lagoon temperature	-0.016463	0.00848	**0.074**
	Ambient temperature	-0.001524	0.00708	**0.8328**
	Wind speed	0.051834	0.02703	**0.0745**
8	Intercept	2.065969	0.50043	0.0014
	pH	-0.032196	0.05637	**0.5784**
	Lagoon temperature	-0.017075	0.00926	**0.0873**
	Ambient temperature	-0.002616	0.0075	**0.733**
9	Intercept	2.211002	0.43846	0.0002
	pH	-0.07547	0.05381	**0.1831**
	Lagoon temperature	-0.017868	0.00496	0.0076
	Wind speed	0.052399	0.02715	**0.0728**
10	Intercept	1.263457	0.54647	*0.0382*
	pH	-0.002854	0.06568	**0.9662**
	Ambient temperature	-0.003814	0.0053	**0.4825**
	Wind speed	0.100247	0.02692	0.0019
11	Intercept	1.315891	0.18564	<.0001
	Lagoon temperature	-0.005659	0.01032	**0.5933**
	Ambient temperature	-0.000177	0.00734	**0.9811**
	Wind speed	0.091226	0.0328	*0.014*
12	Intercept	1.739304	0.51573	0.0048
	pH	-0.006914	0.05981	**0.9096**
	Ambient temperature	-0.01326	0.00475	*0.016*
13	Intercept	0.955639	0.35017	*0.0289*
	pH	0.029795	0.04902	**0.5609**
	Wind speed	0.097403	0.027	0.0026
14	Intercept	1.782638	0.07244	<.0001
	Lagoon temperature	-0.015974	0.00908	**0.101**
	Ambient temperature	-0.001281	0.00713	**0.8602**
15	Intercept	1.318016	0.1736	<.0001
	Lagoon temperature	-0.005881	0.00577	**0.3379**
	Wind speed	0.090879	0.03087	*0.011*

Table G-37. Fit and evaluation statistics for H_2S emission models for dairy lagoons.

Model	2LogL	AIC	AICc	BIC	Corr.	LNME[a] (%)	NME[b] (%)	ME[b] (kg day^{-1}m^{-2})	MB[b] (kg day^{-1} m^{-2})	NMB[b] (%)
1	-36	-26	-20	-33	0.667	4.219	20.74	0.241	0.003	0.22
2	-32	-24	-20	-29	0.381	5.254	26.32	0.305	#NUM!	-0.02
3	-36	-28	-24	-33	0.652	4.379	21.67	0.252	0.003	0.262
4	-86	-76	-75	-81	0.657	9.05	62.46	0.489	-0.015	-1.925
5	-83	-75	-75	-79	0.632	9.258	63.69	0.499	-0.011	-1.403
6	-80	-72	-71	-75	0.07	13.58	84.47	0.673	0.007	0.868
7	-40	-26	-10	-35	0.776	3.094	15.3	0.178	0.001	0.056
8	-37	-25	-14	-32	0.663	4.275	20.97	0.244	0.002	0.193
9	-40	-28	-18	-36	0.777	3.103	15.56	0.181	0.001	0.074
10	-42	-30	-21	-38	0.732	3.624	17.87	0.207	0.003	0.271
11	-39	27	17	35	-0.76	3.535	17.47	0.203	0.003	0.215
12	-35	-25	-19	-32	0.519	4.647	23.1	0.268	0.004	0.355
13	-42	-32	-26	-38	0.702	3.736	18.36	0.213	0.002	0.195
14	-36	-26	-20	-33	0.648	4.406	21.83	0.254	0.003	0.252
15	-39	-29	-23	-36	0.757	3.527	17.43	0.203	0.002	0.21

[a] Based on transformed data (i.e., $\ln(H_2S)$).
[b] Based on back-transformed data.

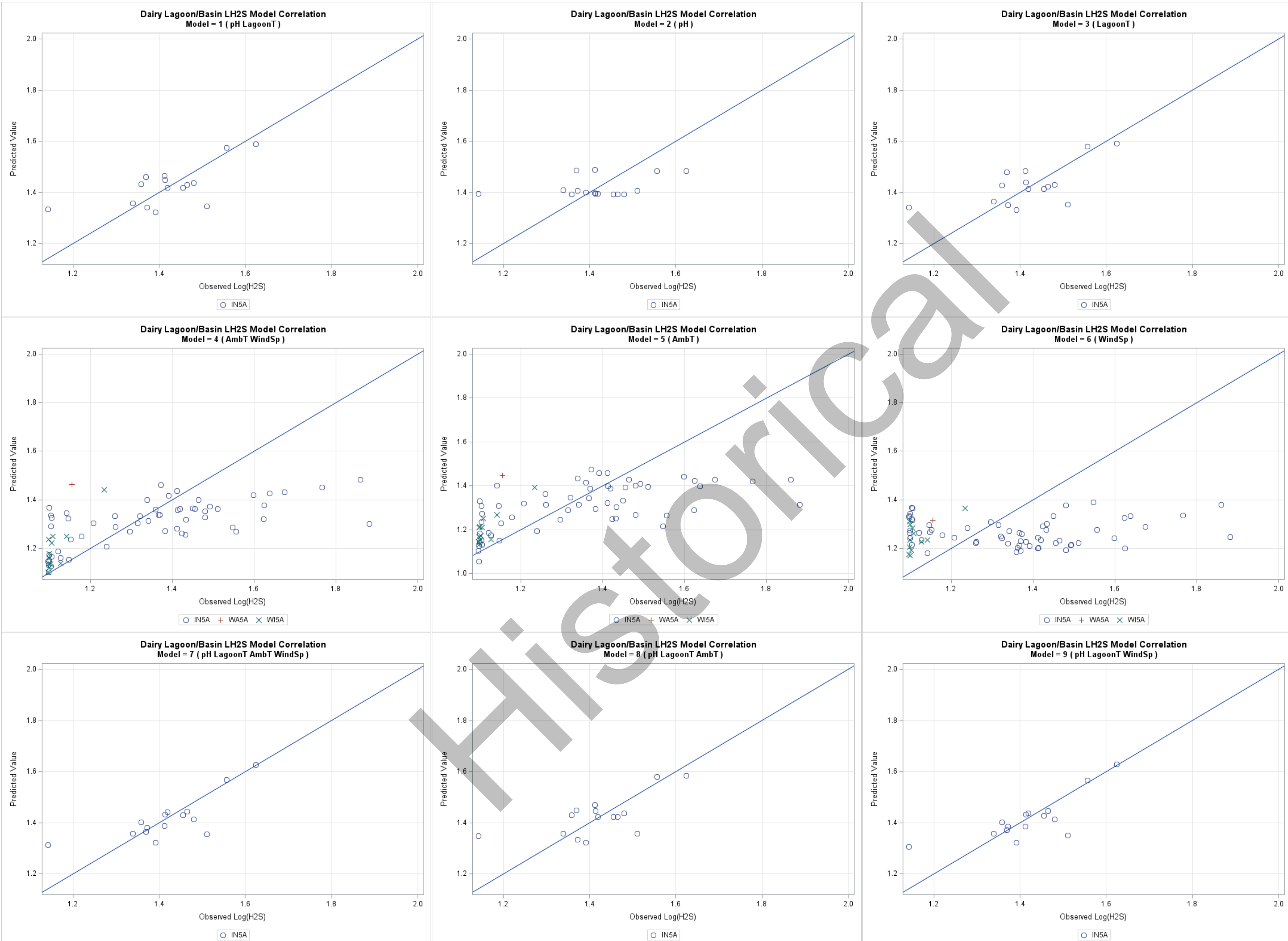


Figure G-71. Dairy lagoon H_2S one-to-one plots models 1 through 9, log transformed.

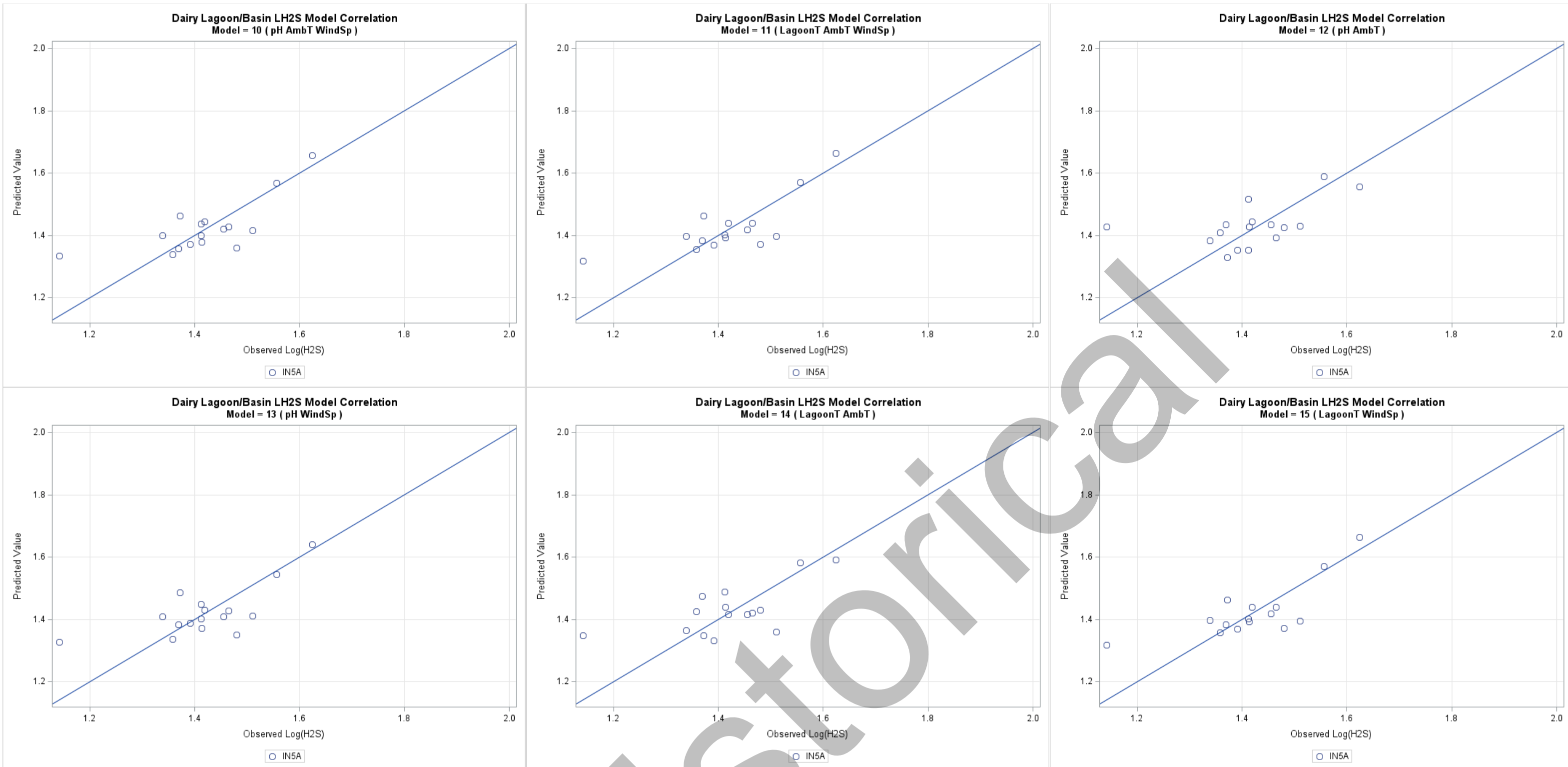


Figure G-72. Dairy lagoon H_2S one-to-one plots models 1 through 9, log transformed.

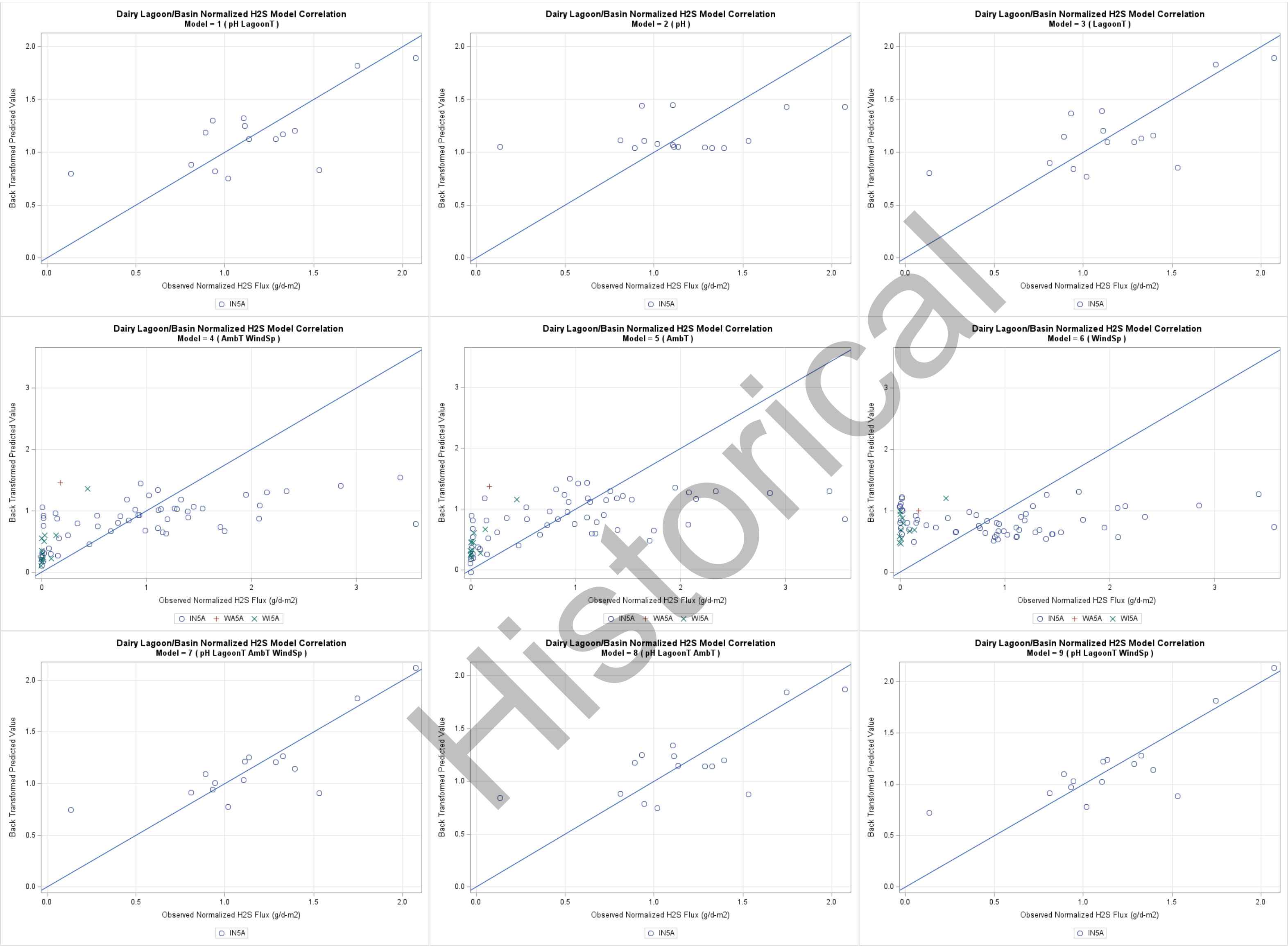


Figure G-73. Dairy lagoon H_2S one-to-one plots models 1 through 9, back transformed.

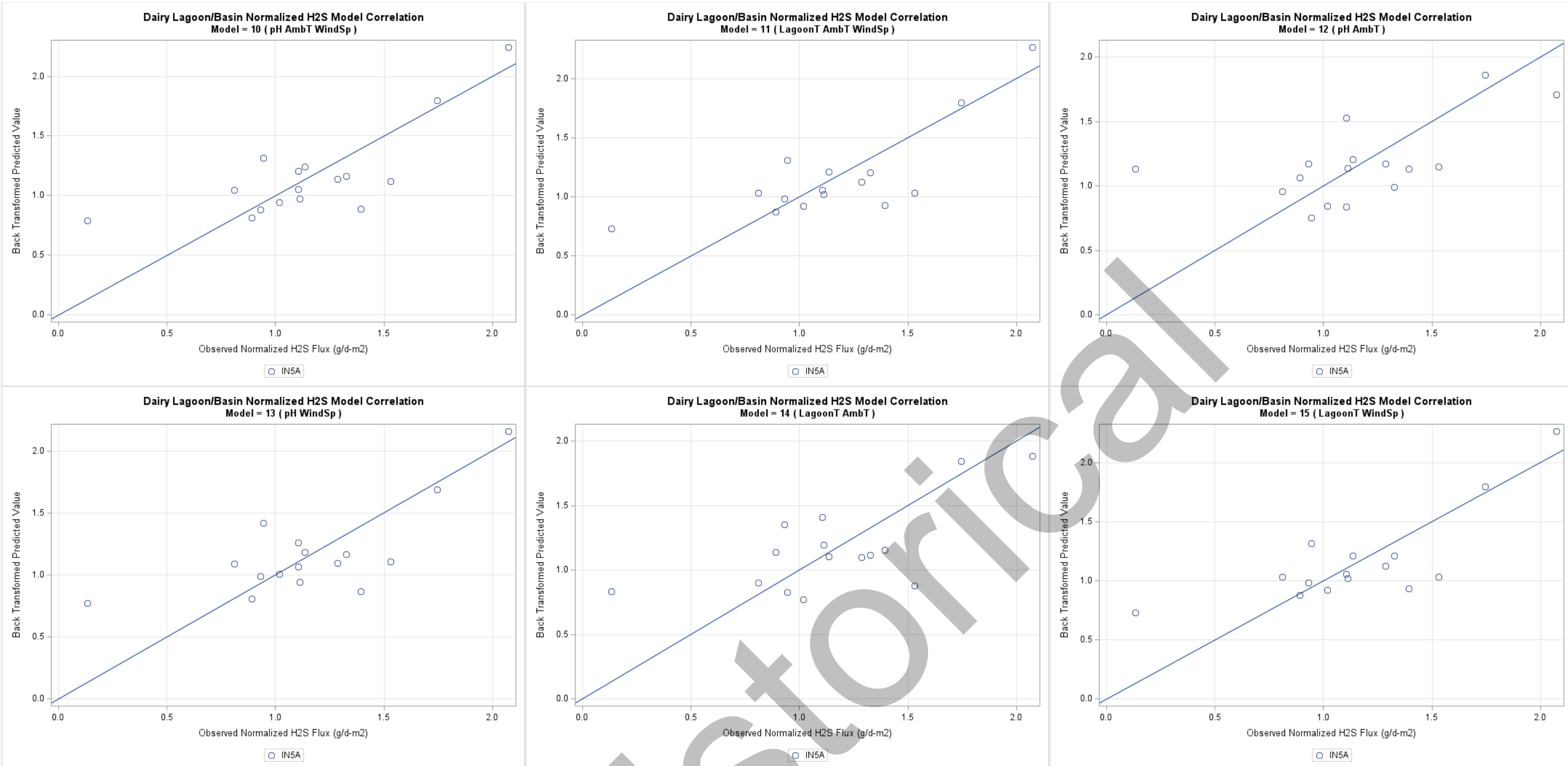


Figure G-74. Dairy lagoon H_2S one-to-one plots models 10 through 15, back transformed.

G.5 Corrals

G.5.1 Ammonia (NH_3)

Table G-38. Parameter and estimates NH_3 emission models for dairy corrals.

Model	Parameter	Estimate	Standard Error	p-value
CR-1a	Intercept	0.763691	0.20329	0.0004
	Ambient temperature	-0.009511	0.00852	**0.2691**
	Ambient relative humidity	0.012295	0.00291	<.0001
	Water vapor deficit	0.02969	0.01167	*0.0135*
	Wind speed	0.051483	0.02037	*0.0142*
CR-2a	Intercept	1.095199	0.16438	<.0001
	Ambient temperature	-0.007421	0.00896	**0.411**
	Ambient relative humidity	0.010416	0.00297	0.001
	Water vapor deficit	0.025559	0.0122	*0.0403*
CR-3a	Intercept	1.108679	0.15818	<.0001
	Ambient temperature	0.01048	0.00358	0.0063
	Ambient relative humidity	0.006897	0.00208	0.0016
	Wind speed	0.043973	0.02121	*0.0426*
CR-4a	Intercept	0.881656	0.17272	<.0001
	Ambient relative humidity	0.010059	0.00206	<.0001
	Water vapor deficit	0.017815	0.00466	0.0005
	Wind speed	0.049059	0.02044	*0.0196*
CR-5a	Intercept	1.497591	0.12214	<.0001
	Ambient temperature	0.016378	0.00684	*0.0203*
	Water vapor deficit	-0.007059	0.00898	**0.4349**
	Wind speed	0.030011	0.02259	**0.1889**
CR-6a	Intercept	1.351154	0.11265	<.0001
	Ambient temperature	0.009972	0.00371	*0.0118*
	Ambient relative humidity	0.005983	0.00212	0.0068
CR-7a	Intercept	1.633829	0.06663	<.0001
	Ambient temperature	0.015112	0.00688	*0.0327*
	Water vapor deficit	-0.006025	0.00911	**0.5109**
CR-8a	Intercept	1.171368	0.13154	<.0001
	Ambient relative humidity	0.008797	0.00211	0.0002
	Water vapor deficit	0.016432	0.00486	0.0019
CR-9a	Intercept	1.487014	0.12166	<.0001
	Ambient temperature	0.011907	0.00381	0.0038
	Wind speed	0.028613	0.02271	**0.2124**
CR-10a	Intercept	1.235356	0.16215	<.0001
	Ambient relative humidity	0.007641	0.00224	0.0012
	Wind speed	0.040427	0.02259	**0.0787**
CR-11a	Intercept	1.554303	0.12582	<.0001
	Water vapor deficit	0.010869	0.00526	*0.0449*
	Wind speed	0.023438	0.02372	**0.3269**
CR-12a	Intercept	1.619652	0.06236	<.0001
	Ambient temperature	0.011295	0.00376	0.0054
CR-13a	Intercept	1.452108	0.1134	<.0001

Model	Parameter	Estimate	Standard Error	p-value
	Ambient relative humidity	0.006779	0.00224	0.0039
CR-14a	Intercept	1.656264	0.06712	<.0001
	Water vapor deficit	0.010833	0.00518	*0.0423*
CR-15a	Intercept	1.630471	0.09345	<.0001
	Wind speed	0.036663	0.01958	**0.0657**
CR-1b	Intercept	0.897152	0.09258	<.0001
	Ambient temperature	-0.003981	0.0039	**0.3115**
	Ambient relative humidity	0.005528	0.00134	0.0001
	Water vapor deficit	0.013337	0.00531	*0.0146*
	Wind speed	0.02136	0.00912	*0.0226*
CR-2b	Intercept	1.03179	0.07648	<.0001
	Ambient temperature	-0.002965	0.00407	**0.4692**
	Ambient relative humidity	0.004789	0.00137	0.0009
	Water vapor deficit	0.011521	0.00551	*0.0406*
CR-3b	Intercept	1.053805	0.07073	<.0001
	Ambient temperature	0.004993	0.00173	0.0069
	Ambient relative humidity	0.0031	0.00095	0.0018
	Wind speed	0.017832	0.00937	**0.0622**
CR-4b	Intercept	0.946391	0.07858	<.0001
	Ambient relative humidity	0.004605	0.00096	<.0001
	Water vapor deficit	0.008399	0.0022	0.0005
	Wind speed	0.02021	0.00908	*0.0301*
CR-5b	Intercept	1.2253	0.05532	<.0001
	Ambient temperature	0.007602	0.00317	*0.0199*
	Water vapor deficit	-0.00327	0.00404	**0.4214**
	Wind speed	0.012747	0.01006	**0.2102**
CR-6b	Intercept	1.147634	0.05358	<.0001
	Ambient temperature	0.004878	0.00179	*0.0103*
	Ambient relative humidity	0.002795	0.00097	0.0057
CR-7b	Intercept	1.281746	0.03227	<.0001
	Ambient temperature	0.007244	0.0032	*0.0278*
	Water vapor deficit	-0.002941	0.00411	**0.4768**
CR-8b	Intercept	1.061536	0.06261	<.0001
	Ambient relative humidity	0.004155	0.00098	0.0001
	Water vapor deficit	0.007899	0.00228	0.0015
CR-9b	Intercept	1.219287	0.05483	<.0001
	Ambient temperature	0.005536	0.00182	0.0048
	Wind speed	0.012282	0.01015	**0.2308**
CR-10b	Intercept	1.114354	0.07143	<.0001
	Ambient relative humidity	0.003353	0.00102	0.0017
	Wind speed	0.017336	0.00988	**0.0847**
CR-11b	Intercept	1.248844	0.05728	<.0001
	Water vapor deficit	0.004788	0.00248	**0.0597**
	Wind speed	0.010938	0.01066	**0.309**
CR-12b	Intercept	1.274696	0.03019	<.0001
	Ambient temperature	0.005373	0.00181	0.0057

Model	Parameter	Estimate	Standard Error	p-value
CR-13b	Intercept	1.202252	0.05362	<.0001
	Ambient relative humidity	0.003084	0.00104	0.0045
CR-14b	Intercept	1.294429	0.03205	<.0001
	Water vapor deficit	0.004931	0.00243	*0.0487*
CR-15b	Intercept	1.280846	0.04185	<.0001
	Wind speed	0.017141	0.00848	*0.0477*

Table G-39. Fit and evaluation statistics for NH_3 emission models for dairy corrals.

Model	2LogL	AIC	AICc	BIC	Corr.	LNME[a] (%)	NME[b] (%)	ME[b] (kg day^{-1})	MB[b] (kg day^{-1})	NMB[b] (%)
CR-1a	-64	-50	-47	-35	0.611	7.499	27.48	0.847	0.002	0.05
CR-2a	-57	-45	-44	-32	0.566	8.023	29.51	0.91	0.01	0.321
CR-3a	-57	-45	-44	-32	0.567	7.746	28.54	0.88	-0.003	-0.101
CR-4a	-62	-50	-49	-38	0.603	7.611	27.83	0.858	0.003	0.082
CR-5a	-47	-35	-33	-22	0.416	8.813	32.02	0.987	0.001	0.026
CR-6a	-53	-43	-42	-32	0.526	8.07	29.73	0.917	0.007	0.228
CR-7a	-45	-35	-34	-24	0.414	8.675	31.57	0.973	0.002	0.062
CR-8a	-56	-46	-45	-36	0.558	8.124	29.81	0.919	0.013	0.415
CR-9a	-46	-36	-35	-26	0.398	8.943	32.66	1.007	0.002	0.078
CR-10a	-49	-39	-38	-28	0.437	7.982	29.41	0.907	-0.004	-0.126
CR-11a	-41	31	30	21	-0.27	8.935	33.05	1.019	0.001	0.046
CR-12a	-45	-37	-36	-28	0.402	8.815	32.06	0.988	0.002	0.066
CR-13a	-45	-37	-37	-29	0.425	8.108	29.36	0.905	-0.003	-0.101
CR-14a	-40	-32	-32	-24	0.306	8.839	32.59	1.005	-0.002	-0.075
CR-15a	-49	-41	-40	-32	-0.02	8.626	31.34	0.978	0.012	0.377
CR-1b	-162	-148	-146	-133	0.62	4.549	28.02	0.247	0.000	-0.01
CR-2b	-156	-144	-143	-132	0.583	4.826	29.79	0.263	0.001	0.143
CR-3b	-156	-144	-142	-131	0.572	4.746	29.19	0.257	0.000	-0.055
CR-4b	-161	-149	-147	-136	0.611	4.613	28.45	0.251	0.000	0.022
CR-5b	-146	-134	-133	-121	0.432	5.359	32.67	0.288	0.000	-0.016
CR-6b	-152	-142	-141	-131	0.54	4.925	30.31	0.267	0.001	0.119
CR-7b	-144	-134	-133	-124	0.435	5.267	32.17	0.284	0.000	0.014
CR-8b	-156	-146	-145	-135	0.575	4.89	30.17	0.266	0.002	0.195
CR-9b	-145	-135	-134	-125	0.417	5.444	33.25	0.293	0.000	0.001
CR-10b	-148	-138	-137	-127	0.423	4.829	29.86	0.263	-0.001	-0.08
CR-11b	-140	-130	-129	-120	0.284	5.485	33.7	0.297	0.000	-0.018
CR-12b	0	-136	-135	-127	0.426	5.337	32.66	0.288	0.000	0.007
CR-13b	-145	-137	-136	-128	0.423	4.804	29.51	0.26	-0.001	-0.064
CR-14b	-139	-131	-130	-123	0.334	5.402	33.29	0.293	-0.001	-0.08
CR-15b	-166	-158	-158	-149	-0.05	5.31	32.04	0.285	0.002	0.198

[a] Based on transformed data (i.e., $\ln(NH_3)$).
[b] Based on back-transformed data.

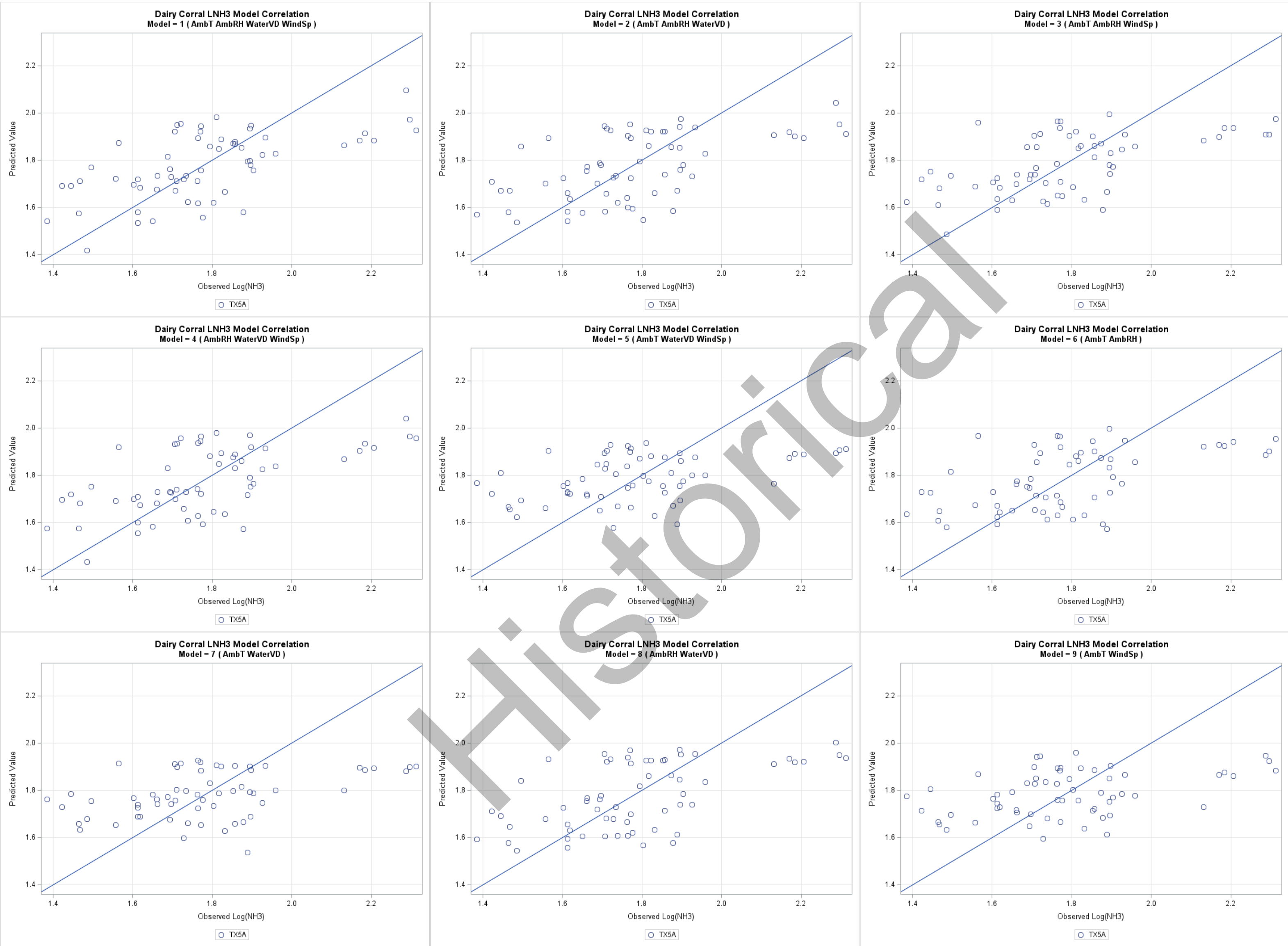


Figure G-75. Dairy corral NH_3 one-to-one plots models 1a through 9a, log transformed.

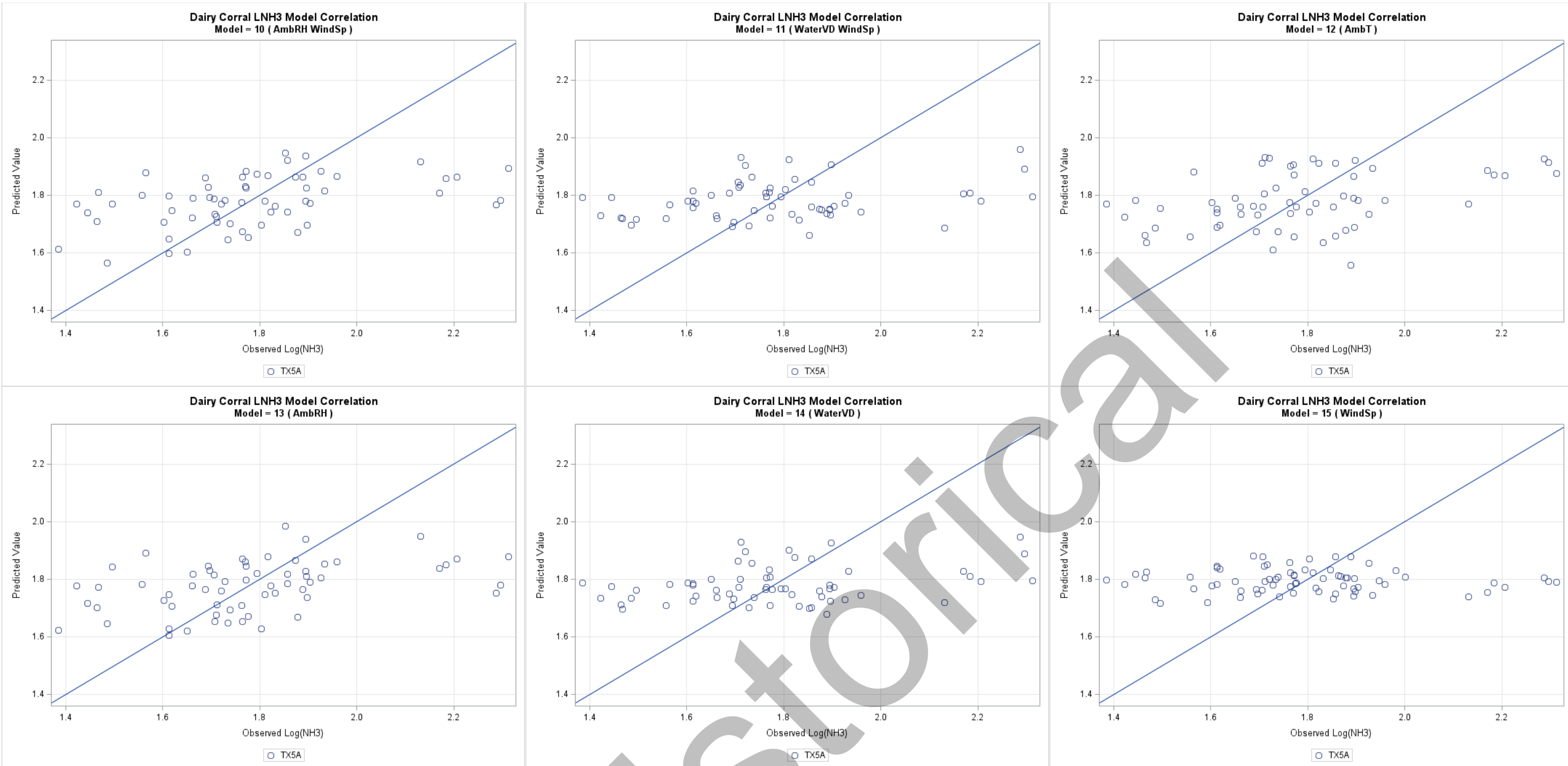


Figure G-76. Dairy corral NH_3 one-to-one plots models 10a through 15a, log transformed.

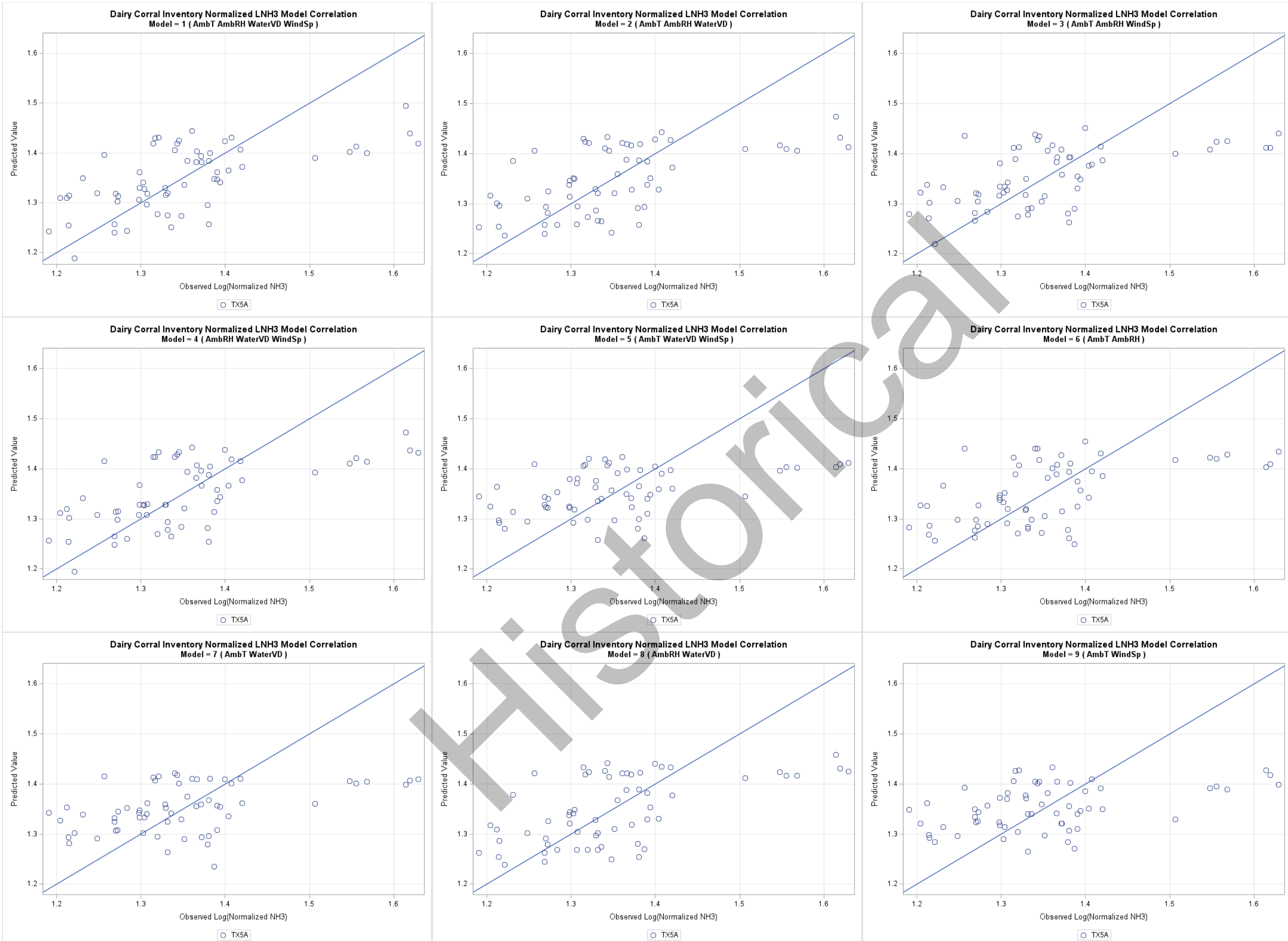


Figure G-77. Dairy corral NH_3 one-to-one plots models 1b through 9b, log transformed.

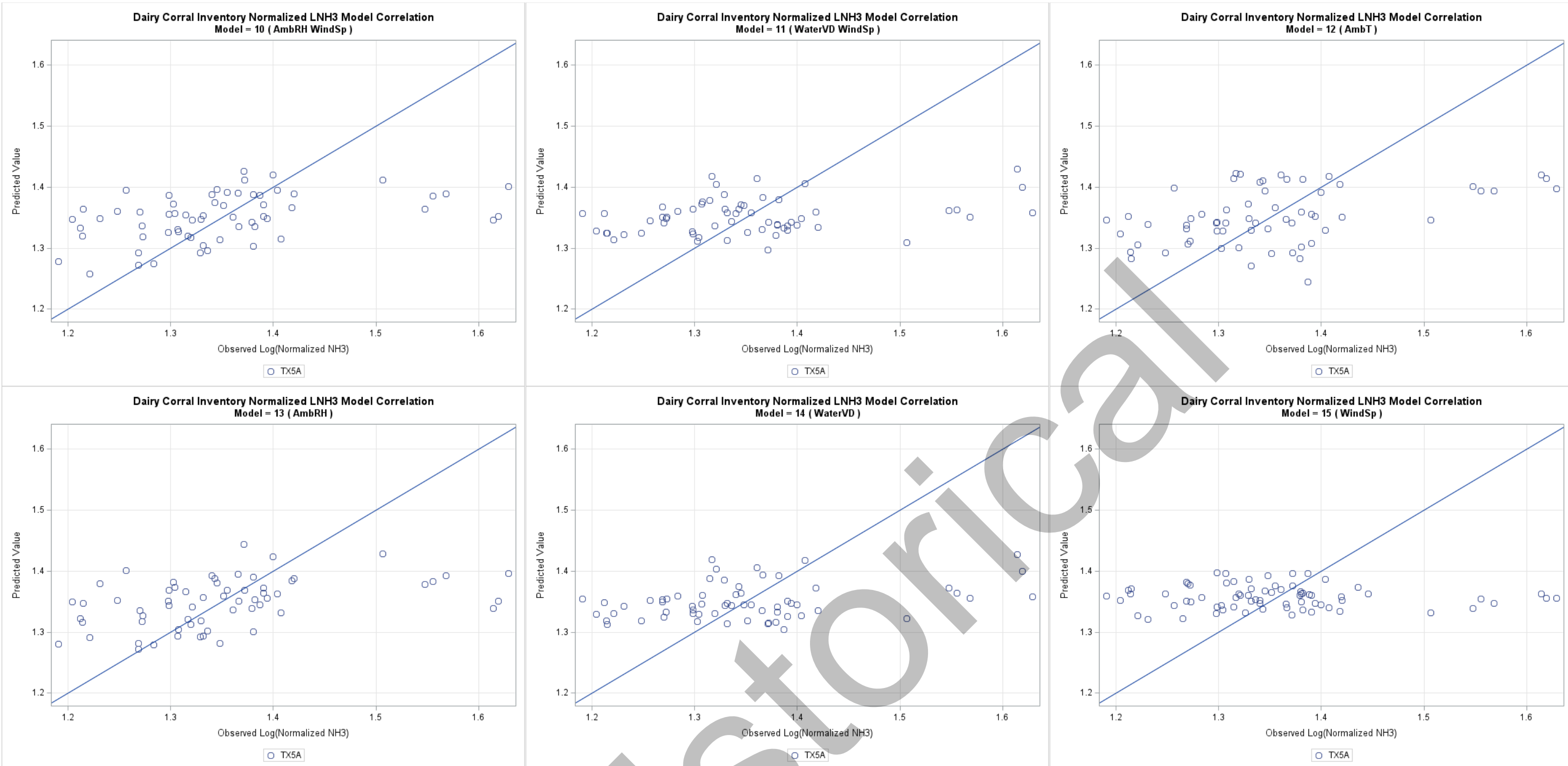


Figure G-78. Dairy corral NH_3 one-to-one plots models 10b through 15b, log transformed.

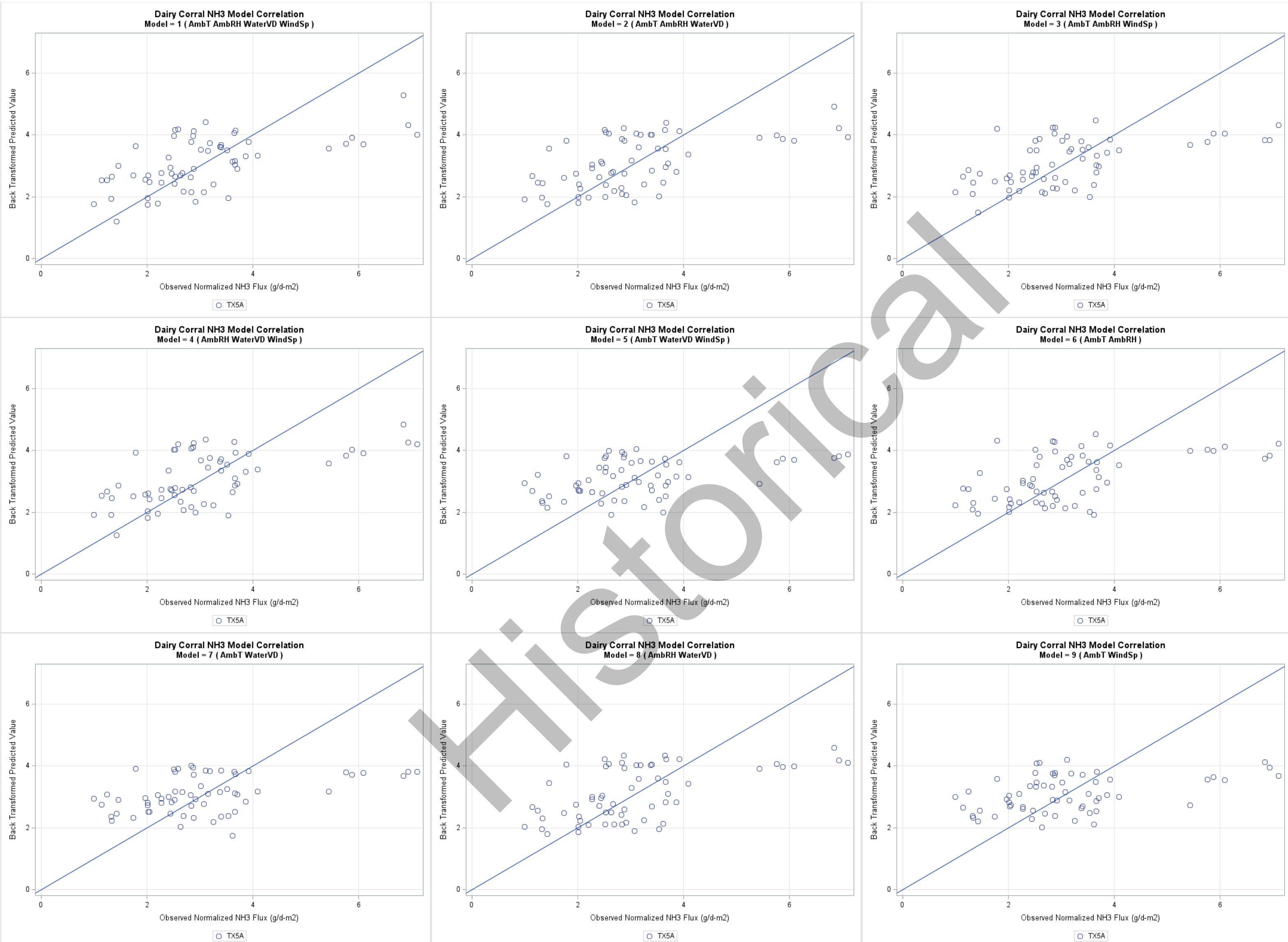


Figure G-79. Dairy corral NH_3 one-to-one plots models 1a through 9a, back transformed.

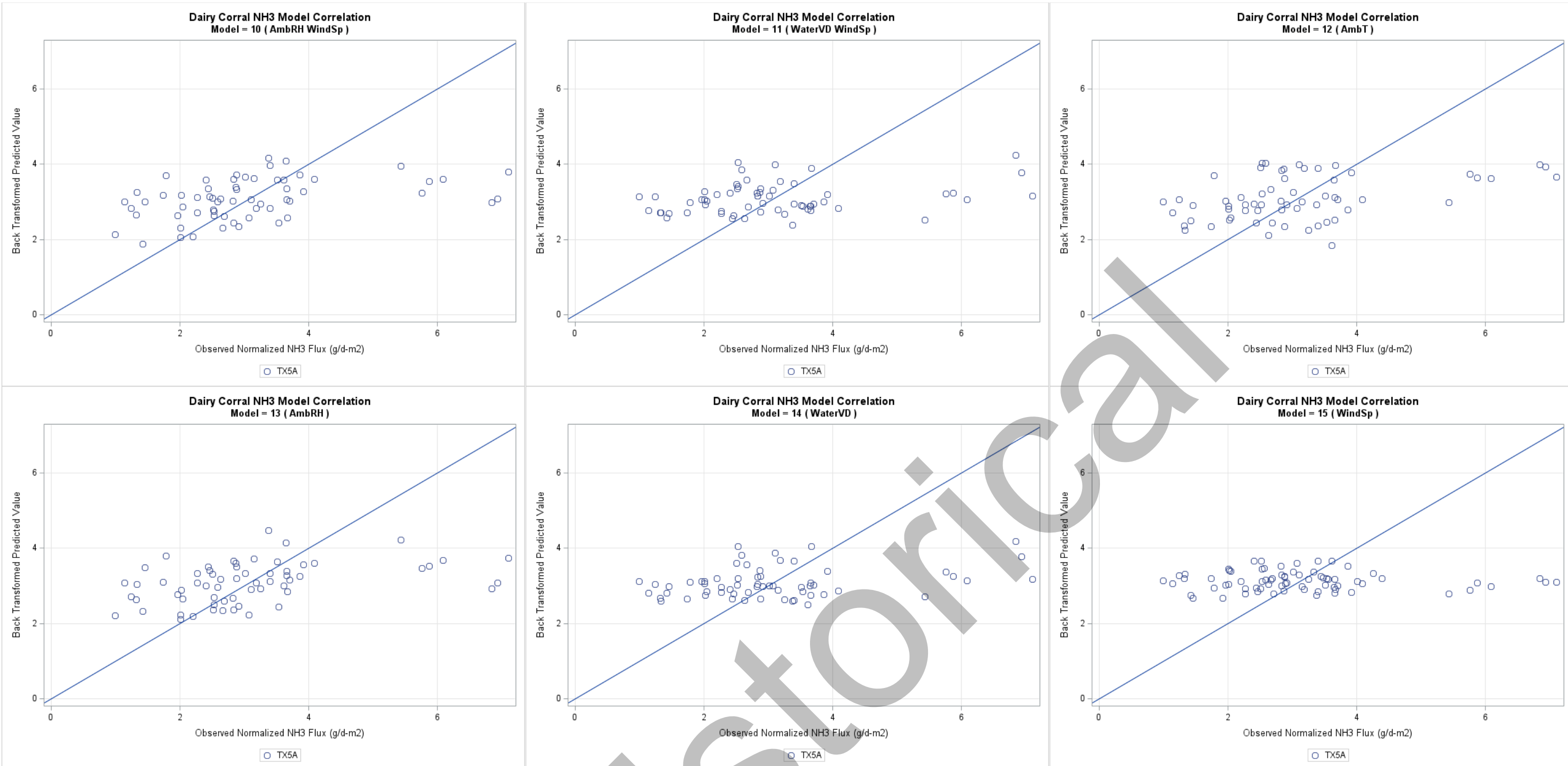


Figure G-80. Dairy corral NH_3 one-to-one plots models 10a through 15a, back transformed.

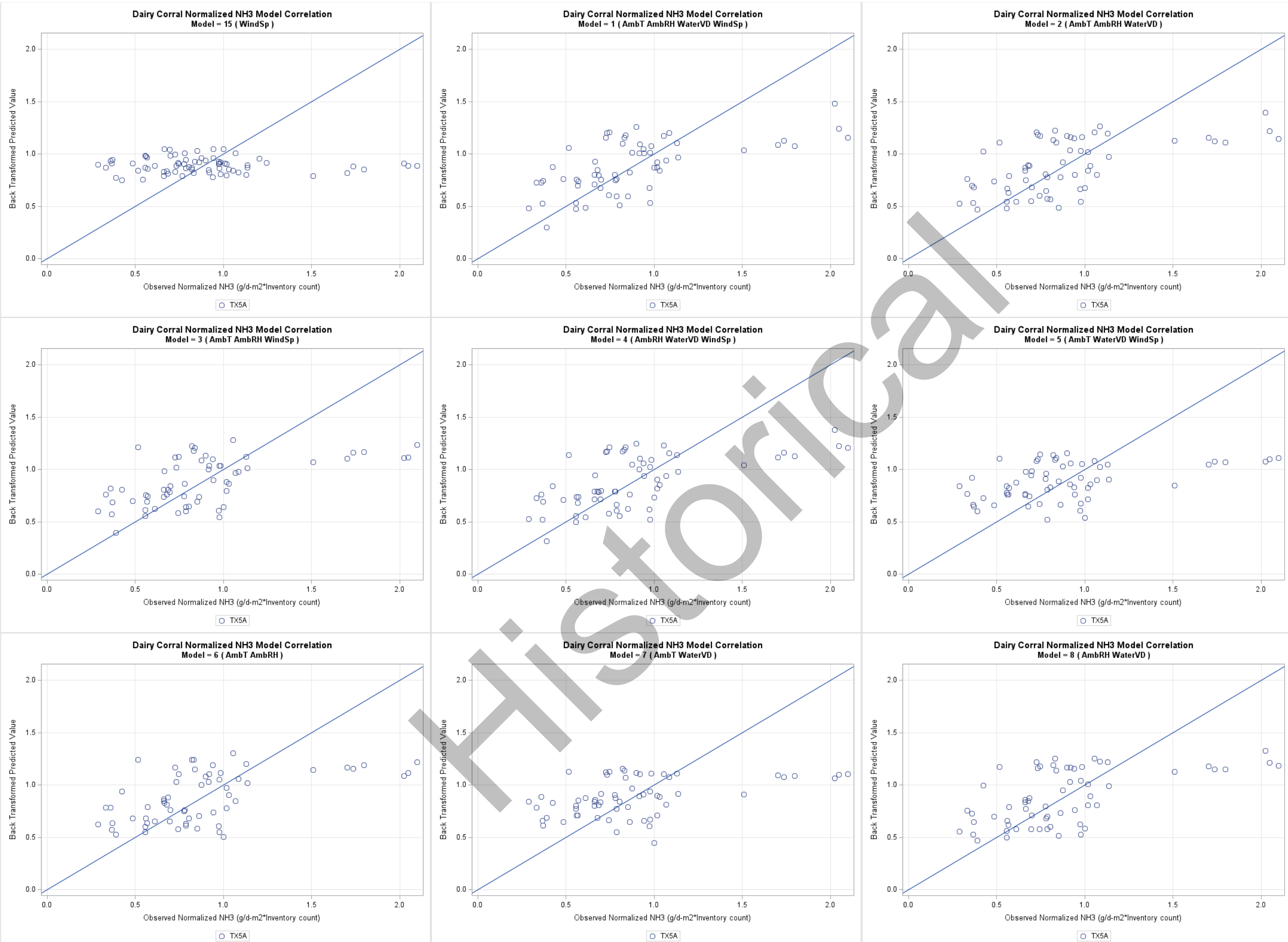


Figure G-81. Dairy corral NH_3 one-to-one plots models 1b through 9b, back transformed.

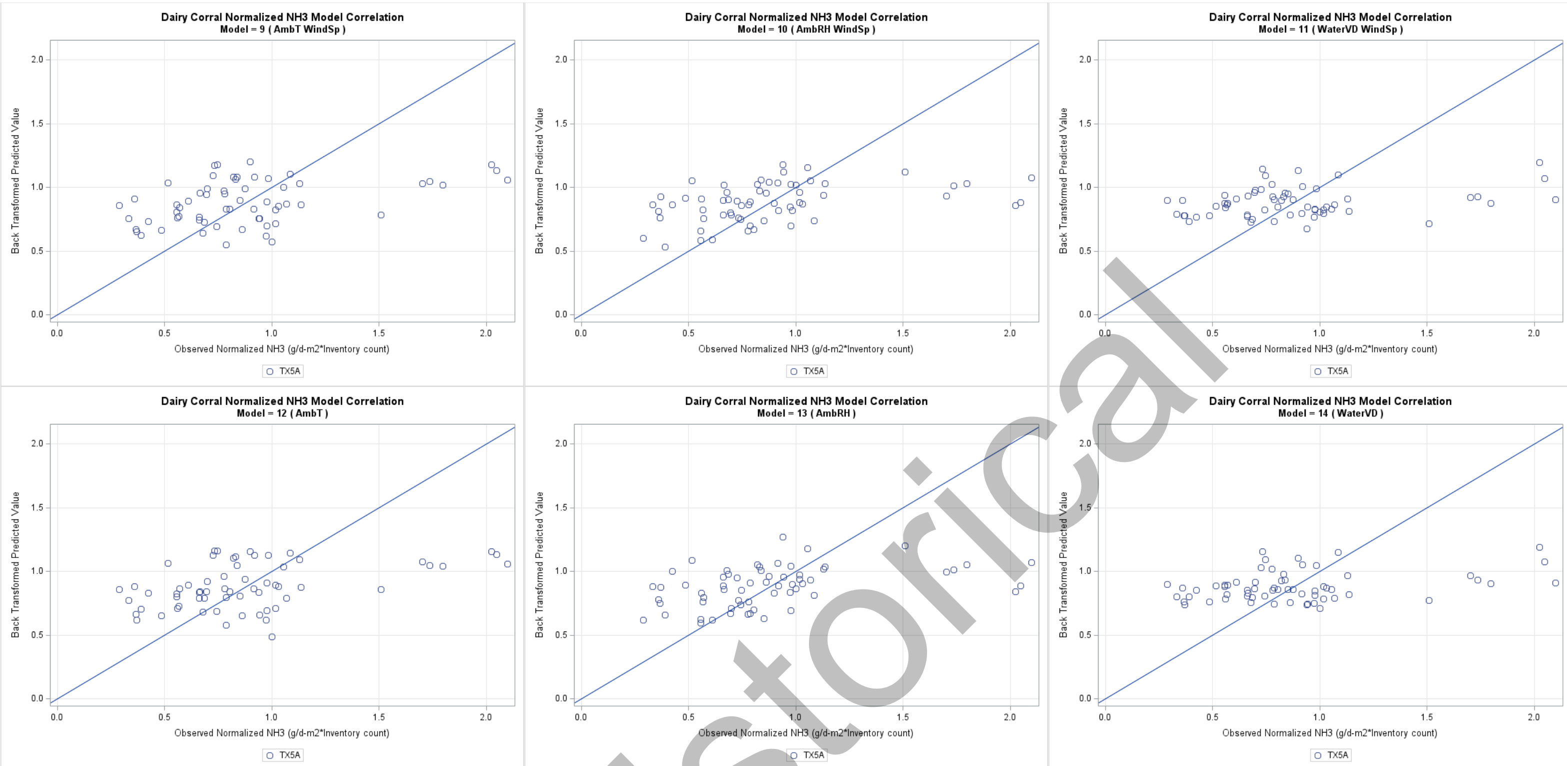


Figure G-82. Dairy corral NH_3 one-to-one plots models 10b through 15b, back transformed.

G.5.2 Hydrogen Sulfide (H_2S)

Table G-40. Parameter and estimates H_2S emission models for dairy corrals.

Model	Parameter	Estimate	Standard Error	p-value
CR-1a	Intercept	2.970638	0.50444	<.0001
	Ambient temperature	-0.009345	0.01773	**0.601**
	Ambient relative humidity	0.012274	0.00727	**0.0994**
	Water vapor deficit	0.010058	0.02412	**0.6787**
	Wind speed	0.068824	0.04038	**0.0957**
CR-2a	Intercept	3.419792	0.41522	<.0001
	Ambient temperature	-0.001785	0.01752	**0.9193**
	Ambient relative humidity	0.008789	0.00695	**0.2139**
	Water vapor deficit	0.00194	0.0241	**0.9362**
CR-3a	Intercept	3.136866	0.31165	<.0001
	Ambient temperature	-0.002867	0.00806	**0.726**
	Ambient relative humidity	0.009747	0.00411	*0.0222*
	Wind speed	0.06504	0.03878	**0.1011**
CR-4a	Intercept	3.139137	0.39428	<.0001
	Ambient relative humidity	0.009432	0.00498	**0.067**
	Water vapor deficit	-0.00146	0.011	**0.8956**
	Wind speed	0.062441	0.03826	**0.1113**
CR-5a	Intercept	3.755593	0.20355	<.0001
	Ambient temperature	0.011631	0.01281	**0.3698**
	Water vapor deficit	-0.02361	0.01369	**0.0926**
	Wind speed	0.049549	0.03869	**0.2072**
CR-6a	Intercept	3.447268	0.24975	<.0001
	Ambient temperature	-0.000519	0.00788	**0.948**
	Ambient relative humidity	0.008329	0.00411	*0.0491*
CR-7a	Intercept	3.923743	0.15146	<.0001
	Ambient temperature	0.014019	0.01286	**0.2819**
	Water vapor deficit	-0.023084	0.01418	**0.1115**
CR-8a	Intercept	3.446605	0.33784	<.0001
	Ambient relative humidity	0.008265	0.00492	**0.1037**
	Water vapor deficit	-0.000304	0.01087	**0.9779**
CR-9a	Intercept	3.714552	0.20898	<.0001
	Ambient temperature	-0.004232	0.0091	**0.647**
	Wind speed	0.047206	0.04025	**0.2473**
CR-10a	Intercept	3.104242	0.3003	<.0001
	Ambient relative humidity	0.00982	0.00412	*0.0214*
	Wind speed	0.062062	0.03834	**0.1142**
CR-11a	Intercept	3.787018	0.2035	<.0001
	Water vapor deficit	-0.014936	0.00973	**0.1324**
	Wind speed	0.057853	0.03842	**0.1403**
CR-12a	Intercept	3.873591	0.15106	<.0001
	Ambient temperature	-0.00154	0.00858	**0.859**
CR-13a	Intercept	3.439236	0.21621	<.0001
	Ambient relative humidity	0.008342	0.00412	*0.049*
CR-14a	Intercept	3.984094	0.14367	<.0001
	Water vapor deficit	-0.011103	0.00958	**0.2531**
CR-15a	Intercept	3.666611	0.18136	<.0001

Model	Parameter	Estimate	Standard Error	p-value
	Wind speed	0.039609	0.03675	**0.2875**
CR-1b	Intercept	2.017076	0.44535	<.0001
	Ambient temperature	-0.007493	0.01562	**0.6338**
	Ambient relative humidity	0.010275	0.00643	**0.1177**
	Water vapor deficit	0.007516	0.02113	**0.7237**
	Wind speed	0.060242	0.03519	**0.0943**
CR-2b	Intercept	2.405151	0.37002	<.0001
	Ambient temperature	-0.000322	0.01532	**0.9833**
	Ambient relative humidity	0.007217	0.00615	**0.2477**
	Water vapor deficit	0.000192	0.02107	**0.9928**
CR-3b	Intercept	2.143018	0.27163	<.0001
	Ambient temperature	-0.002677	0.00729	**0.7172**
	Ambient relative humidity	0.008365	0.00359	*0.0244*
	Wind speed	0.057368	0.03371	**0.0963**
CR-4b	Intercept	2.152013	0.34858	<.0001
	Ambient relative humidity	0.008004	0.00443	**0.0798**
	Water vapor deficit	-0.001621	0.0099	**0.8713**
	Wind speed	0.054825	0.03306	**0.106**
CR-5b	Intercept	2.675305	0.17806	<.0001
	Ambient temperature	0.00986	0.01132	**0.3891**
	Water vapor deficit	-0.020596	0.01183	**0.0898**
	Wind speed	0.044353	0.03369	**0.195**
CR-6b	Intercept	2.407912	0.22223	<.0001
	Ambient temperature	-0.000198	0.00707	**0.9779**
	Ambient relative humidity	0.007171	0.00361	**0.0534**
CR-7b	Intercept	2.821316	0.13542	<.0001
	Ambient temperature	0.012414	0.0113	**0.2782**
	Water vapor deficit	-0.020249	0.01229	**0.1073**
CR-8b	Intercept	2.410015	0.30355	<.0001
	Ambient relative humidity	0.007122	0.00438	**0.1149**
	Water vapor deficit	-0.000212	0.00975	**0.9828**
CR-9b	Intercept	2.637725	0.1827	<.0001
	Ambient temperature	-0.004004	0.00815	**0.6284**
	Wind speed	0.042679	0.03505	**0.2301**
CR-10b	Intercept	2.113231	0.26144	<.0001
	Ambient relative humidity	0.008445	0.00359	*0.0233*
	Wind speed	0.054306	0.0331	**0.1097**
CR-11b	Intercept	2.701641	0.17821	<.0001
	Water vapor deficit	-0.013503	0.00851	**0.1197**
	Wind speed	0.052106	0.03317	**0.1245**
CR-12b	Intercept	2.777138	0.135	<.0001
	Ambient temperature	-0.001264	0.00763	**0.8697**
CR-13b	Intercept	2.404792	0.1906	<.0001
	Ambient relative humidity	0.007177	0.00361	**0.0531**
CR-14b	Intercept	2.876877	0.12785	<.0001
	Water vapor deficit	-0.009855	0.0084	**0.2473**
CR-15b	Intercept	2.593193	0.15874	<.0001
	Wind speed	0.035442	0.03174	**0.2708**

Table G-41. Fit and evaluation statistics for H_2S emission models for dairy corrals.

Model	2LogL	AIC	AICc	BIC	Corr.	LNME[a] (%)	NME[b] (%)	ME[b] (kg day^{-1})	MB[b] (kg day^{-1})	NMB[b] (%)
CR-1a	5	19	22	31	0.351	6.373	26.37	11.92	-0.041	-0.091
CR-2a	8	20	22	30	0.4	6.315	26.24	11.86	-0.207	-0.458
CR-3a	5	17	19	28	0.324	6.449	26.66	12.05	-0.041	-0.09
CR-4a	5	17	19	28	0.338	6.476	26.72	12.07	-0.082	-0.181
CR-5a	8	20	22	30	0.09	6.755	27.81	12.56	0.147	0.325
CR-6a	8	18	19	27	0.395	6.339	26.32	11.89	-0.204	-0.451
CR-7a	9	19	21	28	0.211	6.638	27.39	12.38	-0.086	-0.19
CR-8a	8	18	19	27	0.394	6.353	26.37	11.92	-0.199	-0.44
CR-9a	11	21	22	30	-0.1	6.785	28.27	12.78	0.354	0.783
CR-10a	5	15	17	24	0.349	6.471	26.7	12.07	-0.094	-0.209
CR-11a	9	-19	-20	-27	-0	7.098	29.26	13.22	0.596	1.319
CR-12a	12	20	21	27	-0.02	6.56	27.48	12.42	-0.001	-0.002
CR-13a	8	16	17	23	0.394	6.356	26.38	11.92	-0.197	-0.435
CR-14a	11	19	20	26	0.089	6.496	26.9	12.16	0.039	0.086
CR-15a	9	17	18	25	-0.12	6.694	27.9	12.32	0.173	0.392
CR-1b	-7	7	10	20	0.319	8.137	27.72	3.596	0.001	0.008
CR-2b	-4	8	10	19	0.387	7.975	27.12	3.518	-0.048	-0.37
CR-3b	-7	5	8	16	0.294	8.223	27.94	3.624	0.003	0.021
CR-4b	-7	5	8	16	0.31	8.165	27.66	3.589	-0.01	-0.075
CR-5b	-4	8	10	18	0.058	8.556	29.04	3.767	0.056	0.43
CR-6b	-4	6	8	15	0.386	7.978	27.12	3.519	-0.048	-0.369
CR-7b	-3	7	9	16	0.198	8.364	28.31	3.673	-0.015	-0.113
CR-8b	-4	6	8	15	0.385	7.985	27.14	3.521	-0.048	-0.366
CR-9b	-1	9	10	18	-0.12	8.677	29.63	3.844	0.104	0.801
CR-10b	-6	4	5	12	0.327	8.135	27.55	3.574	-0.015	-0.119
CR-11b	-3	7	8	15	-0.02	9.083	30.79	3.995	0.179	1.38
CR-12b	0	8	9	15	-0.04	8.288	28.39	3.683	0.001	0.006
CR-13b	-4	4	5	11	0.386	7.988	27.15	3.522	-0.047	-0.364
CR-14b	-1	7	8	14	0.066	8.244	27.94	3.625	0.02	0.157
CR-15b	-4	4	5	12	-0.13	8.441	28.85	3.654	0.048	0.377

[a] Based on transformed data (i.e., $\ln(H_2S)$).
[b] Based on back-transformed data.

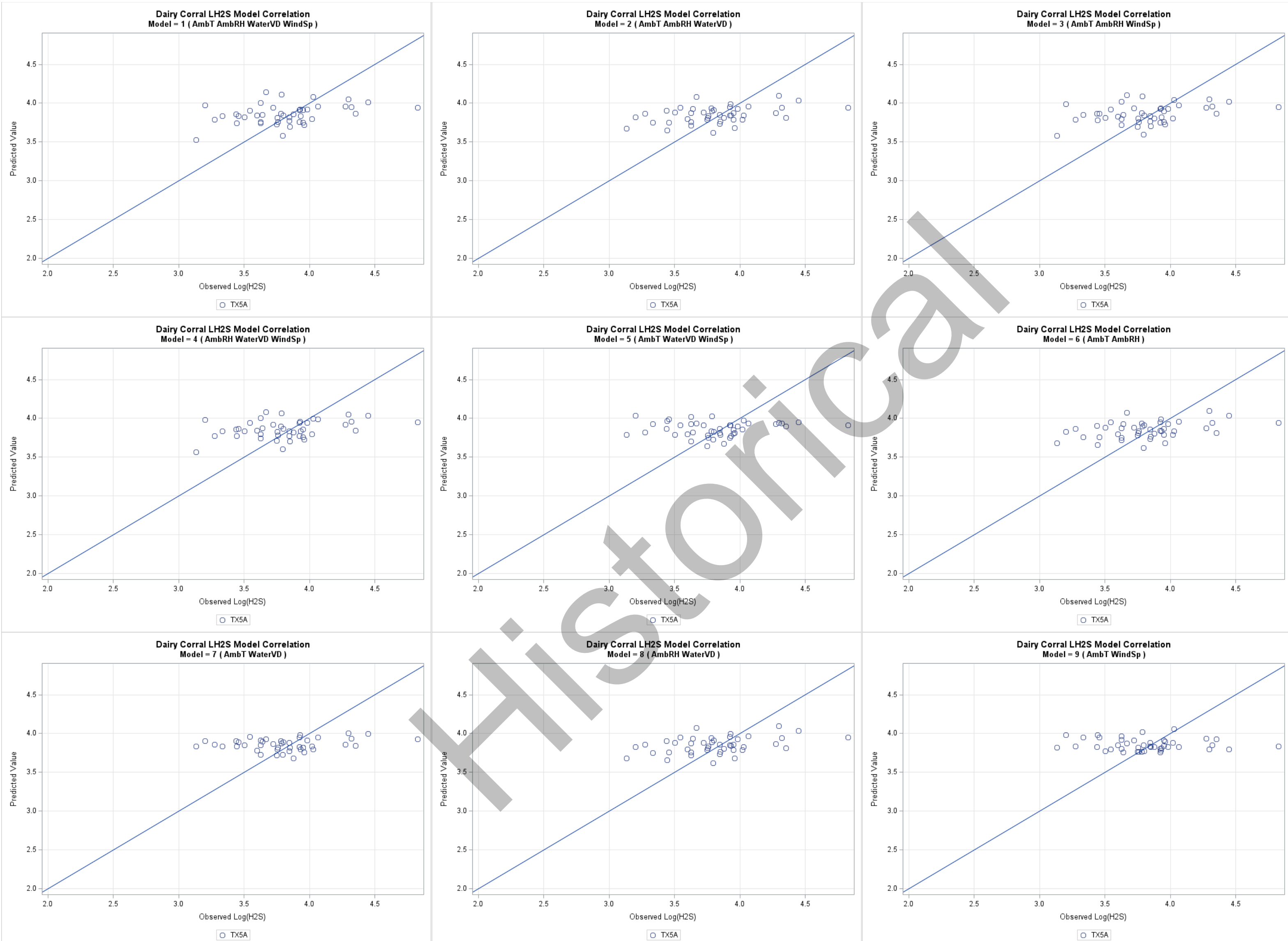


Figure G-83. Dairy corral H_2S one-to-one plots models 1a through 9a, log transformed.

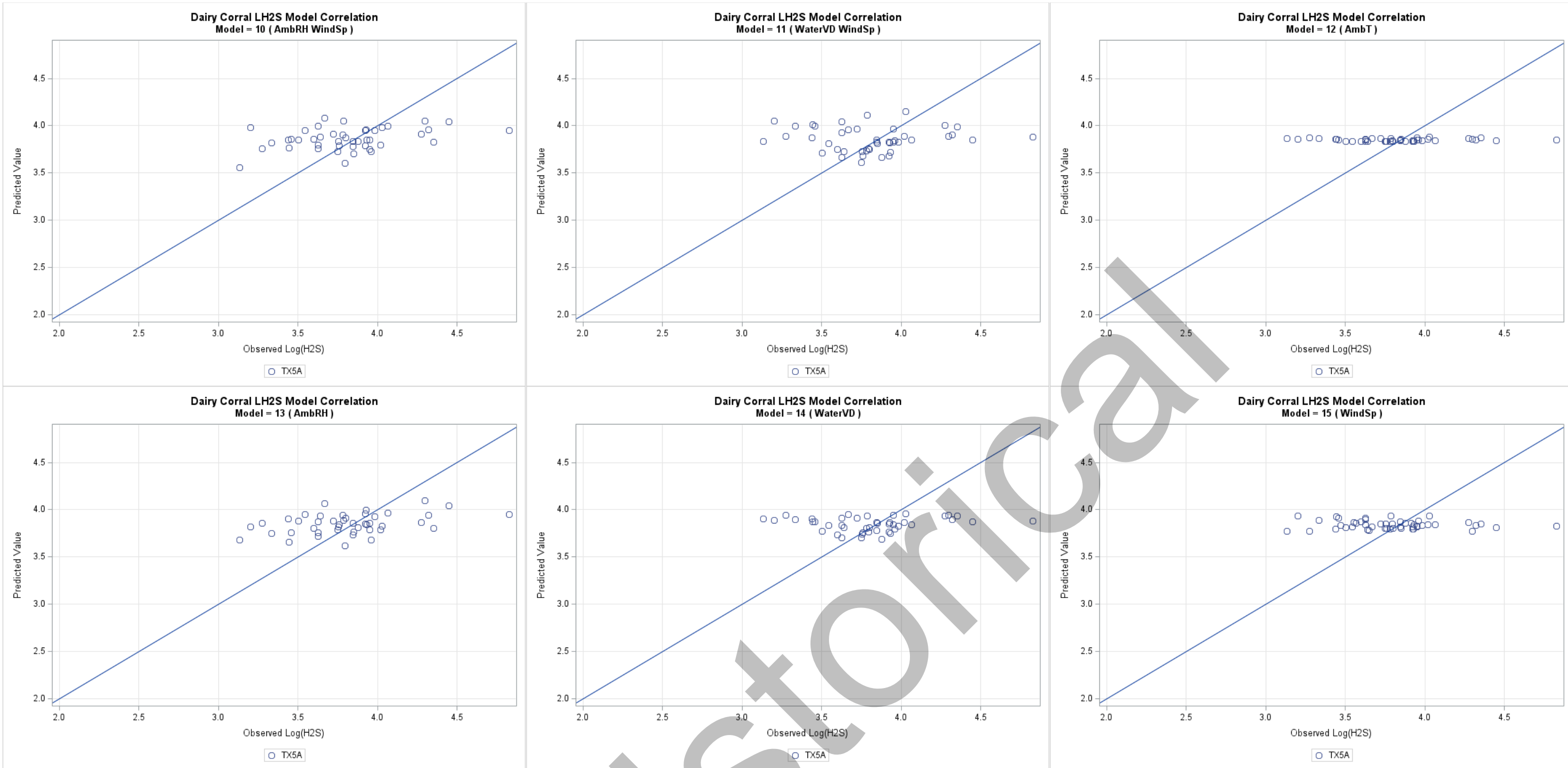


Figure G-84. Dairy corral H_2S one-to-one plots models 10a through 15a, log transformed.

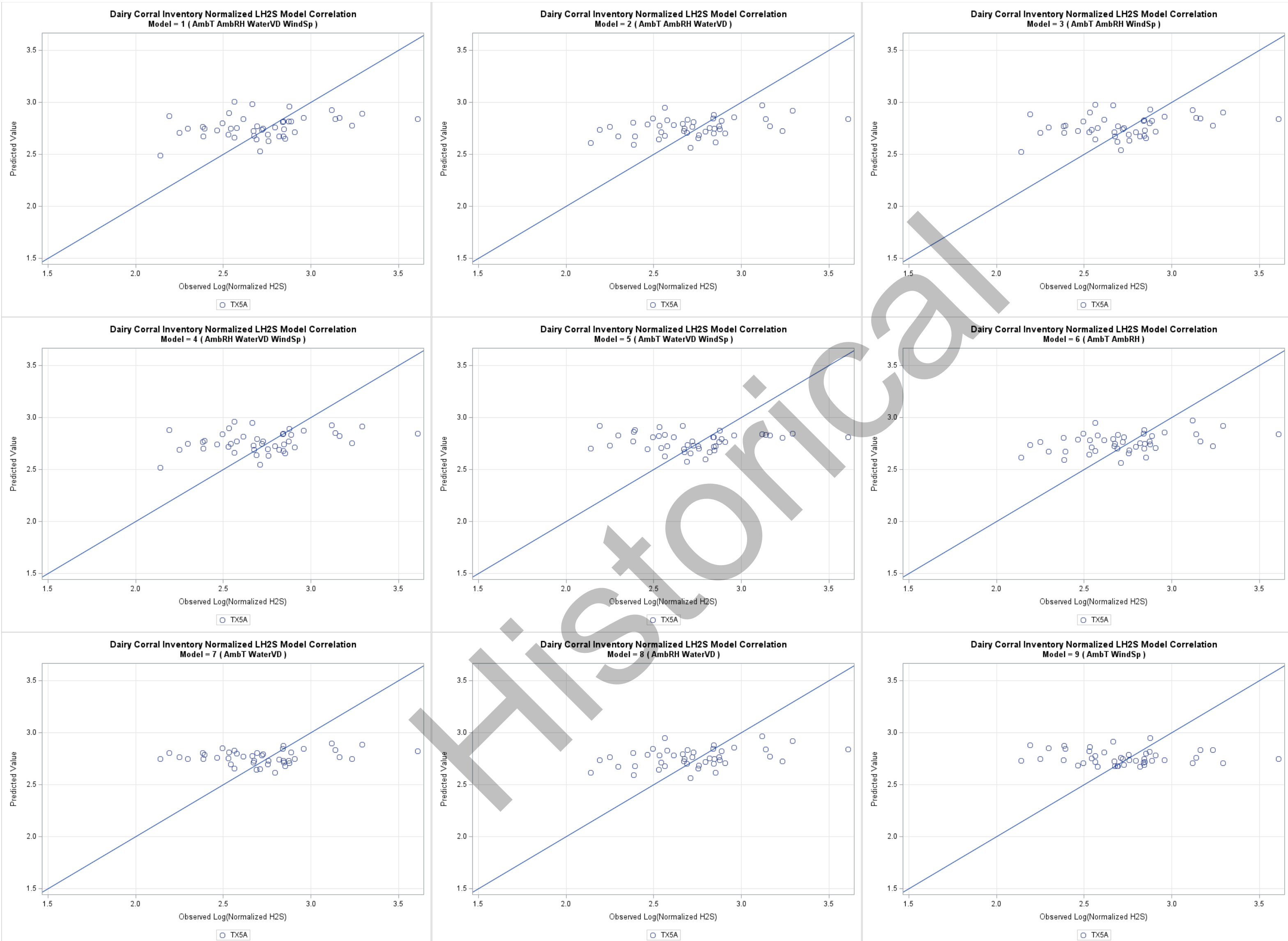


Figure G-85. Dairy corral H_2S one-to-one plots models 1b through 9b, log transformed.

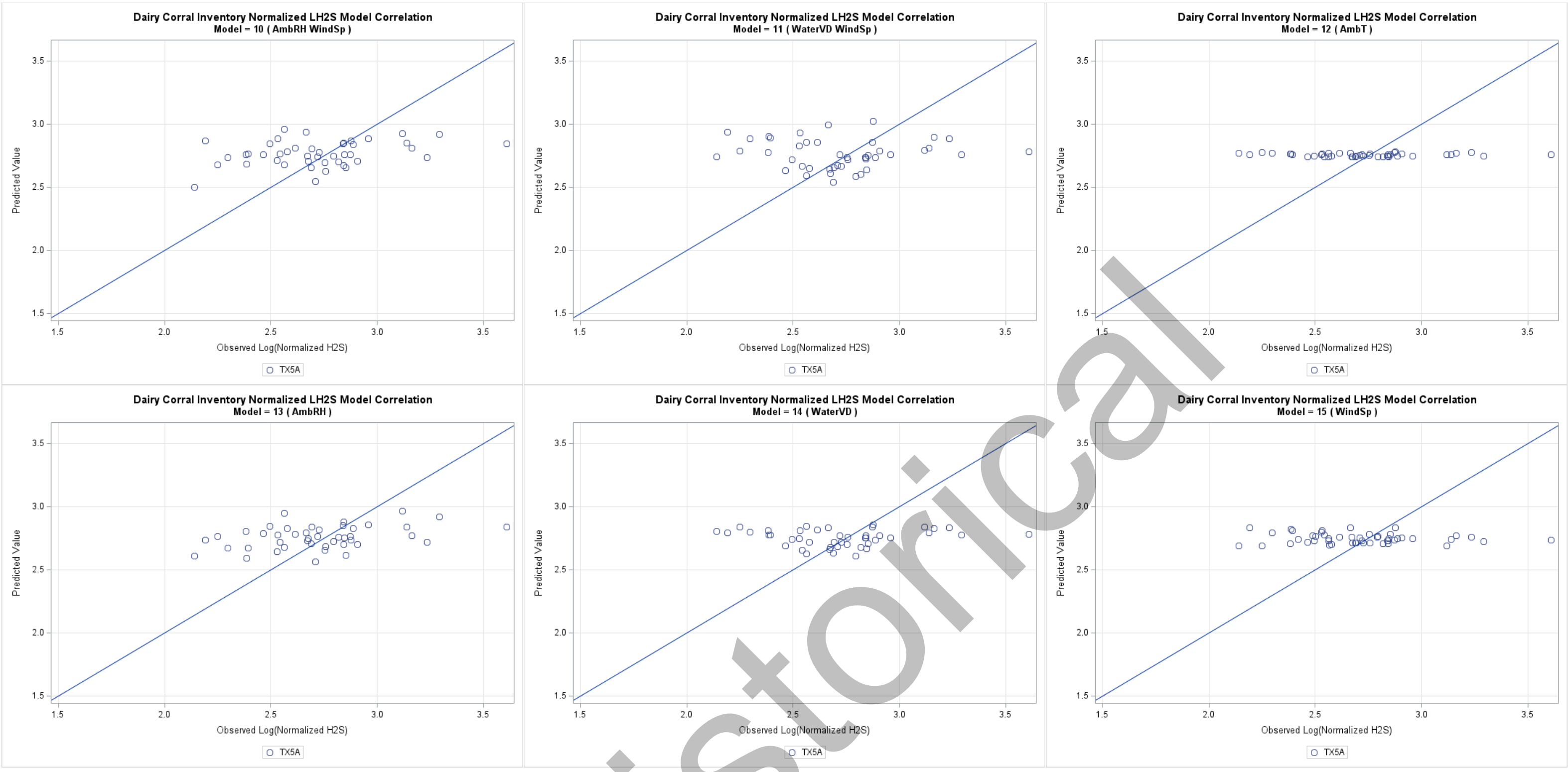


Figure G-86. Dairy corral H_2S one-to-one plots models 10b through 15b, log transformed.

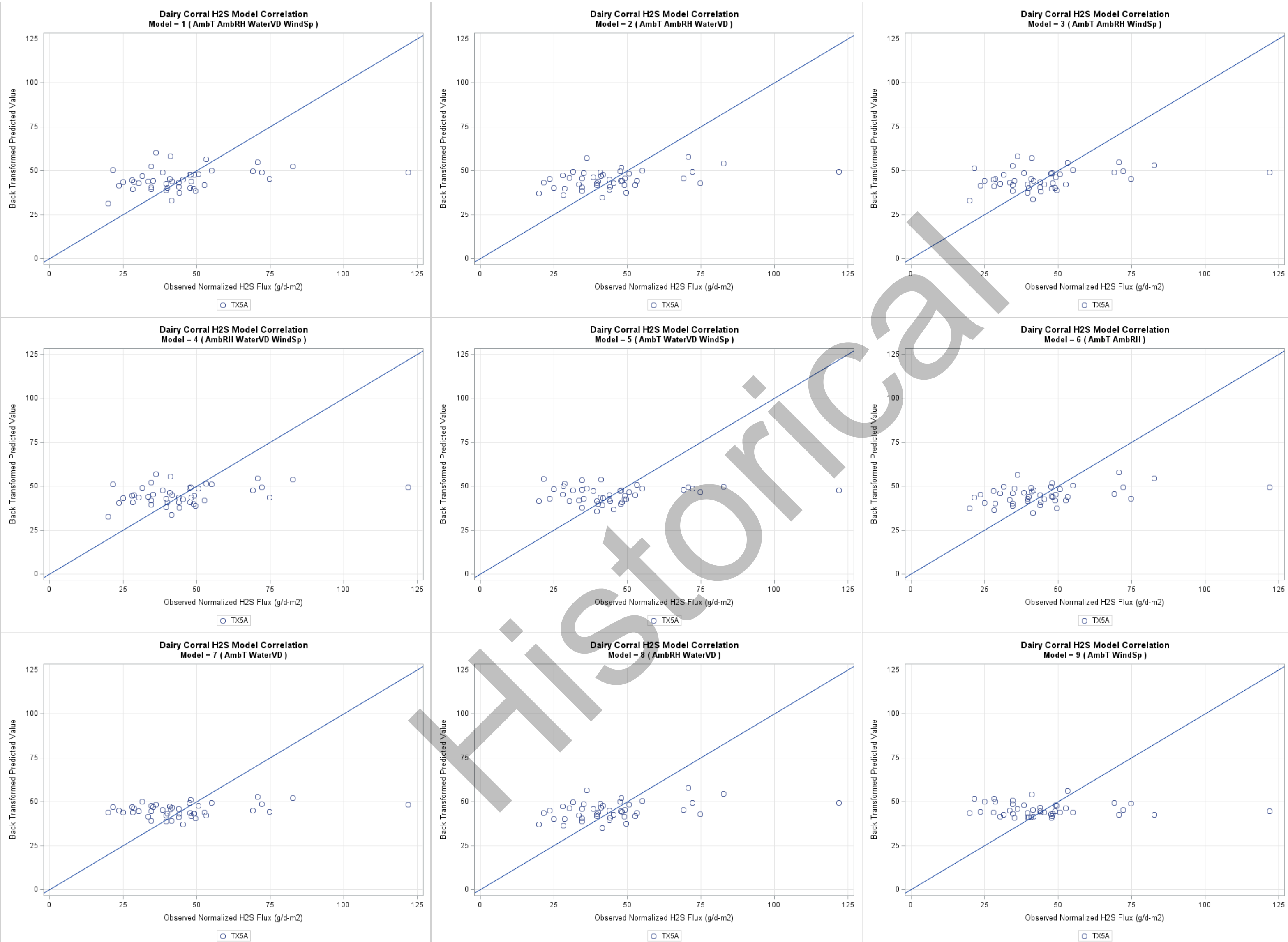


Figure G-87. Dairy corral H_2S one-to-one plots models 1a through 9a, back transformed.

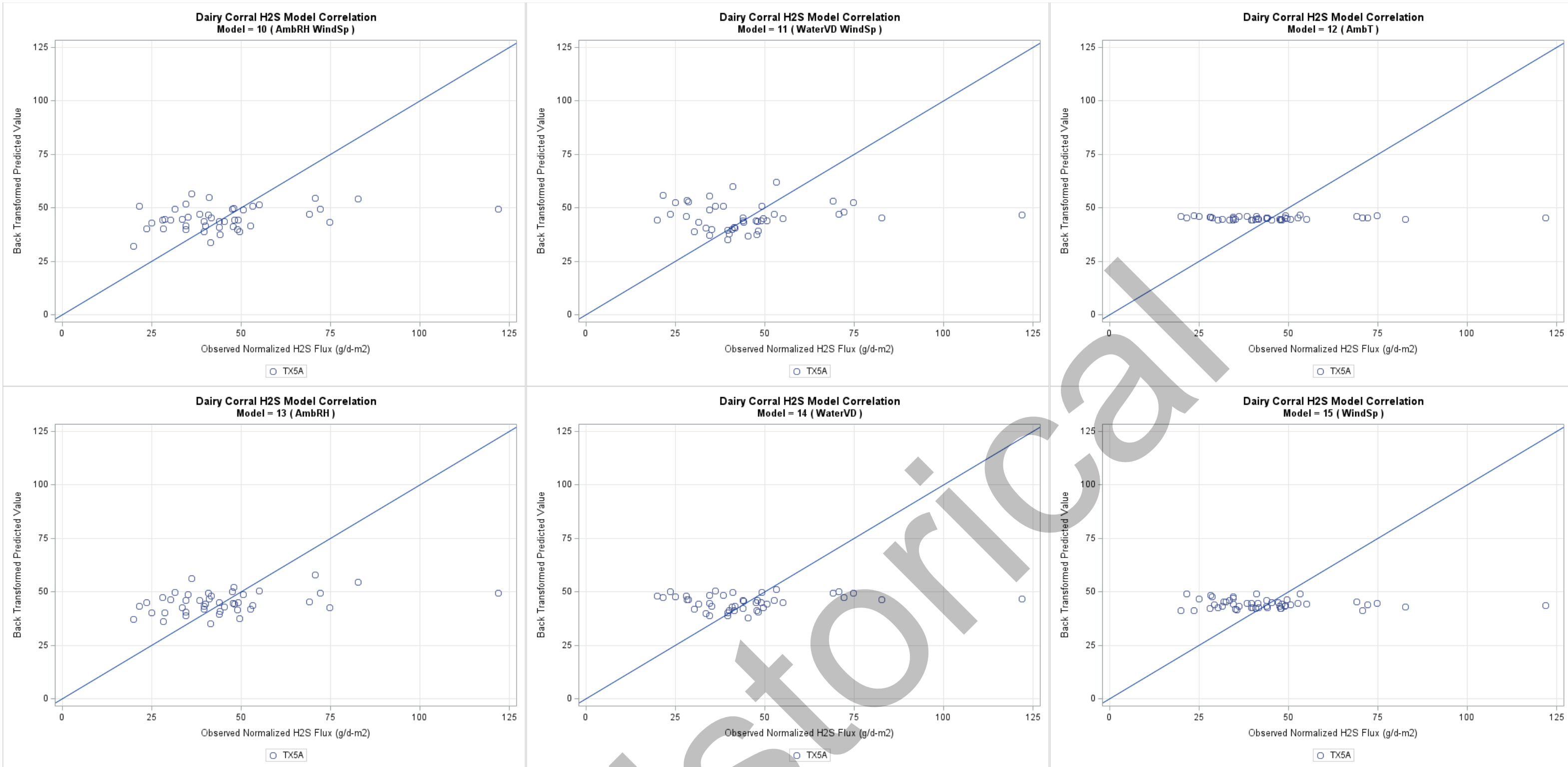


Figure G-88. Dairy corral H_2S one-to-one plots models 10a through 15a, back transformed.

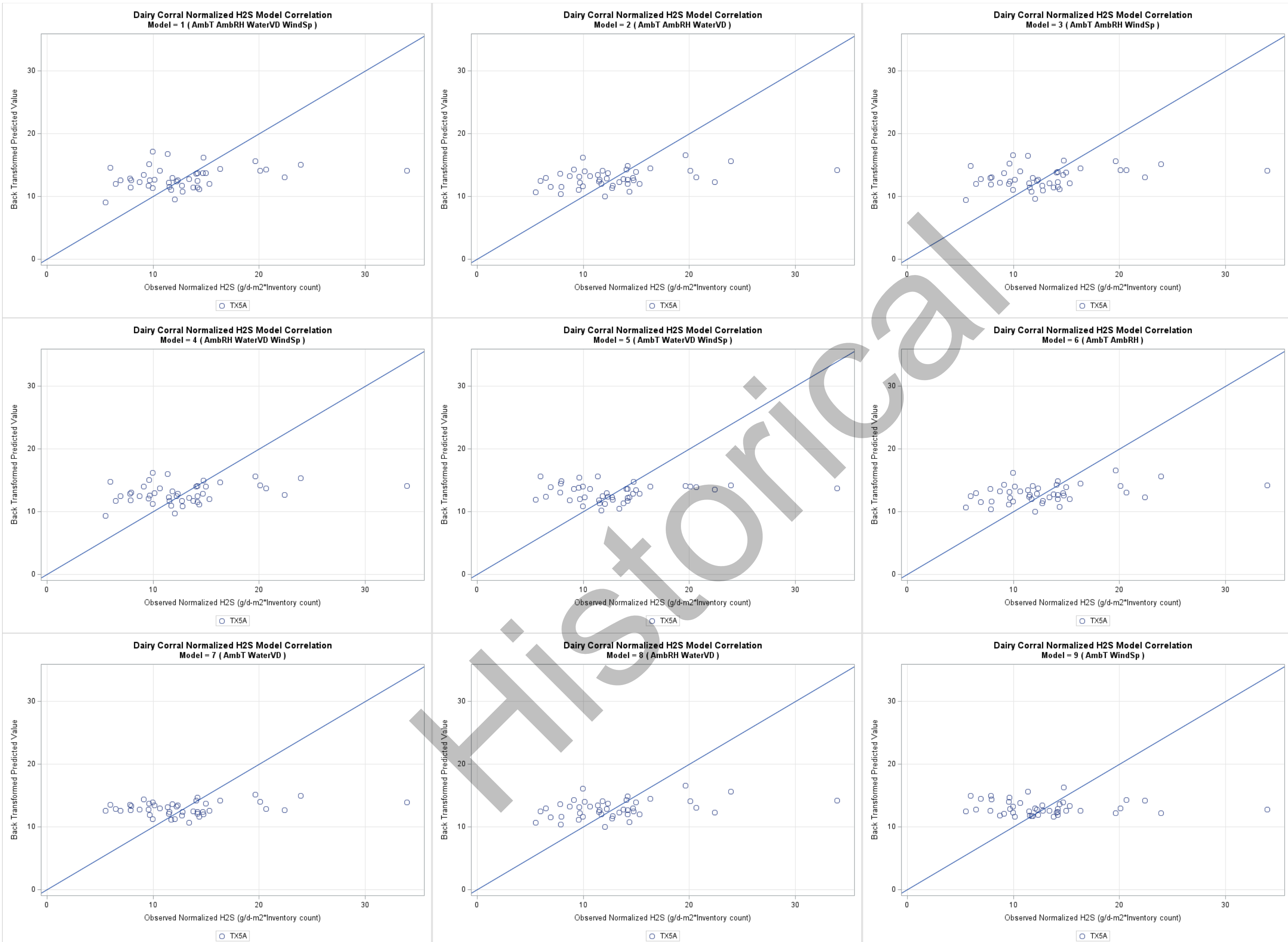


Figure G-89. Dairy corral H_2S one-to-one plots models 1b through 9b, back transformed.

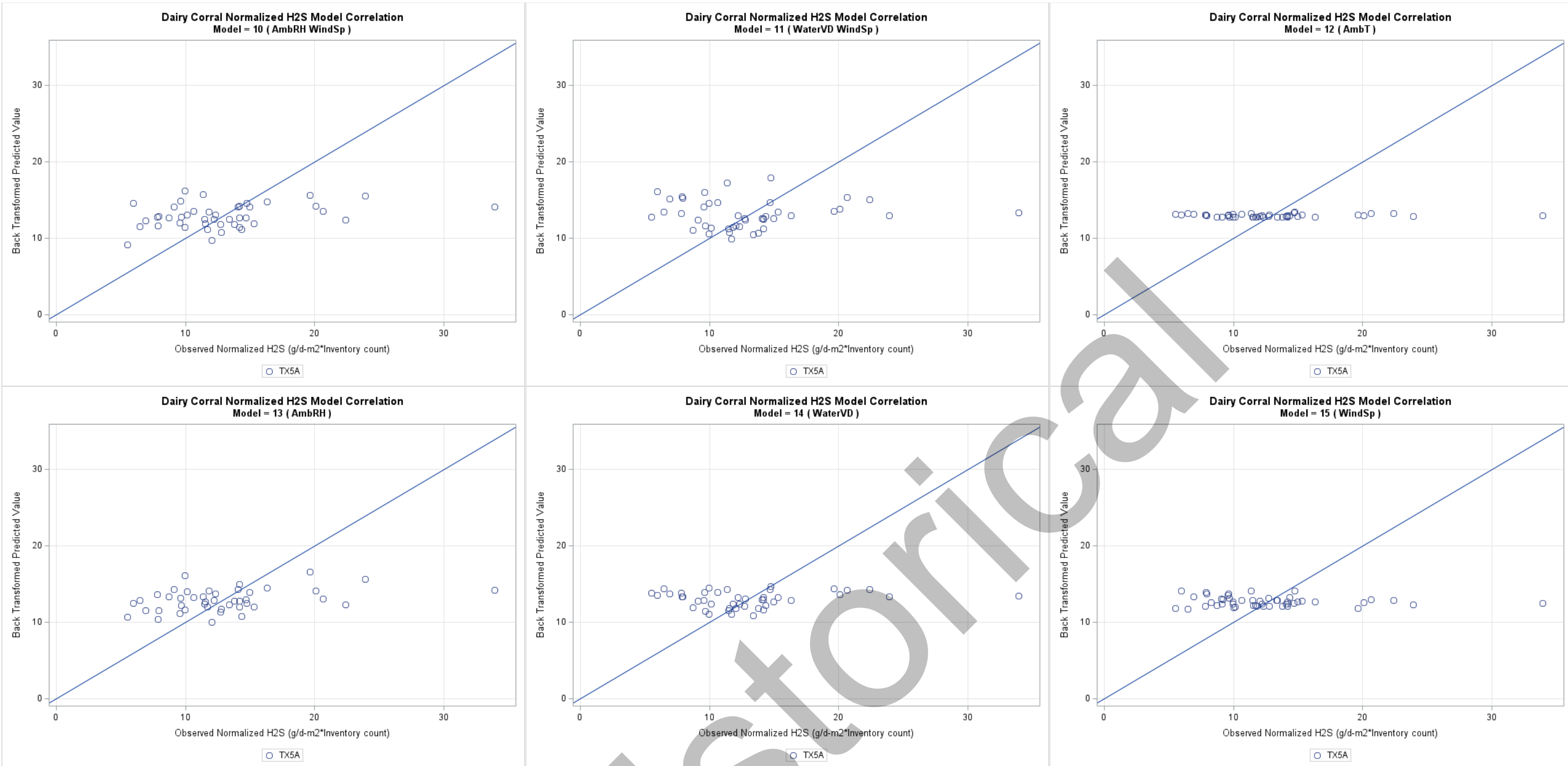


Figure G-90. Dairy corral H_2S one-to-one plots models 10b through 15b, back transformed.