Rice Burning and Asthma Hospitalizations, Butte County, California, 1983–1992

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We investigated the association between rice burning and daily asthma hospitalizations in Butte County, California, from 1983 to 1992. Eighty-two percent of planted rice was burned, with a mean of 555 acres burned on days when burning was permitted. For 60% of the days during this period, no rice burning occurred. Peak burning occurred in fall and spring but was not correlated with criteria pollutants. Asthma admissions averaged 0.65/day and peaked in March. In the basic Poisson model with daily asthma hospitalizations as the outcome of interest, burn acreage showed a small but statistically significant elevation of risk for hospitalization per acre of rice burned [relative risk (RR) = 1.0001; 95% confidence interval (CI), 1.00004–1.0002], after adjusting for maximum daily temperature, seasonal factors, and yearly population. In this model, burn acreage showed a dose–response effect as acreage burned increased. Days with the greatest acreage burned (>499 acres) had the largest risk of hospitalization (RR = 1.23; CI, 1.09–1.39), and days with moderate burning (between 100 and 499 acres) had a slightly lower risk of admission (RR = 1.2; CI, 1.05–1.37). Elevations of air pollutants were not associated with days of increased rice burning; however, rice burn acreage was shown to have a small but statistically significant effect on asthma morbidity in Butte County. This evidence suggests that further limitations on the daily amount of rice straw permitted to be burned should be considered to reduce pulmonary morbidity related to asthma. *Key words*: agricultural burning, asthma, particulate matter, PM_{10}, poisson regression, rice burning, time–series analysis.

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Previous research has raised concern over the role that particulate air pollution plays in the exacerbation of asthma. Recent studies have suggested that respirable particulate pollution (PM_{10}) is significantly associated with increased pulmonary morbidity and mortality at levels well below current federal standards (*1,2*). We were concerned with a problem specific to California—the postharvest burning of waste rice stubble, with the subsequent production of respirable particulates and its possible contribution to asthma hospitalizations.

The practice of burning field stubble and waste rice straw has been occurring annually in the Sacramento Valley of California since the 1920s, when farmers began relying on fire to rid their fields of waste straw that was difficult to plow under in heavy, wet fields (*3*). Today, burning is still seen as the most cost-effective method of clearing waste stubble from fields in preparation for the succeeding planting season, in addition to being the method of choice for controlling stem-rot disease of rice, which can severely decrease crop yield (*4*). A major problem with rice straw burning is the emission of smoke and other pollutants into the atmosphere and their effects on ambient air quality and public health. One study has shown that burning 1 ton of dry rice straw emits about 7 pounds of particulate matter, 80 pounds of carbon monoxide, and 10 pounds of hydrocarbons (*4*). The California Air Resources Board (CARB) estimated that from 1981 through 1994, Sacramento Valley Air Basin residents burned an average of 150,000 acres of rice per year (*5*). With a 1-acre field producing 3 tons of rice straw, the amount of pollutants emitted into the atmosphere from rice burning is significant. While minimal health information regarding the effects of rice straw burning has been compiled at present, many citizen complaints and air pollution problems are reported to occur during the fall rice straw burning period, when pressure to burn acreage is at its peak and meteorological conditions are usually near their worst for smoke dispersion (*4,5*).

Prior to the 1970s, rice stubble burning was unregulated; in 1971, in response to public complaints, the state adopted rules to minimize maximum daily burn totals. In the 1980s the rice-growing industry joined with state officials to set up an air quality monitoring system to determine where and when waste rice straw fires could safely be set (*6*). In 1991 the state legislature passed AB 1378, which mandated a 10% yearly reduction of rice stubble burning, with the elimination of the practice entirely by the year 2000 (*7*). Since that time the annual percentage of acreage permitted to be burned has decreased as mandated; however, because yearly planted acreage has increased, the amount of acreage actually burned each year has only minimally decreased. Presently, the state legislature is being asked to consider a request by rice growers who are asking for a temporary freeze on the annual allowable percentage of rice stubble burned, citing economic hardship. This decision needs to be made using more information regarding the health effects related to the inhalation of emissions from rice smoke.

We reviewed the possible effects of rice burning on asthma hospitalizations in Butte County, California, a rural county with the largest population (182,000) by the 1990 Census (*8*) of any of California's rice-growing counties. Our objectives were to determine the effect of rice straw burning on daily hospital admissions for asthma in Butte County from 1983 to 1992. Additionally, we ascertained whether rice straw burning was related to air quality parameters [suspended particulate matter <10 μm (PM_{10}), coefficient of haze (COH) and carbon monoxide (CO)], which might act as proxies for exposure to rice smoke.

Materials and Methods

Daily asthma hospitalization information was compiled using 1983–1992 discharge data tapes from the California Office of Statewide Health Planning and Development (OSHPD) (*9*). The data elements gathered included age, race, and sex of each patient and the day, month, and year admitted for only those discharges from Butte County hospitals with the principal diagnosis of asthma (*International Classification of Diseases*, Revision 9; ICD-9, code 493) (*10*). There were five hospitals in Butte County that operated throughout the 10-year time period; two were located in Chico, with one each in Oroville, Gridley, and Paradise. See Figure 1 for locations of hospitals and air monitoring stations.

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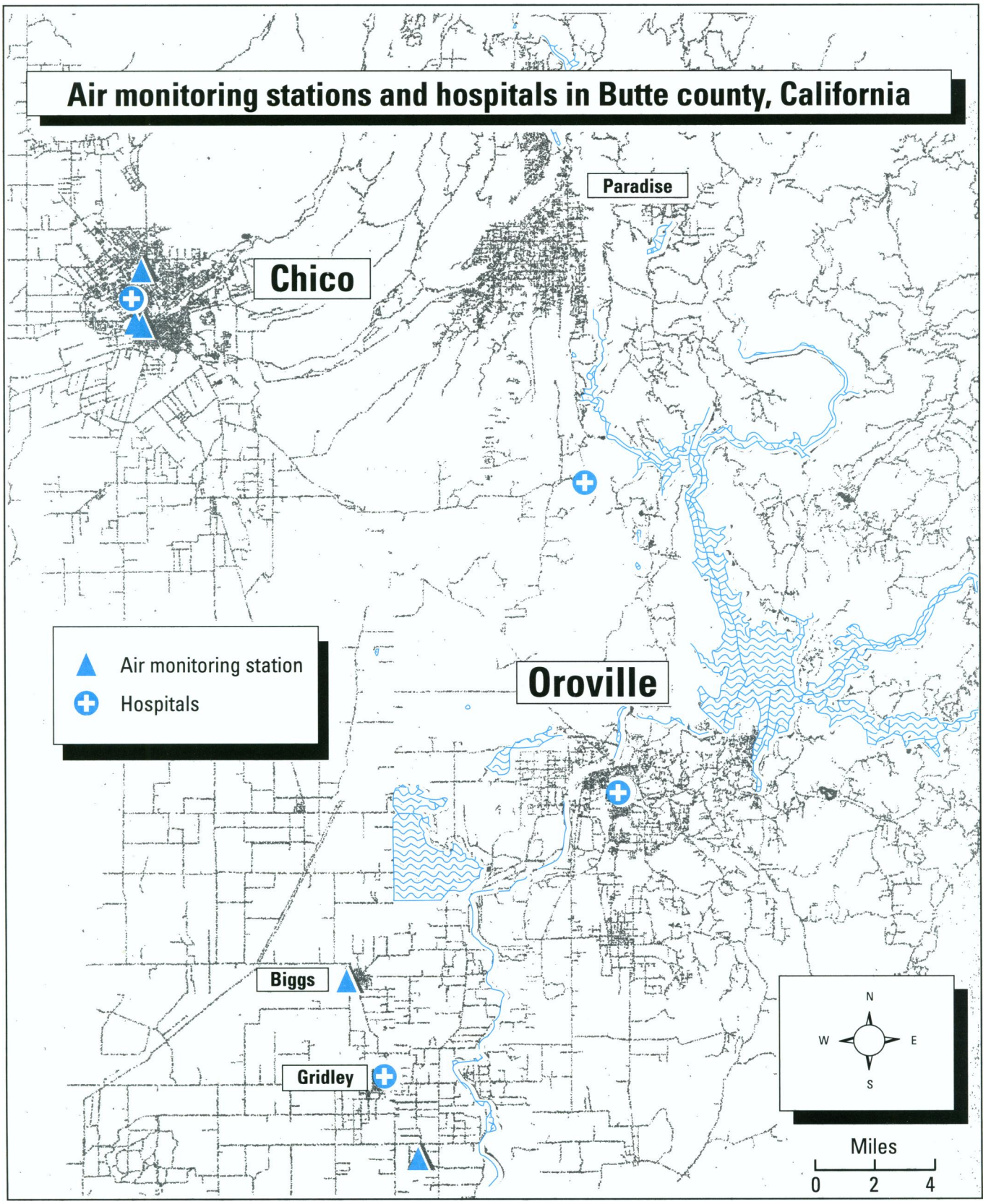

Figure 1. Air monitoring stations and hospitals in Butte County, California. Air monitoring stations were primarily located in Chico, with hospitals situated in Chico (with two), Paradise, Oroville, and Gridley. Rice fields were located in the southern and western portions of the county.

Air quality data were obtained through CARB's Air Quality Data series from 1983 to 1992 (*11*).

Ozone (O_3) values were continuously measured by the ultraviolet absorption photometric method. Hourly average values were recorded on a daily basis by CARB. The highest value of the hourly average values for each day was used in this study as the daily ozone level (ppm) for Butte County. Values were obtained from one site, located in Chico, from 1 January 1983 to 31 December 1992, including 123 days with missing values. Days with missing environmental data were not more prevalent during rice burning periods. There did not appear to be a pattern to the missing data, which most likely reflected monitoring machine malfunction.

Carbon monoxide (CO) levels were measured continuously by the nondispersive infrared radiation method. Hourly average values were recorded on a daily basis by CARB. The highest value of the hourly average values for each day was used in this study as the daily CO level (ppm). CO values were obtained from two monitoring stations in Chico from 1 January 1983 to 31 December 1992 (including 170 and 327 missing values from stations 1 and 2, respectively). These values were averaged to obtain the mean daily CO level for Butte County.

Samples of suspended particulate matter <10 μm (PM_{10}) were collected approximately on every sixth day over a 24-hour period on a quartz fiber filter by using a high volume sampler equipped with a size-selective inlet and operated at 36–44 ft^3/min. This is a measurement of the mass concentration of respirable particles that can deposit in the alveoli. Daily mean values (in micrograms per cubic meter) were recorded from three sites in Chico and from one site in Biggs from 1 January 1983 to 31 December 1992. These values were averaged to produce an every-sixth day PM_{10} level for Butte County. Daily PM_{10} values from the every-sixth day data were calculated by performing a linear regression using PM_{10} as the dependent variable and modeling daily COH measurements, daily O_3 values, precipitation amounts, and an indicator variable for month from a method suggested by Delfino (*12*). These calculated values were recorded as the daily PM_{10} level for Butte County.

Soiling index (COH) measurements were made from particulate matter samples that were collected by a smoke sampler. In this procedure, sample air is drawn through a 1-inch diameter spot of paper filter tape at a rate of 6.25/l/min. A clean spot of the filter paper tape is automatically advanced for sampling every 2–3 hr. A photometer detects the quantity of light absorbed by the particulate matter on the tape and produces a proportional electrical signal. The quantity of light absorbed, often referred to as the soiling index, is reported in the COH scale. Daily COH measurements were recorded from monitoring stations in Chico and Gridley from 1 January 1983 through 31 December 1992. These values were averaged to create a daily COH level for Butte County.

Weather information was compiled using the National Oceanic and Atmospheric Administration's (NOAA) *Climatological Data California* from 1983 to 1992 (*13*). Variables recorded included daily maximum temperature, daily minimum temperature (temperatures are in degrees Fahrenheit and were averaged from hourly temperatures), and daily precipitation totals in inches. All weather variables were obtained from NOAA's monitoring station in Chico from 1 January 1983 to 31 December 1992.

Rice acreage burned was compiled using monthly crop burning acreage tally sheets on file at the California Air Resources Board and the Butte County Air Pollution Control District in Durham, California (*14*). Each air district receives permit applications for agricultural burning from growers in their region. The district also keeps daily records of acreage burned for individual crops and compiles a monthly tally sheet, which is filed at the district level and sent to CARB. Daily burn acreage amounts were obtained from 1 January 1982 through 31 December 1993. There were five missing months of daily data from 1983.

The daily counts of individuals needing admission to hospitals for asthma in this population was relatively rare (mean = 0.65 admissions/day) and follows a Poisson distribution. By contrast, ordinary least squares regression analysis assumes that the outcome is normally distributed. Therefore, we elected to use Poisson regression in our time–series analysis of rice burning and environmental factors. Time–series analyses have been the most sensitive methods for assessing exposure effects when individual exposure data is unavailable. We used the general Poisson equation

$$\log[E(Y_i)] = X_i\beta \qquad (1)$$

where $E(Y_i)$ denotes the expected number of hospital admissions by day (i), X_i is the matrix of covariates stratified by day, and β is the estimated regression coefficient.

The basic Poisson regression model analyzed the association between daily counts of admission to all of the five Butte County hospitals and either an individual air quality parameter (O_3, CO, PM_{10}, or COH) or rice burn acreage. The basic model controlled for temperature (modeled as a continuous variable) because asthma exacerbations have been shown to be affected by both heat and cold (*15*). The basic model also controlled for seasonal effects using indicator variables to account for potential confounders (i.e., pollen), which may not be adequately controlled by temperature, because numerous countries including the United States have described seasonal increases in both emergency room visits and hospital admissions (*16,17*). The county's population grew by approximately 25% over the 10-year time span in this study (*18*), so we used the estimated annual population of Butte County in the model to control for growth in population during the decade of study. We did not control for age, race, or sex in the regression because the distribution of these variables in the population do not vary from day to day and do not influence the expected number of asthma hospitalizations. In addition, the proportions of these demographics in the population remained constant during the period of study. Days with missing environmental data were not considered in the Poisson regressions. Daily asthma hospitalization counts and air pollution parameters were analyzed for serial correlation through ordinary least squares regression, and Durbin-Watson statistics were derived. Residuals of daily asthma admission counts were plotted using autocorrelation–function plots. Both techniques failed to demonstrate serial correlation of admissions or pollution parameters (*19*). The statistical package used for the analysis was STATA 4.0 for Windows [Stata Corporation, College Station, TX (*20*)].

Results

From 1 January 1983 to 31 December 1992 (3,653 days), 837,838 acres of rice were planted in Butte County, an annual average of almost 84,000 acres. Over 690,000 acres were burned (approximately 82% of planted acreage), with an average annual burn of 69,030 acres. There were 2,253 days without any rice burning (60%) during the 10-year period. Of the remaining days, 151 values were not recorded and 1,249 days had burning. When only burn days are considered, the mean acreage burned was 555 acres, with a median figure of 269 acres burned per day (Table 1). The amounts ranged from a low of 1 acre to a high of 4,832 acres burned per day.

Recorded ozone levels averaged 0.05 ppm/day over the 10-year period. The values ranged from a low of zero to a high of 0.13 ppm. Only 1% of daily ozone values exceeded the California standard of 0.09 ppm. Daily carbon monoxide levels had a

Table 1. Daily Butte County summary of environmental, weather, and asthma hospitalization statistics (n = 3,362)

Variable	Mean	Median	Range	CA standard (ppm)
Ozone (1-hr maximum, ppm)	0.05	0.04	0–0.13	0.09 (1 hr)
Carbon monoxide (1 hr maximum ppm)	2.48	2.0	0–13.5	9.0 (8 hr)
COH	2.36	1.8	0–16.5	–
PM_{10} (μg/m^3)	34.3	29.1	6.6–636	50 (24 hr)
Rice burned (acres)[a]	555.02	269	1–4,832	–
Maximum temperature (°F)	75.49	75	35–114	–
Precipitation (inches)	0.07	0	0–2.9	–
Asthma hospitalizations	0.65	0	0–7	–

Abbreviations: CA, California; COH, coefficient of haze; PM_{10}, particulate matter <10 μm aerodynamic diameter.
[a]Burning occurred on permitted days only.

Table 2. Spearman rank correlations for selected parameters, Butte County, California, 1983–1992

Variable	Burn acreage	O_3	CO	COH	PM_{10}	Tmax	Tmin	Precip
Burn acreage	1.00	0.06*	0.06*	0.03	0.04*	0.09*	-0.03*	-0.23*
O_3		1.00	-0.24*	-0.10*	0.34*	0.74*	0.59*	-0.40*
CO			1.00	0.72*	0.54*	-0.31*	-0.51*	-0.08*
COH				1.00	0.81*	-0.25*	-0.42*	-0.12*
PM_{10}					1.00	0.20*	-0.04*	-0.37*
Tmax						1.00	0.83*	-0.49*
Tmin							1.00	-0.20*
Precip								1.00

Abbreviations: COH, coefficient of haze; PM_{10}, particulate matter <10 μm aerodynamic diameter; Tmax, maximum temperature; Tmin, minimum temperature; Precip, precipitation.
*$p<0.05$.

Table 3. Basic Poisson regression model results for Butte County, California, daily asthma hospitalizations using rice burn acreage and controlling for temperature, season, and population, 1983–1992

Variable	Unit	Coefficient[a]	p-Value	RR	CI
Acres burned	1 acre/day	0.000123	0.003	1.0001	1.00004–1.0002
	500 acres/day	0.0615		1.063	1.02–1.1
Season					
Summer	Reference[b]				
Winter		0.1409	0.12	1.15	0.97–1.37
Spring		0.0454	0.51	1.05	0.91–1.2
Fall		0.0306	0.72	1.03	0.87–1.22
Tmax	1°F decrease	-0.0087	0.0001	0.99	0.987–0.995
	10°F decrease	-0.087		0.92	0.88–0.96

Abbreviations: RR, relative risk, CI, 95% confidence interval; Tmax, maximum temperature.
[a]Increase in log number of daily asthma admissions per unit increase in variable.
[b]All other seasons compared to summer.

mean of 2.48 ppm, with values ranging from zero to over 13 ppm. Again, less than 1% of all recorded values during this time were above the federal and state standard of 9.0 ppm. Coefficient of haze values averaged 2.36 COH units, with a median value of 1.8. Approximately 20% of recorded COH values were >1, with approximately 45% of values exceeding 2 units. Daily PM_{10} values had a mean of 34.3 μg/m^3, with a median value of 29.1 μg/m^3. Fifteen percent of the daily values exceeded the California PM_{10} standard of 50 μg/m^3.

During the 10-year period, there were 2,361 admissions to Butte County hospitals with asthma as the primary diagnosis, with a mean of 0.65 admissions/day. When admissions were viewed by day, there were 1,978 days with no admissions (54.1%), 1,153 days with one admission (31.6%), 393 days with two admissions (10.8%), and less than 4% with three or more admissions. Over 50% of all asthma hospitalizations occurred in two hospitals in Chico, the largest city in Butte County. Females constituted 60% of all admissions for asthma in Butte County during this time. When frequencies were standardized by person-years, older adults had the highest rate with 265 admissions/100,000 population, and children under 5 years of age had the second highest rate with 235/100,000 population. The county's overall asthma hospitalization rate was 136 admissions/100,000 population, well below the 1987 U.S. average of 188/100,000 (*21*).

The peak months for admission during this period were January through March, with approximately 30% of all admissions. Admissions slowed in the warmer summer months (less than 6% of total admissions/month) and then began to rise in the fall. Yearly admissions peaked in 1989 with a population-adjusted rate of 177.3 admissions/100,000 population.

Monthly rice burn acreage was observed relative to air pollution parameters to determine whether pollution parameters could be used as proxies for rice burning (Table 2). All air pollutants were poorly correlated with rice burn acreage, with no Spearman rank correlation (*22*) for any pair higher than 0.06. Ozone levels were strongly correlated with maximum daily temperature (0.74), carbon dioxide levels were strongly correlated with daily COH levels (0.72), and COH values were strongly correlated with daily PM_{10} levels (0.81).

The outcome of interest, daily asthma admissions to all hospitals in Butte County, was analyzed in individual Poisson regressions using a basic model with either daily rice burn acreage or an individual air pollution parameter as the exposure of interest (Table 3). All regressions controlled for maximum daily temperature and season and were adjusted for the yearly population of Butte County. All air quality parameters showed small but nonstatistically significant elevations of relative risk (RR) for daily asthma hospitalizations. Elevations of PM_{10} showed the largest risk of admission (RR = 1.04) for an increase of 1 μg/m^3 of PM_{10} concentration. Burn acreage showed a statistically significant elevated risk of admission [RR = 1.0001; 95% confidence interval (CI), 1.00004–1.0002] per acre on the day of hospitalization. In this model, maximum daily temperature showed a statistically significant protective effect for asthma admissions [RR = 0.99; CI, 0.987–0.995). Winter had the largest relative risk of admission for asthma by season in this model (RR =1.15), but this elevation was not statistically significant.

When burn acreage was categorized and analyzed with indicator variables in this model (Fig. 2), we observed a dose–response effect as acreage burned increased. Days with the greatest acreage burned (>499 acres) had the largest risk of hospitalization (RR = 1.23; CI, 1.09–1.39), but days when 100–499 acres were burned also had a statistically significant increased risk of admission (RR = 1.2; CI, 1.05–1.37).

Discussion

While this study suggests that rice burning may be associated with increased asthma hospitalizations, potential intermediates (PM_{10}) were poorly correlated with daily

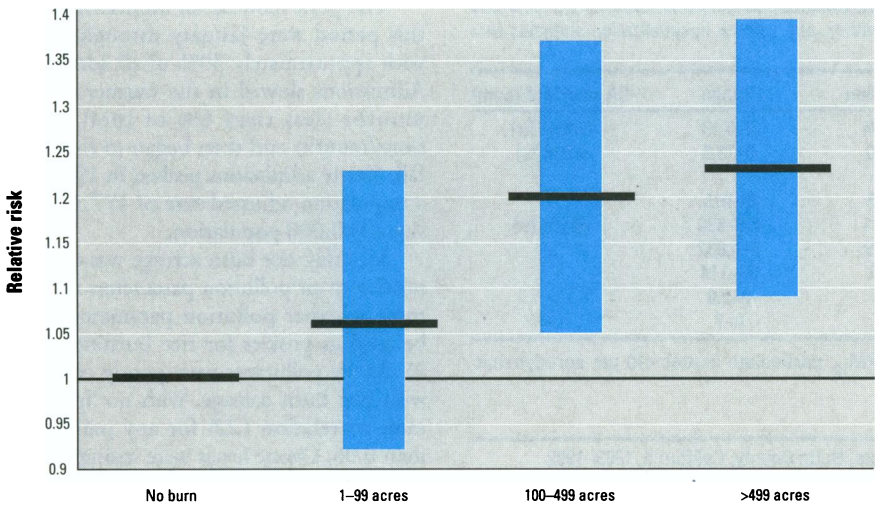

Figure 2. Relative risks (horizontal line) and 95% confidence intervals (bar) for asthma hospitalizations and rice burn acreage categories. Using the basic model, which adjusted for maximum daily temperature, season, and yearly population, the risk of asthma hospitalizations increased in a dose–response fashion with increasing burn acreage categories.

totals of rice stubble burned and failed to show a statistically significant elevation for risk of admission with asthma. This may be due to several reasons. First, because asthma admissions to all Butte County hospitals were quite small (<1/day), the power was insufficient to detect a statistically significant difference in admissions per amount of pollutant measured per day, despite having 10 years' worth of daily data. Other factors that may have affected admissions include problems with access to health care, physician management prerogative, and severity of the asthma attack. Measurement error may also have played a role in failing to find an elevated risk of asthma hospitalization for population exposures due to criteria pollutants.

Because there is inherent misclassification in the use of fixed-site outdoor monitors to represent overall population exposure to air pollutants (*12*), a significant amount of measurement error may have been introduced into this study. Because the majority of monitoring stations were located in Chico, it is questionable whether the measured pollution values were truly representative of the population's exposure. In this study it was assumed that each individual in Butte County was exposed to the same amount of pollution, which may be either an overestimate or underestimate of the actual exposure. Since only about 25% of the county's residents live in Chico, three-fourths of the population may potentially be misclassified. Additionally, CARB burning restrictions may be protective for larger cities like Chico. These restrictions limit and direct burning so that rice smoke and particulates produced in the southern and western part of the county are blown by westerly winds and may not be measured by monitors located in Chico (more northerly located); therefore, residents in locations in the county other than Chico may be exposed to higher levels of particulates than what is measured in Chico. Also, CARB has regulated rice burning since the early 1980s and prohibits the burning of rice straw on days with poor air quality and dispersion parameters. Days when burning is permitted are relatively cleaner, with lower measured pollutant values before the burning and weather conditions have an increased capacity to mitigate effects from rice burning. Finally, in Butte County, measurements for PM_{10} were only recorded every sixth day. We were able to calculate daily PM_{10} values based on daily COH measurements, but further error may have been introduced into this study by the lack of actual measurements of PM_{10} on over 80% of the days in this study.

Despite these limitations, burn acreage still showed a slight but statistically significant increase in asthma hospitalization per acre of rice burned when modeled with daily maximum temperature, season, and a term for yearly population. An increased risk of admission per acre of rice burned was still evident in succeedingly more complex models, which also included terms for criteria air pollutants. More suggestively, rice burning demonstrated a clear dose–response association with daily admissions for asthma, with the highest level of acreage burned contributing an excess risk of 23%.

Based on the data from this study, approximately 70,000 acres of rice stubble is burned annually in Butte County. Prior studies have shown that substantial amounts of particulate pollution are generated from rice burning, which is taken up by the atmosphere and transported by the wind in thick, acrid clouds of smoke (*4*). CARB tracks smoke complaints from the public during the intensive fall burning period. From 1981 through 1984, the days with smoke-related complaints averaged over 40% (*5*). While this study failed to demonstrate a statistically significant relationship between rice burn acreage and pollution parameters, the high proportion of smoke-related complaints suggests that some Butte County residents are exposed to the smoke and that air pollution monitoring may not accurately reflect the actual exposures in the population.

Limited studies have been published in the medical literature analyzing the effect of rice burning on pulmonary health, although it has been suggested that rice straw smoke produces an irritant effect to the upper airways (*4*). While no prior population-based studies have been performed to examine this question, McCurdy et al. (*23*) recently published their findings of 464 rice farmers in the northern Sacramento Valley, which demonstrated some elevations in respiratory morbidity. They found that the prevalence for physician-diagnosed asthma (7.1% in their cross-sectional study) was moderately above that seen in population-based studies, such as the National Health Interview Study. While rice farmers are exposed to other occupational agents (dusts and pesticides) that may potentially effect respiratory health, this increased prevalence may also be due in part to exposure to rice burning. McCurdy et al. (*23*) also reported that chronic cough (coughing on most days of the week for 3 consecutive months or more during the year) was associated in a dose–response fashion with reported hours per year of burning rice stubble. While farmers would be expected to have higher exposures than individuals living farther from the fields, exposures to these more distant individuals likely occurs, as evidenced by increases in complaints to CARB, during the fall burning season (*5*). The study of McCurdy et al. (*23*) lends biological credence to the inference that exposure to rice smoke may produce or exacerbate asthma.

The data from Butte County suggests that rice burning (especially on days of high volume burning) may produce a small, but potentially preventable, effect on asthma admissions. The population-attributable risk (PAR; the fraction of the total asthma admissions that would have been prevented if rice burning had not occurred) can be calculated from a formula by Bruzzi et al. (*24*) and was

found to be 2.6% (PAR = 1- $1/x \Sigma\ 1/r_i$, where x = the total number of asthma cases and r = each of the relative risks for admission by burn acreage strata) (*24*). Dividing the total number of asthma hospitalizations in Butte County by the period of the study (2361/10) and multiplying by the PAR (2.6%), we see that approximately six asthma cases/year could be attributable to rice burning. While this number is relatively small, it is important to realize that the majority of individuals who may be affected by rice burning may never become sufficiently ill to require hospitalization. These individuals may include those who regard rice smoke as a nuisance and complain to the air board or are silent about this problem. Those with respiratory or cardiac disease may increase the frequency of their medications during burning episodes, visit their regular physicians, or present at the emergency department without being observed in the OSHPD hospital discharge data base.

Our data suggests that while CARB regulations have been effective in mitigating the problem of air pollution caused by rice burning on the basis of monitoring data analysis, it is less clear that these regulations are as effective in preventing hospitalizations for asthma when hospitalizations are analyzed by actual acreage burned.

Conclusion

Increases in rice straw burn acreage were shown to contribute to hospital admissions for asthma in Butte County, California, during a decade of observation. Rice burn acreage was not correlated to air pollution parameters monitored by CARB in limited parts of the county. These pollution parameters were not associated with increases in asthma hospitalizations. The time–series method, although insensitive compared to traditional case–control methods, demonstrated an apparent association between acres burned and daily asthma admissions. Additionally, a dose–response effect was seen, with the risk of asthma hospitalization increasing as the number of acres burned increased. Future studies should attempt to better clarify exposure perhaps using exposure models broken down by zip code areas. In addition, future studies may consider using visits to emergency rooms or local physicians' offices as a better indicator of respiratory exacerbations. While the use of hospitalization data was considerably easier in terms of time spent extracting records and cheaper in terms of cost, it may have underestimated the number of those affected with asthma because there are many fewer hospitalizations for asthma than visits to emergency rooms.

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