Virginia Journal of Science
Volume 45, Number 4
Winter 1994

Estimated Methane Production by Fauna Under Anthropogenic Influence in Virginia

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ABSTRACT

Methane production by fauna in Virginia was studied at a county-wide scale to determine and characterize regions of methane productivity. Rockingham, Clarke, Augusta, and Wythe counties ranked in the upper fifth percentile of production (> 1,538,719 kg/ha/yr) while Arlington, Buchanan, Dickenson, and Northampton were in the lowest fifth percentile (< 138,306 kg/ha/yr). Because of their high abundance and methane output, cattle constituted the bulk of faunal methane produced in Virginia, and were the prevalent source of methane in counties producing the greatest amount of methane. Termites and deer also produced significant amounts of methane and accounted for a larger proportion of the total in counties producing lower amounts of methane.

INTRODUCTION

Air samples of various ages taken from ice cores in Antarctica and Greenland reveal that atmospheric methane levels have more than doubled during the last century (Craig and Chou, 1982; Stauffer et al., 1985; Khalil and Rasmussen, 1987). Recent findings estimate that the global concentration of atmospheric methane (CH_4) is increasing annually at a rate of 16.6 ± 0.4 ppbv, or 1.02 ± 0.02% (Khalil and Rasmussen, 1990). Increased atmospheric methane concentrations may lead to elevated global temperatures, depletion of hydroxyl radicals (OH) in the troposphere, an increase of stratospheric and tropospheric ozone (O_3), increased atmospheric carbon monoxide (CO), and increased water vapor in the stratosphere (Khalil and Rasmussen, 1985).

The rise in the concentration of atmospheric methane can be attributed to two main factors. The first is elevated methane emissions. Methanogenic bacteria found in the guts of enterically fermenting animals such as cows and termites account for a large portion (15-25%) of global methane production (Crutzen et al., 1986). Anaerobic habitats such as aquatic sediments and lowland rice fields also emit substantial amounts of methane (Sheppard et al., 1982). The rise in methane emissions corresponds with increasing numbers of cows and rice fields needed to feed a growing human population (Ehhalt, 1985). Increasing methane concentrations may also be related to a depletion of its major sink, tropospheric hydroxyl radicals, resulting from an increase in carbon monoxide levels (Khalil and Rasmussen, 1985).

Because of the potential environmental change implicated with increases in methane concentration and its relation to human activities, many studies have attempted to quantify methane production. However, most have only considered global or hemispheric scales. Here, I report the geographic distribution of methane production by fauna at a county-wide scale for Virginia. Smaller scale studies may yield better estimates of the distribution of methane production relative to land use patterns, at a scale where remediation is possible. Furthermore, small scale distributions provide an important tool in assessing any local or regional effects of methane.

METHODS

To estimate methane production by faunal sources at the county scale, estimates of both methane production rates per animal and the abundances of methanogenic animals in each county were needed.

Animals selected were those considered to be major producers of methane and for which methane production rates and abundance were known, or could be calculated. This included most mammalian livestock as well as deer. Small mammalian herbivores such as voles and woodchucks have no established methane production values, but may be a source of small amounts of methane. I used rates of methane production for mammals from Crutzen et al. (1986). Cows have the highest production rate (55.0 kg/cow/year), followed by horses (18.0 kg/horse/yr), deer (15.0 kg/deer/yr), sheep (8.0 kg/sheep/yr), and pigs (1.5 kg/pig/yr). Humans have a rather low methane production rate of 0.05 kg/human/yr. Wood and cellulose eating insects such as termites, as well as some cockroaches and beetles also emit methane, however only termites have available methane production data. For termites, I used a production rate of 0.146×10^{-6} kg/termite/yr (Zimmerman et al., 1982).

Population numbers for livestock were taken from the Census of Agriculture (1987). Deer populations were estimated for each county by multiplying the percent of the total 1990 quarry taken by hunters for a particular county by the estimated Virginia deer population of 850,000 (Virginia Department of Game and Inland Fisheries, 1991). This approach assumes a consistent hunting effort from county to county. Human populations are from the 1990 US census (US Bureau of Census, 1990). I evaluated termite densities for three habitat types. Temperate forest was estimated to have 600 termites/m^2, and termite density for cultivated land was estimated to be 2831 termites/m^2 (Zimmerman et al., 1982). Because these two habitat types are not inclusive of all possible termite habitats, I used a value of 400 termites/m^2 for habitats not included in forested or cultivated land. This value is somewhat more conservative than for agricultural and forested habitats because it includes areas uninhabitable by termites (e.g. lakes), however this category also includes urban and suburban areas which may support high termite densities. Areas of each county were taken from the 1990-91 report of the Secretary of the Commonwealth, forested acres were taken from the 1985 survey of timberland (Virginia Department of Forestry, 1986), and agricultural acreage was taken from the 1987 census of agriculture. The sum of agricultural and forested land was subtracted from the total county area to arrive at an area for the third habitat category.

To calculate faunal methane production, abundances of each animal in each county were multiplied by their respective production rate (kg/individual/yr). Gross methane production was divided by the area of each county to generate a

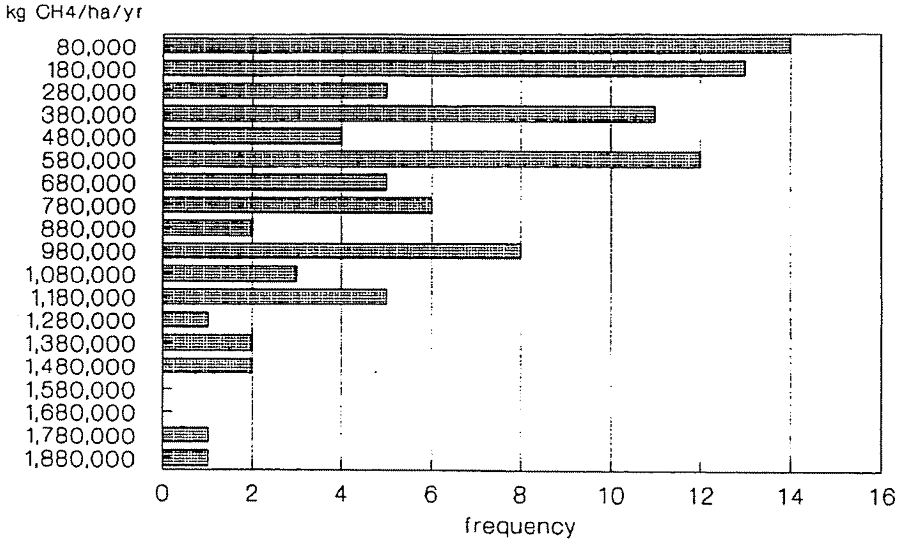

FIGURE 1. The frequency distribution showing the number of counties versus methane production (thousand kg/ha/yr). Midpoints of the classes were separated by 100,000 kg/ha/yr. Mean county methane production was 665,889 46,361 and ranged from 70,966 to 1,965,033 kg/ha/yr.

methane production rate per unit area. To characterize productive regions, methane production per hectare was plotted for each county and used to create a map of faunal methane production. Complete data for Suffolk, Chesapeake and Virginia Beach counties, as well as incorporated cities were not available, and were not used in any analysis.

To evaluate differences in the sources of faunal methane between counties producing high or low amounts of faunal methane, the percentage of the gross methane production attributable to each source was compared between counties in the uppermost quartile, the middle 50%, and in the lowest quartile of methane production per hectare using multivariate analysis of variance (MANOVA). Before analysis percentages from each source were arcsine square-root transformed to better meet the assumptions of homoscedasticity and normality (Sokal and Rohlf, 1981).

RESULTS

The total faunal methane production for Virginia was estimated to be 112,186,000 kg methane/yr. By virtue of their high production rate and abundance, cows accounted for 74.1%, or 83,101,000 kg/yr of the faunal methane produced in Virginia. Termites produced 13,643,000 kg/yr, or 12.0% of the total production, followed by deer producing 12,751,000 kg/yr or 11.4%. Pigs, horses, sheep, and humans together produced 1,600,000 kg/yr and accounted for < 3% of the total faunal methane production.

Mean county-wide faunal methane production for Virginia was 665,889 ± 46,361 kg/ha/yr. The distribution of methane production by individual counties

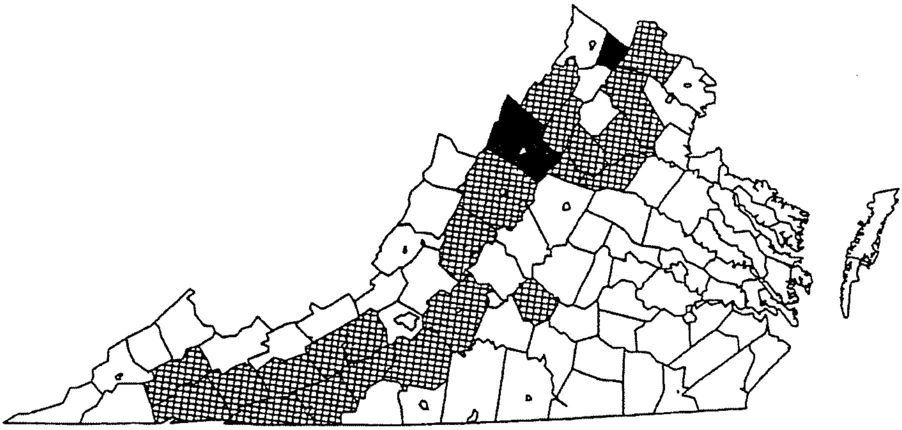

FIGURE 2. The distribution of methane production by county in Virginia. Counties producing greater than 1,800,000 kg/ha/yr are indicated by a solid pattern. Those with methane production between 1,200,000 and 1,800,000 are crosshatched, and those less than 600,000 are outlined only. Areas for which no data was available appear as open areas within counties or have no outline (see text).

(Figure 1) ranged from 70,966 to 1,965,033 kg/ha/yr, and was skewed to the right, i.e. counties with low production were closer to the mean than counties with high production. Rockingham, Clarke, Augusta, and Wythe counties were in the upper fifth percentile of methane production (> 1,538,719 kg/ha/yr), while Arlington, Buchanan, Dickenson, and Northampton, were in the lowest fifth percentile (< 138,306 kg/ha/yr).

Faunal methane production in Virginia showed a general increase moving from east to west, with the lowest areas being along the coast (Figure 2). Areas of high faunal methane production were generally in the western part of the state, in and around the Blue Ridge and Shenandoah Valley regions.

The contribution of sources of faunal methane production showed significant differences between counties in the highest quartile, middle 50%, and lowest quartile of gross methane production (MANOVA, Hotelling's $T^2 = 2.74$, approx. $F_{14} = 17.44$, $P < 0.00$). Univariate F-tests also showed significant differences in the percent composition of methane sources between counties producing high, medium, and low amounts of faunal methane for all sources except horses (Table 1). Cows, deer, and termites dominated methane production across all methane production levels. The proportion of total production attributable to bovine sources showed a general increase as gross faunal methane production increased, whereas the proportions from deer and termites tended to decrease with increasing methane production (Table 2).

DISCUSSION

This study shows that regionally high faunal methane production is generally a function of cattle farming. Percent composition data tends to confirm that cows

TABLE 1. Univariate F-tests comparing the arcsine square-root transformed percentage of gross methane production comprised by each source between counties producing high (upper 25th percentile), moderate (middle 50th percentile), and low (lowest 25th percentile) amounts of methane.

	Hypoth. MS	Error MS	$F_{2,98}$	P
DEER	0.37437	0.02612	14.33297	0.000
COWS	2.22362	0.02993	74.28289	0.000
PIGS	0.02014	0.00609	3.30471	0.041
HORSES	0.00633	0.00205	3.09413	0.050
SHEEP	0.02713	0.00257	10.56508	0.000
HUMANS	0.07782	0.00648	12.00986	0.000
TERMITES	0.82930	0.01213	68.34851	0.000

TABLE 2. Means and standard errors of the percentage of gross methane production for each methane source in counties producing high (upper 25th percentile), moderate (middle 50th percentile), and low (lowest 25th percentile) amounts of methane.

Source	High (N=24)	Moderate (N=50)	Low (N=25)
DEER	0.07 ± 0.01	0.19 ± 0.01	0.26 ± 0.04
COWS	0.82 ± 0.01	0.61 ± 0.03	0.29 ± 0.03
PIGS	0.00 ± 0.00	0.01 ± 0.00	0.02 ± 0.00
HORSES	0.01 ± 0.00	0.01 ± 0.00	0.02 ± 0.00
SHEEP	0.01 ± 0.00	0.01 ± 0.00	0.00 ± 0.00
HUMANS	0.00 ± 0.00	0.00 ± 0.00	0.03 ± 0.02
TERMITES	0.09 ± 0.00	0.17 ± 0.01	0.38 ± 0.03

are responsible for the bulk of production in counties that produce large amounts of methane, both because of their abundance and high methane production rate. Termites and deer tend to produce approximately equal percentages of methane in high production counties, while in counties with lower methane production termites become the major source. Counties (e.g. Arlington) that are generally more urban, have smaller deer and livestock populations, and thus produce less methane from faunal sources. Termites however, are fairly ubiquitous and may be a major source of methane in all areas.

Land usage may be a good predictor of methane production. Unlike most atmospheric pollution problems (e.g. carbon monoxide), methane is associated with rural rather than urban or industrial areas. The counties producing the highest amounts of methane in Virginia tended to be agrarian counties, devoted to livestock farming. Identifying major sources of methane and typifying the productive regions provides an important first step towards any mediation of the problem.

Despite providing an approximation of faunal methane production this study has obvious limitations. Much conjecture also surrounds the importance of methane production by termites (cf. Collins and Wood, 1984). County-wide habitat data was available only for forested and agricultural land necessitating a catch-all category. This approximation introduces some error because the category encompasses habitats where no termites live and other areas of possible high density. Methane production also varies from termite species to species and is habitat and temperature dependant (Collins and Wood, 1984), thus finding an adequate estimate for both termite density and methane production is difficult.

Another limitation of this study is that it only considers faunal sources of methane, which globally account for only approximately 15-25% of methane emissions (Crutzen et al., 1986). Almost any anaerobic habitat produces methane. Production for wetlands, lakes, and streams are not included, and may comprise up to 75% of global methane emissions (Sheppard et al., 1982). These sources, however, are generally not under human control for and constitute 'natural' background methane emissions. Non-biogenic, anthropogenic sources, such as biomass burning, natural gas refining, and asphalt production were also not included in this analysis, and may account for 10-15% of global emissions (Sheppard et al., 1982). Thus the total amount of methane produced will be higher than would be estimated using only a faunal approach.

Despite these limitations, the results of this study show that agricultural counties, especially those devoted to cattle farming, may have high levels of methane production and that the bulk of faunal methane in Virginia is produced in the Shenandoah Valley region. Urban/suburban and crop farming counties tend to produce less faunal methane with non-bovine sources accounting for a greater proportion of the total.

ACKNOWLEDGEMENTS

I would like to thank M. Bowers, E. Connor, J. Dooley, B. Hayden, and an anonymous reviewer for helpful comments on this manuscript.

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