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Recent Geographic Patterns of Lung Cancer and Mesothelioma Mortality Rates in 49 Shipyard Counties in the United States, 1970–94

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Background *Lung cancer mortality rates among white males in the United States were observed to be elevated during 1950–69 in counties with shipbuilding industries during World War II; risk was found to be associated with asbestos exposure. We evaluated the geographic patterns in more recent years, 1970–94, for whites and compared them with the 1950–69 patterns.*
Methods *We calculated age-adjusted rates and estimated rate ratios between comparison groups.*
Results *Rates generally were higher in shipyard counties than in all nonshipyard counties and in coastal nonshipyard counties for both sexes and time periods. Rates increased markedly from 1950–69 to 1970–94 in all groups, with the changes more pronounced in females than males. Pleural mesothelioma mortality rates were also significantly higher in shipyard counties than coastal nonshipyard counties in all regions among males but not among females.*
Conclusion *The more pronounced changes in lung cancer mortality rates among females in shipyard counties may be attributed to the combined effects of low asbestos exposures and changes in smoking behavior.* Am. J. Ind. Med. 37:512–521, 2000.
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KEY WORDS:* *asbestos; lung cancer; mesothelioma; shipyard; shipbuilding

INTRODUCTION

Mapping the distribution of lung cancer mortality rates for white males in the United States for the 1950–69 period revealed that counties with high rates clustered along the northeast and south coasts [Mason et al., 1975]. To identify possible reasons, an ecological study of respiratory cancer mortality in 49 shipyard counties was conducted, and elevated mortality rates in shipyard counties compared to nonshipyard counties were reported [Blot et al., 1979]. Subsequent analytical studies [Blot et al., 1978, 1980, 1982; Harrington et al., 1978; Gottlieb et al., 1979; Kolonel et al., 1980, 1985] consistently found shipyard employment and asbestos exposure to be risk factors for lung cancer, with risk ratios ranging from 1.4 to 1.7. Similar results were documented in many countries, including the United Kingdom [Irvine et al., 1993] and Italy [Puntoni et al., 1979].

In this paper, we report the changing patterns of lung cancer mortality rates among white males and females in the 49 shipyard counties of the United States compared with coastal nonshipyard counties and all nonshipyard counties. In addition, we present the rates of pleural mesothelioma among whites residing in the shipyard and nonshipyard counties.

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MATERIALS AND METHODS

The shipyard counties used in this study, as defined in the previous ecological respiratory cancer mortality study [Blot et al., 1979], are the 49 counties where there was construction or repair of 2000-ton ships during World War II [Fasset, 1948; Blot et al., 1979]. The remaining counties were considered as a group, and a subgroup of 222 coastal nonshipyard counties was identified.

Based on mortality data from the National Center for Health Statistics (NCHS) and population estimates based on Census Bureau data, sex-specific cancer mortality rates directly age-adjusted to the 1970 U.S. population were computed for two study periods (1950–69, 1970–94) for whites residing in shipyard and nonshipyard counties of the entire US and of only coastal regions. The 95% confidence intervals for the ratios of the standardized rates were obtained using the Miettinen [1972] method. Variations in lung cancer mortality rates were investigated in shipyard and nonshipyard counties according to region (Midwest, Northeast, South, and West), degree of urbanization (urban and rural), and population size category ($\leq 250{,}000$; $>250{,}000$ to 1 million; >1 million to 2.5 million; >2.5 million).

Deaths due to cancer of the lung, bronchus, trachea, and pleura [International Classification of Disease (ICD), 9th revision, codes 162, 163 (WHO, 1977)] were included in the lung cancer mortality data. Pleural mesothelioma (ICD code 163) rates were calculated only for 1970–94 because the pleura did not have a separate ICD code until 1968; these rates were analyzed only by region, due to sparse data. Maps were prepared with ATLAS PRO/GIS to show the shipyard and nonshipyard counties and the rankings of the mortality rates by decile, as described in Devesa et al. [1999]. Criteria for a county to have rates based on sparse data are as stated for State Economic Areas by Devesa et al., [1999].

RESULTS

Figure 1 shows the location of the 49 shipyard and 222 coastal nonshipyard counties. Lung cancer mortality rates among white males during 1970–94 were elevated across broad stretches of the southeast, particularly along the eastern seaboard, across the Gulf coast, and along the Mississippi valley (Figure 2a), in contrast to high rates during 1950–69 in urban areas of the Northeast, in areas along the southeast Atlantic and Gulf coasts and throughout the far West (Figure 2b). Rates among white females were elevated during 1970–94 along both the Atlantic and Pacific coasts, including most of Florida and California (Figure 3a), whereas there was only limited clustering of high rates during 1950–69 (Figure 3b).

In most instances, rates were higher in the urban than rural counties, especially in the past (Table I). In all regions except the Midwest, lung cancer mortality among males was significantly higher in the shipyard than nonshipyard

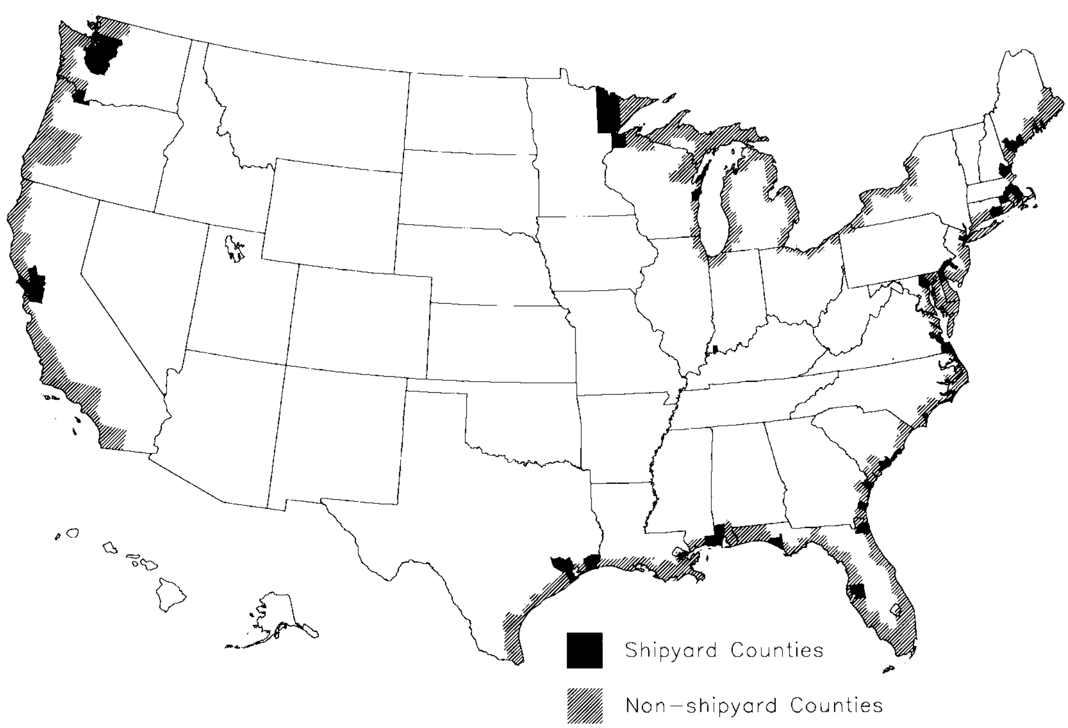

FIGURE 1. Locations of shipyard and coastal nonshipyard counties.

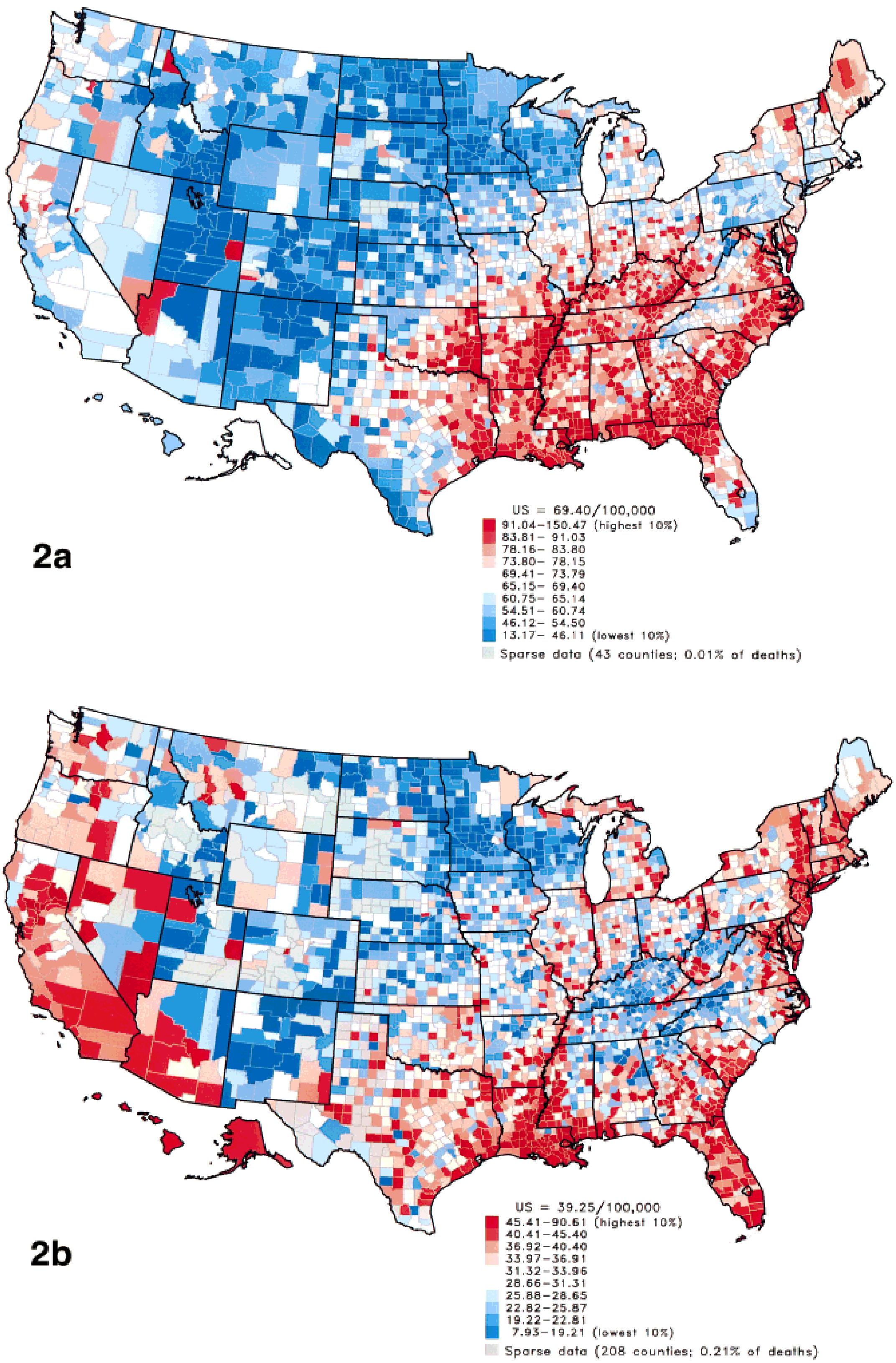

FIGURE 2. Lung cancer mortality rates among white males for 1970–94 (a) and 1950–69 (b).

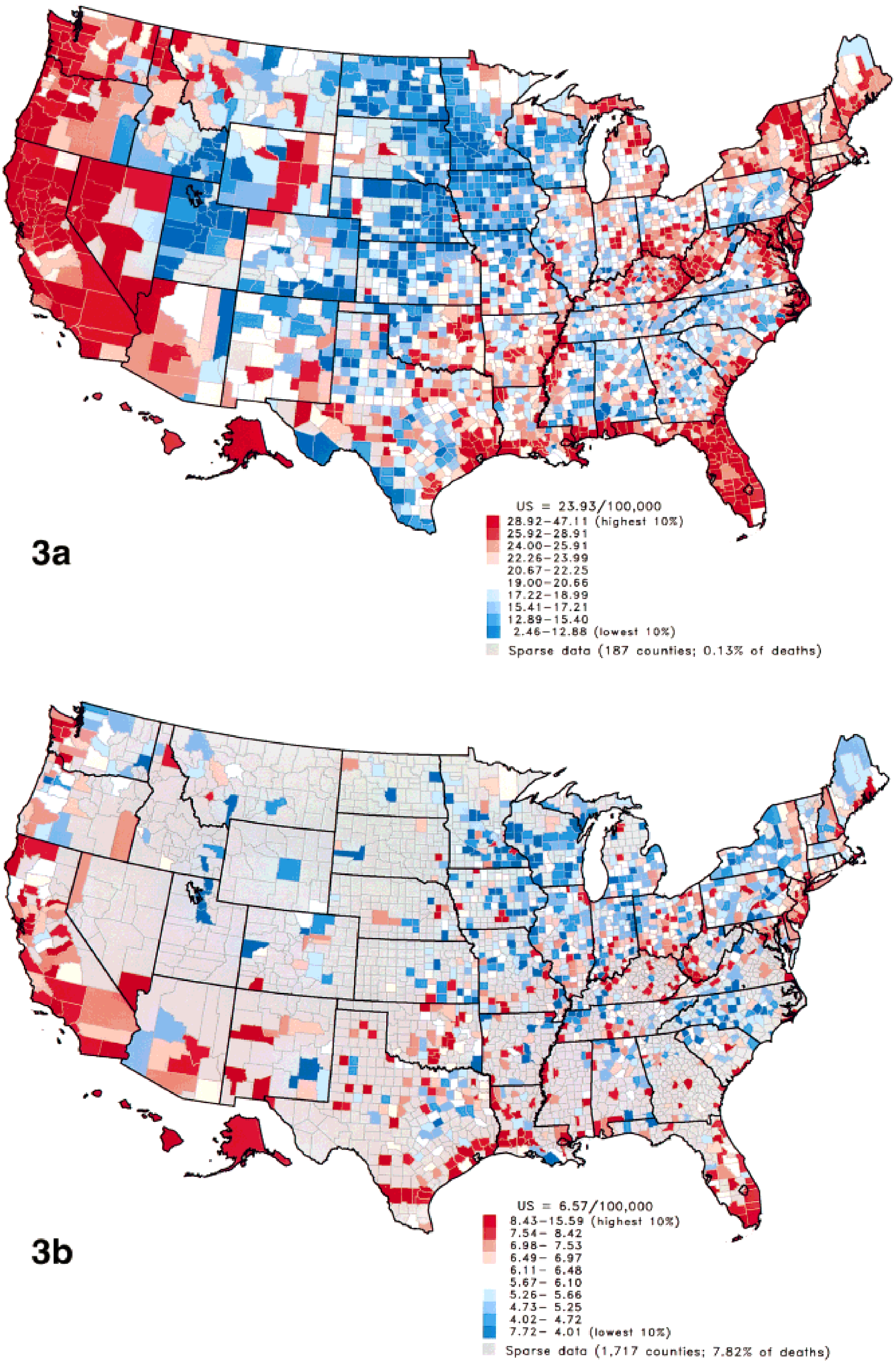

FIGURE 3. Lung cancer mortality rates among white females for 1970–94 (a) and 1950–69 (b).

TABLE I. Lung Cancer Mortality Rates (per 100,000 Person-Years) in Shipyard (SYC), Nonshipyard (NSYC), and Coastal Nonshipyard Counties (CNSYC) by Region and Degree of Urbanization

	White males				White females			
	Northeast	South	West	Midwest	Northeast	South	West	Midwest
Rural, 1950–69								
SYC	41.32	49.42	33.70	30.09	6.36	6.50	6.11	5.97
NSYC	36.35	34.24	31.48	29.52	5.73	5.69	5.81	5.22
CNSYC	40.75	44.12	33.98	33.45	6.58	6.32	6.88	5.21
Rural, 1970–94								
SYC	71.31	90.94	67.92	57.13	28.00	30.29	30.10	18.70
NSYC	67.60	78.37	60.37	64.93	22.63	22.77	24.59	19.72
CNSYC	71.51	75.69	67.70	63.90	26.45	28.77	30.57	21.46
Urban, 1950–69								
SYC	50.02	58.03	43.12	39.27	7.60	8.29	7.87	7.55
NSYC	45.67	45.20	40.09	43.40	7.53	7.20	7.32	6.85
CNSYC	47.42	48.05	42.24	46.83	7.95	7.80	7.93	7.34
Urban, 1970–94								
SYC	74.73	85.98	66.77	85.25	25.34	30.45	28.89	26.37
NSYC	65.42	73.00	60.64	71.82	23.51	25.83	26.16	24.47
CNSYC	64.04	65.63	60.95	71.30	23.51	26.83	27.38	24.00

counties, during both time periods (Table II). Rates among females were also elevated in shipyard counties, although not always significantly, in all regions except the Midwest (Table III). Restricting the comparison to the 222 coastal nonshipyard counties (Figure 1) generally reduced the rate ratios of shipyard to nonshipyard counties, becoming less than one in several instances, more so in rural than urban counties. The ratios remained significantly elevated, however among males in the South, were higher in the urban than rural areas, and increased over time. Among females, three of the four ratios in the South were significantly elevated, where the ratios also were higher in urban areas and rose over time. Elevated ratios became apparent during 1970–94 among females in the urban areas of the Midwest and West, and in urban and rural areas of the Northeast. Accounting for population size had very little influence on the comparisons between the shipyard and nonshipyard categories (data not shown).

Rates increased over time among both males and females (Tables II and III). The temporal rate ratios (1970–94 to 1950–69) were twice as high among females than males, and among females they tended to be higher in shipyard than nonshipyard counties, except in the Midwest, in both rural and urban areas. When county-specific lung cancer mortality rates were ranked for each sex and study period, the proportion of shipyard counties in the top 10% for females rose from 22.4% in 1950–69 to 51.0% in 1970–94 (Table IV). In contrast, the proportion of shipyard counties in the top 10% for males dropped from 53.0% in 1950–69 to 14.3% in 1970–94. The proportion of coastal nonshipyard counties with rates in the top 10% also rose among females and declined among males, but the corresponding percentages were lower in the coastal nonshipyard counties than in the shipyard counties in each instance. Ranking of rates for shipyard counties by proportion of the population employed in the shipbuilding industry during the second World War showed a slight but unconvincing pattern (data not shown).

Pleural mesothelioma mortality rates were much lower than those for lung cancer (Table V). However, regional rates among males during 1970–94 were significantly higher in shipyard counties than coastal nonshipyard counties, with rate ratios (shipyard/nonshipyard counties) ranging from 1.2 in the Northeast to 2.3 in the West. The rates among females, much lower than among males, were higher in shipyard counties than coastal nonshipyard counties in the South and West and lower in the Midwest and Northeast, but none of the differences was significant.

DISCUSSION

Our data showed that lung cancer mortality rates among females during 1970–94 were significantly higher ($P < 0.05$) in shipyard counties than coastal nonshipyard

TABLE II. Lung Cancer Mortality Rate Ratios Within and Between Shipyard (SYC), Nonshipyard (NSYC), and Coastal Nonshipyard Counties (CNSYC) by Region and Degree of Urbanization, White Males

	White males							
	Northeast		South		West		Midwest	
	Ratio	95% CI	Ratio	95% CI	Ratio	95% CI	Ratio	95% CI
Rural, 1950–69								
SYC/NSYC	1.14	1.09–1.18	1.44	1.34–1.55	1.07	1.01–1.13	1.02	0.96–1.08
SYC/CNSYC	1.01	0.97–1.06	1.12	1.05–1.20	0.99	0.93–1.06	0.90	0.85–0.95
Rural, 1970–94								
SYC/NSYC	1.05	1.03–1.08	1.16	1.13–1.20	1.13	1.10–1.15	0.88	0.85–0.91
SYC/CNSYC	1.00	0.97–1.02	1.20	1.16–1.24	1.00	0.97–1.03	0.89	0.86–0.93
Rural, 1970–94/1950–69								
SYC	1.73	1.66–1.80	1.84	1.74–1.95	2.02	1.92–2.12	1.90	1.78–2.02
NSYC	1.86	1.84–1.88	2.29	2.27–2.30	1.92	1.90–1.95	2.20	2.18–2.22
CNSYC	1.75	1.71–1.80	1.72	1.68–1.75	1.99	1.93–2.06	1.91	1.86–1.96
Urban, 1950–69								
SYC/NSYC	1.10	1.08–1.11	1.28	1.26–1.31	1.08	1.05–1.10	0.90	0.84–0.98
SYC/CNSYC	1.05	1.04–1.07	1.21	1.18–1.23	1.02	1.00–1.04	0.84	0.78–0.91
Urban, 1970–94								
SYC/NSYC	1.14	1.13–1.15	1.18	1.17–1.19	1.10	1.09–1.12	1.19	1.13–1.25
SYC/CNSYC	1.17	1.15–1.18	1.31	1.29–1.33	1.10	1.08–1.11	1.20	1.14–1.26
Urban,1970–94/1950–69								
SYC	1.49	1.47–1.52	1.48	1.46–1.50	1.55	1.52–1.58	2.17	1.99–2.37
NSYC	1.43	1.42–1.44	1.62	1.60–1.63	1.51	1.50–1.53	1.65	1.64–1.67
CNSYC	1.35	1.34–1.36	1.37	1.34–1.39	1.44	1.42–1.46	1.52	1.51–1.54

counties, except in rural counties in the West and Midwest. More importantly, the proportion of shipyard counties in the top decile of all rates among females markedly increased, from 22.4% in 1950–69 to 51.0% in 1970–94. These patterns might be related to later increases in cigarette smoking prevalence and to lower asbestos exposure, compared to males, resulting in longer latency periods after first exposure.

Smoking and asbestos exposure have a synergistic effect on lung cancer [Selikoff et al., 1968; Hammond and Selikoff, 1973; Saracci, 1977; Blot et al., 1978]. Selikoff and his colleagues [1968] reported that the risk of dying from lung cancer among asbestos workers who smoke was eight times higher than for nonsmoker asbestos workers and 92 times higher than for nonsmoker nonasbestos workers. Also, Blot and his coworkers [1978] documented that the relative risk of lung cancer for shipbuilders increased from 1.8 in workers who had stopped smoking at least 10 years previously to 8.6 in workers who smoked 2–3 packs of cigarettes a day. Data on smoking patterns are scarce. No historical data are available on smoking at the county level to correlate with the distribution of lung cancer mortality in shipyard and nonshipyard counties. The earliest sex-specific smoking data available at the state level are for 1985, although the data are not race-specific [Shopland et al., 1992; Devesa et al., 1999]. Nevertheless, females in the United States started smoking later than men, with the highest percentage of smoking occurring among the 1931–40 birth cohorts, in contrast to the 1921–30 birth cohorts among men [Harris, 1983], a difference of about 10 years. Thus, the high proportion of shipyard counties in the top decile of rates among females for the recent period might be due to the later synergistic effect of asbestos and cigarette smoking. Nicholson and his colleagues [1982] projected that the excess lung cancer deaths related to shipbuilding and repair will peak around in 1990 among women. The contrasting decline in the proportion of shipyard counties in the top decile of rates among men may be due to a relative declining effect of asbestos exposure in men; lung cancer mortality related to shipbuilding was projected to peak in 1985 [Nicholson et al., 1982]. The earlier widespread prevalence of smoking among men is the dominant factor influencing the recent lung cancer mortality patterns. Camus

TABLE III. Lung Cancer Mortality Rate Ratios Within and Between Shipyard (SYC), Nonshipyard (NSYC), and Coastal Nonshipyard Counties (CNSYC) by Region and Degree of Urbanization, White Females

	White females							
	Northeast		South		West		Midwest	
	Ratio	95% CI	Ratio	95% CI	Ratio	95% CI	Ratio	95% CI
Rural, 1950–69								
SYC/NSYC	1.11	1.01–1.22	1.14	0.97–1.35	1.05	0.92–1.20	1.15	1.00–1.32
SYC/CNSYC	0.97	0.87–1.07	1.03	0.87–1.22	0.89	0.77–1.02	1.15	0.99–1.33
Rural, 1970–94								
SYC/NSYC	1.24	1.20–1.28	1.33	1.27–1.40	1.23	1.18–1.28	0.95	0.89–1.01
SYC/CNSYC	1.06	1.02–1.10	1.06	1.01–1.10	0.98	0.94–1.03	0.87	0.82–0.92
Rural, 1970–94/1950–69								
SYC	4.40	4.11–4.72	4.66	4.19–5.18	4.93	4.52–5.38	3.13	2.77–3.53
NSYC	3.95	3.88–4.03	4.00	3.95–4.06	4.23	4.12–4.33	3.78	3.72–3.84
CNSYC	4.02	3.84–4.21	4.55	4.39–4.73	4.44	4.20–4.70	4.12	3.92–4.33
Urban, 50–69								
SYC/NSYC	1.01	0.98–1.04	1.15	1.11–1.20	1.08	1.03–1.12	1.10	0.92–1.32
SYC/CNSYC	0.95	0.92–0.99	1.06	1.01–1.12	0.99	0.95–1.04	1.03	0.87–1.22
Urban, 1970–94								
SYC/NSYC	1.08	1.06–1.09	1.18	1.16–1.20	1.10	1.08–1.12	1.08	1.00–1.16
SYC/CNSYC	1.08	1.06–1.10	1.13	1.12–1.15	1.06	1.04–1.07	1.10	1.02–1.19
1970–94/1950–69								
SYC	3.33	3.25–3.43	3.67	3.57–3.77	3.67	3.55–3.80	3.49	2.99–4.07
NSYC	3.12	3.08–3.16	3.59	3.53–3.65	3.57	3.52–3.63	3.57	3.52–3.62
CNSYC	2.96	2.91–3.00	3.44	3.34–3.54	3.45	3.38–3.52	3.27	3.20–3.34

TABLE IV. Ranks of Lung Cancer Mortality Rates in the 49 U.S. Shipyard Counties and Coastal Nonshipyard Counties

	White males						White females					
	1950–69			1970–94			1950–69			1970–94		
Rank (%)	No.	%	Cum. %[a]	No.	%	Cum. %[a]	No.	%	Cum. %[a]	No.	%	Cum. %[a]
Shipyard counties												
Highest 10%	26	53.0	53.0	7	14.3	14.3	11	22.4	22.4	25	51.0	51.0
10-19.99	9	18.4	71.4	11	22.4	36.7	15	30.6	53.0	16	32.6	83.6
20-29.99	7	14.3	85.7	7	14.3	51.0	13	26.5	79.5	1	2.0	85.6
30-49.99	5	10.2	95.9	10	20.4	71.4	7	14.3	93.8	5	10.2	95.8
≥ 50	2	4.0	100	14	28.5	100	3	6.1	100	2	4.1	100
Coastal nonshipyard counties												
Highest 10%	66	29.7	29.7	28	12.6	12.6	42	18.9	18.9	84	37.8	37.8
10–19.99	42	18.9	48.6	22	9.9	22.5	38	17.1	36.0	43	19.4	57.2
20–29.99	42	18.9	67.5	16	7.2	29.7	31	14.0	50.0	29	13.1	70.3
30–49.99	39	17.6	85.1	64	28.8	58.5	44	19.8	69.8	36	16.2	86.5
≥ 50	33	14.9	100	92	41.4	100	67	30.2	100	30	13.5	100

[a]Cumulative %.

TABLE V. Pleural Mesothelioma Mortality Rates (per 100,000 Person-Years) in U.S. Shipyard (SYC) and Coastal Nonshipyard (CNSYC) Counties, 1970–94

		White males		White females	
Region	**Counties**	**Rate**	**95% CI**	**Rate**	**95% CI**
US		0.269	0.263–0.276	0.066	0.063–0.068
Northeast					
	SYC	0.386	0.342–0.431	0.076	0.059–0.093
	CNSYC	0.319	0.295–0.343	0.078	0.067–0.088
	Ratio[a]	1.21	1.05–1.40	0.97	0.75–1.27
South					
	SYC	0.470	0.418–0.523	0.080	0.062–0.099
	CNSYC	0.369	0.338–0.400	0.078	0.065–0.091
	Ratio[a]	1.27	1.10–1.48	1.03	0.77–1.37
West					
	SYC	0.636	0.572–0.699	0.086	0.066–0.106
	CNSYC	0.280	0.253–0.307	0.066	0.054–0.078
	Ratio[a]	2.27	1.93–2.66	1.30	0.95–1.77
Midwest					
	SYC	0.563	0.387–0.740	0.069	0.003–0.134
	CNSYC	0.276	0.249–0.302	0.091	0.077–0.104
	Ratio[a]	2.04	1.31–3.18	0.76	0.32–1.77

[a]Ratio: SYC/CNSYC.

et al. [1998] recently studied the risk of death due to lung cancer among women in two chrysotile-asbestos–mining areas of the province of Quebec, Canada, and found no measurable excess risk. However, it is noteworthy that asbestos exposure from mills and mines carries much less risk compared to asbestos exposure from industries [McDonald et al., 1980; Dement et al., 1983]. The percentage of women currently smoking during 1989 was slightly less in the two asbestos mining areas (25%) than in the reference areas (31%); the authors believed that the confounding effect from this differential smoking pattern was not substantial. The Quebec smoking percentages are comparable to the U.S. female rates of 28 and 24% during 1985 and 1990, respectively [Pamuk et al., 1998]. Unfortunately, we have no data regarding smoking prevalence in the coastal counties, but the prevalence may have been higher, as suggested by the elevated lung cancer mortality rates.

In presenting a model for estimating lung cancer risk at low levels of asbestos exposure, Enterline [1978] assumed that the time to develop a tumor (latency) was dose-dependent, in that a lower dose requires a longer time to tumor appearance. Compared to males, asbestos exposure levels in females were low. Females accounted for only 10–20% of the total U.S. shipyard industry work force in 1944–45, with relatively short periods of employment [Selikoff et al., 1979]. Also, nonoccupational sources of asbestos exposure to females, including residing in an environment close to an asbestos-processing facility [McDonald, 1985] or having a member of the family working in the shipyard industry [Kilburn et al., 1985], are likely to be low-level. No epidemiologic studies have attempted to validate Enterline's hypothesis that asbestos-induced lung cancer latency is dose-dependent, except for a preliminary study by Liddell [1980] that failed to support the hypothesis. Nevertheless, the relatively high lung cancer mortality rates among women in U.S. shipyard counties in the recent period might be a result of long latency after low levels of asbestos exposure, in line with Enterline's hypothesis.

Until 1950, when the wide industrial use of asbestos began, the incidence of mesothelioma among both males and females was about the same, averaging two per million [Ross and McDonald, 1995]. Since then, however, the rate has increased steeply among males but not among females, as reported in Canada [McDonald and McDonald, 1980], the United States [Connelly et al., 1987], and Great Britain [Ross and McDonald, 1995]. Using SEER data, Connelly and his coworkers noted that the incidence of pleural mesothelioma among white males in the United States rose from 5.1 per million per year in 1973 to 14.1 in 1984, whereas in females, the rate remained fairly stable at approximately two. Incidence for the most recent period (1990–95) in the US, using the same data source, was 16.3 per million among white males and 2.6 among females (SEER, 1973–95), indicating that the rate is still increasing among men but at a less rapid rate. In view of these findings, the differences in mortality rates for males and females in Table V are not unexpected.

The reasons for the underlying sex difference in trends of mesothelioma are unclear. Spirtas et al. [1994] reported that the attributable risks of asbestos exposure for pleural and peritoneal mesothelioma were 88 and 58%, respectively, among males and 23% for the combined sites among females. McDonald [1985] suggested that the contribution of environmental exposure to the development of pleural mesothelioma is trivial. From a different perspective, Tagnon et al., [1980] suggested that more intense exposure may be necessary to induce mesothelioma than to induce lung cancer, based on their finding that, compared to lung cancer patients, most mesothelioma patients in coastal Virginia were carrier employees and worked as pipe coverers and pipe fitters, whose asbestos exposure was likely to be intense. Thus, the underlying sex difference in pleural mesothelioma mortality trends may be only a reflection of the low proportion of women working in the shipbuilding or asbestos-processing industries, and thus of their lower exposure to asbestos. This reasoning may also explain the lack of significant differences between shipyard and coastal nonshipyard counties in mesothelioma mortality rates among females.

Lung cancer mortality rates tended to be higher in urban than rural counties. Moreover, most of the differences between the shipyard and coastal nonshipyard counties were due to differences between urban counties. The proportion of urban counties in shipyard counties is much lower in the West (20%) than in the rest of the regions (>60%). As a result, the majority of comparisons in the West were nonsignificant. The same explanation can be given for the apparently more pronounced differences between shipyard and nonshipyard counties by ranking than by rate ratio estimates. About 63% of shipyard counties were urban, compared to 20% of coastal nonshipyard counties.

Over the study period, lung cancer mortality rates increased substantially. Thus, in preparing the maps, we ranked the county-specific rates and created the deciles for each race-, sex-, and period-specific map independently, resulting in the use of different scales for each map. If we were to use the same scale for all the maps, most of the counties in the earlier period would have been blue and most of the counties in the recent period would have been red, making interpretation of geographic variation within each time period much more difficult.

It would have been interesting to stratify the World War II shipyard counties according to whether shipbuilding continued in the post-war years. We were not able to find data to separate the 49 shipyard counties with respect to continuing post-war shipbuilding status. However, the total number of workers employed in shipyards in the US decreased dramatically, from about 1.68 million in 1944 [U.S. Bureau of Labor Statistics, 1945] to 98,000 in 1996 [U.S. Bureau of Census, 1998].

Our study has certain limitations. Exposure was not linked to individuals. Data on cigarette smoking prevalence, the dominant risk factor for lung cancer, were unavailable at the county level, making it impossible to investigate differential smoking habits. It is possible that women married to shipyard workers were more likely to smoke than women married to nonshipyard workers.

The relationship between asbestos exposure and lung cancer is well established and causal. Therefore, the slight but significantly higher rates in shipyard counties than nonshipyard coastal counties, not apparent earlier among females, and the substantial increase in the proportion of shipyard counties in the top decile of rates among females in the recent period may reflect (1) exposure to low levels of asbestos, occupationally or possibly from contaminated household environments; (2) the earlier adoption of smoking among females in shipyard than coastal nonshipyard counties; and (3) the later adoption and the lower lifetime cumulative prevalence of cigarette smoking among women compared to men, resulting in a longer latent period from first asbestos exposure.

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