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Every breath you take? Environmental justice and air pollution in Christchurch, New Zealand

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Abstract. In a number of environmental-justice studies it has been noted that the exposure to an array of air pollutants varies between different social groups. This inequality in exposure is one possible explanation for the variations in pollution-related health outcomes such as lung cancer and other respiratory diseases. Previous environmental-justice studies that have focused upon air pollution have tended to be concerned with exposure to industrial and vehicle pollution and rely upon simple estimates of exposure, ignoring the complex interaction of emissions, topography, and meteorology that determine pollution levels in many urban areas. In this paper we use accurate and geographically detailed estimates of pollution calculated from an atmospheric dispersion model to examine issues of environmental justice related to air pollution sourced from domestic heating in Christchurch, New Zealand, a city with particularly high levels of particulate pollution during winter months. We consider whether there is a social gradient in exposure to air pollution in Christchurch by comparing estimates of particulate pollution for small areas across the city to a range of demographic and socioeconomic indicators including age, ethnicity, income, and deprivation. Furthermore, we examine whether there is a social gradient in exposure to extreme pollution episodes. We demonstrate that different social groups in the Christchurch population are exposed to different levels of both ambient air pollution and extreme air-pollution episodes. In particular, pollution is significantly higher among more disadvantaged communities. We also find evidence which suggests that the groups responsible for producing a large proportion of the pollution in Christchurch are not the same groups exposed to high levels of particulate air pollution.

Introduction

A number of epidemiological studies have found air pollution to be a significant cause of various types of ill health. Exposure to air pollutants such as nitrogen dioxide, particulate pollution, carbon monoxide, sulphur dioxide, and ozone have been shown to be significantly related to several health outcomes including mortality and morbidity, specific diseases such as lung cancer and chronic respiratory diseases, as well as hospital admissions (Brunekreef and Holgate, 2002). In addition, it has been noted in a number of studies that there is a social gradient in these health outcomes, with higher rates of ill health among the more socially and materially disadvantaged (Boyle et al, 2004). A number of possible explanations for the social inequalities in health outcomes and status have been suggested including differences in employment type, housing quality, material deprivation, and access to health-care provision (Graham, 2000). Recently, the results of a number of studies have demonstrated that there is also a social gradient in the mean exposure to ambient air pollution with higher levels of exposure among socially disadvantaged groups. For this reason, it has been suggested that inequality in exposure to air pollution is one pathway that may help to explain the socioeconomic variations in types of ill health where air pollution is a significant aetiological factor. It has been noted that not only do more-socially-deprived groups have higher exposure to air pollution but because of material deprivation and psychosocial stress, they may be more susceptible to the health effects of air pollution and hence suffer greater effects from exposure (O'Neill et al, 2003).

These concerns with the disproportionate burden of environmental problems among disadvantaged social groups have led to a growing interest among researchers and policymakers in issues of environmental justice (Mitchell and Dorling, 2003). Environmental justice can be defined as the "equal access to clean environment and equal protection of issues of environmental harm irrespective of race, income, class or any other differentiating feature of socioeconomic status" (Cutter, 1995). In this paper we aim to examine equity issues associated with levels of air pollution in Christchurch, New Zealand. In particular, we examine pollution sourced from residential properties from domestic heating. This paper is the first to be focused on issues of environmental justice with explicit reference to pollution from domestic sources and the first paper on New Zealand to examine issues of environmental justice and air pollution.

In this paper we have two aims that are central to the tenet of environmental justice. First, we consider whether otherwise possibly disadvantaged populations in Christchurch are more likely to be exposed to higher levels of particulate pollution. In particular, we examine whether people in different age, ethnic, and socioeconomic groups have equal exposure to pollution. Second, we estimate the extent to which people living in each community contribute towards the levels of pollution. In order to address these questions, we pursue three objectives. First, we compare the mean pollution levels with demographic and socioeconomic indicators of disadvantage, namely measures of age, ethnicity, income, and deprivation. It has been noted in a number of studies that the health effects of exposure to a smaller number of extreme pollution episodes may be more important than longer-term average exposure in explaining health outcomes such as asthma and respiratory disease (Katsouyanni, 2003). Therefore, in order to examine whether disadvantaged communities are disproportionately exposed to extreme pollution episodes, the second part of the analysis compares the proportion of nights that exceed the government-defined maximum pollution levels to the demographic and socioeconomic indicators of disadvantage. Third, mean pollution from domestic sources are compared with the levels of usage of wood and coal for residential heating. Before turning our attention to the methods adopted to meet these objectives, we provide a brief overview of the development of environmental-justice research with a particular focus upon studies that have addressed environmental-justice issues with respect to air pollution.

Air pollution and environmental justice

It has been noted in previous studies that different population groups, particularly the disadvantaged, are exposed to differential levels of ambient air pollution. For example, Jerrett et al (2001) compared interpolated estimates of total suspended air-pollution exposure in Hamilton, Canada with socioeconomic and demographic census data. They demonstrated that measures of low income and unemployment were significant predictors of exposure. Similarly, Brainard et al (2002) found that estimates of exposure to carbon monoxide and nitrogen dioxide in the city of Birmingham, UK were strongly related to indicators of ethnicity and poverty. The results of these local studies are supported by the results of a national study in Britain that assessed exposure to nitrogen dioxide among different population groups across the country. It was found that pollution was most concentrated in Britain's poorest communities and where the young tended to live (Mitchell and Dorling, 2003).

The higher exposure to air pollution among groups of lower social status has led to calls for initiatives to reduce inequalities in pollution exposure and the associated health effects, partly as a result of the environmental-justice movement. The environmental-justice movement emerged in the 1980s and was guided by a focus on addressing community involvement and social-justice issues. The essence of the claim made by the environmental-justice movement is that disadvantaged groups have to bear disproportionate environmental burdens (Anand, 2004). The early environmental-justice work tended to focus upon the close proximity of toxic chemical emission sources to areas with large ethnic-minority communities (United Church of Christ, 1987; US General Accounting Office, 1983). For example, Bullard (1983) examined the location of solid-waste sites in Houston, Texas and found that the sites were predominantly found in black neighbourhoods and near to black schools, which he attributed to institutionalised racism. More recently, the research agenda has broadened as studies have been focused not only upon race, and the relationship between wider indicators of social status and exposure to toxic chemicals have started to be considered. The consensus of these studies is that marginalised social groups tend to bear a disproportionate burden of residential exposure to industrial emissions (Korc, 1996). For example, a recent Environment Agency report noted that in England there was a strong tendency for the major sources of authorised industrial pollution to be located in the country's most deprived communities. Furthermore, the authors found that a greater burden of air-quality exceedances is borne by deprived communities in England rather than by the more affluent (Walker et al, 2003). For a review of the environmental-justice and air-pollution literature see Mitchell and Dorling (2003).

Although issues of environmental justice have been recognised by legislative and regulatory bodies and within the academic literature in countries such as the United Kingdom, the United States, and Canada (Wheeler, 2004), environmental-justice issues have received very little attention in New Zealand. Among the few exceptions is a study which found a strong positive association between the location of hazardous substance sites and the level of socioeconomic deprivation of the surrounding neighbourhoods in the city of Wellington. The authors noted that 40% of the population in the most deprived communities had hazardous sites in their neighbourhood, compared with only 10% of those in the most socioeconomically advantaged areas (Salmond et al, 1999). Similarly, a report on the location of landfill sites in New Zealand found that communities which are more socially advantaged are consistently more effective in avoiding final selection for hosting landfill sites (Taylor Baines and Associates, 2001). Although recent environmental-justice-related legislation in New Zealand has not reflected the substantial policy responses that have been seen in other countries, there have been two important and related pieces of legislation. The implementation of the Waitangi Tribunal in 1985 and the Resource Management Act in 1991 have attempted to address historical grievances of the indigenous population and promote future sustainable management practices. However, issues of social and environmental equity are not explicitly addressed within this legislation and environmentally unjust situations are likely to continue to arise.

Although the international literature demonstrates some clear empirical evidence which suggests that issues of environmental justice are operating with respect to air pollution, the theoretical basis for these observations remains unclear. As a consequence, a number of explanations for why some segments of the population suffer from environmental damage more than other segments have been postulated (Helfand and Peyton, 1999). First, there may be income effects that operate in a number of different ways. The demand for environmental quality may increase with income level, which would suggest that less compensation would be necessary to induce poor people to tolerate a polluting facility. In addition, the labour market associated with the polluting facility is likely to largely comprise low-income groups and hence employees are likely to live in close proximity to the facility. Similarly, industrial facilities are likely to be located in areas where property and land values are low. Second, there may be information effects whereby disadvantaged communities may be less well educated and hence do not appreciate the potentially adverse effects and be more vulnerable to misinformation. Third, disadvantaged communities are likely to suffer from a lack of political organisation and therefore have less influence over political structures. These communities would be less capable of resisting a polluting facility than another community with greater political unity.

Finally, racism (both institutional and discriminatory) has been suggested as an influence over the siting of industrial pollution sources (Bullard, 1983; United Church of Christ, 1987). Racism may explain observed environmental justices through the power relations, which manifest themselves in terms of industrial managers and community decisionmakers favouring particular ethnic groups. For example, it was found in a study in Chicago that exposure to particulate matter less than 10 μm in diameter (PM_{10}) was higher among the African-American population than the white population (Ito and Thurston, 1996). However, it has been noted in previous studies that it is difficult to disassociate the effects of race from the effects of poverty and inadequate educational opportunities that may be independent of discrimination (Helfand and Peyton, 1999). In New Zealand, studies have not examined whether there is an ethnic gradient in exposure to air pollution despite the substantial body of evidence which has found that pollution-related health outcomes, such as lung cancer and asthma, tend to disproportionately affect ethnic-minority groups (Reid, 1999).

In this study we consider issues of environmental justice with respect to air pollution in Christchurch, New Zealand. Previous studies of environmental justice and air pollution have tended to be focused upon the discriminatory nature of exposure to industrial sources of pollutants, particularly the siting of industrial facilities (Elliot et al, 2004; Pulido et al, 1996) rather than on pollution from domestic sources. The focus upon domestic pollution is important, particularly in areas that rely upon the burning of fuel for heating, as in some locations domestic-pollution levels can be far higher than pollution from industrial sources, and the processes that lead to any injustices are likely to be different. Christchurch provides an ideal location to examine issues of environmental justice because of its high levels of particulate air pollution during winter months that result from the large proportion of households that burn fuel as their main source of heating. Therefore, the majority of the pollution is sourced from residential properties. This disparity in exposure between different social groups has received limited attention in New Zealand despite the numerous studies that have noted ethnic and social differentials in potentially pollution-related health outcomes among New Zealanders such as hospital admissions, asthma, and most cancers (Ellison-Loschmann et al, 2004). For this reason it is desirable to consider which groups are exposed to the highest levels of air pollution in Christchurch and whether these are the same groups who are responsible for producing the pollution.

Air pollution in Christchurch

The city of Christchurch on the south island of New Zealand has a winter air-pollution problem, which has been recognised since the 1880s (Gray, 1889) and systematically monitored since the 1950s (Wilkinson, 1959). Since the Clean Air Act (1972), levels of pollutants such as sulphur dioxide, nitrogen dioxide, and lead have dropped to levels well below health guidelines. However, levels of particulate pollution and carbon-monoxide levels are very high by world standards and continue to exceed maximum guideline values (Spronken-Smith et al, 2002). The 24-h PM_{10} guideline is exceeded an average of thirty times each year while the carbon-monoxide 8-h guideline is exceeded approximately ten times each year (Environment Canterbury, 2004). Numerous studies have highlighted the many health implications associated with the exposure to high levels of PM_{10} pollution, which in Christchurch has resulted in an increased number of 'restricted activity days', and higher mortality rates (Hales et al, 2000).

The high pollution concentrations in winter months are a result of the heavy use of coal and wood for domestic heating juxtaposed with the settled anticyclonic conditions and the local topographical influences which cause the convergence of air over the central city (Spronken-Smith et al, 2002). The results of a recent survey suggest that 78% of PM_{10} emissions result from domestic solid-fuel heating whereas only 12% are from transport sources and 10% from industry sources (Wilton and Gurnsey, 2001).

Data and methods

Pollution exposure

A key methodological consideration in a study of environmental justice and air pollution is the specification of exposure assessment (Bowen, 2002; Maantay, 2002). It has been demonstrated that relatively minor changes in the exposure-estimation procedure can alter the relationship between air pollution and the variables used to represent aspects of the social and demographic environment (Jerrett et al, 2001). There are two key methodological considerations in the procedure for estimating exposure to pollution. First, previous studies that have estimated the exposure to air pollution have tended to rely upon the simple presence or absence of a polluting facility in an area (such as a census unit or postal area), the concentric buffering around a facility, or methods of spatial interpolation such as kriging (Jerrett et al, 2001). However, these approaches take no account of the climatological and meteorological factors that influence pollution levels, especially in a city that is close to a mountainous area, such as Christchurch (Spronken-Smith et al, 2002). Second, it has been suggested that the geographical unit used to investigate these issues can fundamentally influence the results (Bowen, 2002). For example, the utilisation of pollution estimates for large geographical areas, such as regions or counties, is inappropriate if they fail to accommodate important localised variations in pollution levels. Instead, the choice of spatial unit used for the prediction of pollution exposure needs to capture the underlying spatial processes that influence exposure.

Levels of particulate pollution were simulated across the study area using 'The Air Pollution Model' (TAPM), which is a PC-based atmospheric dispersion model with meteorological and air-pollution components (Hurley, 2002). The meteorological module of TAPM predicts the local-scale circulations, such as sea breezes and slope flows, in conjunction with larger-scale synoptic meteorological fields. In addition to meteorological data, the other key input into the model is emissions data collected locally by the Regional Council (Wilton, 2000). The TAPM model simulated PM_{10} concentration for 1 km grid squares for 1999, from domestic, vehicle, and industrial sources. The 1 km grid squares were subdivided into 100 m grids and then each one was allocated to the Census Area Unit (CAU) in which it was located (CAUs are the second smallest unit of dissemination of census data in New Zealand, each representing approximately 2300 people). The CAU exposure value was defined as the mean of the estimates from the 100 m grid squares which fall within the CAU. A more comprehensive discussion of the methodology used to estimate pollution exposure in Christchurch can be found in Zawar-Reza et al (2005).

In order to compare the demographic and socioeconomic variables to a measure of the extreme pollution episodes, the total number of days that exceeded the Ministry for the Environment 24-h average PM_{10} guideline value of 50 μg m^{-3} (Ministry for the Environment, 2002) were calculated for each CAU. The TAPM model is used to calculate hourly means based on meteorology and emissions and these were used to calculate average 24-h values.

Demographic and socioeconomic data

In order to examine whether exposure to particulate pollution disproportionately effects the more disadvantaged social groups in Christchurch, the pollution estimates calculated for CAUs across the city were compared with a range of demographic and socioeconomic indicators of age, ethnicity, and income from the 2001 Census as well as an index of social deprivation. The collection date of the census variables overlapped closely with the 1999 estimates of air pollution.

The mean air-pollution concentration among different age groups was examined because the health effects of exposure to air pollution are age dependent for three reasons. First, children are less mobile than adults and spend a large part of their time at home and school, locations that, in Christchurch, tend to be in close proximity to each other (especially for younger primary-school-age children). Second, children are inherently more susceptible to air pollution as their lung function and immunological systems are still developing (Mitchell and Dorling, 2003). Third, the elderly are more susceptible to the direct health effects of exposure to air pollution (Filleul et al, 2004).

The ethnic dimension of air-pollution exposure was explored by calculating the mean levels of predicted annual exposure for the four largest ethnic groups in New Zealand (European, Maori, Pacific People, and Asian). Given the social gradient in air-pollution exposure noted elsewhere, the Christchurch pollution concentration estimates were examined in two ways. First, mean pollution levels were compared with levels of household income, an important component of disadvantage. Second, the levels of pollution were compared to the 2001 New Zealand Deprivation Index (NZDep 2001), which combines nine measures from the 2001 New Zealand Census to provide deprivation decile scores for all census units across the country (Salmond and Crampton, 2002). Indices of deprivation provide an alternative measurement of disadvantage to income levels as they incorporate a number of the additional components of deprivation and social exclusion rather than just income. In addition to the comparison with the mean pollution levels, the NZDep 2001 score was also compared with the mean number of exceedance days in order to consider whether there is a social dimension to the exposure to the short-term but extreme pollution episodes that occur in Christchurch.

Table 1. Summary statistics of demographic and socioeconomic variables used in regression analysis.

Variable name	Variable description
NZDep 2001 score	New Zealand Index of Deprivation (2001)
European	Individuals in European ethnic group (%)
Maori	Individuals in Maori ethnic group (%)
Pacific Peoples	Individuals in Pacific Peoples ethnic group (%)
Asian	Individuals in Asian ethnic group (%)
Young	Individuals aged under 15 years (%)
Older	Individuals aged over 64 years (%)
Income < \$15 000	Households with total income of NZ \$15 000 or less (%)
Income < \$25 000	Households with total income of NZ \$25 000 or less (%)
Wood	Households using wood to heat dwelling (%)
Coal	Households using coal to heat dwelling (%)

Domestic heating and air pollution

In Christchurch, the major source of annual pollution is from the burning of wood and coal for domestic heating. Therefore, in order to consider the extent to which people living in a community contribute to the air pollution in the area in which they live, the domestic-pollution estimates were compared with measures of the sources of household heating taken from the 2001 New Zealand Census. We used data on the proportion of households heated by wood and coal and compared each variable with the estimates of domestic-pollution concentration and total pollution concentration.

Analytical methods

In order to examine whether there are exposure inequities with respect to air pollution in Christchurch, the pollution estimates were compared with the demographic and social indicators outlined above by calculating the mean pollution levels in the appropriate data quintiles. Each variable was divided into quintiles in order to consider how pollution varied between groups that were relatively demographically and socially homogenous. This comparison allowed us to examine the relationship between air pollution and age, ethnicity, income, and deprivation in Christchurch. In addition to examining the estimates of the total annual pollution, we also considered whether pollution exposure from domestic sources was higher in areas where there were a high proportion of households burning wood and coal for domestic heating. Mean domestic-pollution levels were calculated for wood-usage and coal-usage quintiles.

To allow us to consider whether there are independent relationships between air pollution and the demographic and social variables, the variables were examined in a set of regression models with mean annual total pollution as the dependent variable. This analysis allowed us to examine whether any relationships were significant and independent of each other. The variables examined in a univariate model were age (the proportion of the population who were under 15 years and the proportion over 65 years), ethnicity (European, Maori, Pacific People, and Asian), social deprivation (NZDep 2001 score), and low income (household incomes of less than NZ $15 000 and NZ $25 000). It was also desirable to consider whether any effects were independent of social deprivation (Bowen, 2002) and hence, in addition to the univariate models, age, ethnicity, and income were examined in multivariate models that controlled for deprivation (NZDep 2001 score). The domestic-pollution levels were compared with the use of wood and coal as the dominant form of heating (proportion of households that rely on wood for heating and the proportion of households using coal). A full list of the social and demographic variables examined in this analysis is presented in table 1.

Table 1 (continued).

Mean	Minimum	Maximum	Standard deviation
980*	878**	1170***	63.21
82.79	64.78	93.76	6.51
6.35	0.79	17.39	3.46
2.13	0.00	11.98	2.06
5.44	1.28	21.24	4.51
12.43	2.33	18.13	3.02
13.55	5.05	23.68	3.54
13.99	4.29	27.70	5.36
26.55	9.76	44.44	7.68
23.64	7.27	38.71	5.21
3.97	0.00	7.93	1.39

*NZDep decile 5; **NZDep decile 1; ***NZDep decile 10.

As detailed earlier, there is evidence to suggest that the most significant health effects relating to pollution levels are due to personal exposure to high-pollution episodes. Therefore, an examination of issues of environmental justice and air pollution require a consideration of the interaction between high-pollution episodes and the social and demographic measures. Therefore, the demographic and socioeconomic variables were also compared with the proportion of days in each CAU that exceeded the Ministry for the Environment 24-h PM_{10} guideline value of 50 μg m^{-3}.

Results

Pollution exposure

Mean levels of particulate pollution (PM_{10}) were calculated for CAUs across the city of Christchurch with atmospheric modelling techniques. The levels of pollution were not uniform across the city with higher levels of exposure in the central city compared with the suburbs and higher levels to the north and east of the centre (figure 1). The darkest shaded CAUs represent areas with values above the 20 μg m^{-3} Ministry for the Environment annual PM_{10} guideline value. This reflects differences in emissions related to denser housing and more traffic in the central city and variations in local meteorological conditions (for a more detailed discussion see Zawar-Reza et al, 2005). The calculated total air-pollution levels in the Christchurch CAUs ranged from 0.06 μg m^{-3}

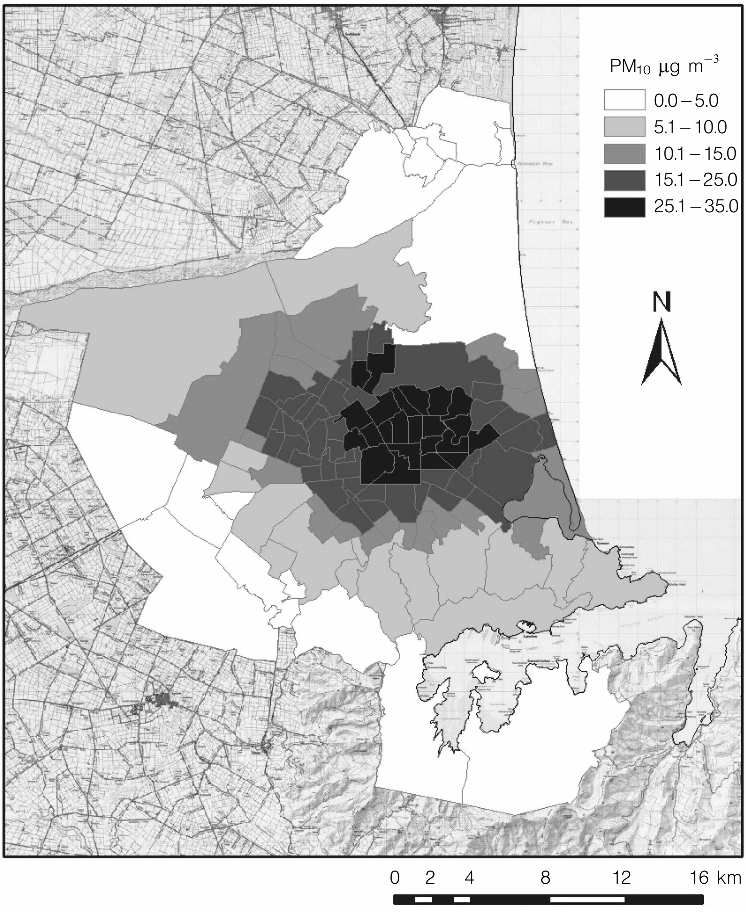

Figure 1. Map of annual exposure to particulate matter less than 10 μm in diameter (PM_{10}) for census area units in Christchurch, New Zealand.

Table 2. Summary statistics of modelled CAU annual pollution levels.

	Mean	Minimum	Maximum	Standard deviation
Total ($\mu g\ m^{-3}$)	14.26	0.06	31.02	8.38
Domestic ($\mu g\ m^{-3}$)	11.25	0.06	25.01	6.47
Industrial ($\mu g\ m^{-3}$)	1.55	0.00	8.11	1.72
Vehicles ($\mu g\ m^{-3}$)	1.47	0.00	4.59	1.15
Percentage of days exceeding 50 $\mu g\ m^{-3}$ each year	3.30	0.00	16.16	4.66

to 31.02 $\mu g\ m^{-3}$ and the mean was 14.26 $\mu g\ m^{-3}$ (table 2). However, the mean annual values do not reveal the extreme events that occur in many CAUs, particularly in winter months. The proportion of days that exceeded the recommended mean pollution threshold (50 $\mu g\ m^{-3}$) in each CAU produced a similar geographical pattern to the mean pollution levels, with higher values in the centre of Christchurch. On average, the pollution threshold was exceeded on 3.30% of days (or 12 days per year) but this ranged from 0.00% to 16.16% (or 59 days per year) (table 2). The verification process demonstrated that there was a close agreement between the observed number of exceedance days measured at the monitoring site (31) and the number of exceedances that were predicted by the model (32) (Zawar-Reza et al, 2005).

Age

For each CAU in Christchurch the percentage of the population in each of eight age bands was calculated (0–9 years, 10–14 years, 15–24 years, 25–34 years, 35–44 years, 45–54 years, 55–64 years, 65+ years). Results were sorted into ascending order for each age group and placed into quintiles, so that the upper quintiles are characterised by the greatest proportion of people in the specified age group (Mitchell and Dorling, 2003). The mean estimate of total pollution was then calculated for each age-group quintile. There are significant variations in total-pollution concentrations within and between age groups (figure 2). For example, for those aged 35–44 years, in the lowest

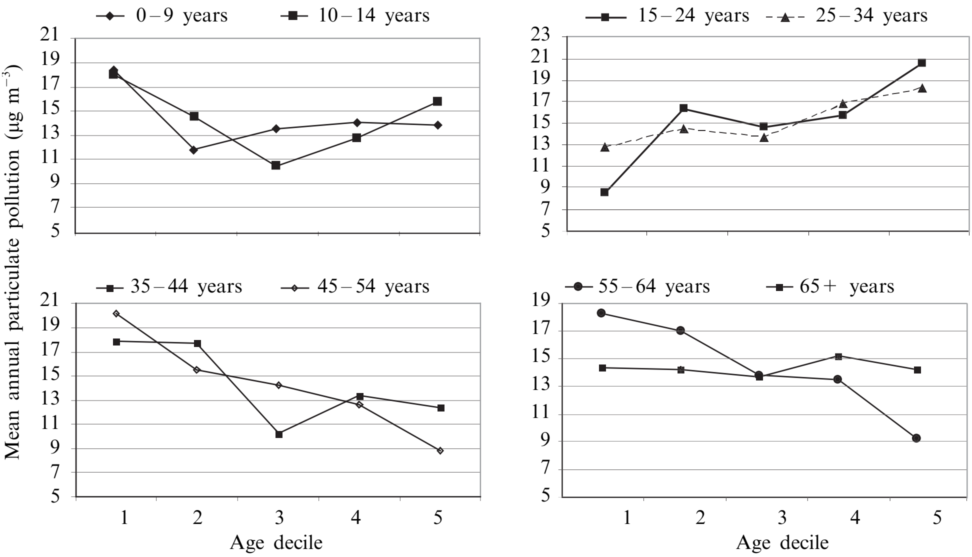

Figure 2. Mean annual particulate pollution by age quintile for the proportion of the population in different age groups.

quintile (the quintile with the lowest proportion of people aged 35–44 years) the mean level of total pollution was 17.89 μg m^{-3} compared with 12.33 μg m^{-3} in the highest quintile (the quintile with the highest proportion of people aged 35–44 years). In other words the least polluted CAUs had a greater proportion of adults aged 35–44 years than the more polluted CAUs. However, this pattern is reversed in the 15–24 years and 25–34 years age groups where levels of pollution are greatest in CAUs with high levels of residents of these ages.

The age gradient in the pollution estimates is reflected in figure 3 which shows the ratio of the mean pollution estimate in the highest and lowest quintile for each age group. Plotting this ratio by age clearly shows how equity in residential exposure to particulate pollution varies by age. CAUs with a high proportion of children (0–9 years and 10–14 years) and a high proportion of people aged between 35 years and 64 years have a negative ratio value, which suggests that CAUs with high proportions of people in these age groups have lower levels of particulate pollution than areas with few people of these ages. In contrast, those areas with a high proportion of people aged between 15 years and 34 years are characterised by high levels of particulate pollution, particularly in those areas with a high proportion of people aged 15 years to 24 years.

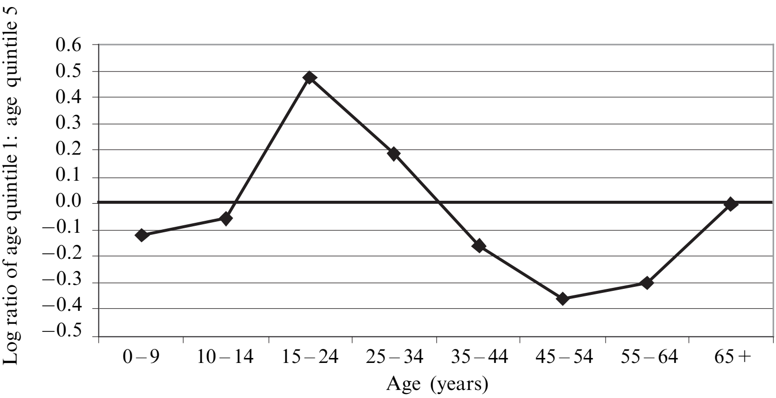

Figure 3. Ratio of the estimate of mean pollution in highest and lowest age quintiles.

Social and economic deprivation

Socioeconomic differences in exposure to air pollution were investigated in three ways. First, mean pollution values were calculated for nine yearly household-income bands ranging from no income to over \$100 000. There was a distinct difference in mean exposure between the highest-income and lowest-income categories (figure 4). For the four lowest income bands (under \$30 000 per year), mean pollution levels tended to be substantially higher in the lowest quintile compared with the highest quintile. This result suggests that air pollution is higher in areas were there is a large proportion of low-paid workers. Conversely, the pattern of mean pollution levels was the opposite for the households on a higher wage (over \$50 000 per year). The mean annual pollution exposure estimates were highest in quintile 1 (low) compared with quintile 5 (high), which suggests that air-pollution exposure is lower in areas with a large proportion of workers on higher pay.

Second, the distribution of particulate pollution relative to material deprivation was investigated by comparing the mean pollution levels in deprivation quintiles calculated from the NZDep 2001 score (the upper quintile representing the 20% most-deprived CAUs in New Zealand). The mean pollution levels are similar in deprivation quintiles 1 and 2 (low deprivation) but are significantly higher in deprivation quintiles 3, 4, and 5

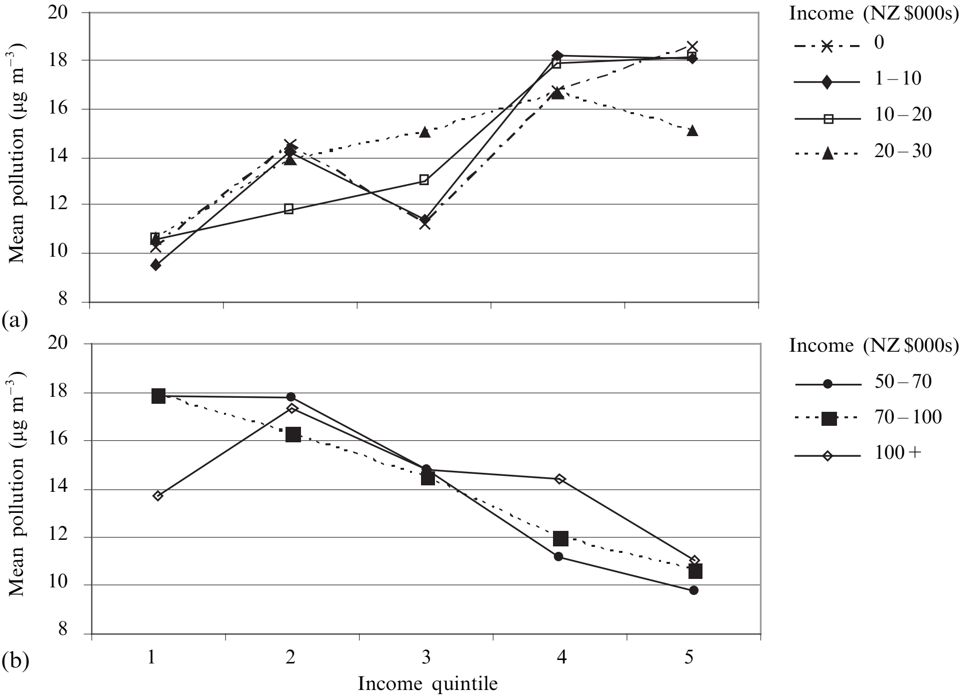

Figure 4. Mean annual particulate pollution by income quintiles. (a) Lowest-income categories; (b) highest-income categories.

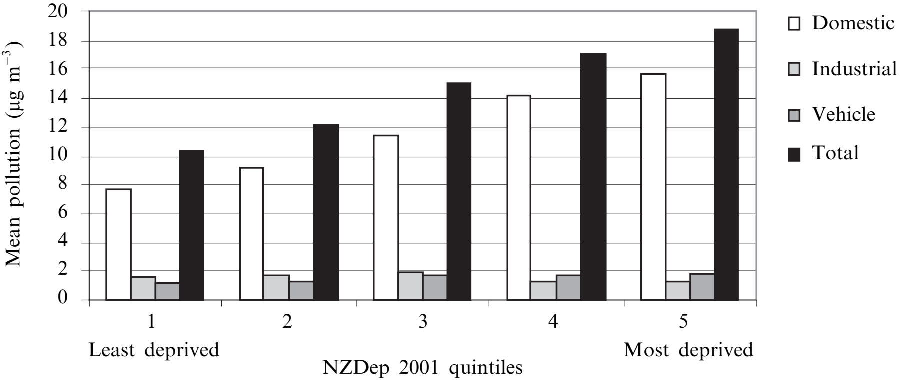

Figure 5. Mean annual particulate pollution by deprivation quintiles.

(figure 5). There is a similar pattern for domestic and vehicle pollution. The variation in the mean industrial pollution levels between the quintiles is low.

Finally, the mean number of days in which the pollution levels exceeded the recommended 24-h mean pollution threshold (50 µg m^{-3}) in each CAU was compared to the NZDep 2001 score (figure 6, see over). The mean number of exceedances progressively increased from the lowest-deprivation quintile (1.81% or 6.60 days per annum) to the highest-deprivation quintile (5.56% or 20.31 days per annum).

Ethnicity

The concentration of particulate pollution relative to the distribution of ethnic groups was investigated by calculating the mean pollution levels for CAUs divided into quintiles according to the proportion of European, Maori, Pacific People, and

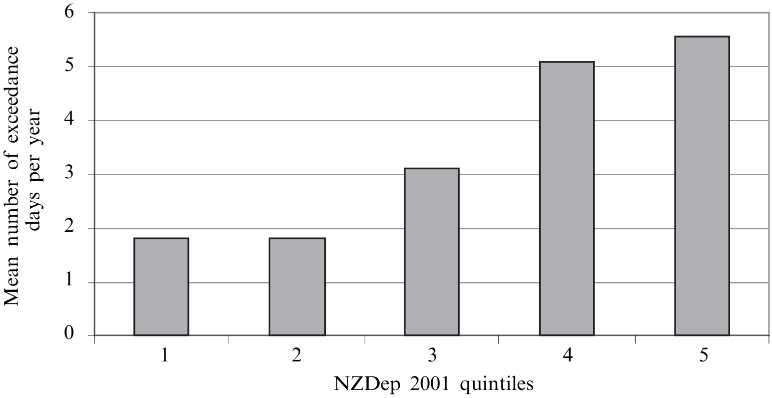

Figure 6. Mean number of exceedance days by deprivation quintiles

Asian populations. The mean levels of pollution in the three deciles with the highest proportion of European were lower than in the two lowest European quintiles (figure 7). The pattern among Maori was less clear, with significantly higher mean pollution levels in quintile 4 (the quintile with the second highest proportion of Maori), yet the quintile with the highest proportion of Maori had mean pollution levels that were lower than the quintile with the lowest proportion of Maori (quintiles 1 and 2, respectively). The pattern for the Pacific People and Asian populations was a little clearer than it was for the Maori, as the mean pollution levels were significantly larger in the highest Pacific People and Asian quintiles than the corresponding lowest quintiles.

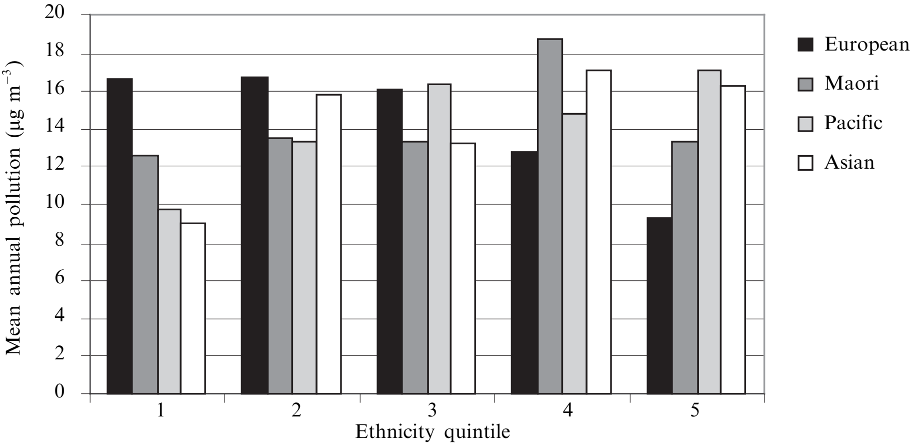

Figure 7. Mean annual particulate pollution for specified ethnic groups.

Despite the nonlinearity of the results across the ethnicity quintiles, a comparison of quintiles 1 and 5 provides evidence to suggest that there is an ethnic disparity in the pollution estimates. For the European population the pollution levels are lower for quintile 5 (high proportion of European) compared with quintile 1 (low proportion of European). However, for the Maori, Pacific People, and Asian communities the pattern is reversed with higher levels of pollution in the highest quintile (high proportion of each ethnic group) compared with the lowest quintile (low proportion of each ethnic group).

Domestic heating and air pollution

The distribution of particulate pollution produced from domestic sources and the percentage of households using wood and coal as their primary source of heating was compared by calculating the mean domestic-pollution levels in CAUs divided into quintiles according to the proportion of households heated by the burning of wood and coal (figure 8). The results demonstrate that, for the burning of wood, the mean levels of domestic and total pollution are highest in quintile 1 (lowest proportion of households heated by burning wood) and lowest in quintile 5 (highest proportion of households heated by burning wood), although the pattern is not linear. However, the large discrepancy between quintiles 1 and 5 suggests that there may be injustices present with respect to the burning of wood for heating. For coal, however, the pattern is reversed, as the mean levels of domestic and total pollution are lower in quintile 1 (low proportion of households heated by the burning of coal) compared with quintile 5 (high proportion of households heated by the burning of coal).

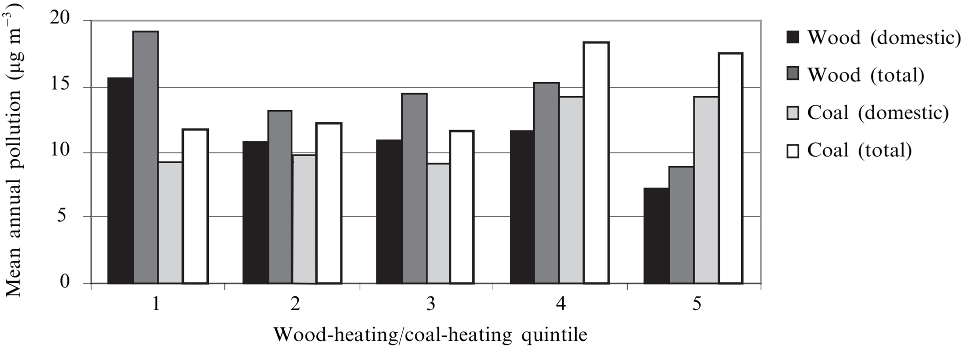

Figure 8. Mean annual particulate pollution for wood-heating and coal-heating quintiles.

Regression analysis

Regression analysis was used to examine whether the relationships between the estimates of pollution exposure in Christchurch and the demographic and socioeconomic variables were statistically significant. The results of the regression analysis are reported in four stages. First, the relationship between total pollution exposure and each of the demographic and socioeconomic variables were tested in a set of univariate models (table 3). The variables that were significant in explaining the variations in mean total annual pollution were the 2001 NZDep score and the two measures of low income (households with net total income of less than \$15 000 and \$25 000). The variables relating to ethnicity and age were not significant.

Table 3. Results of univariate regression analysis with mean pollution levels as dependent variable (variable descriptions are given in table 1).

Variable	Estimate	Standard error	*t*-value	R^2
NZDep	0.050	0.012	4.155	0.144
European	−0.443	0.120	−0.343	0.117
Maori	0.297	0.237	1.253	0.015
Pacific Peoples	0.734	0.396	1.856	0.032
Asian	0.341	0.181	1.888	0.033
Young	−0.536	0.269	−1.991	0.037
Older	0.124	0.234	0.531	0.003
Income < NZ\$15 000	0.637	0.141	4.504	0.165
Income < NZ\$25 000	0.436	0.099	4.405	0.159

Table 4. Results from multivariate regression analysis with total pollution as the dependent variable (variable descriptions are given in table 1).

	Model 1 ($R^2 = 0.144$)			Model 2 ($R^2 = 0.150$)			Model 3 ($R^2 = 0.265$)		
	estimate	standard error	*t*-value	estimate	standard error	*t*-value	estimate	standard error	*t*-value
Intercept	−35.133	11.922	−2.947	−9.253	32.032	−0.289	−94.019	18.112	−5.191
NZDep (2001)	0.050	0.012	4.155	0.038	0.019	1.974	0.120	0.020	5.896
European			−0.161	0.185	−0.871				
Maori							−1.531	0.372	−4.114
	Model 4 ($R^2 = 0.161$)			Model 5 ($R^2 = 0.188$)			Model 6 ($R^2 = 0.190$)		
	estimate	standard error	*t*-value	estimate	standard error	*t*-value	estimate	standard error	*t*-value
Intercept	−51.131	−16.200	−3.156	−39.191	11.795	−3.323	−29.371	11.888	−2.471
NZDep	0.068	0.017	3.951	0.052	0.012	4.399	0.052	0.012	4.394
Pacific peoples	−0.770	0.531	−1.450						
Asian				0.392	0.167	2.352			
Young							−0.604	0.249	−2.427
	Model 7 ($R^2 = 0.169$)			Model 8 ($R^2 = 0.170$)			Model 9 ($R^2 = 0.163$)		
	estimate	standard error	*t*-value	estimate	standard error	*t*-value	estimate	standard error	*t*-value
Intercept	−46.142	13.361	−3.453	−9.858	18.254	−0.540	−11.190	19.620	−0.570
NZDep	0.056	0.012	4.513	0.018	0.021	0.841	0.018	0.025	0.716
Older	0.391	0.222	1.758						
Income $<$ NZ$15 000				0.460	0.254	1.814			
Income $<$ NZ$25 000							0.310	0.202	1.531

Second, the relationship between ethnicity and pollution exposure was examined once deprivation had been controlled for, using the NZDep 2001 score (table 4). Of the ethnicity variables, the proportion of Maori and the proportion of Asian variables were significant independently of deprivation (models 2 to 5). The parameter estimates suggest that as the proportion of Maori increased, the mean pollution levels decreased, whereas the mean pollution levels increased in areas of high Asian population. The models that included the age variables (models 6 and 7) indicate that pollution levels are lower in areas with a high proportion of children (aged under 15 years) but increase in areas with a high proportion of elderly population (aged over 64 years), although only the former is significant. Both of the variables representing low-income households were insignificant once deprivation had been controlled for (models 8 and 9).

Third, the results of the regression analysis with pollution from domestic sources as the dependent variable are shown in table 5. Domestic-pollution levels are negatively related to the proportion of households that burn wood as the main form of heating (model 1) and the relationship is significant. This relationship remains once deprivation has been controlled for (model 2). The relationship between domestic-pollution levels and the proportion of households that burn coal for heating is also significant but this time the relationship is positive (model 3). However, once deprivation has been controlled for, coal heating is no longer significant (model 4).

Table 5. Results of the regression analysis with domestic pollution as the dependent variable (variable descriptions are given in table 1).

	Model 1 (R^2 = 0.214)			Model 3 (R^2 = 0.113)		
	estimate	standard error	*t*-value	estimate	standard error	*t*-value
Intercept	24.900	2.633	9.456	5.030	1.820	2.764
Wood	−0.577	0.109	−5.300			
Coal				1.573	0.433	3.631
	Model 2 (R^2 = 0.324)			**Model 4 (R^2 = 0.229)**		
	estimate	standard error	*t*-value	estimate	standard error	*t*-value
Intercept	−14.024	9.868	−1.421	−31.547	9.492	−3.324
Wood	−0.429	0.108	−3.987			
Coal				0.567	0.480	1.181
NZDep	0.036	0.009	4.073	0.041	0.011	3.917

Finally, the relationship between the socioeconomic variables and the average number of days exceeding the recommended pollution threshold was examined. NZDep 2001 is positively and significantly related to the number of exceedance days, which suggests that exposure to extreme air-pollution episodes is more common among disadvantaged populations. Once deprivation has been controlled for, ethnicity and income are not significant in explaining the variation in extreme pollution events. Of the age variables, only the variable representing a high proportion of young people was significant and the parameter estimate was negative, which suggests that pollution levels were lower in areas that have a high proportion of young people.

Discussion

In this paper we have considered issues of environmental justice and air pollution in the city of Christchurch, New Zealand. The research has investigated the relationship between the estimates of particulate pollution that have been calculated for small areas across Christchurch and a range of demographic variables, indices of deprivation, and resource consumption. Previous studies have noted that the relationship between socioeconomic variables and estimates of pollution exposure are sensitive to the specification of pollution (Jerrett et al, 2001). This research has used accurate and geographically specific estimates of air pollution that have been calculated with atmospheric modelling techniques.

The main finding is that there is evidence to suggest that different population groups in Christchurch may be exposed to differing levels of particulate pollution. Levels of air pollution vary with the age structure of the population with those aged 15 years to 34 years being more likely to be exposed compared with the younger and older age groups. These results are generally consistent with previous studies although higher mean levels of pollution among young children have been noted (Mitchell and Dorling, 2003). The disparities in pollution exposure are not limited to different demographic groups. Mean pollution levels in Christchurch also vary by deprivation quintile with higher mean annual pollution levels in areas of high deprivation. These results support previous studies that have found a social gradient in pollution exposure (Wheeler, 2004). Similarly, the average number of days exceeding the recommended 24-h average threshold was greater in more-deprived areas than in less-deprived areas. Furthermore, the regression modelling demonstrated that deprivation was a significant predictor of air pollution exposure. This result suggests that the poorest communities in Christchurch suffer from higher environmental inequality and are afflicted more than people of average or high affluence. This observation is important in helping to explain the social gradient in health in three interdependent ways. First, and most obviously, the unequal exposure to air pollution between advantaged and disadvantaged groups provides a direct causal explanation for the socioeconomic gradient in ill health, particularly for those diseases related to air pollution such as asthma and lung cancer. Second, as well as suffering greater levels of exposure, disadvantaged populations are likely to be more susceptible to the effects of air pollution upon health. This inequity arises because communities with higher levels of relative disadvantage experience, poorer provision of medical care, housing, and access to facilities such as grocery stores, and adverse psychosocial conditions. Third, disadvantaged communities have a higher susceptibility to predisposing health conditions such as diabetes and asthma, because of socioeconomic differences including occupation, social support, and medical care, which renders them more sensitive to the effects of air pollution. Therefore, this combination of factors relating to environmental justice provides a set of interrelated mechanisms that help to illuminate some of the pathways that lead to inequalities in health.

Although we have found evidence of a social gradient in pollution exposure, there is, at best, only weak evidence of an ethnic gradient in pollution exposure in Christchurch. Although the Maori, Pacific People, and Asian populations tend to be exposed to higher mean levels of air pollution compared with the European population, when tested in regression models the relationships were not all significant. The only ethnicity variable that was significant once social deprivation had been controlled for and which had positive parameter estimates was the proportion of Asian population. In fact, the proportion of Maori population was negatively associated with air pollution, suggesting that areas with a high proportion of Maori population tend to have lower levels of pollution. There is considerable discussion of the ethnic disparities in pollution exposure in the literature, with the debates centring on the concept of environmental racism, in the United States mainly (Cole and Foster, 2000) but more recently in Canada (Buzzelli and Jerrett, 2004) and the United Kingdom (Brainard et al, 2002). The tenet of environmental racism is that people in ethnic-minority groups are exposed to greater quantities of toxins (Macey et al, 2001). In Christchurch, the results of this study do not provide strong support for the assertions of environmental racism. However, the positive and significant relationship between the percentage of Asian population and the air-pollution exposure suggests that the Asian population, a group consisting of a large proportion of recent immigrants (over 75% of the Asian population in New Zealand were born overseas), are exposed to disproportionately high levels of pollution compared with other ethnic groups in Christchurch. Similar conclusions were drawn in a study in Hamilton, Canada where it was found that recent immigrants are exposed to higher levels of air pollution than the remainder of the population, which the authors suggest is related to economic status at the time of entry (Buzzelli and Jerrett, 2004).

A note of caution should be added to our interpretation of the relationship between the measures of ethnicity and air pollution because Christchurch is relatively ethnically homogenous, especially compared with many other parts of New Zealand, with relatively small populations from non-European ethnic groups (for example, only 6.6% of the Christchurch population identify themselves as Maori and 5.3% as Asian). Furthermore, there are definitional issues regarding the use of the term Maori, as Maori are not an ethnically homogeneous mass (Barnett et al, 2005). Currently, Statistics New Zealand defines Maori as persons who have identified themselves ethnically as Maori and Maori only, as well as persons who considered themselves to be Maori but who also identified with another ethnic group.

These results draw attention to the environmental inequities which exist in Christchurch with respect to air pollution. However, the strong relationship between deprivation and pollution juxtaposed with the weak relationship between ethnicity and pollution demonstrate that there are important differences between the environmental-justice debates in the United States and those in New Zealand where, despite a long history of relative disadvantage among indigenous and ethnic-minority groups, environmental-justice issues are not restricted to issues of race but, rather, extend beyond ethnic boundaries. Although issues of environmental justice and environmental racism have become almost synonymous in the United States, in this paper we have demonstrated the need to make a distinction between the two approaches. We have found that the race–class debates in New Zealand are markedly different from the debates in the United States. In New Zealand, patterns of environmental inequality appear to reflect differences in social deprivation rather than the geographical variation in the ethnic composition of areas. Researchers in future studies would be well advised to make the important distinction between environmental racism and environmental inequality.

In addition to finding evidence of inequalities in exposure to ambient air pollution, we have found evidence that the sociopolitical processes that produce environmental injustice are operating in Christchurch with respect to the generation of pollution. It has been demonstrated that those who have the greatest exposure to pollution are not necessarily the largest producers of pollution. The relationship between domestic pollution levels and the proportion of households heating their homes by burning wood demonstrated that those areas with a large proportion of wood burning were exposed to the lowest levels of domestic and total air pollution. In other words, those who are contributing the least to the pollution levels in Christchurch are those suffering the greatest degree of exposure and likely to be disproportionately experiencing the detrimental health effects. The discrepancy between pollution production and exposure provides evidence that environmental injustices could be operating in Christchurch.

It is recognised that in this examination of issues of environmental justice with relation to air pollution, there are a number of limitations. First, this is a study of residential-pollution exposure and implicitly assumes that people are nonmobile and are not exposed to pollution at other locations or from different sources. This is unlikely to be true as daily mobility is likely to result in individuals moving between different locations. However, the effects of daily migration on measures of mean pollution exposures are likely to be less significant in Christchurch where the majority of the pollution is sourced from the burning of wood or coal for domestic heating purposes, which is produced during winter months and produces the highest levels in the evening and early morning when most people are at home. The levels of mobility during these times of day in winter months is likely to be relatively low and hence levels of pollution at a residential address are an appropriate measure of wintertime pollution exposure.

Second, in this paper we have considered just one type of pollutant (particulate) and it should be recognised that there is another pollutant that also exceeds government guidelines: carbon monoxide. However, these exceedances occur infrequently compared with those for particulates, and particulate pollution is the most significant pollutant in Christchurch, particularly during winter months, and almost certainly has the most-significant health effects.

In this study we have examined issues of environmental justice with respect to particulate air pollution in Christchurch, New Zealand, a city with unusually high levels of ambient pollution during winter months. This is one of the first environmental-justice studies to use such accurate and geographically detailed estimates of air pollution. We have found evidence of social inequities in exposure to particulate pollution. Levels of pollution are higher in more deprived communities and the same communities are exposed to a greater proportion of extreme pollution events which potentially have the greatest health effects. We have provided evidence of one pathway that helps to explain variations in ill health between different social groups, particularly pollution-related outcomes such as asthma, lung cancer, and hospital admissions. Policy initiatives in New Zealand aimed at reducing air-pollution exposure have, until now, been focused on reducing pollution over larger (for example, city-wide) areas rather than targeting neighbourhoods with particularly high levels of pollution exposure. We conclude that it is important that policymakers who are concerned with narrowing the health divide between the most prosperous (and healthiest) and poorest (least healthy) groups in society address issues of environmental justice.

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