1995

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Abstract

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Keywords

exposure, ambient, air, pesticides

Publication Details

J. Beard, V. Westley-Wise & G. Sullivan, "Exposure to pesticides in ambient air", Australian Journal of Public Health 19 4 (1995) 357-362.

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Abstract: Ambient air was monitored for pesticides at four sites in Coffs Harbour, a coastal town (population about 50 000) surrounded by banana plantations. Air was sampled continuously for five consecutive months during the peak agricultural spraying period using vacuum pumps set to sample one litre per minute through ORBO-42 adsorption tubes. Six pesticides were detected: three organochlorines and three organophosphates. The most commonly detected pesticide (14 per cent of all samples) was chlorpyrifos (maximum detected level 208.0 ng/m^3, mean 3.6 ng/m^3). Heptachlor was detected in 7.1 per cent of all samples (maximum detected level 133 ng/m^3, mean 2.7 ng/m^3). Other pesticides were only rarely detected. The only pesticide applied by air in the district (propiconazole) was not detected. If international health guidelines are used as a yardstick, these levels of exposure appear unlikely to present an appreciable health risk. Chlorpyrifos detection was associated with low wind speed ($P = 0.012$) and high temperature ($P = 0.015$), and detection at one site was associated with detection at another ($P < 0.001$). Chlorpyrifos detection was also associated with domestic applications within the town area as reported by pesticide applicators ($P = 0.045$). Peak agricultural use of chlorpyrifos did not coincide with peak detection periods. None of the detected organochlorines is registered for agricultural use, although at the time, heptachlor was permitted for use as a domestic termiticide. Even in a semirural town with nearby widespread use of agricultural chemicals, community exposures to pesticides in ambient air may largely relate to their nonagricultural use. (*Aust J Public Health* 1995; 19: 357–62)

The town of Coffs Harbour, part of Coffs Harbour Local Government Area (1991 census population 51 520), is one of the fastest growing urban areas in New South Wales (NSW). It lies in a valley bounded by the sea to the east, by a ridge to the west and by lower ridges to the north and south, which are mainly covered by banana plantations. In late 1984, a cluster of six cases of cleft lip and palate in local children focused community attention on possible environmental exposures that may have explained these birth defects.[1] Much of this attention was directed at possible community exposures to agricultural chemicals.

This report details extensive ambient air monitoring for a range of pesticides undertaken in Coffs Harbour during the summer of 1992–1993 in response to these concerns.

The sampling period was chosen to coincide with the period of aerial spraying of the banana plantations. Although the only pesticide applied by aerial spraying within the Coffs Harbour area is propiconazole (in Tilt), other agricultural chemicals are used on banana plantations, including nematocides (for example, ethoprophos) and insecticides for controlling banana weevil borer (for example, chlorpyrifos, ethoprophos and diazinon). These are usually sprayed from the ground once or twice annually, the two spraying periods generally being October to December, and March to mid-May.

The study period for this ambient air monitoring survey spanned the period of maximum agricultural application of pesticides, both aerial and ground-sprayed, in Coffs Harbour.

Methods

During the 23-week period beginning 26 November 1992, pesticide levels in ambient air were monitored daily at four sites. Three sites were in residential areas bounded by banana plantations in the main Coffs Harbour valley, and one site was within the Coffs Harbour Central Business District (Figure 1). All sites lay within a radius of 1.5 kilometres from the city centre. The siting of the ambient air monitors complied with the relevant Australian Standard (AS2922).

Miniature gas-sampler vacuum pumps (BREY Model G604 6V) were calibrated using a standard volumetric flowmeter, and reset each morning to sample approximately one litre per minute of ambient air for the next 24 hours, through ORBO-42 adsorption tubes containing a cleaned porous styrene–divinylbenzene copolymer. These commer-

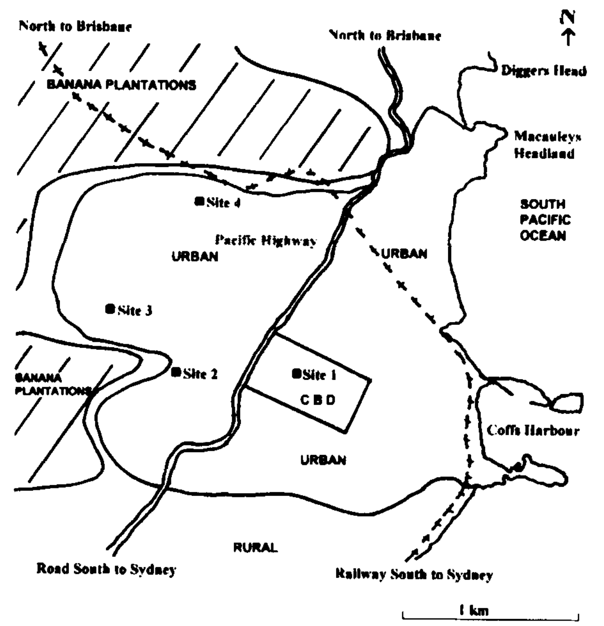

Figure 1: Map of Coffs Harbour showing sites of air monitors

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cial adsorption tubes have been shown to collect efficiently a broad range of pesticides, including heptachlor, chlorpyrifos, chlordane and diazinon (90 per cent, 96 per cent, 95 per cent, 92 per cent recovery respectively).[2] The contents of each tube were screened by the NSW Health Department's Division of Analytical Laboratories for 16 organochlorine pesticides, 30 organophosphate pesticides, and propiconazole. The Division's Pesticide Residue Laboratory is registered with the National Association of Testing Authorities. The detectable limits were 10 ng/tube and, for a short period towards the end of the monitoring period, 20 ng/tube.

The average volume of air sampled by each tube was 1.44 m^3 (that is, one litre per minute over 24 hours), but the detected levels and detectable limits in micrograms were calculated, taking into account the exact period each tube was used for sampling, and the estimated mean air flow during the sampling period (calculated from the average of the air flow at the beginning and end of sampling). Such an estimation assumes a linear decline in flow rate. The median difference in flow rate was 7 per cent. For 87 per cent of samples the difference in flow rate was 0.2 litres per minute or less, and for 98 per cent, the difference was 0.4 litres per minute or less. All samples were included in analysis. If decline was not linear but instead occurred for all samples immediately at the start of the sampling period, this estimation could underestimate exposures by up to 6.5 per cent.

The range, median and mean concentrations in ambient air of the two most commonly detected pesticides (heptachlor and chlorpyrifos) were estimated for each of the four sites and for all four sites combined. Mean concentrations were calculated by combining the observed data above the detection limit with extrapolated below-limit values, using the robust probability plotting method.[3] This method develops a linear regression equation using the observed values to extrapolate the below-detectable-limit values. These summary statistics, as well as the extent of concurrence (that is, simultaneous occurrence) of pesticide detection at each of the sites, were calculated using the SAS program.[4]

Meteorological data

Meteorological data were obtained from the Coffs Harbour station of the Bureau of Meteorology for the months November 1992 to April 1993. These data included daily measurements of temperature, rainfall, evaporation, and maximum wind gust direction. Estimated mean wind speeds for each 24-hour period beginning at 9.00 a.m. daily (corresponding to the usual air sampling period) were calculated using the registered three-hourly readings of wind velocity. The registered maximum daily gust direction was used as a proxy measure of prevailing wind direction.

The associations between daily meteorological variables and pesticide detection were tested by multiple logistic regression analysis using the stepwise selection procedure.

Pesticide application

All pest control operators in the Coffs Harbour area were asked to provide records of days on which heptachlor and chlorpyrifos, the two most commonly detected pesticides, were applied during the study period. The association between pesticide detection and application by operators (that is, the concurrence of detection and application on the same day) was tested with the chi-square statistic.

Results

The rates of detection of pesticides are shown in Table 1. Of a possible 644 air samples taken and analysed during the 23-week monitoring period, only 477 (75 per cent) were available for analysis, owing to technical problems at each of the sites and because the Site 3 pump was stolen after only 59 samples had been taken.

Six pesticides were detected during the monitoring period: three organochlorines (heptachlor, chlordane and dieldrin) and three organophosphates (ethyl-chlorpyrifos, ethoprophos and diazinon). The only pesticide aerially applied in the district, propiconazole (in Tilt) was not detected at any site.

Five of the six pesticides were detected at two sites, Sites 2 and 4, both of these sites being in residential areas near banana plantations and without new building developments in the immediate vicinity. Only one pesticide, chlorpyrifos, was detected at the other two sites, Site 1 being within the central business district and Site 3 being in a developing residential area close to the banana plantations. That no Site 3 samples were positive for heptachlor or chlordane and few were positive for chlorpyrifos, may have been because of the small number of samples successfully taken at this site.

The most commonly detected pesticide was chlorpyrifos, being identified in 69 (14 per cent) samples, including 32 (23 per cent) at Site 2 and 25 (17 per cent) at Site 4. There was a significant tendency for detection at these sites to coincide ($P < 0.001$), this occurring on 15 of the 25 days (60 per cent) when chlorpyrifos was detected at Site 4. On 22 of the 25 days when chlorpyrifos was detected at Site 4, chlorpyrifos was detected at Site 2 either on that day or the day immediately before or after.

Table 1: Pesticides detected in ambient air: numbers and percentages of sites with detected levels (mg/m^3)

	Number	Heptachlor					Chlorpyrifos					Chlordane		Ethoprophos		Diazinon		Dieldrin	
	of samples	*n*	%	Range	Median	Mean	*n*	%	Range	Median	Mean	*n*	%	*n*	%	*n*	%	*n*	%
Site 1 (CBD)	134	0	0.0	ND[a]	ND	ND	7	5.2	ND–12.0	ND	1.9	0	0.0	0	0.0	0	0.0	0	0.0
Site 2	138	3	2.2	ND–21.0	ND	0.544	32	23.2	ND–208	ND	7.4	0	0.0	2	1.4	1	0.7	1	0.7
Site 3	59	0	0.0	ND	ND	ND	5	8.5	ND–12.0	ND	2.95	0	0.0	0	0.0	0	0.0	0	0.0
Site 4	146	31	21.2	ND–133	ND	7.23	25	17.1	ND–25.0	ND	3.9	7	4.8	4	2.7	1	0.7	0	0.0
All sites	477	34	7.1	ND–133	ND	2.70	69	14.5	ND–208	ND	3.6	7	1.5	6	1.3	2	0.4	1	0.2

Note: (a) Nil detected.

Chlorpyrifos detection at Sites 1 and 3 also tended to coincide with detection at Site 2 or Site 4 (four of the five days for Site 3, and five of the seven days for Site 1).

Heptachlor was detected in 34 (17 per cent) samples, almost exclusively from Site 4. Two of the three days when heptachlor was detected at another site (Site 2) coincided with days when heptachlor was detected at Site 4. There was also a statistically significant association between the detection of heptachlor and chlorpyrifos. At Site 4, heptachlor was detected on 11 of the 25 days (44 per cent) when chlorpyrifos was detected ($P = 0.01$.). On two of the three days when heptachlor was detected at Site 2, chlorpyrifos was also detected.

Chlordane was detected at low levels (6–8 ng/m^3) on seven occasions at Site 4, all on days when heptachlor was detected at relatively high levels (20–65 ng/m^3). The ratio of heptachlor to chlordane concentrations detected on these occasions ranged from 3:1 to 8:1, with a mean ratio of 6:1. Technical-grade heptachlor generally contains chlordane in a ratio of 4:1.

Table 1 also shows the summary statistics for concentrations of heptachlor and chlorpyrifos found at each site and all four sites combined. The maximum detected level of heptachlor was 133 ng/m^3, at Site 4. The mean level of heptachlor at Site 4, calculated using extrapolated below limit values, was 7.23 ng/m^3, and at all sites combined was 2.70 ng/m^3. The maximum detected concentration of ethyl-chlorpyrifos was 208 ng/m^3, at Site 2. The mean level of chlorpyrifos at Site 2 was 7.39 ng/m^3, and at all sites combined was 3.58 ng/m^3.

Meteorological variables

The detection of pesticides, either heptachlor or chlorpyrifos, was not significantly associated with any of the 16 possible prevailing wind directions (nor groupings of adjacent wind directions) at any of the sites.

The mean and median wind speeds were generally lower on days when heptachlor or chlorpyrifos were detected, compared to days when they were not detected (Table 2). Chlorpyrifos detection was significantly associated with both wind speed ($P = 0.012$) and temperature ($P = 0.015$), detection being more likely on days with lower wind speeds and higher temperatures. Although wind speeds were generally lower on days when heptachlor was detected, the only significant meteorological association with heptachlor detection was evaporation, which was generally lower on days of detection.

Pesticide application

Five of six pest control operators provided daily records of heptachlor and chlorpyrifos application. These records showed that chlorpyrifos was applied on 23 days and heptachlor on 15 days during the study period. Thirteen of the 61 samples (21 per cent) from residential monitoring sites in which chlorpyrifos was detected were taken on days when chlorpyrifos was reported to be applied by pest control operators. The relative odds of detection on days when chlorpyrifos was applied by operators was significantly higher than on other days (odds ratio (OR) 2.22, 95 per cent confidence interval (CI) 1.02 to 4.80, $P = 0.045$). No significant association was found for heptachlor application.

Exposure and risk assessment

To assess the potential health risk associated with the pesticide levels detected in ambient air in this survey, possible inhalational exposures have been calculated and compared with international reference criteria. Total inhalational exposures to chlorpyrifos, heptachlor and propiconazole were estimated using various assumptions (Table 3).

The mean indoor air concentrations used in these calculations were estimated from indoor pesticide concentrations (before termiticide treatment) reported in a study of NSW homes in 1992.[5] Detected mean outdoor concentrations were about an order of magnitude lower than the estimated mean indoor concentrations.

While propiconazole was not detected in any samples, the detection limit of 10 ng/tube (or 20 ng/tube for later parts of the study) represents the equivalent of 6.9 ng/m^3 (or 13.9 ng/m^3) propiconazole in ambient air. Estimated daily exposures were calculated using these levels as a maximum possible concentration.

An 'acceptable daily intake' (ADI) has been set for many pesticides by the Joint Meeting on Pesticide Residues of the World Health Organization and the Food and Agriculture Organisation.[7] This level takes

Table 2: Pesticide detected in the ambient air, and meteorological factors

	Positive samples		Negative samples		Multiple logistic regression analysis	
	Mean	Median	Mean	Median	Odds ratio	CI[a]
Heptachlor or chlorpyrifos						
Wind speed (knots)	5.9	5.3	7.5	7.3	0.87	0.77 to 0.97
Temperature (°C)	18.7	18.6	18.1	18.5	1.20	1.01 to 1.43
Evaporation (mm)	5.1	5.2	5.9	6.0	0.71	0.55 to 0.91
Heptachlor						
Wind speed (knots)	5.9	4.7	7.0	6.9	—	—
Temperature (°C)	17.6	17.4	18.6	18.6	—	—
Evaporation (mm)	4.7	4.2	5.8	5.8	0.68	0.51 to 0.90
Chlorpyrifos						
Wind speed (knots)	5.7	5.2	7.3	6.9	0.84	0.74 to 0.96
Temperature (°C)	19.0	18.9	18.1	18.4	1.23	1.04 to 1.46
Evaporation (mm)	5.3	5.6	5.7	5.8	—	—

Note: (a) CI = 95% confidence interval

Table 3: Estimated daily inhalational exposures (ng/kg body weight) [a] to heptachlor, chlorpyrifos, and propiconazole under various assumptions

Assumption	Concentration (ng/m³)	Infant (5 kg)	Child (10 kg)	Adult (70 kg)
Heptachlor				
24 hours exposure to mean ambient air concentration in Coffs Harbour (all sites)	2.7	3.8	1.0	0.9
24 hours exposure to mean ambient air concentration at Site 4	7.2	10.1	2.7	2.3
24 hours exposure to maximum ambient air concentration in Coffs Harbour	133.0	186.0	50.5	43.3
24 hours exposure to mean indoor air concentration in NSW [b]	97.5	136.0	37.1	31.8
Chlorpyrifos				
24 hours exposure to mean ambient air concentration in Coffs Harbour (all sites)	3.6	5.0	1.4	1.2
24 hours exposure to mean ambient air concentration at Site 2	7.4	10.3	2.8	2.4
24 hours exposure to maximum ambient air concentration in Coffs Harbour	210.0	294.0	79.8	68.4
24 hours exposure to mean indoor air concentration in NSW [b]	35.6	49.8	13.5	11.6
Propiconazole				
24 hours exposure to ambient air at detectable limit (10 ng/tube)	6.9	9.6	2.6	2.2
24 hours exposure to ambient air at detectable limit (20 ng/tube)	13.9	19.4	5.3	4.5

Notes:
(a) Assumed air intakes are: 22.8 m³ for 70 kg adult, 3.8 m³ for 10 kg child and 6.99 m³ for 5 kg infant.
(b) *Source:* Cantrell [5]

into account published toxicological data on cells in culture, experimental animal studies and human epidemiological studies. In practice, the ADI is usually calculated by applying various safety factors to the lowest-observable-adverse-effect level or the no-observable-effect level for each substance.

The United States Environment Protection Agency (US EPA) has developed a similar yardstick, the reference dose, which provides an estimate of the daily exposure to the general human population that is likely to be without appreciable risk of deleterious effects (apart from cancer) during a lifetime of exposure.[6] Safety factors to account for interspecies and intraspecies variation are included in this estimate, commonly of an order of magnitude each.

For potentially carcinogenic substances, the US EPA expresses toxicity values as slope factors.[6] The slope factor is usually, but not always, the upper 95 per cent confidence limit of the slope for the dose–response curve, expressed as $(mg/kg/day)^{-1}$. This gives a plausible, but conservative, upper bound estimate of the probability of developing cancer from a unit exposure to the chemical being assessed. A 'weight-of-evidence' evaluation is also made of the quality of evidence available in making this assessment.

Combined, these criteria provide a summary of current knowledge of the potential adverse effects on health associated with a particular chemical. All deleterious effects, including teratogenicity, are considered in their derivation, although the chemicals are considered individually and the potential effect of combined exposure is not assessed.

The World Health Organization has set an ADI for heptachlor of 1×10^2 ng/kg/day, and an ADI for ethyl-chlorpyrifos of 1×10^4 ng/kg/day.[8] The US EPA sets an oral reference dose for heptachlor of 5×10^2 ng/kg/day and a slope factor of 4.5×10^6 ng/kg/day and has set an oral reference dose for chlorpyrifos of 3×10^3 ng/kg/day.[9,10] No ADI has been set for propiconazole, but the US EPA has set an oral reference dose of 1.3×10^4 ng/kg/day.[11]

Teratogenicity studies reported by the US EPA Integrated Risk Information System (IRIS) database identify no-observable-effect levels for propiconazole of 30 mg/kg (ossification retardation in rats) and 180 mg/kg (rabbits). These no-effect levels are many orders of magnitude above the maximum possible exposure to propiconazole recorded in this study of 3.9 ng/kg/day. The database identifies a teratogenicity no-observable-effect level for chlorpyrifos of 10×10^6 ng/kg/day (increased skeletal variations at 25×10^6 ng/kg/day), and records data gaps for rat and rabbit teratology studies for heptachlor. The maximum detected levels of chlorpyrifos and heptachlor in ambient air in this study would lead to exposures of 294 ng/kg/day and 188 ng/kg/day respectively.

For a 5 kg infant, 24-hour exposure to the mean daily ambient air concentration in this survey comprises 3.8 per cent of the ADI for heptachlor and 0.8 per cent of the reference dose. Exposure to the mean daily ambient air concentration for chlorpyrifos comprises 0.05 per cent of the ADI. Exposures for older children and adults are considerably less.

For a 5 kg infant, 24-hour exposure to the maximum daily ambient air concentration in this survey comprises 186 per cent of the ADI for heptachlor (37.2 per cent of the reference dose) and 2.9 per cent of the ADI for chlorpyrifos.

Applying the US EPA slope factor, mean detected ambient air levels of heptachlor represent an attributable individual lifetime risk of cancer of less than 1 in 100 000.

Table 4 presents estimated total daily exposures to heptachlor and chlorpyrifos, including background, based on average time activity patterns to mean ambient air concentrations at site 4. Indoor and outdoor weightings are based on the US EPA Exposure Factors Handbook which identifies mean daily times spent indoors for adults of 92.4 per cent, and 88.2 per cent for children aged between 3 and 11 years. Infants have been given the adult female weighting of 93.5 per cent indoors.[13] We estimate that less than 1.5 per cent of the total exposure doses of heptachlor and of chlorpyrifos for all age groups, are accounted for by exposures to ambient air.

Discussion

This survey failed to detect any evidence of the only pesticide applied by aerial spraying in the district (propiconazole, in Tilt, which has a medium to low volatility of 1.3×10^{-6} mbars vapour pressure at 20°C).

Table 4: Daily total exposure doses of heptachlor and chlorpyrifos (ng/kg body weight)

	Heptachlor						Chlorpyrifos					
	Infant		Child		Adult		Infant		Child		Adult	
Source	Dose[a]	%[b]	Dose	%	Dose	%	Dose	%	Dose	%	Dose	%
Background[c]												
Food[d]	0.0	0.0	0.0	0.0	0.0	0.0	1.0	2.1	7.0	30.8	11.0	48.0
Water[e]	0.0	0.0	0.25	0.8	0.07	0.2	0.0	0.0	3.5	15.4	1.00	4.4
Soil[e]	0.0	0.0	0.01	<0.1	0.0004	<0.1	0.0	0.0	0.035	0.2	0.01	<0.1
Subtotal	0.0	0.0	0.25	0.8	0.07	0.2	1.0	2.1	10.5	46.3	12.0	52.4
Inhalational[f]												
Outdoor	0.7	0.6	0.3	0.9	0.2	0.7	0.7	1.4	0.3	1.3	0.2	0.9
Indoor	127.2	99.5	32.7	98.3	29.4	99.0	46.6	96.5	11.9	52.4	10.7	46.7
Subtotal	127.9	100.0	33.0	99.2	29.6	99.7	47.3	97.9	12.2	53.7	10.9	47.6
Total	127.9	100.0	33.25	100.0	29.7	100.0	48.3	100.0	22.7	100.0	22.9	100.0

Notes:
(a) Exposure (E) calculated from formula E = (intake rate × contaminant concentration × bioavailability)/body weight
(b) Percentage of total dose
(c) Oral bioavailability for heptachlor assumed to be 10%, for chlorpyrifos 70%
(d) Background food exposures calculated from the 1990 National Market Basket Survey[12]
(e) Soil and water exposures estimated assuming soil and water concentrations of half the detectable limit of soil sampling by Coffs Harbour City Council (Dupen, personal communication, 1993) and water sampling by the North Coast Public Health Unit
(f) Inhalational bioavailability assumed to be 100% for both heptachlor and chlorpyrifos

This absence of detection probably represents relatively low rates of drift during application and minimal evaporation afterwards, resulting in little movement of the pesticide away from its site of initial use. It may, however, be that aerosol drift did occur and that particulates were not trapped efficiently on the porous medium of our low-volume sampling equipment. Further work needs to be done to quantify the degree of drift of particulates after aerial application.

The study did, however, detect six other pesticides in ambient air. Although the detected concentrations of these chemicals are unlikely to have adverse effects on human health, it is useful to identify the origin of this contamination, as concentrations are likely to be higher at their source. Establishing whether this source is domestic or agricultural will also indicate whether or not these results can be extrapolated to more urban sites.

Interviews with residents of all sites and adjacent buildings, and with licensed pest control operators, confirmed that none of the detected chemicals had been applied on or adjacent to monitoring-site properties, at least for several years. Soil sampling at all sites failed to detect contamination at levels that may have influenced the results of this survey. Over 150 samples of soil recently taken from undeveloped land in the study area also failed to detect heptachlor, chlordane or chlorpyrifos, although dieldrin, which was previously used in the banana industry, was a frequent low-level contaminant (Peter Dupen, NSW Environment Protection Authority, personal communication). It is therefore also unlikely that the pesticides detected in ambient air result from past agricultural use.

Heptachlor and chlordane

There are no registered agricultural uses for cyclodienes in NSW, although at the time of this survey, they were permitted for use as subterranean termiticides, under concrete slabs and in other inaccessible sites, in accordance with Australian Standards AS2057 and AS2178.

Technical grade heptachlor contains about 20 per cent chlordane, which almost certainly explains the close relationship between the ambient air concentrations of heptachlor and chlordane.

The most likely source of the detected heptachlor is recent application in nearby buildings. This hypothesis is supported by the fact that heptachlor was not detected consistently throughout the air monitoring period, but was almost exclusively detected after about mid-February. This closely parallels the pattern of application of heptachlor by local licensed pest control operators; their records show that eight of the 13 days when heptachlor was applied were in March. This restricted period of application, coinciding as it does with low evaporation periods, may also explain the negative association between heptachlor detection and evaporation.

Chlorpyrifos

It is more difficult to identify the origin of the chlorpyrifos detected in this study, because it has a number of common and registered uses: as an agricultural pesticide; as a post-construction termiticide; and as a general household insecticide, both for professional treatments and by home-owners.

Chlorpyrifos was detected at all monitoring sites, although infrequently at Site 1, the only monitoring site which was not within 1 km of banana plantations. However, as Site 1 is located in the central business district, less domestic application would also be expected in this area. Soil sampling at all sites failed to detect any chlorpyrifos.

The usual chlorpyrifos agricultural spraying periods in Coffs Harbour do not coincide with the weeks of maximum detection of chlorpyrifos. Few banana growers spray chlorpyrifos in January or February, yet January was the period of the most frequent and highest levels of chlorpyrifos detection in this study.

Detection of chlorpyrifos was, however, significantly associated with its application by pest control operators to properties in the Coffs Harbour area ($P = 0.04$). Many of these applications were indoors.

The ambient air levels of both heptachlor and chlorpyrifos in our study lie almost midway between

Table 5: Comparison of mean air concentrations (ng/m³) between the United States, and Coffs Harbour–Sydney

	Heptachlor		Chlorpyrifos	
	Outdoor	Indoor	Outdoor	Indoor
Coffs Harbour and Sydney[a]	7.2	97.5	7.4	35.6
US high-pesticide-use area[b]	14.6	130.2	7.6	230.8
US low-pesticide-use area	0.2	17.5	7.0	7.5
US average of high- and low-pesticide-use areas	7.4	73.8	7.3	119.1

Notes:
(a) The outdoor concentrations are the highest of the mean values for individual sites (Site 4 for heptachlor and Site 2 for chlorpyrifos). The indoor concentrations were calculated using data from a study of Sydney homes,[7] using the robust plotting method.
(b) The concentrations have been derived from those reported from the US EPA Nonoccupational Pest Exposure Study, by taking an average of the reported values for each season.[13]

those in high and low pesticide use urban areas in the United States, as reported from the recent Nonoccupational Pesticide Exposure Study by the US EPA (Table 5).[14] These findings lend weight to the view that the pesticides detected in ambient air in Coffs Harbour originate, at least in part, from nonagricultural applications.

Conclusions

The findings of this study suggest that exposure to pesticides in ambient air is very low when ADIs are used as a guide. Even in an area of high agricultural pesticide use such as Coffs Harbour, community exposures to pesticides in ambient air may largely relate to their nonagricultural use.

This study spans the period of maximum agricultural application of pesticides in Coffs Harbour. Only two pesticides—heptachlor and chlorpyrifos—were detected in more than 2 per cent of samples. The source of the heptachlor detected in the ambient air was almost certainly from its application as a termiticide, its only current registered use.

A significant association between the detection of chlorpyrifos and its application by local licensed pest-control operators suggests that the source(s) of this pesticide were also largely related to its nonagricultural uses as a postconstruction termiticide or household insecticide.

We estimate that 24-hour inhalational exposures to heptachlor in typical ambient air in Coffs Harbour would represent, at most, about 3.8 per cent of the ADI set by the World Health Organization. Similarly, 24-hour exposure to the typical ambient air concentrations of chlorpyrifos in Coffs Harbour would represent, at most, 0.05 per cent of the ADI. The no-observable-effect levels for teratogenicity are many orders of magnitude more than the maximum pesticide levels detected, or, for propiconazole, the detection limits of the survey. These yardsticks suggest that inhalational exposures to heptachlor and chlorpyrifos in ambient air are almost certainly no cause for concern.

However, given the probable sources of these pesticides, in arriving at an estimate of total daily exposure we need to take into account that about 90 per cent of our time is spent indoors,[15] and that indoor air levels may be at least an order of magnitude higher than outdoor air levels. Such a differential was reported in the large NOPES study in the US,[14] and is consistent with the differential between the indoor air levels recorded in Sydney homes[5] and the outdoor levels in Coffs Harbour residential areas recorded in this study.

Despite the limitations of the data and the inherent uncertainties in risk assessment, we can conclude that the risks from community exposure to pesticides in ambient air in Coffs Harbour and (we assume) in other parts of Australia are likely to be negligible. Typical indoor air concentrations of heptachlor and postapplication indoor air levels of chlorpyrifos may be associated with more significant inhalational exposure doses.

Acknowledgments

The authors would like to thank Mr Ray McKee, staff of Gumnut Cottage, and Coffs Harbour City Council for allowing the use of their properties for sampling; Coffs Harbour City Council Environmental Health Officers for sample collection; the NSW Division of Analytical Laboratories for sample analyses; Coffs Harbour pesticide operators for their cooperation; Mr Lindsay Campbell and Mr Kerryn McDougall from NSW Agriculture; Mr Phil Cantrell from NSW Workcover Authority; staff of the Coffs Harbour station of the Bureau of Meteorology; and members of the Coffs Harbour community, in particular Mr Don Want, for their help throughout the project.

References

1. Lancaster P, Baker J. *Report on the incidence of major congenital malformations in the Coffs Harbour region of New South Wales.* Sydney: National Perinatal Statistics Unit, 1985.
2. Leidy RB, Wright CG. Trapping efficiency of selected adsorbents for various airborne pesticides. *J Environ Sci Health* 1991; B26: 367–82.
3. Helsel DR. Less than obvious statistical treatment of data below the detection limit. *Environ Sci Technol* 1990; 24: 1767–74.
4. *SAS/STAT, version 6* [computer program]. Cary, NC: SAS Institute Inc., 1987.
5. Cantrell P. *Exploratory air monitoring studies to determine the fate of domestic termiticides.* Sydney: NSW Workcover Authority, 1992.
6. Agency for Toxic Substances and Disease Registry. *ATSDR public health assessment guidance manual.* MI: Lewis, 1992.
7. *Pesticide residues in food—1991.* Environment and the WHO Expert Group on Pesticide Residues, Geneva, September 1991. FAO Plant Production and Protection Paper 111, Food and Agriculture Organisation of the United Nations, Rome, 1991.
8. *Organophosphorus insecticides: a general introduction.* Environmental health criteria, no. 63. Geneva: World Health Organization, 1986.
9. Agency for Toxic Substances and Disease Registry *Toxicological profile for heptachlor/heptachlor epoxide.* Washington: US Public Health Service and US Environmental Protection Agency, 1989.
10. *Heptachlor. Integrated risk information system.* Washington: US Environmental Protection Agency, 1991.
11. *Propiconazole. Integrated risk information system.* Washington: US Environmental Protection Agency, 1992.
12. National Health and Medical Research Council and National Food Authority. *The 1990 Australian market basket survey.* Canberra: Australian Government Publishing Service, 1991.
13. *Exposure factors handbook.* EPA 600 8-89/043. Washington: US Environmental Protection Agency, 1990.
14. Immerman FW, Schaum JL. *Nonoccupational pesticide exposure study (NOPES): project summary.* EPA/600/S3-90/003. Washington: US Environmental Protection Agency, 1990.