

# Original Research

## Wildland forest fire smoke: health effects and intervention evaluation, Hoopa, California, 1999

**ABSTRACT** ● **Objectives** To assess the health effects of exposure to smoke from the fifth largest US wildfire of 1999 and to evaluate whether participation in interventions to reduce smoke exposure prevented adverse lower respiratory tract health effects among residents of the Hoopa Valley National Indian Reservation in northwestern California. ● **Design** Observational study: epidemiologists from the Centers for Disease Control and Prevention retrospectively reviewed medical records at the local medical center and conducted survey interviews of reservation residents. ● **Setting** Humboldt County, California. ● **Participants** Interviews were completed with 289 of 385 residents, representing 26% of the households on the reservation. Of the 289 participants, 92 (31.8%) had preexisting cardiopulmonary conditions. ● **Results** During the weeks of the forest fire, medical visits for respiratory illnesses increased by 217 visits (from 417 to 634 visits, or by 52%) over the previous year. Survey results indicated that although 181 (62.6%) of 289 participants reported worsening lower respiratory tract symptoms, those with preexisting cardiopulmonary conditions reported more symptoms before, during, and after the smoke episode. An increased duration of the use of high-efficiency particulate air cleaners and the recollection of public service announcements were associated with a reduced odds of reporting adverse health effects of the lower respiratory tract. No protective effects were observed for duration of mask use or evacuation. ● **Conclusions** Timely actions undertaken by the clinical staff of the local medical center appeared beneficial to the respiratory health of the community. Future programs that reduce economic barriers to evacuation during smoke episodes may also improve intervention participation rates and decrease smoke exposures. Although promising, the effectiveness of these and other interventions need to be confirmed in a prospective community intervention trial.

Community smoke exposures resulting from wildland forest fires have been associated with increased emergency department and hospital admissions for chronic obstructive pulmonary disease, bronchitis, asthma, and chest pain.<sup>1-3</sup> Although population expansion into wildland environments continues, interventions to prevent these smoke-related adverse health effects have not been validated under conditions of typical use.<sup>4</sup>

In 1999, the fifth largest wildfire in the United States burned from August 23 to November 3 near the Hoopa Valley National Indian Reservation in northern California. On 15 days, smoke from the fire produced ambient concentrations of particulate matter (PM<sub>10</sub>) on the reservation that exceeded the US Environmental Protection Agency's 24-hour air quality standard of 150 µg/m<sup>3</sup> of air. On October 21 and 22, particulate concentrations exceeded the agency's 24-hour hazardous level of 500 µg/m<sup>3</sup>.

Concern over the health effects of the smoke prompted local officials and medical officers to implement several interventions to reduce smoke exposure in the community. However, medical personnel were frustrated over the lack of a scientific basis that could have been used to set public action levels or to recommend appropriate precautionary measures during this emergency. As a result, on November 5, 1999, the Hoopa Valley Tribal Council requested that the Centers for Disease Control and Prevention (CDC) assist them in retrospectively assessing lo-

### Summary points

- During wildfires, people in a nearby community experienced increased lower respiratory tract symptoms due to exposure to smoke
- The effectiveness of various interventions to reduce adverse health effects of smoke exposure has not been studied
- Our study found lessened lower respiratory tract symptoms with longer use of high-efficiency particulate air cleaners
- Public service announcements were also associated with fewer reported adverse health effects
- This study provides some initial answers to questions about the community health effects of wildfire smoke, the identification of susceptible individuals, and the effectiveness of interventions

cal adverse health effects and evaluating the interventions that were implemented during the smoke episode.

### METHODS

A community survey was completed by 289 of 385 (75.1%) selected residents. We oversampled persons with preexisting cardiopulmonary conditions by attempting to interview all who were treated at the reservation medical center in the past year for coronary artery disease, asthma,

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chronic obstructive pulmonary disease, or other lung diseases (n = 92). We also interviewed one randomly sampled person per household who did not have any preexisting conditions, from 197 randomly sampled households. These persons represented 26% of all of the tribal households on the reservation.<sup>5</sup>

The survey instrument included questions about family demographics, intervention participation, and lower respiratory tract symptoms linked with forest fire smoke exposures elsewhere (table 1).<sup>4,6,7</sup> The respondents self-reported the frequency of chest pain, breathing difficulty, and cough on a Likert scale (1 = never to 5 = always) for three time periods: before the smoke episode began (which serves as a baseline), during the smoke episode (August 23-October 26, 1999), and after the smoke episode ended (October 27-November 15, 1999). For each of these periods, individual symptom frequencies were combined to form overall respiratory symptom scales. Two dichotomous outcomes reflect whether respiratory symptoms increased in frequency (hereafter referred to as “became worse”) from before to during the smoke episode and from before to after the smoke episode.

### Clinic visits and air quality

We compared weekly counts of medical visits for any respiratory problem (*International Classification of Diseases,*

*Ninth Revision [ICD-9]*,<sup>8</sup> codes 460-519) during August 14 through November 4, 1999, with weekly average PM<sub>10</sub> concentrations for the same period. We then compared these data with similar data from 1998 when no fires were burning.

### Interventions

During the fires, the staff of the local medical center and other tribal organizations implemented several interventions:

- Filtered and nonfiltered masks were distributed free of charge
- Vouchers for free hotel services in nearby towns were distributed to facilitate evacuation
- Portable high-efficiency particulate air (HEPA) cleaners were distributed to the population
- Several public service announcements (PSAs) were released through local media outlets (table 2)

Because of resource constraints, the distribution of free hotel vouchers and HEPA cleaners was prioritized to persons who had adverse health effects during the smoke or who had been treated within the past year for any of the preexisting conditions.

Logistic regression analyses were used to examine the relationship between the duration of intervention partici-

Table 1 Demographic characteristics, intervention participation, and reported worsening of lower respiratory tract symptoms among study participants, by the presence of any preexisting conditions

Variable	Preexisting conditions (n = 92)		No pre-existing conditions (n = 197)	
	Subjects, no. (%)	95% CI	Subjects, no. (%)	95% CI
<b>Demographic characteristics</b>				
Male	38/89 (42.7)	32.4-53.9	94/191 (49.2)	42.1-56.3
Household income at or below poverty level	44/92 (47.8)	37.6-58.0	109/197 (55.3)	48.4-62.2
Age, yr				
<23	36/92 (39.1)	29.1-49.1	69/195 (35.4)	28.7-42.1
24 to 54	27/92 (29.3)	20.1-38.7	103/195 (52.8)	45.8-59.8
>55	29/92 (31.5)	22.0-41.0	23/195 (11.8)	7.3-16.3
<b>Intervention participation</b>				
Wore a mask during the smoke	29/91 (31.9)	22.3-41.5	71/195 (36.4)	29.6-43.2
Evacuated area during the smoke	53/91 (58.2)	48.1-68.3	87/196 (44.4)	37.4-51.4
Ran a HEPA cleaner at home during the smoke	47/91 (51.7)	41.4-62.0	51/196 (26.0)	19.9-32.1
Recalled at least one PSA to reduce exposure	72/89 (80.9)	72.7-89.1	166/195 (85.1)	80.1-90.1
<b>Reported worsening of lower respiratory tract symptoms</b>				
Symptoms worsened before-to-during the smoke episode	59/92 (64.1)	54.3-73.9	119/197 (60.4)	53.6-67.2
Symptoms worsened before-to-after the smoke episode		15.2-32.6		16.0-27.6
Increased difficulty breathing during the smoke	22/92 (23.9)	31.2-51.4	43/197 (21.8)	16.5-28.1
Increased chest pain during the smoke	38/92 (41.3)	7.9-22.5	44/197 (22.3)	8.5-17.9
Increased cough during the smoke	14/92 (15.2)	43.1-63.5	26/197 (13.2)	49.5-63.3
	49/92 (53.3)		111/197 (56.3)	
<b>Reported lower respiratory tract symptoms, no. (mean)</b>				
Before the smoke	90 (1.1)	0.8-1.3	192 (0.4)	0.3-0.5
During the smoke	90 (1.5)	1.3-1.7	193 (1.1)	0.9-1.2
After the smoke	88 (0.9)	0.7-1.1	192 (0.5)	0.4-0.6

CI = confidence interval; HEPA = high-efficiency particulate air; PSA = public service announcement.

Table 2 Reported type and duration of intervention participation\*

Intervention	Participant, no. (% or mean)		95% CI
<b>Among those who wore masks (n = 100)</b>			
Wore a filtered mask (N95 mask)	29/100	(29.0)	20.1-37.9
Wore a nonfiltered mask	56/100	(56.0)	46.3-65.7
Wore a bandana	9/100	(9.0)	3.4-14.6
Unspecified	6/100	(6.0)	1.3-10.7
Mean days per week mask was worn	95	(3.8)	3.4-4.3
Mean hours per day mask was worn	95	(3.5)	2.7-4.3
<b>Among those who evacuated off of the reservation (n = 140)</b>			
Mean days spent away in evacuation, no.	139	(7.6)	6.6-8.7
Evacuated during each of the 3 days with highest levels of PM <sub>10</sub> (10/18, 10/21, and 10/22)	22/129	(17.1)	10.6-23.6
<b>Among those who ran a HEPA cleaner in their home (n = 98)</b>			
Mean hours per day that HEPA cleaner was run	97	(19.2)	17.8-20.7
Mean total days that HEPA cleaner was run	93	(14.9)	11.8-18.1
Ran a HEPA cleaner during each of the 3 days with highest levels of PM <sub>10</sub>	42/86	(48.8)	38.2-59.4
<b>Among those who could recall a PSA (n = 238)†</b>			
Mean PSAs recalled, no.	237	(2.1)	2.0-2.2
Recalled PSA to remain indoors	187/238	(78.6)	73.4-83.8
Recalled PSA to wear face covering	105/238	(44.1)	37.8-50.4
Recalled PSA to evacuate area	82/238	(34.4)	28.5-40.5
Recalled PSA to close windows	57/238	(23.9)	18.6-29.4
Recalled PSA to limit outdoor actions	46/237	(19.4)	14.4-24.4
Recalled PSA to use air conditioning	23/238	(9.7)	5.9-13.5
Source			
Radio or scanner	123/238	(51.7)	45.4-58.0
Physician or clinic personnel	88/238	(37.0)	30.9-43.1
Friend or family member	50/238	(21.0)	15.8-26.2
Place of employment	41/238	(17.2)	12.4-22.0
Television	33/238	(13.9)	9.5-18.3
Newspaper	15/238	(6.3)	3.2-9.4
School or teachers	11/238	(4.6)	1.9-7.3
Emergency personnel	10/238	(4.2)	1.7-6.7
Other source	7/238	(2.9)	0.8-5.0
Tribal council	5/238	(2.1)	0.3-3.9
Did not take action because of PSAs	81/238	(34.0)	28.0-40.0
Took action because of PSAs	157/238	(66.0)	60.0-72.0
<b>Among those who took action because of PSAs (n = 157)</b>			
Action taken			
Stayed inside	131/157	(83.4)	77.6-89.2
Other	29/157	(18.5)	12.4-24.6
Left area	25/157	(15.9)	10.2-21.6
Used mask	22/157	(14.0)	8.6-19.4
Used air cleaner	2/157	(1.3)	0.0-3.1

\*Abbreviations are explained in table 1.

†Percentages may not add up to 100% because persons may have recalled multiple PSAs or received PSAs from multiple sources.

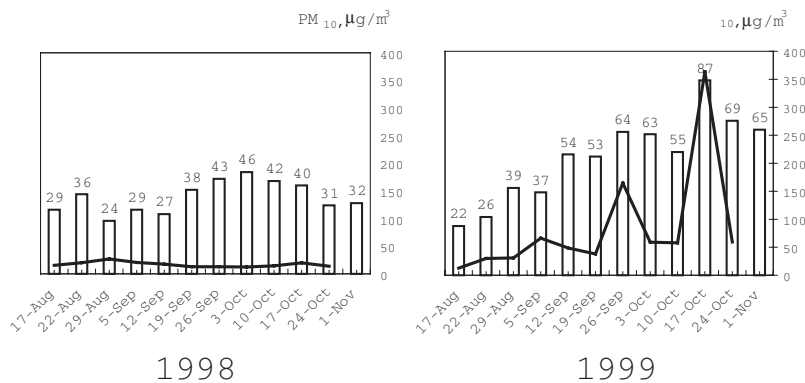
pation and the odds of reporting worsening respiratory symptoms from baseline to the postfire period.<sup>9</sup> The post-fire period was the only time when we could be certain that reported symptoms occurred after participation in any interventions. Because reported respiratory problems were, by definition, positively correlated with intervention participation, it was necessary to evaluate interventions by looking for dose-response relations within groups of persons who received each intervention.

## RESULTS

### Clinic visits and air quality

During the smoke episode in 1999, medical visits for respiratory problems increased by 217 (from 417 to 634

visits, or by 52%) over the previous year. The proportion of all visits for respiratory problems increased from 8.9% (95% confidence interval, 7.5%-10.3%) in September 1998 to 11.9% (10.4%-13.4%) in September 1999, from 10.7% (9.1%-12.3%) in October 1998 to 19.2% (17.2%-21.3%) in October 1999, and from 13.8% (9.4%-18.2%) during the first week of November 1998 to 19.5% (15.2%-23.8%) during the first week of November 1999. Weekly PM<sub>10</sub> concentrations were considerably higher in 1999 than in 1998 and were positively correlated with the weekly number of patients presenting to the facility with respiratory illnesses (Pearson's correlations were  $r = 0.74$  in 1999, and  $r = -0.63$  in 1998) (Figure).



Average weekly ambient concentrations of particulate matter (PM<sub>10</sub>) (horizontal lines) and number of medically attended respiratory visits (*ICD-9* codes 460-519) (vertical bars) among residents of the Hoopa Valley National Indian Reservation, by week, August 17 to November 4, 1998 and 1999. The bivariate correlation coefficient for 1998 was  $r = -0.63$  and for 1999 was  $r = 0.74$ .

### Community survey

More than 60% of respondents (178/289) reported increased respiratory symptoms during the smoke (table 1). Two weeks after the smoke cleared, more than 20% (65/289) continued to report an increased frequency of respiratory symptoms over baseline levels. Respondents with preexisting conditions reported significantly more symptoms before, during, and after the smoke than others in the community (table 1).

Of the 289 respondents, 140 (of 287 who answered the questions, or 48.8%) evacuated to a location off the reservation, 100 (of 286, or 35.0%) wore a mask or face covering, and 98 (of 287, or 34.1%) ran a HEPA air cleaner in their home at some time during the smoke. Persons with preexisting conditions were significantly more likely to use a HEPA cleaner and marginally more likely to evacuate the reservation, reflecting the selective targeting of these interventions to those with cardiopulmonary problems (table 1).

Among the evacuees, the mean duration of evacuation was 7.6 days, and 17.1% (22/129) were away from the reservation during each of the 3 days with the highest PM<sub>10</sub> concentrations (October 18, 21, and 22). Among respondents who ran a HEPA air cleaner in their home, the mean duration of use was 14.9 days, and 48.8% (42/86) ran them during each of the 3 days with highest PM<sub>10</sub> concentrations (table 2). More than 80% of respondents (238/289) were able to correctly recall a PSA without being shown a list of known PSAs. Of these, 66.0% (157/238) reported taking action to reduce smoke exposure as a result of hearing the PSA. "Staying inside more often" was the most common action undertaken (table 2).

The duration of evacuation and mask use were not significantly associated with the odds of reporting worsening lower respiratory tract symptoms (table 3). In contrast, odds ratios (ORs) associated with three measures of HEPA cleaner use indicated significant negative associa-

tions. Among those who ran HEPA cleaners in their home, increased duration of use was significantly associated with decreased odds of reporting worsening respiratory symptoms (OR = 0.54) (see table 3). This association followed a dose-response relation. Those in the highest quartile of duration of use were significantly less likely than those in the lowest quartile of duration of use (the reference group) to report worsening symptoms.

Respondents recalling a PSA were less likely than those who could not recall a PSA to report worsening respiratory symptoms (OR = 0.25) (see table 3). The number of PSAs recalled was also protective in a dose-response manner. Of the actions taken in response to hearing PSAs, only "staying inside more often" displayed any trend toward protection.

### DISCUSSION

One of the challenges health professionals face when forest fires threaten their communities is to implement effective preventive measures when no guidelines exist for protecting the public in these situations.<sup>4,10,11</sup> As a result, a goal of this field study was to assess the effectiveness of interventions that were rapidly deployed by medical staff of the Hoopa Valley National Indian Reservation during an air-quality emergency.

We found mask use to be ineffective and positively associated with outdoor exposure. This finding may be explained by respondent tendencies to use masks inconsistently, without appropriate fit-testing, or by the variable filtration effectiveness of the masks used in this situation.<sup>12-14</sup> We were also surprised that increased duration of evacuation did not appear to be protective. However, smoke exposures from wildland fires are often unpredictable,<sup>15</sup> and among those who evacuated, only 17.1% were away from the reservation during each of the 3 days with the highest smoke concentrations. In contrast, half of those who used HEPA cleaners ran them during these days, and the mean duration of HEPA cleaner use was twice as long as the mean duration of evacuation.

The clean air delivery rate (CADR), measured in cubic feet per minute (cfm), is a function of a HEPA cleaner's efficiency of pollutant removal and rate of air exchange.<sup>4</sup> The American National Standards Institute has approved a standard for air cleaners to have a CADR of 100 cfm for a 12- by 12-ft room and a CADR of 250 cfm for a 20- by 20-ft room.<sup>16</sup> The HEPA cleaners provided to the population by the Hoopa Valley Tribal Council had a CADR of 150 cfm, suggesting that they would have been suitable for most rooms in the small single-family dwellings on the reservation. Although the use of portable HEPA air cleaners has previously been reported to reduce the concentration of fine particles indoors to an acceptable level during smoke episodes,<sup>4</sup> these findings provide additional support for their effectiveness because increased duration of



Please see this article on our web site, [www.ewjm.com](http://www.ewjm.com), for a link to table 3



use significantly reduced the odds of reporting worsening respiratory symptoms.

Economic and occupational barriers to leaving home may have dissuaded reservation residents from evacuating. When asked why they chose not to evacuate to a hotel, 45% of the responses of those who did not evacuate indicated an inability to take time away from work. An additional 12% cited economic constraints. In a locale with a 32% unemployment rate, the forest fires brought economic opportunities. This may be best illustrated by the finding that among working-age adults, residents with preexisting cardiopulmonary conditions were as likely to work for salary in the fire camps during the fires as others in the community. Future interventions that involve the temporary relocation of residents may need to consider the positive effects of employment (and associated disincentives to evacuation) in order to be implemented effectively.

Existing research has generally indicated that, to be most effective, the release of PSAs should be coupled with other behavioral interventions.<sup>17-19</sup> A growing body of literature, however, has suggested that PSA campaigns alone can have significant effects on public health behaviors.<sup>20-23</sup> In this situation, the timely dissemination of PSAs through radio broadcasts and telephone messages was associated with a reduction in reported respiratory symptoms in large segments of the general population. Whereas some evidence suggests that the PSAs may have produced this effect by influencing recipients to remain indoors, their mechanism of effect appeared mostly unmeasured by our survey instrument and remains an area requiring additional investigation.

In a situation where resources were limited, the interventions were appropriately prioritized to persons with preexisting cardiopulmonary conditions, who reported more severe respiratory problems at all time points in the study. The effect of each of the four interventions was of similar magnitude in those who had and those who did not have preexisting conditions and was also independent of the respondent's participation in any of the other interventions. However, a limitation to this study was the potential for recall bias. To reduce this, respondents were asked to report symptoms for each of three separate time periods rather than their own change in symptoms over time. Intervention dissemination was also not randomized and was confounded by the severity of lower respiratory tract condition. To reduce the effects of this confounding, several interventions needed to be evaluated by examining dose-response relations among those who received them.

As population expansion into wildland environments continues, local health professionals will be repeatedly faced with the challenges of making rapid decisions to protect their communities from forest fires.<sup>10,11,24-26</sup> Until randomized trials can be undertaken, these findings

provide some initial guidance to the effectiveness of several possible community interventions.

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