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A SYSTEMATIC REVIEW OF THE HEALTH IMPACTS OF OCCUPATIONAL EXPOSURE TO WILDLAND FIRES

EMILY GROOT[1,2,3], ALEXA CATURAY[2,3], YASMIN KHAN[3,4], and RAY COPES[5]

[1] Northern Ontario School of Medicine, Thunder Bay, Canada
Clinical Sciences
[2] Queen's University, Kingston, Canada
Department of Family Medicine
[3] Public Health Ontario, Toronto, Canada
Communicable Diseases, Emergency Preparedness and Response
[4] University of Toronto, Toronto, Canada
Department of Medicine
[5] Public Health Ontario, Toronto, Canada
Environmental and Occupational Health

Abstract
The aim of the paper is to summarize the evidence of health impacts of occupational exposure to wildland fires. The authors searched 3 databases for relevant articles and screened the results. After full-text review, articles were included based on pre-determined criteria. The authors identified 32 relevant articles. Occupational exposure to wildland fires affects lung function in the short term and may increase the risk of hypertension in the long term. Exposure to wildland fires is also associated with post-traumatic stress symptoms. There was insufficient evidence to comment on most longer-term risks, and in particular on respiratory disease or cancer risks. Further research is required to understand whether occupational exposure to wildland fires results in clinically significant impacts on respiratory function, and to further clarify the relationship between occupational exposure and blood pressure, mental health, and cancer outcomes. Int J Occup Med Environ Health. 2019;32(2):121–40

Key words:
firefighter, inhalation, smoke, burns, wildfires, stress disorders

INTRODUCTION

Wildfire prevalence and severity has increased as the earth's climate has changed [1]. These changes are predicted to increase the occupational health risks posed to firefighters [2]. Fighting wildland fires can result in exposure to smoke, especially because commercially available personal protective respiratory equipment is lacking for this occupational group. Smoke is a complex mixture which includes polycyclic aromatic hydrocarbons, such as naphthalene and phenanthrene [3,4], carbon monoxide [4–6], benzene [4,7], aldehydes, including formaldehyde and acrolein [4], levoglucosan [6], and fine particulate matter [4,6,8]. Wildfire fighters are also exposed to noise doses above those allowable by the U.S. Occupational Safety and Health Ad-

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Corresponding author: Ray Copes, Public Health Ontario, Environmental and Occupational Health, 480 University Avenue, Suite 300, Toronto, Ontario, Canada M5G1V2 (e-mail: ray.copes@oahpp.ca).

ministration [9] as well as physical and mental health hazards [10]. A risk assessment accounting for daily exposure, the annual number of working days, and career length suggests that exposures to benzene, formaldehyde, acrolein, and particulate matter are sufficient to pose health concerns [4]. Understanding the impacts of wildland fires on the health of firefighters can inform mitigation strategies and policies to protect workers.

The risks posed by wildland firefighting differ from those posed by structural firefighting [11]. Wildland firefighters are exposed to hazards during fire suppression activities and while housed in base camps [12]. Wildland firefighters often work for longer periods of time than structural firefighters and work multiple shifts fighting the same fire with little down time. The risks posed by wildland fire to firefighters also differ from those posed to the public. Firefighting is a strenuous physical activity, with concomitant increases in respiratory and heart rates, as well as exposure to more intense smoke than most members of the public [13].

There have been recent reviews of the health impacts of non-occupational exposure to wildfires [13–16]. In the general public, exposure to wildfire smoke is associated with respiratory morbidity and possibly all-cause mortality [15]. Although Adentona et al. include 14 articles concerning occupational exposure to wildland fires in their review of health effects of wildfire smoke, they exclude mental health impacts [13]. With this systematic review, the authors' objective is to examine health impacts broadly and include both physical and mental health impacts on firefighters exposed to wildland fires.

MATERIAL AND METHODS

Search strategy

The authors searched 3 databases, i.e., MEDLINE (including e-publications ahead of print, in-process, and other non-indexed citations), Embase, and Environment Complete, for relevant articles. The search was performed using the Ovid interface for the first 2 databases and the EBSCOhost interface for the latter database. The search was limited to peer-reviewed, English-language articles published in 1 January 1946 – 3 January 2017, reporting on research involving humans and non-residential vegetation fires. The search terms are listed in Table 1.

Study selection

Two authors independently screened the search results and identified articles eligible for full-text review if, based on the title or abstract, the article appeared to meet the inclusion criteria. The authors then obtained and reviewed the full-text versions of the eligible articles for final inclusion, based on both the inclusion and exclusion criteria. Disagreements at either stage were resolved by the decision of a third author.

Inclusion criteria:
- peer-reviewed journal article,
- published in 1 January 1946 – 3 January 2017,
- published in English.

The article describes the relationship between exposure to wildland fire and any mental or physical health outcome in firefighters, where wildland fires are defined as both unintentional wildfires and prescribed burns of any natural fuels, including forests, grasslands, and brush [7].

Exclusion criteria:
- conference abstracts,
- studies examining the health impacts of the work of firefighting other than wildland fire exposure,
- studies examining biomass burning for heat or cooking,
- simulation or modelling studies.

Data extraction and quality assessment

One author used a standardized data extraction form to extract data from the included articles. The extraction form was developed based on the Cochrane Collaboration's data collection form [17], amended to contain fields relevant to this review. The data extracted included the authors' names, year of publication, article title, study design, brief description of the study, location, setting (e.g., prescribed

Table 1. Search strategy used in the review study on the evidence of health impacts of occupational exposure to wildland fires

Database	No.	Searches
MEDLINE	1	Fires/ and (bush* or biomass or forest* or grass* or habitat* or vegetation or wild* or ecosystem* or savanna* or agricultur* or prescribed burn* or prescribed fire*).ti,ab,kw,kf.
	2	(bushfire* or forestfire* or grassfire* or wildfire* or smoke pollution event* or (fire* adj3 (bush* or biomass or forest* or grass* or habitat* or vegetation or wild* or ecosystem* or savanna* or agricultur*)) or prescribed burn* or prescribed fire*).ti,ab,kw,kf. and ("in data review" or in process or publisher or "pubmed not medline").st.
	3	(mo or ae or to).fs.
	4	(casualt* or dead or died or death* or disease* or illness* or morbidity or mortality or (health adj3 effect*) or (adverse* adj3 effect*) or (negative* adj3 impact*) or (health adj3 impact*) or (health adj3 affect*) or (negative* adj3 affect*) or (adverse* adj3 affect*) or (health adj3 problem*) or (human* adj3 health) or (health adj3 hazard*) or toxic*).ti,ab,kw,kf.
	5	Carcinogens, Environmental/ or Environmental Monitoring/ or Environmental Exposure/ or Particle Size/ or particulate matter/ or smoke/ or soot/ or Dust/ or Air Pollution/ or Air Pollutants/ or Inorganic Chemicals/ae, an, me, to or exp Polycyclic Hydrocarbons, Aromatic/ or exp Metals, Heavy/ or Acrolein/ or Benzene/ or Formaldehyde/ or Carcinogens/ or hydrocarbons/ or carbon dioxide/ or carbon monoxide/ or nitrogen oxides/ or nitrogen dioxide/ or nitrous oxide/ or sulfur dioxide/ or sulfur oxides/ or exp gases/ to or Ozone/ae, me, po, to or Aerosols/ae, me, po, to or Tetrachlorodibenzodioxin/ or Benzofurans/ or exp Dioxins/ or Soil pollutants/
	6	(carcinogen* or environmental monitor* or expos* or particulate* or PM* or smoke or soot or dust or air pollut* or air quality or soil pollut* or particle* or chemical* or PHA or polycyclic aromatic hydrocarbon* or acrolein or benzene or formaldehyde or carcinogen* or hydrocarbon* or carbon dioxide* or carbon monoxide* or nitric oxide* or nitrogen oxide* or nitrogen dioxide* or nitrous oxide* or sulfur dioxide* or sulfur oxide* or Ozone or Aerosol* or Benzofuran* or chlorinated dibenzofuran* or polychlorodibenzo* or Tetrachlorodibenzodioxin* or dioxin* or O3 or NOx or NO or N20 or NO2).ti,kw,kf. or (carcinogen* or environmental monitor* or expos* or particulate* or PM* or smoke or soot or dust or air pollut* or air quality or soil pollut* or particle* or chemical* or PHA or polycyclic aromatic hydrocarbon* or acrolein or benzene or formaldehyde or carcinogen* or hydrocarbon* or carbon dioxide* or carbon monoxide* or nitric oxide* or nitrogen oxide* or nitrogen dioxide* or nitrous oxide* or sulfur dioxide* or sulfur oxide* or Ozone or Aerosol* or Benzofuran* or chlorinated dibenzofuran* or polychlorodibenzo* or Tetrachlorodibenzodioxin* or dioxin* or O3 or NOx or NO or N20 or NO2).ab. /freq = 3
	7	exp Hospitalization/ or Emergency Service, Hospital/ or exp Death/ or mortality/ or "cause of death"/ or child mortality/ or fatal outcome/ or fetal mortality/ or hospital mortality/ or infant mortality/ or maternal mortality/ or mortality, premature/ or perinatal mortality/ or survival rate/
	8	(hospitalization or hospitalisation or ((hospital* or emergency) adj3 (visit* or admission)) or survival or casualt* or dead or died or death* or mortality).ti,kw,kf. or (hospitalization or hospitalisation or ((hospital* or emergency) adj3 (visit* or admission)) or survival or casualt* or dead or died or death* or mortality).ab. /freq = 2
	9	exp "wounds and injuries"/
	10	(wound* or injury or injuries or burn or burns or smoke inhal*).ti,ab,kw,kf.
	11	exp Pregnancy Complications/ or Fetal Growth Retardation/ or exp Neurodevelopmental Disorders/ or Maternal Health/ or Maternal-Fetal Exchange/ or Maternal Exposure/ or Prenatal Care/ or Pregnancy/ or Maternal Mortality/ or Maternal Welfare/ or maternal-child nursing/ or neonatal nursing/ or exp fetal monitoring/ or placental function tests/ or preimplantation diagnosis/ or exp prenatal diagnosis/ or uterine monitoring/ or Fetoscopy/

Table 1. Search strategy used in the review study on the evidence of health impacts of occupational exposure to wildland fires – cont.

Database	No.	Searches
	12	(pregnan* or fetus or fetal or foetal growth or retard* or maternal or prenatal or neonatal or placenta* or uterus or uterine or fetoscop*).ti,ab,kw,kf.
	13	Asthma, Occupational/ or Occupational Exposure/ or Air Pollutants, Occupational/ or occupational injuries/
	14	(((occupation or occupational or firefighter* or personnel or paramedic* or responder* or police or emergency medical technician*) adj5 (health or disease* or illness* or expos* or pollut* or disorder* or symptom*)) or asthma*).ti,ab,kw,kf.
	15	exp respiratory tract diseases/ or exp diagnostic techniques, respiratory system/ or exp Respiration/
	16	(asthma* or bronchi* or lung* or dyspnea or laboured breath* or breathing difficult* or ARDS or (respiratory adj2 (distress or disease* or illness or insufficien*))).ti,ab,kw,kf.
	17	exp hypersensitivity/
	18	(hypersensitivity* or allerg*).ti,ab,kw,kf.
	19	exp Eye Diseases/ or exp diagnostic techniques, ophthalmological/ or exp Vision, Ocular/
	20	(eye or ocular or vision or ophthalmolog*).ti,ab,kw,kf.
	21	exp cardiovascular diseases/ or exp diagnostic techniques, cardiovascular/
	22	(cardio* or cardiac* or heart or myocardial or pulmonary).ti,ab,kw,kf.
	23	exp mental disorders/ or mental health/ or exp Behavioral Symptoms/
	24	(mental or psych* or behavio*).ti,ab,kw,kf.
	25	1 or 2
	26	or/3-24
	27	25 and 26
	28	27 not [Animals/ or (exp Animals/ not Humans/)]
	29	limit 28 to English language
	30	remove duplicates from 29
Embase	1	(fire/ or "fire and fire related phenomena"/) and (bush* or biomass or forest* or grass* or habitat* or vegetation or wild* or ecosystem* or savanna* or agricultur* or prescribed burn* or prescribed fire*).ti,ab,kw.
	2	(ae or to).fs.
	3	(casualt* or dead or died or death* or disease* or illness* or morbidity or mortality or (health adj3 effect*) or (adverse* adj3 effect*) or (negative* adj3 impact*) or (health adj3 impact*) or (health adj3 affect*) or (negative* adj3 affect*) or (adverse* adj3 affect*) or (health adj3 problem*) or (human* adj3 health) or (health adj3 hazard*) or toxic*).ti,ab,kw.
	4	exp carcinogen/ or environmental monitoring/ or environmental exposure/ or particle size/ or smoke/ or soot/ or exp "dust and dust related phenomena"/ or air pollution/ or air pollutant/ or inorganic compound/ae, an or exp polycyclic aromatic hydrocarbon/ or exp heavy metal/ or acrolein/ or benzene/ or formaldehyde/ or hydrocarbon/ or carbon dioxide/ or carbon monoxide/ or nitrogen oxide/ or nitrogen dioxide/ or nitrous oxide/ or sulfur dioxide/ or sulfur oxide/ or exp gas/to or ozone/ae or aerosol/ae or 2,3,7,8 tetrachlorodibenzo para dioxin/ or benzofuran derivative/ or dioxin/ or soil pollutant/

Table 1. Search strategy used in the review study on the evidence of health impacts of occupational exposure to wildland fires – cont.

Database	No.	Searches
	5	(carcinogen* or environmental monitor* or expos* or particulate* or PM* or smoke or soot or dust or air pollut* or air quality or soil pollut* or particle* or chemical* or PHA or polycyclic aromatic hydrocarbon* or acrolein or benzene or formaldehyde or carcinogen* or hydrocarbon* or carbon dioxide* or carbon monoxide* or nitric oxide* or nitrogen oxide* or nitrogen dioxide* or nitrous oxide* or sulfur dioxide* or sulfur oxide* or ozone or aerosol* or benzofuran* or chlorinated dibenzofuran* or polychlorodibenzo* or Tetrachlorodibenzodioxin* or dioxin* or O3 or NOx or NO or N20 or NO2).ti,kw. or (carcinogen* or environmental monitor* or expos* or particulate* or PM* or smoke or soot or dust or air pollut* or air quality or soil pollut* or particle* or chemical* or PHA or polycyclic aromatic hydrocarbon* or acrolein or benzene or formaldehyde or carcinogen* or hydrocarbon* or carbon dioxide* or carbon monoxide* or nitric oxide* or nitrogen oxide* or nitrogen dioxide* or nitrous oxide* or sulfur dioxide* or sulfur oxide* or ozone or aerosol* or benzofuran* or chlorinated dibenzofuran* or polychlorodibenzo* or Tetrachlorodibenzodioxin* or dioxin* or O3 or NOx or NO or N20 or NO2).ab. /freq = 3
	6	hospitalization/ or emergency health service/ or exp death/ or mortality/ or "cause of death"/ or childhood mortality/ or fatality/ or fetus mortality/ or hospital mortality/ or infant mortality/ or maternal mortality/ or premature mortality/ or perinatal mortality/ or survival rate/
	7	(hospitalization or hospitalisation or ((hospital* or emergency) adj3 (visit* or admission)) or survival or casualt* or dead or died or death* or mortality).ti,kw. or (hospitalization or hospitalisation or ((hospital* or emergency) adj3 (visit* or admission)) or survival or casualt* or dead or died or death* or mortality). ab. /freq = 2
	8	exp injury/
	9	(wound* or injury or injuries or burn or burns or smoke inhal*).ti,ab,kw.
	10	exp pregnancy complication/ or intrauterine growth retardation/ or exp mental disease/ or maternal welfare/ or fetomaternal transfusion/ or maternal exposure/ or prenatal care/ or pregnancy/ or maternal mortality/ or maternal child health care/ or newborn nursing/ or fetus monitoring/ or exp prenatal diagnosis/ or uterine activity monitoring/ or fetoscopy/
	11	(pregnan* or fetus or fetal or foetal growth or retard* or maternal or prenatal or neonatal or placenta* or uterus or uterine or fetoscop*).ti,ab,kw.
	12	occupational asthma/ or occupational exposure/ or air pollutant/ or occupational accident/
	13	(((occupation or occupational or firefighter* or personnel or paramedic* or responder* or police or emergency medical technician*) adj5 (health or disease* or illness* or expos* or pollut* or disorder* or symptom*)) or asthma*).ti,ab,kw.
	14	exp respiratory tract disease/ or exp respiratory tract examination/ or exp breathing/
	15	(asthma* or bronchi* or lung* or dyspnea or laboured breath* or breathing difficult* or ARDS or (respiratory adj2 (distress or disease* or illness or insufficien*))).ti,ab,kw.
	16	exp hypersensitivity/
	17	(hypersensitivity* or allerg*).ti,ab,kw.
	18	exp eye disease/ or exp visual system examination/ or exp vision/
	19	(eye or ocular or vision or ophthalmolog*).ti,ab,kw.
	20	exp cardiovascular disease/ or exp cardiovascular system examination/
	21	(cardio* or cardiac* or heart or myocardial or pulmonary).ti,ab,kw.
	22	exp mental health/

Table 1. Search strategy used in the review study on the evidence of health impacts of occupational exposure to wildland fires – cont.

Database	No.	Searches
	23	(mental or psych* or behavio*).ti,ab,kw.
	24	1 and (or/2-23)
	25	24 not [animal/ or (exp animal/ not human/)]
	26	limit 25 to embase
	27	limit 25 to exclude medline journals
	28	26 or 27
	29	limit 28 to English language
	30	remove duplicates from 29
Environment Complete	S1	DE "FOREST fires" OR DE "GROUND cover fires" OR DE "WILDFIRES" OR TI ((bushfire* OR forestfire* OR grassfire* OR wildfire* OR "prescribed burn*" OR "smoke pollution event*" OR (fire* N3 (bush* OR biomass OR forest* OR grass* OR habitat* OR vegetation OR wild* OR ecosystem* OR savanna* OR agricultur*)) OR "prescribed fire")
	S2	(DE "HEALTH impact assessment" OR DE "HEALTH risk assessment") OR TI ((casualt* OR dead OR died OR death* OR disease* OR illness* OR morbidity OR mortality OR (health N3 effect*) OR (adverse* N3 effect*) OR (negative* N3 impact*) OR (health N3 impact*) OR (health N3 affect*) OR (negative* N3 affect*) OR (adverse* N3 affect*) OR (health N3 problem*) OR (human* N3 health) OR (health N3 hazard*) OR toxic*) OR KW ((casualt* OR dead OR died OR death* OR disease* OR illness* OR morbidity OR mortality OR (health N3 effect*) OR (adverse* N3 effect*) OR (negative* N3 impact*) OR (health N3 impact*) OR (health N3 affect*) OR (negative* N3 affect*) OR (adverse* N3 affect*) OR (health N3 problem*) OR (human* N3 health) OR (health N3 hazard*) OR toxic*)
	S3	(DE "EFFECT of air pollution on human beings" OR DE "EMISSIONS (Air pollution)" OR DE "AIR pollution -- Physiological effect" OR DE "INDOOR air pollution -- Risk assessment" OR DE "INDOOR air pollution -- Physiological effect") OR ((DE "CARCINOGENS" OR DE "EMISSIONS (Air pollution)" OR DE "ATMOSPHERIC deposition" OR DE "AIR pollutants" OR DE "AIR pollution" OR DE "POLLUTANTS" OR DE "ACETALDEHYDE" OR DE "AEROSOLS (Sprays)" OR DE "CARBON disulfide" OR DE "DUST" OR DE "PARTICULATE matter" OR DE "ATMOSPHERIC nitrogen dioxide" OR DE "NITROGEN oxides" OR DE "ATMOSPHERIC nitrogen oxides" OR DE "NITROGEN dioxide" OR DE "NITROUS oxide" OR DE "NITROXIDES" OR DE "EMISSION exposure") AND (DE "TOXICOLOGY" OR DE "BIOLOGICAL monitoring" OR DE "ENVIRONMENTAL toxicology" OR DE "TOXICITY testing")) OR TI ((carcinogen* OR "environmental monitor*" OR expos* OR particulate* OR "PM*" OR smoke OR soot OR dust OR "air pollut*" OR "air quality" OR "soil pollut*" OR particle* OR chemical* OR "PHA" OR "polycyclic aromatic hydrocarbon*" OR acrolein OR benzene OR formaldehyde OR carcinogen* OR hydrocarbon* OR "carbon dioxide*" OR "carbon monoxide*" OR "nitric oxide*" OR "nitrogen oxide*" OR "nitrogen dioxide*" OR "nitrous oxide*" OR "sulfur dioxide*" OR "sulfur oxide*" OR ozone OR aerosol* OR benzofuran* OR "chlorinated dibenzofuran*" OR polychlorodibenzo* OR tetrachlorodibenzodioxin* OR dioxin* OR "O3" OR "NOx" OR "NO" OR "N20" OR "NO2"))
	S4	(DE "ENVIRONMENTAL health" OR DE "EFFECT of environment on human beings" OR DE "HEALTH") OR TI ((hospitalization OR hospitalisation OR ((hospital* OR emergency) N3 (visit* OR admission)) OR survival OR casualt* OR dead OR died OR death* OR mortality)) OR KW ((hospitalization OR hospitalisation OR ((hospital* OR emergency) N3 (visit* OR admission)) OR survival OR casualt* OR dead OR died OR death* OR mortality))

Table 1. Search strategy used in the review study on the evidence of health impacts of occupational exposure to wildland fires – cont.

Database	No.	Searches
	S5	DE "WOUNDS & injuries" OR DE "RADIATION burns" OR DE "RADIATION injuries" OR TI ((wound* OR injury OR injuries OR burn OR burns OR "smoke inhal*")) KW ((wound* OR injury OR injuries OR burn OR burns OR "smoke inhal*"))
	S6	DE "CONGENITAL disorders" OR DE "HUMAN abnormalities" OR DE "PREGNANCY tests" OR TI (pregnan* OR fetus OR fetal OR foetal growth OR retard* OR maternal OR prenatal OR neonatal OR placenta* OR uterus OR uterine OR fetoscop*) OR KW (pregnan* OR fetus OR fetal OR foetal growth OR retard* OR maternal OR prenatal OR neonatal OR placenta* OR uterus OR uterine OR fetoscop*)
	S7	(DE "ENVIRONMENTALLY induced diseases" OR DE "ENVIRONMENTALLY induced diseases in children" OR DE "MULTIPLE chemical sensitivity" OR DE "SICK building syndrome") OR TI ((((occupation OR occupational OR firefighter* OR personnel OR paramedic* OR responder* OR police OR "emergency medical technician*") N5 (health OR disease* OR illness* OR expos* OR pollut* OR disorder* OR symptom*)) OR asthma*)) OR KW ((((occupation OR occupational OR firefighter* OR personnel OR paramedic* OR responder* OR police OR "emergency medical technician*") N5 (health OR disease* OR illness* OR expos* OR pollut* OR disorder* OR symptom*)) OR asthma*))
	S8	(DE "ASTHMA" OR DE "OCCUPATIONAL asthma" DE "BRONCHIOLITIS" OR DE "Lungs" OR DE "LUNG volume measurements" OR DE "SARS (Disease)" OR DE "RESPIRATORY syncytial virus infections" OR DE "INFLUENZA") OR TI ((asthma* OR bronchi* OR lung* OR dyspnea OR "laboured breath*" OR "breathing difficult*" OR ARDS OR (respiratory N2 (distress OR disease* OR illness OR insufficien*)))) OR KW ((asthma* OR bronchi* OR lung* OR dyspnea OR "laboured breath*" OR "breathing difficult*" OR ARDS OR (respiratory N2 (distress OR disease* OR illness OR insufficien*))))
	S9	DE "ALLERGENS" OR DE "ALLERGY" OR TI (hypersensitivity* OR allerg*) OR KW (hypersensitivity* OR allerg*)
	S10	TI (eye OR ocular OR vision OR ophthalmolog*) OR KW (eye OR ocular OR vision OR ophthalmolog*)
	S11	DE "HEART diseases -- Environmental aspects" OR TI (cardio* OR cardiac* OR heart OR myocardial OR pulmonary) KW (cardio* OR cardiac* OR heart OR myocardial OR pulmonary)
	S12	DE "PSYCHOBIOLOGY" OR DE "HUMAN behavior" OR TI (mental OR psych* OR behavio*) OR KW (mental OR psych* OR behavio*)
	S13	S2 OR S3 OR S4 OR S5 OR S6 OR S7 OR S8 OR S9 OR S10 OR S11 OR S12
	S14	S1 AND S13
	S15	S1 AND S13 AND LA (English)

burn, grass fire, forest fire), year of fire, number and type of participants included in the final analysis, comparator, sample demographics, exposure measure, outcomes of interest, outcome measure, results, and confounders considered.

The authors assessed the quality of the articles with the criteria proposed by a recent review on the health impacts of non-occupational wildfire smoke exposure: sample size, exposure assessment methods, outcome assessment methods, and control of potential confounders [15]. In addition, the authors considered whether outcome assessments measured acute physiological responses or health outcomes, as Adetona et al. identified that the literature on clinically significant outcomes of wildland fire exposure, as well as study design, is lacking [13]. The scoring rubric is listed in Table 2 and the final quality level for each article is listed in Table 3 (summary table).

Table 2. Quality scoring rubric in the review study on the evidence of health impacts of occupational exposure to wildland fires

Description	Score
Exposure assessment	
self-reported exposure severity	1
shift or season duration	2
individual- or area-level monitoring	3
Outcome assessment	
self-reported health outcomes	1
markers of acute physiological response	2
objective measurement of health outcome	3
Control for potential confounders	
no or unclear	0
yes	1
Sample size in analysis	
case report	0
< 50 participants	1
≥ 50 participants	2
Study design	
case report or description	0
ecological or cross-sectional	1
case-control	2
cohort	3
randomized control trial	4
Quality level	
high	≥ 12
moderate	8–11
low	≤ 7

RESULTS

Search results

The authors identified 3442 records in the database search and excluded 374 duplicate results. The authors screened the remaining 3068 records for eligibility and identified 52 articles eligible for full-text review. After full-text review, 32 articles met the inclusion and exclusion criteria. The study selection process and results at each stage are summarized in the modified PRISMA flow diagram [18] in Figure 1.

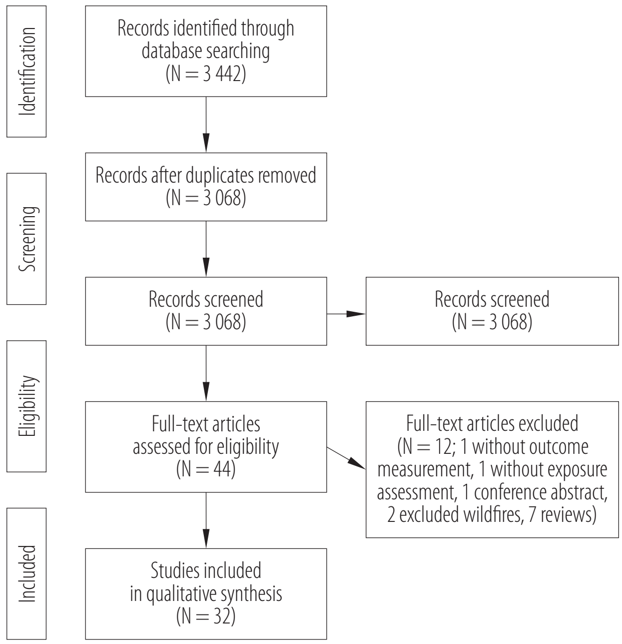

Figure 1. Modified PRISMA 2009 flow diagram [18]

Of the 32 articles, the majority (17/32) described fires that took place in North America. Seven articles described the outcomes of the firefighters who managed the 1983 Ash Wednesday bush fire in Southeastern Australia [19–25], while additional 2 articles discussed the 2010 Carmel Forest fire in Israel [26,27]. The authors assigned most (28/32) articles a low or moderate quality score.

Cancer morbidity

The authors identified 2 articles of low to moderate quality that examined cancer outcomes. A recent cross-sectional survey of U.S. wildland firefighters found that the self-reported prevalence of all cancer types was < 1% in survey respondents, with the exception of basal cell cancer (3%) and squamous cell cancer (SCC) (2%). The study authors did not comment on the relationship between cancer prevalence and years worked as a wildland firefighter [28]. Also a case report regarding a 65-year-old man with a history of over 30 SCCs of the lower extremities was identified. The authors attribute the SCCs to heat exposure from the patient's 28-year career as a wildland firefighter [29].

Table 3. Summary of included papers on the evidence of health impacts of occupational exposure to wildland fires

Reference	Study design	Setting	Sample size (in analysis)	Summary of results	Quality level
Adetona et al., 2011 [6]	cross-shift cohort	prescribed forest burns in Savannah River Site, South Carolina, 2003 and 2004	24	lung function declined cross-shift on both burn days and non-burn days; each additional day of work during a burn day was associated with declines in pre-shift FVC (24 ml, $p < 0.01$ in non-allergic firefighters) and pre-shift FEV_1 (24 ml, $p < 0.01$ in non-allergic firefighters)	moderate
Adetona et al., 2013 [6]	cross-shift cohort	prescribed forest burns, Savannah River Site, South Carolina, 2004	19 (214 urine samples pre- and post-shift)	$PM_{2.5}$ levels in individual breathing zone samplers were not associated with cross-shift changes in urine malondialdehyde or urine 8-oxo-7,8-dihydro-2′-deoxyguanosine, although 8-oxo-dG concentrations were higher in this sample than in the general population; there was no cross-shift increase in lipid peroxidation as measured by creatinine-adjusted MDA; creatinine-adjusted 8-oxo-dG levels increased cross-shift in firefighters who had worked for ≤ 2 years, but not in firefighters who had worked for > 2 years	moderate
Amster et al., 2013 [27]	cross-sectional survey	wild forest fire in Carmel Forest, Israel, 2010	272	during the Carmel Forest fire, the most commonly reported symptoms were eye irritation (77% of respondents), fatigue (71%), cough (60%), and headache (53%); only 4.4% of respondents reported receiving medical attention and 1% reported being hospitalized	low
Betchley et al., 1997 [39]	cross-shift cohort cross-season cohort	prescribed forest burns in the Cascade Mountains, Washington and Oregon states, 1992 and 1993	76 (cross-shift analysis) 53 (cross-season analysis)	no significant increase in self-reported respiratory symptoms cross-shift or from the start to the end of the firefighting season; significant declines in FVC, FEV_1, and $FEF_{25–75}$ cross-shift (mean declines of 0.065 l, 0.150 l, and 0.496 l/s, respectively) and significant declines in FEV_1 and $FEF_{25–75}$, but not FVC, from the start to the end of the firefighting season (mean declines of 0.104 l, 0.275 l/s, and 0.033 l, respectively); in most cases, spirometry results returned to pre-exposure levels during the winter	moderate
Britton et al., 2013 [35]	ecological study	wildland fires managed by U.S. federal agencies required to report to the National Interagency Coordination Centre, 2003–2007	(867 fires)	less complex fires were associated with a greater risk of firefighter injury	moderate
De Vos et al., 2009 [40]	double-blind randomized trial	prescribed forest burns in Western Australia (no date provided)	67	across all study participants, there was a significant decline in FEV_1 and SaO_2 after 60 min (0.08 l, $p < 0.05$; 1.2%, $p < 0.05$, respectively) and 120 min (0.15 l, $p < 0.05$; 1%, $p < 0.05$, respectively) of smoke exposure, but declines were not associated with the type of the respiratory filter used	high
Doley et al., 2016 [19]	cohort	Ash Wednesday bushfire in Southeastern Australia, 1983	277	28% of respondents reported symptoms of psychiatric impairment 7 years after the Ash Wednesday	low

Table 3. Summary of included papers on the evidence of health impacts of occupational exposure to wildland fires – cont.

Reference	Study design	Setting	Sample size (in analysis)	Summary of results	Quality level
Gallanter and Bozeman, 2002 [49]	descriptive	wildfire in Flagler County, Florida, 1998	3 404 patients	the most frequently reported (33%) reasons for visits to the Disaster Medical Assistance Team were related to prevention (e.g., requests for sunscreen or moleskin); respiratory complaints comprised 1% of visits; burns (0.7% of visits) and blunt trauma (0.4% of visits) were the least common complaints	low
Gaughan et al., 2008 [37]	open cross-season cohort	wildfires and prescribed burns in Alaska, California, Montana, Wyoming, 2004–2006	58	FEV_1 declined a mean of 224 ml ($p < 0.001$) from preseason to post-fire, then increased in the postseason to levels similar to the preseason; mean sputum albumin concentrations, ECP, and MPO did not differ significantly between the preseason, post-fire, and post-season	moderate
Gaughan et al., 2014 [30]	cross-shift cohort	Red Eagle wildfire in Colorado, 2006	17	exhaled breath CO increased significantly cross-shift, from a mean of 1.8 ppm to 3.2 ppm; mean FEV_1 declined cross-shift, but the difference was not statistically significant	moderate
Gaughan et al., 2014 [36]	cross-sectional	Sand Gulch wildfire in Colorado, 2011	38	increases in measures of oxidative stress were significantly associated with increases in mean augmentation index %, a measure of arterial stiffness; urinary levoglucosan was significantly associated with increases in oxidative stress measures	moderate
Hejl et al., 2013 [31]	cross-shift cohort	prescribed forest burns in Savannah River Site, South Carolina, 2011	12	interleukin-8 was the only biomarker of inflammation that increased cross-shift (cross-shift ratio of 1.7, 95% CI: 1.35–2.13); there was no association between cross-shift changes in inflammatory biomarker concentrations and self-reported respiratory symptoms, and the cross-shift changes in interleukin-8 were not associated with the levels of $PM_{2.5}$ or CO exposure; igniting fires was associated with greater increases in interleukin-8 than maintaining the fire	moderate
Innes and Clarke, 1985 [34]	cross-sectional survey	bushfire in Adelaide, Australia, 1983	72	emotional support from co-workers and spouses was protective against physical and mental stress during and immediately after the fire; perceived danger of the fire did not predict physical or mental stress	low
Jacquin et al., 2011 [41]	cross-shift cohort cross-season cohort	wildfires in Corsica, France, 2007	108	lung function declined significantly cross-shift (FEV_1 –0.53 l; FVC –0.59 l; PEF –53 l/min^{-1}, $p < 0.05$); 3 months post-season, spirometry demonstrated persistent decreases from the baseline (FEV_1 –0.28 l; FVC –0.34 l; PEF –45 l/min^{-1}, $p < 0.05$)	moderate
Leykin et al., 2013 [26]	cross-sectional survey	wild forest fire in Carmel Forest, Israel, 2010	65	12.3% of study participants had scores above the conservative cut-off for probable PTSD; there was a curvilinear relationship between post-traumatic symptoms and post-traumatic growth	low

Liu et al., 1992 [42]	cross-season cohort	wildfires in Northern California and Montana, 1989	63	cross-season, pulmonary function decreased (mean individual declines of 0.09 l, 0.15 l, and 0.44 l/s in postseason values of FVC, FEV_1, and $FEF_{25–75}$, respectively) and airway responsiveness increased	moderate
McFarlane, 1989 [20]	cohort	Ash Wednesday bushfire in Southeastern Australia, 1983	315	neither the severity of exposure nor the losses sustained predicted post-traumatic morbidity at 29 months post-fire	low
McFarlane, 1988 [21]	sub-group analysis of a cohort	Ash Wednesday bushfire in Southeastern Australia, 1983	50	neuroticism and introversion predicted the development of PTSD post-fire	low
McFarlane, 1988 [22]	cohort	Ash Wednesday bushfire in Southeastern Australia, 1983	469	exposure severity did not predict PTSD	low
McFarlane, 1988 [23]	cohort	Ash Wednesday bushfire in Southeastern Australia, 1983	469	10.4% of respondents reported psychological morbidity at 3 months, 11 months, and 29 months post-fire, while 51.2% of respondents reported psychological morbidity in at least 1 survey; most individuals (69%) who were symptomatic at 4 months post-fire developed chronic PTSD	low
McFarlane, 1987 [24]	cohort	Ash Wednesday bushfire in Southeastern Australia, 1983	469	9% of the mental trauma score variance was attributed to recent life events, including the wildfire disaster	low
McFarlane, 1986 [25]	cohort	Ash Wednesday bushfire in Southeastern Australia, 1983	315	the level of mental health morbidity 4 months after the disaster remained almost unchanged at 29 months: 21% of firefighters experienced intrusive imagery of the fire 29 months post-fire	low
Miranda et al., 2012 [43]	cross-shift cohort cross-season cohort	wildfires in Leiria, Coimbra, Aveiro districts of Portugal, 2008–2010	10 (exposure assessment) 35 (outcome assessment)	threshold limit values of both the time-weighted average for an 8-h work day and 5-day work week, and short-term limit values were exceeded for CO, but no exceedances were noted for NO_2; FEV_1 (–1.66 ml), F_{25} (–11.69 ml), F_{50} (–4.88 ml), and MEF (–5.97 ml/s) had statistically significant declines between the 2008 pre-season and the 2010 post-season	moderate
NIOSH, 2002 [48]	case study	grass fires in the U.S., 1999	2	2 wildland firefighters managing grass fires were exposed to an electrical hazard resulting in their deaths	low
Psarros et al., 2008 [33]	cross-sectional survey	wildfire in the Greek Peloponnese, 2007	102	37% of firefighters met criteria for PTSD; these individuals were more likely to be younger, seasonal firefighters, and have higher anxiety and less experience dealing with disasters than those who did not meet the criteria	low
Rothman et al., 1991 [44]	cross-season cohort study	wildfire in the Sierra Nevada Mountains, Northern California, 1988	52	cross-season, pulmonary function decreased: FEV_1 –1.2% (95% CI: –0.5–(–2)% and FVC – 0.3% (95% CI: 0.4–(–1)%), and respiratory symptoms increased; decreases were strongly, significantly associated with hours of recent firefighting activity	moderate

Table 3. Summary of included papers on the evidence of health impacts of occupational exposure to wildland fires – cont.

Reference	Study design	Setting	Sample size (in analysis)	Summary of results	Quality level
Semmens et al., 2016 [28]	cross-sectional survey	United States	499	the longer an individual had been a wildland firefighter, the more likely they were to have hypertension, with an OR of 4.2 (95% CI: 1.3–14) for individuals who had worked for 10–19 years and an OR of 5 (95% CI: 1.3–20.2) for individuals who had worked > 20 years, compared to individuals who had worked for < 10 years; risk of elevated cholesterol, hearing loss, asthma, arthritis, or depression was not associated with length of wildland firefighting career	low
Serra et al., 1996 [46]	cross-sectional	county or forest fires in Sardinia, Italy (no date provided)	92 firefighters, 51 police officers	firefighters had significantly poorer FEV_1, FVC/FEV_1, FEF_{75}, FEF_{50}, FEF_{25}, and RV than police officers, after controlling for age, height, pack-years, and previous smoking habits; there was no significant difference between firefighters and police officers for measures of TLC, FVC, and D_{LCO}	low
Slaughter et al., 2004 [38]	cross-shift cohort	prescribed forest burns in the U.S., 1992 and 1993	65	lung function decreased significantly from pre- to post-shift: Δ (95% CI): FEV_1 –0.125 l (95% CI: –0.176–(–0.74)), FVC –0.067 l (95% CI: –0.107–(–0.026)), $FEF_{25–75}$ –0.451 l/s (95% CI: –0.652–(–0.249)); no significant associations were found with lung function measurements and any of the 4 exposure measurements	moderate
Smith et al., 2013 [47]	case-control	wildfires in the Western U.S., 2007–2009	66 firefighters, 39 controls	no statistically significant elevations of the blood mercury level were identified	low
Swiston et al., 2008 [32]	cross-shift cohort	wildfires in British Columbia, 2004 and 2005	52	there was no change in FEV_1, or sputum lymphocyte, monocyte, macrophage, and bronchial epithelial cells cross-shift; there were small, but statistically significant, increases in the numbers of inclusion-positive macrophages and granulocytes in sputum cross-shift; circulating WBCs and PMNs increased cross-shift for both firefighting and other strenuous work, while band cell counts, IL-6, and IL-8 increased cross-shift for firefighting only	moderate
Wolfe et al., 2012 [29]	case report	wildfires and prescribed burns, Florida, 1976–2004	1	case report of retired wildland firefighter with over 30 SCCs on his lower extremities, attributed to heat exposure from firefighting	low

D_{LCO} – diffusing capacity; ECP – eosinophilic cationic protein; FEF – forced expiratory flow; FEV_1 – forced expiratory volume in 1 s; FVC – forced vital capacity; MDA – malondialdehyde; MEF – midexpiratory flow rate; MPO – myeloperoxidase; PEF – peak expiratory flow; PMN – polymorphonuclear leukocytes; PTSD – post-traumatic stress disorder; RV – residual volume; SaO_2 – oxygen saturation; SCC – squamous cell cancer; TLC – total lung capacity; WBCs – white blood cells.

Cardiovascular morbidity

The authors identified 3 studies that examined cardiovascular outcomes, all of moderate quality. A cross-sectional study of 38 U.S. male wildland firefighters found that increases in oxidative stress, as measured by urinary 8-iso-prostaglandin F2α and 8-hydroxy-2′-deoxyguanosine, were associated with increased arterial stiffness, as measured by the pulse wave analysis of the aortic augmentation index. The authors developed an oxidative stress score composed of the mean Z-scores of oxidative stress measures and found that every 1 unit increase in the oxidative stress score was associated with a 10.2% increase in the mean augmentation index (95% CI: 1.35–19%). Oxidative stress was also significantly and positively associated with levoglucosan concentration, a biomarker of smoke exposure [30].

A recent cross-sectional survey of U.S. wildland firefighters found that the self-reported prevalence of hypertension was positively associated with the length of career as a wildland firefighter. Compared to individuals who had worked for < 10 years, the adjusted odds ratio for hypertension was 4.2 (95% CI: 1.3–14) for individuals who had worked for 10–19 years, and 5 (95% CI: 1.3–20.2) for individuals who had worked > 20 years. The authors adjusted for age, sex, race, and household income. The authors did not find any association between the length of wildland firefighting career and hypercholesterolemia, although the p-value of 0.065 may be suggestive of a trend [28].

In a third cross-sectional survey of 272 firefighters and police officers who responded to the 2010 Carmel Forest fire disaster in Israel, 19% of respondents reported experiencing chest pain during the fire response. However, none of the 4 (1.4%) respondents who were hospitalized were diagnosed with cardiovascular events [27].

Oxidative stress and inflammatory response

The authors identified 3 studies that examined oxidative stress or inflammation and wildland fire exposure. Two were rated as moderate in quality [6,31] and the third as high in quality [32]. All 3 studies were small, cross-shift cohorts and the results were inconsistent across the studies.

Adentona et al. did not observe significant cross-shift changes in urinary malondialdehyde or 8-oxo-7, 8-dihydro-2′-deoxyguanosine, or an association with biomarkers of oxidative stress and $PM_{2.5}$ levels [6]. Similarly, Hejl et al. [31] did not observe significant cross-shift changes in interleukin-1β, C-reactive protein, serum amyloid A, inter-cellular adhesion molecule-1, or vascular cell adhesion molecule-1; however, interleukin-8 showed a significant cross-shift increase with a post- to pre-work shift ratio of 1.7 (95% CI: 1.35–2.13). Firefighters who ignited fires had significantly greater cross-shift increases in interleukin-8 levels than firefighters who maintained fire. Swiston et al. [32] also identified a significant cross-shift increase in interleukin-8, as well as cross-shift increases in circulating white blood cells, polymorphonuclear leukocytes, band cells, and interleukin-6 levels. This study noted that some inflammatory markers increased cross-shift in both firefighters exposed to wildland fires and those who performed similar work outside of wildland fire conditions; only band cell counts, interleukin-6, and interleukin-8 increased in firefighting individuals alone.

Mental health impact

The authors identified 11 articles that examined the mental health impact of wildland firefighting. Seven of these articles examined the same group, a cohort composed of volunteer firefighters who responded to the Ash Wednesday bushfire disaster in Australia [19–25]. All of these studies were of low quality. Of the 1500 original questionnaires distributed, 469 were returned (the response rate of 31.3%) [24]. One in 10 respondents reported psychological morbidity in the surveys at 4 months, 11 months, and 29 months post-fire [23].

Leykin et al., in their moderate quality cross-sectional survey of firefighters who responded to the Carmel Mountain fire in Israel, reported a similar prevalence of probable post-traumatic stress disorder (PTSD), 12.3% (8/65) [26]. A separate, moderate quality cross-sectional survey of firefighters and police officers who responded to the Carmel Mountain fire found that 25% (68/272) of respondents reported at least 1 stress-related symptom after the fire and 10% had persistent post-traumatic stress symptoms (27/272) [27]. Similarly, Psarros et al. reported a prevalence of PTSD of 19% (19/102) in their lower-quality cross-sectional survey of firefighters who responded to a wildfire in the Greek Peloponnese [33]. Psarros et al. found that individuals who met the criteria for PTSD were more likely to be younger, seasonal firefighters, and have higher anxiety and less experience dealing with disasters than those who did not [33]. None of these 3 studies reported the prevalence of PTSD in the general population.

In the Ash Wednesday cohort, most individuals (69%) who reported psychological morbidity at 4 months post-fire developed chronic PTSD [23,25]. Neither self-reported severity of exposure nor individual losses sustained predicted post-traumatic morbidity [20,21,24]; however, the personality traits of neuroticism and introversion did predict the development of post-traumatic stress disorder [22]. The cohort originally assembled by McFarlane [25] was surveyed again by Doley et al. [19] 7 years after the Ash Wednesday fire. Of the 469 individuals who originally responded to McFarlane, 277 responded to Doley et al. [19] (the response rate of 59%). Almost one-third of respondents reported psychological morbidity 7 years after the Ash Wednesday fire [19]. In contrast, a recent moderate-quality cross-sectional survey of U.S. wildland firefighters found no relationship between the number of years worked as a wildland firefighter and the risk of depression [28].

In a low-quality study of Australian firefighters, Innes and Clarke [34] surveyed members of the South Australian Metropolitan Fire Service after they responded to a large bushfire. Similar to McFarlane [20–25], Innes and Clarke concluded that the perceived danger of the fire did not predict future psychological distress. They also found that emotional support from co-workers and spouses was protective against stress during and immediately after the fire [34].

Injuries and musculoskeletal morbidity

The authors identified 2 studies that examined the impact of wildland firefighting on musculoskeletal morbidity and injuries. In a high-quality ecological study, Britton et al. [35] used data from the U.S. National Interagency Fire Center to determine fire characteristics associated with firefighter injury. They found that the more complex the fire, based on the peak incident management level assigned by the responding agency, the fewer injuries per 10 000 person-days were sustained: the mean rate of injury per 10 000 person-days was 3.6 (SD = 5.35) for type I fires (the most complex), 11.7 (SD = 30.1) for type II fires (moderately complex), and 15.2 (SD = 56.9) for type III fires (the least complex) ($p < 0.001$) [35]. A recent, moderate-quality cross-sectional survey of U.S. wildland firefighters found no relationship between the number of years worked as a wildland firefighter and the risk of arthritis [28].

Respiratory morbidity

The authors identified 14 studies of moderate to high quality that examined respiratory outcomes of occupational exposure to wildland fires. Most studies presented p-values rather than 95% confidence intervals. With the exception of 2 studies [36,37], most studies that examined cross-shift [32,38–41] or cross-season [39,41–44] spirometry found small, but statistically significant, declines in lung function after wildland fire exposure. A single study controlled for the possibility that cross-shift declines in lung function may be attributable to diurnal variation rather than wildland fire; Adetona et al. [45] found that lung function declined between the beginning and the end of shifts on both burn days and non-burn days. The authors hypothesized the cross-shift decline might be due to circadian effects rather than smoke exposure.

Two studies assessed the relationship between exposure measurements and lung function. In a cross-shift cohort of 65 U.S. wildland firefighters, Slaughter et al. did not find any association between $PM_{3.5}$, acrolein, formaldehyde, or carbon monoxide exposure and lung function [38]. In contrast, in a cross-shift cohort of 38 U.S. wildland firefighters, Gaughan et al. found that participants in the high-levoglucosan exposure group had a mean forced expiratory volume in 1 s (FEV_1) decline of 0.23 l, compared to a mean decline of 0.02 l in the low-levoglucosan exposure group [36].

The results for lung function recovery after exposure were mixed. Betchley et al. found that spirometry results returned to the pre-exposure baseline during the winter (mean, 77 days post-firefighting) [39], while Jacquin et al. found that FEV_1, forced vital capacity (FVC), and peak expiratory flow (PEF) remained below the baseline at 3 months post-firefighting [41]. In a study comparing the lung function of Sardinian wildland firefighters to police officers that controlled for age, height, and pack-year smoking history, firefighters had significantly lower forced expiratory volume (FEV) (3.9 l vs. 4.04 l), FEV_1/FVC (80.07 l vs. 83.89), forced expiratory flow at 75 (FEF_{75}) (8.37 l vs. 8.3 l), FEF_{50} (4.73 l vs. 5.54 l), FEF_{25} (1.58 l vs. 1.99 l), and residual volume (RV) (1.57 l vs. 1.76 l), but total lung capacity (TLC), FVC, and diffusing capacity (D_{LCO}) were the same between both groups. However, there was no association between the years of work and respiratory outcomes [46].

Studies of self-reported respiratory symptoms also provided mixed results. Betchley et al. found no significant increase in self-reported respiratory symptoms from pre-shift to post-shift, or from the start of the firefighting season to the end of that season [39]. In contrast, in a cross-season cohort of 58 U.S. hand crew members, Gaughan et al. found that self-reported respiratory symptoms were more common post-fire than pre-season or post-season [37]. Similarly, in a cross-sectional survey of 272 firefighters and police officers who responded to the Carmel Mountain fire, 60% reported cough, 27% reported shortness of breath, and 22% reported wheezing during the fire response, although none were hospitalized for respiratory symptoms [27]. In a randomized controlled trial of 3 respirator types, a smaller proportion of subjects (18%) reported respiratory symptoms during wildland fire exposure compared to the control group without functional respirators [40].

While wearing a respirator reduces the incidence of respiratory symptoms [27,40] and the decline in lung function [40], wearing a cotton bandana does not [44]. Gaughan et al. also found that the number of days spent fighting fires throughout one's career was significantly associated with more upper respiratory symptoms [37], while a cross-sectional survey of U.S. wildland firefighters found no association between self-reported asthma and the number of years worked [28].

Other health impacts

The authors identified 3 studies that investigated other health impacts of wildland fires. In a study of moderate quality, Smith et al. [47] examined pre- and post-season blood mercury levels in 66 firefighters and 39 controls. They did not find any statistically significant elevations of the blood mercury level [47]. A moderate-quality cross-sectional survey of U.S. wildland firefighters found no relationship between the number of years worked as a wildland firefighter and the risk of hearing loss [28]. Authors from the National Institute for Occupational Safety and Health described 2 cases of wildland firefighter exposure to electrical hazards resulting in death. Both deaths occurred in volunteer firefighters who were attending to grass fires [48]. This study was assigned a lower-quality score because it was a case series.

Health system use

The authors identified 2 studies, both of moderate quality, that reported on the healthcare system use of wildland firefighters. Gallanter and Bozeman [49] described the reasons for which firefighters and support personnel visited the disaster medical assistance team during a wildfire in Florida. During this fire event, there were 3404 patient visits. The most common chief complaints were in the preventive/hygiene/environmental category (33%) (e.g., requests for sunscreen or moleskin). Respiratory complaints comprised 1% of visits, while burns (0.7%) and blunt trauma (0.4%) were the least common complaints. Only 8 (0.2%) patients were transported to the emergency department [49]. In a cross-sectional survey of 272 firefighters and police officers who responded to the Carmel Forest fire in Israel, 9 (3.3%) respondents reported receiving medical attention and only 4 (1.5% of total) of those were hospitalized. The reasons for hospitalization included smoke inhalation, epistaxis, exposure to fire retardant, and dislocated shoulder [27].

DISCUSSION

This review identified 32 published articles that examined the impact of occupational exposures to wildfires on health. Respiratory and mental health were the most commonly-investigated end points. The authors identified consistent, but small, impacts of wildland firefighting on lung function. In some cases, declines in lung function were associated with increases in self-reported respiratory symptoms. Currently, information on the clinical impact or long-term impact of these outcomes is lacking. Information on the impact of different wildland fire types (e.g., wild fire vs. prescribed burn) is also unavailable: exposure studies have suggested that managing prescribed fires results in greater smoke exposure than fighting wildfires [7], but it is unclear from this review if this results in differential health outcomes.

In this review, the authors also identified a relationship between wildland firefighting and mental health outcomes. In cross-sectional surveys and cohort studies, 10–20% of responders report post-traumatic stress symptoms; however, most of these studies are performed on firefighters responding to major disasters [19–25,33], rather than typical wildland fires. Given that physical injuries are more common per days worked in less complex fires [35], it is important to examine if the same relationship holds true for mental injury. Further, the baseline prevalence of mental illness is not well-described in studies investigating the mental health impact of firefighting.

With respect to the cardiovascular impacts of occupational exposure to wildland fires, the authors identified a single cross-sectional survey that linked wildland firefighting to the development of hypertension [28]. A potential pathway for hypertension in this group may be oxidative stress resulting in arterial stiffness [30]. No acute cardiac events associated with occupational exposure to wildland fires were identified, but only 2 studies explicitly reported on this endpoint [27,49].

The work of Britton et al. raises the interesting hypothesis that injury is more common in less complex fires because the duty-assignment strategies for more complex fires are protective against injury [35]. Testing this hypothesis may identify mechanisms to protect wildland firefighters from occupational injury.

The present review did not identify sufficient evidence to comment on the relationship between wildland firefighting and cancer. Similarly, the relationship between wildland firefighting, oxidative stress, and inflammatory response is inconsistent. Given the results of the work by Swiston et al., who found that elevation in some inflammatory markers could be explained by strenuous work [32], future investigations of inflammatory markers should consider this confounder.

The main strength of this review is the extensive search that was undertaken to identify relevant literature. There are 3 main limitations of this review. First, the included studies are highly heterogeneous with respect to quality, exposure and outcomes measures, study design, sample size, and location. This limited the authors' ability to directly compare the findings. Second, almost half of the studies took place in the United States. Because smoke composition is related to vegetation type, moisture, temperature, and wind, results from 1 geographical area may not apply to other geographical areas [50]. Finally, most of the participants of the included studies are young men, so the results of this review may not apply to women or other age groups.

This review also highlights challenges to understanding the health impacts of wildland fires on firefighters: it is difficult to follow firefighters for more than 1 season, so health outcomes with long latencies may not be identified. In order to overcome this challenge, some investigators use biomarkers or proxy measures that may not have a direct link to clinically meaningful outcomes. Finally, it is challenging to accurately assess exposure, and many studies rely on self-reported exposure or duration of time exposure.

CONCLUSIONS

Compared to the understanding of the health impacts of structural firefighting, the understanding of the health impacts of wildland firefighting is still in its infancy. The evidence summarized by the review suggests that occupational exposure to wildland fires results in short-term declines in lung function that may be associated with respiratory symptoms; may result in post-traumatic stress symptoms, the severity of which is determined by individual protective factors; and may increase the risk of hypertension, potentially via oxidative stress. There is insufficient evidence available to comment on long-term respiratory impacts or cancer risk. The evidence on the relationship between wildland firefighting and inflammation is inconsistent. Given the potential for long-lasting morbidity, further elucidating what factors are protective for mental health issues and establishing means of providing the necessary support to wildland firefighters may be one area where further research is warranted. Considering the physical health impacts and establishing whether there are long-term outcomes is another key gap in the current understanding of how wildfires affect those who respond to them. Given that the frequency of wildfires is likely to increase secondary to climate change, it is important to better characterize the health impacts of wildland firefighting to better protect the health of these workers.

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