Perceptions of Wildland Fire Smoke

Literature review and synthesis

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About the Northwest Fire Science Consortium:

The Northwest Fire Science Consortium works to accelerate the awareness, understanding, and adoption of wildland fire science in Washington and Oregon. It connects managers, practitioners, scientists, and local communities and collaboratives working on fire issues on forest and range lands. The Northwest Fire Science Consortium is one of the 15 regional exchanges established by the Joint Fire Science Program's Fire Science Exchange Network to bring fire science users together to address regional fire management needs and challenges. Each regional exchange provides current and regionally-relevant wildland fire science information to users in the region. For more information: http://www.nwfirescience.org/

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Introduction

Smoke from wildland fire presents a serious and growing concern. Mirroring global trends in recent decades, many areas of the US are experiencing increasing wildfire size, severity, and frequency. The health hazard of smoke from wildland fire has been well-documented (see Adetona et al. 2016 and Reid et al. 2016 for reviews on health impacts) and can be orders of magnitude higher than the hazard presented by actual flames (Doer and Santin 2016, Navarro et al. 2018). As the size and severity of wildfires have increased, smoke has at times affected cities hundreds of miles from the source (Brey et al. 2018).

Amid increasing smoke exposure from wildfires, calls for fuels reduction treatments have also increased. However, treatments such as prescribed fire and natural ignitions that are managed for resource benefits also produce smoke and elicit similar health concerns as wildfire smoke (Haikerwal et al. 2015). These treatments can reduce overall smoke exposure by decreasing the risk of more severe, hard to control wildfires in the long-term (Long et al. 2017, Schweizer et al. 2018), but their implementation often depends on public support, as well as public tolerance for the smoke they produce.

With exposure to wildland fire smoke projected to further increase (Barbero et al. 2015) there is a clear need for efforts to better mitigate or adapt to smoke impacts in high-risk areas. Such efforts rely on an understanding of how people perceive, plan for, and respond to smoke. This synthesis compiles published scholarly literature on how individuals perceive wildland fire smoke to offer an overview of current knowledge on wildland fire smoke perceptions. It is intended to serve as a documentation of the scope, parameters, and gaps of research to date in this field. In addition, it is a resource for:

- scholars seeking to add relevant insights to collective understanding of wildland smoke perceptions, ideally as a basis from which to develop further inquiries into this field;
- managers to inform their approaches around smoke or become more familiar with potential areas of concern or opportunities for education.

Approach

To better understand the state of existing research and gaps on individual perceptions of wildland fire smoke, we collected peer-reviewed journal articles. This synthesis was focused on how individuals perceive wildland fire smoke and impacts, and we included only studies based primarily on data from interviews, focus groups, or surveys. We excluded studies based on data that did not examine perceptions (e.g. agency summaries of reported health impacts) or in which smoke was not a primary finding of the research (e.g. smoke was tangentially mentioned in a quote by an interviewee). We included only articles that examined wildland fire as a source of smoke, excluding research that focused only on sources such as interior wood stoves, smokestacks, or agricultural burning.

To capture literature relevant to recent trends, we included only literature published from 2000 through September 2020. Although some literature exists on smoke perspectives prior to 2000, it is limited and reports on perspectives irreflective of recent wildfire and fire management trends. Finally, we included literature conducted anywhere in the United States (US), but given the relevance of federal and state policies to US wildland fire management and practices, we excluded research from other countries.

The initial effort to identify literature was conducted in 2016. For this effort, researchers conducted keyword searches in the Oregon State University library catalog of peer-reviewed literature and on Google Scholar, which produced a list of relevant literature. In 2019–2020, we started with this list and reviewed each source to ensure it aligned with the parameters noted above. We also reviewed the sources cited in each article to con-

firm that any other relevant literature was added to the list. Finally, we conducted additional keyword searches through Google Scholar and the University of Oregon's library catalog of peer-reviewed literature to identify relevant articles that were published after 2016 or that may have eluded inclusion through other means. Keyword searches comprised of different combinations of keyword "smoke" with the following words and phrases: "wildfire*," "human perspectives*," "perceptions*," "prescribed fire*," "fuel* treatment*." For any new sources found, we again reviewed the sources cited in each article to confirm that relevant literature was included.

In total, we identified 36 publications for this synthesis. It is important to note that there is overlap in the authorship of these publications–many articles have been written by the same groups of authors. Publications are summarized alphabetically in Table 1 (pages 4–5). To succinctly summarize the literature in Table 1, we reduced wildland fire smoke down to three source types: wildfire, prescribed fire, and managed fire (i.e., naturally-ignited wildfires that are managed for natural resource benefits instead of being suppressed outright).

In the remainder of this document, we sometimes used different terms for the same activity (e.g., prescribed fire, prescribed burning). This is because we used the language the authors used so their findings were most accurately represented. Similarly, this literature examined several similar yet distinct concepts. For example, some research asked individuals about their *concerns around smoke*, some asked about individuals' *acceptance of smoke*, and some asked about individuals' *tolerance of smoke*. Although the implications that can be drawn from each of these questions may be similar, differences in how individuals are asked about smoke perceptions can yield different results (see Engebretson et al. 2016 for an example and discussion of this). We again used the language that the authors used throughout this document and urge readers to consider differences in wording when drawing conclusions.

Findings

We identified five key themes in the smoke perceptions literature, which we used to organize this document:

1. Public concern about smoke from prescribed fire
2. Influences on individual acceptance or tolerance of smoke
3. Manager perceptions of smoke from wildland fire management actions
4. Smoke communication needs
5. Smoke perceptions and economic impacts

Articles were assigned to themes if some aspect of the research investigated or discussed the theme in depth. For eight of the total 36 articles, multiple themes were relevant. Publications are summarized by theme with main findings in tables in each section.

Some articles in this review did not focus on smoke perceptions exclusively. For example, many articles in the theme on public concern about smoke from prescribed fire examined perceptions around multiple treatments (including non-fire treatments such as mechanical thinning or defensible space actions). Each article, however, included research with insights on perceptions of wildland fire smoke. There are many additional articles examining perceptions in the wildfire science literature that were not included in this review because they did not include findings related specifically to perceptions of wildland fire smoke.

Table 1 Reviewed literature and general research paramaters for each article

Author(s) and year	Smoke Source			Method	Subjects	Study location	Synthesis theme				
	Wildfire	Prescribed fire	Managed fire				Public concern about prescribed fire smoke	Influences on smoke tolerance	Manager perceptions of smoke from management actions	Communication needs	Economic impacts
Ascher et al. 2013		X		Surveys, affective imagery analysis	Residents	Lake Tahoe Basin: CA, NV	X				
Blades et al. 2014	X	X	X	Surveys	Residents	ID, LA, MT, TX		X		X	
Blanchard and Ryan 2007		X		Surveys	Residents	MA	X				
Bowker et al. 2008		X		Surveys	Residents	National: United States	X	X			
Brunson and Evans 2005		X		Longitudinal surveys	Residents	UT	X	X			
Brunson and Shindler 2004		X		Surveys	Residents	AZ, CO, OR, UT	X				
Carroll et al. 2004		X		Case study interviews	Private and tribal lands forest managers	Eastern WA			X		
Cisneros et al. 2018	X	X	X	Formal smoke complaints review	Residents	Southern Sierra Nevada Region, CA & NV					X
Damon et al. 2010	X			Conference breakout groups	Conference panel attendees	MT				X	
Davis et al. 2014	X			Case study interviews	Public	Trinity County, CA					X
Engebretson et al. 2016	X	X	X	Surveys	Residents	CA, ID, LA, MT, OR, SC, TX		X		X	
Haines et al. 2001		X		Surveys	National forest fuels management officers and state forestry agency officials	AL, AR, FL, GA, LA, MS, NC, OK, SC, TN, TX, VA			X		
Jacobson et al. 2001		X		Surveys	Rural and suburban residents	FL	X			X	
Kneeshaw et al. 2004	X	X	X	Surveys	National forest visitors	CA, CO, WA		X			
Lim et al. 2009		X		Surveys	Residents	AL, AR, FL, GA, KY, LA, MS, NC, OK, SC, TN, TX, VA		X			
Loomis et al. 2001		X		Surveys	Residents	FL	X				
McCaffrey 2004		X		Surveys	Residents	NV	X			X	
McCaffrey et al. 2008		X		Surveys	Field tour members	CA			X		

Author(s) and year	Smoke Source			Method	Subjects	Study location	Synthesis theme				
	Wildfire	Prescribed fire	Managed fire				Public concern about prescribed fire smoke	Influences on smoke tolerance	Manager perceptions of smoke from management actions	Communication needs	Economic impacts
Olsen et al. 2014	X	X	X	Interviews	Individuals involved in fire or smoke management	CA, MT, OR, SC				X	
Olsen et al. 2017	X	X	X	Surveys	Residents	CA, MT, OR, SC		X			
Piatek and McGill 2010		X		Surveys	Private forest landowners	WV	X				
Quinn-Davidson and Varner 2012		X		Surveys	Forest Service line officers	CA			X		
Rose et al. 2017	X	X		Surveys	Residents	CA, MT, OR, SC				X	
Ryan and Wamsley 2008		X		Surveys	Residents	NY	X				
Schultz et al. 2020		X		Interviews with key informants	Federal & state land managers and air quality regulators, non-federal partners	Western US			X		
Shindler and Toman 2003		X		Panel data from surveys in 1996 and 2000	Residents	Eastern OR & WA	X	X			
Shindler et al. 2009		X		Interviews and surveys	Forest Service fire and fuels management personnel (interviews) Residents (surveys)	Great Lakes: MI, MN, WI	X				
Thapa et al. 2013	X	X		Surveys	Overnight tourists to Florida	FL					X
Toman et al. 2004		X		On-site compared to mail surveys	Residents	OR		X			
Toman et al. 2014		X		Longitudinal surveys	Residents	AZ, CO, MI, MN, OR, UT, WI	X				
Vogt et al. 2005		X		Surveys	Wildland urban interface homeowners	CA, FL, MI	X				
Weisshaupt et al. 2005		X		Focus groups	Residents	MT, WA	X	X		X	
Williamson 2007			X	Surveys	Forest Service district rangers	USFS Regions 1,3, and 4			X		
Winter et al. 2002		X		Focus groups	Residents	CA, FL, MI	X				
Winter et al. 2004		X		Focus groups and surveys	Residents	CA, FL, MI	X				
Wolcott et al. 2007		X		Surveys	Land managers	FL			X		
Totals	**10**	**33**	**7**				**17**	**10**	**7**	**8**	**3**

I. Public concern about smoke from prescribed fire

Fifteen articles examined public perceptions of smoke from prescribed fire specifically (see Table 2, pages 8–9). These articles focused on measuring how concerned individuals were about prescribed fire smoke generally, identifying specific areas of concern (e.g. health, transportation safety), and examining how concerns influence acceptance and support of prescribed fire. The majority of research in this theme was published in the early 2000s and focused on examining public perceptions around prescribed fire broadly. We note this because findings from these studies included insights on public concerns about prescribed fire smoke that were foundational for subsequent research focusing on smoke perceptions more exclusively and in greater detail (e.g. influences on individual tolerance for smoke, presented in the next theme).

Measuring public concern about prescribed fire smoke

Three articles investigated public concern around prescribed fire smoke broadly through surveys that asked respondents to rate their level of concern. In a national household survey that examined wildland fire knowledge, attitudes, and preferences, Bowker et al. (2008) found that a majority of respondents were at least slightly concerned about smoke from prescribed fire (concern was measured on a 3-point scale: 40% concerned, 15% slightly concerned, 42% not concerned, 2% don't know). Similarly, in surveys of residents from fire-adapted areas in four states (using a 4-point scale of none, slight, moderate, or great concern), most residents expressed at least slight concern about increased smoke from prescribed fire; in two of the locations the majority of residents reported moderate or great concern (Brunson and Shindler 2004). Finally, in a survey of residents living near national forests in the Great Lakes region (using the same 4-point scale), 43% of respondents reported that they had moderate or great concern about the potential of increased smoke from prescribed fire (Shindler et al. 2009). Although these articles took different approaches in terms of the populations surveyed and how concern levels were measured, their findings suggest that a majority of the public has at least slight concern about prescribed fire smoke, with a much smaller portion of the population having moderate or great concern—however levels of greater concern may vary considerably between areas and populations. It is also worth noting that a substantial portion of respondents in most studies indicate slight or no concern about smoke: 42% of respondents in Bowker et al.'s national survey indicated they had no concern about smoke from prescribed fire, and 57% of Shindler et al.'s 2009 survey had either slight or no concern.

Health concerns

Researchers found that smoke-related health impacts were a key public concern around prescribed fire use in seven articles that used a variety of approaches. For instance, a survey of Lake Tahoe Basin residents used imagery analysis to measure affective (emotional) responses to prescribed fire and found that the most prominent negative themes were "images related to smoke and health concerns" (Ascher et al. 2013, p. 270). In two articles, focus groups that explored general concerns and support for prescribed fire found that, even if they considered smoke impacts as acceptable for most of the population, participants were particularly concerned about health impacts from smoke on certain subgroups of the population, such as those with respiratory ailments (Winter et al. 2002, Weisshaupt et al. 2005). In four articles, surveys found that individuals perceived health risks from prescribed fire smoke as more serious than concerns about reduced visibility from smoke but less serious than non-smoke concerns like damage to wildlife habitat or the risk of a fire escaping (Blanchard and Ryan 2007, Brunson and Evans 2005, Jacobson et al. 2001, Ryan and Wamsley 2008).

Visibility and safety concerns

Visibility concerns from prescribed fire smoke were examined in five articles and focused on transportation safety, with respondents assessing their concerns about "impaired visibility due to smoke" (Piatek and McGill 2010), the "effects of smoke on travel safety" (Brunson and Evans 2005), or the likelihood of car accidents due to reduced visibility (Blanchard and Ryan 2007, Jacobson et al. 2001, Ryan and Wamsley 2008). Although visibility was found to be a concern for some respondents, each of these research efforts found that respondents were more concerned about other potential prescribed fire impacts (e.g., damage to wildlife, health issues from smoke, potential for fire escape) than reduced driving visibility from prescribed fire smoke.

Perceptions of smoke and support for prescribed fire

Articles that examined whether perceptions of smoke affected public acceptance or support of prescribed fire collectively found that individuals weighed positive and negative outcomes, including concerns about smoke, when reporting their support or acceptance of prescribed fire. For example, Brunson and Shindler (2004) found that both concerns about increased smoke and beliefs about the effectiveness of prescribed fire in mitigating wildfire activity significantly influenced subjects' reported acceptability of prescribed fire. Many articles found that respondent's perspectives around smoke and support for prescribed fire were complex. For example, in one survey a majority of rural and suburban Florida residents knew fire was a natural process that renewed the forest, felt that prescribed fire was better than wildfire, and agreed that people living near natural areas had to tolerate some prescribed fire smoke; a majority of respondents also felt that protecting air quality was more important than burning natural areas and wanted stricter regulations on burning (Jacobsen et al. 2001). Similarly, three articles found that a majority of surveyed residents agreed that prescribed burning created more smoke short-term but less overall (Winter et al. 2004, Vogt et al. 2005, Toman et al. 2014). However, one of these studies (Vogt et al. 2005), also found that agreement with this statement was not significant in predicting respondents' intention to approve prescribed burning activities, further highlighting the complexity between respondent's beliefs about smoke from prescribed fire and their support of the practice.

Findings from several articles highlighted how individual perceptions around prescribed fire smoke and treatment support can change. In a study that surveyed the same residents in 1996 and 2000, more residents were concerned about prescribed fire smoke in 2000, but support for prescribed fire remained the same (Shindler and Toman 2003). In other studies, exposure to educational materials on prescribed fire was correlated with both a decrease in concerns about smoke and an increase in support for prescribed fire (Loomis et al. 2001, McCaffrey 2004).

Table 2 Theme I literature: Public concern about smoke from prescribed fire

Year	Citation	Research approach	Research objective	Main findings
2001	Jacobson, S.K., M.C. Monroe, & S. Marynowski. 2001. "Fire at the wildland interface: The influence of experience and mass media on public knowledge, attitudes, and behavioral intentions." *Wildlife Society Bulletin* 29(3): 929-937.	Telephone survey of rural and suburban residents in FL.	Understand the influence of experience and mass media on public attitudes, knowledge, and behavioral intentions regarding wildland fire.	Respondents had complex and conflicting perspectives about prescribed fire smoke. A majority knew fire was a natural process that renewed the forest, felt prescribed fire was better than wildfire, and agreed that people living near natural areas had to tolerate some prescribed fire smoke. A majority also felt that protecting air quality was more important than burning natural areas and a majority wanted stricter regulations on burning.
	Loomis, J.B., L.S. Bair, & A. González-Cabán. 2001. "Prescribed fire and public support: Knowledge gained, attitudes changes in Florida." *Journal of Forestry* 99(11): 18-22.	Phone and mail survey of FL residents.	Examine residents' attitudes towards and knowledge of prescribed and wildfire before and after receiving educational materials in Florida.	Exposure to prescribed fire education materials led to a decrease in agreement that prescribed fire should not be used because of the potential health impacts from smoke.
2002	Winter, G.J., C. Vogt, & J.S. Fried. 2002. "Fuel treatments at the wildland-urban interface: Common concerns in diverse regions." *Journal of Forestry* 100(1): 15-21.	Focus groups with wildland-urban interface residents in CA, FL, MI.	Explore common factors affecting acceptance of different fuels treatment techniques in diverse locations.	Smoke impacts were a key consideration in participant evaluations of fuels treatment techniques, and personal concerns about health impacts of smoke influenced acceptance of prescribed fire in some respondents.
2003	Shindler, B. & E. Toman. 2003. "Fuel reduction strategies in forest communities: A longitudinal analysis of public support." *Journal of Forestry* 100(6): 8-15.	Generate panel data from mail surveys of the same residents in eastern OR and WA in 1996 & 2000.	Measure change in public attitudes toward fire management programs on federal lands in eastern OR and WA.	The number of participants who viewed prescribed fire smoke as a problem increased notably between 1996 and 2000. However in both surveys the majority (68% in 1996 and 58% in 2000) reported that smoke levels were acceptable if a healthier forest resulted.
2004	Brunson, M.W. & B.A. Shindler. 2004. "Geographic variation in social acceptability of wildland fuels management in the Western United States." *Society & Natural Resources* 17(8): 661-678.	Mail survey of citizens in 4 locations (in AZ, CO, OR, UT) where fire has been a significant disturbance agent and agencies propose treatments.	Explore social acceptability judgments about different fuels reduction activities on federal lands in the West.	Increased levels of smoke was a key affective concern for respondents regarding prescribed fire use, and this concern significantly influenced prescribed fire acceptability judgements. There was some variation in the level of smoke concern between locations.
	McCaffrey, S.M. 2004. "Fighting fire with education: What is the best way to reach out to homeowners?" *Journal of Forestry* 102(5): 12-19.	Mail survey of homeowners in Incline Village, NV.	Examine how educational efforts may increase homeowner support for wildfire management and mitigation efforts.	Respondents who reported education materials as an information source on prescribed burning were less likely to agree that smoke causes health problems for a member of their household. Smoke concerns appear to be influenced more by personal contacts than government contacts.
	Winter, G., C.A. Vogt, & S. McCaffrey. 2004. "Examining social trust in fuels management strategies." *Journal of Forestry* 102(6): 8-15.	Focus groups and a mail survey of wildland urban interface homeowners in 3 ecosystems (in CA, FL, MI) with different fuels management approaches.	Assess views of fuel management approaches by homeowners in the study locations.	Most respondents believed prescribed fire creates more smoke now but less long-term, though fewer in MI than CA or FL expressed this belief; this belief was associated with trust in agency fuels management approaches in CA and MI.
2005	Brunson, M.W. & J. Evans. 2005. "Badly burns? Effects of an escaped prescribed burn on social acceptability of wildland fuels treatments." *Journal of Forestry* 103(3): 134-138.	Mail survey of residents affected by an escaped prescribed fire in UT in 2003, compared to a 2001 survey of same residents.	Examine acceptability of fuels management practices before and after an escaped prescribed burn caused a major smoke event.	More respondents were concerned about the health impacts of prescribed fire smoke after an escaped burn, but there was no difference in the amount of respondents who felt that because of smoke prescribed fire was not worth it.
	Vogt, C.A., G. Winter, & J.S. Fried. 2005. "Predicting homeowners' approval of fuel management at the wildland-urban interface using the Theory of Reasoned Action." *Society & Natural Resources* 18(4): 337-354.	Mail survey data from 3 wildland urban interface areas of the US (in CA, FL, MI) used to examine hypotheses based on the Theory of Reasoned Action.	Examine the influence of cognitive factors and past experiences on homeowners' intention to approve the implementing of fuels management approaches.	Most respondents from all areas reported some level of certainty that prescribed fire produces more smoke now but less later, but this belief was not a significant predictor of intention to approve fuels management approaches.
	Weisshaupt, B.R., M.S. Carroll, K.A. Blatner, W.D. Robinson, & P.J. Jakes. 2005. "Acceptability of smoke from prescribed forest burning in the northern inland west: A focus group approach." *Journal of Forestry* 103(4): 189-193.	Focus groups in WA and MT of people for whom smoke issues would be salient and who would likely hold divergent opinions.	Examine perceptions and tolerance of smoke from broadcast prescribed burning in the wildland-urban interface of the northern Inland West.	Participants generally accepted smoke from prescribed fire as long as the forest would benefit, and with more information and discussion smoke tolerance seemed to increase, although concerns for health-sensitive populations were persistent.

Year	Citation	Research approach	Research objective	Main findings
2007	Blanchard, B. & R.L. Ryan. 2007. "Managing at the wildland-urban interface in the Northeast: Perceptions of fire risk and hazard reduction strategies." *Northern Journal of Applied Forestry* 24(3): 203-208.	Mail survey distributed to a random sample of seasonal and year-round residents and landowners near the Plymouth Pine Barrens in Plymouth and Carver, MA.	Examine residents' and landowners' perceptions of wildland fire risk and reduction strategies in high-risk areas of the wildland urban interface in the Northeast.	Respondents were more concerned about health risks than reduced visibility from prescribed fire smoke. Respondents who reported firsthand experience with wildland fire had less concern about the health impacts of prescribed fire smoke on nearby residents.
2008	Bowker, J.M., S.H. Lim, K. Cordell, G.T. Green, S. Rideout-Hanzak, & C.Y. Johnson. 2008. "Wildland fire, risk, and recovery: Results of a national survey with regional and racial perspectives." *Journal of Forestry* 106(5): 268-276.	Analysis of responses to the National Survey on Recreation and the Environment.	Examine preferences, knowledge, and attitudes of wildland fire and management with racial, gender, and regional perspectives at the national scale.	A majority of respondents were at least slightly concerned about smoke from prescribed fire, with more concern among African-Americans and Hispanics than Whites, and more concern in the South than the Pacific, Rocky Mountains and Great Plains, or the North.
	Ryan, R.L. & M.B. Wamsley. 2008. "Public perceptions of wildfire risk and forest management in the Central Pine Barrens of Long Island (USA)." *Australian Journal of Disaster and Trauma Studies* 2: 1-16.	Mail survey of residents living in neighborhoods at risk of wildfire in the Central Pine Barrens of Long Island, NY.	Examine residents' perceptions of wildfire risk in relation to previous fire experience, knowledge about management strategies to reduce fire danger, and attitudes towards implementing strategies in local forests.	Residents were more concerned about the health impacts of prescribed fire smoke than transportation safety as a result of reduced visibility, however they were most concerned about non-smoke impacts from prescribed fire such as escaped fire and habitat loss. Residents who were more familiar with prescribed fire were more supportive of it and less concerned about issues like smoke.
2009	Shindler, B.A., E. Toman, & S.M. McCaffrey. 2009. "Public perspectives of fire, fuels and the Forest Service in the Great Lakes Region: A survey of citizen-agency communication and trust." *International Journal of Wildland Fire* 18(2): 157-164.	Interviews with Forest Service fire and fuels management personnel on Great Lakes national forests, followed by mail survey of citizens in forest communities affected by proposed agency plans in MI, MN, and WI.	Examine citizen perspectives of fuels reduction practices and risks, confidence in the US Forest Service to implement practices, and citizen-agency interactions in the Great Lakes region.	Many residents reported that increased levels of smoke from prescribed fire were of moderate or great concern. Respondents who reported firsthand experience with wildland fires had less concern about the health impacts of smoke from prescribed fires on nearby residents.
2010	Piatek, K.B. & D.W. McGill. 2010. "Perceptions of private forest owners in West Virginia on the use of prescribed fire in forestry." *Small-scale Forestry* 9: 227-241.	Mail survey of private forest landowners in 3 regions of WV near national forests.	Explore nonindustrial private forest owners' attitudes and opinions regarding the use of prescribed fire as a forest management tool.	The large majority of respondents were willing to tolerate smoke from prescribed fire a few times per year; air pollution from smoke was more of a concern than impaired visibility from smoke, but non-smoke concerns like escaped fire and community safety were rated higher than smoke concerns. Respondents' belief that they may be affected by future smoke was not a predictor of prescribed fire use approval.
2013	Ascher, T.J., R.S. Wilson, & E. Toman. 2013. "The importance of affect, perceived risk and perceived benefit in understanding support for fuels management among wildland-urban interface residents." *International Journal of Wildland Fire* 22(3): 267-276.	Print surveys dropped off and picked up by a researcher and affective imagery analysis with residents in Lake Tahoe Basin, CA.	Test a model for public support of fuels management based on individual knowledge, exposure, affective response, perceived risk, and perceived benefit associated with fuels management.	The most prominent negative theme associated with affective (emotional) responses to prescribed fire related to smoke and health concerms.
2014	Toman, E., B. Shindler, S. McCaffrey, & J. Bennett. 2014."Public acceptance of wildland fire and fuel management: Panel responses in seven locations." *Environmental Management* 54: 557-570.	Longitudinal study using mail surveys to examine the beliefs and attitudes regarding fire management and fuels treatments of residents in communities adjacent to federal lands in 7 states: AZ, CO, OR, UT, MI, MN, and WI.	Examine factors that influence public support for fuels reduction treatments over time.	A high number of participants in each location agreed that while prescribed fire will result in smoke in the short term, it will reduce long-term emissions, though there were some differences between states– participants in MI rated this outcome as less likely than other areas while OR participants rated as most likely.

II. Influences on individual acceptance or tolerance of smoke

As public acceptance or tolerance of wildland fire smoke has implications for land, fuels, and fire management actions, ten of the reviewed articles examined factors that influence individuals' acceptance or tolerance of wildland fire smoke (see Table 3, page 11). In each of these articles, the majority of respondents in the research reported some acceptance or tolerance of smoke (Blades et al. 2014, Bowker et al. 2008, Brunson and Evans 2005, Engebretson et al. 2016, Lim et al. 2009, Olsen et al. 2017, Shindler and Toman 2003, Toman et al. 2004, Weisshaupt et al. 2005). Acceptance was influenced by a variety of factors, including fire event characteristics like location, smoke origin, and duration; and individual characteristics such as personal health, demographics, and past experiences.

Fire-specific factors: Smoke origin, location, and duration

Articles asking about whether the origin, or source, of smoke affected individuals' reported smoke tolerance had differing findings. In one study, individuals in focus groups indicated they were more accepting of smoke if it originated from prescribed versus wildfire smoke (Weisshaupt et al. 2005). However, two subsequent and larger survey studies found the opposite of this to be true, that respondents were most tolerant of smoke when it came from naturally-ignited (i.e., lightning started) wildfires on which managers were employing full suppression. A survey of residents in the northern Rocky Mountains and south-central US found that respondents were significantly more tolerant of smoke from fires under active suppression than smoke from prescribed fire or from naturally-ignited wildfires being managed for resource benefits (Blades et al. 2014). Olsen et al. (2017) found surveyed respondents across four states had the greatest acceptance of smoke when it came from wildfires compared to five other types of fire (prescribed fire, agricultural burns, managed fire, pile burns, and private land burns such as refuse pile burning). Both of these studies also found that origin of smoke was commonly the most important factor influencing public tolerance to smoke, with a larger influence than other factors examined in the study.

Table 3 Theme II literature: Influences on individual acceptance or tolerance of smoke

Year	Citation	Research approach	Research objective	Main findings
2003	Shindler, B. & E. Toman. 2003. "Fuel reduction strategies in forest communities: A longitudinal analysis of public support." *Journal of Forestry* 100(6): 8-15.	Generate panel data from mail surveys of the same residents in eastern OR and WA in 1996 & 2000.	Measure change in public attitudes toward fire management programs on federal lands in eastern OR and WA.	The number of participants who viewed prescribed fire smoke as a problem increased notably between 1996 and 2000. However in both surveys the majority (68% in 1996 and 58% in 2000) reported that smoke levels were acceptable if a healthier forest resulted.
2004	Kneeshaw, K., J.J. Vaske, A.D. Bright, & J.D. Absher. 2004. "Situational influences of acceptable wildland fire management actions." *Society & Natural Resources* 17(6): 477-489	Conjoint analysis of surveys of national forest users in CA, CO, and WA.	Examine forest users' beliefs about wildland fire management and the effect of fire-specific situational factors on those beliefs.	Air quality was neither the most nor least important factor (of 5) in determining acceptance of wildfire management strategy (direct attack, confine, fire use). Forest visitors were more accepting of strategies of confinement or fire use when air quality was not affected; when there was poor air quality from smoke, visitors accepted direct attack over other strategies.
	Toman, E., B. Shindler, & M. Reed. 2004. "Prescribed fire: The influence of site visits on citizen attitudes." *Journal of Environmental Education* 35(3): 13-17.	Comparison of on-site and mail surveys completed by the same respondents in northeast OR.	Measure the effect of site visits on public perceptions of prescribed fire.	In both mail and on-site surveys, a majority of respondents agreed that smoke levels were acceptable if it meant a healthier forest and a minority agreed that prescribed fire resulted in smoke that decreased air quality to unacceptable levels.
2005	Brunson, M.W. & J. Evans. 2005. "Badly burns? Effects of an escaped prescribed burn on social acceptability of wildland fuels treatments." *Journal of Forestry* 103(3): 134-138.	Mail survey of residents affected by an escaped prescribed fire in UT in 2003, compared to a 2001 survey of the same residents	Examine acceptability of fuels management practices before and after an escaped prescribed burn caused a major smoke event.	More respondents were concerned about the health impacts of prescribed fire smoke after an escaped burn, but there was no difference in the amount of respondents who felt that because of smoke prescribed fire was not worth it.
	Weisshaupt, B.R., M.S. Carroll, K.A. Blatner, W.D. Robinson, & P.J. Jakes. 2005. "Acceptability of smoke from prescribed forest burning in the northern inland west: A focus group approach." *Journal of Forestry* 103(4): 189-193.	Focus groups in WA & MT of people for whom smoke issues would be salient and who would likely hold divergent opinions.	Examine perceptions and tolerance of smoke from broadcast prescribed burning in the wildland-urban interface of the northern Inland West.	Smoke from prescribed fire was generally accepted as long as the forest would benefit, and with more information and discussion smoke tolerance seemed to increase, although concerns for health-sensitive populations were persistent.
2008	Bowker, J.M., S.H. Lim, K. Cordell, G.T. Green, S. Rideout-Hanzak, & C.Y. Johnson. 2008. "Wildland fire, risk, and recovery: Results of a national survey with regional and racial perspectives." *Journal of Forestry* 106(5): 268-276.	Analysis of responses to the National Survey on Recreation and the Environment.	Examine preferences, knowledge, and attitudes of wildland fire and management with racial, gender, and regional perspectives at the national scale.	A majority of respondents were at least slightly concerned about smoke from prescribed fire, with more concern among African-Americans and Hispanics than Whites, and more concern in the South than the Pacific, Rocky Mountains and Great Plains, or the North.
2009	Lim, S.H., J.M. Bowker, C.Y. Johnson & H.K. Cordell. 2009. "Perspectives on prescribed fire in the South: Does ethnicity matter?" *Southern Journal of Applied Forestry* 33(1): 17-24	Analysis of responses from the Southern US to the National Survey on Recreation and the Environment.	Assess preferences for prescribed fire and examine the effect(s) of race and ethnicity, gender, and education on perspectives.	Women showed greater concern about smoke from prescribed fire than men, and African American and Hispanic respondents showed greater concern than white respondents. Concern decreased as years of education increased.
2014	Blades, J.J., S.R. Shook, & T.E. Hall. 2014. "Smoke management of wildland and prescribed fire: Understanding public preferences and trade-offs." *Canadian Journal of Forest Research* 44(11): 1344-1355.	Conjoint analysis of questionnaires of residents in the northern Rocky Mountains (ID, western MT) and the southcentral US (east TX, western LA).	Evaluate how 4 situational factors (health impact, smoke duration, advanced warning, and smoke origin) influence public tolerance of smoke.	Origin of the smoke (wildfire, prescribed fire) and advanced public warning were commonly the most important factors (out of four) influencing public tolerance of smoke. Previous negative health effects from smoke was associated with less tolerance for smoke.
2016	Engebretson, J.M., T.E. Hall, J.J. Blades, C.S. Olsen, E. Toman, & S. Frederick. 2016. "Understanding public tolerance of smoke from wildland fires across the United States." *Journal of Forestry* 114(6):601–609.	Survey analysis to investigate influences on wildland fire smoke tolerance at a broader scale.	Examine public tolerance of smoke from different fire types and the influence of geography, urban/rural residence, and smoke-related health history on tolerance.	Data from 2 surveys together found negligible differences in tolerance across states or between rural and urban areas, but personal health history had a significant impact. Results highlight the importance of communicating the ecological benefits of different types of wildland fire, as well as public health risks of smoke and ways to mitigate them.
2017	Olsen, C.S., E. Toman, & S.S. Frederick. 2017. "A multi-region analysis of factors that influence public acceptance of smoke from different fire sources." *International Journal of Wildland Fire* 26(5): 364-374	Main and online survey of urban and rural residents in 4 states (CA, MT, OR, SC).	Explore the factors that influence public acceptance of smoke from 6 types of fire (wildfire, prescribed fire, agricultural burns, managed fire, pile burns and burns on private lands).	Respondents were overall accepting of smoke, particularly from wildfire or fires they saw as providing benefits to broader society, but a significant minority did not accept smoke. Influences on acceptance varied by fire type, but health risk, confidence in managing agencies, beliefs about the benefits of prescribed fires and rural location influenced acceptance for multiple types of fire. Prior negative health experiences from smoke influenced acceptance for agricultural burn smoke only.

Other fire-specific variables examined in the reviewed literature included location and the duration of smoke impacts. Geographic location was found to have little influence on smoke acceptance in most studies that considered it. A national household survey found little variance in how concerned residents in different parts of the US were about smoke from prescribed fire (Bowker et al. 2008). Two other studies found no significant difference in smoke tolerance or preferences between the rural and urban locations they looked at (Blades et al. 2014, Weisshaupt et al. 2005), and an analysis of data from two household surveys investigating public tolerance of smoke found negligible differences between rural and urban areas (Engebretson et al. 2016). However, Olsen et al. (2017) found that living in a rural area was positively associated with acceptance of smoke for pile burning (as well as smoke from agricultural and private land burns such as refuse pile burning), but not other sources of wildland fire smoke. Smoke duration was found to be an important influence on smoke acceptance, with short duration smoke exposure (6 hours) reported as more tolerable by respondents than over longer durations (3 days or more) (Blades et al. 2014).

Finally, Kneeshaw et al. (2004) examined how fire-specific factors, including air quality impacts from smoke, influenced national forest visitors' acceptance for different wildland fire management strategies. They found that visitors were more accepting of wildland fire management strategies based on confinement ("let the fire burn but contain it so it doesn't get out of control") or wildland fire use ("let the fire burn out on its own without trying to contain it") when there was no effect on air quality; whereas when there was poor air quality due to smoke, forest users were most accepting of direct attack ("immediately put the fire out") over other strategies.

Individual characteristics: Health, demographics, knowledge and beliefs

Personal health concerns and experiences

The reviewed literature identified a number of individual characteristics that can influence smoke tolerance, including personal health concerns relative to current health status and previous experiences with smoke, demographic factors, and knowledge and beliefs about the ecological benefits of fire.

Reviewed literature found that health concerns[1] were one of the most influential factors affecting individuals' acceptance of wildland fire smoke. In multiple survey studies, respondents rated health risks as the most significant prescribed fire smoke concern that they had (Blanchard and Ryan 2007, Brunson and Evans 2005, Jacobson et al. 2001, Piatek and McGill 2010, Ryan and Wamsley 2008). Focus groups that explored views on prescribed fire found that participants were concerned about the health impacts of smoke on vulnerable populations, even when the groups expressed overall tolerance for wildland fire smoke (Winter et al. 2002, Weisshaupt et al. 2005).

Of the articles focused on examining influences on wildland smoke tolerance, one study found that tolerance for smoke decreased as the projected severity of health effects from the smoke increased, and that respondents who had previously experienced negative health effects from smoke were less tolerant of smoke (Blades et al. 2014). Similarly, in longitudinal surveys of residents in an area before and after a prescribed burn escaped and caused significant, unanticipated air quality impacts, more respondents were concerned about health impacts of smoke after the burn. This highlights how negative experiences can cause individuals to adjust perceptions on the health impacts of smoke. However, it also is worth noting that despite the increase in concern, the study found no significant change in the portion of respondents that felt that

[1] Literature examining the physical health impacts of smoke spans multiple disciplines and is much larger than the literature presented here; our focus was only on how health concerns affect individuals' reported tolerance of smoke. For reviews on the health impacts of wildland fire smoke, see:

Reid et al. (2016). "Critical review of health impacts of wildfire smoke exposure."

Adetona et al. (2016). "Review of the health effects of wildland fire smoke on wildland firefighters and the public."

because of smoke prescribed fire was not worth using (12% before and 13% after the escaped burn) (Brunson and Evans 2005).

Interestingly, Olsen et al. (2017) found that negative prior health experiences from smoke were inversely related to tolerance of smoke from agricultural burns but not with tolerance of smoke from wildland fire sources like wildfires or fuels treatments. The authors suggested that perceptions of health risk versus actual prior experience may be what drives individuals' levels of smoke tolerance, and that health concerns may only be important to a small subset of the population with medical conditions. Further, they suggest that this subset with medical conditions is not likely to adjust their tolerance of smoke regardless of other variables like smoke origin or education. The authors' survey found that 28% of respondents indicated that they or a family member had experienced health impacts from smoke in the last 5 years,[2] and the authors noted that special concern for medically vulnerable populations is an issue in need of further study (Olsen et al. 2017).

Demographic factors: race, gender, and education level

A national household survey found that significantly more African-American and Hispanic respondents than White respondents reported concern about smoke from prescribed fire (Bowker et al. 2008). Using the same survey data, Lim et al. (2009) found that women in the southern US were more apprehensive then men about prescribed fire due to side effects like smoke. Olsen et al. (2017) found that women were slightly but significantly less accepting of smoke from all types of fire.

In their analysis, Lim et al. (2009) found that concerns about the side effects of prescribed fire, including smoke concerns, decreased as years of education increased. Olsen et al. (2017) similarly found that education was positively associated with the acceptance of smoke from both prescribed and managed fires (but not other types of fires they examined). Olsen et al. (2017) also found that smoke acceptance was influenced by age, with younger populations generally more accepting of smoke than older, however, the effect of age on acceptance varied significantly between different types of fire.

Individual knowledge and beliefs around fire's ecological benefits

Individual knowledge and beliefs around wildland fire have also been found to influence smoke acceptance. Two studies found that subjects who were more familiar with or who had firsthand knowledge with wildland fire were less concerned about smoke impacts (Blanchard and Ryan 2007, Ryan and Wamsley 2008). In two others, increased awareness around the ecological benefits of prescribed fire was correlated with less concern about the health impacts of prescribed fire smoke (Loomis et al. 2001, McCaffrey 2004). In separate research efforts, Shindler and Toman (2003) and Toman et al. (2004) found that a majority of surveyed respondents were accepting of prescribed fire smoke "if it resulted in a healthier forest." In focus groups, all members expressed general acceptance of prescribed fire smoke as long as the forest would benefit (Weisshaupt et al. 2005). Olsen et al. (2017) found that belief in the benefits of prescribed fire was positively associated with smoke acceptance from four of the six fire types they examined (prescribed fire, agricultural burns, managed fire, pile burns; excluding wildfire and private lands burns).

[2] A 2012 synthesis that focused partly on social science around public understanding of smoke's health effects and what shapes public tolerance for smoke indicated that numerous studies have similarly found that roughly 30% of the population indicates they have a household member whose health would be affected by smoke (McCaffrey and Olsen 2012).

III. Manager perceptions of smoke from wildland fire management actions

A 2000 USDA Forest Service technical report presented the results of a survey of fuels management officers from all US national forests which found that officers rated "air quality and smoke regulations" as the top barrier (of 14) to prescribed burning (Cleaves et al. 2000). In seven of our reviewed articles (see Table 4, page 15), research similarly focused on land, fuels, or fire managers and their perceptions about smoke from wildland fire management actions. These articles all looked at manager perceptions about smoke from prescribed fire, except for one focused on smoke from managed fires (Williamson 2007). Although the degree of specific concerns differed between places and landowners, overall, the articles found that manager concerns about smoke did tend to center on air quality regulations as well as public acceptance of smoke, and in one study (Haines et al. 2001), liability for smoke intrusions.

Research in several articles reiterated that managers perceived air quality regulations among the greatest overall barrier to prescribed burning. One study found that both national forest and state fuels managers reported a) air quality and smoke regulations and b) risk of liability for smoke intrusions among the top three most significant barriers to expanded prescribed burning in 12 southern states (Haines et al. 2001).[3] Other studies found that land managers in Florida rated "smoke management" as the greatest hindrance to using prescribed fire (Wolcott et al. 2007) and that land managers in northern California (including representatives from federal and state agencies, tribes, non-governmental organizations, and timber companies) ranked "air quality regulations" as the second greatest impediment to using prescribed fire, after narrow burn windows (Quinn-Davidson and Varner 2012). Regulations related to smoke were overall reported as a greater obstacle to pre-

[3] The other top three reported barriers to prescribed burning for each manager group were: "public opinion," ranked as the greatest barrier for state and private forest managers, and "shortage of personnel," ranked as the second greatest barrier for national forest managers.

Table 4 Theme III literature: Manager perceptions of smoke from wildland fire management actions

Year	Citation	Research approach	Research objective	Main findings
2001	Haines, T.K., R.L. Busby, & D.A. Cleaves. 2001. "Prescribed burning in the South: Trends, purpose, and barriers." *Southern Journal of Applied Forestry* 25(4): 149-153.	Mail survey of federal, state, and private land and fire managers in the Southern US.	Describe recent and projected prescribed fire use in the U.S. South.	"Air quality and smoke regulations" was rated as the biggest barrier to increased burning by the national forests, and the third biggest barrier (out of fourteen) by state and private forests.
2004	Carroll, M.S., P.J. Cohn, & K.A. Blatner. 2004. "Private and tribal forest landowners and fire risk: A two-county case study in Washington state." *Canadian Journal of Forest Research* 34(10): 2148-2158.	Interviews with nonindustrial private and tribal forest landowners in 2 northeast WA counties.	Use a risk perception frame to examine the role of fire as both a perceived threat and management tool for nonindustrial private and tribal forest landowners in the study area.	Interviewed landowners claimed that the permitting process for creating smoke management plans was burdensome, but were overall not highly concerned about smoke problems from prescribed burning.
2007	Williamson, M.A. 2007. "Factors in United States Forest Service district rangers' decision to manage a fire for resource benefit." *International Journal of Wildland Fire* 16: 755-762.	Telephone survey with all USFS district rangers with Wildland Fire Use Authority in Northern, Intermountain, and Southwestern Regions.	Examine influences district rangers' authorization of wildland fire use to meet resource objectives.	Concerns around smoke–particularly manager concerns about negative public perceptions on smoke–were a main disincentive to district rangers' authorization of wildland fire use for resource benefit.
	Wolcott, L., J.J. O'Brien, & K. Mordecai. 2007. "A survey of land managers on wildland hazardous fuels issues in Florida: A technical note." *Southern Journal of Applied Forestry* 31(3): 148-150.	Online survey distributed to a variety of land managers in FL.	Determine the management techniques used by land managers to mitigate hazardous fuels in Florida.	Respondents rated "smoke management" as the greatest hindrance to prescribed fire use.
2008	McCaffrey, S., J.J. Moghaddas, & S.L. Stephens. 2008. "Different interest group views of fuels treatments: Survey results from fire and fire surrogate treatments in a Sierran mixed conifer forest, California, USA." *International Journal of Wildland Fire* 17(2): 224-233.	In-person surveys about treament preferences following a field tour of of the University of California Blodgett Forest Fire and Fire Surrogate Study Site.	Examine acceptance of and preference for fuels treatments among different interest group participants who attended a field tour of a fire surrogate site.	A minority of respondents indicated that smoke was a somewhat to very important factor in determining treatment preferences for the landscape. Respondents overall ranked smoke as the least important factor (of 11) they would consider when determining treatment preferences.
2012	Quinn-Davidson, L.N. & J. Morgan Varner. 2012. "Impediments to prescribed fire across agency, landscape and manager: An example from northern California." *International Journal of Wildland Fire* 21(3): 210-218.	Online survey of key personnel at federal, state, tribal, NGO's and timber company managers in Northern CA.	Quantify the prescribed burning activities in Northern California across ownerships and identify constraints to increasing prescribed burning.	Air quality regulations were a major limiting factor to prescribed fire use for all federal and state agencies, for timber companies, and for all tribes surveyed (>6 on a scale of 1 (not limiting) – 10 (extremely limiting)).
2020	Schultz, C.A., S.M. McCaffrey, & H.R. Huber-Stearns. 2019. "Policy barriers and opportunities for prescribed fire application in the western United States." *International Journal of Wildland Fire* 28: 874–884.	Interviews with federal and state land managers and air quality regulators in the western US.	Investigate the role of policy barriers and opportunities for prescribed fire application on western USFS- and BLM-managed lands.	Air quality regulation was not consistently cited as a major barrier to increasing application of prescribed fire, except in specific locations.

scribed fire use than factors like lack of adequate funding and staff and personnel shortages (Haines et al. 2001, Quinn-Davidson and Varner 2012). However, much of this work is now over a decade old and more recent research investigating policy barriers and opportunities for prescribed fire in the Western US through interviews (Schultz et al. 2019) "did not find that air quality regulation was consistently cited as a major barrier, except in specific locations" (p. 874). The authors attribute this lack of support for previous findings around smoke and air quality barriers as perhaps due to changes in prescribed fire use, regulations, and agency capacity over the last two decades as well as different leadership and burn boss perspectives; or the fact that air quality can be "an easy barrier to point to" (p. 881) in surveys that do not allow nuanced responses.

Managers reported public opinion as a significant barrier to prescribed fire use in some studies. Cleaves et al. (2000) and Haines et al. (2001) found that "public opinion" was rated by some manager groups and in some regions as the number one barrier to using prescribed fire, but it was not clear if smoke concerns were part of the public opinion barrier in these studies. One study in this synthesis found that manager concerns around smoke–and particularly their concerns about negative public perceptions of smoke–were a main disincentive to district rangers' decisions to authorize wildland fire use to meet resource objectives (Williamson 2007). Some interviewees in Schultz et al. (2019) felt that agency risk aversion due to public support concerns was a barrier to using prescribed fire, however managers expressed these concerns only in certain situations (e.g. political conflict when highly visible wildfires were burning) and did not tie them specifically to smoke.

Collectively, the articles in this theme that investigate smoke as a barrier to prescribed fire use suggest that the barriers land managers perceive around smoke and its management are not the same across contexts. Even among the research that found smoke management to be the largest reported barrier to prescribed fire overall, the degree of limitation varied considerably geographically (Haines et al. 2001) and between different types of land managers (Quinn-Davidson and Varner 2012). In-depth interviews of non-industrial private forest and tribal forest landowners in northeastern Washington found that landowners were not highly concerned about smoke problems from prescribed burning, instead the main reported barriers were around liability and fear related to escaped fires, as well as the costs and expertise needed to use prescribed fire (Carroll et al. 2004). A study that surveyed field tour participants about their acceptance and preferences for fuels treatments, including prescribed fire, found that smoke was rated by all groups (foresters, environmentalists, entomologists, federal agency staff, and educators and students) as the least important issue (of 11) they considered when determining fuels treatment preferences for a landscape in north-central California (McCaffrey et al. 2008).

IV. Smoke communication needs

In a comprehensive literature review of social science research related to wildland fire management, McCaffrey et al. (2013) found that "identifying smoke communication best practices" was one of the top five fire management and public response research needs. Each article in this synthesis has findings relevant to smoke communication efforts, and many discuss these implications. Literature included in previous themes with key implications for smoke communication efforts are reiterated throughout this section alongside the eight articles (see Table 5, page 18) that focus specifically on smoke communication needs, including modes of communication, messaging, and recommendations from practitioners.

Modes of communication

During focus groups, public acceptance of smoke, acceptance increased with ongoing discussions and deliberations of key concerns, prompting the authors of the study to note that "developing a dialogue with the public may be the most important part of any fire prescription" (Weisshaupt et al. 2005, p.192). Several articles found that perceptions about wildland fire and smoke impacts can change through positive relationships with agency actors (Shindler et al. 2009, McCaffrey 2004, Shindler et al. 2014) and confidence in agencies to manage fire (Olsen et al. 2017), emphasizing the importance of effective agency outreach and communication efforts. Weisshaupt et al. (2005) and Olsen et al. (2014) suggested that communication about smoke needs to go beyond delivering facts to the public to develop collaborative efforts aimed at understanding local perceptions and offering engaging forums for discussion. Smoke communication plans can include a range of methods, including standard outlets (e.g. newspapers, TV ads, public meetings, websites, etc.) and more inventive approaches like reverse call systems (a phone call alerting people in a certain geographic area about an emergency situation like a fire or impending smoke event), school programs, community field trips, tapping informal social networks, and face-to-face meetings (Olsen et al. 2014).

Two other articles found that personalized contact could be key in efforts to increase public acceptance of smoke. Personal contacts appeared to be more influential in addressing smoke concerns than government contacts in McCaffrey (2004), and in Blades et al. (2004) respondents preferred a personal phone call warning about smoke over a public service announcement or receiving no advance warning at all.

Table 5 Theme IV literature: Smoke communication needs

Year	Citation	Research approach	Research objective	Main findings
2001	Jacobson, S.K., M.C. Monroe, & S. Marynowski. 2001. "Fire at the wildland interface: The influence of experience and mass media on public knowledge, attitudes, and behavioral intentions." *Wildlife Society Bulletin* 29(3): 929-937.	Telephone survey of rural and suburban residents in FL.	Understand the influence of experience and mass media on public attitudes, knowledge, and behavioral intentions regarding wildland fire.	Public opinion about the benefits of prescribed fire closely matched benefits identified by media, but perceived risks did not reflect media reports and focused on beliefs that fire results in animal mortality/ injury or habitat destruction.
2004	McCaffrey, S.M. 2004. "Fighting fire with education: What is the best way to reach out to homeowners?" *Journal of Forestry* 102(5): 12-19.	Mail survey of homeowners in Incline Village, NV.	Examine how educational efforts may increase homeowner support for wildfire management and mitigation efforts.	Respondents who reported education materials as an information source on prescribed burning were *less* likely to agree that smoke causes health problems for a household member. Smoke concerns appeared to be influenced more by personal contacts than government contacts.
2005	Weisshaupt, B.R., M.S. Carroll, K.A. Blatner, W.D. Robinson, & P.J. Jakes. 2005. "Acceptability of smoke from prescribed forest burning in the northern inland west: A focus group approach." *Journal of Forestry* 103(4): 189-193.	Focus groups in WA & MT of people for whom smoke issues would be salient and who would likely hold divergent opinions.	Examine perceptions and tolerance of smoke from broadcast prescribed burning in the wildland-urban interface of the northern Inland West.	Smoke from prescribed fire was generally accepted as long as the forest would benefit, and with more information and discussion smoke tolerance seemed to increase, although concerns for health-sensitive populations were persistent.
2010	Damon, S.A., R. Naylor, & S. Therriault. 2010. "Public communication in unplanned biomass burning events." *Inhalation Toxicology* 22(2): 113-116.	Analysis of responses during a panel at the 2007 Biomass Smoke Health Effects conference in MT, using the Health Belief and Stages of Change/ Transtheoretical models.	Identify guidelines for preparing communication response strategies for communities with varying degrees of experience in responding to unplanned smoke events.	Challenges to effective air quality response included: air quality staff that may not be trained in emergency response or involved in emergency response planning, and crafting messages flexible enough to be altered quickly to alert populations to new risks and behaviors they may need to practice as smoke changes occur. Challenges to keeping the public engaged on smoke events included needing more data on effectively communicating health effects and needing to keep messages continually new.
2014	Blades, J.J., S.R. Shook, & T.E. Hall. 2014. "Smoke management of wildland and prescribed fire: Understanding public preferences and trade-offs." *Canadian Journal of Forest Research* 44(11): 1344-1355.	Conjoint analysis on questionnaires of residents in northern Rocky Mountains (ID, western MT) and southcentral US (east TX, western LA).	Evaluate how 4 situational factors (health impact, smoke duration, advanced warning, smoke origin) influence public tolerance of smoke.	Origin of the smoke (e.g. wildfire vs. prescribed fire) and advanced public warning were commonly the most important factors influencing public tolerance of smoke. Reported previous negative health effects from smoke was associated with less tolerance.
	Olsen, C.S., D.K. Mazzotta, E. Toman, & A.P. Fischer. 2014. "Communicating about smoke from wildland fire: Challenges and opportunities for managers." *Environmental Management* 54(3): 571-582.	Interviews with individuals involved in fire or smoke management in CA, OR, MT, SC.	Explore challenges and opportunities related to communication (within agencies or to the public) for smoke management.	Strategies to address smoke-related communication challenges included: prioritizing communication within agencies, allocating resources for communication/ outreach training, taking advantage of resources like social networks, and building long-term relationships between agencies and the public.
2016	Engebretson, J.M., T.E. Hall, J.J. Blades, C.S. Olsen, E. Toman, & S. Frederick. 2016. "Understanding public tolerance of smoke from wildland fires across the United States." *Journal of Forestry* 114(6):601–609.	Survey analysis to investigate influences on wildland fire smoke tolerance at a broader scale.	Examine public tolerance of smoke from different fire types and the influence of geography and smoke-related health history on tolerance.	Data from the surveys found negligible differences in tolerance across states or between rural and urban areas, but personal health history had a significant impact. Results highlight the importance of communicating the ecological benefits of wildland fire, as well as public health risks of smoke and ways to mitigate them.
2017	Rose, K.M., E. Toman, & C.S. Olsen. 2017. "Public use of information about smoke emissions: Application of the risk information seeking and processing (RISP) model." *Canadian Journal of Forest Research* 47(11): 1527-1537.	Surveys in 4 communities near national forests in CA, MT, OR, SC; path analysis to apply the Risk Information Seeking and Processing model to examine factors motivating people to seek smoke information.	Assess citizen information-seeking behaviors regarding smoke emissions.	Residents were concerned about smoke emissions and believed that they needed more information; their intentions to seek information were influenced by information (in)sufficiency, the number of sources used, smoke acceptability, and other factors.

Messaging and information adequacy

Jacobson et al. (2001) found that among surveyed residents in Florida, public opinion about the benefits of prescribed fire closely matched benefits identified in the media, but the perceived risks did not reflect media reports and focused instead on beliefs that fire often results in animal mortality, animal injury, and habitat destruction. The authors suggested that communication about prescribed burning should seek to provide data about the positive outcomes of fire to counter these beliefs. As noted throughout this synthesis, multiple research efforts have found that increased knowledge about the ecological benefits of fire increases individuals' reported smoke acceptance (Shindler and Toman 2003, Toman et al. 2004, Ryan 2007, Ryan and Wamsley 2008, Winter 2004), suggesting that effective smoke messaging should highlight ecological benefits of fire as much as possible. This suggestion is reiterated in Engebretson et al. (2016), which after analysis of two household surveys investigating public tolerance of smoke, concluded that to be most effective, communication about smoke should focus on ecological benefits of different kinds of fire while clearly outlining health risks and ways to mitigate them.

Rose et al. (2017) investigated the variables motivating information-seeking behaviors about smoke emissions among citizens in areas with high fire risk. They found that overall, residents were concerned about smoke emissions and felt they needed more information, and that information seeking behaviors were directly influenced by residents' perceived information needs, beliefs about their ability to find information, and the number of sources already drawn on for information. Residents who used multiple resources to find information about smoke emissions reported that they intended to do further research and believed that this information was difficult to find more often than residents referring to fewer resources, suggesting that some individuals needed more information about smoke (e.g. someone in the sensitive health group for smoke exposure might require more detail about smoke emissions than others in the general population). The authors suggest that purposeful engagement with populations more vulnerable to smoke impacts may be a good approach, but they also acknowledge that information needs may be driven by diverse variables requiring more in-depth and local study.

Practitioner recommendations

Damon et al. (2010) and Olsen et al. (2014) investigated land managers and practitioners' perceived needs concerning smoke communication. Olsen et al. (2014) found that communication between agencies, particularly smoke and land management agencies, was often problematic, and that agencies needed to work together to prioritize consistent messaging and develop shared smoke communication plans. Damon et al. (2010) found that efforts to continually craft new messages were important, and that managers needed public communication smoke plans that are consistent, accessible, timely, and adaptable to the location and intended audience. "Knowing the audience" was identified as critical for designing effective smoke communication efforts, including understanding literacy, language needs, and the knowledge levels of audiences; even basic information on smoke-sensitive populations was perceived by managers as increasing the success of smoke message campaigns (Olsen et al. 2014, Damon et al. 2010). However, even with carefully crafted communication plans in place, agency managers still described flagging efforts to communicate with the public and expressed uncertainty about whether or not messages were reaching the intended audiences effectively (Olsen et al. 2014). They additionally described a need for more data on how to better communicate health impacts of smoke (Damon et al. 2010).

V. Smoke perceptions and economic impacts

Research on the economic impacts of smoke is limited and tends to focus on smoke from wildfires. Most of this research has focused on quantifying costs associated with healthcare and lost productivity as a result of smoke inhalation, which can be substantial. Economic analysis and modeling estimates are outside the focus of this synthesis, and thus these articles were not included in the reviewed literature. However, economic studies are important to understanding the human impacts of wildland fire smoke, so we include a brief overview of key literature investigating the economic costs of adverse health from wildland fire smoke in Box 1 (see page 21).

Three articles reviewed for this synthesis included investigations of individual perceptions of economic impacts of smoke (see Table 6, below). Findings from these articles suggest that the public may perceive significant economic impacts as a result of fire smoke. For example, a review of formal citizen complaints to air pollution control centers found that negative impacts on the local economy were one of the primary concerns that citizens had about smoke in a fire-prone central California landscape (Cisneros et al. 2018). Concerns about the economic impacts of wildfire smoke may be particularly strong in areas that rely on tourism or recreation to sustain their economies. After wildfires in Trinity County, California, interviewed residents who depended on tourism for income (e.g. hospitality- and recreation-based businesses) explained how thick smoke from the wildfires led to lost income because tourists cancelled visits (Davis et al. 2014). Thapa et al. (2013) identified three different types of tourists to Florida based on how they perceived risk (conscious, cautious, and courageous travelers) and examined how each said they would respond to specific wildfire-related situations such as news reports of auto accidents due to smoke, reported health problems from smoke and ash, and smoke at their destination area. Their findings show how perceptions of risk can economically impact industries like tourism when smoke impacts from wildfires are reported.

Table 6 Theme V literature: Smoke perceptions around economic impacts

Year	Citation	Research approach	Research objective	Main findings
2013	Thapa, B., I. Cahyanto, S.M. Holland, & J.D. Absher. 2013. "Wildfires and tourist behaviors in Florida." *Tourism Management* 36: 284-292.	Mail survey of non-resident overnight leisure travelers that had previously visited FL.	Examine FL tourist perceptions of risk from wildfire and reactionary behaviors.	Some travelers would consider canceling their trip, changing destination, or changing planned activities if smoke from a current fire, health problems, or car accidents due to smoke were reported in the destination area. Tourists in different risk perception groups reported different reactions, showing how perceptions of risk can have economic impacts in industries like tourism when smoke impacts are reported.
2014	Davis, E.J., C. Moseley, M. Nielsen-Pincus, & P.J. Jakes. 2014. "The community economic impacts of large wildfires: A case study from Trinity County, California." *Society & Natural Resources* 27(9): 983-993.	Case study on impacts of 2008 wildfires in Trinity County, CA including labor market, suppression spending, and interview data.	Examine how large, long-duration fires can affect different sectors in a rural community, and how fires may intersect with broader economic conditions.	Residents who depended on tourism for income (e.g. hospitality- and recreation-based businesses) described economic impacts resulting from smoke, such as lost income from tourists' cancelled visits.
2018	Cisneros, R., E. Alcala, D. Schweizer, & N. Burke. 2018. "Smoke complaints caused by wildland fire in the southern Sierra Nevada region, California." *International Journal of Wildland Fire* 27, 677–683.	Review of formal citizen complaints to air pollution control centers in southern Sierra Nevada, CA region.	Identify the concerns of citizens in central CA who generated formal complaints about smoke exposure from forest fires.	The primary concerns recorded were that smoke from fires caused health problems, required lifestyle change, and negatively impacted the local economy. Complaints often suggested that no amount of smoke was acceptable.

Box 1 Overview of literature investigating the economic costs of adverse health effects from wildland fire smoke

Wildfire smoke in the western US was found to create $165 million in average annual morbidity and mortality health costs from 2005–2015 (Jones and Berrens 2017). Kochi et al. (2010) reviewed the findings on the economic cost of adverse health effects from wildfire-smoke exposure by synthesizing literature from three areas: 1) studies that estimated the health-related economic costs of wildfire-smoke exposure; 2) epidemiology studies related to the health risk of wildfire smoke; and 3) general economic studies that estimated the monetary value of preventing the specific adverse health outcomes (Kochi et al. 2010). Since this review, other key literature measuring economic impacts of the health from smoke exposure has been published, including:

- Valuation of the mortality impacts and morbidity effects of smoke exposure from wildfires in Southern California (Kochi et al. 2012, Kochi et al. 2016);
- Valuation of the health effects of wildfire smoke in Southern California, along with valuation of what people were willing to pay to avoid smoke exposure symptoms (Richardson et al. 2012, Jones and Berrens 2017);
- An estimation of excess mortality and morbidity events along with the economic value of these impacts from wildland fire smoke exposure in the US from 2008-2012 (Fann et al. 2018).

Citations:

Fann, N., B. Alman, R.A. Broome, G.G Morgan, F.H. Johnston, G. Pouliot, & A.G. Rappold. 2018. "The health impacts and economic value of wildland fire episodes in the US: 2008–2012." *Science of The Total Environment* 610: 802–809.

Jones, B.A. & R.P. Berrens. 2017. "Application of an original wildfire smoke health cost benefits transfer protocol to the western US, 2005–2015." *Environmental Management* 60(5): 809-822.

Kochi, I., G.H. Donovan, P.A. Champ, & J.B. Loomis. 2010. "The economic cost of adverse health effects from wildfire-smoke exposure: A review." *International Journal of Wildland Fire* 19: 803-817.

Kochi, I., P.A. Champ, J.B. Loomis, & G.H. Donovan. 2012. "Valuing mortality impacts of smoke exposure from major southern California wildfires." *Journal of Forest Economics* 18 (1): 61-75.

Kochi, I., P.A. Champ, J.B. Loomis, & G.H. Donovan. 2016. "Valuing morbidity effects of wildfire smoke exposure from the 2007 southern California wildfires." *Journal of Forest Economics* 25: 29-54.

Richardson, L.A., P.A. Champ, & J.B. Loomis. 2012. "The hidden cost of wildfires: Economic valuation of health effects of wildfire smoke exposure in southern California." *Journal of Forest Economics* 18: 14-35.

Conclusions

As concerns about wildland fire smoke events have increased in recent decades, there has been a growing emphasis on understanding how individuals perceive smoke, as well as the factors that influence their perceptions. This review synthesizes scholarly research to date on this topic and offers an overview of findings. As the synthesis shows, scientific inquiry on perceptions of wildland fire smoke has evolved over the past two decades. Early research investigating public and land manager concerns around prescribed fire smoke led to studies targeting perceptions of smoke more pointedly, including efforts to identify specific factors that influence how individuals perceive smoke and how communication about smoke can be most effective.

Cumulatively, this body of research has thus far found that most individuals studied have some degree of acceptance for wildland fire smoke, but they also have concerns about smoke impacts on travel, local economies, and most notably, health. This research shows that smoke is a particularly critical issue for populations with preexisting medical conditions, and this synthesis underscores the need identified in multiple studies for research that focuses more explicitly on the most vulnerable populations during smoke exposure events.

In addition to concerns around health impacts, this research shows that acceptance of smoke is also influenced by a variety of other factors. Influences include fire-specific factors like the type of fire producing smoke and the duration of impacts; individual characteristics such as race, age, education level, and personal experiences and beliefs around wildland fire; and agency- and organization- controlled factors such as outreach and communication efforts. From a land management perspective, recent studies suggest that smoke-related barriers to increasing the scope and scale of fuels treatments like prescribed fire may be very place-specific and dependent on state regulations, local public opinion, and the efficacy of agency-public outreach and trust at the community level. Further investigation would improve understanding of where specific barriers exist and strategies for successfully navigating them.

The research in this synthesis highlights the importance of effective communication around smoke and its impacts, including using the most compelling and far-reaching modes and messaging possible. Personalized outreach and dialogue have been identified as more effective at addressing public concerns and increasing acceptance of smoke than more generalized outreach through public service announcements. Research focused on practitioner needs in smoke communication efforts identified a need for strategic investments to focus on better inter-agency communication, more data on how to best communicate the health impacts of smoke, and the necessary capacity to continually craft new messages and engage local audiences.

It is critical to improve scientific and managerial understanding of context-specific smoke concerns. The research noted here shows that: even with information about how to craft smoke messages, managers are still uncertain if messages are effective; outreach requires understanding local contexts; and in some cases, concerns about smoke can impact land managers' decision-making. At the same time, individuals, particularly those most sensitive to poor air quality, depend on management actions and communication that most effectively mitigates the potential adverse effects of smoke. All of these findings point to the need for more applied research on whether and how individuals act on smoke messages, and how efforts can be structured to better meet increasing concerns around wildland fire smoke nationwide.

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These sources provided relevant framing information but were not included in the review. Full citations for reviewed literature are on the following page.

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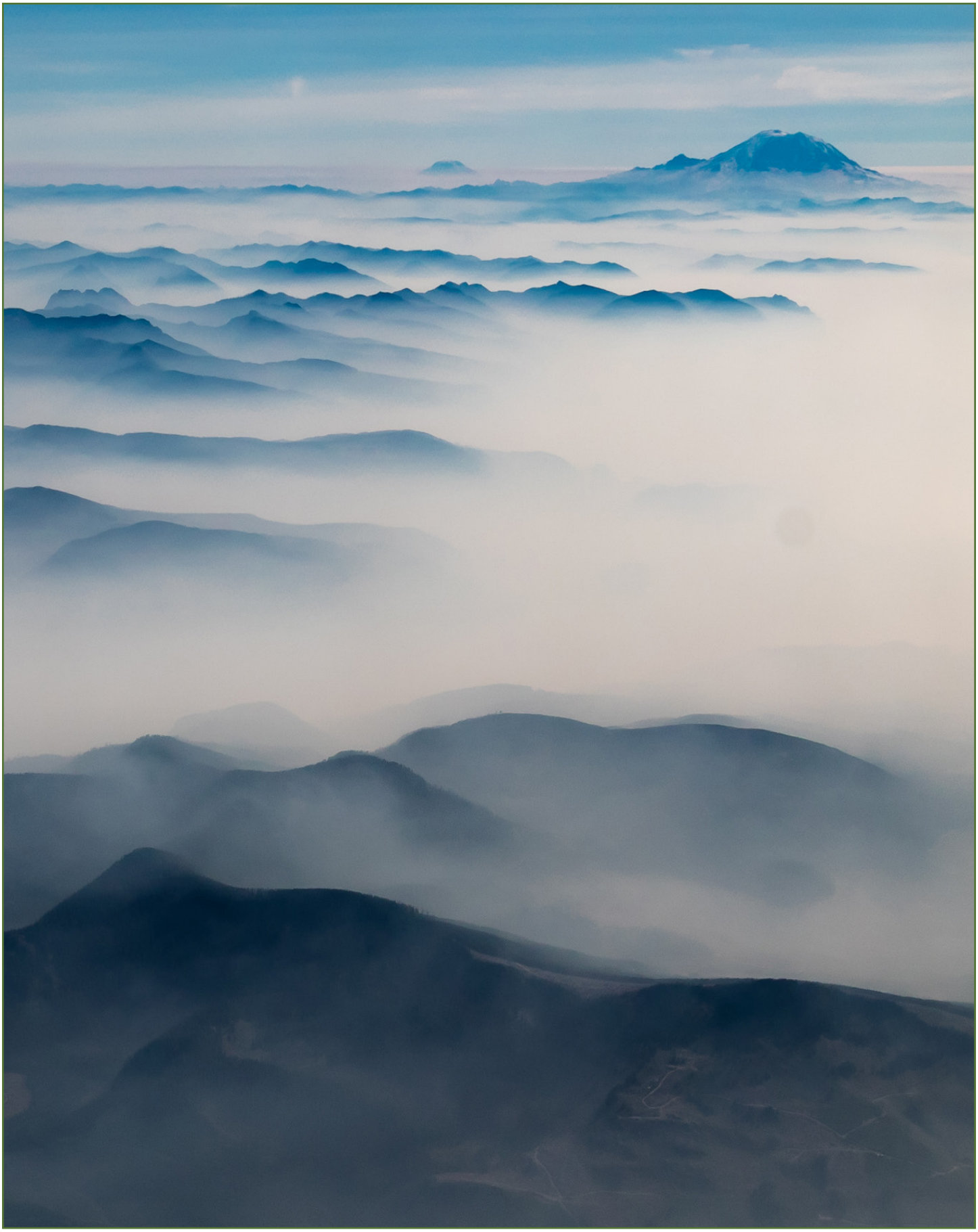

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