A review of the scientific contributions enabled by wilderness fire management

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Abstract

Background

Wilderness areas are important natural laboratories for scientists and managers working to understand fire ecology. In the last half-century, shifts in agency culture and policy have encouraged the management practice of letting some naturally ignited fires burn, allowing fire to fulfill its ecological role and increasing the extent of fire-related research opportunities. With the goal to identify the global scientific advances enabled by this paradigm shift in wilderness fire management, we conducted a systematic review of studies in which 1) protected areas were selected for investigation because of an active fire regime enabled by wilderness fire management, or 2) applied research was conducted to support wilderness fire management.

Results

Our systematic review returned a sample of 222 papers that met these criteria, with an increase in wilderness fire science over time. Studies largely occurred in the United States of America and were concentrated in a relatively small number of protected areas, particularly in the Northern Rocky Mountains. As a result, this sample of wilderness fire science is highly skewed toward areas of temperate mixed conifer forests and historical mixed severity fire regimes. Common principal subjects of papers included fire effects (44%), wilderness fire management (18%), or fire regimes (17%), and studies tended to focus on vegetation, disturbance, or wilderness management as response variables.

Conclusions

This work identifies major scientific contributions facilitated by active fire management, including concepts such as self-limitation of fire, forest dynamics in active fire regimes, and the effect of fire on wilderness recreation. Our work also identifies areas—both geographic and conceptual—where more research attention is needed and highlights under-represented wilderness areas that could serve to fill these knowledge gaps.

Background

Wilderness and other protected areas provide value to society as places for scientific research and knowledge production. This is true in a strict sense for congressionally designated Wilderness Areas in the United States of America (USA), where the Wilderness Act of 1964 explicitly identifies scientific use as one of the six public purposes of wilderness. More generally, scientific study of ecosystems in wilderness and protected areas provides the basis for developing natural models of ecosystem structure and dynamics, including the role of natural disturbances (Franklin et al., 2002; Berkey et al., 2021a). This knowledge informs ecosystem restoration and conservation (Hopkins et al., 2014), including the development of ecologically based management systems used outside of formal reserves (Kuuluvainen et al., 2021).

A profound contribution of wilderness and protected area management has been to catalyze a paradigm shift from fire suppression to fire management for resource benefit (Van Wagtendonk, 2007), especially in the USA. The joint effects of the Leopold report (Leopold et al., 1963), which stimulated the National Park Service to recognize fire as an ecological process (Hunter et al., 2014), and the Wilderness Act, which prompted Forest Service managers in the US Northern Rocky Mountains to manage some natural ignitions (Smith, 2014; Berkey et al., 2021b), began to restore fire as an ecological process and management tool starting in the late 1960s and early 1970s. These policy and management changes followed many decades of diminished fire activity due to the 1935 10 AM Policy—a national policy to suppress all wildfire ignitions—and earlier depopulation and displacement of Native Americans and their use of fire (Kimmerer and Lake, 2001; Ostlund et al., 2005; Kipfmueller et al., 2021; Larson et al., 2021). This shift towards a greater acceptance of fire created opportunities to study fire as an ecological and landscape process and interactions of wildfire with people and socioeconomic systems. It also required development of new knowledge to support fire management decision making (Smith, 2014; Miller and Aplet, 2016).

We assessed the scientific contributions and knowledge production made possible by wilderness fire management. Studies where wilderness fire management either created the opportunity for the research or created the need for the research are the subject of this review. We used systematic literature review methods (Pullin and Stewart, 2006) and placed no disciplinary or subject matter constraints on our review—our objective was to document the full range of scientific contributions made possible by wilderness fire management. Our review is partially motivated by the Wilderness Act's explicit identification of scientific use as one of the purposes of wilderness. Wilderness has in the past been criticized as not delivering on the promise and potential as a place for research (Franklin, 1987). We ask if that holds in the case of wilderness fire science. While wilderness is largely a legal and philosophical construct with origins in the early and middle 20th century environmental protection movement in the USA, many protected areas globally have active fire regimes, and we wanted to include scientific contributions from those regions. Thus, the geographic scope of our study is global. Our specific objectives were to:

1. Summarize the scientific contributions made possible by wilderness fire management in terms of their distribution in time and space; principal subject and environmental resource; and type of study and publication.
2. Assess the representativeness of studies in our sample in climate and fire regime space.
3. Synthesize major areas of scientific advancement and discovery made possible by wilderness fire management.

Methods

To establish the scope of our review, we defined wilderness as protected areas globally where natural disturbances such as fire are sometimes allowed to proceed. Though most naturally-ignited fires in wilderness areas are still suppressed (Miller, 2012), these areas nonetheless tend to have less suppression than outside of wilderness, and are not subject to salvage logging or other intensive post-fire management. To determine which protected areas met our criteria, we used International Union for Conservation of Nature (IUCN) protected area management categories Ia (strict nature reserve), Ib (wilderness), and II (national park) (Dudley, 2013).

Database search: To identify a global sample of studies enabled by wilderness fire management, we first conducted a database search. Initially, we tested several search strings, including [“Wilderness” AND “fire”], [“National Park” AND “fire”], [“National Wildlife Refuge” AND “fire”], [“National Preserve” AND “fire”], and [“National Monument” AND “fire”], as well as searches for individual wilderness areas, national parks, or regions [e.g., “Denali National Park” AND “fire”]. Preliminary analysis of these search strings revealed that searches other that [“Wilderness” AND “fire”] were overly sensitive, returning many studies that did not meet our inclusion criteria. Thus, we ultimately compiled our dataset from a sample of the literature using the single search string [“Wilderness” AND “fire”]. These preliminary and final searches took place during May 2019 using the ISI Web of Science (https://webofknowledge.com) and Treesearch (https://www.fs.usda.gov/treesearch/) databases.

We screened all papers, retaining those that met one of the following criteria: 1) a wilderness or other protected area was selected for investigation because of the modern (post-mid-20th century) active fire regime enabled by wilderness fire management; 2) studies of modern fires or fire regimes deliberately located in wilderness or other protected areas; 3) applied research undertaken to support implementation or continuation of wilderness fire management. We excluded studies conducted in wilderness but with a pre-historical or historical focus where the response variable is before the mid-20th century. We also excluded large scale (e.g., regional to subcontinental scale) studies where the inclusion of protected areas was incidental to the core focus or study area. We retained reviews, syntheses, and meta-analyses when the scope, inference, or conclusions of these papers depended significantly on the contribution of one or more qualifying (as described above) wilderness fire studies. Four of the authors (MRK, MRJ, SAP, AJL) assessed papers for inclusion. We automatically included papers when three or more reviewers independently recommended inclusion in the final dataset, with ties reassessed and decided by the senior author.

To identify the scientific advances within this final dataset, we collected information on each study’s research subject, themes, and location. The same four authors each assessed every paper in the final dataset and collected publication type, study type, principal subject, environmental resource, country, and protected area (Appendix 1). We initially used the Joint Fire Science Program (JFSP) *Findings Data Dictionary* (https://www.firescience.gov/PSR/documents/Findings_Data_Dictionary.pdf) to define to categories for the study type, principal subject, and environmental resource attributes in a manner that would facilitate integration with the existing JFSP Findings database. Preliminary review of qualifying studies in our sample showed a greater breadth of environmental resources and study types than those listed the JFSP data dictionary. Thus, we ultimately adopted the value definitions described in Appendix 2 for definitions of possible publication type, study type, principal subject, and environmental resource categories.

Representativeness: To assess how representative our sample is of fire broadly, we compared patterns of climate and historical fire regimes represented in our sample to those of broader areas. Because most studies focused on protected areas in the contiguous United States, we restricted our representativeness analyses to this area.

To assess the climatic representativeness of sampled areas, we constructed climate envelopes using annual climate water deficit and actual evapotranspiration data (aggregated to 1981–2010 averages) from gridded TerraClimate datasets (Abatzoglou et al., 2018). We compared the climate envelope for sampled wilderness areas to a climate envelope of all wilderness areas in the contiguous USA, as well as to a climate envelope of the entire contiguous USA. To assess the historical fire regime representativeness of sampled areas, we constructed fire regime envelopes using Mean Fire Return Interval (MFRI) and Percent of Replacement-Severity Fire (PRS) from gridded LANDFIRE datasets (Rollins, 2009). We converted these binned categorical values to their average value (e.g., Replacement-Severity Fire of 41–45% converted to 43%). As before, we compared the fire regime envelope for sampled areas to that of all wilderness areas in the contiguous USA, as well as to that of the entire contiguous USA. We accessed TerraClimate and LANDFIRE datasets via Google Earth Engine (Gorelick et al., 2017), and extracted the values of all pixels at 4-km scale that fell within sampled wilderness areas, contiguous USA wilderness areas, and the entire contiguous USA respectively.

Results

Our database keyword search returned 608 papers. Following the screening process, 222 papers were retained in our final sample and analyzed. Code and data to reproduce all results and figures from this paper can be accessed through the Zenodo open-access repository at https://doi.org/10.5281/zenodo.6326355.

Summary statistics

Most studies in our sample reported on research conducted in the USA (90%). Australia (6%) and Canada (5%) were the only other countries with more than one paper, with a handful of additional countries—Dominican Republic, Mongolia, Russian Federation, South Africa, Spain, Zambia, and Zimbabwe—each the subject of a single paper (Figure 1). Percentages sum to greater than one because nine papers focused on more than one country. Papers in our sample were published from 1970–2019, with an increasing trend in papers per year through time (Figure 2).

Most papers in our final sample were journal articles (68%), with proceedings papers another common avenue for wilderness fire science research (18%). The remaining papers were from books or book chapters (5%), General Technical Reports (3%), datasets (2%), management documents (2%), or other

(2%) (Figure 3A). Papers spanned many study types (Figure 3B), with most papers reporting on new data in the form of observational studies (62%) or synthesizing information through reviews/meta-analyses (25%). The remainder of papers were modeling studies (7%), methods papers (3%), datasets (2%), or field experiments (1%).

Papers in our sample focused on a variety of principle subjects (Figure 3C). The most common were papers primarily dealing with fire effects (44%), with additional representation from incident management (18%), fire regimes (17%), and fire ecology (12%). Remaining papers focused on fuel treatments (5%), monitoring (2%), fire behavior (1%), tool assessment (<1%), smoke management (<1%), and fuel characterization (<1%). Beyond their primary focus, papers dealt with an even more varied suite of environmental resources, or response variables. Over half of papers explored fire effects on vegetation (64%), patterns of fire (57%), or wilderness management in the context of active fire management (51%). Papers also reported, in lower numbers, on a wide variety of other response variables (Figure 3D). Because papers could have more than one response variable, percentages sum to more than one.

Papers in our sample focusing on fire ecology and fire effects were more likely to be published in a peer-reviewed journal, while papers focusing on fire regimes, incident management, and fuel treatments were more likely to be published in proceedings papers (Figure 4). Principal subjects of papers also tended to be linked to specific types of environmental resources, with fire ecology, fire effects, and fire regime papers focusing more often on physical variables such as soil, water, vegetation, and biota, while papers with principal subjects of fuel treatment or incident management focused on more abstract variables such as economics or law/policy (Figure 5).

Representativeness

All the papers from the United States of America (n = 199) occurred in the contiguous USA (Figure 1), and we conducted further analysis of representativeness on this sub-sample. Within the USA, studies were largely concentrated in the Northern Rockies, several southwestern wilderness areas, the Sierra Nevada, and the Boundary Waters Canoe Area Wilderness (Figure 1). Climate of wilderness areas represented in our sub-sample occupied a reduced climate envelope (Figure 6E) compared to both wilderness areas in the contiguous USA (Figure 6C) and especially the contiguous USA at large (Figure 6A). Research from this sub-sample has predominately occurred in areas with climate characterizing mixed conifer forests.

In a similar manner, historical fire regimes of studied wilderness areas (Figure 6F) represent a reduced fire regime envelope relative to wilderness areas in the contiguous USA (Figure 6D) and the contiguous USA (Figure 6B). Historical fire regimes of studied wilderness areas were clustered in mixed-severity regime space (i.e., stand-replacing proportion ~0.5 and mean return intervals of 30–100 years). There were few studied wilderness areas with historical frequent low-severity fire regimes, and virtually none with frequent stand-replacing fire regimes (i.e., grassland and shrubland ecosystems).

Every wilderness area in the contiguous USA with extensive fire in the last several decades (i.e., cumulative area >200,000 ha burned 1984–2019) is represented by at least one study in our sample

(Figure 7A). However, many of the wilderness areas with little or no representation in our sample have, in fact, experienced a relatively high amount of fire since 1984 (Figure 7B).

Synthesis:

Beyond the quantifiable metrics of research described above, we identified major conceptual areas in which scientific advancements have been enabled by wilderness fire research.

Self-limitation: A primary scientific advancement enabled by wilderness fire research is the extent to which fire limits the spread and intensity of subsequent fire. A body of research has documented self-limitation across the western USA (e.g., Collins et al., 2009; Parks et al., 2016), while also revealing that the self-limiting effects of fire vary by ecosystem, diminish over time, and are reduced by extreme fire weather (Collins et al., 2009; Parks et al., 2015). Research on self-limitation has been effectively restricted to a few wilderness areas because heavy suppression in other locations provide few instances of interactions between fire perimeters through time. However, this body of research shows the importance of fire in ecosystem self-regulation and highlights how a decision to suppress a fire is a lost opportunity to create natural fuel breaks and restore ecosystem resilience (Parks et al., 2015).

Wilderness fire management decision making: Advancements in our understanding of self-limitation have also equipped wilderness managers with improved tools for predicting when wildfires can be safely managed within wilderness perimeters (Suffling et al., 2008; Scott et al., 2012). Together with this empirical research, a sizeable body of papers identified the social and institutional challenges and solutions to restoring natural fire regimes to wilderness areas (e.g., Parsons, 2000; Miller, 2003; Parsons et al., 2003; Miller et al., 2011). In spite of the tools that this body of research provides, institutional culture and policy still hampers efforts to plan for and implement wilderness fire management outside of a handful of areas with historical precedents for allowing wilderness fire (Seielstad, 2015; Berkey et al., 2021b). Deferring—and often magnifying—risk by suppressing fires may be the most convenient option for managers. Thus, it is vital to create incentives to implement wilderness fire management, build cooperation across administrative boundaries, and increase public understanding of the inevitability of fire events (Berkey et al., 2021b).

Forest ecosystem dynamics under active fire regimes: With high levels of fire suppression in nearly all other outside areas (Calkin et al., 2005; *Quadrennial Fire Review*, 2014), wilderness areas with active fire management offer some of the only insights into how active fire regimes shape forest ecosystems. Wilderness fire science has advanced our understanding of fire effects on forest structure (e.g., Holden et al., 2006; Fulé and Laughlin, 2007; Taylor, 2010; Kane et al., 2013; Larson et al., 2013), tree mortality and survival (e.g., Bratton, 1993; Keane et al., 2006; Belote et al., 2015), fuels (e.g., Stevens-Rumann and Morgan, 2016; Ward et al., 2017), and plant and animal composition (e.g., Catling et al., 2001; Reilly et al., 2006; Jackson & Sullivan, 2009). This body of research in active fire regime wilderness areas has provided important advances beyond inferences from historical reconstructions in fire-excluded forests.

As fire activity increases in many areas (e.g., Schoennagel et al., 2017; Jain et al., 2022), research from wilderness areas will continue to provide an important baseline for understanding how ecosystems may respond to increased fire (Frelich, 2017).

Fire impacts on recreation: Recreation is an important component of many wilderness areas. Since these areas are also where fire is most allowed to burn, wilderness fire science has also advanced understandings of impacts of fire on recreation. Though fires and resulting trail closures may lead to slight declines in recreation (Brown et al., 2008) and reduced support for managing naturally ignited wildfires during high fire-activity years (Borrie et al., 2006), evidence of disturbances can also contribute to wilderness character, leading to recreationalist seeking out recently burned areas (Englin et al., 2008; Dvorak and Small, 2011; Sánchez et al., 2016) and supporting policy to allow lightning ignited wildfires (Borrie et al., 2006).

Aquatic dynamics under active fire regimes: Though representing a much smaller proportion of our sample relative to papers dealing with vegetation, an important body of wilderness fire science has advanced understandings of the effects of fire on fluvial geomorphology and aquatic processes. Wildfires strongly influence the routing of wood and sediment from upland and riparian areas to the channel network (Robinson et al., 2005; Marcus et al., 2011; Kleindl et al., 2015), with important effects on floodplain and channel habitats, including provision of salmonid spawning habitat (Jacobs et al., 2021). Other important conceptual areas include fire effects on aquatic food webs and water chemistry (e.g., Minshall et al., 2001; Spencer et al., 2003), terrestrial subsidies to aquatic food webs (Jackson et al., 2012), aquatic species composition (e.g., Robinson, et al., 2001; Rugenski & Minshall, 2014; Jacobs et al., 2021), and hydrology (e.g., Boisramé et al., 2019).

Discussion

This systematic review illustrates how wilderness fire management has created opportunities for research—and therefore the production of knowledge—related to patterns, processes, and effects of wildfire. Wilderness fire science has increased in pace and scope over the last five decades as more protected areas have been designated and management increasingly allows some fires to burn. Our study differs from previous reviews that focused more narrowly on fire science and did not use systematic methods (Agee, 2000; Miller and Aplet, 2016). We present a diversity of research topics and advancements that have originated from wilderness fire science, while our review also reveals areas—geographic, bioclimatic, and conceptual—where more research attention is needed. Wilderness fire science has largely focused on patterns of disturbance and fire effects on vegetation. While important research has already been conducted on fire effects beyond vegetation, we urge the continued increase of research exploring how fire impacts other domains such as wildlife, fungi, soil, aquatic systems, and human dimensions.

Our sample of wilderness fire science is heavily skewed towards studies from the contiguous USA. Less than 10% of studies in our sample reported on findings from outside of North America, even though many other areas of the world have had much more fire in the last several decades than the USA (Robinne et al., 2019). We only searched for papers in English, and our search string of ["Wilderness" AND "Fire"] may have contributed to the observed bias by identifying less studies from countries with protected areas named with other descriptors (e.g., "Reserve", "National Park", "Provincial Park", "Strictly Protected Area", etc.). However, given that the USA had among the earliest adoption of wilderness fire management, and provided an early model of wilderness areas as a construct ("Wilderness Act 16 U.S. Code § 1131," 1964), it is perhaps not surprising that many of these papers come from landscapes in the USA.

Within the USA, studies were also heavily concentrated in a relatively small number of wilderness areas, particularly in the northern Rockies. This pattern is largely driven by where wilderness managers have allowed fire to burn. For example, the Selway-Bitterroot Wilderness had the most studies in our sample by far, likely because it was the first US Forest Service-managed area to allow for scientific observation of fire (Smith, 2014), as well as the first area to adopt wilderness fire management (Berkey et al., 2021b). Furthermore, fires are almost always suppressed in small wilderness areas (Zimmerman et al., 2006) because unplanned ignitions are more likely to spread outside of wilderness boundaries (Barnett et al., 2016). For this reason, large wilderness areas (e.g., Selway-Bitterroot Wilderness, Frank Church River of No Return Wilderness, Bob Marshall Wilderness Complex, Yellowstone Wilderness, and Gila/Aldo Leopold Wilderness Complex) have allowed for greater use of wilderness fire management, resulting in increased research attention.

Our study is a sample of a broader body of research, and thus does not capture every wilderness fire science study. For example, there are some wilderness areas which did not appear in our sample, but where research has occurred: e.g., Kalmiopsis Wilderness in Oregon (Thompson and Spies, 2009; Donaghy Cannon, 2013) Ventana Wilderness in California (Talley and Griffin, 1980). Our search strings may have not detected studies in designated wilderness, but where the area is better known by another name (e.g., a study conducted in Marjory Stoneman Douglas Wilderness in Florida, but using "Everglades National Park" to describe the study location; Beckage et al., 2003; Ruiz et al., 2013). However, despite the imperfect detection of all wilderness science, we expect that frequencies of wilderness areas in our sample are useful proxies for the relative amounts of fire research attention in wilderness areas, at least in the USA.

This sample of wilderness fire science is not fully representative of climate or fire regimes in the USA, and certainly not globally (Robinne et al., 2019). Rather, the sample is highly skewed toward the climate space of temperate mixed conifer forests and toward mixed severity fire regime space. Of course, wilderness fire science can only occur where there is wilderness and fire. Even if all current wilderness areas in the contiguous USA had active fire regimes, knowledge derived from these areas would still represent a reduced climate and fire regime space relative to the whole country. Nevertheless, even when only considering available wilderness areas, there is potential to broaden the scope of fire science to better include under-represented climates and historical fire regimes. We identify many wilderness areas that have experienced significant wildfire but little or no research (e.g., many of the labeled wilderness areas in Fig. 7B). These under-represented areas offer the possibility for studies that would expand the geographic, climate, and fire spaces of wilderness fire science, thereby helping to address knowledge gaps. Additionally, allowing more fire to burn in wilderness areas with little to no fire currently can create additional research opportunities, especially in wilderness areas that might help to expand the representativeness of the current body of wilderness fire research.

Our review identified over 220 scientific studies enabled by wilderness fire management. Given that we were focused on the relatively narrow topic of wildfire, our sample of scientific literature is an extremely conservative estimate of the *total* scientific contribution of wilderness. Research and scientific use of wilderness is often questioned and challenged by managers (Landres, 2010), and policy of some agencies force researchers to demonstrate wilderness dependence (i.e., the work cannot be accomplished outside of wilderness) of proposed research, a distinction that is not mandated by law or required of other wilderness uses or user groups. Greater effort to quantify the scope, impact, and societal benefits of scientific research conducted in wilderness, or in support of wilderness management, could help wilderness managers better understand the role of wilderness in larger socioecological systems (Parsons, 2007), thereby recognizing scientific research as a valuable and appropriate use of wilderness.

Conclusions

Wilderness fire science has increased in pace and scope over the last five decades, helping to advance knowledge in a variety of conceptual areas, including self-limitation of fire, wilderness fire management decision making, forest and aquatic dynamics under active fire regimes, and fire effects on recreation. Many of these advances would not be possible were it not for the opportunities provided by wilderness fire management and the ability to use wilderness as a natural laboratory. Systematic methods enabled us to detect a wide range of disciplines, however, we show that our sample of wilderness fire science was heavily skewed towards studies from a handful of wilderness areas in the USA. As a result, the climate and fire regime spaces of this sample of studies is not entirely representative of wilderness areas in general, and certainly not of broader geographic areas. We identify several wilderness areas that have experienced wildfire but few or no studies—under-represented areas that offer the possibility for future research to help expand the geographic, climate, and fire spaces of wilderness fire science.

Declarations

Ethics approval and consent to participate: Not applicable

Consent for publication: Not applicable

Availability of data and material: The datasets and scripts generated and analyzed during the current study are available in the Zenodo repository, https://doi.org/10.5281/zenodo.6326355.

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References

Abatzoglou, J.T., Dobrowski, S.Z., Parks, S.A., Hegewisch, K.C., 2018. TerraClimate, a high-resolution global dataset of monthly climate and climatic water balance from 1958–2015. Scientific Data 5, 170191. https://doi.org/10.1038/sdata.2017.191

Agee, J.K., 2000. Wilderness fire science: a state of the knowledge review, in: Wilderness Ecosystems, Threats, and Management., Wilderness Science in a Time of Change Conferenc. USDA For. Serv. Gen. Tech. Rep. RMRS-P-15-VOL-5, pp. 5–22.

Barnett, K., Miller, C., Venn, T.J., 2016. Using Risk Analysis to Reveal Opportunities for the Management of Unplanned Ignitions in Wilderness. Journal of Forestry 114, 610–618. https://doi.org/10.5849/jof.15-111

Beckage, B., Platt, W.J., Slocum, M.G., Panko, B., 2003. Influence of the El Niño Southern Oscillation on Fire Regimes in the Florida Everglades. Ecology 84, 3124–3130. https://doi.org/10.1890/02-0183

Belote, R.T., Larson, A.J., Dietz, M.S., 2015. Tree survival scales to community-level effects following mixed-severity fire in a mixed-conifer forest. Forest Ecology and Management 353, 221–231. https://doi.org/10.1016/j.foreco.2015.05.033

Berkey, J.K., Belote, R.T., Maher, C.T., Larson, A.J., 2021a. Structural diversity and development in active fire regime mixed-conifer forests. Forest Ecology and Management 479, 118548. https://doi.org/10.1016/j.foreco.2020.118548

Berkey, J.K., Miller, C., Larson, A.J., 2021b. A history of wilderness fire management in the Northern Rockies. Gen. Tech. Rep. RMRS-GTR-428. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 88 p. https://doi.org/10.2737/RMRS-GTR-428. 428. https://doi.org/10.2737/RMRS-GTR-428

Boisramé, G.F., Thompson, S.E., Tague, C., Stephens, S.L., 2019. Restoring a natural fire regime alters the water balance of a Sierra Nevada catchment. Water Resources Research 55, 5751–5769.

Borrie, W., McCool, S., Whitmore, J., 2006. Wildland Fire Effects on Visits and Visitors to the Bob Marshall Wilderness Complex. International Journal of Wilderness 12, 32–38.

Bratton, S.P., 1993. Survivorship of Evergreen Hardwoods after Wildfire in Maritime Forest, Cumberland Island National Seashore, Georgia. Castanea 58, 34–44.

Brown, R.N.K., Rosenberger, R.S., Kline, J.D., Hall, T.E., Needham, M.D., 2008. Visitor Preferences for Managing Wilderness Recreation after Wildfire. Journal of Forestry 8.

Calkin, D.E., Gebert, K.M., Jones, J.G., Neilson, R.P., 2005. Forest service large fire area burned and suppression expenditure trends, 1970-2002. Journal of Forestry. 103(4): 179-183.

Catling, P., Coops, N., Burt, R., 2001. The distribution and abundance of ground-dwelling mammals in relation to time since wildfire and vegetation structure in south-eastern Australia. Wildlife Research 28, 555–565. https://doi.org/10.1071/WR00041

Collins, B.M., Miller, J.D., Thode, A.E., Kelly, M., van Wagtendonk, J.W., Stephens, S.L., 2009. Interactions Among Wildland Fires in a Long-Established Sierra Nevada Natural Fire Area. Ecosystems 12, 114–128. https://doi.org/10.1007/s10021-008-9211-7

Donaghy Cannon, M.M., 2013. The Use of Burned Forest By Breeding Birds Following the Biscuit Fire in Southwest Oregon (Ph.D.). Oregon State University, United States – Oregon.

Dudley, N., 2013. Guidelines for applying protected area management categories including IUCN WCPA best practice guidance on recognising protected areas and assigning management categories and governance types. IUCN.

Dvorak, R.G., Small, E.D., 2011. Visitor attitudes towards fire and wind disturbances in wilderness. International Journal of Wilderness. 21(2): 27-31, 36. 21, 27-31,36.

Englin, J., Holmes, T.P., Lutz, J., 2008. Wildfire and the economic value of wilderness recreation. The Economics of Forest Disturbances: Wildfires, Storms, and Invasive Species, 191-208.

Franklin, J.F., 1987. Scientific use of wilderness, in: Lucas, R. C, Ed. Proceedings, National Wilderness Research Conference: Issues, State-of-Knowledge, Future Directions., Gen. Tech. Rep. Ogden, UT, pp. 42–46.

Franklin, J.F., Spies, T.A., Pelt, R.V., Carey, A.B., Thornburgh, D.A., Berg, D.R., Lindenmayer, D.B., Harmon, M.E., Keeton, W.S., Shaw, D.C., Bible, K., Chen, J., 2002. Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example. Forest Ecology and Management, Forest Ecology in the next Millennium: Putting the long view into Practice 155, 399–423. https://doi.org/10.1016/S0378-1127(01)00575-8

Frelich, L.E., 2017. Wildland Fire: Understanding and Maintaining an Ecological Baseline. Curr Forestry Rep 3, 188–201. https://doi.org/10.1007/s40725-017-0062-3

Fulé, P.Z., Laughlin, D.C., 2007. Wildland fire effects on forest structure over an altitudinal gradient, Grand Canyon National Park, USA. Journal of Applied Ecology 44, 136–146. https://doi.org/10.1111/j.1365-2664.2006.01254.x

Gorelick, N., Hancher, M., Dixon, M., Ilyushchenko, S., Thau, D., Moore, R., 2017. Google Earth Engine: Planetary-scale geospatial analysis for everyone. Remote Sensing of Environment 202, 18–27. https://doi.org/10.1016/j.rse.2017.06.031

Holden, Z.A., Morgan, P., Rollins, M.G., Wright, R.G., 2006. Ponderosa pine snag densities following multiple fires in the Gila Wilderness, New Mexico. Forest Ecology and Management 221, 140–146. https://doi.org/10.1016/j.foreco.2005.09.014

Hopkins, T., Larson, A.J., Belote, R.T., 2014. Contrasting Effects of Wildfire and Ecological Restoration in Old-Growth Western Larch Forests. Forest Science 60, 1005–1013. https://doi.org/10.5849/forsci.13-088

Hunter, M.E., Iniguez, J.M., Farris, C.A., 2014. Historical and current fire management practices in two wilderness areas in the southwestern United States: The Saguaro Wilderness Area and the Gila-Aldo Leopold Wilderness Complex. Gen. Tech. Rep. RMRS-GTR-325. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 38 p. 325. https://doi.org/10.2737/RMRS-GTR-325

Jackson, B.K., Sullivan, S.M.P., 2009. Influence of wildfire severity on riparian plant community heterogeneity in an Idaho, USA wilderness. Forest Ecology and Management 259, 24–32. https://doi.org/10.1016/j.foreco.2009.09.036

Jackson, B.K., Sullivan, S.M.P., Malison, R.L., 2012. Wildfire severity mediates fluxes of plant material and terrestrial invertebrates to mountain streams. Forest Ecology and Management 278, 27–34. https://doi.org/10.1016/j.foreco.2012.04.033

Jacobs, G.R., Thurow, R.F., Buffington, J.M., Isaak, D.J., Wenger, S.J., 2021. Climate, Fire Regime, Geomorphology, and Conspecifics Influence the Spatial Distribution of Chinook Salmon Redds. Transactions of the American Fisheries Society 150, 8–23. https://doi.org/10.1002/tafs.10270

Jain, P., Castellanos-Acuna, D., Coogan, S.C.P., Abatzoglou, J.T., Flannigan, M.D., 2022. Observed increases in extreme fire weather driven by atmospheric humidity and temperature. Nat. Clim. Chang. 12, 63–70. https://doi.org/10.1038/s41558-021-01224-1

Kane, V.R., Lutz, J.A., Roberts, S.L., Smith, D.F., McGaughey, R.J., Povak, N.A., Brooks, M.L., 2013. Landscape-scale effects of fire severity on mixed-conifer and red fir forest structure in Yosemite National Park. Forest Ecology and Management 287, 17–31. https://doi.org/10.1016/j.foreco.2012.08.044

Keane, R.E., Arno, S., Dickinson, L.J., 2006. The Complexity of Managing Fire-dependent Ecosystems in Wilderness: Relict Ponderosa Pine in the Bob Marshall Wilderness. Ecological Restoration 24, 71–78. https://doi.org/10.3368/er.24.2.71

Kimmerer, R.W., Lake, F.K., 2001. The Role of Indigenous Burning in Land Management. Journal of Forestry 99, 36–41. https://doi.org/10.1093/jof/99.11.36

Kipfmueller, K.F., Larson, E.R., Johnson, L.B., Schneider, E.A., 2021. Human augmentation of historical red pine fire regimes in the Boundary Waters Canoe Area Wilderness. Ecosphere 12, e03673. https://doi.org/10.1002/ecs2.3673

Kleindl, W.J., Rains, M.C., Marshall, L.A., Hauer, F.R., 2015. Fire and flood expand the floodplain shifting habitat mosaic concept. Freshwater Science 34, 1366–1382. https://doi.org/10.1086/684016

Kuuluvainen, T., Angelstam, P., Frelich, L., Jõgiste, K., Koivula, M., Kubota, Y., Lafleur, B., Macdonald, E., 2021. Natural Disturbance-Based Forest Management: Moving Beyond Retention and Continuous-Cover Forestry. Frontiers in Forests and Global Change 4.

Landres, P., 2010. A framework to evaluate proposals for scientific activities in wilderness. Gen. Tech. Rep. RMRS-GTR-234. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 74 p. 234. https://doi.org/10.2737/RMRS-GTR-234

Larson, A.J., Belote, R.T., Cansler, C.A., Parks, S.A., Dietz, M.S., 2013. Latent resilience in ponderosa pine forest: effects of resumed frequent fire. Ecological Applications 23, 1243–1249. https://doi.org/10.1890/13-0066.1

Larson, E.R., Kipfmueller, K.F., Johnson, L.B., 2021. People, Fire, and Pine: Linking Human Agency and Landscape in the Boundary Waters Canoe Area Wilderness and Beyond. Annals of the American Association of Geographers 111, 1–25. https://doi.org/10.1080/24694452.2020.1768042

Leopold, A.S., Cain, S.A., Cottam, C.M., Gabrielson, I.N., Kimball, T.L., 1963. Wildlife Management in the National Parks. U.S. National Park Service.

Marcus, W.A., Rasmussen, J., Fonstad, M.A., 2011. Response of the Fluvial Wood System to Fire and Floods in Northern Yellowstone. Annals of the Association of American Geographers 101, 21–44. https://doi.org/10.1080/00045608.2010.539154

Miller, C., 2012. The hidden consequences of fire suppression. Park Science 28, 75–80.

Miller, C., 2003. Wildland Fire Use: A Wilderness Perspective on Fuel Management. USDA Forest Service Proceedings RMRS-P-29.

Miller, C., Abatzoglou, J., Brown, T., Syphard, A.D., 2011. Wilderness Fire Management in a Changing Environment, in: McKenzie, D., Miller, C., Falk, D.A. (Eds.), The Landscape Ecology of Fire, Ecological Studies. Springer Netherlands, Dordrecht, pp. 269–294. https://doi.org/10.1007/978-94-007-0301-8_11

Miller, C., Aplet, G.H., 2016. Progress in Wilderness Fire Science: Embracing Complexity. Journal of Forestry 114, 373–383. https://doi.org/10.5849/jof.15-008

Minshall, G. Wayne, Brock, J.T., Andrews, D.A., Robinson, C.T., 2001. Water quality, substratum and biotic responses of five central Idaho (USA) streams during the first year following the Mortar Creek fire. Int. J. Wildland Fire 10, 185. https://doi.org/10.1071/WF01017

Minshall, G.Wayne, Robinson, C.T., Lawrence, D.E., Andrews, D.A., Brock, J.T., 2001. Benthic macroinvertebrate assemblages in five central Idaho (USA) streams over a 10-year period following disturbance by wildfire. Int. J. Wildland Fire 10, 201. https://doi.org/10.1071/WF01018

Ostlund, L., Keane, B., Arno, S., Andersson, R., 2005. Culturally scarred trees in the Bob Marshall Wilderness, Montana, USA - Interpreting Native American historical forest use in a wilderness area. Natural Areas Journal. 25(4): 315-325.

Parks, S.A., Holsinger, L.M., Miller, C., Nelson, C.R., 2015. Wildland fire as a self-regulating mechanism: the role of previous burns and weather in limiting fire progression. Ecological Applications 25, 1478–1492. https://doi.org/10.1890/14-1430.1

Parks, S.A., Miller, C., Holsinger, L.M., Baggett, L.S., Bird, B.J., 2016. Wildland fire limits subsequent fire occurrence. Int. J. Wildland Fire 25, 182. https://doi.org/10.1071/WF15107

Parsons, D.J., 2007. An outside assessment of wilderness research in the Forest Service. International Journal of Wilderness. 13(3): 34-35, 39.

Parsons, D.J., 2000. The challenge of restoring natural fire to wilderness. In: Cole, David N.; McCool, Stephen F.; Borrie, William T.; O'Loughlin, Jennifer, comps. 2000. Wilderness science in a time of change conference-Volume 5: Wilderness ecosystems, threats, and management; 1999 May 23–27; Missoula, MT. Proceedings RMRS-P-15-VOL-5. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. p. 276-282 015.

Parsons, D.J., Landres, P.B., Miller, C., 2003. Wildland fire use: the dilemma of managing and restoring natural fire and fuels in United States wilderness. In: Galley, K.E.M.; Klinger, R.C.; Sugihara, N.G., eds. Proceedings of Fire Conference 2000: the First National Congress on Fire Ecology, Prevention, and Management. Miscellaneous Publication ; no. 13.Tallahassee, FL : Tall Timbers Research Station: 19-26.

Pullin, A.S., Stewart, G.B., 2006. Guidelines for Systematic Review in Conservation and Environmental Management. Conservation Biology 20, 1647–1656. https://doi.org/10.1111/j.1523-1739.2006.00485.x

Quadrennial Fire Review, 2014. US Department of Agriculture Forest Service Fire and Aviation Management and Department of the Interior Office of Wildland Fire, Washington, DC.

Reilly, M.J., Wimberly, M.C., Newell, C.L., 2006. Wildfire effects on plant species richness at multiple spatial scales in forest communities of the southern Appalachians. J Ecology 94, 118–130. https://doi.org/10.1111/j.1365-2745.2005.01055.x

Robinne, F.-N., Burns, J., Kant, P., Groot, B., Kleine, M., Flannigan, M., Albar, I., Amissah, L., Bowman, D., Charlton, V., Cochrane, M., Field, R., Goldammer, J., Khan, M., Kornexl, W., Krasovskiy, A., Mccaffrey, S., Mitchell, A., Mohanty, A.K., Ellison, D., 2019. Global Fire Challenges in a Warming World. World Bank.

Robinson, C.T., Uehlinger, U., Minshall, G.W., 2005. FUNCTIONAL CHARACTERISTICS OF WILDERNESS STREAMS TWENTY YEARS FOLLOWING WILDFIRE. Western North American Naturalist 65, 1–10.

Rollins, M.G., 2009. LANDFIRE: a nationally consistent vegetation, wildland fire, and fuel assessment. Int. J. Wildland Fire 18, 235. https://doi.org/10.1071/WF08088

Rugenski, A.T., Minshall, G.W., 2014. Climate-moderated responses to wildfire by macroinvertebrates and basal food resources in montane wilderness streams. Ecosphere 5, art25. https://doi.org/10.1890/ES13-00236.1

Ruiz, P.L., Sah, J.P., Ross, M.S., Spitzig, A.A., 2013. Tree Island Response to Fire and Flooding in the Short-Hydroperiod Marl Prairie Grasslands of the Florida Everglades, USA. fire ecol 9, 38–54. https://doi.org/10.4996/fireecology.0901038

Sánchez, J.J., Baerenklau, K., González-Cabán, A., 2016. Valuing hypothetical wildfire impacts with a Kuhn–Tucker model of recreation demand. Forest Policy and Economics 71, 63–70. https://doi.org/10.1016/j.forpol.2015.08.001

Schoennagel, T., Balch, J.K., Brenkert-Smith, H., Dennison, P.E., Harvey, B.J., Krawchuk, M.A., Mietkiewicz, N., Morgan, P., Moritz, M.A., Rasker, R., Turner, M.G., Whitlock, C., 2017. Adapt to more wildfire in western North American forests as climate changes. PNAS 114, 4582–4590. https://doi.org/10.1073/pnas.1617464114

Scott, J.H., Helmbrecht, D.J., Parks, S.A., Miller, C., 2012. Quantifying the Threat of Unsuppressed Wildfires Reaching the Adjacent Wildland-Urban Interface on the Bridger-Teton National Forest, Wyoming, USA. fire ecol 8, 125–142. https://doi.org/10.4996/fireecology.0802125

Seielstad, C., 2015. Reconsidering wildland fire use: Perspectives from the Northern Rockies. In: Keane, Robert E.; Jolly, Matt; Parsons, Russell; Riley, Karin. Proceedings of the large wildland fires conference;

May 19-23, 2014; Missoula, MT. Proc. RMRS-P-73. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. p. 207-212. 73, 207–212.

Smith, D., 2014. From research to policy: The White Cap Wilderness Fire Study. Forest History Today. Spring/Fall: 4-12. 4–12.

Spencer, C.N., Gabel, K.O., Hauer, F.R., 2003. Wildfire effects on stream food webs and nutrient dynamics in Glacier National Park, USA. Forest Ecology and Management, The Effect of Wildland Fire on Aquatic Ecosystems in the Western USA. 178, 141–153. https://doi.org/10.1016/S0378-1127(03)00058-6

Stevens-Rumann, C., Morgan, P., 2016. Repeated wildfires alter forest recovery of mixed-conifer ecosystems. Ecological Applications 26, 1842–1853. https://doi.org/10.1890/15-1521.1

Suffling, R., Grant, A., Feick, R., 2008. Modeling prescribed burns to serve as regional firebreaks to allow wildfire activity in protected areas. Forest Ecology and Management 256, 1815–1824. https://doi.org/10.1016/j.foreco.2008.06.043

Talley, S.N., Griffin, J.R., 1980. FIRE ECOLOGY OF A MONTANE PINE FOREST, JUNIPERO SERRA PEAK, CALIFORNIA. Madroño 27, 49–60.

Taylor, A.H., 2010. Fire disturbance and forest structure in an old-growth *Pinus ponderosa* forest, southern Cascades, USA. Journal of Vegetation Science 21, 561–572. https://doi.org/10.1111/j.1654-1103.2009.01164.x

Thompson, J.R., Spies, T.A., 2009. Vegetation and weather explain variation in crown damage within a large mixed-severity wildfire. Forest Ecology and Management 258, 1684–1694. https://doi.org/10.1016/j.foreco.2009.07.031

Van Wagtendonk, J.W., 2007. The history and evolution of wildland fire use. Fire Ecology 3, 3–17.

Ward, A., Cansler, C.A., Larson, A.J., 2017. Black Carbon on Coarse Woody Debris in Once- and Twice-Burned Mixed-Conifer Forest. fire ecol 13, 143–147. https://doi.org/10.4996/fireecology.130288796

Wilderness Act 16 U.S. Code § 1131 [WWW Document], 1964. URL https://uscode.house.gov/view.xhtml?path=/prelim@title16/chapter23&edition=prelim (accessed 4.15.21).

Zimmerman, T., Frary, M., Crook, S., Fay, B., Koppenol, P., Lasko, R., 2006. Wildland Fire Use - Challenges Associated With Program Management Across Multiple Ownerships and Land Use Situations. In: Andrews, Patricia L.; Butler, Bret W., comps. 2006. Fuels Management-How to Measure Success: Conference Proceedings. 28-30 March 2006; Portland, OR. Proceedings RMRS-P-41. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. p. 47-58 041.

Figures

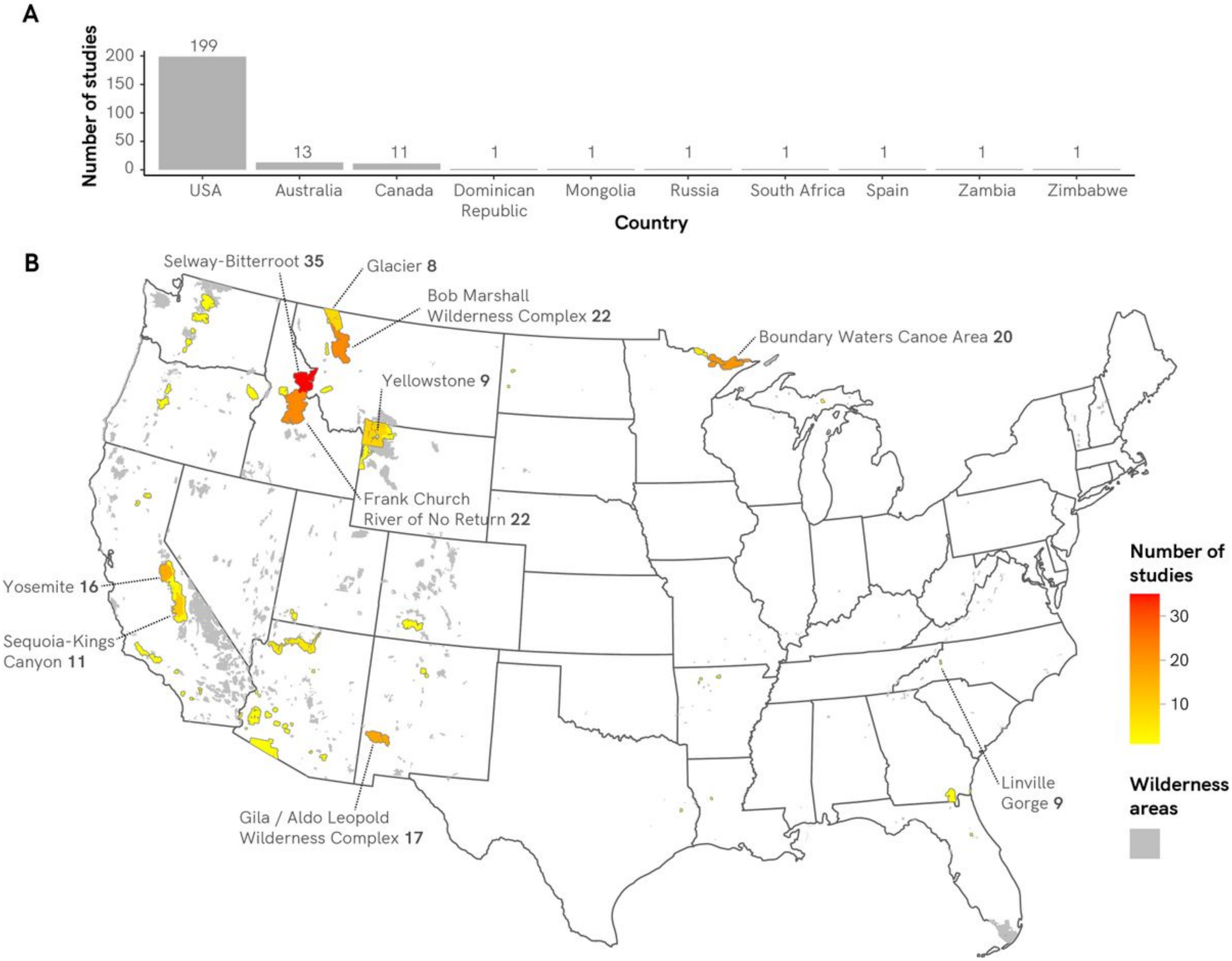

Figure 1

A) Number of studies taking place in each country. Note that some studies (n = 9) reported on research in more than one country. B) Frequency of studies by wilderness area (USA only). Of the 199 studies from the USA in our sample, none documented research outside of the contiguous USA. Labels shown for the 10 wilderness areas with the most studies (Bob Marshall Wilderness, Scapegoat Wilderness, and Great Bear Wilderness were combined into “Bob Marshall Wilderness Complex”; Gila Wilderness and Aldo Leopold Wilderness were combined into “Gila / Aldo Leopold Wilderness Complex”). Note that many studies occurred in multiple wilderness areas.

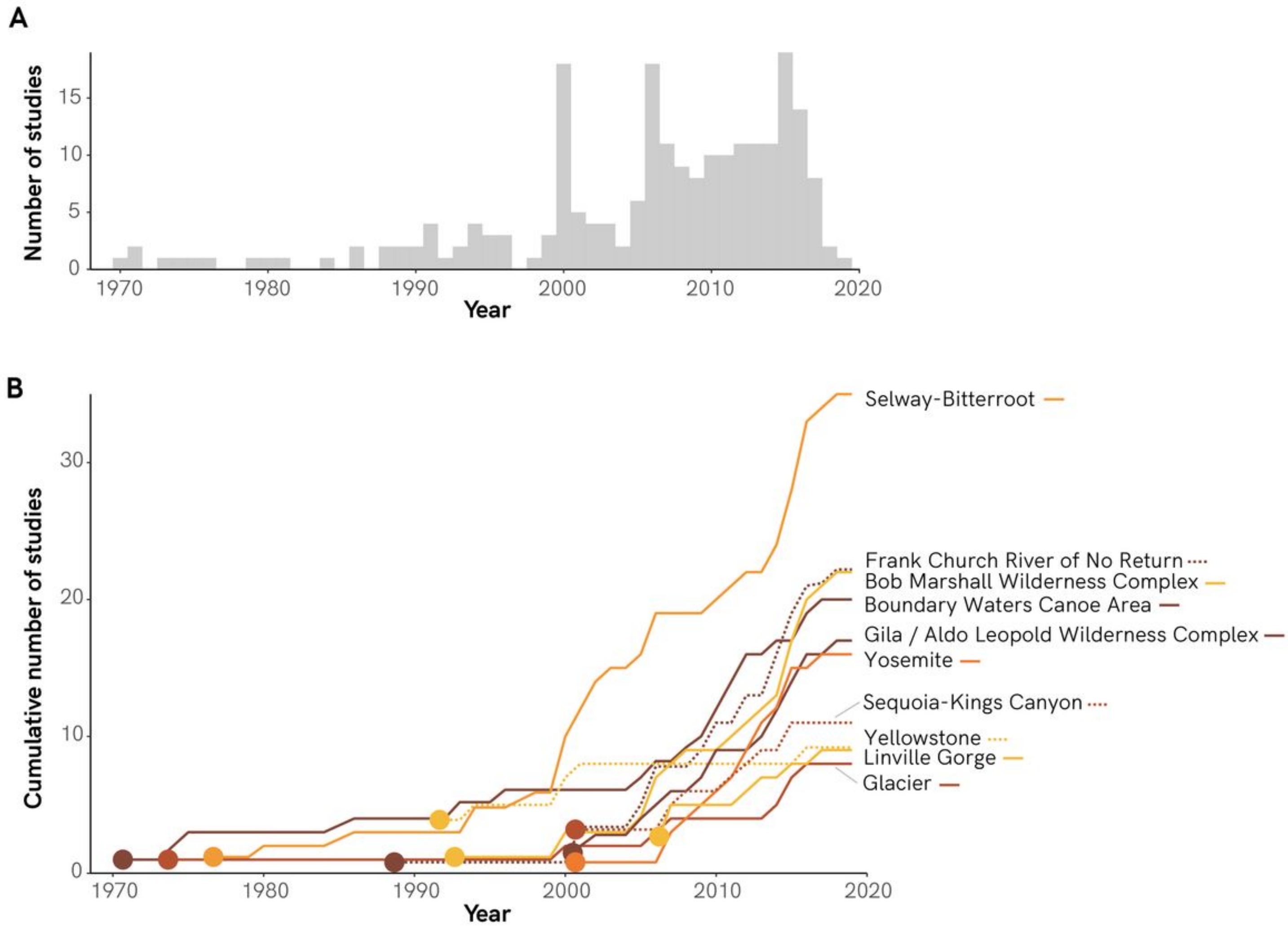

Figure 2

A) Frequency of studies by year. B) Cumulative frequency of the 10 wilderness areas with the most studies. Circles indicate the first year the wilderness area occurs in our sample. Bob Marshall Wilderness, Scapegoat Wilderness, and Great Bear Wilderness were combined into “Bob Marshall Wilderness Complex”; Gila Wilderness and Aldo Leopold Wilderness were combined into “Gila / Aldo Leopold Wilderness Complex”.

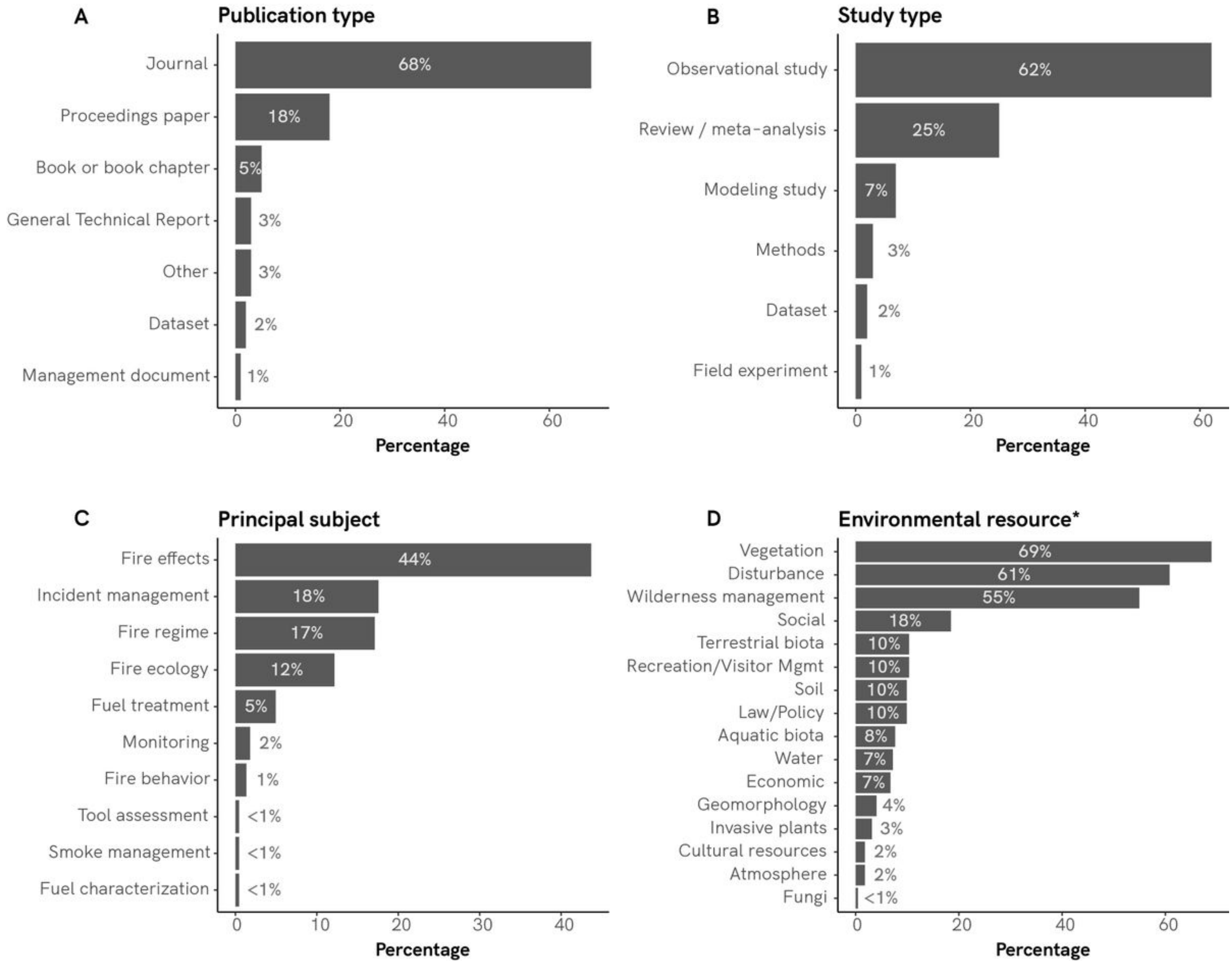

Figure 3

Percentage of studies by A) publication type, B) study type, C) principal subject, and D) environmental resource. *Because studies could have more than one Environmental resource, values sum to greater than 100%.

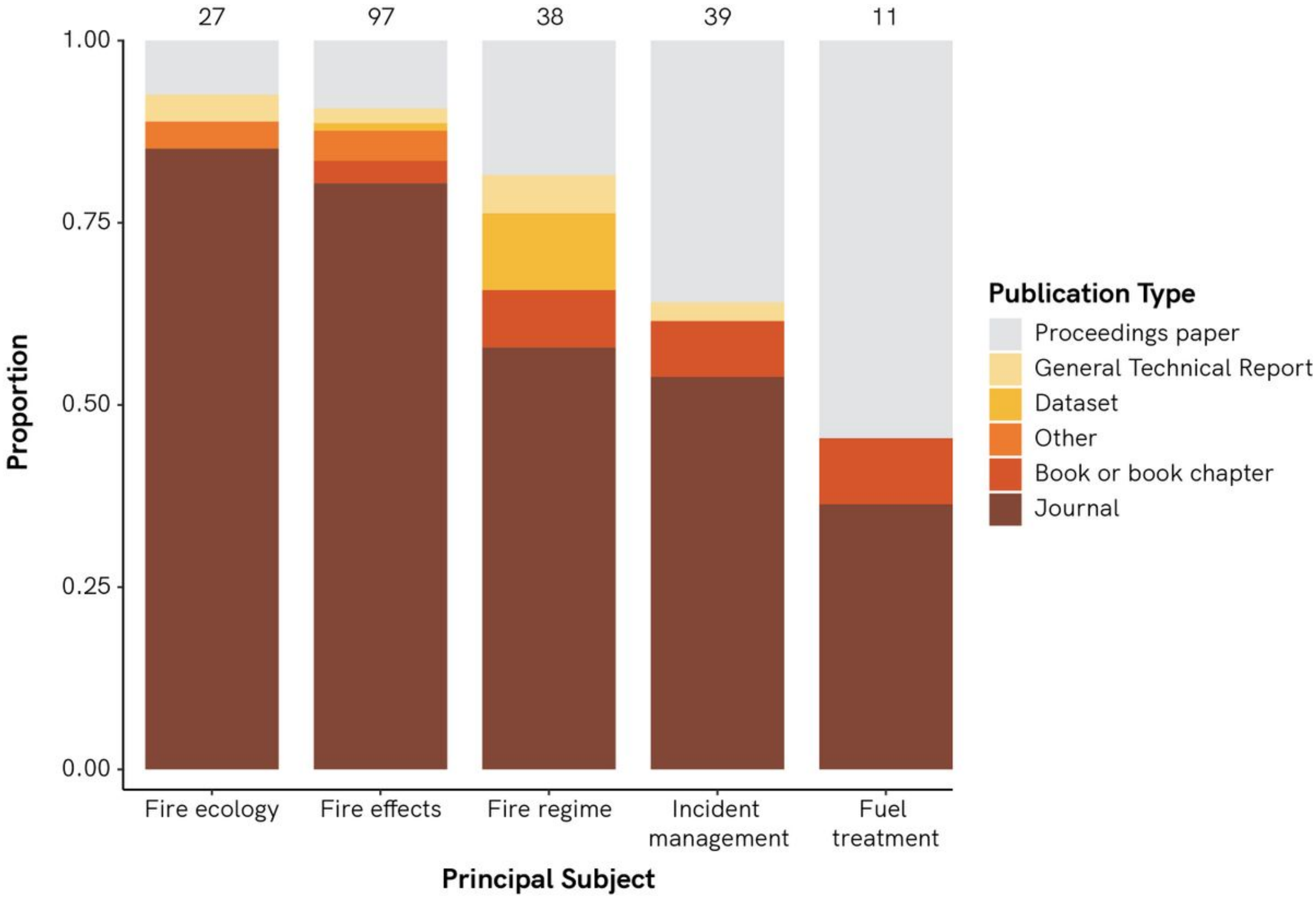

Figure 4

Proportion of publication type by principal subject. Only the 5 principal subjects with the most papers are shown (n = 212; 95% of studies). Numbers on top of each bar indicate the number of studies in that category.

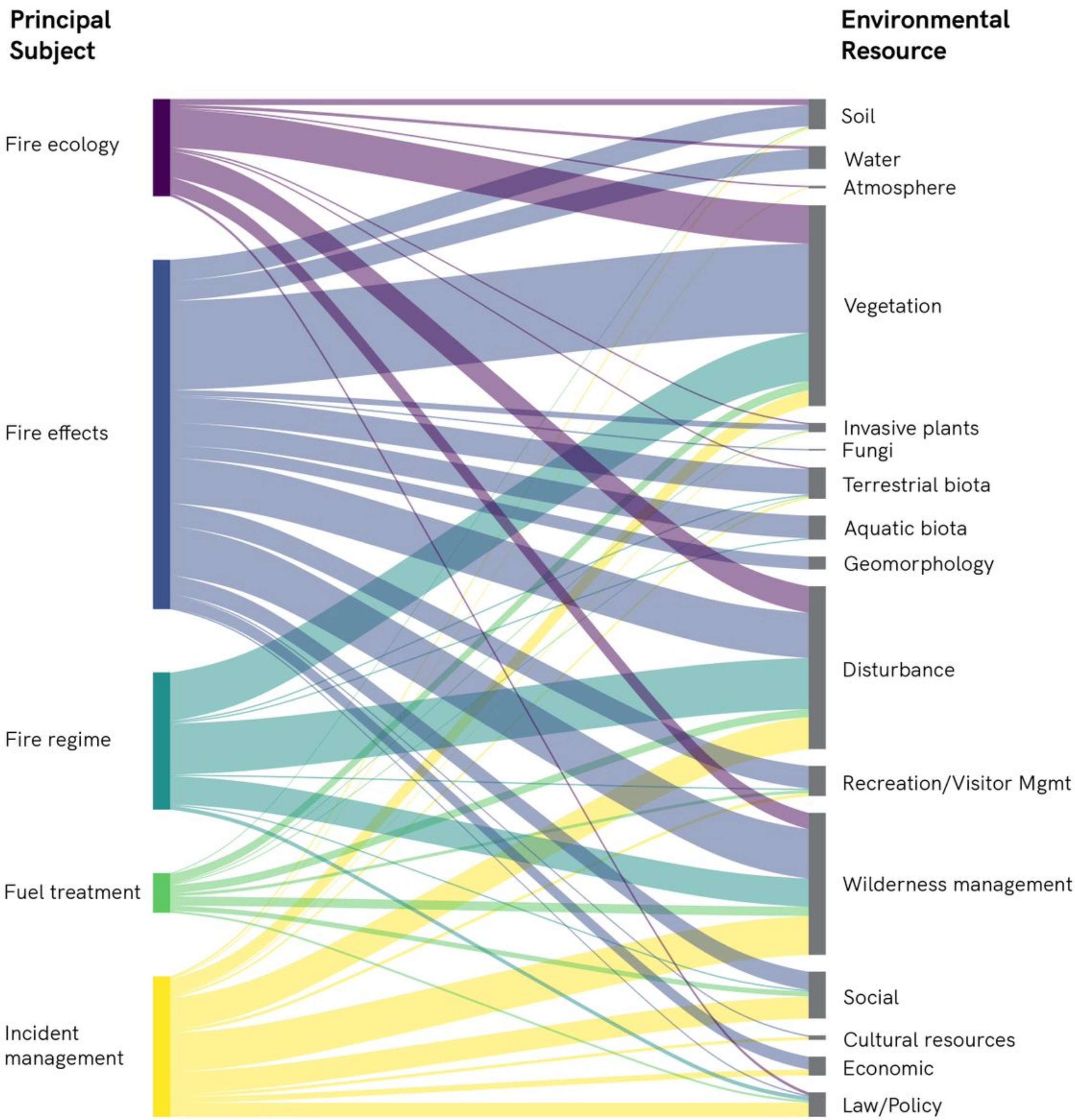

Figure 5

Connections between the principal subjects and environmental resources of papers.

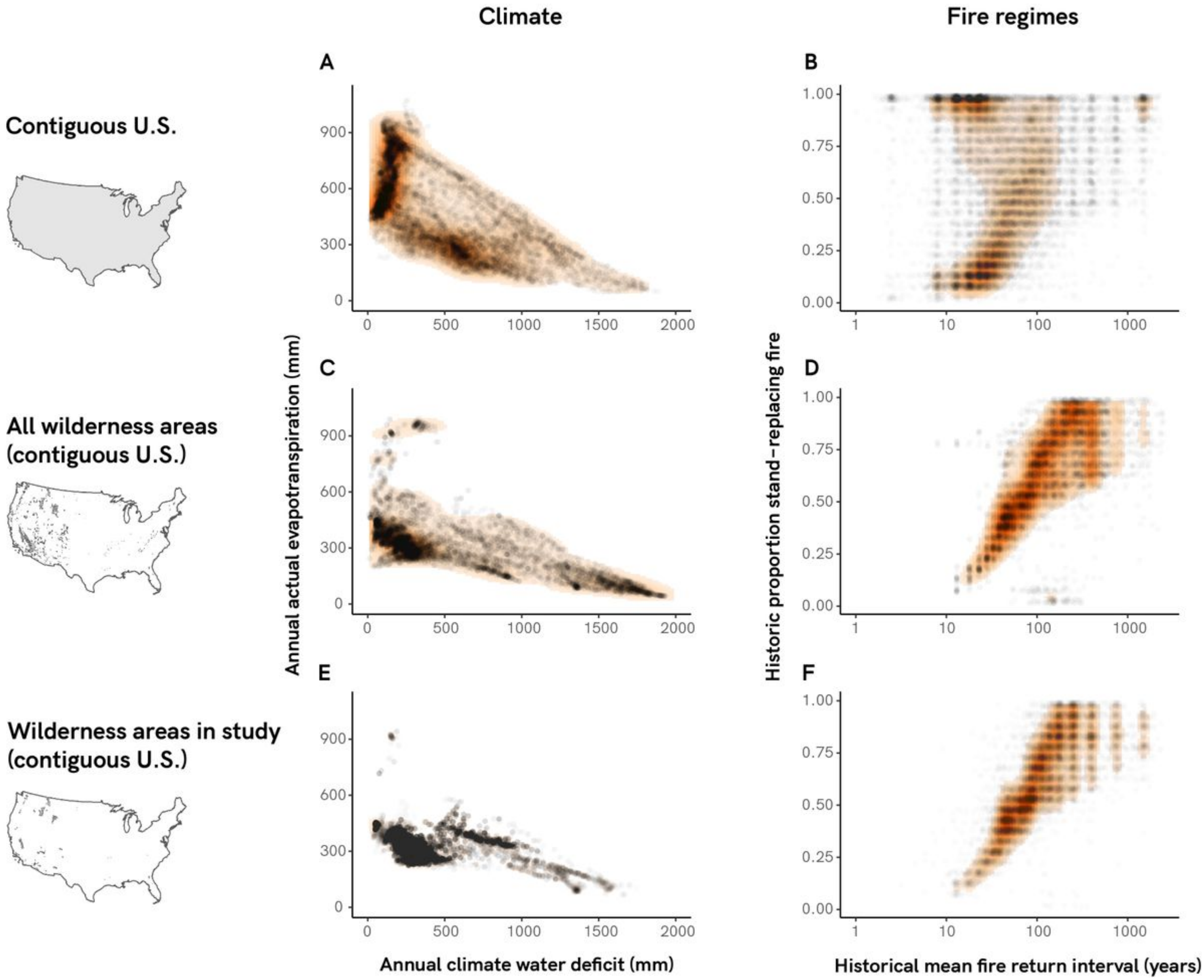

Figure 6

Climate and fire regime envelopes for the contiguous USA (A, B); all wilderness areas in the contiguous USA (C, D); and only wilderness areas in our sample (E, F). Grey shading in the lefthand maps show the spatial extent of pixels contributing to each row. Envelopes are approximated by 2D density plots (orange) with actual values shown by black dots. Data in E and F are proportional to the number of times a wilderness area was included in the sample (i.e., if a wilderness area was included 10 times in the sample, each pixel value from that wilderness area is also included 10 times).

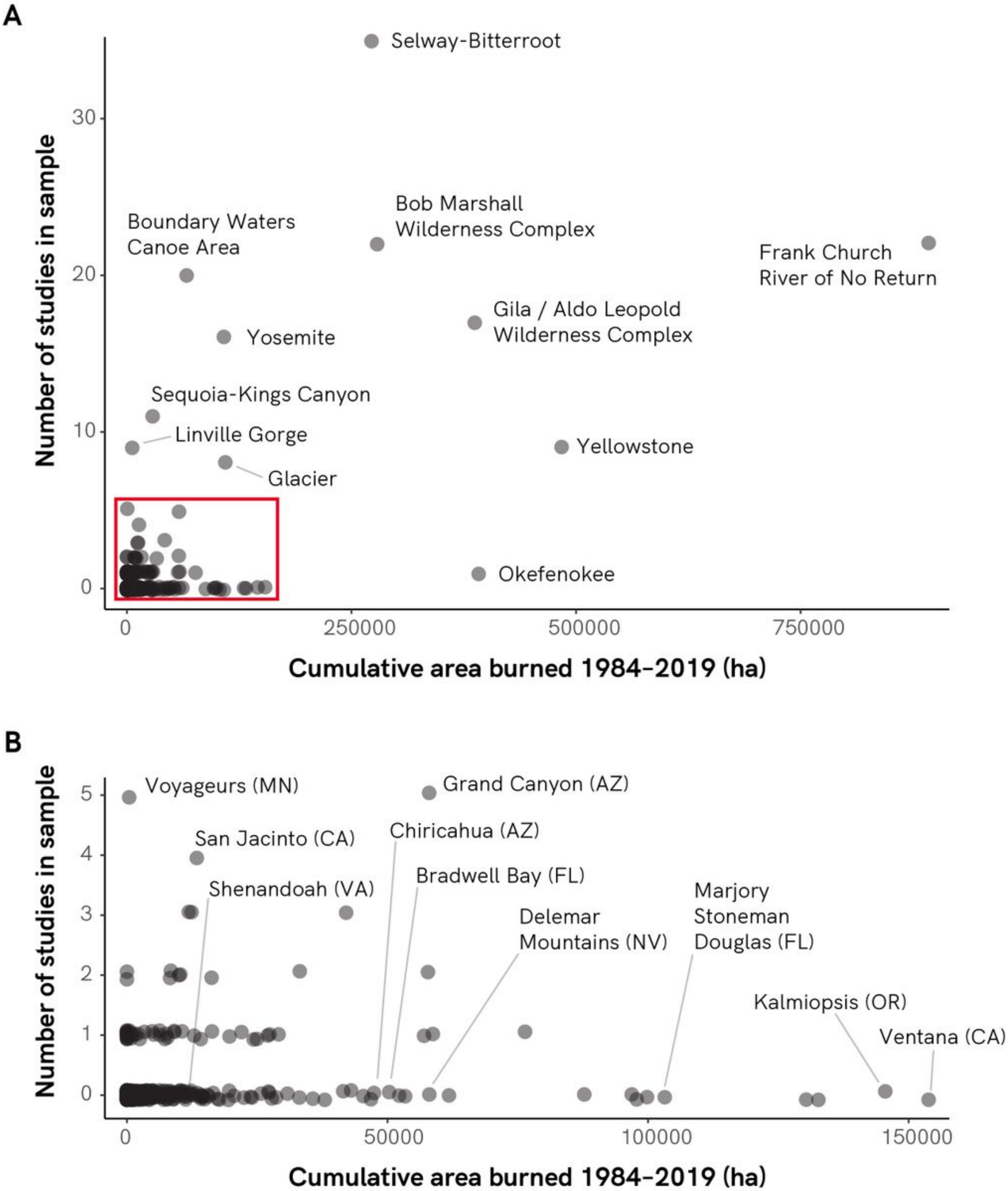

Figure 7

A) Relationship between total amount of fire burned (1984–2019) in each wilderness area in the contiguous USA and the number of times that wilderness area was studied in our sample. B) Inset of wilderness areas falling within the red box in panel A.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Appendix1.docx
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