UNIVERSITY OF CALIFORNIA, MERCED

Navigating the Hazardscape: Mixed-Methods Pathways for Adaptively Managing Connectivity in the Greater Yosemite Region

A dissertation submitted in partial satisfaction of the requirements
for the degree Doctor of Philosophy

in

Environmental Systems

by

Madeline Sue Brown

Committee in charge:
Professor Leroy Westerling, Chair
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2023

The Dissertation of Madeline Brown is approved, and it is acceptable in quality and for form publication on microfilm and electronically:

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2023

Dedication

This dissertation is dedicated to the late Brenda Thomas,
my high school leadership teacher, mentor, and friend.

“Life is not an accumulation; it is about contribution” -S. Covey

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Beth and Taylor. How do I describe the friendship, sillies, serious conversations, and quiet (loud as needed) support you've provided in the last five years? That would be a dissertation of its own. Brian, you are a welcome addition to this funny feminist mini cohort- thank you for reminding us to be more punk. An unanticipated outlet I'd like to thank is the Central Valley (formerly) Twitter crew of educators, adventurers, and #mappymeme.

Last, but not least, Franklin J. Frankweiler Cook (Frankie the Dog), thank you for never asking when I will be done.

Curriculum Vitae

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EDUCATION

University of California, Merced — Fall 2023
PhD, Environmental Systems
Advancement to Candidacy — September 2020
Ph.D. Advisor: Jeffrey Jenkins

University of Southern California — May 2015
Graduate Certificate, Geographic Information Science and Technology

University of California, Santa Barbara — June 2011
Bachelor of Arts, Geography

FELLOWSHIPS AND AWARDS

Total: $51,981

- Save the Redwoods: Giant Sequoia National Monument Recreation Research Fellowship, 2018
- National Forest Foundation: Conservation Connect Fellowship – Lake Tahoe West Restoration Partnership, 2019
- National Science Foundation (NSF) Internet of Things for Ag: IoT4Ag Education and Outreach Fellow, 2021

PUBLICATIONS

1. ***Brown, Madeline*** and Jeffrey Jenkins. "Visitor displacement during fire-driven road corridor closures at Yosemite National Park shows economic impacts to gateway communities." Journal of Outdoor Recreation and Tourism. *Accepted for publication August, 2023.* DOI: Pending

2. Jenkins, Jeffrey and ***Madeline Brown***. "Giant Sequoia—Forest, Monument, or Park?: Political-Legal Mandates and Socio-Ecological Complexity Shaping Landscape-Level Management." Society & Natural Resources, Oct. 2019. DOI: 10.1080/08941920.2019.1672843

3. Nettles, John M., ***Madeline Brown***, Erinn Drage, Ariful Islam, and Patricia Whitener. "Habitat connectivity and island biogeography: A call for community-engaged scholarship to address isolated parks and protected areas." Park Stewardship Forum. 2020. DOI: 10.5070/P536349857

4. Jenkins, Jeffrey and Felber Arroyave, ***Madeline Brown***, Jullianna Chavez, Johnny Ly, Haania Origel, Jacob Wetrosky. "Assessing impacts to national park visitation from COVID-19: A new normal for Yosemite?" Sept. 2021. DOI: 10.13140/RG.2.2.12749.77289

CAREER EXPERIENCE

CALSTART- Clean Transportation Lead Project Manager

Present

- Conduct comprehensive workforce development programs, identifying influence of current market trends and educational opportunities to facilitate transition from internal combustion engine to zero emission vehicle technician roles
- Compose state and federal level grant applications to facilitate zero emission vehicle market acceleration
- Engage with community-based organizations and stakeholders to facilitate access to financial and education resources for zero emission vehicle adoption
- Plan, budget, and implement zero emission vehicle market acceleration events
- Provide support for existing projects across multiple zero emission vehicle initiatives

Merced Irrigation District- Electric Utilities GIS Specialist

May 2015 - June 2019, June 2021- September 2021

- Created and maintained enterprise geodatabases, feature datasets, and feature classes of MID electrical assets and related MCAG and ArcGIS Online data using ArcGIS products
- Created and maintained enterprise geodatabases and supplemental flat files of residential and commercial solar customers and created regional solar irradiance maps.
- Performed multiple site suitability analyses for various user groups, including substation siting.
- Created and maintained the Key Accounts geospatial project, identifying critical infrastructure stakeholders and landowners for special projects and emergency outage communication
- Spearheaded spatial analysis project translating paper-based stranded assets project into digital format. Created reproducible and replicable results through ModelBuilder to identify parcels in which secondary service conduit and conductor were installed without attached meters
- Served as a supporting member of the Revenue Protection Team by providing insights to potential revenue loss sites by compiling GIS data, billing data, aerial imagery, and other resources
- Served as GIS Subject Matter Expert on Smart Meter hardware, CIS software, and OMS software recon and implementation committee
- Served as GIS Subject Matter on Environmental Impact Reports (EIR) for transmission corridor expansion and substation siting
- Facilitated implementation of Cityworks Asset Management system and migrated data to Esri’s Utility Network Model, and trained and supported linepersons utilizing Cityworks

GeoDigital International- Field Lead
January 2012 - May 2015

- Coordinated and executed full cycle field operations of LiDAR collection, processing, and QA/QC
- Served as field liaison for sensitive locations including nuclear power plants and naval bases
- Managed 4-12 crew members, on-site aircraft logistics, military installation access, and third-party contractors
- Used PosPac, GrafNet, and GrafNav software to process static and kinematic GPS networks
- Set up and ran Trimble and Sokkia base station units for static networks and collect ground truthing points
- **GeoDigital International- Field Lead, continued**
- Created and taught comprehensive field training manual for data processors and field leads
- Drafted comprehensive quality analysis documentation for external oversight engineering and design agencies such as Dewberry, to verify data accuracy within 3-5cm
- Served as Field Safety Representative

GeoDigital International- LiDAR Data Processor
June 2011 - December 2011

- Processed LiDAR and imagery using MicroStation with TerraScan and TerraPhoto applications
- Quality checked LiDAR, imagery, and weather probe data to ensure field standards met client specifications
- Analyzed corridor vegetation encroachment for clients to identify compliance with the National Electric Reliability Organization (NERC) and Federal Energy Regulatory Commission (FERC)

USDA Forest Service-Office Automation Clerk (GS-4) and Archaeology Tech (GS-3), Plumas National Forest, Feather River Ranger District (Oroville, CA)
June 2008 - Dec 2010
40 Hours per week, Seasonal

- Used ArcGIS software to create reference maps for resource groups and external companies
- Created and managed databases for Goshawk sightings within the District
- Served as member of the Feather River Ranger District FACTS Data Migration Team
- Surveyed, recorded, and excavated historic and prehistoric sites
- Drafted Archaeological Reconnaissance Records and cataloged artifacts
- Facilitated stakeholder engagement during two Passport in Time (Pit) projects, directing members of the public participating in historic and prehistoric site excavations

LEADERSHIP AND MENTORSHIP EXPERIENCE

- Summerville High School Girls' Varsity Volleyball Assistant Coach — 2021
- CITRIS Expanding Diversity and Gender Equity (EDGE) Mentor — 2021
- Valle de Exploración, UC Merced Panelist — 2020
- George Wright Society Graduate Student Organization Secretary — 2019-2020
- Merced Irrigation District Charitable Foundation Chairperson — 2017-2018
- Merced Irrigation District Charitable Foundation Non-Bargaining Employee Representative — 2017-2018
- American Association of University Women (AAUW): Mariposa Co-President — 2016-2018

COMMUNITY PARTICIPATION

- Yosemite Area Rapid Transit (YARTS) Authority Advisory Committee Member — Present
- Merced County Association of Governments (MCAG) Regional Transportation Plan + Sustainable Communities Strategies Advisory Committee — 2022
- Merced County Associate of Governments (MCAG) Student Representative — 2022-2023
- Tuolumne County Transportation Council: District 4 Citizen Advisory Council — 2021
- UC Merced GeoSummit Planning Committee — 2017-2019
- Mariposa County Fire Safe Council GIS Volunteer — On Call
- Chamberlain Road Fire Safe Corridor Grant Application GIS Volunteer — On Call

TEACHING EXPERIENCE

INSTRUCTOR OF RECORD: ***Full Time***

Spatial Analysis and Modelling (ENGR 180, UC Merced) Summer 22 (A)

Remote lectured-upper division undergraduates from programs including Computer Science and Engineering and Environmental Systems Science three days per week. Hosted lab sessions twice per week. Redeveloped existing lab documentation and final project to fit the condensed timeline. Updated lecture materials to include emphasis on ethics in spatial analysis and the exclusion of cartographic histories due to colonialism. Graded student assignments and provided comprehensive feedback. Designed and utilized new in-lecture "hands on" activities to encourage student engagement in the remote environment. Incorporated student feedback from previous iterations of the course. Analyzed and reported student performance to previous and recurrent Instructor of

Record. Created and maintained Catcourses Canvas site to facilitate communication with students.

TEACHING ASSISTANT: *Part-Time*

Spatial Analysis and Modelling (ENGR 180, UC Merced) F19, 20, 21, 22; Su 21, Sp 22, F22, Sp23

Developed and implemented curriculum in alignment with Program Learning Outcomes. Overhauled existing assignments from ArcGIS Desktop (ArcMap) to ArcGIS Pro. Developed weekly lab mini-lecture content and hosted lab sessions for 30 to 60 students. Designed three iterations of a site suitability analysis final project. Hosted weekly "drop-in" hours to engage with students in one-on-one and small-group work environments. Provided socio-emotional support and guidance by directing students to campus and community-based resources regularly throughout semesters.

GIS Decision Analysis in Management (MIST 132) Sp 20

Developed and implemented weekly lab curriculum and sourced accompanying assignments in alignment with Program Learning Outcomes. Hosted weekly lab sessions for undergraduate and graduate enrollees. Held weekly office hours to engage with students. Graded assignments and provided student academic support. Provided socio-emotional support and guidance by directing students to campus and community-based resources regularly throughout semester.

Earth Systems Science (ESS02) Sp 21

Lab module refinement and implementation and weekly TA group meetings with two other TAs and the Instructor of Record. Weekly teaching and office hours. Held weekly office hours to engage with students. Graded assignments and provided student academic support. Provided socio-emotional support and guidance by directing students to campus and community-based resources regularly throughout semester.

Parks and Public Lands (MIST 120) F 21

Developed discussion section modules to complement lecture content and implemented them weekly in a discussion format. Weekly teaching and office hours. Graded assignments and provided student academic support. Provided socio-emotional support and guidance by directing students to campus and community-based resources regularly throughout semester.

PRESENTATIONS AND PANELS

UC Merced GeoSummit	2018	*Reclaiming Stranded Assets: Tracking the Recovery of Undeveloped Parcels with GIS*
UC Merced MIST Spatial Analysis	2018	*GIS in Action*

Sequoia-Kings Canyon Science Symposium	2018	*Forest, Monument, or Park? Giant Sequoia National Monument Recreation Constraints and Opportunities Analysis*
UCM ESS Lightning Talks	2018	*Yosemite All Hazards Region Geospatial Coordination Group*
UCM Spark Seminar	2019	*Researching as a Geographer*
American Association of Geographers	2020	*Enabling Effective Interagency Coordination across Pairings of Complementary Digital Platforms*
American Association of Geographers	2021	*Shared Context, Separate Policies: Comparative Policy Analysis of Plans and Hazards in the Yosemite Region.*
UC GIS Week Pedagogical Panel	2022	*How Industry Knowledge Can Shape Pedagogy for Students*
Sierra Nevada Research Institute (SNRI) Symposium	2023	*Visitors to Pacific West National Parks Not Deterred from Attendance Despite Decreased Air Quality*

1. Introduction: Dimensions of connectivity In the greater Yosemite National Park region

The greater Yosemite National Park region comprises overlapping static and dynamic thresholds influenced by politico-legal, social, ecological, and economic factors across multiple spatial and temporal scales. These dimensions of connectivity and associated challenges are captured within socio-ecological systems (SES) theory which encompasses interconnected human factors, such as legislation and natural processes (Dietz, 2003; Ostrom, 2009). This dissertation quantifies and qualifies **connectivity** through human and economic movement and transportation planning integration across the landscape within the greater context of climate change.

Transportation systems and planning, though appropriate for engaging in an SES management framework, have not fully embraced adaptation and resilience thinking given that transportation planning is largely reactive, operationally based with an emphasis on response versus proactive policymaking and utilizes historical conditions for future planning. Socio-ecological systems theory emphasizes stakeholder engagement and institutions to facilitate resilience. Resilience is an emergent property, necessitating the belief that issues can be resolved through adaptive approaches and effective co-management of interrelated, dynamic challenges within a complex socio-ecological system (Beratan and Karl, 2012). Challenges for socio-ecological systems in the greater Yosemite region necessitate addressing problems at the landscape **scale** rather than attempting to create plans within jurisdictional boundary confines, irrespective of natural processes and physical landscapes.

The term region is used colloquially and non-critically in casual language and doesn't necessarily identify specific boundaries to conceptualize a **region** (McKinnon and Hiner, 2016). Variability in how a region is defined enables exploring individual challenges at localized scales (Walker, 2003). For qualitative and quantitative analyses in this dissertation, we define the greater Yosemite **region** as Yosemite National Park and its four contiguous counties – Madera, Mariposa, Mono, and Tuolumne – each with concrete physical, political, social, and economic connectivity to Yosemite. Shifting and **conflicting epistemologies** from the commodity-extracting Old West to the amenity-valuing New West continually influence development in the transition-dense region (Duane, 2000; Bramwell, 2016). Multiple policy scales primarily designate the region as rural, despite urban level wear and tear, driven by Yosemite's high visitation.

The region consists of extended stretches of high-hazard risk and an ever-expanding **wildland-urban interface** in the foothills into lower montane zones (Radeloff et al., 2005; Radeloff et al., 2018). Physical geography and geology constrain development in the region, limited by largely granitic features, steep ridges, and deep canyons. The region's development is further constrained by formalized, stringent environmental **legislation,** including the Wild and Scenic Rivers Act and the Merced River Act, which limits development within proximity to select invaluable riverine corridors. Despite protecting critical environmental, wildlife, and ecosystem services, the regulations dictated by the Wild and Scenic Rivers Act and Merced Rivers Act are at odds with the historical development and contemporary demand of existing critical (and limited) corridors. Routes first established to provide connectivity between indigenous groups on either side of the Sierra Nevada, run cattle, and support extractive mining and logging are still used, though more significantly engineered, to move millions of people throughout the region. Environmental hazards along these same routes are exacerbated by climate-change-influenced landscapes, demonstrating increased fuel loads, decreased vegetation health, expanding fire season, and fluctuations in precipitation timing and intensity.

The interconnectivity between physical landscapes, policy, societal influences, global connectivity, and contemporary hazards collectively embodies the hazardscape framework (Mustafa, 2005). Wildfires are natural processes within Yosemite's hazardscape, influenced by acute conditions, such as relative humidity, fuel load, and an ignition source, whether natural or anthropogenic (Van Wagtendonk and Lutz, 2007). Regional transportation systems demonstrate anthropogenically generated exposure to hazards as a confluence of contributing factors including human proximity to dense, susceptible fuels in proximity to assets, resources, and population centers tucked into constrained spaces (Jenkins, 2022). For example, a faulty catalytic converted ignited dry grasses, expanding across steep terrain through dry fuels, ultimately leading to Yosemite Valley's evacuation after multiple days of subsequent corridor closures (Associated Press, 2017). Combined with pyrogenic conditions, centuries of policies enacting beneficial paradigms across the landscape generate path dependency for how people utilize such corridors for travel, work, and recreate.

Some socio-ecological systems naturally persist, self-managing independently, while others have been managed or restored to ecologically functional conditions. These demonstrate Gunderson and Hollings' **adaptive cycles**, where a system is exploited[1] as it matures and enters a conservation stage, is impacted by a release force, and ultimately enters a phase of reorganization where its resilience grows, entering another adaptive cycle (Gunderson and Holling, 2002). Transportation systems must be considered across multiple scales – the theory of Panarchy- where, in a functional and adaptable system, smaller systemic components energize adaptive cycle hierarchies, driving transitions away from destructive release forces upwards (and back) to mid-scale functional conservation in the *revolt process*. Smaller-scale processes occur comparatively quickly, which enables revolt through high turnover without systemic breakdown. Meanwhile, larger scales exert downward controlling forces from conservation to mid-scale reorganization through *remember,* as large-scale processes are slow and stabilize the contexts in which more minor scales operate. Like the relationships between a tree, a stand, and a forest, a single vehicle influences traffic on corridors, and traffic on

[1] Literature also refers to the stages as growth, equilibrium, creative destruction, and renewal

corridors influences the complete transportation system. Individual vehicles energize system connectivity, influencing high-level decision making, but ultimate constraining factors exert control from the top down (i.e., existing policy operationalized as plans across the built environment).

Connectivity extends beyond people in vehicles to those traveling through and spending time and money in gateway communities financially dependent on neighboring parks and public lands (Gabe, 2016). Mariposa and Mono counties demonstrate significant proportions of jobs and income directly associated with recreational demand, with 43 to 68% of all jobs tied directly to travel and tourism (Headwaters Economics, 2022). The Tuolumne County economy is double the national average, with 29% of jobs in travel and tourism, while Madera County remains more economically connected to the agricultural Central Valley, with 15% of roles directly associated with travel and tourism. Service-based roles in rural counties have skyrocketed since the 1970s, while non-service (i.e., agriculture) and government roles have remained largely stable.

With vehicles first entering the Park in the 1910s, contemporary transportation has remained an ongoing challenge – repeatedly identified through formal documentation since the implementation of the General Management Plan in 1980. Ultimately designed to manage visitor experience by strategically routing visitors to promote scenic vistas while minimizing degradation via social trails, improve facilities and access, and preserve natural and cultural resources, the Plan was initiated out of over-engineering, overuse, and overcrowding. Privatization and commercialization strongly influenced Park development over the previous century, prioritizing an entertaining atmosphere in the short term with ecologically insensitive activities at the expense of functional ecosystems, preservation goals, and longitudinal, sustainable enjoyment (Sellars, 2009).

Activities such as Yosemite Firefall entertained visitors from the late 1800s through 1968 featured ecologically harmful spectacles for visitor enjoyment, from pushing embers over Glacier Point, mimicking a glowing waterfall, leading to severe degradation of meadow viewing areas, dense traffic, and substantial litter; in other Park locations, bears were encouraged to feed in waste facilities, generating dangerous habituation to humans, increasing human-wildlife interaction (Childers, 2017; Mazur, 2015). The General Management Plan included substantial public input and ecological considerations. General Management Plan efforts coincided with transitioning from a phase of infrastructure expansion and controlling nature from the 1930s through the early 60s into a phase of informing decision-making through science in the late 1970s through the mid-80s (Jenkins, 2022).

Managerial paradigms shifted from controlling nature and visitor experience with highly designed infrastructure and visitor experiences to increased conservation and systems thinking to combat congestion, riverbank degradation, and human-wildlife interactions (National Park Service, 1980). Societal shifts paralleled managerial shifts through influential publications and subsequent related legislation – particularly Silent Spring and the establishment of the EPA in 1970, followed by the implementation of the Wild and Scenic Rivers

Act in 1972, with the Merced River included in 1987 and 1992 (Scarlett, 2012; Bureau of Land Management, 2023). The General Management Plan sought to remedy the following specific issues- reclaim priceless natural beauty, allow natural processes to prevail, reduce crowding, promote visitor understanding and enjoyment, and markedly reduce traffic congestion, with the specific goal to "*remove all private vehicles from Yosemite Valley*" (page. 3). Following catastrophic flooding in 1997, the Park entered an era of politico-legal complexities (Fitzsimmons, 2012).

Contrary to adaptive cycles, which successfully transition out of the reorganization phase into exploitation, *maladaptive* systems are engrained with dysfunction due to misuse or external forces such as a human (overuse) or physical disruption (landslide) (Holling, 2001). Regional transportation systems demonstrate a maladaptive system rigidity trap, where transportation system planning has largely been unable to adapt due to interrelated geologic and geographic constraints, and historical and legislative inertia yet face misuse in the form of capacity exceedance. *Poverty traps* result when constraints are maintained through minimal capital resources, increasing demand, and worsening conditions. Dysfunctional transportation systems persist despite increasingly frustrated users and dangerous conditions due to high connectedness between transportation systems and top-down controls.

Transportation systems limited by rigidity and poverty traps have cascading effects into surrounding communities. Regional population density is low, and population centers are isolated at significant distances from one another, limiting alternative transportation options. All four counties demonstrate high transportation inequities disproportionately impacting disadvantaged communities, such as people with physical disabilities relying on limited dial-a-ride options and low-income families with limited personal vehicle access relying on public transit to access appointments in distant communities. Funding constrains the counties' ability to facilitate commuting and access to critical resources during clear-skies situations, let alone wildfire emergencies. Where limited transit options exist, collaborative agencies – the Yosemite Area Regional Transit System (YARTS) in particular, has filled a gap in demand for Park employees to use for mass transit to and from work, as well as to connect foothill communities with critical resources lower in the Central Valley (YARTS, 2018).

The YARTS transit agency began serving four corridors into the Park in 2000 but was initially conceptualized just before a critical, solidifying incident in the early 1990s. In 1995, Park management implemented an aggressive, short-term command and control approach to mitigate severe congestion (Weinstein Nelson and Tumlin, 2000). Park management alternately closed entrance gates for several hours at a time to limit parking and congestion issues in Yosemite Valley. This maladaptive action disrupted park attendance for months, exacerbating visitor frustrations and planning concerns. The co-occuring YARTS formation demonstrated a nascent approach to collaborative adaptive management attempting to overcome regional rigidity traps.

Generated out of preceding adaptive management principles recognizing the need for management considering evidence-based incremental changes over time, collaborative adaptive management approaches landscape scale socio-ecological challenges through inter-agency collaboration (Gunderson and Holling, 2002). Expanding to a landscape-level view of socio-ecological issues, such as wildfire impacts to transportation corridors, improves resilience and cohesion through integrated and cross-boundary solutions and thereby transformational management (Berkes and Ross, 2013). Collaborative adaptive management incorporates dialogue from diverse information providers around scientific, technical, and experiential expertise that may otherwise remain siloed within a singular agency (Beratan and Karl, 2012).

State level policy emphasis on urban areas overlooks smaller rural communities, generally managed at county scales across the Sierra Nevada (Walker, 2003). Engagement from stakeholders at smaller scales can aid in reducing conflict in unincorporated areas by linking policy to multifunctional outcomes in the wildland-urban interface that collectively confer resilience to high-severity wildfire (Chase, 2015). Localized institutions, such as at the county scale utilized in subsequent chapters, must ultimately be connected to larger scale institutions (e.g., CalTrans and Yosemite National Park) through flexible, adaptable, and resilient means to effect meaningful change for larger cross-scale systemic issues longitudinally (Beratan and Karl, 2012). Therefore, this dissertation begins by framing current policies across scales and their ability to affect transportation resilience to environmental hazards, specifically wildfire.

Chapter 2, *An assessment of inter-agency resilience to wildfire through transportation plan integration in the greater Yosemite region*, utilizes mixed methods through quantifying resilience indicators across regional transportation planning documents. The region comprises multiple transportation planning and management scales overlayed with complex policies, geographies, and environmental hazards. Combined with high levels of tourism (i.e., vehicles), the region faces substantial urban-level wear and tear in an area whose built environments and economic foundations are primarily rural. Multiple planning scales can contribute to decreased transportation system resilience and, therefore, increased risk of disruption and harm to users due to misalignments in various planning considerations, starting with whether transportation plans recognize a specific hazard – in this case, recurrent, substantial impacts to regional corridors from wildfire. The chapter first uses the Plan Integration Resilience Scorecard (PIRS™) methodology to evaluate the integration and resilience of regionally relevant plans from county through federal scales (Berke et al., 2015).

Evaluated plans do not consistently recognize the severity, impact, and adaptive capacity needed for resilience to environmental hazards in a dynamic, climate change-driven landscape. Plans demonstrate misalignments in science, policy, and recommended action for forward-facing transportation planning and development. Despite recurring update intervals, most plans are rigid and reactive, based on historical criteria leading into a planning window rather than emphasizing forecast conditions. Plans remain static as wildfires and other events associated with the full hazardscape are exacerbated by dynamic conditions. County transportation planners should incorporate collaborative adaptive management approaches to propel transportation development and alleviate challenges related to low population densities but high transient demand. The mid-scale YARTS entity demonstrates collaborative adaptive management efforts through holding quarterly meetings to facilitate engagement and solicit stakeholder input across local to federal scales, scaling financial requirements of member agencies, active solicitation of member agencies aligning with agency goals of providing cross-boundary transportation to and from Yosemite, collecting and incorporating data, and generating guiding plans with shared goals and objectives. Despite ongoing efforts, YARTS remains limited by funding challenges.

Meanwhile, state and federal agencies engage in collaborative adaptive management approaches in acute, project-based instances but are constrained by existing legislation, potential legal challenges, and limited funds, from engaging in larger-scale transportation planning approaches. Two specific concerns emerge from several sub-themes, including budgetary and equity challenges. Low-resilience plans lack definitive language counteracting high confidence in projected conditions, and outsourced plan development lacks critical epistemologies, or ways of knowing, operationalized into planning considerations (Reed et al., 2017). Regional agencies largely do not maintain sufficient personnel or capacity to leverage normative knowledge- knowledge beneficial for institutional transformation generated through shared objectives, contexts, tools and actions, and purposes.

Lack of funding and person-power may lead to outsourcing projects via public Request for Proposals (bidding processes), resulting in the loss of valuable co-produced, localized knowledge (Alexander, 2005; Alexander, 2016). Outsourcing plan development ultimately enables resultant plans to *meet the letter of the law, but not the spirit*. Therefore, the conclusion strongly recommends specific actions by the California Transportation Commission to mandate climate-specific *quantified* considerations for hazard impacts to transportation plans, rather than a checklist approach, for regional transportation plans. Additionally, facilitating increases in funding to county-scale transportation agencies and collaborative entities attempting to fill transportation vacuums to leverage valuable locally generated knowledge within in-house plan development will advance transportation resilience across the region.

Chapter 3, *Decreased air quality shows minimal influence on peak summer attendance at forested Pacific West national parks,* explores the relationships between peak season attendance to national parks in the Pacific West and distill trends in visitation across variations in normalized visitors per unity area (a proxy for popularity) and spatial scales during instances of decreased air quality (PM 2.5). Park visitation peaks parallel to California's fire season – creating conditions where recreators may engage in exertional activities during reduced air quality conditions, as despite active threats, visitors choose to still access the Park (Brown and Jenkins, 2023). Recent developments in recreational and ecological fields have established that reduced air quality does not have a tipping point at which attendance decreases, corresponding to a perceived visitor threshold (Clark et al., 2023).

Given that overall visitation in western National Parks does not demonstrate significant attendance reductions, this chapter specifically explores relevance to public lands management and implications across ecoregions with similar conditions but differentiating contexts such as infrastructure design or geographic variation, which may influence recreational and managerial outcomes. Different Park facilities offer varied recreational opportunities and environmental conditions facilitating exposure as well as diverse built environments in which visitors can gain respite from poor air quality. Results demonstrate no statistically significant fluctuation based on ecoregion, park size (spatial scale), or visitors per unit area (as a proxy for demand). There is the least deviation from mean attendance as air quality categories reduce from Good to Hazardous. Despite dangerous conditions- visitation persists up until the point of park closures.

While National Park management relies on the shared implementation of actions emanating from policy at the foundational level, each park demonstrates independence in operations, contextual challenges, and funding acquisition. Parks continually face challenges with financial constraints and maintenance backlogs due to deferred maintenance practices, but approaches to triaging issues are influenced by factors, including advocacy for supplemental resource appropriations from the federal government, type and location of infrastructure in need of repair or replacement, and staffing reductions despite increased visitation (Walls, 2022).

Parks with comparatively decreased attendance may be disproportionately impacted by high seasonal levels of visitation, whereas more popular parks may more readily absorb challenges associated with high visitation levels during reduced air quality, including, but not limited to, incident response (e.g., respiratory distress) and traffic management due to increased appropriations. Ecoregion context may also influence management, as the way smoke, including PM 2.5 is entrained in topography and through localized weather patterns (Barbuzano, 2019). In Yosemite National Park, reduced air quality tends to be “socked in” to Yosemite Valley in the summer- the most populous destination- and demonstrates diurnal fluctuations providing intervals of relief and coupled with temperature extremes. Meanwhile, Olympic National Park demonstrates consistent- and consistently lower- temperatures throughout the day which may facilitate recreating in equivalently Unhealthy air quality conditions, as temperatures remain comparatively stable.

Results indicate that management should implement attendance limitations, given that persistent visitation levels will likely continue during instances of reduced air quality. For ecological systems - compound stressors (e.g., high foot traffic and reduced air quality) cause exceptionally increased harm to vegetation through compounded stressors and the likelihood of human-wildlife interactions as wildlife are displaced by PM2.5-generating wildfires. Harm is also possible for humans, as reduced visibility negatively impacts safe, effective evacuation. Smaller attendance ranges during instances of reduced air quality may reflect first-time visitors or "out of towners" with mitigating factors driving attendance, whereas those within convenient drive times may choose to temporally displace until conditions improve (Manning and Velliere, 2001; Hansen et al., 2022). Persistent visitation may be attributed to socio-economic factors, including, but not limited to, highly constrained rules for cancellations resulting in "use it or lose it" mentalities, limited vacation time availability constraining when visitors are able to vacation for extended periods, and reception and recognition of public health messaging.

Resulting patterns indicate visitation persists, and moving forward, may not be reduced in relation to increasingly harmful air quality conditions due to wildfire. This will remain a significant public health concern as wildfire conditions and associated outcomes intensify associated with climate change stressors (Abatzoglou et al., 2021). Additionally, and most importantly for human health, people can continue to engage in physically harmful exertion in sub-optimal and dangerous conditions, often unwittingly. As with COVID-19, mitigating steps should be taken to increase educational messaging and reduce exposure to public safety risks by limiting recreation respective to the ecoregion, exposure, and exertion potential.

Chapter 4, *Wildfire-driven entry closures influence visitor displacement and spending to alternative park entrance corridors and gateway communities around Yosemite National Park.* This final chapter addresses the socio-economic concerns of partial closures on Yosemite National Park. As demonstrated recently with the 2017 Detwiler and 2018 Ferguson near mega-fires, Yosemite National Park may remain open even with wildfires burning within proximity to the Park. While the Park has fully closed occasionally, when some, but not all, gates are closed, visitors must determine if they should displace temporally (come back later), displace spatially (go to a different entrance at least one hour away), or disperse into gateway communities. Dispersal would bolster local economies through extended visitor engagement and associated spending, critical for business success for gateway communities economically impacted by environmental hazards, which lose millions in revenue due to recurrent environmental hazards (Gabe, 2016).

This chapter builds on displacement research completed one decade ago, calling for increased dispersal into gateway communities to alleviate congestion and increase ecological and economic sustainability (Gladfelter and Mason, 2013). In partnership with National Geographic's geotourism initiative, the authors summarized how initiatives ultimately may not lead to decreased congestion via dispersal in the long term and that alternative access and transportation options were not feasible. Findings indicate that visitors are still not substantially dispersing into gateway communities, associated with minimal to no grocery or restaurant spending fluctuations. Instead, visitors are still choosing to *spatially* displace to other gates, quantified through increases in gasoline spending. Aside from economic shifts associated with displacing to nearest-available corridors, traffic condenses at increasingly limited ingress and egress routes, creating dangerous emergency response and evacuation conditions. Transportation planners and managers have not fully embraced socio-ecological systems thinking for Yosemite region transportation networks. Supporting and legislating agencies (i.e., the California Transportation Commission) must facilitate increased funding opportunities to improve transportation resilience through reducing poverty traps within planning agencies, financially enabling collaborative adaptive management practices and opportunities for collaboration.

Intentional collaborative adaptive management approach enables escaping from rigidity traps through subjective decision-making based on objective evidence, such as tailoring messaging for promoting dispersal based on hazard conditions, bridges physical and politico-legal boundaries, and promotes regional economic resilience. Agencies across scales should expand upon successful project-scale collaborative adaptive management operationalization and intentionally expand to the landscape scale to improve planning resilience and cohesion, manage the potential harm to visitors, and promote dispersal into gateway communities through increasingly definitive language and pragmatic decision-making in the face of dynamic climate concerns.

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2. Chapter 1: An assessment of inter-agency resilience to wildfire through transportation plan integration in the greater Yosemite region

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Abstract

California wildfires generate and exacerbate physical threats to transportation corridors, often across mosaics of private, local, state, and federal lands. Wildfires directly and indirectly damage infrastructure, affecting transportation infrastructure and access to Yosemite National, neighboring gateway communities, and recreational opportunities. The region incurs high levels of seasonal tourism from late spring through early fall, with visitors navigating traffic congestion in geographically constrained corridors prone to bottlenecks and recurrent closures from environmental hazards. As climate change-exacerbated wildfires become more frequent and severe, transportation infrastructure is exposed to increased damage and disruptions. Therefore, we ask: How do agency transportation plans in the Yosemite National Park region reflect the severity, impact, and adaptive capacity needed for resilience to environmental hazards in a dynamic, climate change-driven landscape? What are the opportunities and challenges of interagency regional collaboration on transportation infrastructure and mobility? This paper utilizes the AREA input criteria to explain how agencies' fundamental planning differences lead to transportation and hazard-based constraints operationalized in the built environment. By quantifying transportation plan-specific inputs within the Plan Integration and Resilience Scorecard framework, we identify transportation plan resilience within the context of wildfire threats and plan integration. We outline barriers and pathways to increasing resilience through inter-agency and regional collaborative adaptive management. Findings indicate key criteria and themes that actively decrease resilience and plan integration across the region which may contribute to inequitable outcomes in preparing for, during, and recovering from wildfire hazards. We discuss the convergence of resilience-based themes in plan content and structure as Restorative Capacity through community engagement, which transportation planning agencies may use to inform plan updates, centering the discussion on successful examples of collaborative efforts in the region. We strongly recommend adopting collaborative approaches to

adaptively managing climate-change-associated environmental threats to transportation systems to facilitate the shift from rigid, historic input-dependent to future-facing, resilient plan construction across multiple management scales. Transportation planning agencies must definitive rhetoric and increase specificity based on high degrees of confidence in projected conditions. Additionally, governing bodies must provide expanded financial support for agencies to incorporate increased substantive and normative knowledge through valuable in-house plan composition.

Keywords: National Park, Climate Change, Transportation Planning, Wildland-Urban Interface, Natural Hazards

2.1 Introduction

Transport to, within, through, and from Yosemite National Park (henceforth referred to as "the Park") is regularly disturbed by climatically induced and exacerbated hazards, such as the July 2018 Ferguson Fire. Over the first days of the fire, routes into and out of the Park were incrementally closed. Ultimately, three of the four primary transportation corridors into the Park were closed- as well as the total evacuation of densely populated and visited Yosemite Valley which generated confusion over which corridors were open and safe for visitors to evacuate. Critical information was digitally siloed across jurisdictional boundaries, representing misalignments in practices, plans, and policies across critical interfaces (YAHR, 2018).

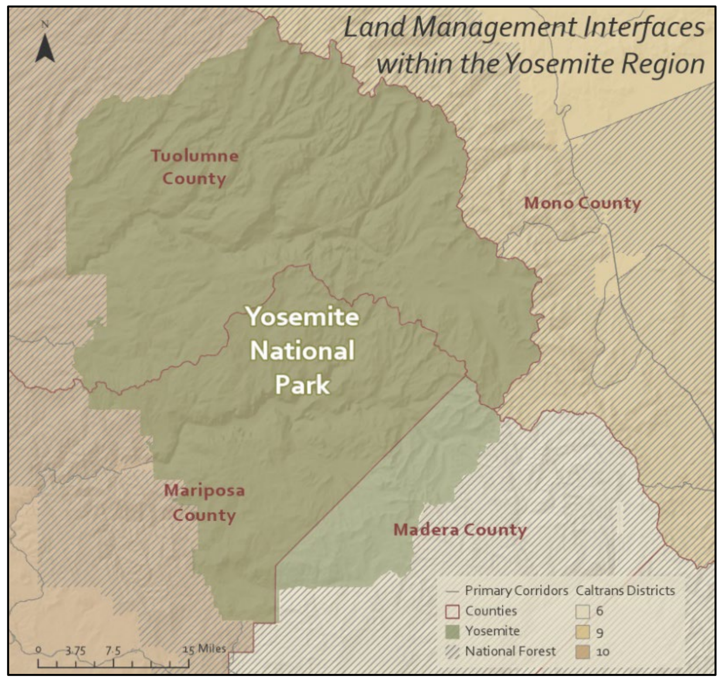

Figure 1- Overview of the multiple interfacing politico-legal boundaries across county through federal scales. Map by authors. Basemap via Esri.

The Park stretches across three counties, abuts a fourth, and two Caltrans Districts abutting a third. It is surrounded by four national forests.In addition to political boundaries, the Park region contains legislation-based boundaries, such as the Wild and Scenic Rivers Act and Merced River Plan, which constrain transportation infrastructure repair and expansion and multiple other considerations (Cathcart-Rake, 2009). Identifying and understanding differences within and across adjoining agencies' management approaches and conterminous legislation is necessary to facilitate safe and effective transportation systems and maintain resiliency in light of increasingly destructive environmental hazards (i.e., wildfire) (Wipulanusat et al., 2021; Oswald Beiler, 2016; Schulz et al., 2017). Figure 1 demonstrates the complex boundaries.

The Park continuously reconciles multiple barriers to physical infrastructure and policy updates due to numerous underlying factors; lack of an effective coalition, damaging framing (of solutions), scientific uncertainty, economic questions, skepticism over access, and substantial visitation demand (Yochim and Lowry, 2016). The greater Park region has multiple coalitions, with a significant portion centered on Yosemite Valley "where each natural feature and view has its own constituency" (Cathcart-Rake, 2009). Transportation networks may lack comparative appeal and influence embedded in charismatic special interests (Rea and Frickel, 2023). National parks co-evolved with car culture, embedding transportation systems as an implicit component encompassed in the Yosemite landscape, unexamined by the public (Youngs et al., 2007; Taff et al., 2013). Though a regional transportation network exists in the greater Yosemite area, network disruptions and frustrations persist for private vehicles and public transit alike. The Yosemite Area Regional Transit System (YARTS), initiated in 1992, provides cross-county public transit access to the Park as a Joint Powers Authority, operating four main routes- corresponding to the four corridors into and out of the Park. The YARTS experiment demonstrated how to address a resource-based challenge through innovative methods incorporating the practice of collaborative adaptive management across an inter-agency, regional scale (Holling, 1978; Lee, 1999; Leong, 2009; Thomson et al., 2009).

Only after operationalizing landscape-scale systems and understandings are science, policy, and public domains aligned to achieve initial success and ongoing resilience in transportation plans (Shafer, 2012; Markolf, 2018). Resilience is a critical, calculable factor for ensuring sustainable outcomes within the greater climate change context. Without realizing the necessary preceding conditions or actions rooted in climatic challenges, counties, coalitions, and public lands managers may not yet be able to yield sustainable and resilient outcomes.

Additional globally popular destinations confront analogous challenges associated with disjunctures in management and complex politico-legal boundaries threatening resilience. The Sequoia-Kings Canyon region demonstrates similar needs to coordinate across agency scales to boost resilience, as ecologically and culturally valuable amenities and features face varying protections and associated anthropogenic impacts directly reflecting multi-jurisdictional context and varying policies from private, tribal, local, state, and federal land managers (Jenkins and Brown, 2019). Like the Yosemite region, the Sequoia-Kings Canyon region experienced intensive historical resource extraction, present day forest structure and fuel loads reflecting former fire suppression policy, and economically dependent gateway communities and transportation corridors repeatedly disrupted by wildfires. The built environment and transportation infrastructure reflect a persistent mis-alignment in science, policy, public, and action (i.e., the co-production of knowledge), resulting in losing shared skills, resources, and the ability to maintain resilience across socio-ecological challenges, including transportation settings (Edler et al., 2022; Plank et al., 2021).

We utilize comparative policy analysis through the Plan Integration Resilience Scorecard (PIRS) methodology with transportation-specific inputs as recommended to the Transportation Research Board of the National Research Council to answer the following: Do agency transportation plans in the Yosemite National Park region reflect the severity, impact, and adaptive capacity needed for resilience to environmental hazards in a dynamic, climate change-driven landscape? What are the opportunities and challenges of regional collaboration on transportation infrastructure and mobility? We quantify divergences in plans across agencies at multiple scales. We first review the region's geographic context to establish the physical and historical foundation for understanding the implications of policy variation in a complex setting. We then discuss our methodological approach to policy analysis, ultimately summarizing and discussing the impact of plan components contributing to the increase or decrease of transportation plan resilience and identifying potential collaboration points and application opportunities through collaborative adaptive management to promote regional transportation resilience.

2.2 Background

Policy and plan research rely heavily on context to identify problems and solutions (Geva-May et al., 2018). Comparing documents across spatially disparate settings poses challenges for interpreting outcomes, as the specific contexts in which plans are operationalized vary (Radin and Weimer, 2018). The analyzed plans within this study and relevant agencies share situational context – a semi-rigid understanding of what composes the greater Yosemite region-generated through complex spatial and temporal factors. Regional geography establishes the biophysical context for analyzing and interpreting plans, while regional historical development contribute to the epistemologies through which plans are analyzed and interpreted.

California's indigenous populations, particularly the Southern Sierra Miwuk established initial corridors and inter-state trade networks (Kleam, 2019). Following European occupation, transportation shifted from regional trade routes to prioritizing to-market corridors with widened roads. Networks expanded as transportation technologies and needs grew, including changes to support mining throughout the mid-1800s. (Weber, 2005; Johnson, 2012). As contemporary economies expanded, developers and early concessionaires propelled disorganized road and infrastructure development until the formal establishment of the National Park Service in 1916, which streamlined operations (Hyde, 1990). Following an initial ban on automobiles in the 1910s, National Park Service management permitted the new mechanism of travel, leading to the improvement of existing corridors, such as Tioga Road (Mono County) and installation of new routes including Mariposa County's Old Highway, the precursor to present day's All Weather Highway - Highway 140 (Quin, 1991).

Civilian Conservation Corps projects in the 1930s improved existing corridors and expanded routes with grading and paving (Jenkins et al., 2019). After World War II, the region experienced continued transportation system changes to accommodate car culture and increased leisure time in American lifestyles. Over time, improved understanding of human activities' ecological impacts further influenced system development, and public participation supported or constrained incremental projects (Johnson, 2012). The Wild and Scenic Rivers Act (WSRA) and subsequent Merced River Plan reflect increased public pressure and legislative action promoting increased ecological understanding and protective measures throughout the 1960s and 1970s (Wild and Scenic Rivers Act, 1968). WSRA legislation protects river segments with scenic, ecological, and recreational value and constrains development within a specific corridor area parallel to key Yosemite region corridors. Transportation infrastructure resilience became increasingly inflexible as engineers based designs on probable conditions and historical data, and spatial and policy constraints reduced opportunities to adapt infrastructure and plans (Buhl and Markolf, 2023; Goytia et al., 2016). Existing resilience within transportation infrastructures and systems is continually undermined as anthropogenic climate change exacerbates environmental hazards' predictability and severity (Chester et al., 2021).

Like the Yosemite region, the full State experienced incremental, regionally driven network expansion through the early 1900s. The amalgamation of piecemeal networks into a greater connected system undermined the need to increase efficient connectivity (Garrett, 2016; Weber, 2005). Localized roads, funded by special taxes or fees on adjacent properties were absorbed over time into increasingly larger networks (Garret, 2016; Warwick, 2014). The historic bottom-up development of California's expansive paved transportation system is in tension with transit agencies' and public land managers' top-down management approaches. Laws and policies that set agency mandates and ultimately lead to management actions demonstrate federal preemption and institutionalization of hierarchical "top-down" management and centralized decision-making structure where mission-oriented and budgetary priorities dictate agency-wide outcomes (Clarke and McCool, 1994).

Landscape-level management approaches begin at a unit's widest extents aligned with ecological considerations and landscape-level management best practices, then approach individual projects at minor scales per guiding agency policy (Shindler, 2000; Gucinski et al., 2004). Analyzing transportation policy across agencies and scales of governance are two critical lenses for interpreting local adaptation to climate change (Vogel and Henstra, 2015; Berke et al., 2015). As transportation managers oversee high volumes of visitation during the busy season, they must contend with existing bottom-up developed transportation corridors while applying top-down best practices for administrative and procedural management and high-level oversight and consideration of landscape-level ecological processes for the continued protection, well-being, and enjoyment of public spaces.

Agencies in the region have recently experienced shifts to their seasonal transportation surges due to COVID-19 restrictions implementation and relaxation over time. In addition to complete closures, the Park implemented a reservation system limiting attendance, thereby decreasing travel through the surrounding corridors and communities. In July 2023, the Park lifted the reservation system, only to experience an extreme bounce back in attendance, leading to extended wait times and affecting visitor experiences (NPS, 2023). With visitors facing ongoing paradigm shifts for visitation, there is low social cost and high opportunity for reorganization into increasingly resilient transportation plans to alleviate transportation and climate change-associated challenges (Pescaroli and Alexander, 2016; Angeler et al., 2016).

2.2.2 Defining Resilience and Collaborative Adaptive Management

Drought intensification, expanding megafires, intensifying precipitation events, and increased extremes are significant concerns for public managers (Crockett and Westerling, 2018; Wang et al., 2017). Infrastructure, especially in California, is increasingly exposed to wildfire impacts due to the proximity of humans and infrastructure to fire-primed locations (Li and Chester, 2023; Modareshi Rad et al., 2023). While improvements in large-scale modeling have generated an improved understanding of long-term climate issues, decreased predictability in acute environmental hazards requires active reflection on an entity's ability to plan for and respond to increasingly damaging systemic disturbances (Fraser et al., 2020). Functional socio-ecological systems, interconnected human and natural processes, and networks must be resilient, adaptable, and transformable (Walker et al., 2004). The socio-emphasis lies in the human (agency) engineered and managed infrastructure systems, with ecologically based natural systems including wildfire. Functional transportation systems absorb shocks and return to operational status while amid active change, have actors actively influencing resilience, and will evolve into a new, transformed state to accommodate declining sustainability in social, ecological, and other conditions. In the decade following the conceptualization of socio-ecological systems, transportation resilience reflected isolated, acute adaptations to specified impacts; currently, interdisciplinary frameworks within socio-ecological systems theory are applicable, though underutilized, to assess climate change’s effects on transportation systems (Hayes et al., 2019).

We define resilience in alignment with socio-ecological frameworks as a system's ability to absorb disturbances without catastrophic change while maintaining relationships between variables (Holling, 1973; Holling, 1996; Walker et al., 2004). Resilient transportation systems contribute to community well-being during system shocks, such as safe, efficient evacuation routes during a wildfire - rather than just maintaining normal function during clear-skies conditions (Mattsson and Jenelius, 2015; Reggiani, 2013; Weilant et al., 2019). We emphasize a system's ability to prepare for internal and externally-caused disturbances in advance, such as increased severity fires associated with persistent drought conditions in the West (Engle, 2011; Mattsson and Jenelius, 2005). For a transportation plan to be resilient, it should utilize definitive language to guide operationalization of a resilient system, which reflects projected conditions (Reed, 2017).

Agency managers are the primary driver of a system's interactions, functions, and adaptive capacity and may mitigate negative impacts and losses through compartmentalization or confinement of impacts (Walker et al., 2004). Larger agencies may be able to minimize hazard impacts as the agencies occupy larger physical space compared to smaller agencies, where the same issue may occupy a more significant proportion of the area and agency resources. Despite the ability to build resilience into transportation networks, planning, and policy remain overwhelmingly reactive approaches by transit agencies to combat climate change effects due to several factors (Miao et al., 2018). Factors contributing to reactivity rather than proactive considerations include limited set-aside funds for weather emergencies, lack of investment in improved technologies and equipment, appropriate cost estimation for emergency response, and maintaining pre-existing infrastructure in high risk areas. In some instances, agencies cannot afford to be proactive due to budgetary constraints influencing number of available personnel and associated capacity (Zhang and Maroulis, 2021). Beyond funding capacity, reactivity is also an artifact of traditional operational (hands-on, during event) approaches to emergency response and management, and agencies have not been able to translate goals into actionable plans (Miao et al., 2018; Wang et al., 2020).

Wildfires compromise the Park's ability to meet internal mandates to promptly restore functional conditions when compounded with other challenges, such as budgetary constraints (National Park Service, 2010; Biber and Esposito, 2016). Therefore, short-duration and high-impact emergency response projects operate as triage to maintain system functionality, such as rapidly restoring single route functionality following rockslides to restore full systemic function (Jenkins, 2022; Millar et al., 2007). Climatically induced or exacerbated environmental hazards, such as wildfires, require multiple scales of temporal, spatial, and socio-economic consideration to maintain transportation system resilience and reduce vulnerability (Wang, 2015). Interdisciplinary and collaborative approaches are required to define and apply vulnerability and resiliency concepts across transportation systems (Mattsson and Jenelius, 2015; Hickford et al., 2018). To succeed in addressing overarching or large-scale challenges, individual agencies must leverage intra-agency collaboration, which can be operationalized as quantifiable performance metrics reflecting internal goals (Choi and Moynihan, 2019). Goals related to resilience-demanding challenges such as wildfire demand inter-agency collaboration and cooperation.

Adaptive management originated in the 1970s as an approach to actively exercise incremental evidence-based changes over time (Holling, 1973). Recognizing ongoing institutional reactivity across multiple natural-resource-based management frameworks around the turn of the century, scholars encouraged novel approaches for agencies to shift paradigms towards more collaborative approaches (Walters, 1997, Ascher, 2001, Schreiber et al., 2004).

Adaptive management expanded into the theory and practice of collaborative adaptive management to address complex landscape-scale problems through incremental learning within the implementing institution and relevant collaborative agencies (Thomson, 2007; Leong, 2009; Scarlett, 2013). Localized, short term success may be possible for transportation planning, but eventually be negatively impacted by systemic challenges over extended temporal scales. In order to be effective, smaller scale institutions must be connected to larger institutions through flexible, adaptable, and resilient means (Beratan and Karl, 2012).

While natural resource management has traditionally employed collaborative adaptive management, existing transportation policy and planning structures exhibit analogous uncertainty, complexity, and change- facets of a system beneficial to collaborative adaptive management practices (Scarlett, 2013). Physical transportation infrastructure, transportation planning, policy, and utilization are reflective of other network-based systems undergoing adaptive management in similar complex situations. California's Bay Delta and its linear canal system move a limited common pool resource (water, or in our case, transportation corridors) with a specific mission, directionality, fluctuating demand, complex legal and political scenarios, and multiple scales of governance across misaligned socio-ecological boundaries with bottom-up historical development and present-day top-down controlling factors. (Kallis et al., 2009).

2.2.3 Transportation Plan Creation and Oversight

In California, the development of local level policies is largely constrained by higher-level planning and policy direction (Garrett, 2016). For instance, the Federal Government requires long-term transportation plans with rolling short-term updates known as Regional Transportation Plans (RTPs). The California Transportation Commission updates planning guidelines (CTC, 2023). The main objective of these plans is to guide long-term planning and funding decisions over a period of 20 years, and they are used as a reference point for subsequent planning at smaller spatial and temporal scales (Handy, 2008). The plans, in essence, are collaborative. Community stakeholder engagement ensures oversight for stakeholders within the region of interest (i.e., county lines), utilizing a "horse race" style of mis-applied adaptive management, where stakeholders vote on several options for incremental plan updates (Allen et al., 2010). Ultimately, local plans are developed with a lack of *lateral* connectivity to other regional plans due to challenges including, but not limited to, differences across consulting agencies' epistemologies, variations in staffing capacity and skill sets, and comprehensive, equitable inclusion of disparate stakeholder communities (Karner, 2016; Sciara, 2017).

Transportation agencies throughout the State face financial challenges resulting from funding structures originating from policy crafted for California's first highways over a century ago (Garrett, 2016). RTPs are completed at the county level through Regional Transportation Planning Agencies (RTPAs) for rural communities and Metropolitan Planning Organizations (MPOs). Climate change amplifies social inequities; many rural counties lack sufficient funding, limiting further plan development and implementation, despite the well-understood benefits of proactively planning to reduce environmental hazard vulnerability and therefore reducing costlier damages (Chirisa et al., 2023). Forgoing proactive planning and hazard consideration exposes agencies to substantially greater costs (Twumasi-Boakye and Sobanjo, 2018). The Park region spans a rural area, including an entire county with no permanent stoplights, while enduring urban-level wear and tear as millions of visitors navigate limited corridors into the National Park. The region is composed of three RTPAs and one MPO, which feature varying state-mandated requirements for RTPs along with state (Caltrans) and Federal (National Park Service) transportation agencies. The Yosemite Area Regional Transit System (YARTS) operates across the entire region of interest, utilizing existing local through federal scale infrastructure.

Initial stakeholders formulated the plan for YARTS in 1992 around challenges with significant visitation, parking issues, and corresponding gate closures to mitigate congestion issues. In 1997, catastrophic flooding led to the removal of existing transportation infrastructure and established the need for designing and building more resilient Valley infrastructure (Weinstein Nelson and Tumlin, 2000). As many public transit agencies experience, its solvency depends on the financial contributions of individual member agencies, stakeholders, and inconsistent appropriations from the federal government (Wasserman and Gahbauer, 2023). Over 30 years later, transportation agencies and plans in the region still grapple with funding shortfalls, demand challenges, and environmental hazards, though now at increased magnitudes.

2.3 Methods

2.3.1 Comparative Policy Analysis

We analyzed, quantified, and interpreted relevant transportation plans and analogous documents using context-sensitive comparative policy analysis approaches (Geva-May et al., 2018; Radin and Weimer, 2018). The PIRS framework was leveraged using transportation plan-specific Absorptive Capacity, Restorative Capacity, Equitable Access, and Adaptive Capacity (AREA) inputs (Weilant, 2019). Comparative policy analysis enables identifying variations in policy in space and time, which allows the identification of divergences and convergences across policies belonging to various agencies (Cyr and De Leon, 1975). Multiple studies utilize PIRS within hydrological contexts, utilizing PIRS to analyze access to critical facilities following coastal and inland flooding events (Berke, 2015; Berke et al., 2019; Kim and Marcouiller, 2020). Other studies utilize or adapt the PIRS approach for master plans (Norton et al., 2019; Horney et al., 2020; Newman et al., 2020). The PIRS framework has been used to assess the interconnected effects of environmental hazards such as floods, landslides, and earthquakes (Arvin et al., 2023), but to our knowledge it has not previously been used to assess the resilience of transportation plans concerning fire specifically. Therefore, we capture transportation and wildfire-specific input criteria from the

AREA assessment as inputs into the PIRS framework. The PIRS framework was designed to accomplish two main goals: assessing how networks of plans integrate to reduce vulnerability (increase resilience) and enabling comparisons across plans and their exposure to specific hazards (Berke et al., 2015).
We explore inputs into systems of local plans specifically through a resiliency lens using Absorptive Capacity, Restorative Capacity, Equitable Access, and Adaptive Capacity (AREA) inputs for resilience (Weilant et al., 2019).

Absorptive Capacity criteria are indicators of plan ability to "soften the blow" of environmental hazards by inclusion and reflection across plans and the ability to maintain normal function despite shocks to the system. Restorative Capacity is a system's ability to quickly return to normal function following a system shock or stress. Equitable Access considerations mitigate adverse effects on vulnerable populations through providing access across communities during system shocks. Adaptive Capacity refers to a system's ability to change due to shocks or stresses while maintaining functionality (Weilant, 2019). The AREA criteria align with recognizing transportation infrastructure and management as a socio-ecological system, quantifiably embedding dynamic components associated with environmental hazards, and considering social, technical, economic, and ecological concerns (Markolf et al., 2018; Hayes et al., 2019).

2.3.2 Three Phase PIRS Approach

To prepare geospatial data incorporated into the PIRS approach, all utilized data from external sources, as well as internally digitized data, were projected into California State Plan Zone III (SPCS 0403). Alternatives included UTM Zone 11, which bisects the region of interest, and California Teale Albers, which is at a larger spatial extent than SPCS 0403 and would include increased distortion.

Phase 1: Intersect Planning Districts with Hazard Areas

Intersecting districts with regional hazards (in this instance, county through federal scales) identifies risk- the likelihood that something will happen in a specific area- across agency plans. We incorporate the county level as the smallest policy scale for effectively analyzing local plan networks. The United States Forest Service provides nationwide authoritative, cross-jurisdictional coverage of hazard zone equivalents through its publicly available Wildfire Risk to Communities Datasets.

We incorporate the geospatial subset- Wildfire Hazard Potential (2020) for a high-level overview of categorical risk for wildfire hazards across the region of interest- Water, Non-Burnable, Very Low, Low, Moderate, High, Very High. This dataset is comprised of likelihood and intensity to understand the risk of a fire that would be *difficult to suppress* (i.e., manage safely), thereby needing increased fuels management and is intended for long-term planning (Dillon and Gilbertson-Day, 2015; USFS, 2023). Figure 2 demonstrates risk across the full region of interest. We then isolated Moderate, High, and Very High risk levels in the region of interest. Similar datasets exist, such as California's Fire Hazard Severity Zones(FHSZ), but do not provide coverage across federal lands (i.e., Yosemite National Park). We first vectorized the Wildfire Hazard Potential dataset to hazard zone percent coverages for the agencies of interest.

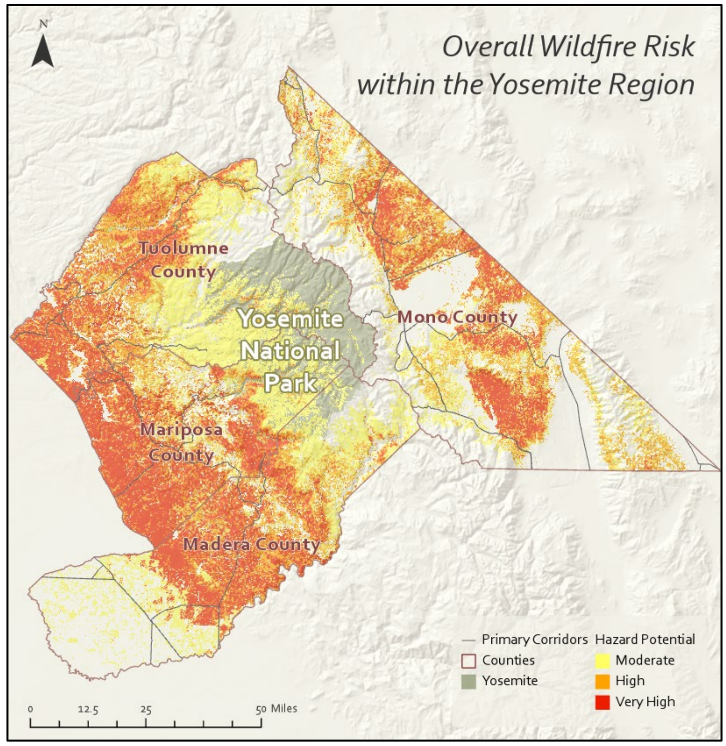

Figure 2- Highest wildfire risk runs parallel to the Sierra Nevada foothills, and reflects changes in geology, fuel load, and fuel type along the crest of the Sierra Nevada Mountain range, before dropping down into Mono County in the east. Map by authors. Basemap via Esri.

Phase 2: Determine Vulnerability

For identifying both physical and social vulnerabilities in the greater Yosemite region- to whom and what the risks apply- we incorporate Caltrans Wildfire Vulnerability Analysis geospatial dataset (Boynton et al., 2021). The dataset is best available to understand physical, as well as social, vulnerability to wildfire. The analysis generating this dataset was updated in 2020 in collaboration with UC Davis and incorporates essential input data beyond Caltrans' specific corridors to include traffic counts, lifeline routes, census data (in alignment with assessed values in Table 2), timber loads, and additional criteria. Notably, there are two data gaps of approximately 25 miles. Therefore, we considered additional relevant datasets, including the California Public Utilities Commission (CPUC) Utilities Risk and the USFS's Wildfire Risk to Potential Structures, ultimately confirming the Caltrans Wildfire Vulnerability Analysis as the best fit due to incorporated criteria, scale, and specificity.

Phase 3: Evaluate Network of Plans

A list of transportation agencies and government entities with a specific transportation component was identified through web searches, referencing geospatial layers of local, state, and federal land managers and supplemented through pre-existing regional familiarity. Agencies were selected, ranging from the federal to the county level, based on containment of, or contiguity to, Yosemite National Park. The county level was carefully chosen as the smallest common spatial denominator. There is no smaller uniform spatial scale across the region of interest with formalized transportation policy. Of the four counties containing or contiguous to the Park, one county has zero incorporated communities (Mariposa County), and two others have only one incorporated community (Mono County and Tuolumne County). Madera County has two incorporated communities.

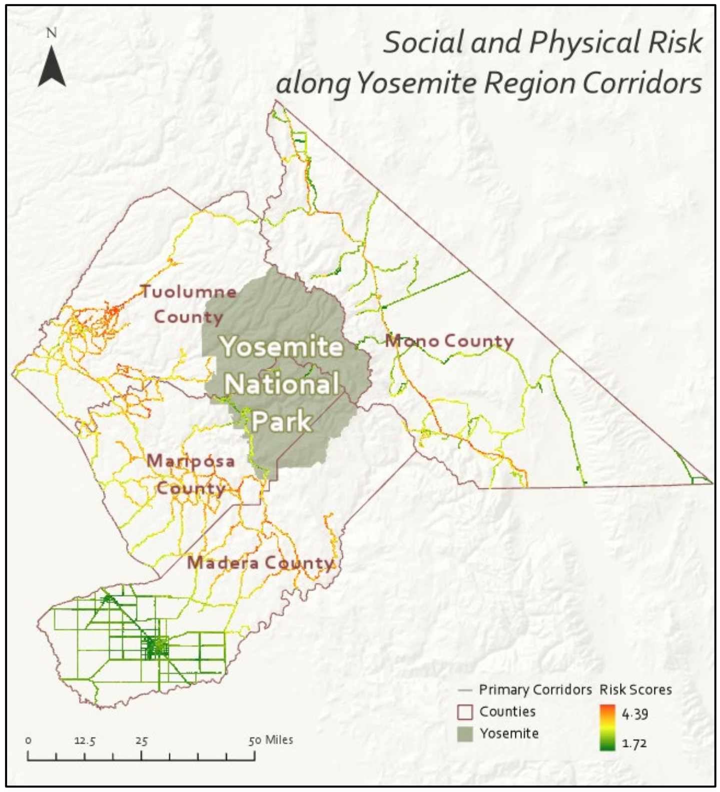

Figure 3- Combined social and physical risk to transportation corridors in the region of interest, generated by UC Davis in collaboration with Caltrans. Map by authors. Basemap via Esri.

Agencies publish and update transportation plans at varying temporal increments. The most recent policies were selected as of September 2020, resulting in a policy pool ranging from 1980 to 2019, listed in Table 1. The authors communicated with The Me-Wuk Tribe via email. There is currently no public-facing transportation plan to incorporate into this study. Public comments and supplemental documentation were analyzed on a case-by-case basis to maintain streamlined analysis and prevent external biases.

Table 1- List of plans from largest to smallest agency scales utilized in the study and their accompanying longevity information. Plan ages range from over 40

years old to just a few years. Some plans are routinely updated at a designated interval, while others persist with no designated end date.

Table 1- Transportation plans and plan longevity included in this analysis, as collected from public sources.

Agency	Plan	Year	Longevity (years)	Update (years)
Yosemite National Park	General Management Plan	1980	10	n/a
	Yosemite Valley Plan	2000	15-20	n/a
California Dept of Transportation	State Highway System Management Plan	2019	10	2
Yosemite Area Regional Transit System	Short Range Transportation Plan	2018	5	n/a
County	Madera County RTP	2018	20	4
	Mariposa County RTP	2017	25	5
	Tuolumne County RTP	2016	25	0-10
	Mono County RTP	2019	20	4

To conceptualize and implement metrics for quantification, we utilized both sample criteria from guiding AREA documentation and context and hazard-specific considerations. As this approach is fully scalable and has no maximum amount of inputs, we limited our analyses to 5-10 criteria per AREA input theme to maintain a reasonable project scope, duration, and comprehension. We completed a critical reading of each document, then identified occurrences (or lack thereof) of specified criteria utilizing keywords and synonyms. In alignment with the PIRS approach, we use a -1, 0, and +1 scoring system to identify plan components that increase or reduce vulnerability. Each AREA-adapted input was evaluated within Table 2 as present (reduces vulnerability, +1) or absent (increases vulnerability, -1). In some instances, criteria were addressed, but with unclear or irrelevant context, but still demonstrate the capacity for future incorporation. For example, a document's Electricity Infrastructure Absorptive Capacity may address electric infrastructure concerning vehicle *charging* potential but not electric infrastructure within the context of the total transportation network. Including charging potential demonstrates consideration for a topic markedly different from complete omission (-1).

Specific criteria were obtained from, or calculated through, external sources. For example, when considering Equitable Access, we utilized Headwaters Economics data to generate a quantifiable, normalized metric for all plans for equity considerations. Demographic data are readily available and consistent based on the location of residence (i.e., counties) through sources such as Headwaters Economics, while Park attendance and public transportation ridership do not track the same data across consistent, comparable metrics. Future work may expand upon preliminary demographic datasets through surveys specific to input criteria, such as vehicle ownership. Numeric (ratio with "true zero") data, such as road centerline miles normalized per unit area, are assigned as reducing or increasing vulnerability within the specific context of fire as a hazard. Centerline miles per unit are utilized as a proxy for challenges with evacuation planning and evacuations.

Multiple factors influence what constitutes safe and effective evacuation, including, but not limited to, the ability to change flow direction, urban versus rural, road layout, road condition, grade (steepness), demand (people), and lane counts. We ultimately used a threshold of 2 miles per square mile, as length per unit area is an established connectivity measure (Dill, 2004; Handy, 1996). Values for thresholds in published literature were consistently site-specific but reflected values near 2 for low, rural street densities (Matley, 2000). The threshold ultimately aligned with natural breaks in the data and is slightly more conservative than the national road density average (1.7). Multiple contexts exist with varying thresholds for centerline miles per square mile, including impacts on riparian area functionality and effects on wildlife (NOAA, 1996).

Table 2- There were 30 metrics associated with AREA inputs incorporated into the PIRS analysis.

AREA Criteria	Category	Metric
Absorptive Capacity *Present (+1)* *Absent (-1)* *Incorrect Context (0)*	Exposure Metrics	High Value Destination: Hospitals
		High Value Destination: Refuse Disposal
		High Value Destination: Schools
		Recognized Hazard(s): Fire
		Electricity Infrastructure
		Recurrent Maintenance
		Routine Inspections
		Transportation Workforce Training
Restorative Capacity *Present (+1)* *Absent (-1)* *Incorrect Context (0)*	Response Resources	Response Budget
		Equipment Counts
		Equipment Status or Storage
		Interagency Partnerships
		Worker counts
	Community Planning Efforts	Non-govt Disaster or Risk Reduction Planning
		Community Organization Meetings
		Organization Meeting Attendance
		Multiple Engagement Modes
		Defined Disaster Roles
Adaptive Capacity *Present (+1)* *Absent (-1)* *Incorrect Context (0)*	Network expansion and improvement	Transportation Funding
		Document Longevity
		Document Update
		Current Motorized Facility Miles

		Planned Motorized Facility Miles
Equitable Access *Above National Average (+1)* *Below National Average (-1)* *Within 1% National Average (0)*	Underserved Populations (%)	Households Without a Car
		Under 18 Years
		Over 65 Years
		Individuals Below Poverty
	Communication Capabilities (%)	Those Who Speak English "very well"
		Disabilities
		Population Without Internet Access

2.4 Results and Discussion

Composite scores for plan resilience across the criteria of Absorptive Capacity, Restorative Capacity, Equitable Access, and Adaptive Capacity are detailed below in Table 3. The full scoring sheet is available in Appendix A. Overall, plan contents demonstrate light resilience to wildfire impacts on transportation plans when averaged across all metrics. Despite overall positive results, there are substantial variations across AREA input criteria and plan integration.

Table 3- Output PIRS scores for identifying resilience as a function of AREA input criteria. Full values available in published data repository.

			AREA Input Criteria [-30 to 30 range]				
Agency	**Plan**	**Year and Update Period [Years]**	**Absorptive Capacity**	**Restorative Capacity**	**Equitable Access**	**Adaptive Capacity**	**Total Plan AREA Score**
Madera	RTP	2018 [4]	-1	+4	0	+3	+6
Mariposa	RTP	2017 [5]	+1	+6	-4	+1	+4
Tuolumne	RTP	2016 [0-10]	+3	+6	0	+1	+10
Mono	RTP	2019 [4]	+6	+10	+3	+1	+20
YARTS	Short Range Transit Plan	2018 [na]	+6	+6	-1	-1	+10
CALTRANS	State Highway System Management Plan	2019 [2]	+2	+2	+4	+3	+11
	Valley Plan	2000 [na]	+6	+6	+3	+3	+18

Yosemite National Park	General Manageme nt Plan	1980 [na]	+1	-6	-2	-1	-3
Average Criteria Score – All Plans			*3.125/8*	*4.25/10*	*1.25/5*	*0.875/7*	*9.5/30*

First, we do not see substantial inconsistencies across all plans that may imply plan integration reflects agency spatial or politico-legal scales specifically. Instead, the most geographically isolated (Mono) and the most geographically integrated (YARTS) are the plans with the highest integration. YARTS' Strategic Management Plan must consider multiple geographic landscapes and social contexts while crisscrossing policy and physical thresholds across the greater Yosemite region. Both YARTS and Mono County must overcome the limitations of seasonal closures impacting access to Yosemite National Park. Operating within the most comparable spatial and policy contexts, the Yosemite Valley Plan (2000) and the Yosemite General Management Plan (1980) demonstrate a broad difference in Restorative Capacity regarding temporal scales. Compared to RTPs, both Park documents are old. Both documents demonstrate normative conditions for transportation-related plans, where drafting is designed to accommodate long-term scenarios assuming inputs based on past operating conditions, technology, and weather conditions (Chester et al., 2021). Their respective scores of 6 and -6 in Restorative Capacity demonstrate that temporal scale, as a function of recurrent updates, may not be as critical as where a plan falls respective to agency, scientific, and technological updates, particularly regarding public engagement and engagement across multiple media (i.e., email, web platforms, etc.).

Major paradigm shifts in the management of public lands occurred in the 20 years between the implementation of the General Management Plan and the Valley Plan. Specific internal and external events contributing to paradigm shifts around plan development include high levels of human-bear and vehicle strike interactions in the 1980s through the late 1990s, programmatic gate closures to manage congestion (early 1990s), the 1990 A Rock Fire which led to the first full-park closure, the 1995-1996 federal government shutdowns, the 1997 megaflood, experimental concessionaire contracts resulting in the Concessions Policy Act of 1998 (Ansson, 1999; Jenkins, 2022; Townes et al., 2000; Weinstein Nelson and Tumlin, 2000). In particular, the resultant H.R.3019 - Omnibus Consolidated Rescissions and Appropriations Act of 1996 enabled the federal government to provide supplemental non-specific appropriations to National Park Service units and appropriations within the specific context of environmental hazards (Omnibus Act, 1996).

These resilience-defining metrics and supplemental contextual considerations demonstrate that the region may benefit from expanding and formalizing collaborative adaptive management across new scales to increase resilience to wildfire disturbances outside of stationary politico-legal boundaries. Leveraging static county boundaries to mandate future-facing transportation plans severely limits collaborative opportunities reflective of actual transportation functionality across the region. None of the four counties in the region have had boundary changes since the late 1890s (CSAC, 2023). Yosemite National Park most recently experienced boundary downsizing in 1906, then underwent external boundary additions in the 1930s through 1949 (Golden Kroner et al., 2016; Qin et al., 2019). In the three-quarters of a century since, construction design best practices, engineering principles, ecological understandings, systems thinking, agency policy, and the greater climatic context have all evolved, while boundaries have remained stationary.

Mono County demonstrates the strongest plan integration and AREA-based transportation plan resilience to wildfire, totaling 20 criteria that contribute positively to increased resilience, while at the opposite end, Yosemite National Park's General Management plan demonstrates decreased resilience totaling -3. Ultimately, based on this preliminary study, temporal and agency scales do not immediately reflect plan integration and resilience. While no two documents are identical in structure or content, several themes contributing to, or reducing transportation resiliency, emerge within and across plans- ecological, social, and technological thresholds. Critical initial themes emerging from the plan integration and resilience analysis include the bifurcation of AREA criteria into two groups: Resilience in Restorative Capacity and comparative non-resilience in Adaptive Capacity, Equitable Access, and Adaptive Capacity.

Despite the ability to engage in communication (contributing Restorative Capacity) with populations, Equitable Access for the same communities remains low due to high populations of youth, impoverished individuals, and disabled individuals highlights potential populations disproportionately impacted by wildfire risk, transportation challenges, and climate change overall (Kosanic, et al., 2022; Levine and Karner, 2023; Sanson et al., 2019; Stein and Stein, 2022). Mariposa County, for example, identifies the need to "*address the long-term expansion of transit operating revenues*" in response to "*additional demand will be placed on fixed route transit and paratransit services"* due to an anticipated 30% increase in population over 65, including a near doubling of population age 75 and older (pg. 20).

Restorative Capacity facilitates returning to pre-event conditions and is composed of community-engagement and integration metrics and designated funds and roles for emergency conditions. Overall improvements to underfunded transportation networks in the region are regularly augmented by emergency-designated funding for longstanding, pre-existing, improvement needs (Jenkins et al., 2021). All reviewed plans include discussion of interagency partnerships, and most plans include coverage of specific disaster-defined roles, and multiple modes of engagement with the public. This demonstrates capacity for collaborative adaptive management through existing interagency contacts and established lines of communication.

The Absorptive Capacity metrics demonstrate increased susceptibility to wildfire impacts associated with budgetary shortfalls, lack of addressed longitudinal inspections and training, and specific wildfire hazard recognition.

Overall, plan integration metrics demonstrate consideration of wildfire (6 of 8 documents), but shortcomings emerge in how and how often threats are addressed within plan documentation. Madera County's low Adaptive Capacity for transportation resilience to wildfire is (-1/8) includes lack of discussion of routine inspections or workforce training. Most notably, Madera County's RTP includes *zero* mentions of wildfire at all, despite Highway 41 and 49 in Madera being designated as Regionally Significant Road Systems for their connectivity to Yosemite National Park. These corridors and associated communities have been repeatedly impacted throughout history, with substantial damage and corridor disruption, including extended closures in recent years with the 2017 Railroad Fire. While other plans do include mention of wildfire, their contexts and depth of inclusion vary. This stretch of the corridor into Yosemite National Park has been repeatedly impacted by substantial and extended closures, such as with the Railroad Fire in 2017, which led to closures over ten days, preventing visitors from accessing Yosemite through the South gate (Jenkins and Brown, 2023).

Mariposa County, which also scores low in Adaptive Capacity, briefly mentions wildfire impacts to transportation through exceptionally vague statements within the context of climate change adaptation:

"…The fire season in California has begun earlier and ended later in recent years. Intensity of fires has also been increasing. In addition to direct damage to transportation infrastructure, fire may create indirect damage when burned slopes become susceptible to landslides during storm events following fires. The Ferguson Fire in 2018, the Detweiler Fire in 2017, the Rim Fire in 2013, and landslides closing SR 140 and other roads are examples of such events. Evacuation routes may need to be considered in future road planning and demands on transportation related firefighting infrastructure are likely to increase." (pg. 28)

These statements using modal rhetoric ("may") minimize the actualized severity of impacts to transportation networks by mentioned events as well as forecast increasing severity and damage associated with evolving wildfire and climate conditions.

Mono County demonstrates the highest scores for (6/8) Absorptive Capacity discusses wildfire comprehensively and definitively across multiple transportation-influencing themes including air quality (visibility), firefighting aircraft, high wildfire risk, collaboration with CalFire for emergency access to private property, and utilizing geospatial technologies to support "route awareness" for wildfire and other emergency response. Additionally, they specifically call out external emergency response plans as *"links in the chain connecting the detailed standard operating procedures (SOPs) of local public safety agencies to broader state and federal disaster plans"* (pg. 54) demonstrating capacity for collaborative adaptive management, and recognizing the need for connection with higher level agencies for meaningful change (Beratan and Karl, 2012). Additionally, they specifically recognize transportation corridor disruptions due to wildfire and encourage interagency collaboration with named entities: Caltrans, the USFS, the BLM, the CDFW, the LTC, the County, and the Town of Mammoth Lakes (p. 72).

Best summarized by the Mariposa County RTP – "*Governmental action in preparation for or response to climate change may also directly influence transportation planning. Metropolitan Planning Organizations are already required to develop Sustainable Community Strategies with their Regional Transportation Plans. Though RTPAs such as (Mariposa County Local Transportation Commission) MCLCTC are not currently required to develop such strategies, other requirements may be placed on RTPAs in the future"* (pg. 37). As the State legislature dictates content, we strongly recommend the California Transportation Commission incorporate more specific criteria centered on mitigating environmental hazards impacting transportation planning within RTPs, as hazards will continue to impact transportation corridors with increased resulting damages and disruptions. The lack of discussion of wildfire specific considerations decreases resilience by not considering high-confidence projected conditions (Reed, 2017.)

Of critical import is the factor of Mono County and Madera County's Regional Transportation Plans, along with Caltrans' State Highway System Management Plan and Yosemite General Management and Yosemite Valley Plans were composed in-house. All but one of these five plans (Yosemite's General Plan) demonstrate increased overall resilience and plan integration. Mariposa County and Madera County plans were contracted out through bidding processes to external transportation engineering firms and have substantially lower plan integration and resilience scores, which may reflect the benefit of localized epistemologies, or how knowledge is constructed, influencing plan construction and content. Contracted firms include one out of Visalia, CA and Fresno, CA, both situated within California's Great Central Valley, which may limit normative knowledge, such as shared values with stakeholder grounds, the ability to identify needs based on personal knowledge and shared experiences, and substantive knowledge- empirical, descriptive knowledge- akin to context including local norms, familiarity with demographics, and lifestyles (Alexander, 2005). Outsourcing enables resultant plans to "meet the letter of the law, but not the spirit." Limited normative and substantive knowledge detract from one of the two linked components of planning- knowledge and planning. Relevant situational knowledge is omitted despite actions being successfully undertaken (Alexander, 2016; Friedman, 1987).

Regional Transportation Plans, which reflect county boundaries as contextual limits, may contribute to oversight politico-ecological considerations that extend beyond county-centric perspectives. While Yosemite is a significant economic driver in Mariposa, Mono, and Tuolumne counties, Madera County's main economic driver is agriculture and freight in the lower elevations, driving inherent policy and subsequent planning bias. Madera, Mono, and Tuolumne operate under RTPA criteria, while Madera operates under MPO criteria. The MPO bifurcates Madera County's transportation goals, generating a rural-urban divide through required urban policy considerations. Higher elevation communities, including Oakhurst and Sugar Pine- which *are* economically dependent on Yosemite, are largely omitted from RPT discussions, including the impacts of environmental hazards on transportation corridors.

Transportation planning agencies and overarching policy must transition document development and guidance from recognizing current, complicated dynamics to accommodate systemic complexities (Chester et al., 2021). YARTS comprehensively demonstrates integrated systems thinking, as integration is built into foundational agency policy, and systems thinking is required for complex multi-county routing while maintaining compliant ridership needs and overall management (Weinstein Nelson and Tumlin, 2000). The high variation in integration scores for remaining plans demonstrates the outstanding potential to shift to systems thinking – though the politico-legal plans terminate at county lines, climatic, social, and ecological influences do not. While this partially reflects state RTP requirements, multiple opportunities exist to expand into more systems-based thinking and design. Expanding beyond considering localized networks into systems thinking is an essential paradigm shift for resilience respective to anthropogenic climate hazards, such as wildfire (Markolf et al., 2018).

While YARTS demonstrates successes of collaborative adaptive management along with some of the highest levels of resilience and integration in planning, it's critical to note that, like the rural counties included in the study, they too face significant funding challenges, though for operational and less so infrastructural maintenance. Across all agency scales, Caltrans recognizes in its State Highway System Management Plan (2019) that asset deterioration is "accelerating at a faster rate than in previous decades" due to age and traffic demands, notably excluding any connection of degradation to anthropogenic climate change and associated environmental hazards. Researchers have called "for reimaging the relationship between socio-ecological systems and fire," reflecting the co-evolution of systems, which can and should include cross-scale transportation systems (Modareshi Rad et al., 2023).

Outsourced plan development or internal oversights due to the subjective nature of community engagement and plan development may overlook additional contextual criteria- who can be engaged depends on who has the temporal and financial capacity to be involved (Flavin, 2012; Weber, 2020). Though beyond the scope of this paper, we recognize the strong contextual influence that politics across scales influences the co-production of knowledge and, thereby, policy and plan development at local through federal levels (Dilsaver and Wyckoff, 2005; Bryson et al., 2018; Maas et al., 2022).

Specific criteria may seem negligible or have unclear connectivity until explored through contextual connections. The High Value Destination: Refuse Disposal input criteria demonstrated significant oversight in including waste management considerations in transportation planning. Mariposa and Mono Counties do not office consolidated public waste services. Mono County does recognize waste management in its RTP, but Mariposa does not. Following disruptive events such as fires and power outages, such as extended PSPS (already disproportionately impacting disadvantaged communities), substantial proportions of residents must self-transport waste to few and far between County dump facilities, impacting transportation networks, where responders may still be engaging in "mop-up," and residents re-entering communities.

A short stretch of Highway 140 skirting the Ferguson Ridge, is ultimately a microcosm of the multiple facets required for systems thinking, developing transportation resilience through inter-agency planning approaches and formalized collaborative adaptive management. A small slide disrupted the corridor in 1999, followed by a massive slide in 2006. Temporary bridges built in 2006 were replaced in 2008 to accommodate larger vehicles, as the turn radius on the initial bridges ultimately limited economic benefits to the corridor. Due to constraints associated with the Endangered Species Act, state legislators passed a law permitting the relocation of sensitive species to facilitate environmentally considerate corridor reconstruction. The installation of a rock shed (essentially an open-air tunnel allowing active earth movement over the top) at the rockslide demonstrates a novel collaboration between Caltrans and a private partner in the State's first Construction Manager General Contractor project which engages construction companies earlier in project design processes. Mariposa County regularly moves the soil from the Ferguson Rockslide construction zone to the County landfill to alternate layers between refuse and fill, saving the County nearly one million dollars (Mariposa County Grand Jury, 2015).

Despite progressive approaches to collaboratively managing infrastructure design and construction, historic development’s path dependency threatens transportation system efficacy during wildfires and wildfire conditions. Two timed stoplights at either end of the construction zones condense contributing factors for catastrophic wildfire- anthropogenic ignition sources, limited lanes, dry fuels, and steep terrain during periods of reduced relative humidity and down-canyon winds (summer), all in the presence of extended wait times and idling traffic (i.e., gridlock) at the stoplights during peak travel hours- all combining for deadly burnover conditions (Soga et al., 2021; Link and Maranghides, 2022).

Solutions specific to these plan integration and resilience concerns may result from reimagining and leveraging existing relationships across agencies to de-silo knowledge and expand social learning capacities (Berkes, 2009). The Covid-19 pandemic generated reductions in traffic volumes by up to 65%, immediately followed by substantial increases to "normal" levels once returned to pre-Covid practices. (Chester et al., 2021). This boomerang effect has resulted in significant frustrations for transportation users through private and public transit. Those in personal vehicles are frustrated by traffic, and public transit users are frustrated with the speed at which transit systems return to full operation. These frustrations are in full effect in the Yosemite region, where Yosemite National Park is implementing a visitor study as of Summer 2023 (NPS, 2023).

The closure of a single corridor within this network demonstrates required systems thinking beyond just moving people from source (point of origin) to sink (Yosemite), with surrounding economies fluctuating reflective of corridor closures as visitors choose to spatially displace to open corridors in other counties (Brown and Jenkins, 2023). This study alone includes seven agencies, commuters, recreational users, multiple interest groups, and legislative filters through which the transportation system is managed, utilized, and ultimately degraded. A collaborative adaptive management approach is a functional method for managing socio-ecological systems, such as the greater Yosemite region, within "multiple jurisdictions, resource users, and viewpoints" (Pratt Miles, 2013). Despite scholars specifically identifying that adaptive management approaches may benefit the built environment, the discussion of collaborative adaptive management-specific approaches to managing transportation systems remains sparse within transportation-based scholarly literature and underutilized across the landscape (Malekpour and Newig, 2020). Intentionally construction plan efforts through collaborative adaptive management will promote moving the needle forward simultaneously across agencies despite rigid legal boundaries, as transportation networks and socio-ecological systems necessitate regional resilience in the face of wildfire threats to transportation systems.

The recurrent 4-5 year interval of RTP deliverables facilitates adaptive approaches to streamlining climate inclusion in planning across the relevant region. Yosemite's active Visitor Access Management Plan study provides a timely opportunity to improve systems considerations in alignment with timing RTPs across the greater Yosemite Region. As agencies update their RTPs at approximately 4 to 5-year intervals, and most are approaching the release of their next plan update (e.g., Mono County is in the process of workshopping their next RTP, following their 2019 version as of Summer 2023), they should emphasize points of non-resilience across regional plans (Mono County, 2023). At the full region level, the current YARTS structure may be expanded in its physical and policy-based reach to accommodate shortcomings in RTP resilience, particularly for improving transportation equity in the greater Yosemite region. At the highest level, State and Federal governments should improve plan construction frameworks to consistently enable resilient design through more stringent, dictated content requirements, as current RTPA-specific instructions may be considered adaptive management lite (a/m lite), an illusory inclusion of adaptive management necessitating contexts (i.e., climate change) (Craig et al., 2017). Specifically, designing plan requirements must be updated from a simple checklist of covered topics to enable a/m lite or unaddressed uncertainty (Allen et al., 2010). Plan instruction should actively utilize new information on climate hazards, infrastructure conditions, demand, and other quantifiable factors for regional transportation planning (Pratt Miles, 2013; Susskind et al., 2011). Top-down specification of collaborative adaptive considerations may remedy omissions through the justification of allocating limited temporal and financial resources (Malekpour and Newig, 2020).

2.5 Conclusion

By exploring agency policies through the Plan Integration Resiliency ScorecardTM, we identify the constraints of Absorptive Capacity, Adaptive Capacity, and Equitable Access through plan integration across multiple agencies. Differences in qualitative agency priorities limit transportation corridors' management, utilization, and resiliency in and around Yosemite National Park. Agencies with comparatively higher resilience may provide valuable insights into plan development across scales, facilitating expanded inter-agency collaboration. Shortened windows for RTP updates facilitate discussions across agencies of ongoing challenges or any surpassed societal, technological, or other thresholds to help plan developmental leaps, supplemental to incremental knowledge expansion, to ensure resilience for more extended periods through collaborative adaptive management and increased consideration of environmental hazards specifically applied to transportation planning. Points of decreased resilience, such as inconsistencies across Equitable Access, allow for collaborative opportunities. In contrast, attributes of high resilience promote a shared regional identity and expanded collaborative capacity for improving points of less integration and decreased resilience- promoting Equitable Access benefit the complete transportation systems' resilience.

Both quantified and contextual qualitative findings drive shifts towards complex systems thinking and implementation of collaborative adaptive management to combat climate change's systemic, multi-scale impacts dynamically. Our results underscore the importance of interactions within and across agencies to understand connectivity in an area of global importance and cultural, emotional, and ecological value- shifting towards considering transportation infrastructure as a more extensive, dynamic system component. We encourage transportation planning agencies and managers to look outward to contributing factors to decreased resilience in plan integration across agencies to leverage novel collaborations and increase coalition successes in the greater Yosemite region to strengthen resilience in an increasingly intense climate-change-driven hazard regime.

Data Availability Statement: Data and code are publicly available via Mendeley Repository at the Reserved DOI: 10.17632/77yyw49ms5.1

2.6 Appendix A

Table 4 – Preliminary plan scoring by AREA criteria.

AREA Theme	Step of Logic Model	Category	Key Metrics	Search Terms or Source: Used in conjunction with qualitative context	Madera	Mariposa	Mono	Tuolumne	YARTS Short Range Transit Plan	CalTrans State Hwy System Management Plan	NPS YNP Yosemite Valley Plan [must be transpo context]	NPS YNP General Management Plan [must be transpo context!]
Inputs and Activities												
Absorptive Capacity	Inputs	Exposure Metrics	High value destination: Hospitals	Hospitals, Medical Center	1	1	1	1	1	-1	1	1
			High value destination: Refuse disposal	Waste, Dumps, Trash, Landfill, Refuse	-1	-1	1	-1	-1	1	1	1
			High value destination: Schools	Schools, University, Education	1	1	1	1	1	-1	1	1
			High Value Infrastructure: Bridges	Bridge(S)	1	1	1	1	1	1	1	1
			Recognized Hazard(s): Fire	Fire, Wildfire	-1	1	1	1	1	1	1	-1
			Electricity infrastructure	Substation, Electric, Electricity, Power	0	0	0	0	1	1	1	1
			Recurrent Maintenance	Maintenance, Upkeep	1	1	1	1	1	1	1	1
			Routine Inspections	Inspection, Inspect, Annual	-1	-1	0	1	1	1	1	-1
			Transportation Workforce Training	Training, Workforce	-1	-1	1	-1	1	-1	-1	-1
Restorative Capacity	Inputs	Response Resources	Response budget	Budget, Cost	1	1	1	1	1	1	1	-1
			Equipment counts	Equipment, Counts, Tallies	-1	-1	1	-1	1	1	-1	-1
			Equipment status or storage	Equipment, Status, Lifecycle	-1	-1	1	-1	1	1	1	1
			Interagency partnerships	Interagency, Community, Partnerships, Collaboration	1	1	1	1	1	1	1	1
			Worker counts	Employees, Workers	1	1	1	1	-1	-1	1	-1
		Community Planning	Grassroots or non-govt planning for disaster risk or reduction	Interagency, Community, Partnerships, Collaboration, Risk, Hazard	1	1	1	1	-1	-1	1	-1
			Community organization meetings	Interagency, Community, Partnerships, Collaboration	1	1	1	1	1	-1	1	-1
			Organization meeting attendance	Interagency, Community, Partnerships, Collaboration	1	1	1	1	1	-1	1	-1
			Multiple modes of engagement	Communications, Email, Engagement, Contact, ITS	1	1	1	1	1	1	1	-1
			Defined disaster roles	Roles, Responsibilities	-1	1	1	1	1	1	1	-1
Adaptive Capacity	Inputs	Network expansion	Transportation funding	Funding, Cost	1	1	1	1	1	1	1	-1
			Document Longevity	Length, Duration, Years	1	1	1	1	1	1	1	1
			Document Update	Length, Duration, Years, Update	1	1	1	1	-1	1	-1	-1
			Current significant motorized facility miles	Normalized to line miles per square mile	1.08	0.58	0.22	0.42	0.04	0.08	4.76	0.18
			Planned motorized facility miles (+20 years)	Planned, Miles, Facility (ies), Centerlines	1	-1	-1	-1	-1	1	1	1
Equitable	Inputs	Underserv	Percent households without a car	Headwaters Economics Communities at Risk [Nat Avg = 8.3]	2.7	4.4	2.6	3.7	3.35	4.4	16.3	12.6
			Percent under age 18	Headwaters Economics Demographics [Nat Avg = 17]	27.6	16.8	21.4	17.9	20.925	22.8	1.5	0.75

			Percent over age 65	Headwaters Economics [Nat Avg =26.2]	13.9	28.2	8.3	19.3	17.425	14.4	7.8	23.9
			Percentage individuals below poverty	Headwaters Economics [Nat Avg = 12.6]	19.6	13.7	10	9.9	13.3	12.3	10.9	6.9
		Communication	Percentage of those who speak English "very well"	Headwaters Economics [Nat Avg = 8.2]	19.5	2.4	8.1	1.8	7.95	17.2	6.9	3.45
			Percentage with disabilities	Headwaters Economics Neighborhoods at Risk [Nat Avg= 12.6]	12.8	17.9	9	20.3	15	10.1	9.2	11.9
			Percentage in region without internet access	Headwaters Economics Rural Capacity Map and Census Bureau [Nat Avg = 9.9]	13	19	9	15	14	7.1	0	0

Table 5- Consolidated plan scoring by AREA criteria.

AREA Theme	Step of Logic Model	Category	Key Metrics	Search Terms or Source: Used in conjunction with qualitative context	Madera	Mariposa	Mono	Tuolumne	YARTS Short Range Transit Plan	CalTrans State Highway System Management Plan	YNP Yosemite Valley Plan	YNP General Management Plan
Inputs and Activities												
Absorptive Capacity	Inputs	Exposure Metrics	High value destination: Hospitals	Hospitals, Medical Center	1	1	1	1	1	-1	1	1
			High value destination: Refuse disposal	Waste, Dumps, Trash, Landfill, Refuse	-1	-1	1	-1	-1	1	1	1
			High value destination: Schools	Schools, University, Education	1	1	1	1	1	-1	1	1
			Recognized Hazard(s): Fire	Fire, Wildfire	-1	1	1	1	1	1	1	-1
			Electricity infrastructure	Substation, Electric, Electricity, Power	0	0	0	0	1	1	1	1
			Recurrent Maintenance	Maintenance, Upkeep	1	1	1	1	1	1	1	1
			Routine Inspections	Inspection, Inspect, Annual	-1	-1	0	1	1	1	1	-1
			Transportation Workforce Training	Training, Workforce	-1	-1	1	-1	1	-1	-1	-1
				Absorptive Capacity	-1	1	6	3	6	2	6	2
Restorative Capacity	Inputs	Response Resources	Response budget	Budget, Cost	1	1	1	1	1	1	1	-1
			Equipment counts	Equipment, Counts, Tallies	-1	-1	1	-1	1	1	-1	-1
			Equipment status or storage	Equipment, Status, Lifecycle	-1	-1	1	-1	1	1	1	1
			Interagency partnerships	Interagency, Community, Partnerships, Collaboration	1	1	1	1	1	1	1	1
			Worker counts	Employees, Workers	1	1	1	1	-1	-1	1	-1
		Community Planning Efforts	Grassroots or non-govt planning for disaster risk or reduction	Interagency, Community, Partnerships, Collaboration, Risk, Hazard	1	1	1	1	-1	-1	1	-1
			Community organization meetings	Interagency, Community, Partnerships, Collaboration	1	1	1	1	1	-1	1	-1
			Organization meeting attendance	Interagency, Community, Partnerships, Collaboration	1	1	1	1	1	-1	1	-1

			Multiple modes of engagement	Communications, Email, Engagement, Contact, ITS	1	1	1	1	1	1	1	-1
			Defined disaster roles	Roles, Responsibilities	-1	1	1	1	1	1	-1	-1
				Restorative Capacity	4	6	10	6	6	2	6	-6
Adaptive Capacity	Inputs	Network expansion	Transportation funding	Funding, Cost	1	1	1	1	1	1	1	-1
			Document Longevity	Length, Duration, Years	1	1	1	1	1	1	1	1
			Document Update	Length, Duration, Years, Update	1	1	1	1	-1	1	-1	-1
			Current significant motorized facility miles	Normalized to line miles per square mile	-1	-1	-1	-1	-1	-1	1	-1
			Planned motorized facility miles	Planned, Miles, Facility (ies), Centerlines	1	-1	-1	-1	-1	1	1	1
				Adaptive Capacity	3	1	1	1	-1	3	3	-1
Equitable Access	Inputs	Underserved Populations	Percent households without a car	Headwaters Economics Communities at Risk [Nat Avg = 8.3]	1	1	1	1	1	1	-1	-1
			Percent under age 18	Headwaters Economics Demographics [Nat Avg = 17]	-1	0	-1	0	-1	-1	1	1
			Percent over age 65	Headwaters Economics [Nat Avg =26.2]	1	-1	1	1	1	1	1	1
			Percentage individuals below poverty	Headwaters Economics [Nat Avg = 12.6]	-1	-1	1	1	0	0	1	1
		Communication capabilities	Percentage of those who speak English "very well"	Headwaters Economics [Nat Avg = 8.2]	1	-1	0	-1	0	1	-1	-1
			Percentage with disabilities	Headwaters Economics Neighborhoods at Risk [Nat Avg= 12.6]	0	-1	1	-1	-1	1	1	0
			Percentage in region without internet access	Headwaters Economics Rural Capacity [Nat Avg = 9.9]	-1	-1	0	-1	-1	1	1	1
				Equitable Access	0	-4	3	0	-1	4	3	2
				Sum Scores (30 max)	6	4	20	10	10	11	18	-3

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3. Chapter 2: Decreased air quality shows minimal influence on peak summer attendance at forested Pacific West national parks

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Abstract (310/350)
Wildfires are increasing in duration and intensity across the western United States, resulting in heightened particulate matter from smoke in the atmosphere. Levels of peak particulate matter are concurrent to peak visitor attendance at National Parks, given seasonal alignment with summer vacation travel and heightened forest fire conditions. Particulate matter threatens visitor health and safety and contributes to poor visibility and a deteriorated visitor experience. To assess visitation response to diminished air quality, we utilized wildfire-generated particulate matter (PM2.5) data in conjunction with monthly attendance records for three ecoregions containing eight national parks in Washington, Oregon, and California from 2009-2019. We analyzed daily PM2.5 levels from data gridded at the 10km scale for National Park Service units by Level III forest ecoregions within the National Park Service's Pacific West Unit. Data were then compared to normalized monthly visitation trends for each of the ecoregions using two statistical methods: Kendall's Tau and Analysis of Variance (ANOVA) with post-hoc Tukey tests. Results demonstrate that attendance at these national parks does *not* decrease in response to increased PM2.5 levels. Instead, we see several statistically significant increases in attendance across these ecoregions during periods of reduced air quality. Of 115 shifts between air quality categories during the busy season of July to September, there are no significant decreases in attendance as air quality worsens. These findings suggest that visitors are willing to tolerate reduced air quality compared to other factors such as temperature or precipitation. Given that park units within each ecoregion feature diverse historical contexts, varied built environments, and unique ecological systems, our discussion specifically addresses managerial concerns associated with maintained high levels of visitation during suboptimal, and potentially dangerous, conditions. There is substantial need for specific, scalable approaches to mitigate adverse health and experiential impacts as visitors are exposed to increased risks during a range of exertional activities associated with diverse settings.

Keywords: Air Quality, Visitation, Tourism, Environmental Hazards, Public Lands

3.1 Introduction

Many United States national parks have repeatedly broken their attendance records in recent years (NPS, 2022a), particularly in response to the COVID-19 pandemic. Simultaneously, climate change is contributing to increasingly large and recurrent devastating wildfires across western states (Abatzoglou and Williams, 2016; Crockett & Westerling, 2018), which release harmful aerosols hazardous to human health and well-being into the air (D'Evelyn et al. 2022). Unfortunately, national park visitation peaks in July across the western US, contemporaneous to the peak in area burned by wildfire (NPS, 2022b; EPA, 2022). As the highest levels of visitors enjoy the great outdoors, they are potentially more likely to be exposed to adverse wildfire impacts, from physical harm due to breathing particulate matter to a negative user experience due to deteriorating visibility and services limiting engagement with park attractions.

The National Park Service implements varied management strategies to limit adverse outcomes for visitors. Successful and sustainable park management relies largely on task predictability (Mohr and Wolfram, 2010), but predictability in public lands management is challenged by the complex dynamics of plasticine systems with nested components, from pest management to legal challenges (Thomas, 1996). Management solutions for coupled human-natural systems are rarely "one size fits all." Decisions are primarily contextual, multi-dimensional, intentionally flexible, and may include having to make tradeoffs in the interest of the public and the ecological setting to preserve predictable, thereby safe, and sustainable, and prescriptive, outcomes (Schindler and Hilborn, 2015; Spernbauer et al., 2022). For example, wildlife responses to human behaviors become unsafe and potentially deadly for humans and animals when humans engage in non-predictable behaviors, such as approaching wildlife or making physical contact (Gunther et al., 2015).

Maintaining predictable outcomes to interactions within coupled human-natural systems also expands into the built environment. Multiple sites limit access into specific park units or sections of parks to maintain predictable visitor movement outcomes. Devils Postpile National Monument, Denali National Park, and the Mariposa Grove of Giant Sequoia trees in Yosemite National Park, for example, are all primarily only accessible by shuttle bus or on foot. Shuttle bus use simultaneously decreases single-vehicle usage, thereby reducing congestion, and protects sensitive environments from physical wear (Manning et al., 2014; Monz et al., 2016). Similarly, Yosemite National Park management's response at the beginning of the COVID-19 pandemic in 2020 demonstrates another tradeoff made in the public interest. Management enacted a vehicle-based day-use reservation system in responding to public health recommendations and increased demand (Jenkins et al. 2021). By reducing overall user demand, the strategy effectively increased visitor dispersal, which can decrease traffic congestion and crowding and improve the visitor experience (White, 2007; Lawson, 2009).

The National Park Service explicitly and adaptively manages the 'visitor experience' through formal social-science-based practices encapsulated in the Interagency Visitor Use Management Framework (Cahill et al., 2018). While air quality has long been a consideration in managing the visitor experience, more frequent poor air quality specifically associated with increased western US wildfire activity in recent years may predicate the need to adapt management strategies. Poor air quality is strongly associated with acute and chronic health conditions and mortality rates worldwide (Kelly and Fussell, 2015). In the western US, decreased air quality is associated with summer wildfires that emit harmful aerosols, including ozone (O_3), carbon dioxide (CO_2), and particulate matter (Bowman et al., 2009; Williams and Abatzoglou, 2016), typically from July through September (Wiedinmyer, 2006). Of these, particulate matter is the most widely tracked, particularly the 2.5 micron size class (denoted as PM2.5) composed of elemental and organic carbon, nitrate, and sulfate (Jacobs and Winner, 2009), because PM2.5 poses the most significant health risk compared to other particulates as the particles are small enough to enter human lungs and bloodstreams (EPA, 2022). The US Environmental Protection Agency (EPA) uses PM2.5 to classify air quality categorically from Good to Hazardous based on specific ranges for the EPA Air Quality Index (AQI), as detailed in Table 1. The EPA cautions that fine particulates are the most harmful component of smoke, and that people should stay inside and avoid smoky conditions or wear specialty respirators outdoors. Additionally, it urges using "common sense" for being active during heightened air pollution (EPA, 2022).

Table 6- Per the EPA, the following air quality categories are associated with specified ranges of PM2.5 and corresponding risk, as well as potentially impacted groups.

AQI Category	PM2.5 micrograms per square meter	Corresponding AQI Index Value	PM2.5 Specific Description
Good	0-12	0-50	Air quality is satisfactory, and air pollution poses little or no risk.
Moderate	12.1-35.4	51-100	Unusually sensitive people should consider reducing prolonged or heavy exertion
Unhealthy for Sensitive Groups	35.5-55.4	101-150	People with heart or lung disease, older adults, children, and people of lower socioeconomic status should reduce prolonged or heavy exertion.
Unhealthy	55.5-150.4	151-200	People with heart or lung disease, older adults, children, and people of lower socioeconomic status should avoid prolonged or heavy exertion; everyone else should reduce prolonged or heavy exertion.
Very Unhealthy	150.5-250.4	201-300	People with heart or lung disease, older adults, children, and people of lower socioeconomic status should avoid all

			physical activity outdoors. Everyone else should avoid prolonged or heavy exertion.
Hazardous	250.5+	301+	Everyone should avoid all physical activity outdoors; people with heart or lung disease, older adults, children, and people of lower socioeconomic status should remain indoors and keep activity levels low.

Decreased air quality hampers visitor experience aesthetically, but also by exposing visitors to health risks. In order to mitigate such risks, either visitors must first recognize the presence of particulate matter and take appropriate actions or parks must notify visitors of the risks and similarly take management actions. Public perception of pollution is not directly related to numerical air quality measurements in the United States (Brody et al., 2004). Instead, additional criteria influence whether people recognize pollution as being present, such as whether residents are urban or rural, a location's developmental context, and the pollution source. Pollution sources also largely determine how air quality is perceived– industrial pollution is more readily perceived, while pollution from wildfires may appear more "natural" within the context of national parks (Cori et al., 2020; Reames and Bravo, 2019). Previous research indicates that visitors can perceive very low pollution levels impacting views in national parks (Hyslop, 2009). The key question is whether this perception then leads to mitigation actions such as displacement from impacted areas.

Climate, topography, localized weather, seasonality, and other factors determine types of recreation undertaken in national parks, but extreme events exacerbated by climate change, such as heat waves, impact outdoor recreation and lead to recreationist displacement from preferred locations and activities (Halofsky et al., 2022). Similarly, wildfires and smoke may also produce localized displacement. For example, in Yosemite National Park, most visitors generally engage in lower, shorter-term exertion activities such as walking and visiting interpretive facilities in Yosemite Valley. However, Yosemite Valley is subject to extreme inversion layers due to its topography during periods of decreased air quality, as its steep walls limit air mixing (Colette et al., 2003). Visitors can reduce their exposure during inversions by displacing outside of Yosemite Valley to other parts of the Park, however, it is unknown to what extent this occurs.

Given the significant increase in wildfire area burned in the western US over the last three decades due to anthropogenic climate change (Abatzoglou and Williams, 2016), there is a critical need to understand how visitor experience is affected by, and potentially even responding to, increased wildfire smoke impacts during peak visitation season. Determining whether visitors are self-mitigating smoke exposure by not going to parks can help inform both park management strategies and education efforts around the risks of particulate matter to human health. Researchers have identified air quality and its potential influences on visitation within the greater context of climate change as a specific gap in the literature (Rutty et al., 2022), and Clark et al. (2023) specifically assessed the impacts of remotely-sensed black carbon on visitor attendance. They found no decrease in attendance, but one of the key limitations of their study was the coarse spatial resolution of the black carbon data they utilized (0.625° × 0.5°; or >50 km pixels) and whether or not it reflected surface level air quality accurately.

We build on Clark et al. (2023) by using ground-level air quality observations to ask how diminished air quality from wildfire smoke affects visitor attendance at eight national parks in the western US. Specifically, we ask whether visitor attendance varies in relation to particulate matter during peak visitation season of July, August, and September. We explore results across three scales; park unit, ecoregion, and National Park Service region to discuss implications for park management, resource allocation, and challenges associated with seasonal environmental hazards in the West.

3.3 Data and Methods

3.3.1 Study Area

For this study, we assessed eight Pacific West region national park units in Washington, Oregon, and California (Figure 4), including Crater Lake, Lassen Volcanic, Mount Rainier, North Cascades, Olympic, Redwood, Sequoia-Kings Canyon, and Yosemite National Parks. The full name of Redwoods National Park, Redwoods National and State Parks reflects a unique partnership, pairing the National Park Service and the State of California in a collaborative management agreement and shared general plan for several non-contiguous units (National Park Service, 2022). However, attendance data are specific to the National Park component of the units. These eight parks all experience peak visitation in late summer, have naturally occurring wildfire, and have seen similar climate change impacts through increased

Figure 4-The eight National Parks grouped by EPA Level III ecoregions stretching from Northern Washington south through Central California.

drought, tree mortality, and wildfire (Halofsky et al., 2020; Kolden et al., 2015; Libby, 2017; Steel et al., 2015). They vary in attendance ranging from as few as roughly 2,000 visitors per month (North Cascades) to over a quarter-million visitors per month (Yosemite) during peak season.

Table 7- Ecological descriptors and associated visitation averages for National Parks included in study. Attendance is normalized to each park's median values for July, August, and September for 2009-2019.

Eco-region	Park Unit	Description	Hectares	Median Summer Attendance
Cascades	North Cascades	The Cascades feature diverse landscapes, with lower elevations showcasing pine forests and higher elevations with subalpine meadows and alpine tundra. Air quality varies, with urban areas experiencing higher pollution levels, while higher elevations enjoy cleaner air and are influenced by down canyon winds. There are distinct seasons, with wet winters and dry, warm summers, and have historically experienced both low-intensity and high-intensity fires, although recent years have seen more intense wildfires due to climate change.	204,226	6,752
	Crater Lake		74,148	111,194
	Mount Rainier		95,641	269,951
Coast Range	Redwood	Coast Range forests consist of evergreen and deciduous trees, including Redwoods. The Pacific Ocean moderates air quality, resulting in cool and moist weather with fog acting as a filter for pollution. However, fog can also trap particulates and release them during dry spells. While the region has been relatively spared from megafires, recent years have seen increased fire activity due to climate change.	31,450	57,666
	Olympic		369,643	515,266
Sierra Nevada	Sequoia-Kings Canyon	The Sierra Nevada feature diverse vegetation, ranging from oaks and chaparral in lower elevations up to coniferous giant sequoias, pines, and cedars. The Mediterranean climate brings hot, dry summers and cool, wet winters, with higher elevations receiving more precipitation and snow. Air quality varies, with pollution influenced by the Central Valley, but is good overall, improving with elevation. Natural processes and human activities have historically shaped fire regimes, with recent decades demonstrating fuel	350,352	270,000
	Lassen Volcanic		43,101	90,517
	Yosemite		307,435	615,892

		accumulation and increased incidence of extreme wildfires.		

3.3.2 Data Sources

A national dataset of daily PM2.5 levels at 10-km resolution generated from wildfire smoke (Childs et al., 2022) was utilized for the analysis. PM2.5 daily data were aggregated to the monthly mean to align with the monthly scale of the attendance data. Each month was also assigned an EPA Air Quality categorical rating (Table 1) to ascertain whether specific thresholds of hazardous air quality altered visitation. National park attendance for all recreation visits in recorded years was collected from the National Park Service's Integrated Resource Management Applications (IRMA) Park Visitor Use Statistics for each park. The data were then subset to 2009-2019. The decade range 2009 through 2019 was explicitly selected for the observational period, as it is after the most recent recession and before the Covid-19 pandemic. Attendance data were then normalized into percentage deviation from the median through calculating the median monthly summer attendance across July, August, and September for 2009-2019 for each park (n= 33). We then aggregated data to ecoregion and unit wide to facilitate comparisons at three total managerial scales and to increase the number of data points and to minimize anomalies associated with single park closure events. As the number of parks varies by ecoregion, the number of air quality-attendance month-pairs also varied with each ecoregion (Cascades: n = 99; Coast Range: n = 66; Sierra Nevada: n = 99). Both PM2.5 measurements and calculated deviations from the median demonstrated non-normal distributions.

3.3.3 Analysis Methods

We utilized the non-parametric test Kendall's Tau for evaluating the association between monthly normalized median attendance deviation and PM2.5 values at three spatial scales: individual park unit, ecoregion, and the full Pacific West region (Kendall, 1938). We also utilized analysis of variance (ANOVA) and post hoc Tukey HSD tests to assess the relationship between continuous normalized attendance values and categorical air quality categories across each of the three scales (Tukey, 1949). We then summarized the data to assess the directionality of median values for each air quality category, providing additional insights into the relationship between air quality and attendance. We created supplemental box plots demonstrating departure from the median and results tables to visually present the statistical results and identify attendance trends reflecting air quality. Relying solely on categorical data can potentially obscure underlying trends due to aggregation, which is why both categorical and numerical data were considered in this analysis.

3.4 Results

3.4.1 Variation in Peak Visitation Attendance across Scales

3.4.1.1 Kendall's Tau

Across all three scales, only Yosemite National Park demonstrated a significant decline in visitor attendance at higher PM2.5 levels. Additionally, there were three statistically significant instances in which attendance actually increased with higher PM2.5 in North Cascades, Mount Rainier, and Olympic National Parks. When aggregated to ecoregion, results indicate a slight positive relationship between increasing particulate matter and attendance for the Cascades ecoregion parks. There is no statistically significant relationship between particulate matter and deviations from median attendance at the scale of the Pacific West unit.

Table 8- Kendall's Tau and p-values by park, ecoregion, and the entire Pacific West ecoregion. The asterisk (*) demonstrates a statistically significant relationship.

By Park Unit		
Unit	**Kendall's Tau**	**P-Value**
North Cascades	0.238	0.053*
Crater Lake	-0.048	0.698
Mount Rainier	0.244	0.047*
Redwood	-0.188	0.125
Olympic	0.306	0.013*
Sequoia-Kings Canyon	0.059	0.059
Lassen Volcanic	0.155	0.209
Yosemite	-0.347	0.005*
By Ecoregion		
Unit	**Kendall's Tau**	**P-Value**
Cascades	0.146	0.033*
Coast Range	0.074	0.381
Sierra Nevada	-0.020	0.774
Full Region		
Pacific West Region	0.063	0.130

3.4.1.2 Analysis of Variance

Of 115 instances of shifts between air quality categories at the park unit level, there were zero statistically significant shifts in which attendance decreases below the median corresponding to increases in particulate matter (p adj = 0.05, 95% CI). There is one statistically significant result in which attendance increases corresponding to increases in particulate matter from the Good air quality category (-18% below median attendance) to Moderate (22% above median attendance) for North Cascades national park (Figure 2).

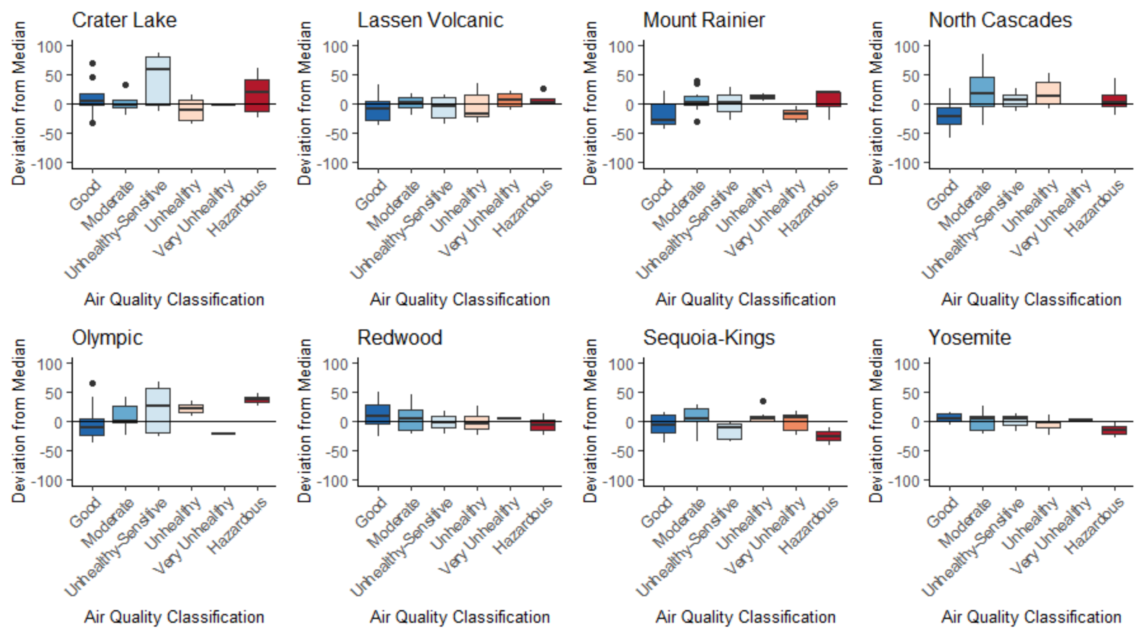

Figure 5-Categorical shifts from Good through Hazardous air quality for each of the eight national parks, visually demonstrating general overall increases in attendance departure from median attendance corresponding to decreases in air quality category.

When aggregated to the ecoregion level, as well as full Pacific West region, there are no statistically significant shifts in which attendance decreases below the median corresponding to increases in particulate matter. For air quality category shifts in ecoregions, there are two statistically significant shifts within the Cascades ecoregion, both as air quality decreases from Good (-10.27% below median) to Moderate (12.38 above median), and Good to Unhealthy (23% above median). This positive increase in deviation from the median is also present at the Pacific West level in one instance shifting from Good to Moderate air quality (Figure 3).

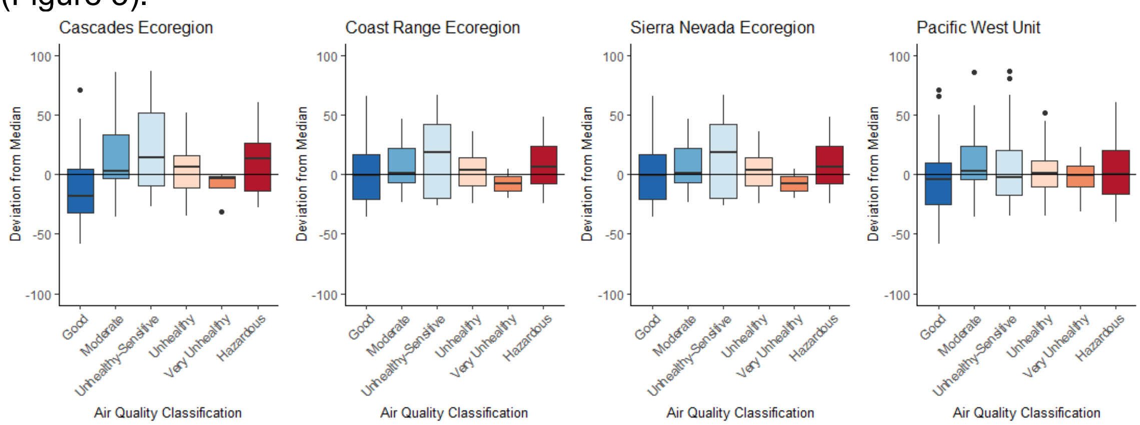

Figure 6-Categorical shifts from Good through Hazardous air quality for each of the three ecoregions and the overall Pacific West, demonstrating light overall increases in attendance departure from median attendance corresponding to decreases in air quality category.

3.5 Discussion

Results support previous research that attendance does not generally decrease corresponding to increased particulate matter in the air for Pacific West national parks, regardless of analysis scale from individual park through full region, and in several parks attendance actually increases slightly despite the poor air quality. These results echo Clark et al. (2023), albeit at higher spatial resolution, but also provide more questions than answers. One of the uncertainties of the analysis is whether the monthly temporal resolution is effective for detecting changes in attendance due to poor air quality from wildfires, which tends to occur at daily-to-weekly resolution, but park visitation data are not reported at these time scales. However, there are also a multitude of reasons why park visitors would still visit the parks despite poor air quality and potentially even increase attendance.

When air quality is compromised at highly local scales due to nearby fires, visitors may be still attend and be electing to displace elsewhere within parks, seeking refugia from reduced air quality, or tolerating conditions despite risk. As wildfires can deteriorate air quality over hundreds of square kilometers, visitors may also be seeking to displace from cities into the parks in hopes of finding better air quality. Visitors generally change their behavior based on conditions within their respective locations, which vary based on park contexts and ecoregion considerations such as microclimate and topography, with more diverse parks and regions featuring increased adaptive capacity (Wilkins et al., 2022). Many visitors to national parks in the Pacific West region may also choose to visit despite poor air quality and other barriers (such as partial closures) because of sunk costs associated with long-planned reservations or bookings, and they consider the visit a necessity or financial obligation rather than a discretionary choice (Hartman et al., 2021).

Lower attendance at Yosemite National Park associated with decreased air quality can be interpreted myriad ways. It may reflect the local effect of visitors choosing not to attend on short notice (e.g., those within reasonable drive time or increased schedule flexibility to “try again”). Locals can stay home and reschedule on comparatively shorter notice, while a substantial proportion of visitors have traveled further and have sunk costs associated with accessing national parks, such as booking flights, limited back country permits, or stringent accommodations policies (Brown and Jenkins, 2023). It may also reflect park closures due to wildfire, however, this seems less likely as Brown and Jenkins (2023) found that during closure of one or more park gates (i.e., reduced park ingress) due to wildfire-driven road closures, Yosemite visitors still entered parks, rather than displace to gateway communities.

3.5.1 Management Implications

There are multiple potential impacts and associated managerial implications for persistent park visitation during increasing poor or hazardous air quality periods under climate change. Overall persistent attendance corresponding to high levels of particulate matter throughout summer will require adaptive management strategies for addressing related challenges and outcomes. For instance, during periods of poor air quality, parks may require staffing changes to address the associated challenges, such as interpretive rangers communicating directly with visitors, or placing temporary signage, in contrast to times when air quality is improved. Any such adaptive strategies will impact park staffing and financial resources, providing additional challenges for an NPS system that has been combatting a backlog of maintenance challenges and budgetary shortfalls in recent years (Loris, 2020; Walls, 2022). Resource allocation is essential to ensure the safety and sustainable enjoyment of visitors, however, despite a 9% increase in visitation over the past decade, there has also been a 9% reduction in staffing across the National Park Service. Ultimately, fewer people perform park-sustaining tasks during normal conditions (Congressional Research Service, 2022), and the trend towards longer and more frequent wildfires (Abatzoglou et al., 2021) has already increased strain on firefighting resources in both emergency response and proactive, planned control burns (and managed wildfire) (Bloem et al. 2022).

Managing visitors is an especially critical challenge regarding increased attendance volumes during instances of harmful air quality. The National Park Service is mandated…

"...to conserve the scenery and the natural and historic objects and the wild life (sic) therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations..." - National Park Service Organic Act, 1916.

Summarily – to preserve functional environmental conditions while facilitating visitor experiences. Responses to managerial challenges associated with decision-making around decreased air quality may be complicated by the National Park Service juggling these fundamentally conflicting mandates. Climate projections for the Sequoia-Kings Canyon national park region suggest increased overall temperatures, decreased precipitation, increased climatic extremes, and increased levels of PM2.5 over the next century (Low, 2021; Ford et al., 2018). Researchers have explicitly called for adaptive actions, such as more mitigative prescribed fire in the Sierra, as visitors will be increasingly exposed to reduced and harmful air quality in pursuit of recreation (Cisneros et al. 2017). Management challenges are generally divisible into three categories: managing visitor experience, minimizing ecological degradation, and maintain visitor access.

As air quality diminishes, visitors may face increased physical discomfort and health risks depending on personal health, exposure duration, and exertion levels. Managers have historically encouraged displacement to other areas of the park that have improved air quality to mitigate these concerns. For example, scenic viewpoints are popular destinations across the full Park Service landscape that significantly enhance the overall visitor experience and operate as a microcosm of the interface between visitors and decreased air quality condition.

Visitors collect at pre-determined destinations, such as intentionally engineered and maintained scenic vistas often congested with people, vehicles, and potentially higher particulate matter (Yosemite National Park, 2010). Despite reduced visibility and harmful air quality conditions, scenic vistas and overlooks (such as Yosemite's famous Tunnel View visualized in Figure 4) still function as a "checkbox" for visitors associated with an auto-centric, consumptive park agenda (Louter, 2006; Taff et al., 2013). An adaptive management strategy may be to promote less congested park areas to disperse visitors to different microclimates (such as higher elevations), thereby decreasing densities in areas with increased particulate matter levels.

Figure 7- The view from the popular Tunnel View scenic vista, which includes El Capitan, Clouds Rest, Half Dome, Glacier Point, Sentinel Dome, Cathedral Rocks, and Bridalveil Fall. Photograph by M. Brown, 2012.

Visitor experience is also a function of expected types of engagement with the park. As described above, many visitors seek specific viewing experiences or photo ops, which may be impeded by smoke (Hooker and Cooper, 2022). Though visitor attitudes are shifting toward recognizing smoke as a component of vital, natural ecological processes, visitors have not yet fully embraced the concept of smoke being an essential part of the park environment (Zajchowski et al.,2019). Visitors have varied tolerance of smoke depending on the smoke source (e.g., prescribed versus managed wildfire) and whether they see fire as necessary versus those who do not (Ellison et al., 2021; Peterson et al., 2022). Recreation is a significant driver of park visitation and given sustained attendance levels during instances of reduced air quality, we can ascertain corresponding levels of exertion based on specific activities available at the included parks. Hiking is present across all parks for varied distances, weather conditions, and required exertion levels for desired outcomes. For example, visitors can enjoy lake vistas at Crater Lake National Park with minimal physical exertion required due to the proximity to roads and visibility from within the Visitor Center. Meanwhile, other locations, such as Sahale Glacier in North Cascades National Park, feature a strenuous hike across complex terrain, requiring extended cardiovascular exercise that would be substantially impacted by unhealthy air quality.

Across park sites, topography, time of day, climatic conditions, and other influences determine the level of potential particulate entrainment. In Redwoods National and State Parks, the proximity to the Pacific Ocean moderates weather and air moisture content, leading to predictable temperatures throughout the day, but can also trap smoke close to the ground due to a lack of air mixing, creating a particulate-laden fog called “vog” (Hurt, 2021). Meanwhile, in Sequoia-Kings Canyon National Parks, steep topographic gradients cause diurnal wind patterns that trap smoke in nightly inversion layers and then flush it out in the morning (Buysse et al., 2018). Visitors must weigh the benefits of exposure to potentially harmful air quality with the goals of their visitation experiences (Tainio et al., 2021). Reduced visibility from particulate matter not only negatively impacts visitor health and experience, it also increases likelihood of vehicle accidents. Visitors on unfamiliar mountainous roads already face an increased risk of accidents in clear conditions and reduced visibility further amplifies risk. National Park sites regularly feature a limited number of ingress and egress corridors (i.e., limited ways in and out during emergency scenarios, such as a mass evacuation (Federal Highway Administration, 2023).

To mitigate health risks to visitors and employees, park managers may consider offering designated respite areas, as seen frequently in other situations harmful to public health, such as heatwaves. The concept of a cooling center may be directly translated into a designated relief space in instances of reduced air quality through the addition of air filtration and ventilation in park buildings. As most park buildings do not currently have air conditioning, this would be a substantial fiscal commitment, but as seen with Covid-19, cheap supplemental filtration systems (e.g., Corsi-Rosenthal boxes) may be utilized to improve localized air quality, such as in a campground restroom facility. By proactively managing crowds and promoting healthier alternatives, park managers support options for visitors to recreate safely.

NPS must also manage for the ecological impacts of sustained visitor attendance during periods of poor air quality. Such impacts occur due to altered park use patterns, lowered visibility, and pressure to deviate from fire management strategies that may be generating the smoke, such as prescribed fire and managed wildfire. Fire is an inherently natural process, with landscapes in the West long-adapted to recurring fire to reduce ladder fuels and underbrush, induce plant generation, and provide shelter to a variety of species, amongst other benefits (Sugihara et al., 2006; Van Wagtendonk and Lutz, 2007; Montagné-Huck and Brunette, 2018; Urgenson et al., 2017). After a century of extreme fire suppression, public land managers are turning more often to managed fire, including facilitating natural lightning ignitions (managed wildfire, beginning in the 1970s) and increased site-specific control burns in more populated regions (Van Wagtendonk et al., 2012; Jones et al., 2022). However, decades of fire suppression and climate change are contributing to extreme wildfire and smoke events that exceed the natural elasticity of these fire-adapted systems (Williams et al. 2023).

Maintained high levels of visitation during instances of decreased air quality compounds negative ecological impacts. Compounded hazards to ecological settings, or "multiple stressors", are more harmful- beyond simply additive- to ecological function and healthy environments than singular damaging influence (Paine et al., 1998; Pirotta et al., 2022). Reduced air quality weakens plant growth and function (Weber and Grulke, 1994). PM2.5 negatively impacts plants through deposition directly on foliage and through uptake in soil moisture, disrupting plant metabolic processes (Leser, 2021). Furthermore, PM2.5 impacts how foliage breakdown and reincorporates into the soil by reducing breakdown speeds. In turn, PM2.5 dissolution into the soil impacts aquatic ecosystems, perpetuating cyclical ecological functions and potentially contributing to biodiversity loss (Wu and Zhang, 2018; Leser, 2021). Therefore, in a region already enduring degradation by social trails (walking off established paths), vegetation is subject to increased wear resulting from compound stressors of decreased air quality and human behavior of persisting visitation levels during reduced air quality.

Multiple fern species (*Polystichum munitum, Struthiopteris spicant*) in Redwood National and State Parks are highly susceptible to disruption. They currently face extirpation due to climate change, particularly rising temperatures, and are vulnerable to compound stressors, exacerbated in areas of understory disruption (e.g., trails) (Kassuelke et al., 2022). Coast Redwoods (*Sequoia sempervirens*) in Redwood National and State Parks, and Giant Sequoia (*Sequoiadendron giganteum*) trees in Sequoia and Kings Canyon National Parks feature shallow and sensitive root systems and are incrementally undergoing protections to remove direct human impacts at popular groves (Blom and Teraoka, 2014; Jenkins and Brown, 2019). In Yosemite Valley, the most heavily trafficked portion of Yosemite National Park, fragile meadow ecosystems and unique plant species are particularly susceptible to compounded hazards as they already face degradation due to social trails and drought stressors (Walden-Schreiner and Leung, 2013). Sensitive species cannot adapt quickly enough to shift limited geographic ranges to reduce physical and environmental stressors.

Similarly, wildlife is constantly threatened by vehicle traffic at national parks, where vehicle collisions are a significant source of mortality (Huijser et al., 2017). Reduced visibility due to smoke and impaired senses irritated by particulate matter only increase the potential for such collisions by increasing perception and stopping time. By contrast, some proposed measures to mitigate the negative effects of air quality to visitors may also help wildlife by reducing vehicle traffic and concentrating visitors in areas of built infrastructure where clean air refuges would be most effectively located.

Park managers face a final key challenge in addressing the quandary of sustained attendance despite poor air quality: the need to maintain visitor access to national parks. There are multiple adaptive management strategies that park managers can implement or assess to mitigate negative impacts of smoke-induced poor air quality to visitor experience and ecological systems. First, they can explore effective crowd management strategies already utilized within other contexts to combat ecological, resource, and experiential challenges associated with decreased air quality. One approach is the implementation of timed entry systems, which can help regulate the flow of visitors and reduce congestion during peak reduced air quality time frames.

In recent decades, select sites within the National Park Service have implemented quota and access systems to limit entry to public areas to maintain predictable thresholds for visitation to sensitive destinations. For example, Zion National Park's shuttle system, implemented in 2000, directly resulted from overcrowding and degradation in the popular Zion Canyon (Wadsworth, 2009). The National Park Service maintains the ability to adjust shuttle timing and frequency as a function of demand, resulting in desired prescriptive, sustainable outcomes (Mace, 2013; Schindler and Hilborn, 2015). Implementing the shuttle system to combat a dynamic challenge is an example of park management incorporating adaptive management principles, generally defined as the ongoing update and improvement of management strategies and approaches in response to changes in information and the environment (Prato, 2006). Adaptive management relies on data-driven decision-making to observe and evaluate decisions, then adapt as needed to reach specific goals. Managing predictable anthropogenic disturbances at localized scales, such as social trail degradation, contributes to ecological system resilience, while much of ecosystem conservation is based in unpredictable or computationally difficult to model ecological dynamics (Sasaki et al., 2015).

As a direct response to the Covid-19 pandemic, multiple National Parks implemented visitor reservation systems beginning in 2020 – an adaptive management approach using data to drive decision-making to achieve a specified goal with updates to the plan as needed based on changes in data. Reservation systems were designed to reduce crowding and meet social distancing guidelines, with the additional benefit of easing congestion and mitigating impacts of overuse, particularly at popular trails and front country destinations (Jenkins et al., 2021). Parks implementing reservation systems had visitors access a web-based permitting system, allowing visitors to select the day and time frame they would like to enter. NPS leveraged the web platform www.recreation.gov to implement, remove, and adjust reservation systems multiple times, previously utilizing it to book recreational reservations. Instead of fluctuating services as a function of demand (as with shuttle systems), operational adjustments were made based on infection levels and guidance at a per-park level. The flexibility of the web booking system could not only offer visitors the ability to manage reservations reflecting current and forecast air quality conditions but also allow management to adaptively limit visitation to reduce exposure to harm for humans and ecological systems alike.

The implementation of Covid-19 associated park access constraints (i.e., reduced visitation limits and reservation systems) provides an example of adaptive management to mitigate risks. It highlights the importance of utilizing adaptive management strategies to address public health risks, as these results demonstrate relying solely on individuals to mitigate health risks is insufficient. Recalling that an essential component of successful management is predictability, it is essential to update and improve of management strategies as a response to fluctuations, generating consistency in, visitation thresholds during instances of increased PM2.5 and reduced air quality (Prato, 2006). Key to implementing and updating these management strategies, however, is improved data acquisition to understand daily fluctuations in visitor attendance and a need for social science to understand how visitors perceive smoke impacts and what drives their attendance response.

3.6 Conclusions

Despite risks to personal health and degradation of experiences, visitation does not decrease at select National Parks, corresponding to increased levels of particulate matter. To preserve visitors' health and experience, there is a need for NPS to examine adaptive management strategies to decrease the number of visitors exposed to particulate matter's harmful effects. Specific actions parks can take immediately include increasing public education around risks associated with recreating in reduced air quality conditions, providing supplemental rest and clean-air facilities, limiting access to especially sensitive ecological areas, and encouraging dispersal into other park microclimates and destinations. Long-term assessments of potentially limiting park entry would benefit substantially from improved data collection and analysis at individual parks and more granular data scales to better understand the influence of particulate matter and air quality from park-area microclimates and anticipated trends in future visitation to National Parks.

3.7 Appendix A

Table 9- Analysis of Variance (ANOVA) full results by park, ecoregion, and full Pacific West unit.

CRLA				
	diff	lwr	upr	p adj
Moderate-Good	14.33333	-24.59615	53.26282	0.8654
Unhealthy-Sensitive-Good	25.53333	-20.38538	71.45205	0.5411818
Unhealthy-Good	27.33333	-39.60412	94.27079	0.8078933
Very Unhealthy-Good	-15.66667	-107.5041	76.17076	0.994775
Hazardous-Good	41.83333	-25.10412	108.77079	0.4152505
Unhealthy-Sensitive-Moderate	11.2	-39.49289	61.89289	0.9830512
Unhealthy-Moderate	13	-57.29839	83.29839	0.9924122
Very Unhealthy-Moderate	-30	-124.31519	64.31519	0.9220522

Hazardous-Moderate	27.5	-42.79839	97.79839	0.8336704
Unhealthy-Unhealthy-Sensitive	1.8	-72.59682	76.19682	0.9999996
Very Unhealthy-Unhealthy-Sensitive	-41.2	-138.60831	56.20831	0.7846277
Hazardous-Unhealthy-Sensitive	16.3	-58.09682	90.69682	0.9836693
Very Unhealthy-Unhealthy	-43	-151.9058	65.9058	0.8283343
Hazardous-Unhealthy	14.5	-74.42121	103.42121	0.9957672
Hazardous-Very Unhealthy	57.5	-51.4058	166.4058	0.5945676
LAVO				
	diff	lwr	upr	p adj
Moderate-Good	8.8	-29.57871	47.17871	0.9800364
Unhealthy-Sensitive-Good	0.9666667	-32.53302	34.46635	0.9999991
Unhealthy-Good	3.7	-31.83178	39.23178	0.9995056
Very Unhealthy-Good	14.3	-24.07871	52.67871	0.8595753
Hazardous-Good	15.05	-23.32871	53.42871	0.832281
Unhealthy-Sensitive-Moderate	-7.8333333	-49.70794	34.04127	0.9920007
Unhealthy-Moderate	-5.1	-48.61736	38.41736	0.9991229
Very Unhealthy-Moderate	5.5	-40.37133	51.37133	0.9990207
Hazardous-Moderate	6.25	-39.62133	52.12133	0.9981908
Unhealthy-Unhealthy-Sensitive	2.7333333	-36.54853	42.01519	0.9999317
Very Unhealthy-Unhealthy-Sensitive	13.3333333	-28.54127	55.20794	0.9217387
Hazardous-Unhealthy-Sensitive	14.0833333	-27.79127	55.95794	0.9034806
Very Unhealthy-Unhealthy	10.6	-32.91736	54.11736	0.9740269
Hazardous-Unhealthy	11.35	-32.16736	54.86736	0.9652197
Hazardous-Very Unhealthy	0.75	-45.12133	46.62133	0.9999999
MORA				
	diff	lwr	upr	p adj
Moderate-Good	23.3538462	-4.986773	51.69447	0.1522681
Unhealthy-Sensitive-Good	18.4871795	-24.669178	61.64354	0.7757339
Unhealthy-Good	29.6538462	-21.523298	80.83099	0.4973024
Very Unhealthy-Good	-0.3461538	-51.523298	50.83099	1
Hazardous-Good	21.4871795	-21.669178	64.64354	0.651594
Unhealthy-Sensitive-Moderate	-4.8666667	-49.220192	39.48686	0.9993625
Unhealthy-Moderate	6.3	-45.890652	58.49065	0.9989883
Very Unhealthy-Moderate	-23.7	-75.890652	28.49065	0.7316815
Hazardous-Moderate	-1.8666667	-46.220192	42.48686	0.9999944
Unhealthy-Unhealthy-Sensitive	11.1666667	-50.340606	72.67394	0.9930289
Very Unhealthy-Unhealthy-Sensitive	-18.8333333	-80.340606	42.67394	0.9328765
Hazardous-Unhealthy-Sensitive	3	-52.013777	58.01378	0.9999796
Very Unhealthy-Unhealthy	-30	-97.377842	37.37784	0.7471529
Hazardous-Unhealthy	-8.1666667	-69.67394	53.34061	0.9984011
Hazardous-Very Unhealthy	21.8333333	-39.67394	83.34061	0.8820482
NOCA				

	diff	lwr	upr	p adj
Moderate-Good	40.927273	3.589789	78.26476	0.0263439
Unhealthy-Sensitive-Good	25.227273	-40.46164	90.91619	0.7952778
Unhealthy-Good	38.060606	-5.308876	81.43009	0.1065703
Hazardous-Good	26.727273	-23.167038	76.62158	0.53363
Unhealthy-Sensitive-Moderate	-15.7	-81.892284	50.49228	0.9567771
Unhealthy-Moderate	-2.866667	-46.994856	41.26152	0.9996944
Hazardous-Moderate	-14.2	-64.755192	36.35519	0.922747
Unhealthy-Unhealthy-Sensitive	12.833333	-56.93946	82.60613	0.9827792
Hazardous-Unhealthy-Sensitive	1.5	-72.505223	75.50522	0.9999971
Hazardous-Unhealthy	-11.333333	-66.49357	43.8269	0.9741467
SEKI				
	diff	lwr	upr	p adj
Moderate-Good	12.333333	-18.008667	42.67533	0.8107769
Unhealthy-Sensitive-Good	-9.166667	-39.508667	21.17533	0.9363657
Unhealthy-Good	16	-14.342	46.342	0.5958197
Very Unhealthy-Good	5.9	-26.128934	37.92893	0.9925466
Hazardous-Good	-18.5	-62.91614	25.91614	0.7950248
Unhealthy-Sensitive-Moderate	-21.5	-53.936963	10.93696	0.3520709
Unhealthy-Moderate	3.666667	-28.770296	36.10363	0.9992635
Very Unhealthy-Moderate	-6.433333	-40.453507	27.58684	0.9915938
Hazardous-Moderate	-30.833333	-76.706126	15.03946	0.3373673
Unhealthy-Unhealthy-Sensitive	25.166667	-7.270296	57.60363	0.1997683
Very Unhealthy-Unhealthy-Sensitive	15.066667	-18.953507	49.08684	0.7512516
Hazardous-Unhealthy-Sensitive	-9.333333	-55.206126	36.53946	0.9882764
Very Unhealthy-Unhealthy	-10.1	-44.120173	23.92017	0.9406603
Hazardous-Unhealthy	-34.5	-80.372792	11.37279	0.2270001
Hazardous-Very Unhealthy	-24.4	-71.405625	22.60562	0.6114943
YOSE				
	diff	lwr	upr	p adj
Moderate-Good	-5.125	-27.33976	17.089761	0.9794929
Unhealthy-Sensitive-Good	-4.6666667	-33.12434	23.791003	0.9956542
Unhealthy-Good	-11	-33.21476	11.214761	0.6567079
Very Unhealthy-Good	-2.5	-35.10236	30.102356	0.9998896
Hazardous-Good	-20.7142857	-43.53118	2.10261	0.0915526
Unhealthy-Sensitive-Moderate	0.4583333	-25.92263	26.839299	0.9999999
Unhealthy-Moderate	-5.875	-25.35863	13.608634	0.9368485
Very Unhealthy-Moderate	2.625	-28.18133	33.431331	0.9998146
Hazardous-Moderate	-15.5892857	-35.75676	4.578192	0.2029214
Unhealthy-Unhealthy-Sensitive	-6.3333333	-32.7143	20.047632	0.975607
Very Unhealthy-Unhealthy-Sens	2.1666667	-33.40542	37.738753	0.9999646
Hazardous-Unhealthy-Sensitive	-16.047619	-42.93759	10.842351	0.4653881

Very Unhealthy-Unhealthy	8.5	-22.30633	39.306331	0.9559872
Hazardous-Unhealthy	-9.7142857	-29.88176	10.453192	0.681809
Hazardous-Very Unhealthy	-18.2142857	-49.45761	13.029036	0.490727
REDW				
	diff	lwr	upr	p adj
Moderate-Good	-6.1	-37.52452	25.32452	0.9905273
Unhealthy-Sensitive-Good	-12.6	-63.91603	38.71603	0.9731155
Unhealthy-Good	-13.85	-45.27452	17.57452	0.7549165
Very Unhealthy-Good	-7.1	-76.58224	62.38224	0.999549
Hazardous-Good	-17.35	-56.54327	21.84327	0.7515894
Unhealthy-Sensitive-Moderate	-6.5	-58.87421	45.87421	0.9988437
Unhealthy-Moderate	-7.75	-40.87436	25.37436	0.978193
Very Unhealthy-Moderate	-1	-71.26737	69.26737	1
Hazardous-Moderate	-11.25	-51.81889	29.31889	0.9550637
Unhealthy-Unhealthy-Sensitive	-1.25	-53.62421	51.12421	0.9999997
Very Unhealthy-Unhealthy-Sensitive	5.5	-75.63777	86.63777	0.99994
Hazardous-Unhealthy-Sensitive	-4.75	-62.12307	52.62307	0.9998391
Very Unhealthy-Unhealthy	6.75	-63.51737	77.01737	0.9996664
Hazardous-Unhealthy	-3.5	-44.06889	37.06889	0.999803
Hazardous-Very Unhealthy	-10.25	-84.31832	63.81832	0.9980515
OLYM				
	diff	lwr	upr	p adj
Moderate-Good	14.33333	-24.59615	53.26282	0.8654
Unhealthy-Sensitive-Good	25.53333	-20.38538	71.45205	0.5411818
Unhealthy-Good	27.33333	-39.60412	94.27079	0.8078933
Very Unhealthy-Good	-15.66667	-107.5041	76.17076	0.994775
Hazardous-Good	41.83333	-25.10412	108.77079	0.4152505
Unhealthy-Sensitive-Moderate	11.2	-39.49289	61.89289	0.9830512
Unhealthy-Moderate	13	-57.29839	83.29839	0.9924122
Very Unhealthy-Moderate	-30	-124.31519	64.31519	0.9220522
Hazardous-Moderate	27.5	-42.79839	97.79839	0.8336704
Unhealthy-Unhealthy-Sensitive	1.8	-72.59682	76.19682	0.9999996
Very Unhealthy-Unhealthy-Sensitive	-41.2	-138.60831	56.20831	0.7846277
Hazardous-Unhealthy-Sensitive	16.3	-58.09682	90.69682	0.9836693
Very Unhealthy-Unhealthy	-43	-151.9058	65.9058	0.8283343
Hazardous-Unhealthy	14.5	-74.42121	103.42121	0.9957672
Hazardous-Very Unhealthy	57.5	-51.4058	166.4058	0.5945676
CASCADES ECO				
	diff	lwr	upr	p adj
Moderate-Good	22.6477273	0.001726298	45.29373	0.0499709
Unhealthy-Sensitive-Good	33.2727273	2.801219625	63.74423	0.0239624
Unhealthy-Good	14.0852273	-11.63043795	39.80089	0.6046274

Very Unhealthy-Good	0.7727273	-43.91935412	45.46481	1
Hazardous-Good	21.3560606	-7.10003744	49.81216	0.2551818
Unhealthy-Sensitive-Moderate	10.625	-21.14743664	42.39744	0.9253172
Unhealthy-Moderate	-8.5625	-35.80713965	18.68214	0.9418661
Very Unhealthy-Moderate	-21.875	-67.46400187	23.714	0.7291387
Hazardous-Moderate	-1.2916667	-31.13667408	28.55334	0.9999954
Unhealthy-Unhealthy-Sensitive	-19.1875	-53.21604402	14.84104	0.5739594
Very Unhealthy-Unhealthy-Sensitive	-32.5	-82.44024939	17.44025	0.4124935
Hazardous-Unhealthy-Sensitive	-11.9166667	-48.06076557	24.22743	0.9294296
Very Unhealthy-Unhealthy	-13.3125	-60.50160011	33.8766	0.9629663
Hazardous-Unhealthy	7.2708333	-24.96545903	39.50713	0.9861445
Hazardous-Very Unhealthy	20.5833333	-28.15335969	69.32003	0.8215611
COAST RANGE ECO				
	diff	lwr	upr	p adj
Moderate-Good	5.76	-19.01255	30.53255	0.9830249
Unhealthy-Sensitive-Good	12.76	-20.32756	45.84756	0.864679
Unhealthy-Good	0.96	-27.99161	29.91161	0.9999987
Very Unhealthy-Good	-9.74	-66.59984	47.11984	0.9958274
Hazardous-Good	6.76	-28.4158	41.9358	0.9928644
Unhealthy-Sensitive-Moderate	7	-28.06418	42.06418	0.9914949
Unhealthy-Moderate	-4.8	-35.99144	26.39144	0.9974869
Very Unhealthy-Moderate	-15.5	-73.53233	42.53233	0.9688311
Hazardous-Moderate	1	-36.04115	38.04115	0.9999995
Unhealthy-Unhealthy-Sensitive	-11.8	-49.93153	26.33153	0.9422181
Very Unhealthy-Unhealthy-Sensitive	-22.5	-84.53917	39.53917	0.8921877
Hazardous-Unhealthy-Sensitive	-6	-49.04828	37.04828	0.9984346
Very Unhealthy-Unhealthy	-10.7	-70.63554	49.23554	0.9949353
Hazardous-Unhealthy	5.8	-34.15702	45.75702	0.9980982
Hazardous-Very Unhealthy	16.5	-46.6776	79.6776	0.9717053
SIERRA NEVADA ECO				
	diff	lwr	upr	p adj
Moderate-Good	6.7971014	-9.574492	23.168695	0.8318537
Unhealthy-Sensitive-Good	-4.4028986	-21.668489	12.862692	0.9760666
Unhealthy-Good	4.0778032	-12.050293	20.2059	0.9769486
Very Unhealthy-Good	7.0395257	-12.03169	26.110742	0.8904284
Hazardous-Good	-5.2541806	-23.305745	12.797384	0.9577275
Unhealthy-Sensitive-Moderate	-11.2	-29.387553	6.987553	0.4759081
Unhealthy-Moderate	-2.7192982	-19.830756	14.392159	0.9972779
Very Unhealthy-Moderate	0.2424242	-19.667316	20.152164	1
Hazardous-Moderate	-12.0512821	-30.986578	6.884014	0.4381038
Unhealthy-Unhealthy-Sensitive	8.4807018	-9.48798	26.449384	0.7426754
Very Unhealthy-Unhealthy-Sensitive	11.4424242	-9.208709	32.093558	0.5925683

Hazardous-Unhealthy-Sensitive	-0.8512821	-20.564653	18.862089	0.9999955
Very Unhealthy-Unhealthy	2.9617225	-16.74828	22.671725	0.9979155
Hazardous-Unhealthy	-9.3319838	-28.057151	9.393183	0.6963211
Hazardous-Very Unhealthy	-12.2937063	-33.606324	9.018911	0.5492911
ALL UNITS				
	diff	lwr	upr	p adj
Moderate-Good	12.82183908	0.4111676	25.232511	0.038306
Unhealthy-Sensitive-Good	11.13541667	-3.9294783	26.200312	0.2790558
Unhealthy-Good	6.71111111	-6.7035866	20.125809	0.7047323
Very Unhealthy-Good	3.43137255	-15.8168421	22.679587	0.9956904
Hazardous-Good	6.76344086	-8.4746318	22.001514	0.7987559
Unhealthy-Sensitive-Moderate	-1.68642241	-17.574694	14.201849	0.9996456
Unhealthy-Moderate	-6.11072797	-20.4439142	8.222458	0.8247615
Very Unhealthy-Moderate	-9.39046653	-29.2897097	10.508777	0.7537695
Hazardous-Moderate	-6.05839822	-22.1109672	9.994171	0.8875968
Unhealthy-Unhealthy-Sensitive	-4.42430556	-21.1086252	12.260014	0.9736332
Very Unhealthy-Unhealthy-Sensitive	-7.70404412	-29.3582856	13.950197	0.9104428
Hazardous-Unhealthy-Sensitive	-4.37197581	-22.5546947	13.810743	0.982907
Very Unhealthy-Unhealthy	-3.27973856	-23.8201677	17.260691	0.9974431
Hazardous-Unhealthy	0.05232975	-16.788523	16.893182	1
Hazardous-Very Unhealthy	3.33206831	-18.4430086	25.107145	0.9979132

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4. Chapter 3: Wildfire-driven entry closures influence visitor displacement and spending to alternative park entrance corridors and gateway communities around Yosemite National Park*

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Abstract

Visitor attendance to national parks is affected by road closures from environmental hazards, particularly wildland fire in the American West. Visitors must often decide between displacing to other entrance stations to access sites within the park, and spending time in gateway communities and nearby locations during closures. We analyze variance of county sales tax revenue during fire-driven road closure extents to show whether visitors to Yosemite National Park are displacing, and how their movement is reflected in spending to further understanding of contemporaneous economic impacts to gateway communities. We find that visitors are choosing to displace to entry gates that remain open, rather than pursue activities in surrounding communities. Additionally, our findings indicate that contemporaneous economic impacts are largely dependent on categories of visitor spending, rather than presence/absence of visitors during entrance station closures. While visitors are spatially displacing to access other gates, their spending is not reflected in gateway communities where they are displaced across spending categories. Routine-based spending, such as at restaurants, does not increase with a through-flux of visitors. Need-based spending, particularly gasoline, increases contemporaneous to increases in gate attendance. When one gate closes, monthly attendance increases consistently at primary gates that remain open by approximately 50%, respective to their mean attendance. This is accompanied by an equivalent increase in need-based spending. Put simply, during fire-driven closures of park entrances and corresponding highway corridors substantially more visitors are passing through neighboring gateway communities, but not spending time there, and thereby not contributing significantly to these tourism-dependent economies.

Keywords: Displacement, Transportation, Hazards, Public Lands, Gateway Communities, Wildland Fire

4.1 Introduction

Detrimental wildfire impacts strongly influence visitation to public lands, particularly national parks in the American West (Kim and Jakus, 2019). In recent decades, there has been an anthropogenically exacerbated increase in fire severity and duration in the west (Abatzoglou and Williams, 2016; Williams et al., 2019). In Mediterranean climates, peak visitation to western national parks collides with the historical late summer and early fall fire season (Swain, 2021). Increased visitation during fire season heightens visitor exposure to negative experiential impacts and health risks. Impacts range from obscured views to unhealthy air quality, traffic congestion, road closures, and even mandated evacuations. Visitors to public lands that feature access through limited corridors, particularly national parks, may be displaced totally- choosing to forego any visitation, spatially- choosing to go somewhere else, or temporally- visiting at a different time (Perry et al., 2021).

During a corridor closure, visitors must decide between displacing to a different corridor (or return later) or dispersing to surrounding areas. Dispersal indicates distribution over a wider area and displacement refers to a collective shift to a new place or position. One strategy to reduce overcrowding effects in Yosemite has been to encourage dispersal of use among different communities through promoting the diverse regional network of historic, cultural, and recreational attractions beyond Yosemite's boundaries (Gladfelter and Mason, 2012) However, this strategy may not fully account for displacement at park entrance stations due to climatic hazards such as fire.

Place attachment drives visitation, despite increased risks associated with hazardous events. Both recurring visitors and first timers may be strongly influenced to continue with visitation despite degrading conditions and decreased safety, but for divergent reasons. Repeat visitation and increased familiarity with navigating challenges in a park establishes strong place attachment for repeat visitors (Perry, 2021). Ideographic perspective (such as seeing places in popular culture and media) influences first timer attachment. Financial and temporal commitments due to inflexible policies, such as airline tickets and lodging reservations, are associated with out-of-state and international visitation (Ram et al., 2016).

Corridor closures negatively impact economies dependent on public spending and tourism impacts, traffic congestion, and increased commute times (Harp et al., 2008). Approximately three-quarters of a million fewer people visit national parks annually- directly resulting from wildfire-specific closures (Cai, 2021 preprint). Even when scenarios are sub-optimal for safety, visitors still desire to access popular locations (De Dominicis et al., 2015; Perry et al., 2021). Visitors must pass through gateway communities for resources (e.g., fuel) and to access destinations, including during hazardous events.

Diverse locational contexts and varied research needs lead to multiple gateway community definitions (Stoker et al., 2020). Our research question focuses on economic impacts to low population and economically homogenous communities, specifically incorporating State-regulated taxes in our analysis;

therefore, we utilize gateway communities' legal definition. Gateway communities are legally encoded in California documentation as those places that are 'significantly affected economically, socially, or environmentally by planning and management decisions regarding Federal lands…' (H.R. 1014). We further define gateway communities as "towns adjacent to and having economic ties to public lands...most have a population below 15,000," as our research question focuses on economic impacts to low population and economically homogenous communities (Kurtz, 2010). These communities exist within a checkerboard matrix of rural and agricultural land uses on both public and private lands that pose challenges for contiguous landscape-scale management of hazards including wildland fire (Jenkins and Brown, 2020).

While recreational opportunities vary by climate and geography, the economic transformation for many tourism areas globally has been from extractive resource to recreation-based economies, and gateway communities, which serve as economic hubs to facilitate regional tourism are a notable trend manifestation (Mules, 2005; Fredman and Yuan., 2011; Walpole and Goodwin, 2000). Recent literature has explored the fire's impacts on gateway communities' economics. While literature relating to post-fire responses to recreation, economies, and other systems expands, researchers note a significant gap in the literature specific to understanding contemporaneous hazard impacts on gateway community economies (Kim and Jakus, 2019; Duffield et al., 2013; White et al., 2020). Serving initially as simplified to-and-from routes, trade, and "to-market" development, transportation corridors connect Yosemite to gateway communities and further downslope into the Central Valley (Weber, 2005). These corridors feature environments where ecological processes, human dynamics, and economies are inextricably intertwined – known as coupled-human natural systems and socio-ecological systems. (Walker, 2004; Liu et al., 2007; Ostrom, 2009; Miller et al., 2022).

Comparative opportunities exist in spatial and temporal aspects, addressed in Gladfelter and Mason (spatial) and Kim and Jakus (temporal). Therefore, we ask two key questions, utilizing Yosemite National Park and its surrounding region as a case study. First, during a wildland fire hazard event resulting in closures to some, but not all, of a park's entrance corridors, do visitors displace to other open entrance stations? Furthermore, how is dispersal (or displacement) reflected in contemporaneous spending across adjacent counties and their corresponding entrance corridors? This article analyzes Yosemite's entrance closures and resultant corresponding visitor displacement across entrance stations. We additionally analyze regional county tax revenues to understand shifts in visitor movement-driven spending patterns during hazard events to distill the contemporaneous fire impacts on local economies.

4.2 Background

Yosemite National Park stretches across four counties (Fig. 10), each with a singular corresponding entrance corridor. Vehicle counts (a proxy for visitor count) are tallied at each entrance station when accessing Yosemite. We can see how many vehicles are entering through each corridor, but not the corridor through which they depart. Over 90% of all visitation is centered in Yosemite Valley. Yosemite Valley can be directly accessed through the Arch Rock entrance from Highway 120 while the other three corridors descend into the valley from higher elevations.

In response to the Covid-19 pandemic, Park management implemented a day use reservation system to limit vehicular access and control crowd densities (Jenkins et al., 2021). The reservation system applied to access between 6am and 4pm. Though the reservation system was disengaged for Summer 2023, there is substantial likelihood that it will return in a similar form. Park management is actively engaging in a Visitor Access Management Plan to combat extended wait times and vehicle congestion that ultimately returned when the reservation system was lifted (NPS, 2023). Additionally, management has implemented recurring, short-term reservation requirements around popular events generating high access demand, such as “Firefall”, when lighting illuminates a particular waterfall such that it looks like it is on fire.

While applying the reservation system to an already limited transportation networks restricted access overall, it was not entrance station specific (NPS, 2022). During hazard events resulting in select entrance station closures, visitors must access this densely visited area through the remaining open corridors, thereby compounding entrance station wait times. As experienced during the 2013 Rim Fire, though individual corridors may be closed, the Valley may be beautiful, clear, and most operationally critical - safe- therefore still promoted for visitation by Park representatives.

‘Park officials said the fire has not impacted the park itself, which can still be accessed via State Routes 140 and 41 from the west, as well as State Route 120 from the east side. Yosemite Valley is clear of smoke, all accommodations and attractions are open, and campgrounds are full, said park spokesman Scott Gediman’ - Visalia Times-Delta, August 23, 2013

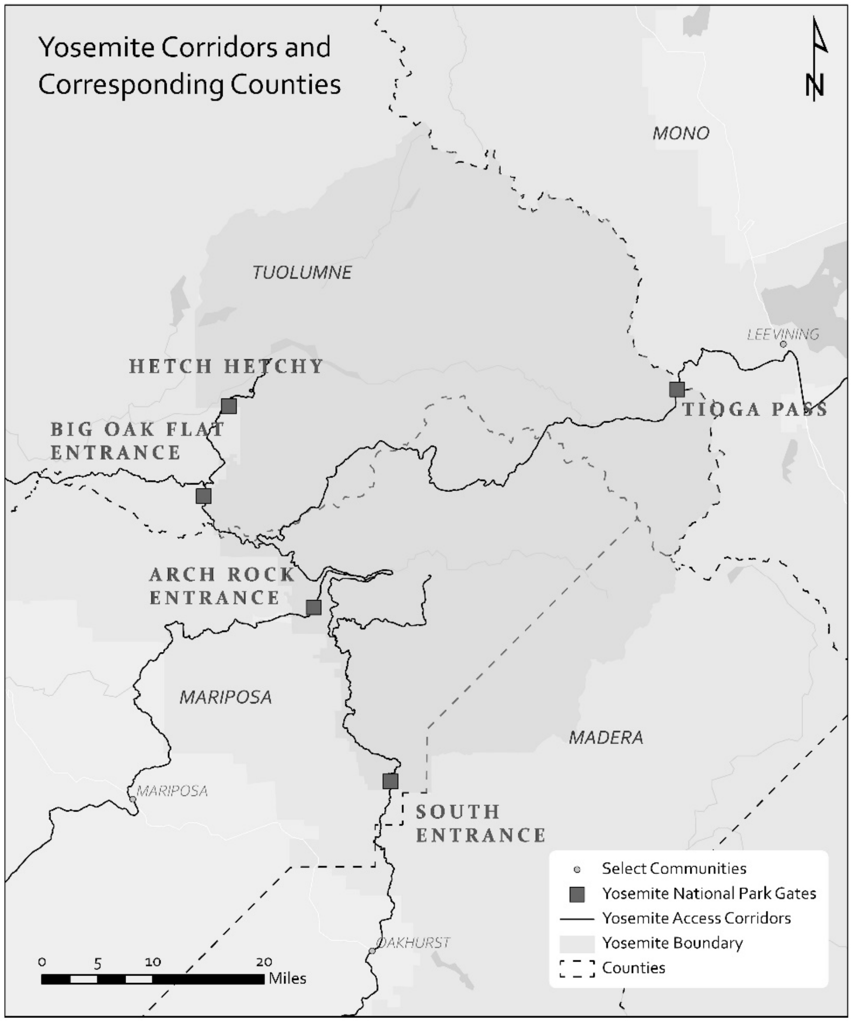

Figure 8- Map overview of Yosemite National Park with entrance corridors and corresponding gates. Map by Author. Sources: Author, CalTrans, Esri Living Atlas, National Park Service. Basemap: Esri et al.

So long as Yosemite Valley remains open (and promoted for visitation), visitors remain drawn to the region, along with their spending money for lodging, fuel, food, and other goods and services.

Large wildland fires within and near Yosemite National Park have led to disruptions in the visitor flows in recent decades given the entrance station and road corridor closures that were necessary to maintain safety and allow for emergency response. While closures are usually limited to one entrance station, in some cases high-severity fires and associated smoke impacts have led to park-wide closures that have displaced would-be visitors later into the season, or entirely (Jenkins, 2022). Despite Yosemite remaining open, entrance station closures due to fires within or proximate to park boundaries physically prevent park visitors from accessing intended entrances. Park visitors must reroute through another ingress or egress point, at a minimum one-hour drive time from ‘gate to gate.’

Independent of hazardous events, Yosemite National Park is heavily impacted by visitation and usage-induced degradation, known as ‘hotspots.’ Implemented in the early 2000s, the Yosemite National Park Geotourism Initiative, in collaboration with National Geographic was designed to disperse visitors across gateway communities to reduce congestion and hotspot degradation within Yosemite’s boundaries. Since Beyond Boundaries: An Assessment of the Yosemite National Park Geotourism Initiative was published in 2012, nearly a decade after the Geotourism Initiative’s implementation, visitation has increased by 10%, at an average of 2% per year over the previous decade- ultimately the desired dispersal to reduce negative wear-and-tear within Yosemite was not achieved (IRMA, 2022).

The greater Yosemite region and the Sierra Nevada have undergone an ecotransformation of ecologies and economies from resource extraction to recreation-based economic development (Duane, 1999). The Mariposa community experienced extensive economic disturbance during the complete multiday evacuation during the 2017 Detwiler Fire, along with Highway 140 corridor closures (Arch Rock Entrance) (Associated Press, 2017). For extended corridor interruptions, such as the Ferguson Rockslide, economic impacts to local communities totaled nearly five million USD (Harp, 2008).

Emotional connection to Yosemite may be driven by powerful visuals recognizable in popular culture and media, such as well-known recreational gear branding and documentaries. This connection utilizes the concept of place attachment, defined as ‘a space that has been given meaning through personal, group, or cultural processes’ (Altman and Low, 2012). Nearly 50% of summertime visitors (corresponding temporally with fire season) are first time visitors to Yosemite, compared to wintertime visitors, where approximately one-quarter of visitors are first timers (Le et al., 2008). Iconic ‘pull factors,’ such as El Capitan and Half Dome, draw visitors to Yosemite through ideographic or physical features of a place (Brown, 2003; Ram et al., 2016). Visual pull factors strongly influence visitor motivations, and thereby spatial behavior (Smith et al., 2021).

People rarely deviate from established, individualized daily routines, as expounded through the Theory of Planned Behavior (Ajzen 1985), even when on vacation. Within the Valley itself, visitor navigational decision making is further influenced by collectivized car-culture and corresponding ease of access to pull factors and motivating constructs. First time visitors largely access Yosemite through personal vehicles. Repeat visitors and those who have experience in other National Parks with robust public transit systems tend to utilize public transit option in the Valley (Youngs et al., 2008). The power of habit has been recently reinforced in sustainability studies, detailing how habit drives recreators' behavior and decision-making (MacInnes et al., 2022).

4.2.1 Regional Hazardscape

The physical landscape, human activity, and development around Yosemite National Park interact dynamically to create a unique landscape of hazards (Corson, 1999; Cutter, 2001). This hazardscape is constructed via the interconnectedness between contemporary hazards with emphasis on global connectivity, technological, and societal influences (Mustafa, 2004).

Prior to European arrival in the Ahwahnee (now called Yosemite Valley) region, indigenous Ahwahneechee utilized managed fire on the landscape for harvesting resources and maintaining desirable conditions (Spence, 1996; Thornton and Bhagwat, 2020). Deliberate and controlled seasonal burning facilitated the proliferation of desirable plant species while simultaneously decreasing potential fuels. Later shifts in economic and transportation priorities – particularly logging and wooden rail infrastructure- led to paradigm and practice shifts towards burning and fire suppression, leading to overly dense forests, particularly susceptible to drought, insect infestations, and wildfire. Land management and legislation decisions further constrain corridors by preventing route expansion, reinforcing limited redundancies, and heightening risk. The Wild and Scenic Rivers Act restricts development along the Merced and Tuolumne Rivers, co-located with two of the four transportation corridors in Yosemite National Park (Catchcart-Rake, 2009).

Granitic geology largely dictates Yosemite's physical hazardscape. Steep drainages, such as the Merced River Canyon (Arch Rock Corridor), constrain transportation infrastructure, which significantly increases visitor vulnerability to environmental hazards (Fraser et al., 2020). Biophysical processes impacting the region include wildland fire, flood, rockfalls and rockslides, and cyclical drought. These phenomena have become socially constructed hazards through historical-dependent development patterns and anthropogenically exacerbated and interconnected landscape-scale environmental disturbances which literally place communities and visitors in harm's way of otherwise naturally-occurring phenomena (Jenkins, 2022; Bramwell, 2015).

Climate change has led to landscape-scale ecological disturbance throughout the region. In addition, extensive drought and subsequent bark beetle infestation compounded by years of fire suppression policy exacerbate conditions for megafires experienced in Mediterranean climates in recent decades (Korshidi et al., 2018; Crocket and Westerling, 2018). California receives most of its annual precipitation through atmospheric rivers – intense, punctuated rainfall events (Dettinger et al., 2011). Heavy precipitation events can initiate landslides in previously burned areas due to ground cover loss and decreased slope stability (Van Asch et al., 1999; AghaKouchak et al., 2018). Consecutive fires, floods, and landslides created compound hazard scenarios, experienced seasonally through the region.

Social vulnerability to hazards increases with increasing population density – in our case, both permanent and transient (temporary, travel-based) occupation (Cutter and Finch, 2008). Within Yosemite's boundaries, permanent and seasonal employees live in several key sites, while thousands of visitors also enter and exit each day. Externally, there are approximately one dozen small hamlets and growing gateway communities in foothill and mountainous regions. Radial and grid style connected transportation networks, typifying urban areas, are limited in the region due to topography. Path dependency on limited hierarchical corridors heightens risk for travelers using the minimal corridor options (Litman, 2013).

The California Department of Transportation (CalTrans) oversees Yosemite National Park access corridors, external to Park boundaries; Highway 120 East and West, Highway 41, and Highway 120. CalTrans categorizes closures as planned and unplanned (CalTrans, 2020). The unplanned classification describes emergency conditions as 'damage to the state highway system that are recent, unexpected, and event-driven.' Events like rockslides experienced in Mariposa County's Highway 140 corridor, which occurred in 2006 are considered unplanned (Harp, 2008). Bridges constructed across the Merced River and back to circumvent the slide-covered highway segment are still deemed temporary, despite being utilized for nearly two decades due to ongoing land movement and constraints associated with the Wild and Scenic Rivers Act.

Dynamic closure events such as wildfires have more plasticity and complexity than a punctuated event like a rockslide. For example, following wildfire (and the predictable fire-atmospheric river-landslide cycle), roads can be preemptively closed to ensure driver safety. While we can heed red flag warnings during critical fire weather, it is impossible to pinpoint specific locations and fire movement due to multiple variables from ignition source and location to day-to-day weather patterns. Fires, therefore, fall under the unplanned emergency classification.

4.2.2 Yosemite Gateway Community Economic Trends

Global climate change impacts affect gateway communities earlier than non-gateway communities due to connectivity to, and dependence on, associated parks and public lands. The Sierra region containing Yosemite National Park accounts for one-third of the entire State of California’s federal-lands based contributions (Winter et al., 2021). When hazardous events physically disconnect gateway communities from their parent park, communities are directly impacted by associated financial losses (Gabe, 2016). Conventional outdoor recreation activities such as hiking and camping and ‘other’ outdoor recreational events and festivals inject between $350 and $400 billion of value into the national economy in the 2010s (Highfill and Franks, 2019). Between 1998 and 2019, recreational-based roles increased by 82.8%, and food service and accommodations-based roles increased by 16.6% (Headwaters Economics, 2022).

When visitors are physically prevented from entering Yosemite National Park in accordance with their primary route during a road closure, they may spatially displace themselves through other gateway communities to gain access. As visitors continue to access Yosemite, they contribute to neighboring communities’ economies. In 2009, groups spent a median amount of $490 ($584 adjusted for inflation to 2019 buying power) and stayed overnight in the vicinity for 3.5 days (Blotkamp et al., 2009). Gateway communities often provide supplementary goods and services unavailable within their associated park (Joyner et al., 2019). For example, within Yosemite National Park the only two gas stations are located in the Crane Flat and Wawona regions. There is no gas available in Yosemite Valley.

4.3 Materials and Methods

Data for this study were constrained to the 2000-2020 timeframe. Ultimately, 2020 was removed from all utilized datasets due to Covid-associated full park closures and implemented reservation systems reflecting dynamic federal policy interventions (Curtis et al., 2021; Jenkins et al., 2021).

4.3.1 Data Collection and Refinement

4.3.1.1 Attendance Data

We utilized visitor attendance in the form of vehicles accessing Yosemite at each primary entrance gate, collected from the National Park Service's Integrated Resource Management Applications website (IRMA) at the necessary monthly scale for each access point. There is no publicly available data for exit counts, but previous survey-based studies indicate that many visitors exit through a different corridor than which they entered (Le et al., 2008).

4.3.1.2 Economic Data

Regional economic data in the form of quarterly sales tax by county were collected through the California Department of Tax and Fee Administration’s Open Data Portal from 2009 through 2020. To obtain years 2000 through 2008, we submitted a public records request and fulfilled it via email pursuant to the California Public Records Act (Gov. Code, § 6250 et seq.). Quarterly sales taxes were tabulated in Excel files as transactions in thousands of dollars for the following categories within Retail Stores: Apparel stores, general merchandise stores, food stores, eating and drinking places, home furnishings and appliances, building materials and farm implements, service stations, and other retail stores. Quarterly sales tax spending was used as a proxy to undergird visitor counts as movement indicators impacting local economies. For this study, the following three categories were ultimately utilized for analysis given their connection to tourism-dependent spending: Food and Drink Stores, Eating and Drinking Places, and Gasoline Stations.

Though other indicators may seem more indicative of visitor presence in a gateway community, shortcomings lead to their deliberate omission. Overnight hotel stay counts are not appropriate due to confounding factors such as strict no-cancellation policies, inconsistencies in reporting, and data privatization. Each county has a Transient Occupancy Tax (TOT), surcharges for motel and hotel guests, and paid overnight stay locations. TOTs may not adequately represent visitor movement due to cancellation policies. Taxable sales were normalized to account for inflation in alignment with purchasing power in 2019 through utilizing the US Bureau of Labor Statistics CPI Inflation Calculator and entering sales tax per category in dollars, given the middle month of Quarter 3 (August of July through September). Values were rounded to the nearest whole dollar.

4.3.1.3 Wildfire Data
We collected historic fire perimeters from California Fire Perimeters hosted feature layer in ArcGIS Pro, via egis.CALFIRE. Data were then refined to 2000 to 2020 within 1 mile of each key corridors using Select by Attribute and Select by Location. All unnamed fires and fires less than 1 acre were eliminated from the dataset. The process resulted in 61 named fires within 1 mile of the four key corridors. Upon initial report to the response agency, all fires receive an alphanumeric unique identifier for internal tracking. This is common across varying agencies. Certain agencies name the fire at the time of reporting (CalFire), while other agencies may wait for the fire to cross a minimum acreage or resource-use threshold (USFS). We deliberately excluded unnamed fires, as fire names are critical for media communications. US-based media uses fire names rather than agency unique codes in reporting (e.g., the 2018 Ferguson Fire was Incident # 00000745 for CalFire, but is referred to in media as the Ferguson Fire). Given the utilization of newspaper-based media to identify road closures based on wildfires, we specifically required a fire name to search.

4.3.1.4 Road Closure Dates
Road closure dates were collected via extensive news media searches online, mainly through the newspaper repository www.newspapers.com. Search criteria were refined by combining ‘fire name’, Yosemite, and road clos%, open and related terms. Textual criteria were paired with the fire year and locational criteria set to California. Each of the 61 fires was searched using the criteria, along with supplemental searches for highway numbers and abbreviations, such as ‘Hwy.’ We maintained a database documenting each fire with any associated closure and reopening date and articles which documented the dates.

Resident-only reopening dates were omitted from the dataset. It is important to note that hard closures are not necessarily at the exact named entrance station. Closures may be outside the associated entrance station or within park bounds. To correctly attribute a road closure to an associated impacted gate- the assignment was based on which entrance station the driver would be accessing Yosemite Valley. The road closure dates were used to assign a categorical variable to the full month of Open or Closed for the following analysis.

4.3.2 Methods
All statistical analyses were completed using the R programming language and R Studio graphical user interface Version 2021.09.1 build 372.

4.3.2.1 Movement Analysis– Fire Closures
Preliminary data exploration and analysis using analysis of variance (ANOVA) and post hoc Tukey HSD indicated statistical significance (p adj = 0.00052, 95%

CI) in the relationship between the variables across select entrance station pairings. First, we analyzed connectivity between all entrance stations using analysis of variance (ANOVA), comparing the categorical open/closed status variables for closures at any corridor (25 closures across the dataset) to the continuous attendance variable. Q-Q Plots indicated normal distribution with slight left skew and fat tails, reflecting seasonal variation attendance fluctuations at Tioga Pass and Big Oak Flat corridors.

H0 (null): When entrance station A closes, there is no change to attendance at the other entrance station
[visitors are not displacing to remaining entrances]
HA1 (alt): When entrance station A closes, there is an increase in attendance at the other entrance station
[visitors are displacing to remaining entrances]
HA2 (alt): When entrance station A closes, there is a decrease in attendance at the other entrance station
[fewer visitors at all gates typically are not accessing the park]

Upon validation, further ANOVA tests were completed for closure for each of the four corridors, with accompanying fluctuations at other entrance stations to identify any statistically significant visitation shifts. For statistical results, Pr(>F) indicates the statistical significance associated with the F statistic (a variance ratio between two mean squares), where if Pr(>F) is less than 0.05, we can reject the null hypothesis. Per RStudio, significance codes for ANOVA results are; *0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1*

4.3.2.2 Economic Analysis
Attendance data were aggregated from monthly to quarterly sums to work on the same temporal scale as each county's quarterly taxable sales data. Open and closed statuses were also aggregated to the quarterly level, where any three-month period with a closed attribute was ascribed to the full quarter. Simple linear regression models for each entrance station and their corresponding county were used to identify any relationships between tallied quarterly attendance and quarterly taxable sales records. Analysis of variance was then used to compare the categorical open/closed status and numeric quarterly taxable sales.

4.4 Results

4.4.1 Entrance Station Displacement Results

Preliminary iterations of analysis of variance (ANOVA) with a Tukey test completed on the results between our continuous variable attendance and categorical variables of fire (open/closed) indicate statistically significant connectivity in attendance fluctuation between gates. The statistical significance thereby validates additional analysis to distill contemporaneous inter-gate influence further.

Data were subset by Open and Closed to find the fluctuations in attendance means during closure and non-closure scenarios. Then basic summary statistics were run. Median values were not used due to seasonal closures at Tioga Pass, leading to medians of 0. Upon completing the secondary ANOVA, we rejected the null hypothesis for select gates with a statistically significant increase in attendance contemporaneous with fire-driven closure events.

Arch Rock Closures

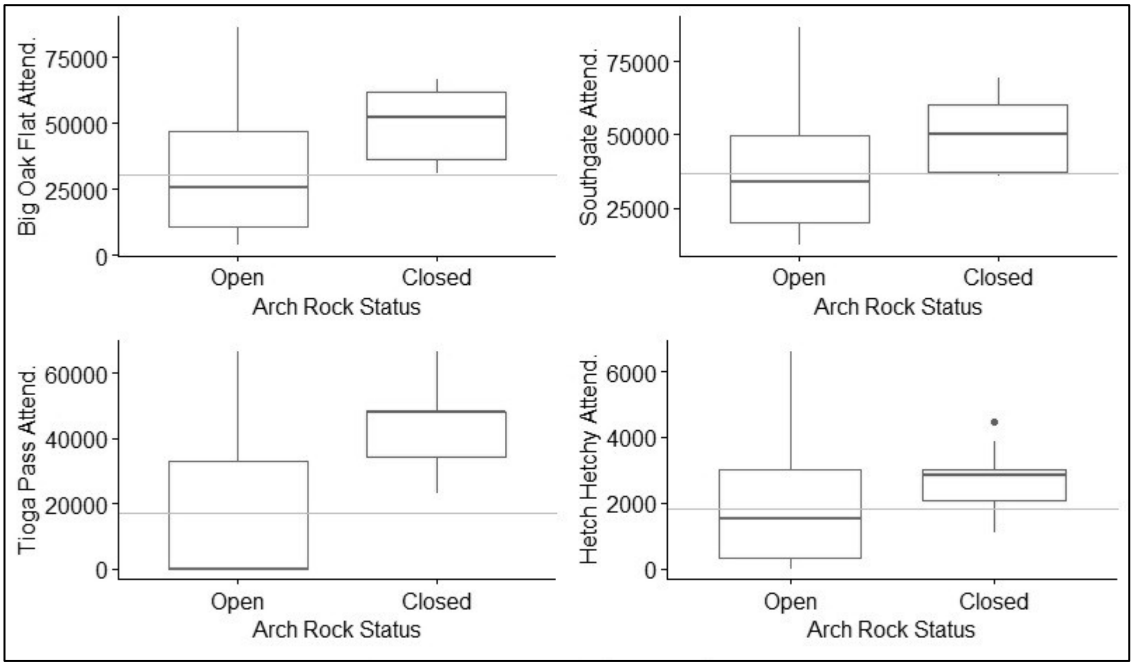

Figure 9- Box plots representing shifts in attendance across gates when Arch Rock corridor is Open and Closed (fire), along with mean annual attendance indicated via the gray abline. Source: Author.

Table 10- Statistical results for ANOVA, comparing corridor status (Open/Closed) to Attendance fluctuations for Arch Rock corridor. Source: Author.

.Gate Impacted	*Gate Influenced*	*Open Mean Attendance*	*Closed Mean Attendance*	*Relative % Change (+/-)*	*F Statistic*	*Pr(>F)*
Arch Rock Mean Attendance: 32,455	Big Oak Flat	29513	49982	+ 69.36	8.89	0.00317**
	Hetch Hetchy	1796	2717	+ 51.28	3.174	0.0761
	South	36358	50603	+ 39.18	5.593	0.0188*
	Tioga Pass	16043	45611	+ 184.31	16.22	0.59e-05 ***

There were 6 instances of fire-driven closures to the Arch Rock corridor between 2000 and 2019. Arch Rock is approximately mid-way between Big Oak Flat and

South Gate corridors. Arch Rock corridor passes through the Merced River canyon and is regularly subject to fire-flood-landslide cycles. Significant increases in Tioga Pass attendance are representative of seasonality, as Arch Rock entrance is open year-round, and Tioga Pass closes in the winter.

Big Oak Flat Closures

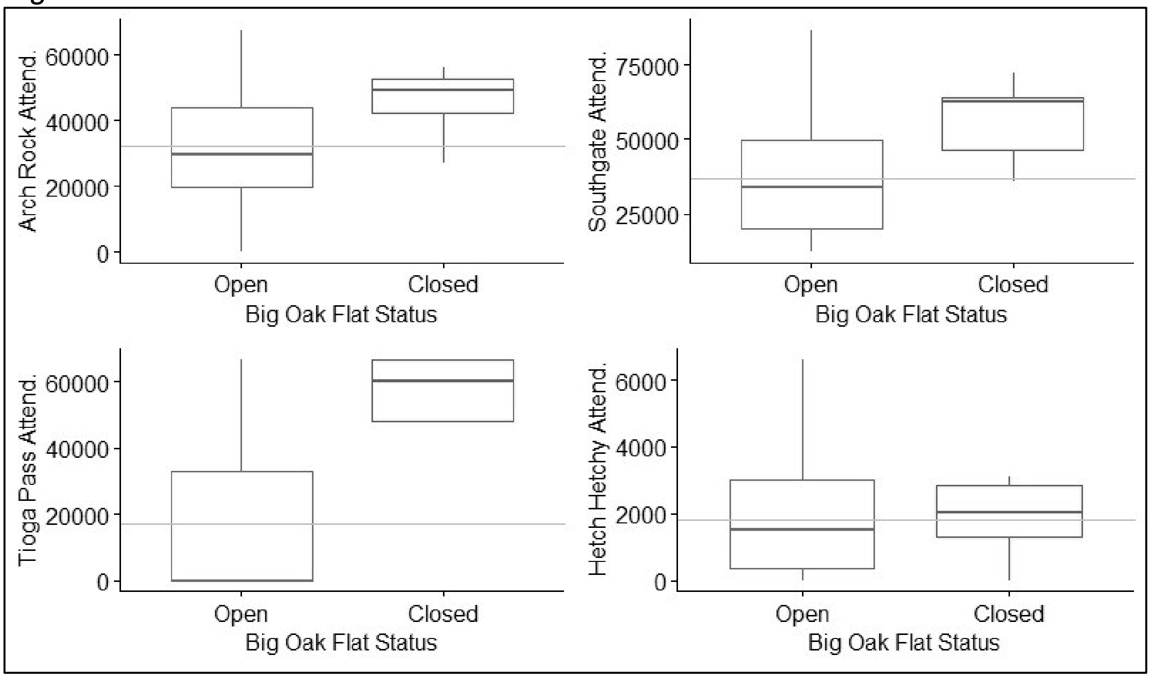

Figure 10- Box plots representing shifts in attendance across gates when Big Oak Flat corridor is Open and Closed (fire), along with mean annual attendance indicated via the gray abline. Source: Author.

Table 11- Statistical results for ANOVA, comparing corridor status (Open/Closed) to Attendance fluctuations for Big Oak Flat corridor. Source: Author.

Gate Impacted	*Gate Influenced*	*Open Mean Attendance*	*Closed Mean Attendance*	*Relative % Change (+/-)*	*F Statistic*	*Pr(>F)*
Big Oak Flat (BOF- shared corridor) Mean Attendance: 30,281	Arch Rock	32043	46153	+ 44.03	6.687	0.0103 *
	Hetch Hetchy	1828	1918	+ 4.92	0.023	0.878
	South	36324	55817	+ 53.66	8.308	0.00431 **
	Tioga Pass	15932	57743	+ 262.43	26.47	5.6e-07 ***

There were 4 instances of fire-driven closures to the Big Oak Flat corridor between 2000 and 2019. Big Oak Flat offers the most direct access (driving) from California's Bay Area, featuring major international airports in San Francisco, Oakland, and San Jose. Significant increases in Tioga Pass attendance are representative of seasonality, as Big Oak Flat entrance is open year-round, and Tioga Pass closes in the winter. We may infer significant shifts to the southernmost entrance station – South Gate - in deference to the most direct transportation corridors (Highway 99) as well as gateway community amenities and available resources (Oakhurst). Private vehicle corridors between Big Oak Flat and Arch Rock are via the narrow winding Highway 49- known for scenic views, but not travel efficiency.

South Gate Closures

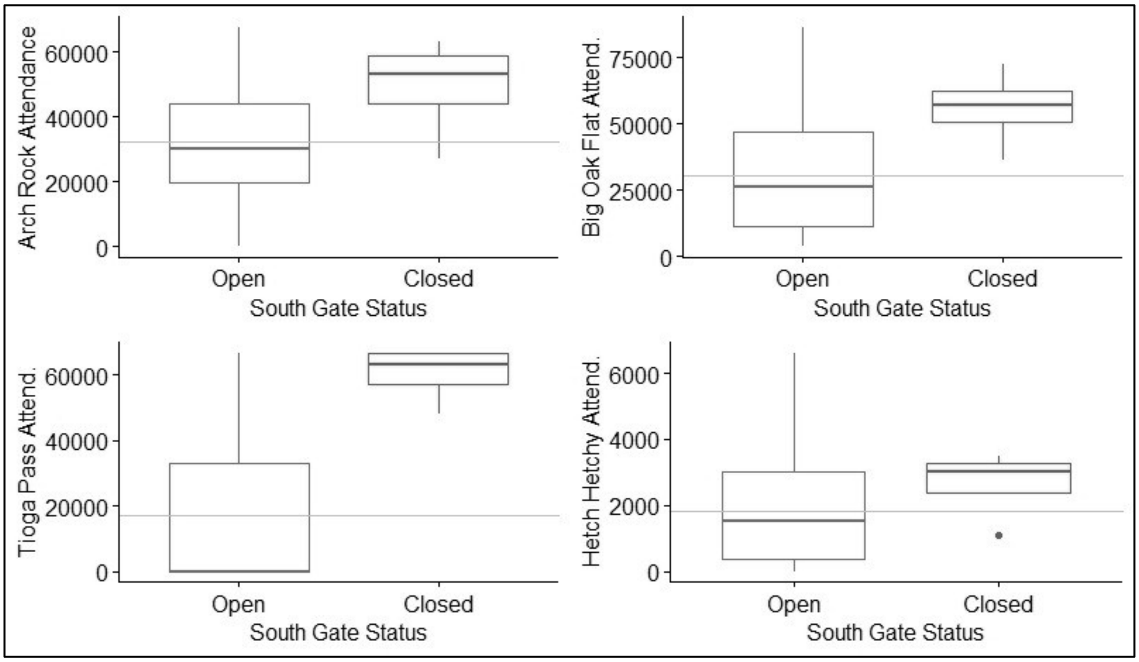

Figure 11- Box plots representing shifts in attendance across gates when South Gate corridor is Open and Closed (fire), along with mean annual attendance indicated via the gray abline. Source: Author.

Table 12- Statistical results for ANOVA, comparing corridor status (Open/Closed) to Attendance fluctuations for South Gate corridor. Source: Author.

Gate Impacted	*Gate Influenced*	*Open Mean Attendance*	*Closed Mean Attendance*	*Relative % Change (+/-)*	*F Statistic*	*Pr(>F)*
South Mean Attendance: 36,893	Arch Rock	32170	49294	+ 53.23	5.678	0.018 *
	Big Oak Flat	29850	55696	+ 86.59	6.37	0.0123 *
	Hetch Hetchy	1817	2645	+ 45.57	1.156	0.283
	Tioga Pass	16421	60294	+ 267.18	16.21	7.6e-05 ***

There were 4 instances of fire-driven closures to the South Gate corridor between 2000 and 2019. This corridor offers the first point of access to Yosemite National Park for visitors travelling from the Interstate 5 and Highway 99 corridors in California's Central Valley. Additionally, this would be the first point of access for visitors 'doing the loop,' by visiting other popular destinations across

California, including not just other public lands and National Parks such as Sequoia-Kings Canyon, but also major attractions stretching from Disneyland to San Francisco. South Gate consistently has the highest mean attendance month to month.

Tioga Pass Closures

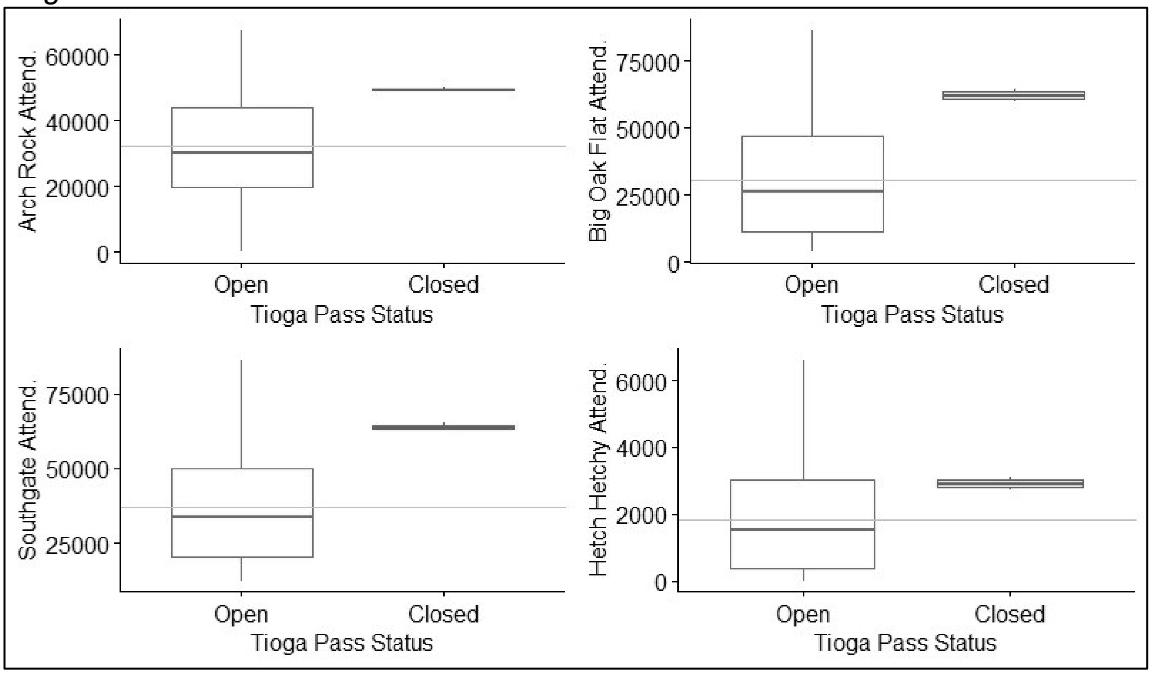

Figure 12- Box plots representing shifts in attendance across gates when Tioga Pass corridor is Open and Closed (fire), along with mean annual attendance indicated via the gray abline. Source: Author.

Table 13- Statistical results for ANOVA, comparing corridor status (Open/Closed) to Attendance fluctuations for Tioga Pass corridor. Source: Author.

Gate Impacted	*Gate Influenced*	*Open Mean Attendance*	*Closed Mean Attendance*	*Relative % Change (+/-)*	*F Statistic*	*Pr(>F)*
Tioga Pass Mean Attendance: 17,152	Arch Rock	32312	49487	+ 53.15	2.846	0.0929
	Big Oak Flat	30014	62009	+ 106.6	4.893	0.0279*
	Hetch Hetchy	1822	2908	+ 59.60	1.001	0.318
	South	36666	63868	+ 74.19	1.156	0.283

Tioga Pass is the furthest removed entrance station and corridor from Yosemite Valley, located on the eastern slope of the Sierra Nevada mountains, as well as the only eastern access to Yosemite National Park. There are only two noted fire-caused road closures along the Tioga Pass corridor during the 2000-2019 window. Limitations associated with low sample size are further discussed in the latter section on Confounding Factors and Challenges. In both closure instances, all other gates experienced an increase in visitation. Notably, the increase in visitation at Big Oak Flat (Tuolumne County) is statistically significant (within consideration of constraints). Big Oak Flat is the next closest entrance station to Tioga Pass.

4.4.2 Economic Fluctuation Results

After understanding where visitors displace to during closure events, we can compare this to see if there is a correlation between spending and shifts in visitation counts. To identify preliminary correlation between attendance and county sales tax incomes, we plotted the dependent variable (attendance) against county sales tax income to verify positive correlation.

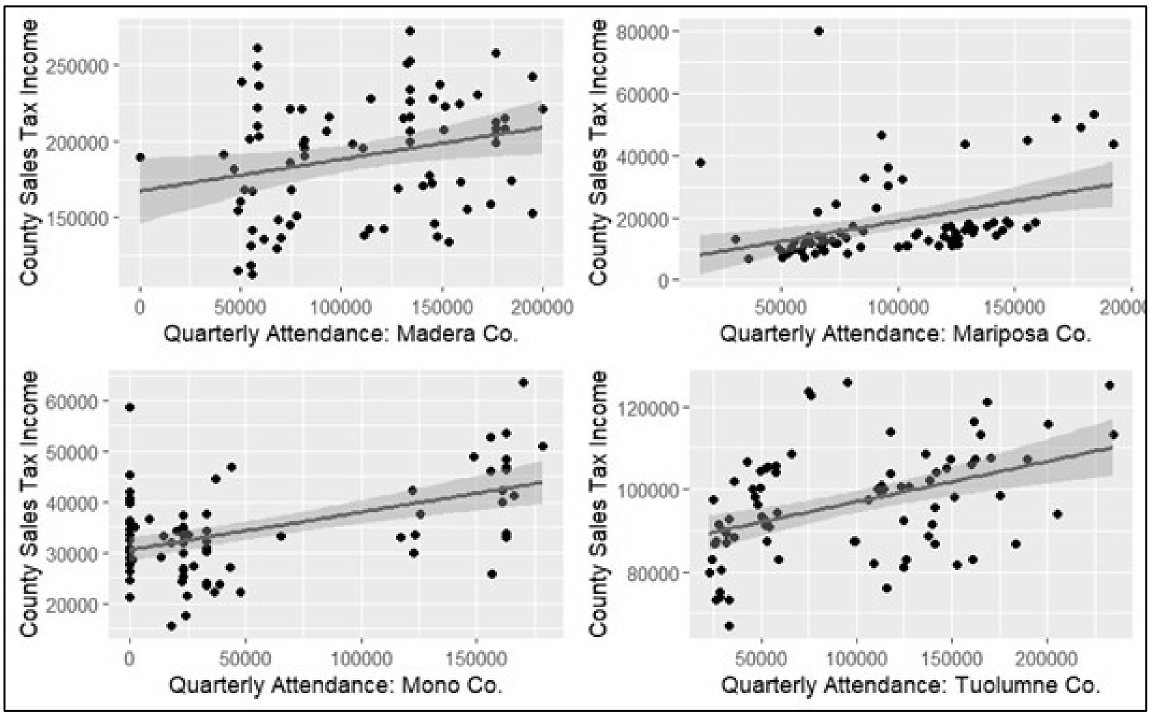

Figure 13- Plots for each county indicate positive relationships between quarterly attendance and quarterly sales tax revenue by county and corresponding corridor. Source: Author.

Before and after conversion based on inflation, we still see consistent trends in increasing spending overall, corresponding to upward trends in National Park attendance, excluding Covid years (NPS IRMA, 2021). For the statistical analysis for each category, values were limited to Quarter 3 (July, August September), as it is peak fire season. All but one closure in the sample occurred in Quarter 3. By limiting analysis to Quarter 3, this ensured we were analyzing comparable months.

However, this positive correlation did not directly translate into statistically significant fluctuations in taxable spending during regular open periods and closures due to fire hazards during the analysis of variance (ANOVA) analyses, as demonstrated in supplemental Tables A-C. Therefore, we then subdivided analyses into three subcategories of tax data from the parent dataset to further distill the potential influence of partial closures on displacement ‘gate to gate,’; Food and Drink Stores, Eating and Drinking Places, and Gasoline Stations, where Pr(>F) is less than 0.10.

ANOVA analysis of categorically subset data indicates several statistically significant relationships between entrance station status and gas spending in other counties. For example, when South Gate (Madera County) experiences closures, there is a statistically significant increase in gas spending in Tuolumne County. In addition, all analyses of ‘gate to gate’ gas spending shifts return increases in mean gasoline sales tax earnings, ranging from minor increases of just over 1% to over 35%. All closures resulted in increases to mean Gasoline Station sales tax, though only three locations’ increases were statistically significant. Results for spending in Food and Drink Stores and Eating and Drinking Places were inconsistent, with only two of 24 analyses resulting in a statistically significant fluctuation – results for these latter categories did not have any consistent trends like that of wholly positive increases in Gasoline Station sales tax. All but two results were between +/-10 percent in fluctuation.

4.4.3 Confounding Factors and Challenges

There are several challenges and confounding factors to recognize in this study on contemporaneous visitor displacement and spending around Yosemite National Park. First, while wildfire occurrence and intensity are increasing in the American West, fire occurrences (N=61) within the context of this study fall short statistically significant population sizes for applied statistics in managerial contexts of N >100 (Singh and Masuku, 2014). Due to the lower sample size of fires, it is difficult to distill economic influence of displacement on the three analyzed sales tax categories. While there are few notable statistically significant fluctuations in sales tax income, it is critical to note that the fluctuations in means, though comparatively minor, still represent large values in real dollars for rural, tourism-based economies. Headwaters Economics reports that three of the four key corridor counties depend significantly on private-sector jobs based on travel and tourism: Mono County (68%) , Mariposa County (43%), Tuolumne County (29%), and Madera County, with its strong connection to Central Valley agriculture at a 15% (Headwaters Economics, 2022). Therefore, this study approach should be repeated longitudinally as additional events and data become available. Despite low statistical sample sizes available for analysis, results are supplemented and ground-truthed through anecdotal evidence.

Second, this study utilizes two data aggregations at two temporal scales. Closure data were aggregated from days per fire to days per month to align with monthly Yosemite attendance. This may introduce bias in grouping, as one fire could burn through the end of one month into the beginning of another. The second aggregation for analyses of movement with spending as a proxy is the aggregation of monthly attendance up to quarterly. This is required, as tax data are not available at any granularity smaller than the three-month quarter. This aggregation may result in obscuring outliers. In both instances of aggregation, we lose the specificity of data at their initial collection granularity. Analyses may be rerun should increasingly granular data become publicly available.

A third challenge in analysis of contemporaneous visitor displacement and spending is being unable to determine visitor sources – where people are travelling *to* Yosemite from. Points of trip initiation may impact where visitors divert to should their initial access point close resulting from management strategy decisions to close routes due to environmental threats. For example, when South Gate closes, we see a statistically significant increase at the Big Oak Flat and Tioga Pass Gates – which would be the most direct access points for visitors from the Bay Area and Southern California, respectively. Given that we do not have point of origin information, we cannot draw conclusions about *why* specific gates are chosen during displacement.

4.5 Discussion and Conclusions

Our results indicate that Yosemite National Park visitors' displacement actions depend mainly on the primary corridor choice's proximity to other gates- they are displacing spatially, not temporally, represented through statistically significant increases in mean attendance. Most notably, during Tioga Pass fire-generated corridor closures, the singular statistically significant increase in attendance occurred at the Big Oak Flat corridor, the closest drive-time for visitors who still want to access Yosemite. When accessing Yosemite with Tioga Pass closed, the nearest pass is Highway 178 (Sonora Pass) to the north, offering access to the Big Oak Flat Corridor. The closest southerly route to cross the Sierra Nevada and access Yosemite if diverted from Tioga Pass would be State Route 178 (Walker Pass), hours out of the way to the south.

Previous studies emphasize incorporating deliberate and strategic visitor dispersal to decrease negative impacts to degradation hotspots in Yosemite National Park (Gladfelter and Mason, 2012; Walden-Schreiner and Leung, 2013). Our attendance results at various gates during closure events indicate visitors are choosing to *not* disperse, as visitation rises at entrances remaining open during closure events. Visitors opting to utilize the next-closest ingress corridor reinforces negative impacts of condensed visitation and degradation instead of the goals of dispersed visitation across the greater region to reduce overuse, such as the goals of Yosemite National Park Geotourism Initiative (Gladfelter and Mason, 2012).

In non-emergency instances, limited corridors may prove beneficial as limited infrastructure can be a mitigating factor for demand, with improved accessibility increasing demand (Tverijonaite et al., 2018). In a region already overburdened by demand, yet limited in infrastructure capacity, Yosemite has repeatedly undergone reconfigurations of existing corridors (Federal Highway Administration, 2016). However, within the context of closure events and limited options for ingress corridors, there are additional risks to visitors displacing to the next nearest corridor during a closure event. As the number of routes further decreases, visitor density along open routes increases, contributing to increased wait times to access Yosemite. Shifted access patterns may then disrupt first responders and emergency services. Within these rural communities, geography can be a major contributor to increased (slowed) response times, increased distance to medical services, and increased fatalities during emergencies (Gonzalez, 2006). While corridors pass through rural regions, within the immediate vicinity of Park boundaries and within Yosemite itself, traffic experiences are recognizably urban – with backlogs, limited parking, and even roundabouts.

Within the context of fire, traffic congestion due to displacement to limited corridors may delay first responders. Navigating through and waiting in traffic congestion increases fuel utilization and extends burn durations, as fire burns exponentially quicker over time (Brent and Beland, 2020). Daily summer arrivals to entrance stations peak between 3 pm and 4 pm, leading to wait times upwards of a half hour (Yosemite Gateway Partners, 2022). Extended wait times of a half hour exist when all gates are open. With varied gates closed and visitors displaced, condensing access through fewer entrance stations dramatically increases entrance wait times.

The risk potential for new fire ignitions is exacerbated through the increased presence of people and vehicles displaced to limited routes, further compounded by the day's lowest relative humidity and atmospheric turbulence (Taylor, 2020). With fire behavior shifting due to anthropogenic climate change, visitors attempting to access Yosemite before 6 am and after 4 pm correspond with warmer, dryer conditions. In contrast, night and early mornings were previously associated with decreased fire activity (Balch et al., 2022). In regions with wider roads, response can adapt to increased traffic volumes – this is not possible in the Greater Yosemite region due to legislative and geologic constraints, such as the steep Merced River Canyon corridor, regularly impacted by rock falls, and restricted from expansion by the Wild and Scenic Rivers Act.

Response to route disruptions at additional National Parks in the Sierra Nevada were recently demonstrated in Lassen Volcanic National Park. Lassen was closed entirely to visitors to facilitate uninterrupted firefighting equipment movement during the Dixie Fire in Summer 2021- forcing dispersal, rather than allowing for, visitor-choice displacement of select corridors. Additionally, the KNP Complex (a complex being a collection of contemporaneous regional fires managed as one) in Sequoia-Kings Canyon National Parks began with closures of the highly visited Generals Highway corridor in mid-September 2021. Closures expanded throughout the fire's duration to include intra-park corridors and additional entrance stations, then the entire park by the month's end (Inciweb, 2021). Two recent fires demonstrate challenges with both responders and public regional movement (Amaro, 2022). The Washburn Fire ignited within Yosemite boundaries and burned outward from park, impacting park communities (Wawona), whereas the Oak Fire began external to Yosemite's boundaries, impacting a gateway community (Mariposa/Midpines), and impacted ingress and egress routes. Similar to Yosemite, Lassen Volcanic and Sequoia-Kings Canyon National Parks have a limited number of ingress and egress corridors, impacting visitor movement, park personnel, and emergency resources during hazard events. Additionally, tourism-dependent gateway communities near these parks have close economic ties to seasonal visitor flows, like the gateway communities surrounding Yosemite and other parks.

Our results further existing conversation on contemporaneous economic impacts, as preceded by Kim and Jakus (2019) and Duffield (2013), of large, catastrophic wildfires. While the data verify that visitors choose to displace spatially to another ingress route, we find few significant fluctuations in economic inputs to local economies, despite spatial displacement – potentially reflecting people being ‘creatures of habit’ who do not deviate from their regular routines. Increases in need-based spending (e.g., gasoline) indicate people are passing through gateway communities – and stopping to fill their gas tanks at least. However, increases are not reflected in routine-based spending (e.g., eating lunch at a restaurant). This is supported by three statistically significant gasoline station sales tax income increases. Gasoline station sales tax consistently increases contemporaneous to fire events. Entrance station closures may not significantly impact meal routines and habits. Due to limited ingress options from physical path dependency, visitors must fuel up along their new route. Moving forward, fluctuations to economic inputs on local economies may shift due to post-Covid day use reservation systems updates forcing stability in, and temporal distribution of, visitors.

By expanding systems thinking in relation to transportation networks as comparatively simple binary inputs – open/closed, in/out, moving/stationary- managers and gateway communities can better manage visitor access and gateway engagement (McCool, 2022). Thereby, circular, causal relationships of closures can be disrupted intentionally to improve dispersion. During displacement events, partner organizations and communities may capitalize on visitor through flux with marketing targeted at open corridors through novel methods. Specifically, agencies and localized visitor bureaus – designed to positively influence visitor dispersion into communities - could co-locate informational kiosks or visitor centers in gateway communities.

Increased promotion of neighboring communities’ resources and recreational opportunities may result in increased dispersion. New marketing and visitor communications approaches, particularly phone applications, may increase visitation and spending in gateway communities and direct visitors to activities (Oppegard and Shine, 2014). Public land management agencies, Yosemite included, across multiple scales from local through federal, are increasingly utilizing mobile apps to supplement web and paper-based information. Management recommendations for positively influencing dispersion should have clearly stated goals and objectives (Riley et al., 2015). Managerially subjective promotion of alternative dispersion activities is temporally relevant considering the extended Covid-19 pandemic, where visitors may desire reduced interpersonal contact (Miller-Rushing et al., 2021). Tailoring communication to specific motivating factors and similar opportunities may influence spatial behavior, and thereby dispersion into gateway communities- whether visitors are hoping to feel a sense of isolation from other humans (wilderness experience), learning (museum locations), or achievement (hiking or scenic opportunities) (Smith et al., 2021). Dispersion into gateway communities supplemented by mobile devices benefits local economics, provides recreationists with increased control over routine, and promotes self-guided and smart (technology) tourism for activities with analogous motivations (Shen, 2020).

Visitation displacement findings across gates during partial closure events at Yosemite National Park supplement previous studies by Gladfelter and Mason (2012), Duffield et al. (2013), and Kim and Jakus (2019), specifically within parks and public lands management context. We demonstrate that visitors are displacing amongst entry gates contemporaneous to fire hazard events. We show that visitors still access their destination through spatial displacement despite disturbances to initial ingress points. Our results demonstrate statistically significant shifts in spending in non-habit-based, trip-specific gasoline spending and mixed fluctuations in spending in habit-based categories associated with meal spending. Policymakers and emergency response agencies may utilize the information for decision making, such as proactively utilizing forced dispersal by closing all corridors as seen in Lassen Volcanic National Park, supported by statistical insights that visitation is displacing, thereby concentrating, in increasingly limited available corridors. Additionally, land management agencies may utilize displacement findings to implement or update reservation system policies to further entrance station efficiency, visitor experience, and staff and visitor safety. Future research would benefit from carrying out this study longitudinally to better understand potential changes in contemporaneous attendance displacement trends and hazard’s economic impacts in the National Park and surrounding gateway communities.

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4.6 Appendix A

Analysis of Variance Results by Category

Table 14- Sales Tax Income Category: Gasoline Stations.

Gate Impacted	*County Influenced*	*Open Mean Gas Tax Rev (Q3)/1000*	*Closed Mean Gas Tax Rev (Q3)/1000*	*% Change in Gas Tax Revenue (+/-)*	*F*	*Pr(>F)*
Arch Rock (Mariposa) 6 closures	Madera County	61254	62220	+ 1.55	0.009	0.925
	Mono County	12800	13083	+ 2.20	0.071	0.794
	Tuolumne County	19507	21683	+ 11.15	0.746	0.399
Big Oak Flat (Tuolumne) 4 closures	Mariposa County	3706	4309	+ 16.27	2.519	0.13
	Madera County	57214	78865	+ 37.84	4.353	0.0514*
	Mono County	12492	14458	+ 15.74	3.012	0.0998*
Hetch Hetchy (Tuolumne)	No Hetch Hetchy Rd closures were identified during data collection					
South (Madera) 4 closures	Mariposa County	3158	4150	+ 31.41	1.832	0.193
	Mono County	12659	13788	+ 8.92	0.893	0.357
	Tuolumne County	19134	24262	+ 26.80	3.647	0.0723*
Tioga Pass (Mono) 2 closures	Madera County	61167	64940	+ 6.17	0.06	0.809
	Mariposa County	3822	3864	+ 1.10	0.006	0.94
	Tuolumne County	19968	21879	+ 9.57	0.24	0.63

Table 15- Sales Tax Income Category: Eating and Drinking Locations.

Gate Impacted	*County Influenced*	*Open Mean Eating and Drinking Tax Rev (Q3)/1000*	*Closed Mean Eating and Drinking Tax Rev (Q3)/1000*	*% Change in Eating and Drinking Tax Revenue (+/-)*	*F*	*Pr(>F)*
Arch Rock (Mariposa) 6 closures	Madera County	29,899	30,125	+ 0.75	0.011	0.917
	Mono County	17,157	17,106	- 0.30	0.003	0.958
	Tuolumne County	18,679	19,177	+ 2.70	0.311	0.584

Big Oak Flat (Tuolumne) 4 closures	Mariposa County	5726	5691	- 0.61	0.004	0.948
	Madera County	29475	31936	+ 8.35	1.083	0.312
	Mono County	17233	16774	- 2.66	0.181	0.676
Hetch Hetchy (Tuolumne)	No Hetch Hetchy Rd closures were identified during data collection					
South (Madera) 4 closures	Mariposa County	5,696	5810	+ 2.00	0.046	0.833
	Mono County	17,262	16,660	- 3.49	0.313	0.583
	Tuolumne County	19,060	17,903	- 6.07	1.355	0.26
Tioga Pass (Mono) 2 closures	Madera County	29943	30186	+ 0.81	0.00	0.941
	Mariposa County	5693	5947	+ 4.46	0.13	0.723
	Tuolumne County	18974	17513	- 7.70	1.207	0.286

Table 16- Sales Tax Income Category: Food and Drink Stores.

Gate Impacted	*County Influenced*	*Open Mean Shop Tax Rev (Q3)/1000*	*Closed Mean Shop Tax Rev (Q3)/1000*	*% Change in Shop Tax Revenue (+/-)*	*F*	*Pr(>F)*
Arch Rock (Mariposa) 6 closures	Madera County	32305	32325	+ 0.06	0	0.993
	Mono County	6494	6519	+ 0.38	0.009	0.926
	Tuolumne County	13704	13114	- 4.31	0.219	0.645
Big Oak Flat (Tuolumne) 4 closures	Mariposa County	4275	4626	+ 8.21	1.227	0.283
	Madera County	32966	29693	- 9.93	1.786	0.198
	Mono County	6528	6356	- 2.63	0.298	0.592
Hetch Hetchy (Tuolumne)	No Hetch Hetchy Rd closures were identified during data collection					
South (Madera) 4 closures	Mariposa County	4229	4810	+ 13.74	3.812	0.0666*
	Mono County	6561	6274	- 4.37	1.083	0.313
	Tuolumne County	14054	11420	- 18.74	4.025	0.0601*
Tioga Pass (Mono) 2 closures	Madera County	32554	30123	- 7.47	0.519	0.481
	Mariposa County	4308	4686	+ 8.77	0.783	0.388
	Tuolumne County	13711	11876	- 13.38	0.945	0.344

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