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Viewsheds and Recreation Demand: Approaches for Capturing Visual Qualities of the Landscape Post-Fire

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Abstract: Spatial data metrics are commonly used to capture environmental quality for recreation and visitation studies. Spatial data and tools, such as viewshed analysis, provide methods to incorporate spatial attributes into nonmarket valuation studies of consumer preferences, like portraying changes in visual-sensory qualities (e.g., from wildfires). We review the use of viewsheds in the nonmarket valuation literature and summarize insights from viewshed-based studies in other disciplines. We offer a conceptual framework for how to incorporate viewsheds into recreation demand studies, including to capture post-fire landscape changes. We discuss recent innovations in methods and data and identify avenues for future research.

Keywords: Wildfire, viewshed, nonmarket valuation, recreation demand, landscape

JEL classification: Q51, Q57

Running head: Viewshed and Recreation Demand Post-Wildfire

Short description: We discuss the ways incorporating viewsheds into nonmarket valuation studies, and in particular, recreation demand models can help us to better understand visitor behavior and capture post-fire landscape changes.

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Introduction

Wildfires are a regular occurrence during summer in the Western United States. These fires can cause changes in ecosystem composition, structure, and function. Wildfire size and severity have increased over time (Parks and Abatzoglou, 2020), highlighting the importance of studying the effects of wildfires on visitor behavior and changes in visual qualities of recreation sites on public land. Visitation data from several sources can be used to address these questions including wilderness permits (e.g., Hilger and Englin, 2009), surveys of visitors' post-fire (e.g., Hesseln et al., 2004) and crowdsourced data (e.g., White et al., 2023). Increased availability of spatial data and tools presents

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opportunities to incorporate visual qualities into recreation demand models in a systematic way. Visual qualities include measures related to the impact of wildfire, like burn severity.

The term "viewshed" is defined as "the natural environment that is visible from one or more viewing points" (*Merriam-Webster Dictionary*, n.d.). Visual quantification methods exist, including viewshed analysis, a type of visibility analysis used to quantify the portion of a landscape that is visible, given a set of observation points (Ingris et al., 2022). Viewshed analysis has been used in many applications and disciplines, but primarily outside of nonmarket valuation. Examples include prioritizing land areas for further conservation along a scenic drive in a National Park (Anderson and Rex, 2019), quantifying levels of terrain ruggedness, greenness, and privacy in the viewsheds of new exurban developments (Vukomanovic et al., 2018), and assessing the visual impacts of expanding an electricity transmission line through a National Forest (Palmer, 2019).

Several studies within the nonmarket valuation literature use or allude to the concept of viewshed, and some quantify viewsheds using a geographic information systems (GIS)-based approach. Most are hedonic property value (e.g., Hindsley et al., 2013; Hugett et al., 2008; McCoy and Walsh 2018; Shultz and Schmitz, 2008; Stetler et al., 2010) or stated preference studies (e.g., Arnberger et al., 2018; Molina et al., 2019; Mueller et al., 2018; Sánchez et al., 2016; Tanner et al., 2022). To the best of the authors' knowledge, within the recreation demand literature, only Baerenklau et al. (2010) and Garnache and Lupi (2018) have explicitly used viewshed analysis. Nonmarket valuation studies incorporate the viewshed concept and analysis in a few ways, including the area which is visible: (1) from a home (e.g., Hindsley et al., 2013; Hugett et al., 2008; McCoy and Walsh, 2018; Shultz and Schmitz, 2008; Stetler et al., 2010), (2) within a set radius of a parking lot (e.g., Garnache and Lupi, 2018), (3) from trailheads and trails within their study area (e.g., Baerenklau et al., 2010), and (4) based on a distance metric to divide the landscape into bands of immediate foreground, foreground, middle ground and background (e.g., Molina et al., 2019).

This paper provides an overview of the literature related to the incorporation of viewshed analysis to capture the visual qualities of recreation sites pre- and post-wildfire. We present key terminology, methods, and a conceptual framework for the incorporation of viewshed analysis into recreation demand models and offer future directions for research in this area.

Viewshed Analysis and Valuing Visible Space

How people relate to and, by extension, value what they see involves understanding the visual qualities of a site at different distances from the point where the person is located. Intuitively, this can be thought of as categorizing what is visible relative to distance from the object to the viewer (Molina et al., 2018). In the arts, artists compose paintings based on relative distance from the artist to objects in the foreground, middle ground, or background, using depth to delineate proximity. Spatial tools are available to capture viewsheds in commonly used GIS software including ArcGIS and QGIS. The specific method to use will depend on the research question and may be constrained by the geographic scope of the problem, the specific conditions of the study area, the availability of data (e.g., vegetation, elevation and/or Light Detection and Ranging (LiDAR)), and/or computer processing power.

Hedonic property value studies used viewshed analysis to capture the visual impact of an amenity or disamenity on a home value. Views of a lake (e.g., Shultz and Schmitz, 2008) or the Gulf of

Mexico (e.g., Hindsley et al., 2013) are generally considered amenities whereas a burn scar post-wildfire may be a disamenity (e.g., Huggett et al., 2008; Stetler et al., 2010). Huggett et al. (2008) and Stetler et al. (2010) looked specifically at the effects of wildfire and environmental amenities on property values, the former in Chelan County, Washington, and the latter in Northwest Montana, and find that a property's proximity and view of wildfire-burned areas results in large and persistent negative effects on property values.

Land cover spatial attributes are more commonly incorporated into stated preference studies through their depiction in maps and images to convey potential landscape changes (e.g., Arnberger et al., 2018; Mueller et al., 2018; Sánchez et al., 2016; Tanner et al., 2022). Some studies measure visual changes at a site through responses to a series of photographs showing the scene as if individuals were present, also known as the "first perspective". This approach has been used to assess visual changes due to bark beetle infestations (Arnberger et al. 2018) and visual changes due to wildfire (Sanchez et al. 2016; Tanner et al. 2022). Visitors typically direct their attention towards changes in the environmental quality of their nearby surroundings or foreground. Sánchez et al. (2016) find that burn severity and the proportion of the viewshed burned have no statistically significant effects on visitor preferences for a site; which they posit may be due to the novelty of burned trail conditions at the time. Tanner et al. (2022) find visitors prefer sites with trees and/or along streams, rivers or lakes, whereas post-fire visible effects are less preferred. Mueller et al. (2018) investigated willingness to pay (WTP) for wildfire suppression and wildfire restoration in Flagstaff, Arizona, an area with views of mountain peaks. They find respondents' WTP for forest restoration is inversely proportional to their distance from the proposed wildfire restoration area. However, respondents in their study with a high-quality view of mountain peaks had a lower WTP, a difference driven by a desirable focal point in the background of the viewshed.

Incorporating Viewshed into Recreation Demand Models

Recreation Demand Model Framework

Recreation demand models are nonmarket valuation approaches used to quantify the value of recreation opportunities. In recreation demand models, the values of environmental goods and services not bought and sold in the marketplace are captured through the instrumental value of nature, namely, how the specific components of nature facilitate the recreational activity being studied (e.g., forests or alpine meadows for hiking, bird species for birdwatching, etc.). Models may include measures to capture whether a site has views, or the type of landcover or vegetation represented (e.g., Englin et al., 2006; Haab and McConnell, 2002; Kolstoe et al., 2018), unless these are being captured by site-level fixed effects. Thus, viewshed analysis may be a relevant tool to capture visitors' *ex ante* expectations of site attributes (Baerenklau et al., 2010; Garnache and Lupi, 2018).

The repeated discrete choice random utility maximization (RUM) model underlies many recreation demand models, and it uses variation in trips across space and time to empirically estimate the parameters of the model which are subsequently used to derive estimates of marginal WTP. We will use a RUM model here, to lay out our example conceptually. The recreation demand model within a RUM framework assumes individual i is taking a trip to site j at time t because this choice gives them higher utility than other sites in their choice set. Researchers often specify the indirect utility function to be linear in parameters and variables for ease of estimation (Haab and McConnell, 2002). The indirect utility function for a recreation demand model for individual *i* at site *j* and time *t* is:

$$U_{jt}^{i} = \alpha(Y^{i} - C_{jt}^{i}) + \theta' A_{jt} + \varepsilon_{jt}^{i} \quad (1)$$

The variables in the model include income net of travel cost, $Y^{i} - C_{jt}^{i}$, where $Y^{i}$is income and C_{jt}^{i} is travel cost to site *j*, a vector of site attributes A_{jt} and the error term, ε_{jt}^{i}. The estimated parameters include α the marginal utility (MU) of net income and a vector of θs, which are the MUs of site attributes. The ratio of these θ MUs to the MU of net income, α, are then used to monetize the values of site attributes, capturing the tradeoffs between travel costs and site attributes.

The inclusion of site attributes in a recreation demand model depends on what attributes are salient to the recreational visitor (Haab and McConnell, 2002). Historically, information on site attributes included in recreation demand models comes from guidebooks or databases of site attributes maintained by government agencies or nonprofits. Nowadays, however, sources of attribute information may also include GIS and/or remote sensing data (Englin et al., 2006; Haab and McConnell, 2002; Kolstoe et al., 2018). For example, the Monitoring Burn Severity and Trends (MTBS) program provides GIS data on wildfires in the United States since 1984, to include burn area and severity. These variables can be incorporated into the model by including a vector of wildfire-related site attributes B_{jt}, to equation (1):

$$U_{jt}^{i} = \alpha(Y^{i} - C_{jt}^{i}) + \theta_{1}' A_{jt} + \theta_{2}' B_{jt} + \varepsilon_{jt}^{i} \quad (2)$$

Vector B_{jt} includes variables that measure the scope and/or severity of a wildfire at a site. Incorporation of variables in vector B_{jt} range from using an indicator variable for the presence to continuous measures, such as percentage burned, or percentage burned by burn severity category. The use of continuous measures may facilitate the use of estimates for benefit transfer purposes.

Considerations When Measuring Viewshed

The viewshed provides a starting point of which landscape or vegetation site attributes need to be quantified in the model to represent the visual qualities visitors may see at sites post-wildfire. RUM models rely on the assumption that environmental quality influences the value of the outdoor experience. Thus, it is necessary to consider what people are seeing, particularly for closer views, in contrast to sights that are visible but far away from the recreation activity. Elevation and vegetation are key features on the landscape that may factor into what is visible to a visitor at a site. For example, visibility in forested areas depends on the canopy height, crowdedness of trees, and the density of the vegetation in the understory. In a limited viewshed, any view of the burn scar may be obscured by vegetation or steep ridgelines. In an expansive viewshed, however, elevation and vegetation are such that the individual can see much of the landscape around them, including a sizable portion of the burn scar. Figure 1 provides a conceptual representation of a viewshed in forested landscapes, with photographs illustrating differences in the visual experience and how it depends on the composition of the surrounding forest. In a limited viewshed, as shown in Panel A of Figure 1, an individual's view is limited to the dense trees and vegetation immediately surrounding them. In an expansive viewshed, as shown in Panel B of Figure 1, trees and understory are sparse and an individual's view includes areas well outside of their immediate surroundings.

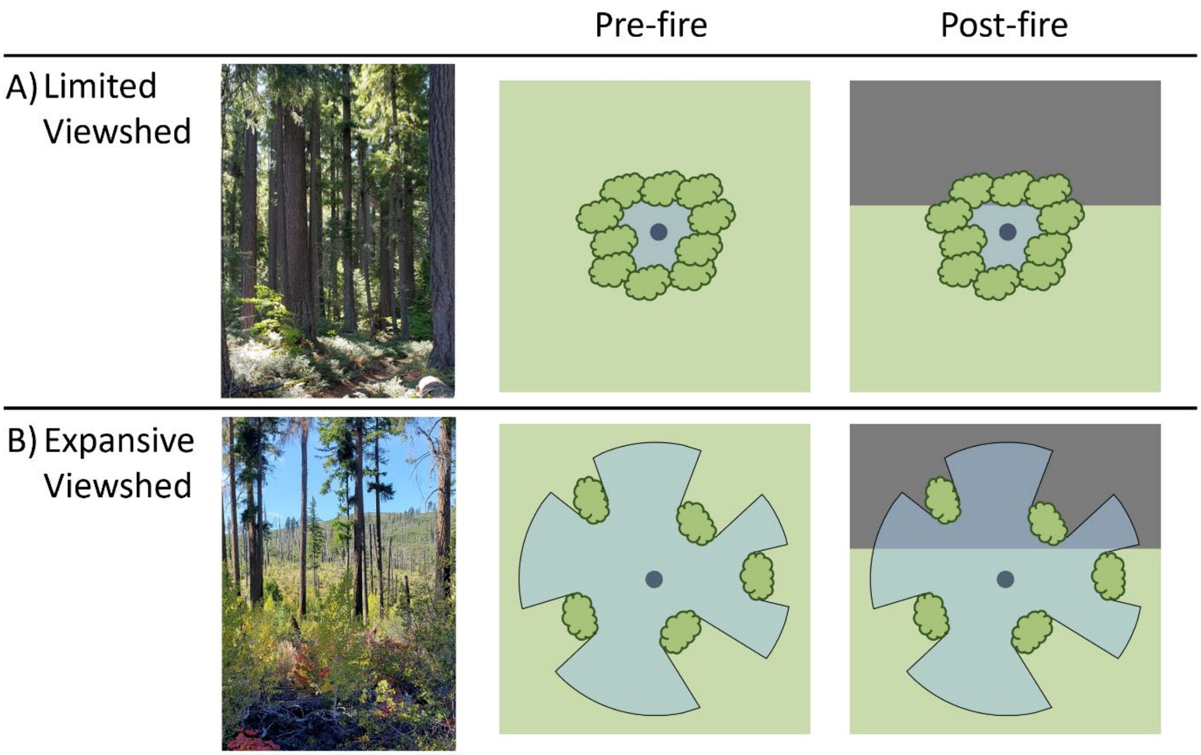

Figure 1. Conceptual visualization of a limited viewshed (A) and an expansive viewshed (B) in different types of forested landscapes. Pictures in panels A and B offer a real-world example of the visual experience of an individual standing in each type of viewshed along the Jefferson Lake Trail in the Deschutes National Forest in Oregon. In the conceptual images, the blue area is the area visible to an individual (represented by the point), which may be obstructed by physical barriers such as trees or understory vegetation. The forested areas are represented in green and the burn scar in the post-fire case is represented in grey. Photographs in Figure 1 were taken by Sonja Kolstoe on October 1st, 2023.

Figure 2 provides a real example from the 2017 Eagle Creek fire in Oregon in the Columbia River Gorge, east of the Portland metro area, illustrating the impact of elevation and land cover on viewsheds. The area experienced a mixed burn severity as shown in Panel A. Panel B and C are photographs taken in May 2023, almost six years after the fire. Panel B illustrates a limited view whereas Panel C illustrates an expansive viewshed. Panel B is taken from the lower portion of the Herman Creek Trail and illustrates how this trail within the burn area experienced a low intensity burn. Notably, charring exists on the lower portions of trees, but the area has largely regenerated. Panel C is taken from the lower portion of the Eagle Creek Trail looking at a moderate-to-high intensity burn area across the canyon from the trail. The area is marked by standing deadwood and fewer living trees.

The early research on viewsheds focused on accounting for elevation (Inglis et al., 2022). An elevation-only approach may be suitable in some landscapes (e.g., prairies, deserts, alpine areas), but this approach may not be suitable in others, like forests (Vukomanovic et al., 2018). The review article by Inglis et al. (2022) points to the need to understand vegetation structure, as it influences what is visible.

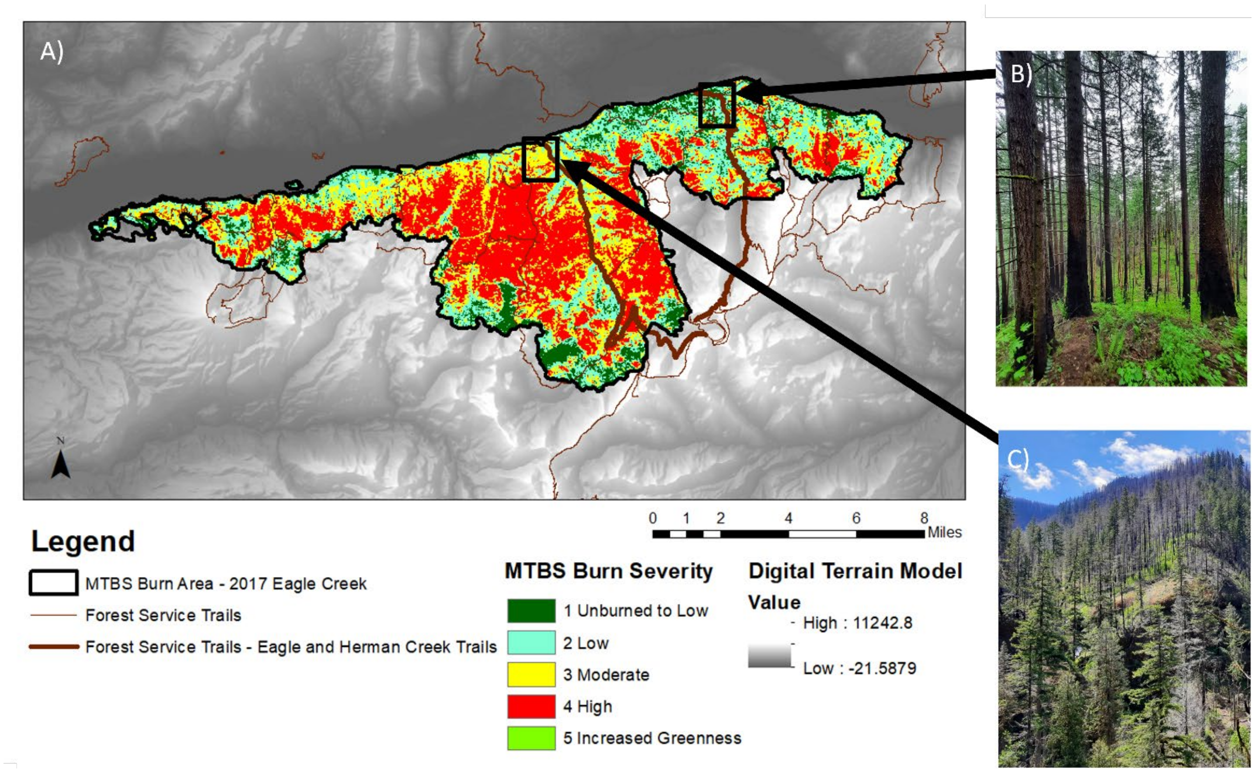

Figure 2. Panel A depicts the burn severity of the 2017 Eagle Creek Fire in the Columbia River Gorge. The fire started on September 2nd, 2017, on the Eagle Creek Trail after a firework was tossed into the steep river canyon. Most of the growth in fire size happened September 4th and 5th; in total 48,861 acres burned (USDA Forest Service 2018). Panels B and C are photographs of two trails in the area: B from the Herman Creek Trail (e.g., limited viewshed) and C from the Eagle Creek Trail (e.g., expansive viewshed). The arrows for Panels B and C indicate approximately the vantage point for each photograph. The map uses data from Oregon's Department of Geology and Mineral Industries (Oregon Spatial Library 2023), USDA Forest Service (2023), and MTBS (2023). Photographs were taken by Sonja Kolstoe on May 8th, 2023.

Analyses are increasingly using LiDAR data or LiDAR-derived surface models over bare-earth elevation models to compute 3D viewsheds. High resolution LiDAR data is now readily available for much of the United States (US), and searchable through the US Geological Survey 3DEP LidarExplorer map interface. Recently, Lang et al. (2023) published a global canopy height database based on 2020 satellite imagery. Vegetation may also vary seasonally, such as presence or absences of leaves on deciduous trees, thus altering the viewshed on a seasonal basis.

The incorporation of visual analyses into recreation demand models will need to consider the specific recreational activity. For some, it may be reasonable to conduct the viewshed analysis for a single point or a general area. Other contexts where the activity assumes travel along a specific route may require accounting for the viewshed along the entire route of the path or trail. The type of recreational activity may be evident based on the data source, or it may be deduced using appropriate analytical methods (Winder et al., 2022).

Directions for Future Research

Real-time and near-real-time data about conditions at recreational sites sometimes already exists (e.g., online forums, web cams at sites or along highways and interstates, and weather forecasts). People use these data to inform their decisions about where to go for any given excursion. Data extracted from posted photographs and site or road webcams about local conditions may be a potentially fruitful option to pursue to understand how high frequency vs. low frequency *ex ante* measures of site conditions impact model results. This may be particularly important if using data from a platform that provides updates on site conditions.

The increased availability of spatial and recreation data over time, in the form of administrative datasets as well as crowdsourced data, presents researchers with opportunities to study visitor behavior in response to changes in visual qualities of sites post-wildfire. When such data are available over time, researchers may consider testing to see whether visitor behavior is consistent, or whether changes in visual qualities of a site post-wildfire led to a structural change in visitation patterns. Posts consisting of images and text provide a record for researchers to process and can permit the researcher to learn more about an individual's experience at a site (Dagan and Wilkins, 2023). Text posts can be used to classify experiential qualities and setting characteristics (e.g., Derrien et al., 2023). The qualitative results may help inform the specification of the quantitative recreation demand model. Such complementary qualitative and quantitative analysis methods may provide an avenue for new insights to inform land managers about visitor behavior and experiences at recreation sites on public lands.

Conclusion

Wildfire burn scars are increasingly becoming a visual element of different vantage points in the landscape. Recent GIS and remote-sensing datasets provide measures of environmental quality with greater spatial and temporal resolution than previously available. Advances in spatial tools (e.g., viewshed analysis), computing power and higher-resolution spatial and temporal data from crowdsourced sources make it possible to leverage the higher-resolution biophysical data to account for what outdoor recreation visitors to public lands may see and experience. Visual analysis techniques offer a systematic approach to quantifying viewshed in recreation demand models, which allows us to improve our understanding of changing visitor behavior in response to visual quality changes at sites post-wildfire.

References

Arnberger, A., Ebenberger, M., Schneider, I. E., Cottrell, S., Schlueter, A. C., von Ruschkowski, E., Venette, R., Synder, S.A., and Gobster, P. H. 2018. "Visitor preferences for visual changes in bark beetle-impacted forest recreation settings in the United States and Germany." *Environmental Management* 61: 209-223.

Baerenklau, K. A., González-Cabán, A., Paez, C., and Chavez, E. 2010. "Spatial allocation of forest recreation value." *Journal of Forest Economics 16*(2): 113-126.

Coulston, J. W., Moisen, G. G., Wilson, B. T., Finco, M. V., Cohen, W. B., Brewer, C. K., Modeling percent tree canopy cover—A pilot study: Photogrammetric Engineering and Remote Sensing, v. 78, no. 7, p. 715–727, at https://doi.org/10.14358/PERS.78.7.715

Dagan, D. T., and Wilkins, E. J. 2023. "What is "big data" and how should we use it? The role of large datasets, secondary data, and associated analysis techniques in outdoor recreation research." *Journal of Outdoor Recreation and Tourism* 100668.

Derrien, M., Winder, S., Wood, S., Miller, L., Lia, E., Cerveny, L. Lange, S., Kolstoe, S.H., McGrady, G., and Roth, A. (2023). "Where wilderness is found: Evidence from 70,000 trip reports" Accepted at *People and Nature.*

Garnache, C., and Lupi, F. 2018. "The Thomas Fire and the Effect of Wildfires on the Value of Recreation Services in Southern California" Selected Paper prepared for presentation at the *2018 Agricultural & Applied Economics Association Annual Meeting*, Washington, D.C., August 5-August 7. Available online at https://ageconsearch.umn.edu/record/274028/files/Abstracts_18_05_21_12_33_08_47__84_209_21_119_0.pdf. [Accessed: August 5, 2023].

Haab, T. C., and McConnell, K. E. 2002. "Modeling the Demand for Recreation." In *Valuing Environmental and Natural Resources*. Edward Elgar Publishing, pp. 137-150.

Hesseln, H., Loomis, J. B., and González-Cabán, A. 2004. "The effects of fire on recreation demand in Montana." *Western Journal of Applied Forestry* 19(1): 47-53.

Hilger, J., and Englin, J. 2009. "Utility theoretic semi-logarithmic incomplete demand systems in a natural experiment: Forest fire impacts on recreational values and use." *Resource and Energy Economics* 31(4): 287-298.

Hindsley, P., Hamilton, S. E., and Morgan, O. A. 2013. "Gulf views: Toward a better understanding of viewshed scope in hedonic property models." *The Journal of Real Estate Finance and Economics 47*: 489-505.

Huggett, R. J., Murphy, A. E., and Holmes, P. T. 2008. "Forest disturbance impacts on residential property values." *The Economics of Forest Disturbances: Wildfires, Storms, and Invasive Species.* pp. 209-228.

Kolstoe, S., Cameron, T. A., and Wilsey, C. 2018. "Climate, land cover, and bird populations: differential impacts on the future welfare of birders across the Pacific Northwest." *Agricultural and Resource Economics Review* 47(2): 272-310.

Lang, N., Jetz, W., Schindler, K., and Wegner, J. D. 2023. "A high-resolution canopy height model of the Earth." *Nature Ecology & Evolution*, 1-12.

McCoy, S. J., and Walsh, R. P. 2018. "Wildfire risk, salience & housing demand." *Journal of Environmental Economics and Management*, 91: 203-228.

Molina, J. R., González-Cabán, A., and y Silva, F. R. 2019. “Wildfires impact on the economic susceptibility of recreation activities: Application in a Mediterranean protected area.” *Journal of Environmental Management 245*: 454-463.

Monitoring Trends in Burn Severity (MTBS). 2023. Burned Areas Boundaries and Burn Severity Mosaics. Available online at https://mtbs.gov/direct-download. [Accessed August 16, 2023].

Mueller, J. M., Springer, A.E., and Lima, R.E. 2018. “Willingness to pay for forest restoration as a function of proximity and viewshed.” *Landscape and Urban Planning* 175: 23-33.

Oregon Spatial Data Library. 2023. Oregon LiDAR: Digital Terrain Model. Available online at https://spatialdata.oregonexplorer.info/geoportal/. [Accessed August 16, 2023].

Palmer, J. F. 2019. “The contribution of a GIS-based landscape assessment model to a scientifically rigorous approach to visual impact assessment.” *Landscape and Urban Planning 189:* 80-90.

Parks, S. A., and Abatzoglou, J. T. 2020. “Warmer and drier fire seasons contribute to increases in area burned at high severity in Western US forests from 1985 to 2017.” *Geophysical Research Letters* 47: e2020GL089858

Sánchez, J. J., Baerenklau, K., and González-Cabán, A. 2016. “Valuing hypothetical wildfire impacts with a Kuhn–Tucker model of recreation demand.” *Forest Policy and Economics 71*:63-70.

Shultz, S. and Schmitz, N. 2008. “Viewshed analyses to measure the impact of lake views on urban residential properties.” *The Appraisal Journal 76*(3): 224.

Stetler, K. M., Venn, T. J., and Calkin, D. E. 2010. “The effects of wildfire and environmental amenities on property values in northwest Montana, USA.” *Ecological Economics 69*(11): 2233-2243.

Tanner, S., Lupi, F., and Garnache, C. 2022. “Estimating visitor preferences for recreation sites in wildfire prone areas.” *International Journal of Wildland Fire*, 31(9): 871-885.

USDA Forest Service. 2023. National Forest System Trails. Available online at http://data.fs.usda.gov/geodata/edw/datasets.php. [Accessed August 16, 2023].

USDA Forest Service. Eagle Creek Fire: At-A Glance Facts. May 2018. Available online at https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd565120.pdf [Accessed: August 5, 2023].

USDA Forest Service. 2023. USFS Tree Canopy Cover Datasets. Available online at https://data.fs.usda.gov/geodata/rastergateway/treecanopycover/#table1 [Accessed October 3, 2023].

USGS. 2023. What is Lidar data and where can I download it? Available online at https://www.usgs.gov/faqs/what-lidar-data-and-where-can-i-download-it [Accessed October 12, 2023].

“viewshed” *Merriam-Webster.com*. 2023. https://www.merriam-webster.com/ dictionary/ viewshed [Accessed August 29, 2023]

Vukomanovic, J., Singh, K. K., Petrasova, A., and Vogler, J. B. 2018. "Not seeing the forest for the trees: Modeling exurban viewscapes with LiDAR." *Landscape and Urban Planning* 170: 169-176.

White, E. M., Winder, S. G., and Wood, S. A. 2023. "Applying Novel Visitation Models using Diverse Social Media to Understand Recreation Change after Wildfire and Site Closure." *Society and Natural Resources* 36(1): 58-75.

Winder, S. G., Lee, H., Seo, B., Lia, E. H., and Wood, S. A. 2022. "An open-source image classifier for characterizing recreational activities across landscapes." *People and Nature* 4(5): 1249-1262.

Wood, S. A., Winder, S. G., Lia, E. H., White, E. M., Crowley, C. S., and Milnor, A. A. 2020. "Next-generation visitation models using social media to estimate recreation on public lands." *Scientific Reports* 10(1): 15419.