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Degradation of visible autumn icons and conservation opportunities: trends in deciduous forest loss in the contiguous US

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Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Data Availability

Analyses reported in this article can be reproduced using publicly available data. Final outputs are available on OSF at [link].

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ABSTRACT

Temperate deciduous forests are one of the most visible biomes on Earth because of their autumn aesthetics and because they harbor some of the most heavily populated regions, including in the United States. Their location and their ability to attract leaf-peeping outsiders may provide greater opportunities for people to experience nature, which has been linked to greater conservation action. However, accelerating human modification of landscapes means continued forest loss and fragmentation. We use spatial overlay analyses to quantify recent (1984-2016) and predicted (2016-2050) forest disturbance in each U.S. ecoregion and the extent to which each ecoregion falls into protected areas. Almost all ecoregions saw a steady decline in deciduous forest cover between 1985 and 2016 with some of the top ecoregions for autumn aesthetics being underrepresented in the protected areas network and vulnerable to additional losses. Generally, ecoregions undergoing greater proportional losses have greater forest area and are less represented in the protected areas network. Under worst-case forecasting scenarios, losses are predicted to continue. However, environmentally focused scenarios suggest there is still opportunity to reverse deciduous forest loss in some ecoregions. The large difference in forest loss estimates in the predictions scenarios emphasizes the importance of human approaches to economic growth and sustainability in securing environmental stability. Increasing public exposure to temperate forests may help ensure conservation of more natural areas and preserve the quantity and quality of autumn forest viewing.

Key-words: temperate forest, autumn foliage, conservation, habitat loss, ecoregion

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INTRODUCTION

Accelerating landscape change threatens biodiversity and climate stability worldwide, with significant implications for society through a degradation of nature's benefits to people (i.e., "ecosystem services"; Sweeney et al. 2004; Carvahlo and Szlafsztein 2019; Colvin et al. 2019; Gómez-Baggethun et al. 2019; IPBES 2019; Diaz et al. 2020). The science makes clear that transformative action is needed to address the threats to nature, with major initiatives being developed at national and international levels (e.g., Convention on Biological Diversit 2020; Udall 2020). In addition to preservation and restoration strategies (e.g., Scolozzi et al. 2014; Minin et al. 2017; Dinerstein et al. 2019; Peng et al. 2019; Clancy et al. 2020; Dinerstein et al. 2020), approaches to addressing these crises also focus on increasing opportunities for people to experience natural environments: when people experience and connect with nature they are also more likely to act in ways that benefit the Earth (Ives et al. 2016). Axiological relationships are often tied to feelings of duty and stewardship and previous research suggests a similar connection between a person's bond with nature and the probability of them taking conservation action (Cooper et al. 2016). Connections with nature can happen emotionally, physically, intellectually, and spiritually, but most often, through direct experience (Wang et al. 2016). Identifying highly visible environments and understanding past and future changes that people have or will experience is therefore important to understanding one social dimension of conservation.

Although they only cover ~7.5% of Earth's terrestrial land surface, temperate forests harbor exceptional biodiversity and carbon stores (Keith et al. 2009; Pan et al. 2011; Thurner et al. 2013; Hofmeister et al. 2019) and provide key ecosystem services such as water filtration (Dellasala et al. 2011; Brandt et al. 2014). Further, temperate forests are one of the most visible biomes because heavily populated and developed regions, including in the United States, are located in or near the biome (Haddad et al. 2015). At the same time, a long history of settlement and development has had dramatic impacts on the forest ecosystems and their biological diversity (e.g., Thompson and Jones 1999; Pennington et al. 2010; Gunn et al. 2019). Although most of the major land changes may have occurred in the past, more recent anthropogenic landscape modifications mean continued forest loss, biodiversity loss, and degradation of ecosystem services. Understanding recent and predicted temperate forest conversion can help identify spatial patterns and clarify the critical role of human perceptions of change that may affect forest conservation.

Among the ecosystem services provided by temperate forests, the biome provides a unique aesthetic appeal with economic benefits. About 15% of the tree species of the temperate regions of the world change their leaf color from green to yellow or red in autumn, a percentage that can reach 70% of species in some regions of the US (Archetti et al. 2013). In this respect, deciduous forests are very visible cultural icons. Autumn aesthetic is often described in terms of its "complex", "reassuring", and "soothing" qualities, attracting outsiders seeking beauty and relaxation in special landscapes (Eroglu and Demir 2016). As such, many U.S. cultures and economies rely on autumn traditions and 'leaf-peeping' tourism, which contributes billions of dollars each year - up to a quarter of annual tourism profit - to state economies of the eastern US. (Sandifer et al. 2015). Continued landscape conversion threatens to reduce the autumn color display directly (i.e., tree removal) or indirectly through increased forest stress, and introduces concerns for reduced future aesthetic values and tourism revenues. Ultimately, fewer visitors to these forests also means fewer opportunities to connect people and nature.

Given the current global biodiversity and climate crises, more conservation action is needed and there is much to gain with temperate forests as a connection between people and nature. The reverse - using personal connections with nature to specifically emphasize

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conservation of temperate forests - could also result in major contributions to biodiversity conservation and climate mitigation. In the U.S., temperate forests are home to high species endemism and hotspots of imperiled species biodiversity (Rosa and Malcom 2020). Additionally, intact temperate forests remove sufficient atmospheric CO_2 to reduce national annual net emissions by 11% and may be a significant contributor to global climate stabilization (Moomaw et al. 2019; Dinerstein et al. 2020). Studies suggest that U.S. temperate forests are likely to act as carbon sinks for decades to come (Finzi et al. 2020). However, most remaining examples of natural ecosystems are fragmented and highly modified with intensive human activities, posing continued threats to biota, carbon sequestration, and ecosystem aesthetics.

General trends in temperate forest land use emphasize continuing rural residential development largely driven by aesthetics, climate and access to recreation. Beyond the direct impacts of forest loss and expanding anthropogenic land cover, biodiversity and ecosystem functions are likely to suffer from fragmentation; forests are smaller, more isolated, and have a greater area located near the edge. This includes degraded ecosystem processes, reduced species diversity, and changes in species all of which affect autumn foliage viewing quality (Haddad et al. 2015; Zhang et al. 2017; Zhang et al. 2019). Fragmentation of the forested landscape may also contribute to the degradation of autumn foliage viewing in a way that is less apparent than with outright forest loss: viewers may fail to notice the creeping change in viewing quality until it is too late (i.e., boiling frog theory; Soga and Gaston 2018).

Given the importance of temperate forests as a symbol for nature and its beauty, forest conversion is among the most distinct impacts of human activity on the forest environment and aesthetic. Here, we identify to what extent each U.S. ecoregion is characterized by deciduous forest and quantify recent (1984-2016) and predicted (2016-2050) forest disturbance. The ability to identify regions with high leaf-peeping opportunities and regions where color has been lost to landscape conversion will help to inform connections between people and the forested landscape. Additionally, understanding patterns of temperate forest loss is also critical to guide efforts in biodiversity conservation and climate mitigation: new calls to expand the protected areas network will benefit from this and subsequent knowledge that builds upon these findings.

METHODS

We used spatial overlap analyses to estimate temperate forest losses and predicted changes across the U.S., summarized by EPA Level 2 ecoregions (EPA 2006). Two main datasets were used for these calculations. First, the National Land Cover Database (NLCD, MRLC) uses digital change detection methods to identify land cover, changes and trends for the United States (Homer et al. 2020). The recently released NLCD 2016 database offers improved cyclical updating of U.S. land cover and associated changes, greatly advancing large-area land cover monitoring through an updated suite of products (Yang et al. 2018). Forest disturbance date is a key addition that provides opportunities to examine US forest cover change patterns from 1985-2016. This product combines information from the NLCD 2016 change detection, land cover classification, and the LANDFIRE Vegetation Change Tracker (VCT) disturbance product to assess where disturbance occurred for forest areas every 2-3 year interval.

NLCD classifications for deciduous forest and mixed forest were included in areal calculations for available years between 1992 - 2016 (1992, 2001, 2004, 2006, 2008, 2011, 2013, and 2016). Modelled historical land use and land cover for the contiguous US were used for estimating forest cover prior to 1992 (Sohl et al. 2018). Similarly, all forest change identified in the forest disturbance date dataset between 1985-2016 that occurred on

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deciduous and mixed forest land cover types was used in calculations of forest loss for each ecoregion.

Second, we used spatially explicit predictive models of 2050 land cover to estimate future forest losses (Sohl et al. 2014). The most extreme forecasting scenarios which were developed based on characteristics consistent with the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emission Scenarios were used to understand the variability in predictions. The economic-growth scenario assumes rapid economic development and very high population growth globally (15 billion by 2100). Initial estimates of this scenario suggest over 500,000 km2 of deciduous/mixed forests would be lost in the contiguous US between 2005 and 2100 (Sohl et al. 2014). The sustainability scenario reflects an emphasis on environmental protection and social equity with lower rates of global human population growth and intermediate levels of economic development. In contrast, over 59,000 km2 of forests may be gained between 2005 and 2100 under the environmental protection scenario (Sohl et al. 2014).

Data on protected areas are from the PADUS 2.0 database. We use U.S. Geological Survey's Gap Analysis Program (GAP) codes, which are specific to the management intent to conserve biodiversity. GAP 1 and 2 areas are managed in ways typically consistent with conservation and are considered 'protected' in this context. We used ArcGIS v. 10.7 (ESRI, USA) to produce maps and run analyses. Maps use the Albers Equal Area Conic projection.

RESULTS

Fourteen out of 20 contiguous US ecoregions have >1% of their area in deciduous or mixed forest, where deciduous forests are the majority ecosystem for two ecoregions (Table S1). The ecoregions with the greatest proportion of deciduous forest cover include the Atlantic Highlands in New England (62.0%), the Ozark/Appalachian forests (61.0%), and the mixed wood shield and plains in the upper Midwest (36.9%) (Figure 1a). Almost all ecoregions saw a steady decline in deciduous forest cover between 1985 and 2016, with exception of two prairie ecoregions and the central plains. In general, ecoregions with less forest cover saw greater percent change in deciduous forest area in the past two decades (logarithmic relationship, $r^2 = 0.14$) with highest percentage changes in the upper Gila Mountains (-82.2%), Tamaulipas (Texas) semi-arid plains (-79.9%), and Western Sierra Madre Piedmont (-70.8%) (Figure 1a). Overall, changes ranged from -82.2% to +2.25% for ecoregions and totaled -17.5% for the contiguous US.

Predictions of deciduous forest cover depended heavily on the scenario employed. The "economic growth scenario" resulted in higher rates of forest loss due to urban increase, agricultural expansion, and higher demand for forest products. Most ecoregions remain in decline by 2050 with the exception of deserts, Mediterranean California and Western Sierra Madre Piedmont. For the top leaf-peeping ecoregions, predicted percent change in forest cover is nearly equivalent to declines from 1985-2016 (Figure 1b). Under the "sustainability scenario," more than half of the ecoregions would have increasing forest cover by 2050. Generally, highest percent increases would occur in ecoregions with relatively low forest cover (logarithmic relationship, $r^2 = 0.12$).

Ecoregions for which deciduous forests make up at least a quarter of the land cover have anywhere between 2.5% and 22.8% protected areas coverage. Declines in forest cover between 1985 and 2050 (economic-growth scenario) exhibited a logarithmic relationship with protected areas coverage across ecoregions, with ecoregions undergoing greater proportional losses having greater forest area and being more often underrepresented in the protected areas network (Figure 2; $r^2 = 0.35$, $p = 0.03$). Under the "sustainability scenario,"

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ecoregions with higher forest cover, but low representation in the protected areas network (i.e., mixed wood plains and southeast plains) will see relatively higher gains in deciduous forest.

DISCUSSION

Forests are an essential component of the natural environment that offer profound aesthetic and spiritual benefits to humanity. As such, forests offer a unique and powerful way to connect people with environmental issues like the biodiversity and climate crises (Ives et al. 2018). Loss of forests, either in large tracts or piecemeal, results in a degradation of these benefits and decreases opportunities for quality experiences in nature (Nisbet et al. 2008; Zylstra et al. 2014; Soga and Gaston 2016). Here we documented extensive temperate forest loss through the context of fall color change. These losses may be changing how people experience nature, such as through the awe inspired by leaf peeping.
Cumulatively, we found that just under 55 million acres of deciduous or mixed forest were disturbed between 1985 and 2016. All ecoregions with deciduous forests incurred losses, but some were more dramatic than others. As expected, the extent of loss was related to the proportion of the ecoregion that is managed as multi-use or is lacking conservation mandates. Underrepresentation in the U.S. protected areas network means that temperate forests are susceptible to continued fragmentation and modification. Under worst-case forecasting scenarios, losses are predicted to continue. However, environmentally focused scenarios suggest there is still opportunity to reverse deciduous forest loss in some ecoregions. Increasing public exposure to temperate forests may help ensure conservation of more natural areas and preserve the quantity and quality of autumn forest viewing.
The top ecoregions for autumn aesthetics are experiencing relatively higher forest losses and are also relatively under-protected. Collectively, ecoregions with greater than a quarter of their area covered by deciduous/mixed forest saw a 16.5% decline in forest area. For these ecoregions, 93% of their lands are currently unprotected suggesting they may face further disturbance or fragmentation. The top ecoregions are also concentrated east of the Mississippi River, where there is less public land and more human disturbance, elevating the importance of restoration efforts (Jenkins et al. 2015; Rosa and Malcom 2020). Spatial incongruities in protected areas and forested ecoregions also impact other ecosystem values. For example, previous research indicates that the siting for current protected areas is often discordant with diversity-rich or carbon-rich areas of the country (Jenkins et al. 2015; Rosa and Malcom 2020). This means the remaining natural habitats in these areas are significantly under-protected; elevating their protections could contribute to both climate mitigation and biodiversity conservation. In particular, states across the Southeast harbor high levels of biodiversity and very few protected areas.

Additionally, trends show that ecoregions with lower forest cover generally experienced greater rates of decline in the past two decades; this suggests that the few cultural and habitat resources that deciduous forests provide in these areas are dwindling relatively fast. In the United States, conversion of privately owned rural lands into low-density residential development (i.e., exurban development) has increased five- to seven-fold between 1950 and 2000 and is the fastest growing type of land use (Suarez-Rubio et al. 2013). Exurban development is prominent in forested ecoregions with dispersed, isolated housing units embedded within a forest matrix. At a more local scale, topography will likely remain a significant constraining factor in development, allowing some areas to persist in forest cover while agricultural, residential and urban uses are concentrated in specific portions of the landscape (Wear and Bolstad 1998). However, land use may intensify without associated changes in land cover if development occurs under the forest canopy: in some cases, forest cover is increasing (rather than declining) with an increase in human population density and development. This suggests that estimates of forest cover and ecosystem impacts derived

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from satellite imagery are conservative and presents limitations to continued tracking and prediction of future trends in forest disturbance.

Projected patterns of land use suggest spatial heterogeneity and large variability in continued anthropogenic landscape modifications. Some ecoregions, mostly prairies and plains, may continue to see forest losses regardless of scenario. But for some, like the mixed wood plains (32.5% deciduous/mixed forest cover), which covers regions of the northeastern coast and upper Midwest, human behaviors could mean the difference between continued forest losses or reversal to gains. Models under the sustainability scenario suggest there is still time to reverse declining trends in deciduous forest loss; 21.5% increase in forest cover is projected for the top five forested ecoregions, collectively. However, even if forest loss is projected to slow or reverse, this may not directly equate to impacts to cultural ecosystem values because of lag times in forest responses to stress (Alexander et al. 2018). Additionally, these are net changes and do not capture spatial changes at a local level where the loss and gain of forest may be disjunct, ultimately resulting in more cumulative forest area, but also more fragmented forest patches. Ecoregions that lack protections will continue to experience greater forest disturbances, which is consistent with global analyses (d'Annunzio et al. 2015). These disturbances (e.g., exurban developments) are often close to protected areas and natural amenities raising concern about their ecological consequences, this is one of many stressors that deciduous forests will continue to face.

Centuries of exploitation demonstrate the resilience of temperate forests, but how much disturbance can be tolerated and what it may mean for forest health and fall colors is still under investigation. Currently, the majority of science on autumn colors focuses on the variation of color pigments and senescence timing with nutrient availability, gene expression, herbivory, and climatic factors. Additionally, there are studies on the impacts of fragmentation and degradation on other forest values such as habitat, but any connections to be made between these stressors and autumn aesthetic will be inferential at best given the current lack of science focused on direct relationships. Understanding the indirect impacts of exurban development and forest fragmentation on fall colors could be one way to generally quantify impacts to cultural ecosystem values without the extra complication of estimating monetary values. For example, under future climate change projections, greater summer heat-stress will cause abbreviated leaf coloration seasons for most tree species (Xie et al. 2018). However, temperature discrepancies which would typically be exacerbated by fragmentation may be dampened by the obscured edges between exurban and forest land covers, highlighting the importance of local- and landscape-scale features on microclimate heterogeneity (Latimer and Zuckerberg 2016; Arroyo-Rodriguez et al. 2017). In addition to landscape conversion, forests are experiencing increasing frequency, extent, and severity of natural disturbances, anthropogenic climate change, and a burgeoning global human population that imposes escalating demands on forests. The synergy of these stressors is even less understood. For example, stressed trees likely undergo earlier senescence and, depending on the stress, more complete coloration, but climate warming can delay timing (Schaberg et al. 2003; Faticov et al. 2019). Recent studies suggest increased vulnerability of temperate forests to disease and invasion during periods of stress, but impacts to autumn aesthetics are unknown. More research is needed to determine how forest loss and fragmentation relate to spatiotemporal changes in autumn color vibrancy and to the quality of human-nature connections.

The large difference in forest loss estimates in the predictions scenarios emphasizes the importance of human approaches to economic growth and sustainability in securing environmental stability. Scenic aesthetic is the most direct and immediate aspect via which people perceive and begin to value landscapes (Gobster et al. 2007; Sargolini 2013). Visually appealing and healthy ecological landscapes evoke positive emotions and promote

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the desire to protect such landscapes (Lee 2017; Gobster et al. 2007). Growing opportunities for U.S. conservation could work to forge deeper connections between humans and nature and motivate the public to take protective actions against detrimental environmental changes. In response to current global biodiversity and climate crises, science-driven guidance to protect 30% of global lands and seas by 2030 have made its way into US federal and state policy proposals. These proposals call for achieving more equitable access to public land, nature and a healthy environment for all communities. Given this framework, the potential benefits of protecting deciduous forests is manifold. In addition to preserving the visual aesthetics and spiritual connections that people make during autumn senescence, conserving temperate forests also means protecting many of the U.S.'s biodiversity hotspots and areas of high carbon potential. Additionally, forest conservation ensures more ecosystems will be more resilient to climate stresses (Xu et al. 2019). Therefore, encouraging the public to experience temperate forest autumn foliage may in turn have broad reaching conservation implications for the future

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REFERENCES

Alexander, J.M., L. Chalmandrier, J. Lenoir, et al. 2018. Lags in the response of mountain plant communities to climate change. *Global Change Biology* 24: 563–579.

Archetti, M., A.D. Richardson, J. O'Keefe, et al. 2013. Predicting climate change impacts on the amount and duration of autumn colors in a New England forest. PLoS ONE 8: e57373.

Arroyo-Rodriguez, V., R.A. Saldana-Vazquez, L. Fahrig, et al. 2017. Does forest fragmentation cause an increase in forest temperature? Ecological Research 32: 81–88.

Brandt, P., D.J. Abson, D.A. DellaSala, et al. 2014. Multifunctionality and biodiversity: Ecosystem services in temperate rainforests of the Pacific Northwest, USA. Biological Conservation 169: 362–371.

De Carvalho, R.M. and C.F. Szlafsztein. 2019. Urban vegetation loss and ecosystem services: The influence on climate regulation and noise and air pollution. Environmental Pollution 245: 844–852.

Clancy, N.G., J.P. Draper, J.M. Wolf, et al. 2020. Protecting endangered species in the USA requires both public and private land conservation. Scientific Reports 10: 11925.

Colvin, S.A.R., S.M.P. Sullivan, P.D. Shirey, et al. 2019. Headwater streams and wetlands are critical for sustaining fish, fisheries, and ecosystem services. Fisheries 44: 73–91.

Cooper, N., E. Brady, H. Steen, et al. 2016. Aesthetic and spiritual values of ecosystems: recognising the ontological and axiological plurality of cultural ecosystem 'services'. Ecosystem Services 21: 218–229.

d'Annunzio, R., M. Sandker, Y. Finegold, et al. 2015. Projecting global forest area towards 2030. Forest Ecology Management 352: 124–133.

DellaSala, D.A., J.R. Karr, D.M. Olson. 2011. Roadless areas and clean water. Journal of Soil and Water Conservation 66(3): 78A–84A.

Dinerstein, E., A.R. Joshi, C. Vynne, et al. 2020. A safety net to reverse biodiversity loss and stabilize Earth's climate. Science Advances 6: eabb2824.

Environmental Protection Agency. 2006. Ecoregions of North America. https://www.epa.gov/eco-research/ecoregions-north-america. Accessed February 25, 2021.

Eroglu, E. and Z. Demir. 2016. Phenological and visual evaluations of some roadside deciduous trees in urban area. Biological Diversity and Conservation 9: 143–153.

Faticov, M., A. Ekholm, T. Roslin, et al. 2019. Climate and host genotype jointly shape tree phenology, disease levels and insect attacks. Oikos 129: 391–401.

Finzi, A.C., M.A. Giasson, A.A. Plotkin et al. 2020. Carbon budget of the Harvard Forest long-term ecological research site: pattern, process, and response to global change. Ecological Monographs 90(4): e01423.

Gobster, P.H., J.I. Nassauer, T.C. Daniel. 2007. The shared landscape: what does aesthetics have to do with ecology? Landscape Ecology 22: 959–972.

bioRxiv preprint doi: https://doi.org/10.1101/2021.03.29.437570; this version posted March 29, 2021. The copyright holder for this preprint (which was not certified by peer review) is the author/funder, who has granted bioRxiv a license to display the preprint in perpetuity. It is made available under aCC-BY-NC-ND 4.0 International license.

Gómez-Baggethun, E., M. Tudor, M. Doroftei. 2019. Changes in ecosystem services from wetland loss and restoration: An ecosystem assessment of the Danube Delta (1960–2010). Ecosystem Services 39: 100965.

Gunn, J.S., M.J. Ducey, E. Belair. 2019. Evaluating degradation in a North American temperate forest. Forest Ecology and Management 43: 415–426.

Haddad, N.M., L.A. Brudvig, J. Clobert et al. 2015. Habitat fragmentation and its lasting impact on Earth's ecosystems. Science Advances 1: e1500052.

Hofmeister, J., J. Hošek, M. Brabec, et al. 2019. Shared affinity of various forest-dwelling taxa point to the continuity of temperate forests. Ecological Indicators 101: 904–912.

Homer, C., J. Deqitz, S. Jin, et al. 2020. Conterminous United States land cover change patterns 2001-2016 from the 2015 National Land Cover Database. ISPRS Journal of Photogrammetry and Remote Sensing 162: 184–199.

Ives, C.D., D.J. Abson, H. con Wehrden, et al. 2018. Reconnecting with nature for sustainability. Sustainable Science 13: 1389–1397.

Keith, H., B.G. Mackey, D.B. Lindenmayer. 2009. Re-evaluation of forest biomass carbon stocks and lessons from the world's most carbon-dense forests. Proceedings of National Academy of Sciences 106(28): 11635–11640.

Latimer, C.E. and B. Zuckerberg. 2016. Forest fragmentation alters winter microclimates and microrefugia in human-modified landscapes. Ecography 40: 158–170.

Lee, L.H. 2017. Perspectives on landscape aesthetics for the ecological conservation of wetlands. Wetlands 37: 381–389.

Di Minin, E., A. Soutullo, L. Bartesaghi, et al. 2017. Integrating biodiversity, ecosystem services and socio-economic data to identify priority areas and landowners for conservation actions at the national scale. Biological Conservation 206: 56–64.

Moomaw, W.R., S.A. Masino, E.K. Faison. 2019. Intact forests in the United States: proforestation mitigates climate change and serves the greatest good. Frontiers in Forests and Global Change 2(27).

Nisbet, E.K., J.M. Zelenski, S.A. Murphy. 2009. The nature relatedness scale: linking individuals' connection with nature to environmental concern and behavior. Environment and Behavior 41(5): 715–740.

Pan, Y., R.A. Birdsey, J. Fang, et al. 2011. A large and persistent carbon sink in the world's forests. Science 333(6045): 988–993.

Peng, J., A. Wang, L. Luo, et al. 2019. Spatial identification of conservation priority areas for urban ecological land: An approach based on water ecosystem services. Land Degradation and Development 30(6): 683–694.

Pennington, D.N., J.R. Hansel, D.L. Gorchov. 2010. Urbanization and riparian forest woody communities: Diversity, composition, and structure within a metropolitan landscape. Biological Conservation 143(1): 182–194.

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Rosa, L.D. and J. Malcom. 2020. Getting to 30x30: guidelines for decision-makers. https://defenders.org/sites/default/files/2020-07/getting-to-30x30-guidelines-for-decision-makers.pdf Accessed February 25, 2021.

Sandifer, P.A., A.E. Sutton-Grier, B.P. Ward. 2015. Exploring connections among nature, biodiversity, ecosystem services, and human health and well-being: opportunities to enhance health and biodiversity conservation. Ecosystem Services 12: 1–15.

Sargolini, M. 2013. Ecology vs aesthetics. In: Sargolini M (ed) Urban Landscapes. Springer, Milan, pp 5–10

Schaberg, P.G., A.K. van den Berg, P.F. Murakami, et al. 2003. Factors influencing red expression in the autumn foliage of sugar maple trees. Tree Physiology 23: 325–333.

Scolozzi, R., U. Schirpke, E. Morri, et al. 2014. Ecosystem services-based SWOT analysis of protected areas for conservation strategies. Journal of Environmental Management 146: 543–551.

Soga, M. and K.J. Gaston. 2016. Extinction of experience: the loss of human — nature interactions. Frontiers in Ecology and the Environment 14(2): 94–101.

Soga, M. and K.J. Gaston. 2018. Shifting baseline syndrome: causes, consequences, and implications. Frontiers in Ecology and the Environment 16(4): 222–230.

Sohl, T.L., R. Reker, M. Bouchard, et al. 2018. Modeled historical land use and land cover for the conterminous United States: 1938-1992: U.S. Geological Survey data release, https://doi.org/10.5066/F7KK99RR Accessed February 25, 2021.

Sohl, T.L., K.L. Sayler, M.A. Bouchard, et al. 2014. Spatially explicit modeling of 1992-2100 land cover and forest stand age for the conterminous United States. Ecological Applications 24: 1015–1036.

Suarez-Rubio, M., S. Wilson, P. Leimgruber, et al. 2013. Threshold responses of forest birds to landscape changes around exurban development. PLoS ONE 8: e67593.

Sweeney, B.W., T.L. Bott, J.K. Jackson, et al. 2004. Riparian deforestation, stream narrowing, and loss of stream ecosystem services. Proceedings of the National Academy of Sciences 101(39): 14132–14137.

Thompson, K. and A. Jones. 1999. Human population density and prediction of local plant extinction in Britain. Conservation Biology 13: 185–189.

Thurner, M., C. Beer, M. Santoro, et al. 2014. Carbon stock and density of boreal and temperate forests. Global Ecology and Biogeography 23: 297–310.

Wang, X., L. Geng, K. Zhou, et al. 2016. Mindful learning can promote connectedness to nature: Implicit and explicit evidence. Consciousness and Cognition 44: 1–7.

Wear, D.N. and P. Bolstad. 1998. Land-use changes in Southern Appalachian landscapes: spatial analysis and forecast evaluation. Ecosystems 1: 575–594.

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Xu, B., M.A. Arain, T.A. Black, et al. 2019. Seasonal variability of forest sensitivity to heat and drought stresses: a synthesis based on carbon fluxes from North American forest ecosystems. Global Change Ecology 26: 901–918.

Yang, L., S. Jin, P. Danielson, et al. 2018. A new generation of the United States National Land Cover Database: requirements, research priorities, design, and implementation strategies. ISPRS Journal of Photogrammetry and Remote Sensing 146: 108–123.

Zie, Y., X. Wang, A.M. Wilson, et al. 2018. Predicting autumn phenology: how deciduous tree species respond to weather stressors. Agriculture and Forest Metrology 250: 127–137.

Zhang, X.J., J. Chen, Q.Y. Li, et al. 2019. Color quantification and evaluation of landscape aesthetic quality for autumn landscape forest based on visual characteristics in subalpine region of western Sichuan, China. Journal Applied Ecology 31: 45–54.

Zhang, Z., G. Qie, C. Wang, et al. 2017. Relationships between forest color characteristics and scenic beauty: case study analyzing deciduous forests at sloped positions in Jiozhai Valley China. Forests 8: 63.

Zylstra, M.J., A.T. Knight, K.J. Esler, et al. 2014. Connectedness as a core conservation concern: An interdisciplinary review of theory and a call for practice. Springer Science Reviews 2: 119–143.

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TABLES & FIGURES

Table 1. Percent deciduous/mixed forest cover from 1985-2050 for ecoregions in the contiguous United States. Percent of the ecoregion that falls within protected areas managed consistently with biodiversity conservation (USGS PADUS 2018; GAP code 1 or 2) is included. For projected forest coverage, 2050a represents the economic-growth scenario and 2050b represents the sustainability scenario.

Ecoregion	Area	% Deciduous/Mixed Forest Cover												% Protected
Level II	(ha)	1985	1988	1991	2001	2004	2006	2008	2011	2013	2016	2050a	2050b	(PADUS)
Atlantic Highlands	1.51E+07	68.64	68.89	69.07	62.01	63.28	62.82	62.59	62.23	62.27	62.02	63.42	68.24	13.00
Ozark/Appalachian Forest	5.21E+07	65.12	65.18	65.16	60.12	61.39	60.93	60.87	60.68	60.93	60.97	57.57	63.75	8.61
Mixed Wood Shield	2.14E+07	43.29	43.52	43.76	38.72	37.08	36.86	36.95	37.00	37.11	36.94	38.14	42.22	22.85
SE Plains	1.03E+08	36.96	37.28	37.50	27.19	26.60	26.26	26.02	25.81	26.00	25.86	30.54	38.69	2.47
Mixed Wood Plains	3.92E+07	36.37	36.72	37.09	31.68	32.82	32.67	32.63	32.52	32.54	32.45	31.15	38.36	2.94
Central Plains	2.26E+07	8.37	8.68	9.24	9.90	10.04	9.98	9.98	9.95	9.95	9.93	7.59	9.59	1.53
SE Coastal Plains	3.40E+07	7.65	7.69	7.64	2.78	2.64	2.59	2.60	2.64	2.66	2.66	6.42	7.80	8.73
Mediterranean CA	1.64E+07	7.36	7.38	7.38	5.29	4.50	4.44	4.14	4.13	4.13	3.99	7.40	7.43	10.25
TX/LA Coastal Plain	7.36E+06	7.32	7.36	7.35	3.00	3.03	2.97	2.95	3.00	3.04	3.03	6.33	9.49	5.23
Marine West Coast	3.64E+07	6.18	6.19	6.19	3.35	3.06	2.99	2.97	2.99	3.02	3.05	5.86	6.14	63.33
Temperate Prairies	5.22E+07	6.16	6.17	6.18	6.01	6.58	6.55	6.54	6.53	6.54	6.55	5.61	6.15	2.37
Western Cordillera	8.22E+07	6.04	6.04	6.03	4.95	4.61	4.58	4.57	4.57	4.58	4.60	5.93	5.93	22.70
Semiarid Plain	5.31E+06	3.22	3.20	3.20	0.61	0.65	0.65	0.64	0.65	0.65	0.65	2.75	3.03	0.32
South Central Prairies	9.97E+07	3.21	3.19	3.16	3.32	3.35	3.31	3.29	3.26	3.26	3.28	2.73	3.08	0.88
Upper Gila Mtns	1.09E+07	1.00	1.00	0.99	0.21	0.22	0.22	0.22	0.21	0.18	0.18	0.97	0.97	11.24
West-Central Prairies	5.91E+07	0.79	0.79	0.79	0.59	0.57	0.57	0.57	0.57	0.57	0.57	0.79	0.80	2.43
Western Sierra Madres	4.31E+06	0.70	0.70	0.70	0.28	0.28	0.28	0.28	0.20	0.20	0.20	0.70	0.70	12.97
Cold Deserts	1.01E+08	0.65	0.65	0.65	0.58	0.56	0.55	0.55	0.55	0.54	0.55	0.65	0.65	12.45
Warm Deserts	4.08E+07	0.14	0.14	0.14	0.02	0.12	0.12	0.12	0.09	0.09	0.09	0.14	0.14	36.62
Everglades	2.20E+06	0.00	0.00	0.00	0.07	0.37	0.36	0.36	0.36	0.36	0.36	0.00	0.00	38.06

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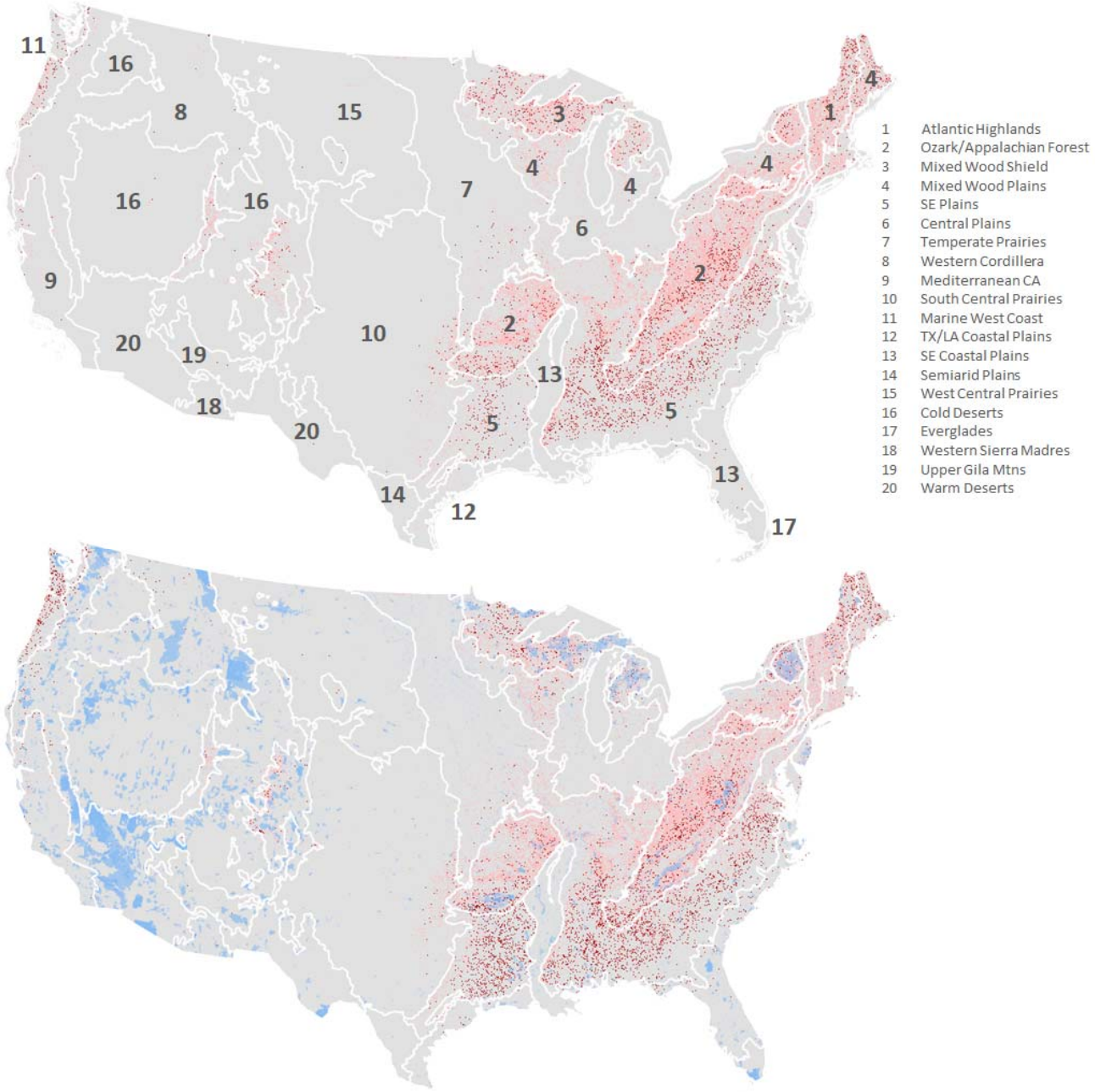

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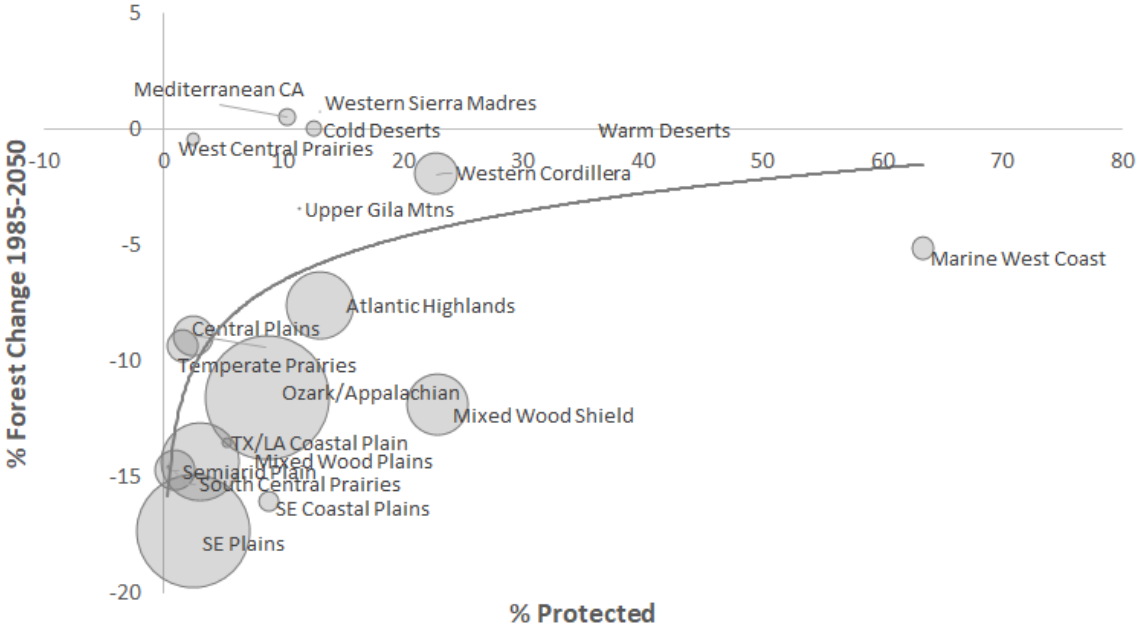

FIGURE LEGENDS

Fig 1 Ecoregions of the contiguous United State with deciduous/mixed forest cover (pink) and disturbed forest (red) from a) 1985-2016 and b) models projecting forest cover in 2050. Numbers indicate rankings of ecoregions by proportion of forest cover in 2016. Blue areas represent protected areas managed consistently with biodiversity conservation (USGS PADUS GAP code 1 or 2).

Fig 2 Percent change in deciduous/mixed forest cover in an ecoregion from 1985 to projections for 2050 as a function of forested area and the percent of the ecoregion that is protected as of 2018 (USGS PADUS GAP code 1 or 2; y = 0.14(protected) - 2.9E-11(forest) - 8.01, $r^2 = 0.35$, $p = 0.03$).