Forest Ecology and Management 553 (2024) 121445

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Perspective

Prioritizing new conservation areas during forest plan updates

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ARTICLE INFO

Keywords:
Forest management
Carbon storage and sequestration
Mature and old-growth forests
Connectivity model
Northwest Forest Plan

ABSTRACT

This paper presents a novel spatial analysis process designed to prioritize new conservation areas in anticipation of upcoming updates to the Northwest Forest Plan (NWFP) for national forests in the western United States. Illustrated through a case study of the Gifford Pinchot National Forest, the approach seeks to identify locations for conversion from matrix to late-successional reserve (LSR) land use allocation, with the goal of enhancing climate resilience, improving carbon storage, and safeguarding mature and old-growth forests. Matrix lands are areas in national forests where timber production and harvest are primary management objectives. Contrary to common assumption, there are many mature and old-growth stands currently located within matrix designation. To prioritize locations for consideration for a matrix to LSR transfer, I used connectivity model outputs (depicting densely clustered mature forests and corridors), forest age data (identifying forests estimated to be over 100 years old), and land management allocation data to rank locations as primary and secondary areas for protection. Working from areas with dense aggregations of these ranks, I then included additional variables—including carbon storage metrics, a secondary age layer identifying forests over 200 years old, locations of recent or current timber harvest projects, and a westside-eastside categorization—to delineate final areas for conservation. This method offers a replicable framework for other national forests and provides a science-based process to guide conservation efforts, inform policy recommendations, and ensure the long-term well-being of mature and old-growth forests and their associated ecosystems.

1. Introduction

Over the past 29 years of managing national forests of the Pacific Northwest under the original framework of the Northwest Forest Plan (NWFP), there have been small changes, such as amendments to guidelines and local revisions, but the land allocations set forth in the original documentation have remained largely unchanged. We are now at a point where change is on the horizon. There is a newly minted federal advisory committee that will be convening and making recommendations for updates to the NWFP. As stated during the announcement of the committee, "[t]he Northwest Forest Plan Area Advisory Committee has been established to solicit advice and recommendations on landscape management approaches to consider for National Forest System lands in the Northwest Forest Plan area to promote sustainability, climate change adaptation, and wildfire resilience (Federal Register Volume 88, Issue 148, 2023)." And, "[t]he Forest Service is particularly interested in obtaining Committee feedback on how to protect and promote late and old structure forest conditions while ensuring national forests are resilient to high-severity wildfire, insects and disease, and other types of disturbances that are being exacerbated by the climate crisis." In addition to this committee, the federal government has called for a thorough review of all mature and old-growth forests on federal lands through an executive order (Executive Order 14072, 2022) and has also released an advance notice of proposed rulemaking regarding management of these older forests (Federal Register Volume 88, Issue 77, 2023).

At the same time, our national forests are facing dramatic climate impacts, both current and projected. Drought and altered seasonal patterns are affecting the health and distributions of species and ecosystems (Abney et al., 2019; Agne et al., 2018; Allen et al., 2010; Hudec et al., 2019), and wildfires are front and center in the collective consciousness. As we look to modernize the NWFP, it is vital that we use this as an opportunity to build meaningful and lasting climate resilience. One of the best methods to both improve climate resilience and enhance carbon storage in the Pacific Northwest is through the protection of mature and old-growth forests (Buotte et al., 2020; Law et al., 2021). Mature and old-growth forests serve critical habitat roles for a wide array of wildlife (Herter et al., 2002; LaHaye, 1999; Meyer et al., 2005; Schwartz et al., 2013), they are more resilient than younger or heavily managed forests (Frey et al., 2016; Lesmeister et al., 2021; Lindenmayer et al., 2009), and

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https://doi.org/10.1016/j.foreco.2023.121445
Received 10 August 2023; Received in revised form 14 September 2023; Accepted 16 September 2023
Available online 15 December 2023

they store large amounts of carbon (Kline et al., 2016; Luyssaert et al., 2008). Unfortunately, many older forests are at risk from logging and road construction.

Of particular importance to this process are the areas designated by the NWFP as late-successional reserves (LSRs) and matrix (Fig. 1). LSRs are areas “identified with an objective to protect and enhance conditions of late-successional and old-growth forest ecosystems, which serve as habitat for late-successional and old-growth forest related species including the northern spotted owl (USFS and BLM, 1994).” They were designed to protect areas with high concentrations of old-growth, and the different LSRs were situated in relatively close proximity to one another to enable dispersal of northern spotted owls between reserves (Johnson et al., 2023). Young stands in LSRs were intended to be managed in a way that advances old-growth characteristics, which is generally accomplished through selective thinning. Matrix lands—along with a portion of “adaptive management areas” that were designated to be managed similarly to matrix—were delineated as areas where regularly scheduled timber harvest would occur under existing Forest Service and Bureau of Land Management plans (Thomas et al., 2006). While timber harvest was considered to be a primary management objective in matrix, the agency was also required to ensure that matrix areas would have sufficient canopy cover and habitat quality to support dispersal of

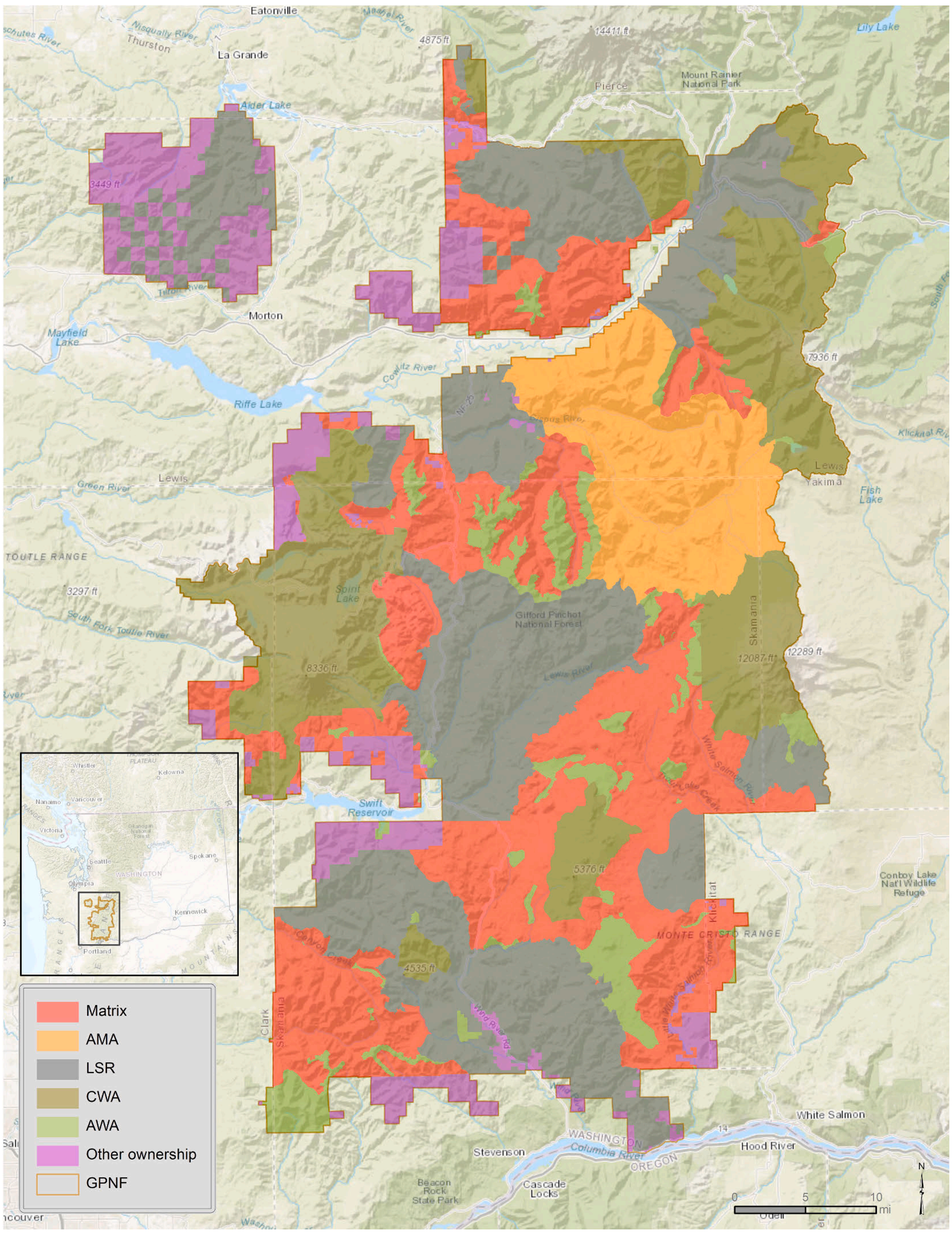

Fig. 1. Land use allocations on the Gifford Pinchot National Forest (GPNF) showing matrix, adaptive management areas (AMA), late-successional reserves (LSR), Congressionally withdrawn areas (CWA), administratively withdrawn areas (AWA), and other ownership, the latter of which commonly consists of privately-owned timberlands.

northern spotted owls. This stipulation, in conjunction with other factors, created a situation where a portion of mature and old-growth forests in matrix were left unlogged. These other factors included: a loss of public support for logging of old-growth forests, litigation over Endangered Species Act violations (Johnson et al., 2023), and the Survey and Manage program that required surveys for "rare and locally endemic species" thought to be associated with late-successional and old-growth forests (USDA, 2000). If these species were found, no-cut buffers around occurrences were required, thereby limiting the amount of acreage where logging was allowed.

While many matrix lands consist of young and mid-age forests, some areas contain mature and old-growth forests. On the Gifford Pinchot National Forest, of the 402,772 acres of matrix land, 169,884 acres are under 100 years of age, 160,031 acres are 100 to 200 years of age, and 72,857 acres are over 200 years in age. Under the direction of the Northwest Forest Plan, these older forests are available for commercial harvest. See Fig. 2 for a spatial overview of forest ages (from 2017 data) in the southern Washington Cascades broken down into three categories: under 100 years old (includes non-forest areas), 100–200 years old, and over 200 years old. Fig. 3 shows forests in matrix that are 100–200 years old and over 200 years old.

In matrix lands, logging practices such as "heavy thinning" and "regeneration harvest" are common. Heavy thinning involves significantly reducing canopy cover, sometimes down to 40 %, while regeneration harvest aims to restart the growth cycle by removing most trees within a logging unit. The latter prescription can result in outcomes similar to a clearcut. The application of these logging prescriptions in old forests contradicts the widely accepted objectives of conserving rare old forests, preserving habitat for dependent species, and responsibly managing carbon storage in Pacific Northwest coniferous forests.

To address the inconsistency between the ecological importance of retaining older forests and a land use allocation that permits logging of

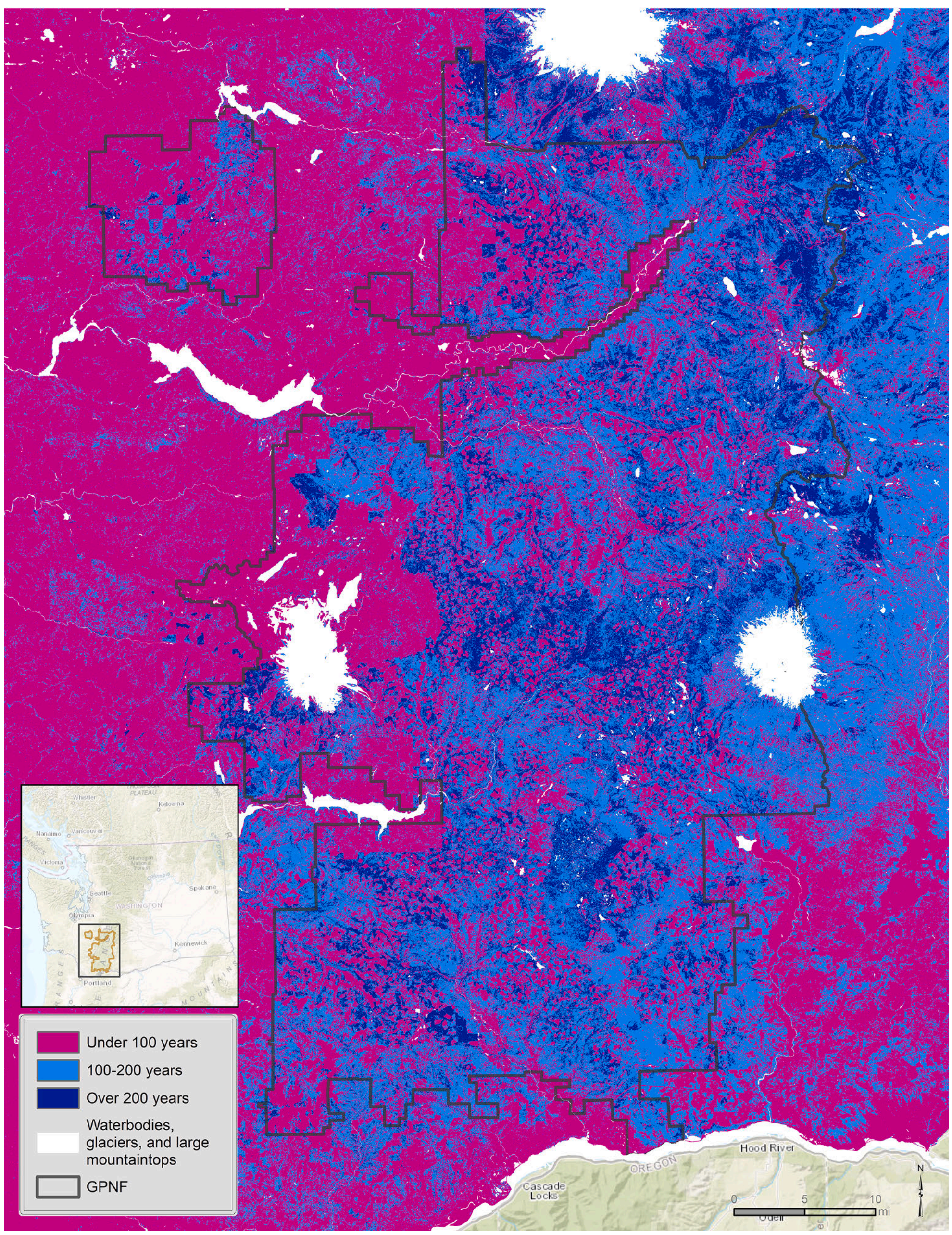

Fig. 2. Areas in the southern Washington Cascades with forests estimated to be under 100 years old, 100 to 200 years old, and over 200 years old. In this visual representation, the first category (areas under 100 years old) includes non-forest areas such as meadows, rocky areas, or developed areas.

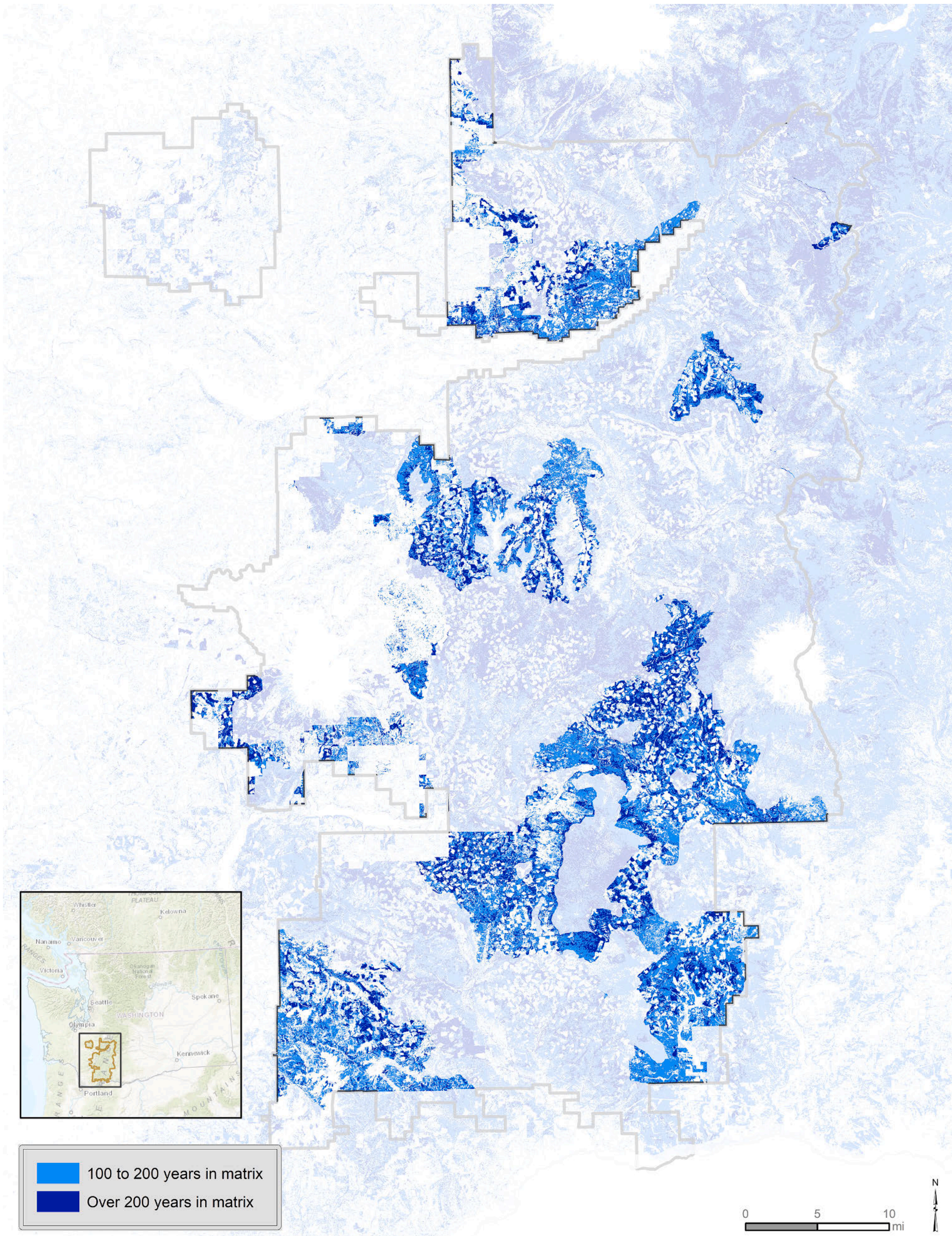

Fig. 3. Forests 100–200 years old and over 200 years old in matrix allocation on the Gifford Pinchot National Forest (GPNF).

the same forests, I have developed a spatial analysis process to prioritize forests for new protections. The process outlined herein aims to identify areas in matrix allocation that are priority candidates for a transfer from designation as matrix lands to designation as LSR lands. This change can be enacted through an amendment or revision of the NWFP or, in a slightly modified manner, through revision of local forest plans, such as the Gifford Pinchot Land and Resource Management Plan for the Gifford Pinchot National Forest. This spatial analysis was developed for the Gifford Pinchot National Forest in southern Washington State, but the methodology can be adapted and applied to other national forests managed under the NWFP.

This methodology captures conservation needs for forest stands, but it does not include conservation of individual mature and old-growth trees that exist outside of the proposed new reserve boundaries. Protection of these trees is best accomplished through updated management guidance that delineates harvest limits for trees that meet certain age or diameter thresholds.

2. Materials and methods

Using ArcGIS, I identified westside forest areas where there is an overlap of matrix allocation, forests estimated as being 100 years or older, and either a mature forest habitat core area (HCA) or a connectivity corridor between HCAs, the latter two variables stemming from a connectivity model.

2.1. Forest age

To determine estimates of forest age, I used spatial data from the Landscape Ecology Modeling, Mapping & Analysis group (LEMMA) (Bell et al., 2021). This data set uses a combination of imagery, Forest Inventory and Analysis (FIA) data, and other spatial information to determine various forest characteristics. As with any model, LEMMA's estimates of forest age are imperfect, but they offer a useful glimpse into the age patterns of forests. I used a threshold of 100 years for this stage of the prioritization process due to the value of these forests for carbon storage, as wildlife habitat, as areas with higher resilience than their younger counterparts, and as forests that are nearing an old-growth state with diverse understories, varied canopy layers, and large downed trees that create habitat niches on the forest floor.

2.2. Connectivity

Connectivity is important in the development of conservation strategies, as it helps sustain ecosystems by enabling wildlife to move between habitats, which increases resilience to climate impacts and reduces the risk of population extirpation due to disturbances like wildfires or drought (Heller and Zavaleta, 2009; Koen et al., 2014). The connectivity model used in this analysis focused on identifying areas where there is a high density of mature forests (habitat core areas; or HCAs) and pathways in between these areas (corridors) where connectivity and wildlife movement would be least encumbered by patches of low-quality habitat or infrastructure. This model used a network analysis tool (McRae and Kavanagh, 2011) in ArcGIS to identify connectivity potential.

The first step in the connectivity analysis was to identify areas where there is a relatively high contiguity of mature forest habitat. Using LEMMA's Old-growth Structure Index (OGSI) layer of mature forest habitat, I ran a density function in ArcGIS to locate dense aggregations of forest stands that measure as OGSI-80 or OGSI-200. The 80-year threshold (OGSI-80) represents forests that have "achieved structure commonly associated with mature, late-successional, and old-growth forests" while OGSI-200 represents forests that have "progressed past maturation and had achieved structure found in the later stages of succession commonly associated with old growth (Davis et al., 2015)." Rather than just considering age, these measures consider structural components associated with healthy maturing forests, such as snags, downed wood, and tree diameter diversity. For the density function, each cell was set to measure density of similar habitat within a 1000 m (3,281 ft) radius. These dense mature forest areas represent relatively contiguous areas of old forest habitat, refugia areas that are not only relatively resilient but are also likely important for the long-term survival of species that rely on mature forests, such as fishers, martens, and northern spotted owls (Lesmeister et al., 2021; Schwartz et al., 2013; Slauson et al., 2007). These areas were used as the habitat core areas (HCAs) in the connectivity model.

In order to focus on relatively large habitat patches for the creation of the corridors, I removed from the connectivity analysis all HCAs that were under 5 km^2 (1.9 mi^2). These patches were, however, used in the subsequent prioritization steps.

The next step in the analysis was to identify connectivity corridors between the large HCAs. These are areas that could be expected to facilitate easier dispersal compared to surrounding areas with less mature forest density. The connectivity analysis calls for the input of a resistance layer to determine where species movement would be limited, such as agricultural land, treeless mountaintops, other areas without sufficient forest cover or maturity, areas with high road densities, and areas likely to convert to non-forest in the future (such as from development or logging). The resistance layer included (1) density of mature forest (inversely calculated), (2) road density, and (3) a Conversion Threats Index measure. For the mature forest density measure in the resistance layer, I used a spatial layer created by the Conservation Biology Institute that identifies forest areas at thresholds of 50 years and 150 years (Jiang et al., 2004). The density analysis included all areas above the 50-year threshold and was ranked inversely in the resistance layer, which allowed me to apply higher resistance values to those areas with little to no tree cover or young forests still lacking the ability to function as mature forest habitat. By using a lower age threshold here (50 years instead of 80, 100, or more), I worked under the assumption that connectivity routes, as dispersal habitat, have lighter canopy cover requirements than HCAs. Road density was measured using the same ArcGIS density function and was ranked to give higher resistance to areas with higher road densities. The Conversion Threats Index was created by Wilson et al. (2014) who used a state-and-transition model to estimate potential future land-use conversion as a result of development or logging. Higher conversation threats were given a higher resistance ranking.

With the base connectivity layers in place, I then ran the connectivity analysis using a "Linkage Mapper" tool created by McRae and Kavanagh (2011). This tool uses network analysis processes in ArcGIS and identifies the "least cost paths" for connectivity, i.e., areas where movements or dispersal are least obstructed. The results of the connectivity model can be found on Fig. 4.

2.3. The prioritization process

With all base layers constructed and ready for use, I was able to begin the prioritization process. A spatial cell had to contain the following overlapping features to be considered in this part of the analysis: matrix allocation, 100-year minimum age, and either an HCA or a corridor. While both matrix allocation and a 100-year age were requirements, the connectivity measures were used to stratify protection values, with HCAs receiving higher value than connectivity corridors due to their higher value for mature forest species as largely contiguous mature forest.

I turned all vector layers into rasters and reclassified spatial cells into the following values:

Matrix: 4
Age > 100: 3
HCA: 2
Corridor: 1

With these four layers overlaid, I then summed them using the raster calculator tool. Sums ranged from 0 to 10. Summation allowed me to categorize cells according to which attributes were contained within each cell. The summation results were as follows:

10: Matrix, > 100 years, HCA, and corridor
9: Matrix, > 100 years, and HCA
8: Matrix, > 100 years, and corridor
7: Matrix, HCA, and corridor; or matrix and > 100 years
6 or under: Cell that is too young or not in matrix allocation

Due to the way the model was constructed and displayed, there can be an overlap of HCAs and corridors, as seen in value 10. The presence of the HCA is the priority variable and overrides any underlying presence of a corridor so I combined values 9 and 10. These values became the top rank (protection rank 1) in the subsequent reclassification step. Cells with a value of 8 became protection rank 2 (Fig. 5). I removed all cells with values of 7 or under as those are lacking the minimum requirement of containing matrix, > 100 years, and either an HCA or a corridor.

The final priority ranking allowed me to have a spatial layer with all cells placed into two categories:

Protection rank 1 (cell values 9 and 10) included all cells that were matrix, 100 years or older, and an HCA.

Protection rank 2 (cell value 8) included all cells that were matrix, 100 years or older, and a corridor.

2.4. Refining the final selection of priority conservation areas

The ranking and reclassification of raster layers resulted in a large number of relatively disjunct areas that would not translate well to management boundaries. To help refine the final recommendations and to bring other relevant variables into consideration, I overlaid: 1) a carbon storage layer from Law et al. (2021) showing priority areas for conserving carbon, and 2) a layer showing old-growth forests over 200 years old (using LEMMA data) (Fig. 6). I also overlaid recent timber harvest areas (using spatial layers supplied by the US Forest Service) and removed these areas from consideration as future harvest is less likely to occur in these areas again in the near future, therefore decreasing need for protection compared to areas where harvest is likely over the next 15–20 years. I also excluded sections of the southeastern part of the

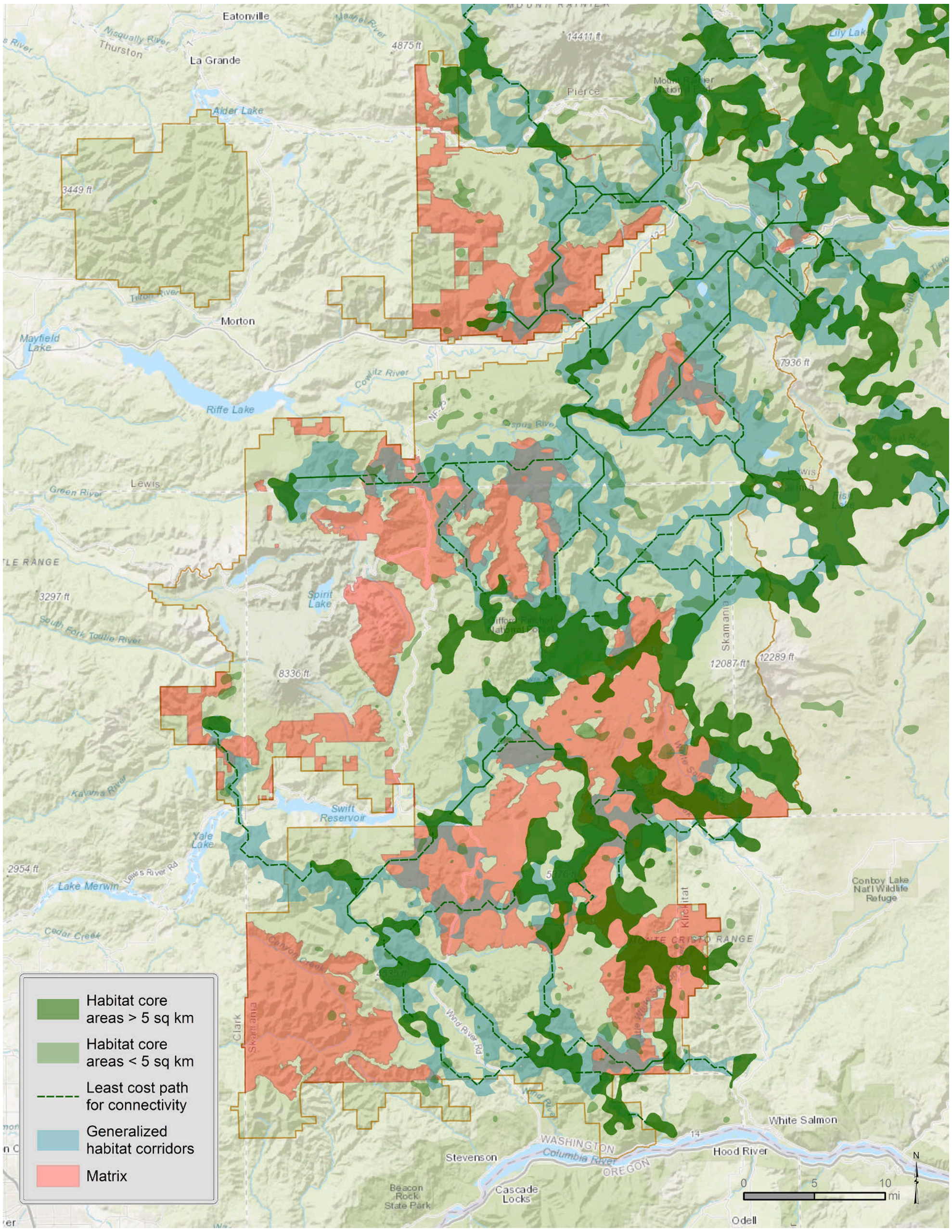

Fig. 4. Connectivity model output.

national forest that fell within the Washington Eastern Cascades classification of the LEMMA data. These areas contain a high proportion of drier, mixed-conifer forests where flexible management may be warranted to restore portions of the landscape back to a more resilient state. Much of this area had also recently undergone timber harvest or planning for upcoming harvests.

To draw the final boundaries, I focused on areas with aggregations of protection rank 1. Working from there, I included nearby areas with densities of protection rank 2 as well as adjacent occurrences of the carbon and old-growth layers (Fig. 7). This qualitative step built upon the locations determined by the previous quantitative steps and required a judgement call regarding the relative densities of carbon storage areas and forests over 200 years old, as well as their proximity to the previously established protection ranks. The quantitatively-based results remained the driving force in determining the locations of the conservation areas, but this final step was important for delineating boundaries that would function well (size-wise) as management boundaries and for enabling the inclusion of relevant ecological inputs that were present near the original aggregations.

3. Results

By focusing on areas where there was a density of overlapping values, I was able to identify multi-value and high-priority areas that are at risk from logging and ideal candidates for future protection. The process yielded 77,818 acres of priority conservation areas for a matrix to LSR transfer (Fig. 8). These areas were spread among 18 separate patches of varying sizes. The conservation areas encompassed 23,747 acres of forests over 200 years old (representing 31 % of the final conservation area), 34,427 acres of forests in the 100–200-year range (representing 44 %), and 19,645 acres under 100 years old (25 %) (see Table 1). In total, 75 % of the conservation area is estimated to be over 100 years old. The inclusion of some younger forests (25 % of the total) was expected due to the nature of density analyses and the checkerboard patterning of the Gifford Pinchot

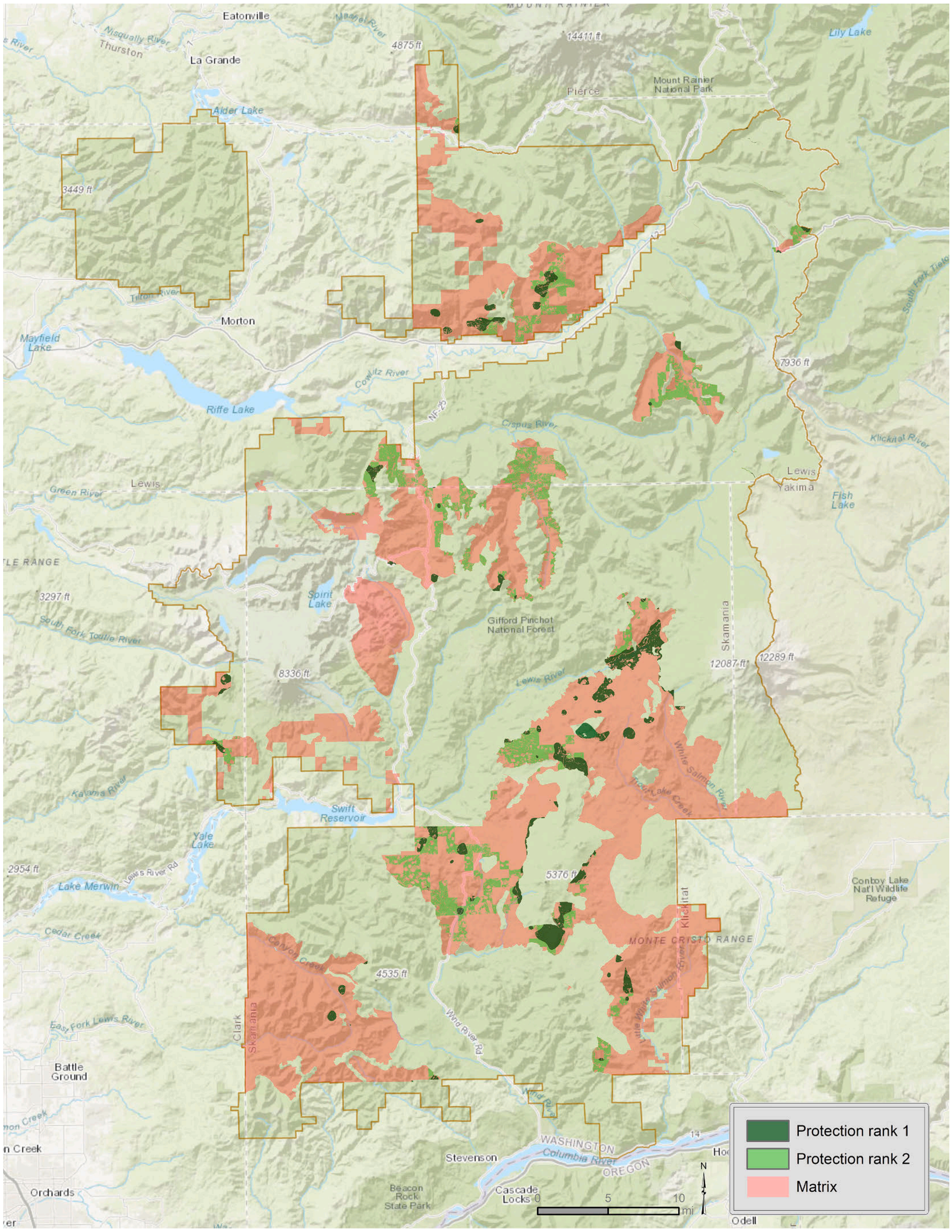

Fig. 5. Protection ranks created through a hierarchical process using forest age, management designation, and connectivity values. Protection rank 1 included cells that were in matrix designation, 100 years or older, and modeled as a habitat core area (HCA) in the connectivity model. Protection rank 2 included cells that were in matrix designation, 100 years or older, and modeled as a corridor in the connectivity model.

National Forest as a result of past logging. Younger areas were incorporated into the analysis during one of the following phases: A) in the initial phase of the process, as a cell contained in an HCA through the density function of the connectivity model or as a corridor in the model; B) when the carbon layer was overlaid; or C) during the creation of the final polygon. The final conservation areas occur largely in forests under 1,219 m (4,000 ft) in elevation, with a small portion in the 1,219 to 1,524 (4,000 to 5,000 ft) elevation band. The species composition of these forests varies with elevation, latitude, and succession, but the dominant and co-dominant species primarily include Douglas-fir, western hemlock, and Pacific silver fir.

4. Discussion

Regional policy change, specifically through an amendment or revision of the NWFP, is the most effective route through which to enact these changes. A regional focus aligns with the upcoming efforts of the federal advisory committee, which will concentrate on addressing forest management issues of climate resilience, wildfires, sustainability, and protection of late-successional forests. Also, compared to the option of enacting changes at the local forest plan level, a regional change offers stronger protections and more direct application to multiple national forests.

While an increase in acreage assigned to the late-successional reserve system on national forest lands may raise concerns about its impact on

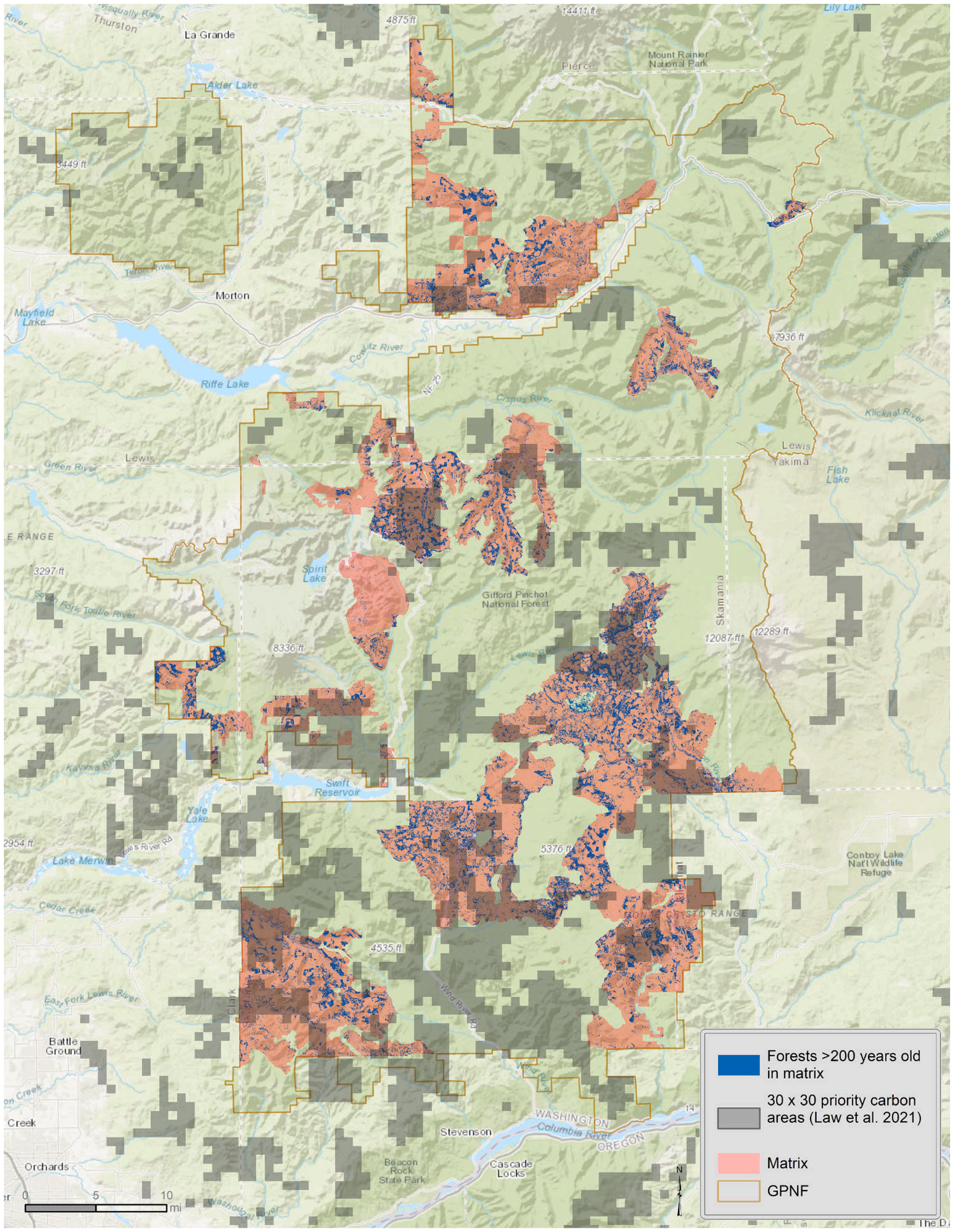

Fig. 6. Locations of the additional variables of 1) forests over 200 years old and 2) priority carbon storage areas from Law et al. (2021).

timber harvest and rural economies, it is important to note that there is a large amount of alternative harvestable area on federal lands, such as plantation stands with young and mid-age trees and dry or mixed-conifer forests where thinning and prescribed fire can be employed to enhance resilience (Hessburg et al., 2016). In addition, the expansive private timberlands and state lands that surround many national forests are already managed for heavy timber extraction—these areas represent the bulk of the timber income for many local communities (Washington Forest Protection Association, 2007; Watts, 2018) and offer more suitable opportunities for timber extraction, reducing pressure on older forests. Relatedly, as areas with cooler microclimates (Chen et al., 1993; Frey et al., 2016), protected older forests can potentially decrease wildfire risk at the landscape-level and thereby increase wildfire protection for surrounding timberlands.

Protecting mature and old-growth forests goes beyond conserving trees and carbon storage; it also benefits the health of river systems (Gurnell et al., 2002), forest soil fungal communities (Spencer et al., 2023), and overall biodiversity (Frey et al., 2016), all of which contribute to ecosystem resilience and ensure diverse ecosystem services. Logging, and the roads needed for it, can degrade aquatic health by increasing sedimentation in waterways (Kastridis, 2020), fragmenting aquatic habitat connectivity (Perkin et al., 2020), and removing tree cover that is critical for mitigating instream temperature increases (Gucinski et al., 2001). Reducing logging also minimizes the risk of unintentionally introducing invasive species that may be spread by logging machines (Adhikari et al., 2020). In addition, the use of heavy machinery needed to carry out logging work can cause soil compaction, which can affect understory vegetation and the root systems of trees (Nazari et al., 2021).

To enhance forest heterogeneity and conserve mature and old-growth trees that reside outside of these recommended conservation areas, forest plan guidance focused on protection of all trees over a certain age or diameter threshold can also be integrated into a forest plan revision or amendment. This additional action aligns with calls to

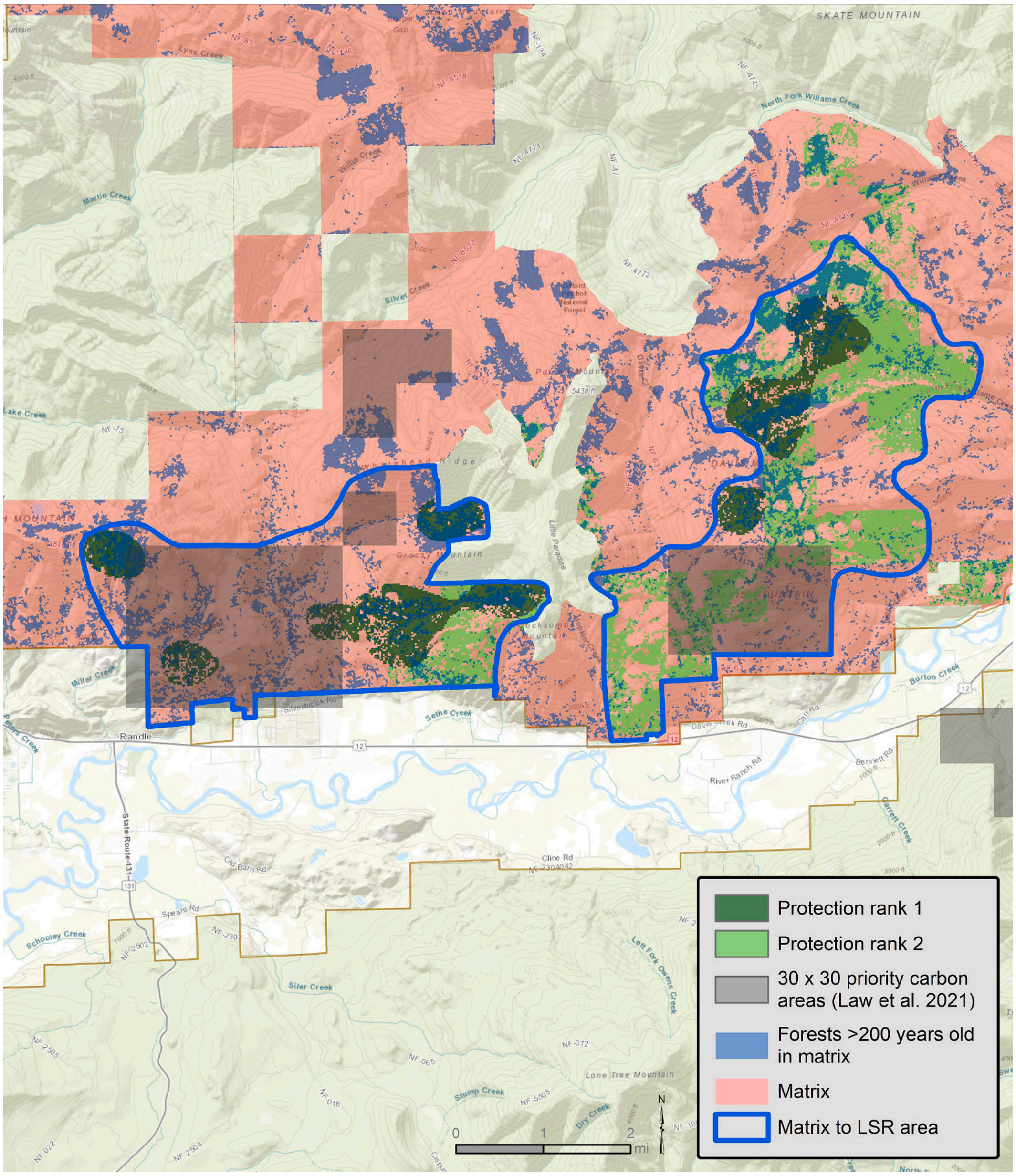

Fig. 7. Scaled-in view of drawn polygon around a priority protection area in the north part of the study area.

advance protections of mature and old-growth forests on federal lands and with original guidance of the NWFP.

There is overlap in terminology between spatial analysis processes for determining connectivity values and wording used in NWFP provisions. Planners of the NWFP used riparian corridors in the guidance framework as a way to ensure connectivity between protected habitat areas. Other corridors, such as terrestrially-based routes through matrix or adaptive management areas, were not used as a method to sustain populations of northern spotted owls. Instead, management guidelines for matrix lands—which in comparison to corridors are larger areas of forest between reserves—were designed to retain a "porous" nature that would enable dispersal of owls between reserves. The application of corridors in the analysis outlined here in this paper carries an inherent understanding that surrounding lands, including matrix, are able to support dispersal to the degree outlined in the NWFP. In other words, they are not the only areas between HCAs that are able to support dispersal of mature forest species. Rather, they are areas modeled to have greater connectivity value than surrounding areas not identified as corridors or HCAs. The inclusion of the connectivity model in this analysis allowed the prioritization of areas with a density of mature forests and connectivity pathways with higher densities of mature forests than surrounding locations. Without the connectivity model, the final reserve areas would have tended to be smaller and more disjunct.

5. Conclusion

The spatial analysis case study presented here highlights a novel and science-based methodology for identifying priority areas for conservation, and this policy recommendation presents an approach that can be employed during upcoming forest plan amendments or revisions. A transfer of select matrix lands to late-successional reserve designation would align with national and regional calls to modernize forest management planning, protect mature and old-growth forests, and improve climate resilience. The method is tuned to the Gifford Pinchot National Forest but can be replicated and applied to other national forests managed under the NWFP. As we move toward more sustainable forest management and improved climate resilience, this method can help protect valuable habitats, wildlife, and carbon storage for the well-being

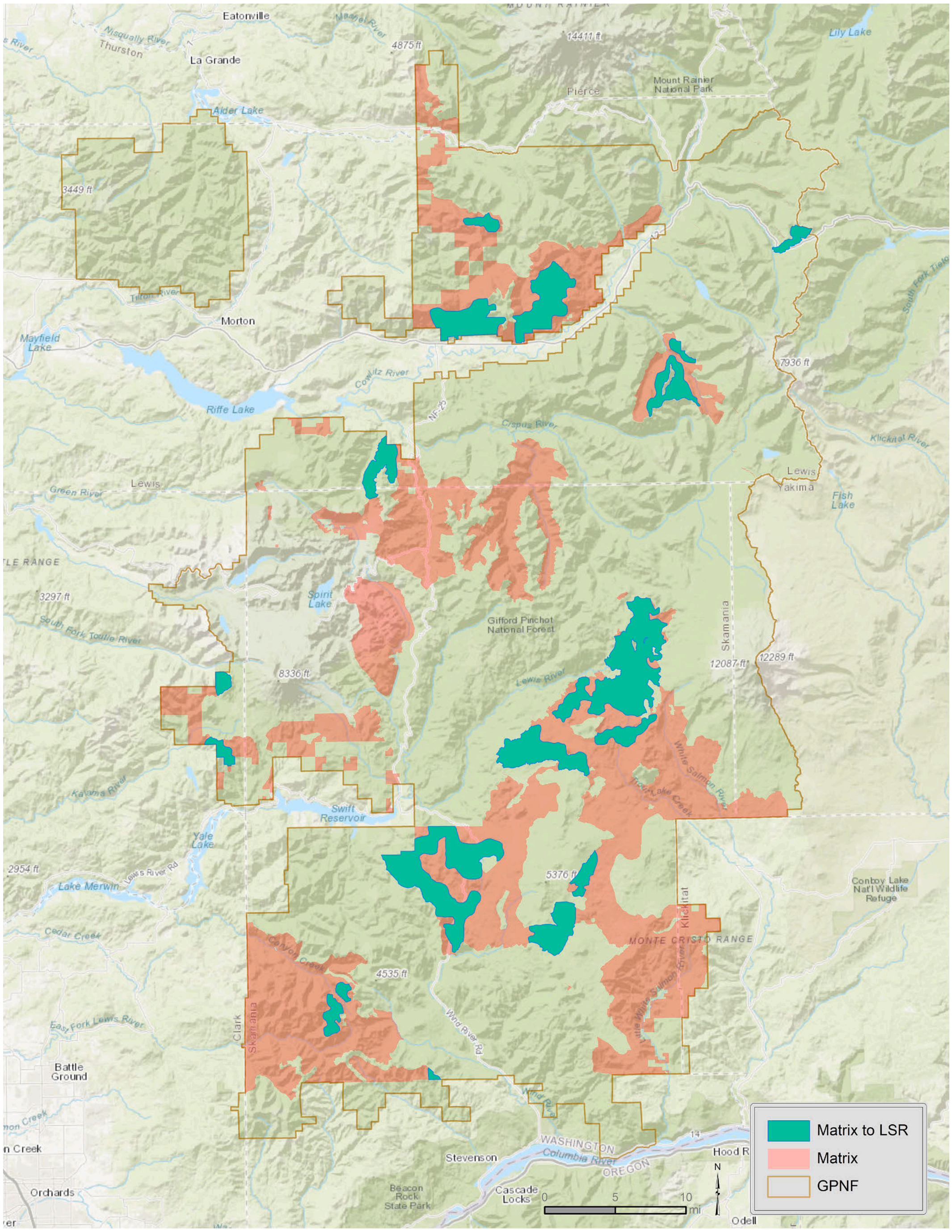

Fig. 8. Final conservation areas recommended for a matrix to LSR transfer.

Table 1
Acreage and Proportion of Total Area by Age Bracket in Different Management Areas.

	Matrix	LSR	Matrix to LSR areas
Under 100 years	169,884 (42 %)	157,590 (36 %)	19,645 (25 %)
100 to 200 years	160,031 (40 %)	181,076 (42 %)	34,427 (44 %)
Over 200 years	72,857 (18 %)	97,136 (22 %)	23,747 (31 %)

Acreage percentages are shown in parentheses and displayed per land allocation of matrix, late-successional reserve (LSR), and proposed areas for a transfer from matrix to LSR.

of present and future generations.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

I would like to thank Norm Johnson for formal review of the manuscript. I would also like to thank Susan Jane Brown, Ashley Short, Suzanne Whitney, and Sean Roome for reviews, proofreading, and helpful feedback during the creation of the manuscript. Funding was provided by Cascade Forest Conservancy.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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