Forest Policy and Economics 142 (2022) 102783

Contents lists available at ScienceDirect

Forest Policy and Economics

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

An assessment of the sustainability of family forests in the U.S.A.

Brett J. Butler[a,b,*], Jesse Caputo[a,b], Jesse D. Henderson[b,c], Scott A. Pugh[a], Kurt Riitters[c], Emma M. Sass[b,d]

[a] USDA Forest Service, Northern Research Station, USA
[b] Family Forest Research Center, USA
[c] USDA Forest Service, Southern Research Station, USA
[d] University of Massachusetts Amherst, Department of Environmental Conservation, USA

ARTICLE INFO

Keywords:
Family forest owners
United States
Montréal process criteria and indicators
Forest inventory and analysis

ABSTRACT

Across the U.S.A., as across many countries, families, individuals, trusts, estates, and family partnerships, collectively referred to as family forest ownerships, own a plurality of the forestland. The Montréal Process Criteria and Indicators (C&I) were used to assess the sustainability of these lands. There are currently 109 million ha of family forestland across the conterminous U.S.A., but this area is decreasing by 1 million ha yr^{-1} with 64% of this acreage going to non-forest uses and the rest going to other forest ownership classes. While forest-type groups have remained relatively constant, the area of forestland in smaller stand sizes has been decreasing and the area in larger stand sizes has been commensurately increasing. These forests provide critical habitat for many species with an average of 3.3 at-risk species per location. There is an estimated 12.7 billion m^3 of wood on these lands with annual timber harvests of 160 million m^3. For most species, the ratio of net growth to removals is well above 1.0, but there are notable exceptions, often associated with insects, changing fire regimes, or other departures from historical conditions. Looking only at timber harvesting, family forests are annually supporting an estimated 47.4 thousand jobs with combined wages of USD$2 billion. Land regulations, taxation, and incentives vary considerably across the U.S.A. with regulations ranging from regulatory to voluntary. Overall, the C&I indicate a mixed prognosis for the sustainability of America's family forests: while many of the general ecological and productivity indicators are positive, the loss of family forestland is of notable concern as are the threats posed by specific disturbances and for specific species. To maintain the sustainability of America's family forest, the analysis suggests focusing on policies, such as conservation easements and preferential property tax programs, aimed at keeping family forests as family forests.

1. Introduction

Families, individuals, family and individual trusts, estates, and family partnerships control 109 million ha of forestland in the conterminous United States (USDA Forest Service, Forest Inventory and Analysis program (USFS FIA), 2021). Family forest ownerships, as they are collectively referred to, control more forestland than any other ownership group in the country. As in the U.S.A., private forest ownership, of which family forest ownership is a subset, dominate in half of the countries reporting ownership statistics in the Global Forest Resources Assessment (FAO, 2020). Family forestlands are critical for supplying society with countless ecosystem services including clean water, wood, and wildlife habitat, in addition to the many benefits provided directly to the owners and their families including privacy, family legacy, and recreational opportunities. Despite the importance of family forests, there have been, to our knowledge, no published assessments of the sustainability of family forests of the U.S.A. explicitly using a criteria and indicators framework which provides a holistic approach and can facilitate a rigorous analysis.

The term "sustainable forest management" means different things to different people. Based on a survey of foresters and forest planners in the U.S.A. (Gutierrez Garzon et al., 2020), the top terms associated with this concept are: stewardship, planning, biodiversity, forest health, and best management practices. Here we adopt the definition of sustainability as

Abbreviations: C&I, Criteria and Indicators; BLS, Bureau of Labor Statistics; FIA, USDA Forest Service, Forest Inventory and Analysis; NLCD, National Land Cover Database; NWOS, USDA Forest Service, Forest Inventory and Analysis, National Woodland Owner Survey.

* Corresponding author at: 160 Holdsworth Way, Amherst, MA 01003, USA.
E-mail address: brett.butler2@usda.gov (B.J. Butler).

https://doi.org/10.1016/j.forpol.2022.102783
Received 19 January 2022; Received in revised form 25 May 2022; Accepted 7 June 2022
Available online 17 June 2022
1389-9341/Published by Elsevier B.V.

expressed within the context of sustainable development: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987) and use the Montréal Process Criteria and Indicators (C&I; The Montréal Process, 2015) as a framework for evaluating it.

The objective of this paper is to assess the sustainability of America's family forests. This ostensibly simple objective quickly becomes complicated due to difficulties in defining sustainability, data limitations, and the challenges of analyzing the results. For broad assessments of forest sustainability (e.g., Robertson et al., 2011; McGinley et al., 2019), the Montréal Process C&I is the most widely used framework in the U.S.A. Through its seven criteria and 54 indicators (The Montréal Process, 2015), this framework provides a broad description of what constitutes sustainability and some guidance on parameterization or interpretation of the indicators, but data availability varies and the topics are inherently complex with end goals that may vary among stakeholders. This paper examines 25 of these indicators (Table 1) and as a proxy for sustainability, we assess levels and trends in forest resource stocks (e.g., inventories), flows (e.g., removals), and external factors (e.g., disturbances).

The Montréal Process C&I emerged from the 1992 Rio Earth Summit in order "to share ideas, and foster collaboration to address common problems and progress toward a shared goal of sustainably managing temperate and boreal forest[s]" and to date has been adopted by Argentina, Australia, Canada, Chile, China, Japan, Mexico, New Zealand the Republic of Korea, Russia, the U.S.A., and Uruguay (The Montréal Process, n.d.). The criteria cover a range of topics including both biophysical (Criteria 1–5) and socioeconomic (Criteria 6 and 7) (Table 1). The biophysical C&I address issues related to biological diversity, forest productivity, forest health, soil and water resources, and carbon sequestration. Although there are only two socioeconomic criteria, they represent over half of the indicators and cover financial and livelihood benefits of forests and the institutional mechanisms intended to foster forest conservation.

The Montréal Process C&I have been used for many national reports (The Montréal Process, 2021) and have been used for subregions, such as states (Michigan Department of Natural Resources, 2020) and U.S.A. affiliated protectorates and territories (McGinley et al., 2019). Although they all follow the same general framework, each has made adaptations to suit specific circumstances and data limitations (Chandran and Innes, 2014). The most recent national report for all U.S. forest ownerships found most sustainability metrics to be positive, including a stable forest base, but there were a number of issues of concern, including

Table 1
Selected Montréal Process Criteria and Indicators (C&I) and associated data sources used to assess the sustainability of family forests in the U.S.A.

Criterion/Indicator	Description	Data source(s)[1]
Criterion 1: Conservation of biological diversity		
1.1.a	Total forest area and forest area by forest type group and stand size	FIA
1.1.b	Forest area in protected areas	NWOS
1.1.c	Forest fragmentation	NLCD
1.2.a	Number of tree species	FIA
1.2.b	Number of at-risk species	NatureServe
Criterion 2: Maintenance of productive capacity of forest ecosystems		
2.a	Percentage of forestland that is productive forestland	FIA
2.b	Total growing stock and annual increment	FIA
2.c	Percentage of forestland that has been planted	FIA
2.d	Annual harvest volume and growth to removal ratios by species	FIA
Criterion 3: Maintenance of forest ecosystem health and vitality		
3.a	Percentage of forest area damaged by disease, insects, or invasive species	FIA
3.b	Percentage of forest area damaged by fire, storm, and land clearing	FIA
Criterion 4: Conservation and maintenance of soil and water resources		
4.1.a	Percentage of forest land managed for the protection of soil or water resources	Literature synthesis
Criterion 5: Maintenance of forest contribution to global carbon cycles		
5.a	Forest carbon pools and fluxes	FIA
Criterion 6: Maintenance and enhancement of socio-economic benefits		
6.1.a	Value and volume of wood and wood products production, including primary and secondary processing	BLS
6.3.a	Employment in the forest sector	BLS
6.3.b	Average wage rates, annual average income and annual injury rates in major forest employment categories	BLS
6.4.a	Area and percent of forests available and/or managed for public recreation and tourism	NWOS
6.5.b	The importance of forests to people	NWOS
Criterion 7: Legal, institutional and economic framework		
7.1.a	Legislation and polices supporting the sustainable management of forests	Literature synthesis; NWOS
7.2.a	Taxation and other economic strategies that affect the sustainable management of forests	Literature synthesis; NWOS
7.3.a	Clarity and security of land and resource tenure and property rights	Literature synthesis
7.3.b	Enforcement of laws related to forests	Literature synthesis
7.4.a	Programs, services and other resources supporting the sustainable management of forests	Literature synthesis; NWOS
7.5.a	Partnerships to support the sustainable management of forests	Literature synthesis
7.5.c	Monitoring, assessment and reporting on progress towards sustainable management of forests	This paper

C&I numbering correspond to the numbering used in the Montréal Process (2015) and descriptions refer to the specific elements that are included in this paper.
[1] BLS: Bureau of Labor Statistics; FIA: USDA Forest Service, Forest Inventory and Analysis plot-based inventory data; NLCD: National Land Cover Database; NWOS: USDA Forest Service, Forest Inventory and Analysis, National Woodland Owner Survey.

fragmentation and disturbances (Robertson et al., 2011). There have also been papers and reports that have looked at specific components of the Montréal Process C&I in the U.S.A., such as: conservation of biological diversity (Criterion 1; Nelson et al., 2015); forest fragmentation (Indicator 1.1.c; Riitters and Robertson, 2021); annual harvest, value, and export of non-wood forest products (Indicators 2.e, 6.1.b, and 6.1.h; Alexander et al., 2011); area used for subsistence purposes (Indicator 6.3.d; Alexander et al., 2011); and legal, institutional, and economic frameworks (Criterion 7; McGinley and Cubbage, 2017, 2020).

The preponderance of family forests and their unique attributes warrant a separate assessment of the sustainability of these lands. Of the forestland in the conterminous U.S.A., 39% is family forest, which is more than any other ownership group (USFS FIA, 2021). Forest ownership patterns vary considerably across the country (Fig. 1) with 51% of the forests in the North being family owned, 56% in the South, 12% in the Rocky Mountain region, and 15% in the Pacific Coast region, excluding Alaska and Hawaii (USFS FIA, 2021). Family forests account for 26% of the annual timber removals in the North, 69% in the South, and 5% in the Pacific Coast region (USFS FIA, 2021); harvest removal data by ownership group are not currently available for the Rocky Mountain region.

Family forests face constraints that are unique from other ownership groups. Size of family forest holdings range from 0.4 ha, the minimum threshold required by USDA Forest Service, Forest Inventory and Analysis program (FIA) to qualify as forestland, to many thousands of hectares with a median size of 2 ha (mean = 12 ha; SE = 0.4) (Butler et al., 2021a). The most common reasons for owning family forests are aesthetics, wildlife, nature, family legacy, and privacy (Butler et al., 2021a). In terms of management, 29% of the family forestland is owned by people who have harvested trees for sale in the previous 5 years, 23% is owned by people who have a written forest management plan, and 34% is owned by people who have received forest management advice in the previous 5 years – these percentages are not exclusive of each other (Butler et al., 2021a).

The basic question we are asking is: are the family forests of the U.S.A. sustainable? We approach this question using the Montréal Process C&I framework. Due to space and data constraints and relevancy, we do not assess all of the indicators. In the methods section we outline the indicators we assessed, the underlying data sources, and the approaches for analyzing the data. The results of the analyses are then presented followed by a discussion of the findings, including data limitations. We conclude with a summary of the findings and potential implications.

2. Methods

The diversity of topics covered by the Montréal Process C&I necessitates a corresponding diversity of data sources and analytical approaches. In addition, not all of the indicators are directly relevant to family forests, and there are numerous data limitations. As has been done with most, if not all, previous assessments using the Montréal Process C&I, our aim is to present analyses across a broad range of indicators with emphasis given to topics that are most relevant to the topic at hand, family forest ownerships, and where we have the most robust data. The indicators presented and the associated data sources are listed in Table 1.

Data sources were selected based on applicability, availability, and robustness, and needed to be verifiable and citable. Where feasible, quantitative data were favored over qualitative data. Data needed to cover all, or at least most, of the conterminous U.S.A. and needed to be able to be subset to family forests. Data sources that allowed temporal and spatial trends were favored as well. The most recent data available were obtained, but the vintages varied by source.

Where feasible, data were presented in term of four regions: North, South, Rocky Mountain and Pacific Coast (Fig. 1). Alaska and Hawaii were excluded due to data limitations. These state groupings correspond to the regions used in the USDA Forest Service's Renewable Resource Planning Act assessments (Oswalt et al., 2019).

2.1. National forest inventory data

The most common data source, used in a third of the indicators assessed, was the USDA Forest Service, Forest Inventory and Analysis (FIA) plot data, which were particularly germane for the biological diversity, productivity, and forest health related C&I (Miles, 2002; McRoberts et al., 2004). FIA plot data and associated analyses and products constitute the U.S.A.'s national forest inventory. The system is based on a set of over 300,000 permanent inventory plots across the U.S.A., on public and private ownerships, that are revisited every 5–10 years depending on the administrative region (Bechtold and Patterson, 2005). On each plot, basic forest mensuration data, such as species and diameter, were collected along with information on environmental conditions and social context, including ownership.

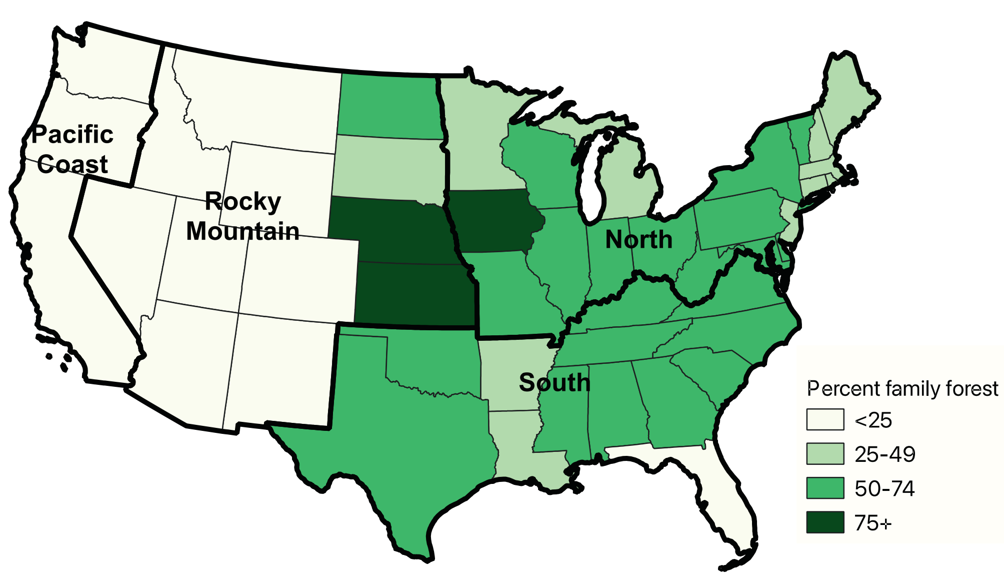

Fig. 1. Percentage of forestland owned by families, individuals, trusts, and family partnerships by state, 2017–2019 (USFS FIA, 2021). Outlines indicate states included in the regions used for presenting results in this report.

Availability of data from the current, annualized FIA system varied regionally due to how the program has been implemented. The nominal years (i.e., terminal years of inventory cycles used to make current estimates) for the FIA plot data used were 2009–2019 for the North, 2010–2017 for the South, 2012–2019 for the Rocky Mountain region, and 2017–2019 for the Pacific Coast region. Due to missing data, Alaska and Hawaii were excluded, the 2013 data for New Mexico were carried back 1 year, and the 2017 data for Wyoming were carried forward 2 years. Removals data were unavailable for the Rocky Mountain region and the states in this region were excluded from the removals analyses. Appendix 1 enumerates the FIA evaluation groups used for this paper.

Apart from total forest area and total carbon sequestered, FIA plot data were reported in relative terms, e.g., per area values or proportions. This removed the confounding impact of the changes in the underlying area of forestland and thus simplified the examination of the other indicators.

2.2. Other data sources

2.2.1. National Woodland Owner Survey (NWOS)

As part of the national FIA program, the USDA Forest Service conducts the NWOS to collect information on the attitudes, behaviors, and other characteristics of family and other private forest ownerships (Butler et al., 2021a, 2021b). An area-based sampling frame was used to collect data from landowners between 2017 and 2018. The probability proportional to size inclusion probabilities were incorporated into the estimators to generate population-level estimates. The results reported here closely match those in Butler et al. (2021a), but they differ slightly because the data reported here were constrained to the conterminous U.S.A.

2.2.2. NatureServe

NatureServe's Map of Biodiversity Importance dataset (NatureServe, 2021) was used to identify the number of at-risk taxa on family forestland. This data source provides counts of the numbers of species in 990 m × 990 m grid cells that are listed as threatened or endangered under the U.S. Endangered Species Act or identified by NatureServe as imperiled or critically imperiled at the global scale. This map was intersected with FIA plots to summarize at-risk species on family forests.

2.2.3. Fragmentation

Forest area density is a metric of forest fragmentation that measures the amount of forest that surrounds a given location with higher values of density implying lower levels of fragmentation (Riitters et al., 2002). The forest area density was calculated for all current FIA plots where the plot center was family forest owned. At each location, the proportion of forestland was calculated in the surrounding 15.2 ha neighborhood based on data from the National Land Cover Database (NLCD) for 2001, 2006, 2011, and 2016 (Homer et al., 2020). The interpretation was that forest area density measures the forest cover fragmentation in the vicinity of the FIA plots; the measured area was larger than the FIA plot so that it is a measure of the plot context.

2.2.4. Bureau of Labor Statistics (BLS)

Forestry-related employment and wages were derived from BLS data for forestry and logging (North American Industry Classification System (NAICS) code 113), sawmill (NAICS 321113), and pulp mill (NAICS 322110) sectors (US-BLS, 2020). The portion attributable to family forests was assumed to be proportional to the FIA estimated share of removals from family forests for the North, South, and Pacific Coast region. For the Rocky Mountain region, where these data were not available, the allocation was based on proportion of family forestland in the region multiplied by the average ratio of family forest ownership to timber removals in the other regions. Wages were adjusted by the implicit price deflator for gross domestic product (BEA, 2021) in order to convert nominal wages to real wages.

2.2.5. Literature synthesis

Peer-reviewed and gray literature were used to identify previous work related to the Soil and Water Conservation and Legal, Institutional, and Economic Frameworks criteria. Sources were found by search terms related to the relevant indicators, primarily using the Family Forest Research Center literature database (FFRC, 2021) and Google Scholar (Google, 2021), and through snowball sampling.

3. Results

The results section is organized by Montréal Process Criteria. Crosswalks between specific Montréal Process indicators and the data presented here are provided in Table 1.

3.1. Criterion 1: conservation of biological diversity

There are an estimated 109 million ha (SE = 0.35) of family forestland across the U.S.A. with 33% of this acreage in the North, 55% in the South, 5% in the Rocky Mountain region, and 7% in the Pacific Coast region (USFS FIA, 2021). This area decreased across all regions during the study period (2009–2019 in the North, 2010–2017 in the South, 2012–2019 in the Rocky Mountain region, and 2017–2019 in the Pacific Coast region) with an average, national annual net loss of 1.0 million ha (Fig. 2). The annual change is −0.4% in the North, −0.8% in the South, −4.1% in the Rocky Mountain region, and − 0.4% in the Pacific Coast region. It is important to note that a loss of family forestland does not necessarily mean a loss of forestland. As is discussed below, an estimated 64% of the loss is conversion to non-forest uses and the other 36% is transfers to other forest ownership categories.

In addition to changes in area of family forestland, there have been changes to the composition and forest structure of these forests. There are a total of 323 species of trees tallied on family owned FIA inventory plots during the most recent inventories (USFS FIA, 2021); this is down from the 335 species observed during the earlier inventories. In the North, the species counts went from 174 to 163 over a 10 year period, in the South they went from 221 to 208 over a 7 year period, in the Rocky Mountain region they went from 121 to 119 over a 7 year period, and in the Pacific Coast region they went from 77 to 75 over a 2 year period. The timespans are based on data availability and are averages across the states in each region.

According to the FIA plot data, there are 32 forest-type groups across America's family forests. In the North, oak/hickory and maple/beech/birch are the dominant forest-type groups, occupying 45% and 23% of the region's family forests, respectively (USFS FIA, 2021); no forest-type groups in this region are showing positive or negative changes of relative area of >0.1 percentage points per year. In the South, oak/hickory and loblolly/shortleaf pine are the most common forest-type groups, occupying 40% and 18% of the family forestland, respectively; the relative area of loblolly/shortleaf is increasing by 0.2 percentage points per year, oak/hickory is decreasing by 0.1 percentage points, and no other forest-type groups are showing substantial changes. Pinyon/juniper, woodland hardwoods, and ponderosa pine are the most common forest-type groups in the Rocky Mountain region occupying 32%, 12%, and 11% of the region's family forestland, respectively; the relative area of the oak/hickory group is increasing by 0.2 percentage points per year while the woodland hardwoods and ponderosa pine groups are decreasing by 0.2 and 0.1 percentage points per year, respectively. Western oak, Douglas fir, and ponderosa pine forest-type groups occupy 35%, 17%, and 11% of the family forestland in the Pacific Coast region, respectively; the relative area of the ponderosa pine group is increasing by 0.1 percentage points per year and the western oak group is decreasing by 0.2 percentage points per year.

Currently, 5.9 million ha (SE = 0.3) of family forestland are owned by people who have at least a portion of their land under a conservation easement (USFS NWOS, 2021), which are legal agreements that permanently constrain specified land uses and practices. These

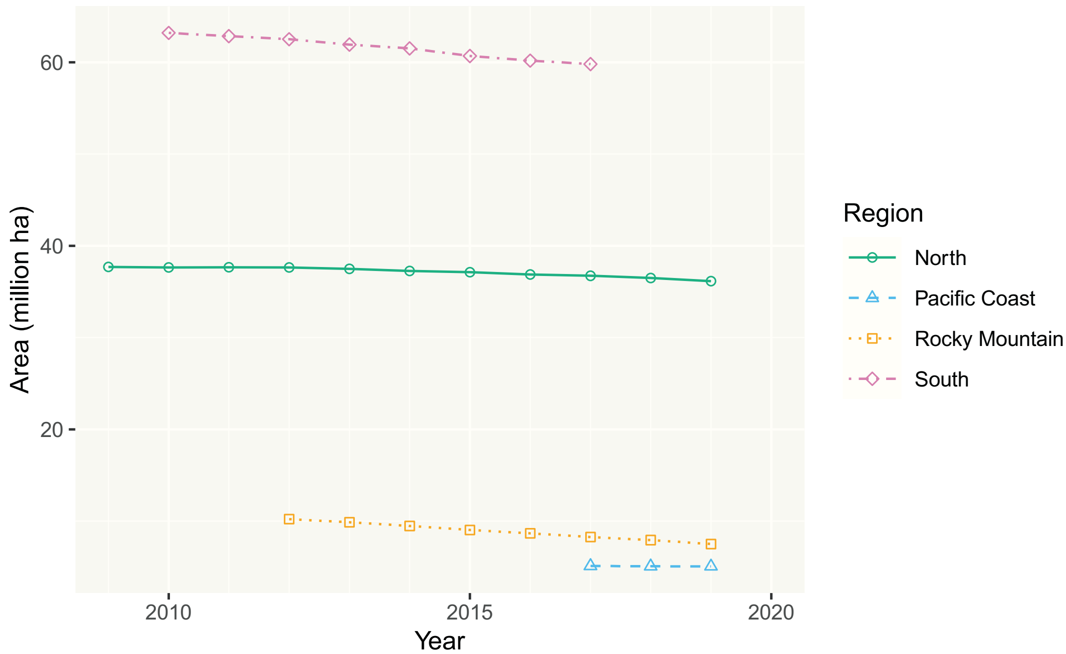

Fig. 2. Area of family forestland by region, U.S.A. 2009–2019 (USFS FIA, 2021).[a] Date ranges vary based on data availability (see Appendix 1 for details). [a]Error bars are excluded to increase readability as the 95% confidence intervals are all relatively small (mean = 0.7 million ha) and obscure the plotting symbols.

ownerships control between 5% and 6% of the family forestland in each region.

Forest area density, the proportion of each sample point surrounded by forest cover and a proxy of forest fragmentation (Caputo et al. 2020), is declining across the U.S.A. from 2001 to 2016 (Fig. 3) implying an increase in fragmentation. This decline is most pronounced in the South (from a mean forest area density of 0.76–0.64). The trends are declining or showing no substantial changes in the other regions, but the large sampling errors suggest that these differences are not statistically significant.

According to NatureServe's Map of Biodiversity Importance data, family forests have an average of 3.3 at-risk species per location. This ranges from no at-risk species up to 18, with averages of 3.3 in the North, 3.7 in the South, 0.8 in the Rocky Mountain region, and 2.6 in the Pacific Coast region.

The proportion of family forestland in stands dominated by large diameter trees[1] is steadily increasing across all regions and the proportion of family forestland in smaller size classes is commensurately decreasing (Table 2). Sixty-four percent of the family forestland in the North is classified as large diameter stands, 51% in the South, 60% in the Rocky Mountain region, and 65% in the Pacific Coast region. Across the regions, the area occupied by large stand sizes is increasing by 0.3–0.7 percentage points per year (USFS FIA, 2021).

3.2. Criterion 2: maintenance of productive capacity of forest ecosystems

Very little family forestland is legally banned from timber harvesting. There are conservation easements associated with 5% of family forests (USFS NWOS, 2021), but most conservation easements allow standard forestry practices, including timber harvesting. There can be local bans on harvesting activities, but these too are currently rare. Some biophysical constraints will impact the feasibility of long-term timber supply, such as low site productivity. Of the total family forestland, 19% is of low timber productivity (i.e., < 1.4 m^3 ha^{-1} yr^{-1}) (USFS FIA, 2021). The percentage of low productivity land varies greatly across the country with <1% of the family forests in the North classified as low productivity, 24% in the South (largely in western Texas and western Oklahoma), 50% in the Rocky Mountain region, and 41% in the Pacific Coast region.

The total volume of live trees, considering just the boles of trees ≥13 cm DBH, on family forests is 12.7 billion m^3 (SE = 0.05) (USFS FIA, 2021). Half (50%) of this volume is in the South, 39% is in the North, 4% is in the Rocky Mountain region, and 7% is in the Pacific Coast region. This equates to 137 m^3 ha^{-1} in the North, 107 m^3 ha^{-1} in the South, 63 m^3 ha^{-1} in the Rocky Mountain region, and 172 m^3 ha^{-1} in the Pacific Coast region. The annual net growth is 376 million m^3 (SE = 2.5) or 2.9 m^3 ha^{-1} yr^{-1} in the North, 4.1 m^3 ha^{-1} yr^{-1} in the South, and 3.8 m^3 ha^{-1} yr^{-1} in the Pacific Coast region; annual net growth data for the Rocky Mountain region are not available.

An estimated 8.6 million ha (SE = 0.1) of the current family forestland is dominated by trees that have been artificially regenerated (e.g., planted stock; USFS FIA, 2021); this represents 8% of the family forestland. The percentage is highest in the South (12%), followed by the Pacific Coast region (7%), the North (3%), and the Rocky Mountain region (<1%). The percentage of artificially regenerated forests has been increasing by 0.1 percentage points per year in the South and has been remaining relatively stable (positive or negative changes of <0.1 percentage points) in the other regions.

Excluding the Rocky Mountain region due to data unavailability, there is an estimated 160 million m^3 yr^{-1} (SE = 2.4) of timber harvested from family forests with 69% of these removals coming from the South, 26% from the North, and 5% from the Pacific Coast region (USFS FIA,

[1] FIA defines stand sizes as: large for stands with ≥50% stocking in medium and large diameter trees and stocking of large diameter trees greater than or equal to stocking of medium diameter trees; medium for stands with ≥50% stocking in medium and large diameter trees and stocking of large diameter trees less than stocking of medium diameter trees; small as stands with ≥50% stocking in small diameter trees; and non-stocked for stands with an all live stocking values of <10 (base 100) (Burrill et al., 2018). Large diameter trees are defined as trees ≥28 cm diameter at breast height (DBH) for hardwoods and ≥ 23 cm DBH for softwoods; medium as trees ≥13 cm DBH and < 28 cm for hardwoods and ≥ 13 cm DBH and < 23 cm for softwoods; and small as trees <13 cm DBH.

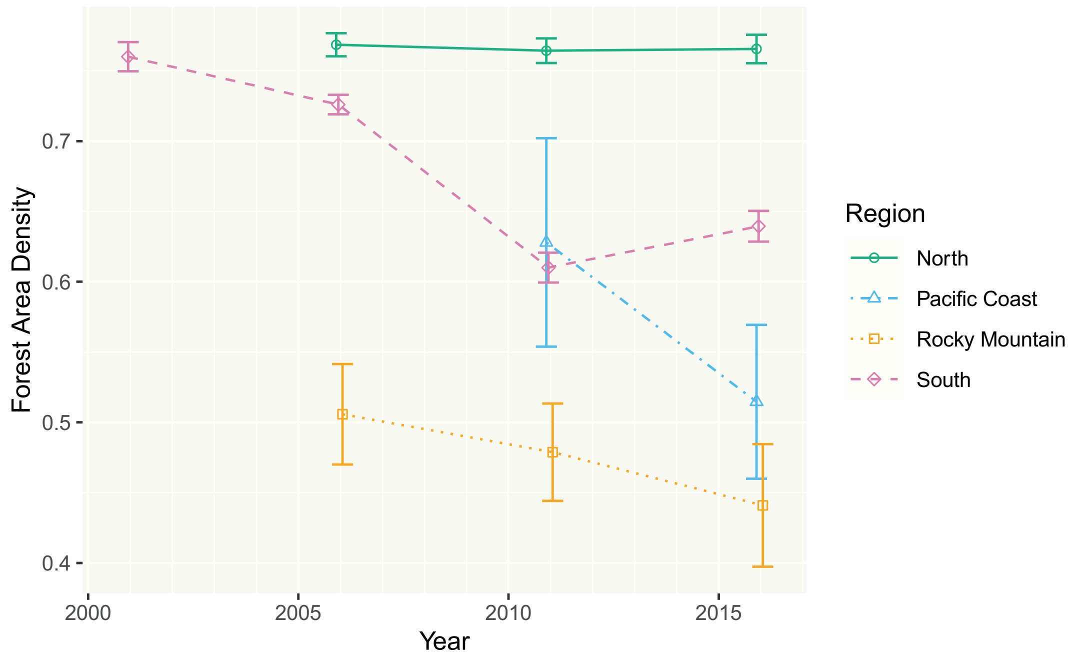

Fig. 3. Mean forest area density in the vicinity of family-owned FIA forest inventory plots by region, U.S.A. 2001–2016. Error bars represent 95% confidence intervals. Date ranges vary based on data availability.

Table 2
Percentage of family forestland in the U.S.A. by stand size[2] and region, U.S.A. 2009–2019 (USFS FIA, 2021).

Region	Stand size			
	Small	Medium	Large	Non-stocked
North	10% (−0.3)	25% (−0.4)	64% (+0.7)	1% (−0.0)
Pacific Coast	10% (−0.3)	23% (−0.0)	65% (+0.3)	3% (+0.0)
Rocky Mountain	18% (−0.2)	16% (−0.2)	60% (+0.4)	6% (+0.0)
South	22% (−0.5)	24% (−0.2)	51% (+0.6)	2% (+0.0)

Numbers in parentheses represent annual change in terms of percentage points. Specific years associated with the data vary by region (see Appendix 1 for details).

2021). This harvest is nearly evenly split between hardwoods and softwoods (49.7% and 50.3%, respectively). The ratios of net growth to removals by hardwood and softwood species groups for the most current inventories exceed 1.0 across regions and range from 2.0 for softwoods in the South to 2.8 for softwoods in the Pacific Coast region (Fig. 4). The net growth to removal ratios for the North appear to have plateaued or begun to decrease (but are still far above 1.0) in recent years and the ratios for the species groups in the other regions have been increasing, especially for hardwoods in the South.

For the majority of the most common species, the ratios of net growth to removals are well above 1.0, but there are a few notable exceptions (Fig. 5). In the North, there is a marked negative trend in *Fraxinus americana* and in the Pacific Coast region, there is a negative trend for *Quercus kelloggii*. Other common species (i.e., current volume $\geq$ 10 million m^3) with net growth to removal ratios of $<$1.0 in the most recent inventories are: *Salix nigra*, *Ulmus rubra*, *Fraxinus pennsylvanica*, *Pinus virginiana*, *Betula papyrifera*, and *Robinia pseudoacacia* in the North; *Quercus marilandica*, *Robinia pseudoacacia*, *Tsuga canadensis*, *Quercus velutina*, *Carya texana*, *Sassafras albidum*, and *Pinus echinata* in the South; and *Quercus agrifolia*, *Tsuga heterophylla*, and *Abies concolor* in the Pacific Coast region.

3.3. Criterion 3: maintenance of forest ecosystem health and vitality

An estimated 3.1 million ha (SE = 0.2) of family forestland are annually disturbed by one or more natural or human vectors (e.g., brush clearing) (Table 3; USFS FIA, 2021). This includes only areas that have been disturbed since the previous inventory (or within 5 years for new plots), the impacted must be at least 0.4 ha, and there has to be significant impacts (i.e., $\geq$ 25% of the trees killed or damaged) (Burrill et al., 2018). As defined by FIA, human disturbances exclude traditional timber management activities, such as final harvests and thinning, and are largely related to brush clearing, trail maintenance, and fire breaks. Natural disturbances of animals, disease, fire, insects, and storms range from 0.0% to 1.7% per year across the four regions in 2019 and human disturbances, including deforestation, but excluding harvesting, range from 0.4% to 2.0% per year in 2019. In the North, an estimated 4% of the family forestland shows disturbance by at least one vector with insects, humans, and diseases being the most common. In the South, an estimated 2% of the family forestland shows disturbance by at least one vector with fire, weather, and humans being the most common. In the Rocky Mountain region, an estimated 3% of the family forestland shows disturbance by at least one vector with human, insect, and disease disturbances being the most common. In the Pacific Coast region, an estimated 3% of the family forestland shows disturbance with humans, diseases, and fire being the most common.

Nationally, most disturbance vectors are showing relative changes of $<$0.1 percentage points between the earliest and most recent inventories, but insect and disease vectors showed increases of 0.2 and 0.1 percentage points, respectively (USFS FIA, 2021). Other vectors that are showing increases of at least 0.1 percentage points are insects in the South and diseases in the Rocky Mountain region. Vectors that are showing decreases of at least 0.1 percentage points are: weather and humans in the North; weather and humans in the South; humans, fire, and weather in the Rocky Mountain region; and humans and diseases in the Pacific Coast region.

In addition to these disturbances on family forests that remained family forests, a gross loss of 627,000 ha (SE = 14,000) of family forestland are annually being converted to non-forest uses across the Northern, Southern, and Pacific Coast regions (USFS FIA, 2021); data

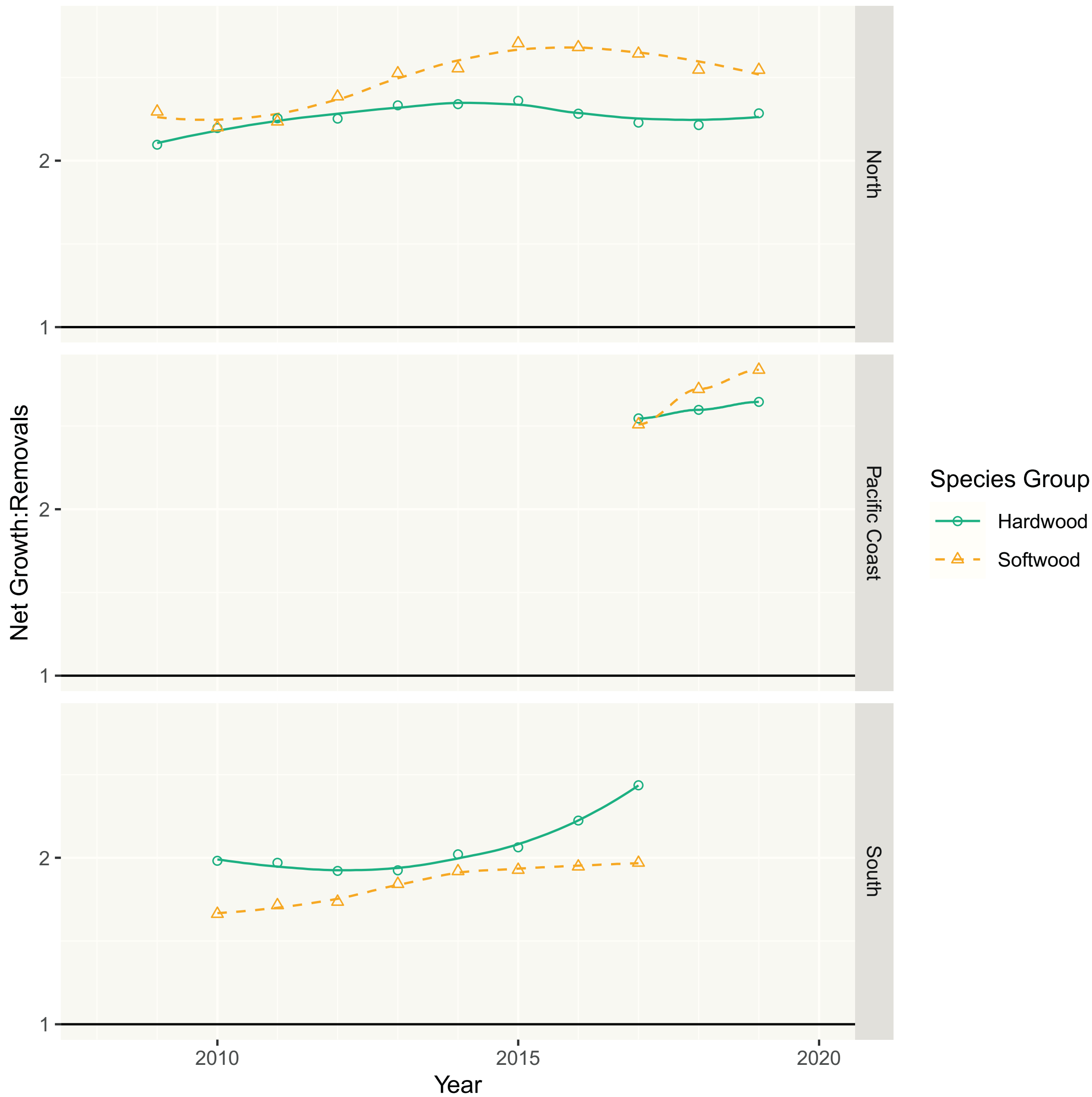

Fig. 4. Ratios of net growth to removals by hardwood and softwood species groups for family forests in the Northern, Southern, and Pacific Coast regions, U.S.A. 2009–2019 (USFS FIA, 2021). The solid, horizontal line at 1 represents the point where net growth and removals are equal. The Rocky Mountain region is excluded due to data unavailability. Date ranges vary based on data availability (see Appendix 1 for details).

are not currently available for the Rocky Mountain region. In the North, this includes annual conversions of 96,000 ha (SE = 5000) to agricultural uses, 53,000 ha (SE = 3000) to developed uses, and 22,000 ha (SE = 2000) to other uses. In the South, this includes annual conversions of 179,000 ha (SE = 8000) to agricultural uses, 132,000 ha (SE = 3000) to developed uses, 99,000 ha (SE = 8000) to rangeland, and 6000 ha (SE = 2000) to other uses. In the Pacific Coast region, this includes annual conversions of 3000 ha (SE = 1000) to agricultural uses, 10,000 ha (SE = 1000) to developed uses, 22,000 ha (SE = 2000) to rangeland, and 3000 ha (SE = 1000) to other uses.

3.4. Criterion 4: soil and water conservation

Water and soil best management practices (BMPs) are implemented at the state level, with forestry BMPs that are non-regulatory (20 states), quasi-regulatory (19 states), or regulatory (11 states) (Cristan et al., 2018). Forestry BMPs have largely been shown to achieve their goal of protecting water quality (Cristan et al., 2016), and compliance is generally high, including on family forestland. A range of studies have found high rates of implementation of water quality BMPs associated with various forestry practices, with an estimated national implementation of 89% across ownership types (Ice et al., 2010). A study in Georgia finds that family forest ownerships have a lower implementation rate than other forest ownership types, although implementation rates are still high, i.e., over 90% (Dwivedi et al., 2018). In East Texas, family forest ownerships had greater improvement in BMP implementation rates compared to other ownership types, from 70% in 1992 to 93% in 2015, although the rates are still lower than on public forestland (Simpson et al., 2015). In a New York watershed, VanBrakle et al. (2013) find that family forest ownerships have only minor deviations from BMP standards across most activities, although some practices show higher deviations. It has also been noted that there can be local variability based on site characteristics and forest disturbance (Slesak et al., 2018). While protecting water quality is the primary focus

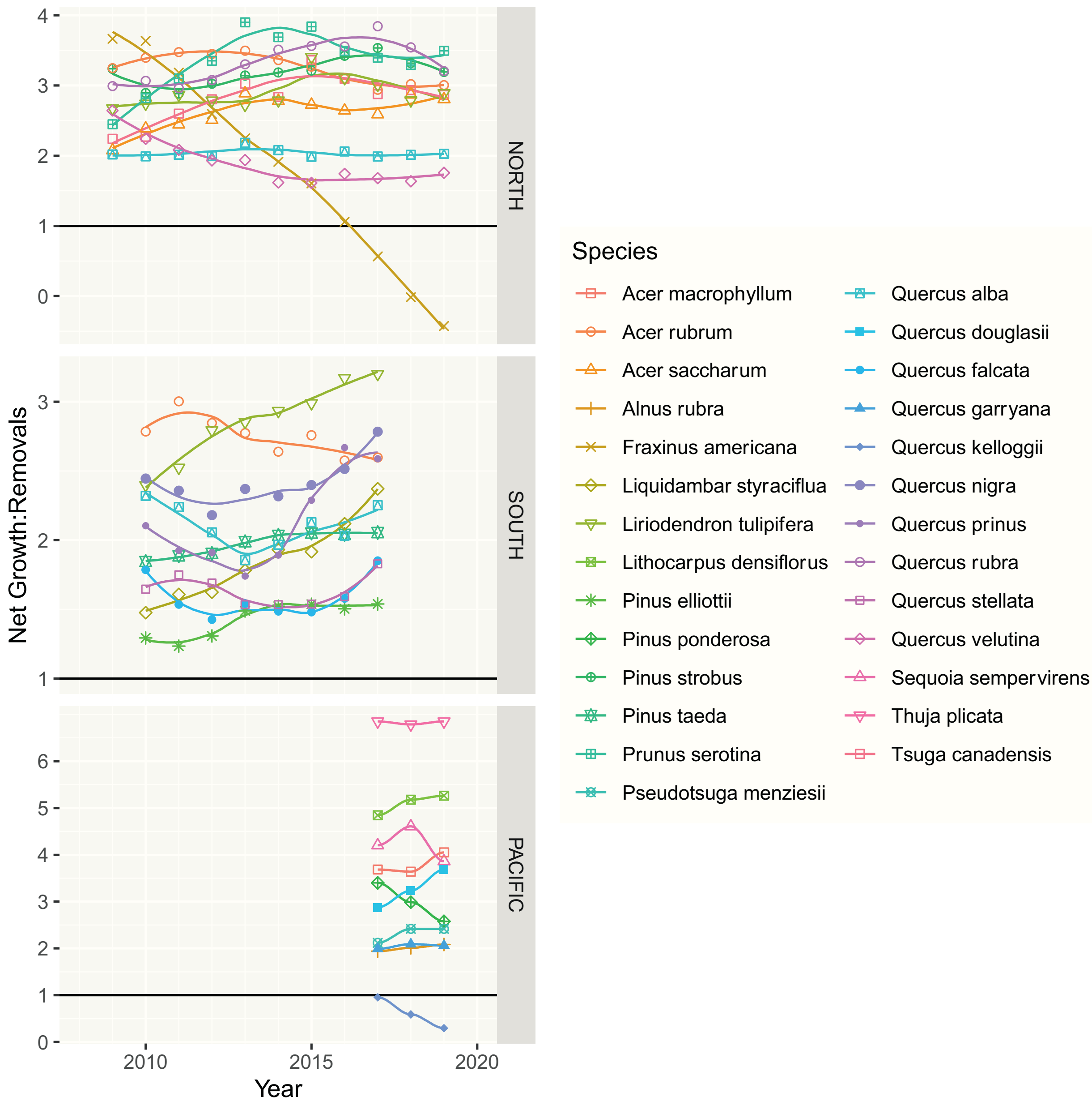

Fig. 5. Ratios of net growth to removals for the 10 most voluminous species on family forests in the Northern, Southern, and Pacific Coast regions, U.S.A. 2009–2019 (USFS FIA, 2021). The solid, horizontal line at 1 represents the point where net growth and removals are equal. The Rocky Mountain region is excluded due to data unavailability. Date ranges vary based on data availability (see Appendix 1 for details).

of many forestry BMPs, they have often been expanded to include soil protection; for example, limiting erosion and compaction and maintaining productivity are often included in BMPs (Aust and Blinn, 2004).

3.5. Criterion 5: carbon sequestration

There are an estimated 15.7 billion metric tonnes (SE = 0.05) of carbon on family forest lands across the conterminous U.S.A. with 43% of the carbon in the soil pool, 35% in aboveground living biomass, 7% in belowground living biomass, 8% in the litter, and 6% in dead woody biomass (USFS FIA 2021). Forty-two percent of the total family forest carbon is in the North, 47% is in the South, 5% is in the Rocky Mountain region, and 6% is in the Pacific Coast region. This equates to 183 MT ha^{-1} in the North, 124 MT ha^{-1} in the South, 95 MT ha^{-1} in the Rocky Mountain region, and 177 MT ha^{-1} in the Pacific Coast region. Per hectare carbon increased by 1–6% across the regions with annual changes in total carbon of <1 % in the North, South, and Pacific Coast regions and an average annual decrease of 2% in the Rocky Mountain region.

3.6. Criterion 6: socio-economic benefits

Family forests support the highest level of employment and wages in the South, followed by the North, the Pacific Coast, and the Rocky Mountain regions (Fig. 6). However, the same ranking holds for the loss of jobs over time. Both employment and total wages have been negatively impacted by the recession circa 2007–2009. While the wages have largely recovered to pre-recession levels, employment has not, but there were some downward trends in employment, especially for the South, prior to the recession. The recession notwithstanding, the long-term

Table 3
Annual area and percentage of family forestland in the U.S.A. annually damaged by diseases, insects, fire, and storms/weather, and deforestation by region (USFS FIA, 2021).

Disturbance/Year	Region							
	North		Pacific Coast		Rocky Mountain		South	
	Area (thousand ha)	*Percent*	*Area (thousand ha)*	*Percent*	*Area (thousand ha)*	*Percent*	*Area (thousand ha)*	*Percent*
Animals								
2019	73.0	0.2	0.5	0.0	5.0	0.1	54.9	0.1
2009	62.0	0.2	1.4	0.0	6.7	0.1	56.8	0.1
Diseases								
2019	272.4	0.8	27.6	0.5	26.4	0.4	89.0	0.1
2009	64.2	0.2	33.3	0.7	22.6	0.3	76.4	0.1
Fire								
2019	14.8	0.0	15.3	0.3	17.7	0.2	302.0	0.5
2009	15.8	0.0	14.3	0.3	60.5	0.8	311.2	0.5
Humans*								
2019	325.3	0.9	68.2	1.3	144.2	2.0	238.7	0.4
2009	534.8	1.4	85.5	1.7	228.3	3.0	459.4	0.7
Insects								
2019	598.9	1.7	5.1	0.1	38.9	0.5	113.5	0.2
2009	50.1	0.1	6.5	0.1	45.9	0.6	39.6	0.1
Storms/weather								
2019	91.6	0.3	11.5	0.2	15.7	0.2	285.2	0.5
2009	301.4	0.8	11.5	0.2	24.8	0.3	565.5	0.9
Other								
2019	167.3	0.5	1.8	0.0	5.0	0.1	43.3	0.1
2009	145.5	0.4	2.1	0.0	2.3	0.0	34.7	0.1
Deforestation								
2019	171.1	0.5	39.2	0.8	– **	– **	417	0.7
2009	168.3	0.4	45.7	0.9	– **	– **	320.7	0.5

Nominal years are listed; see Appendix 1 for details.
* Excludes timber harvesting and other traditional forestry activities; ** The Rocky Mountain region is excluded due to data unavailability.

trend in real total wages is relatively flat compared to employment declines and it can be inferred that wages per employee are rising.

3.7. Criterion 7: legal, institutional, and economic frameworks

In many states, forestry practices on private forestland – including family forestland – are not directly regulated, although the lands are still subject to other state and federal policies, and many states have educational programs as well as voluntary or incentive-based programs aimed at family forest owners (Cubbage et al., 2020b), and as stated above for Criterion 4, most family forest ownerships are subject to either mandatory or voluntary BMPs. Thirty-six states have laws that regulate forest and timber resources, including 23 with laws related to timber harvesting, forestry education, and/or prescribed burning (Defenders of Wildlife, 2000). Despite the many layers of environmental regulation, the lack of legal and policy frameworks for private land can be a challenge to ensuring sustainable forest management (e.g., Michigan Department of Natural Resources, 2020).

Development is largely regulated by local governments through zoning and performance standards, but most of these measures allow for some degree of forest conversion (McGinley and Cubbage, 2020). The Food, Conservation, and Energy Act of 2008 (more commonly know as the 2008 U.S. Farm Bill) requires forest action plans for each state to assess forest trends and support forests across all sectors and ownership types, including family forest owners, in order for states to qualify for federal financial assistance for certain forestry programs (McGinley and Cubbage, 2020). There are also policies to support cross-sectoral sustainable forest management, such as the Forest Legacy Program, which has protected over 850,000 ha of privately held forestland through conservation easements and 186,000 ha through direct acquisitions as of 2015 (USDA Forest Service, 2015). An increasing number of cross-sectoral programs (McGinley and Cubbage, 2020) also support multi-level strategies for protecting forests such as the Smart Growth Network (Smart Growth Network, n.d.) and the EPA Healthy Watersheds Program (U.S. Environmental Protection Agency, 2016).

Economic strategies that support sustainable management include direct payments, tax credit incentives, and market-based programs. For family forest ownerships in the U.S.A., economic strategies include direct payments, often in association with technical assistance, through federal, state, and private sources (Cubbage et al., 2020a); although not limited to payments to family forest ownerships, governmental and nongovernmental programs accounted for over US$2 billion of payments for ecosystem services in 2012 (Cubbage et al., 2020a). In the last 5 years, 13% of family forestland, held by 2% of family forest ownerships, have participated in these types of cost share programs (Butler et al., 2021a).

There are also programs that provide income tax benefits at the federal and state levels and property tax benefits at the local level to encourage landowners to participate in certain forest protection or management practices (Cubbage et al., 2020a). An estimated 9% of family forest ownerships, who own 24% of the family forest acreage, are currently enrolled in preferential property tax programs for their forestland. Eligibility criteria vary by state and may include minimum parcel sizes, specific forest conditions, management plan and harvest requirements, and allowing inspections (Kilgore et al., 2018). Family forest ownerships may be eligible for market-based programs, such as forest certification or cap-and-trade programs for carbon, endangered species, or wetlands mitigation (Cubbage et al., 2020a). While these programs may be available to some family forest ownerships, participation is lower than for cost-share or tax abatement programs (i.e., green certification and carbon sequestration are both <10% of acreage and ownerships). There are also tax credits available to family forest ownerships for donating development rights through easements (Cubbage et al., 2020a).

Land tenure is secure for most, but not all, family forest owners. A notable exception is heirs' property – when property is inherited without a will and caries more tenuous legal status – which is a leading cause of land loss among Black landowners over the last century (Hitchner et al., 2017). Heirs' property is also documented for Native American tribal members (Johnson Gaither, 2016), poor, rural family forest owners in

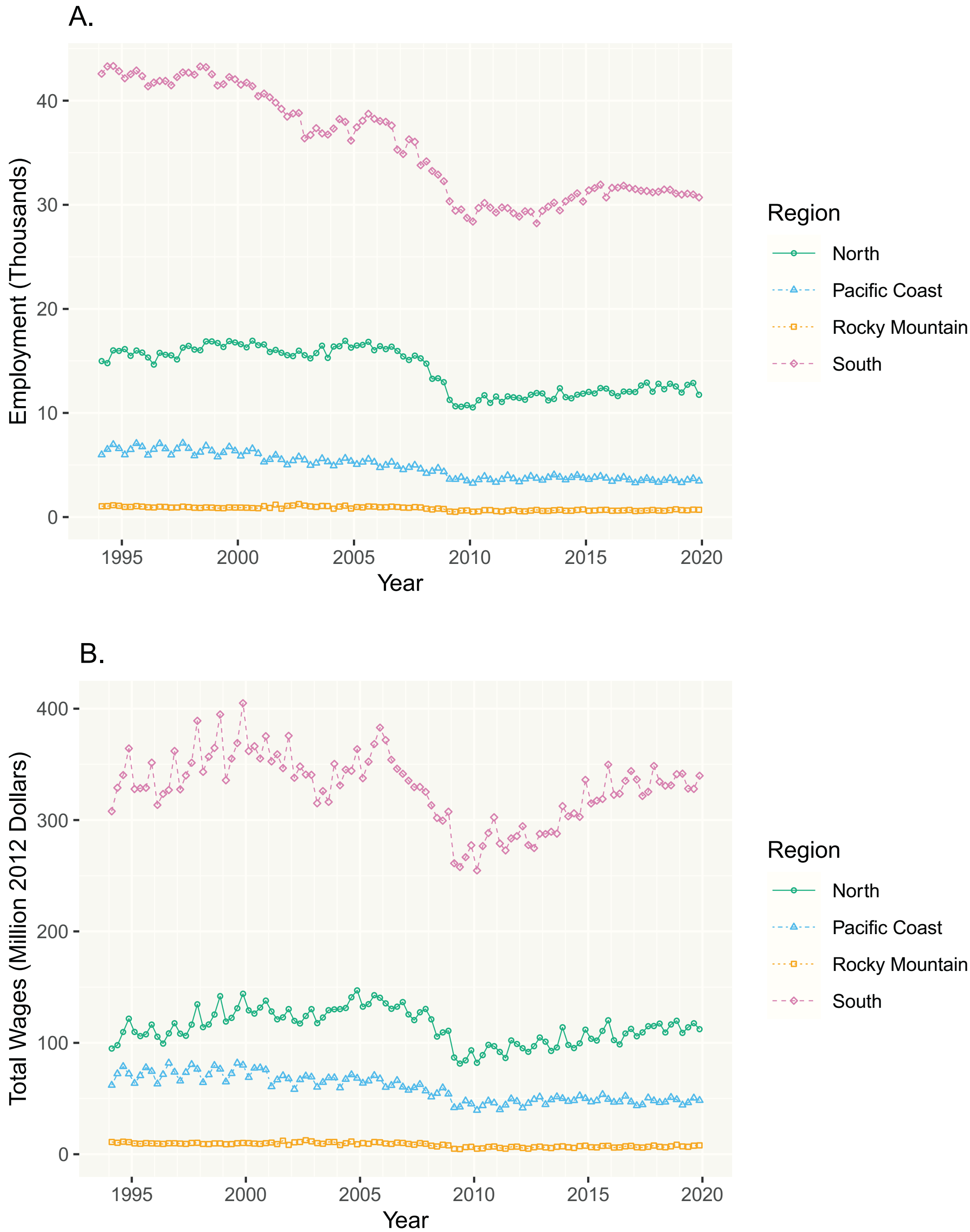

Fig. 6. Forestry-related A) employment and B) wages (US-BLS, 2020) proportionally attributed to family forests by region, U.S.A. 1994–2019.

Appalachia (Deaton, 2012), and other communities. Heirs' property creates barriers to timber harvesting and access to loans, cost-share assistance, and incentive programs (Hitchner et al., 2017). While efforts to assist family forest ownerships with heirs' property to obtain clear titles are underway (e.g., Schelhas and Hitchner, 2020), progress is slow, and Bailey et al. (2019) estimate that at least 647,000 ha across the Black Belt region of the southern U.S.A. are currently held as heirs' property.

4. Discussion

The sustainability of family forests, as with all forests, is a multifaceted concept. The Montréal Process C&I is imperfect in that it is impossible to characterize and quantify all aspects of forest sustainability, but it is among the most widely used broad-scale assessment frameworks. Using this framework, it is clear that there are some attributes of family forests in the U.S.A. that are very encouraging and some that are concerning (Table 4). These strengths and weaknesses will vary over time and space and these spatiotemporal aspects are important in interpreting the overall results and implications.

The most basic metric for forest sustainability is trends in forest area (Montréal Process C&I 1.1.a) – if there is no forestland, then all other metrics are moot. Although the area of forestland across ownerships is relatively stable (Oswalt et al., 2019), there are net decreases in family forestland across all regions of the U.S.A. (Fig. 2) with a decrease of approximately 1.0 million ha yr^{-1} in recent years, a finding that is disconcerting in terms of the sustainability of family forests. But not all forest loss is equal. Although there is a net decrease in family forest area,

Table 4
Trends in selected Montréal Process Criteria and Indicators for family forests in the U.S.A. by region and for the nation.

Criterion/Indicator	Description	Region				U.S.A.
		North	Pacific Coast	Rocky Mountain	South	
Criterion 1: Conservation of biological diversity						
1.1.a	Total forest area	⇩	⇩	⇩	⇩	⇩
	Forest area by forest type group (%)	⇔	⇔	⇔	⇔	⇔
	Stand size (small; %)	⇩	⇩	⇩	⇩	⇩
	Stand size (large; %)	⇧	⇧	⇧	⇧	⇧
1.1.c	Forest density	⇔	⇔	⇔	⇩	⇩
1.2.a	Number of tree species	⇩	⇩	⇩	⇩	⇩
Criterion 2: Maintenance of productive capacity of forest ecosystems						
2.a	Productive forestland (%)	⇩	⇩	⇩	⇩	⇩
2.b	Growing stock volume	⇧	⇧	⇩	⇧	⇧
	Growing stock volume (ha^{-1})	⇧	⇧	⇧	⇧	⇧
2.c	Planted forestland (%)	⇩	⇩	⇩	⇩	⇩
2.d	Annual harvest volume	⇩	⇩	?	⇩	⇩
	Annual harvest volume (ha^{-1})	⇧	⇧	?	⇧	⇧ *
	Net growth to removal ratios for hardwoods	⇧	⇧	?	⇧	⇧ *
	Net growth to removal ratios for softwoods	⇧	⇧	?	⇧	⇧ *
Criterion 3: Maintenance of forest ecosystem health and vitality						
3.a	Forest area damaged by disease (%)	⇧	⇩	⇧	⇧	⇧
	Forest area damaged by insects (%)	⇧	⇩	⇩	⇧	⇧
3.b	Forest area damaged by fire (%)	⇩	⇩	⇩	⇩	⇩
	Forest area damaged by storms/weather (%)	⇩	⇧	⇩	⇩	⇩
	Forest area lost to land use conversion (%)	⇧	⇩	?	⇧	⇧ *
Criterion 5: Maintenance of forest contribution to global carbon cycles						
5.a	Forest carbon	⇧	⇩	⇩	⇧	⇩
	Forest carbon (ha^{-1})	⇧	⇧	⇧	⇧	⇧

Upward arrows (⇧) represent upward trends, downward arrows (⇩) represent downward trends, double sideways arrows (⇔) represent mixed or indeterminant trends, and question marks (?) represent indicators where no trend data are available.
* Excluding the Rocky Mountain region.

an estimated 36% of this forestland is transitioning to other forest ownership categories, such as corporate. Some of these transitions to corporate ownerships are to traditional forestry companies buying family forestland, but other transitions are the result of family forests restructuring as limited liability corporations (LLCs), limited liability partnerships (LLPs), or other legal entities for tax, intergenerational transfer, and other reasons.

The ownership classification approach used by the FIA program aims to classify these LLCs, LLPs, and similar ownerships that are ostensibly the same as other family forest ownerships as family forest ownerships, but this is challenging to do in practice and deserves additional attention. There are also transitions occurring to other ownership types, such as public ownerships, that are being driven by the desires of family forest owners to permanently protect their land. Without knowing whether land that transitions from family to institutional or public ownership will be managed more or less sustainably, it is impossible to know with any certainty the impact of these transitions on the overall sustainability of the forest resource itself in terms of the rest of the criteria and indicators. This remains an important question.

Although family forest owners are often careful land stewards across decades and generations, legal conservation easements represent one of the only *formal* protection mechanisms for ensuring private forests stay forested. An estimated 5% of the family forestland is owned by people who have these legal restrictions on all or part of their forestland and another 2% of the forestland is owned by people who are interested in doing so in the near future (USFS NWOS, 2021). This leaves >90% of the family forestland without any formal, permanent protection. Easements are one of the strongest conservation tools, but they can be problematic for many owners due to their permanence and the restrictions on what current and future generations can do with the land – the same aspects that make them appealing to other owners (Vizek and Nielsen-Pincus, 2017). Low awareness levels are one of the barriers with 49% of the family forestland owned by people being "not at all familiar" with conservation easements (USFS NWOS, 2021). With easements continuing to be relatively uncommon across the landscape, knowing when and where to apply and promote this conservation tool will continue be important.

Apart from the transitions among forest ownership categories, there are losses to non-forest uses. Many of these transitions are related to the dynamics of land going in to and out of agricultural uses, marginal pasture lands in particular, but other losses are to housing and other more permanent transitions (USDA Forest Service, 2012). If the goal is to keep forests as forests, it are these permanent transitions that should be focused on. The factors related to these conversions have largely been modeled as functions of population and economic factors (Lubowski et al., 2008), and it has been shown that it is difficult for forest uses to financially compete with these alternative uses in places where there are societal pressures to develop and expand human habitation and infrastructure. More research on the motivations of individuals for conserving or converting forestland can help policymakers and others devise tools for addressing these issues when and where it is appropriate. While there is a net loss of forestland, there are many hectares of non-forest land that are reverting back to forestland, many of these being marginal pasture and other agricultural lands, and the factors associated with these reversions are also important to understand. It is also important to note that these newly established forests will remain in an early-successional stage for many decades, with impacts (both positive and negative) on forest structure and, consequently, habitat, recreation, carbon dynamics, timber production, and other values disproportionate to the net change in forested area.

The sustainability of family forests inherently depends on what the neighboring landowners do with their forests, and fragmentation indicators, such as forest area density, are designed to assess neighborhood effects. For example, the owner of a small forest parcel may well succeed in conserving unfragmented forest within that parcel, but if the neighbors clear all the surrounding forest, then that small parcel may still be subject to "edge effects" that are associated with fragmentation (Murcia, 1995; Ries et al., 2004). Despite the presented evidence of increasing fragmentation near family forests after 2001, there is also evidence of stabilization or restoration across all ownerships after 2011 in eastern forests (Riitters and Robertson, 2021). Whether fragmentation is increasing or decreasing, a large share of the remaining unfragmented eastern (but not western) forest area is family owned, and efforts to conserve those conditions may require multi-family or "landscape scale" approaches to forest management (Riitters and Costanza, 2019). Although generally considered deleterious, fragmentation can also have some benefits, including increased biodiversity often associated with edge habitat.

Of the family forests remaining family forests, there are slight decreases in observed tree species, some shifts in forest-type groups, and a substantial trend towards larger stand sizes. The decrease in observed tree species may be a result of the decreased area of family forestland and the fact that broad-scale inventories, such as FIA, are not well suited for capturing rare events. Modeling techniques to estimate species accumulation curves or other techniques could be employed to overcome this shortcoming in future research. Classification of forest-type groups is based on the preponderance of specific species. Shifts can occur due to natural succession changing the relative species mixes or can be the result of human or other influences that fundamentally change forest composition and structure.

The increase in artificially regenerated stands across much of the U.S.A., and in the South in particular, is largely due to the increased total financial returns per hectare that these types of stands can earn over naturally regenerated stands under certain conditions. And artificially-regenerated stands have lower risks of regeneration failures or poor stocking that would reduce financial returns. The net increases of family forestland in larger stand sizes are the result of natural growth patterns and the relatively low levels of stand replacing events, be they anthropogenic (e.g., timber harvesting) or natural causes. The shifts will have consequences for wildlife habitat and other ecosystem functions with some species benefitting and others facing challenges due to a lack of resources, especially those associated with early successional habitat.

There is a lot of wood on family forests and there is prodigious growth in terms of both merchantable volume and carbon sequestration. The overall growth to removal ratios are >1.0 for the hardwood and softwood species groups across all regions and for most species, but there are notable exceptions. Although most family forestland is legally and physically available for timber supply, the "social" availability of the timber may be very different with substantially fewer acres being available due to ownership objectives, size of forest holdings, and other factors (Butler et al., 2010). In terms of overall timber supply, these other attributes should be considered to ensure a long-term, sustainable wood supply. The majority of species showing growth to removal ratios of <1.0 are largely due to issues related to insects and diseases, such as the emerald ash borer (*Agrilus planipennis*) decimating *Fraxinus* species across the North, and shifts in regenerations patterns, such as fire suppression and grazing severely impacting the regeneration of some oak species, including *Q. kelloggii* in the Pacific Coast region (Fryer, 2007). It is important to note that these are national and regional trends; local factors, such as pellet mills, may cause different trends at finer-scales than were analyzed in this paper.

The total amount of family forestland that shows disturbance by one or more vectors is moderate, i.e., <5% per year from natural and human disturbances (excluding timber harvesting), but the disturbances will be particularly severe and persistent in some areas and many disturbances will be cumulative and additional acreage will be damaged in the future. Collectively, disturbances from animals, diseases, fire, and storms are impacting 3% or less of the family forestland per year for all regions, and some of those disturbances could presumably be salvage harvested for timber or firewood and these disturbances are also contributing to to nutrient cycling and creation of conditions beneficial to some flora and fauna. Human disturbances in the Rocky Mountain region and insects in the North are currently the two disturbance vectors impacting the greatest percentages of the area. Overall, disturbances on family forestlands tend to be higher than those on Corporate forestlands, lower than those on Federal, State, Other Private, and Tribal forestlands and about the same as Local public forestlands (Butler et al., n.d.).

It is clear that many hectares are being influenced by insects, diseases, fire, people, and interactions thereof, but additional analyses are needed to quantify the impacts on the natural processes and on family forests in particular. In fact, many of these disturbances are part of natural processes and the greater need is to understand the departures from historic (or desired) rates of disturbances. It should also be noted that the disturbance statistics come from FIA data which are based on plots that are measured over multiple, typically 5–10, years; this allows for general trends to be well captured, but it can dampen the signals from large, annual events.

Of paramount importance to the conservation of forests and what they provide to society is the maintenance of clean water supplies and healthy soils. BMPs are well established across most of the U.S.A. using various implementation approaches, e.g., regulatory versus voluntary, and family forest ownerships are largely abiding by them (Ice et al., 2010; VanBrakle et al., 2013; Simpson et al., 2015; Dwivedi et al., 2018). Direct measures of the impacts of the water and soil conditions are lacking for large-scale assessments of family forests, but the BMP adherence is a positive harbinger.

The amount of carbon stored in family forests is substantial with most of it in either the soil or above ground woody biomass. Although it is difficult to influence the soil carbon in areas that remain forested, natural processes and management practices can substantially influence the aboveground component. Related to the increasing stand sizes, there are net increases in the per hectare carbon sequestration across all regions. But while there are net increases in total carbon sequestration on family forestlands in the North and South, there are decreases in the Rocky Mountain and Pacific Coast regions due in part to the overall loss of family forestland.

Family forests provide substantial benefits to the U.S. economy. In 2019, there were an estimated 47.4 thousand jobs generated from forest management, timber harvesting, and primary wood processing and an accompanying US$2 billion in wages. These contributions are tied to broader economic trends including recessions and demand spikes that influence wood markets. All regions show a long-term increase in real wages per employee, however the rate of increase in the Rocky Mountain region is much smaller than it is for other regions. Furthermore, this observed trend is sensitive to the choice of wage deflators (in this case, a gross domestic product deflator), and the real increases in wages do not necessarily imply that the increase is equitably distributed. These estimates of economic contributions miss some economic activity associated with sole proprietorships not included in the BLS data. The estimates also fail to account for non-timber markets (e.g., recreation and non-timber forest products), other ecosystem services (e.g., value of carbon sequestration), and the multiplier impacts of jobs and wages across other sectors.

Overall, the U.S.A. has strong legal, institutional, and economic frameworks for supporting family forests and family forest owners. Land tenure rights are well-defined and well-supported by legal precedent. Most forest-related policies are at the state-level with approaches varying substantially across states. Some states have taken stronger regulatory approaches related to forest management practices and others have taken voluntary approaches. The adoption of cost-share and other incentives, be they national or state sponsored, has remained relatively low and the impact of many of these programs has been called into question (Kilgore et al., 2007). Additional support is provided to landowners through extension and other education programs that are available, to varying degrees, in most states including master forest owner and other peer-to-peer programs (Kueper et al., 2013).

The Montréal Process has no indicators specifically related to diversity, equity, inclusion, or justice issues. For family forest owners, two relevant topics in this area are related to minority and female landowners. There has been a loss of forestland by minority landowners over the past century and the persistence of heirs' properties is at least partially responsible for this loss (Hitchner et al., 2017). In addition, there have been cases litigated involving minority landowners' access to U.S. Department of Agriculture assistance programs (Carpenter, 2012) and minority family forest owners have, overall, lower participation rates in landowner assistance programs (Butler et al., 2020).

The primary decisionmaker for most family forests are men, but the proportion of female primary decisionmakers has increased and many family forests are owned by a man and a woman, often a married couple (Butler et al., 2018). Traditionally most of the people participating in landowner education event have been men. Research suggests that more targeted approaches are needed for female forest owners (Miner et al., 2021) and indeed events and programs are being created specifically for women and "Women Owning Woodlands" groups have been established across the country (Huff, 2017). While this is meaningful progress, more efforts like these are needed and it is important the efforts receive the resources needed to persist and grow.

There are a number Montréal Process C&I that were not assessed as part of this analysis due to data limitations. The data from the FIA national inventory were critical for quantifying many of the indicators, but the lack of data availability for Alaska and Hawaii, the lack of remeasurement data for the Rocky Mountain region, and the short time series available for the Pacific Coast region hamper analyses, but these issues will be overcome as FIA continues to collect data. As another example, there are multiple indicators associated with nontimber forest products, but there is a general lack of information on the markets and valuation of these products across the U.S.A. (Frey et al., 2019) and no way to separate results for family forests. Collection of nontimber forest products is occurring on 19% (SE = 0.4) of the family forestland (USDA NWOS, 2021), but there is no information on the intensity of this collection either in terms of the area each ownership uses for such purposes or the quantities collected.

There are a number of aspects related to family forests that are not captured by the Montréal Process C&I because of its focus on broader forest trends. For example, size of forest holdings has been shown to be highly correlated with many forest ownership attributes (Butler et al., 2021b) and trends in size of forest holdings would make sense for C&I focused on family forests. Looking at trends in size of forest holdings since the 1990s suggests increased inequality among family forest owners (Goyke and Dwivedi, 2021) with the mean size of family forest holdings in the U.S.A. is 11.6 ha (SE = 0.4; median = 2.0 ha) as of 2018, a 2%, decrease from 2013 (11.8 ha, SE = 0.4; median = 2.4 ha) (USDA NWOS, 2021). And even more important than the averages may be the relative changes or stability in the distributions of sizes of forest holdings (Fig. 7).

There are some issues related to the Montréal Process C&I due to them now being somewhat dated. When the Montréal Process C&I were first adopted in 1995, climate change was not assessed the same way it is today. An addition in terms of climate change could be related to drought, such as data from the Palmer Drought Severity Index (Dai, 2017).

A shortcoming (and a strength) of the Montréal Process is that the C&I are not normative – there are limited guidelines on what appropriate trends or levels should be. This is presumably a conscious decision that was made when the Montréal Process C&I were designed and was related to the desired role of the government agencies implementing it – they are arbiters of data, not necessarily of what conditions should be. This latter goal is the responsibility of the broader society and, where it has been considered, has been largely delegated to elected politicians, market mechanisms, and individual landowners. Moreover, determining the sustainability implications of specific indicators or groups of indicators is often highly dependent on context and is best addressed in synthetic analyses incorporating the interactions between indicators and societal goals pertaining to the forests in question.

As an alternative (or supplement) to a C&I approach, outcome-based sustainability frameworks have several advantages. In addition to focusing on the desired outcomes of sustainable management (as opposed to the necessary *conditions* for sustainability), these frameworks are often built around a smaller number of metrics – reducing or eliminating the challenges inherent in multiple-objective optimization with larger groups of metrics. One such framework is the forest health approach outlined by Castello and Teale (2011). A key metric of their proposal is the ratio of growth to mortality. Another key element of their approach is to consider sustainability within the context of the objectives of the owners, or others. For family forest ownerships in the U.S.A., the primary ownerships objectives are related to amenity values, including aesthetics and privacy, wildlife/nature, and family legacy (USDA NWOS, 2021) and the forests that are able to persist are certainly fulfilling these objectives.

5. Conclusions

There is no simple answer nor any simple metrics for assessing forest sustainability. The Montréal Process C&I is a commonly used framework and using it, the conclusions are mixed for family forests of the U.S.A. Examining trends in stocks, flows, and disturbances is useful, but it is uncertain if these are short- or long-run phenomenon and long-term monitoring is required to fully assess impacts. Drawing strong conclusions is hampered by a lack of agreed upon benchmarks – for example, how much early successional habitat should there be? The results presented here are, largely, national level summaries and local trends may be quite different. In addition, the cross-boundary and inter-ownership issues can be important, but that too is outside the scope of this analysis and fodder for separate research (Butler et al., n.d.).

Based on the most basic C&I, forest area (C&I 1.1a), family forests are *not* sustainable in terms of this proxy for stable forest area during the time period examined. The results of this analysis show a net loss of family forestland across the country, and while some of this loss is transfers to other forest ownership groups, most is loss to non-forest uses. The substantial loss of family forestland suggests that policies aimed at keeping family forests as forests would do the most towards maintaining the sustainability of this critical resource. Another disconcerting trend is the loss of structural diversity or more specifically the net loss of early successional habitat. This is largely due to the aging of existing forests and the absence of disturbance rates and disturbance intensities high enough to (re)generate these stand structures. While some disturbance can be beneficial, and is needed for many natural processes, departures from historical ranges of variability (e.g., due to catastrophic wildfires and damage from non-native insects) are threatening some species and habitats.

But there are also a number of positive metrics in terms of the sustainability of family forests in the U.S.A. including a substantial, and increasing, amount of wood and carbon on family forests and most forest-type groups and species appear to be relatively steady. Family forests are contributing substantially to society, and the social, economic, and institutional frameworks in place are, in general, strong across the country.

This paper provides a broad and thorough assessment of the sustainability of America's family forests. Future research should focus on filling in the data gaps and exploring the factors driving the underlying trends. The ties between broad sustainability frameworks, such as the Montréal Process C&I, and forest certification systems can be strengthened by providing data in more accessible formats with higher degrees of spatial, temporal, and topical resolutions; this should prove especially valuable to risk-based assessment approaches. Comparing the results to other ownership groups across the U.S.A. may help demonstrate key differences and commonalities and facilitate more cross-boundary policy discussions. While the data presented here are for the U.S.A., there

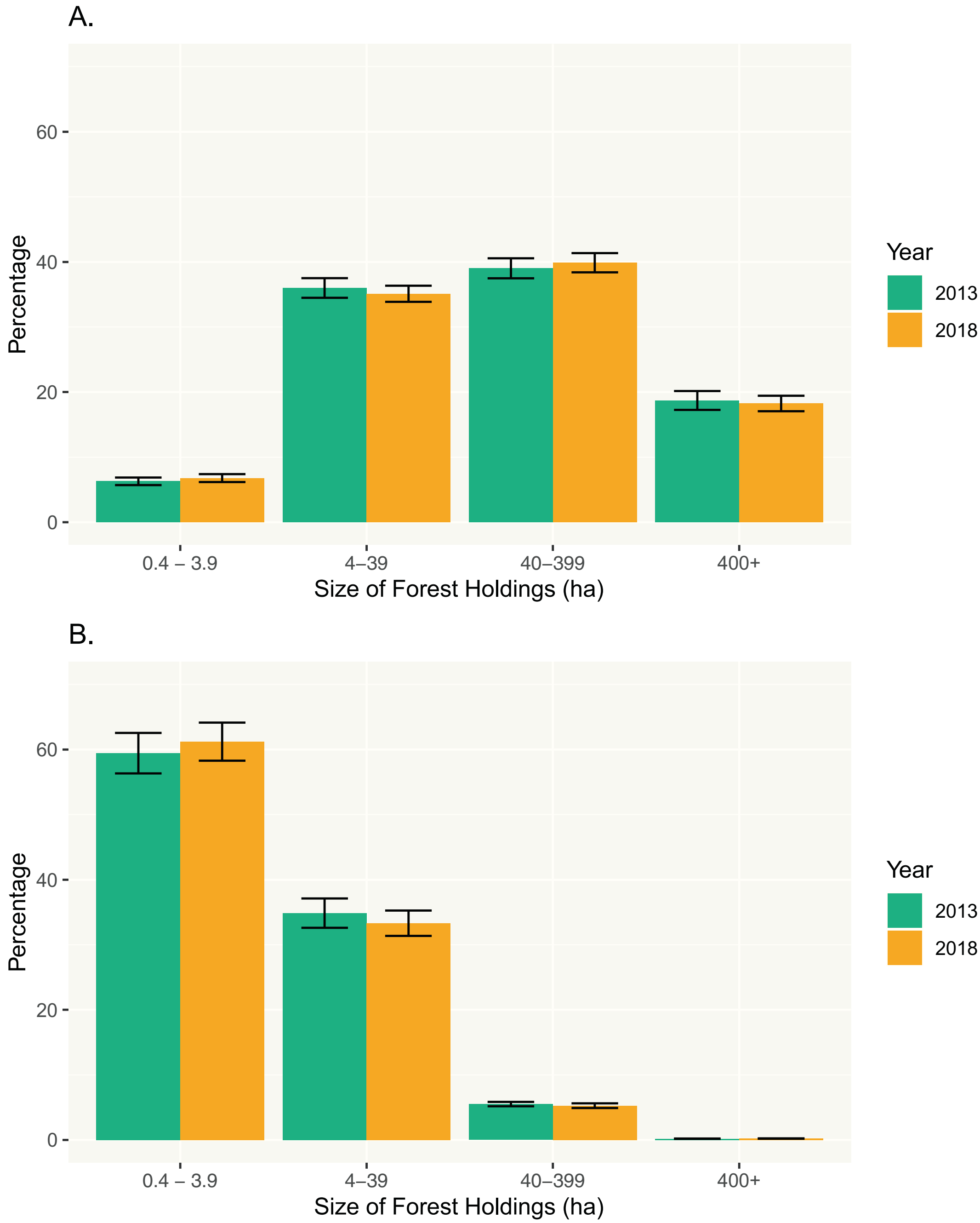

Fig. 7. Proportion of family forest A) acreage and B) ownerships by size of forest holdings, conterminous U.S.A., 2013 and 2018 (USDA NWOS, 2021). Error bars represent 95% confidence intervals.

are potential parallel patterns that can be drawn to other nations with similar ownership patterns, and multi-national comparisons relying on the Montréal Process C&I applied to family forestlands could facilitate more international dialogue and cooperation.

Overall, the Montréal Process C&I appears to be a reasonable way to assess the sustainability of family forests. There are some shortcomings related to not all indicators being germane to family forests, some indicators relevant to family forests being missing, and a lack of data for a number of indicators. The qualitative need of assessing the data is challenging, but is appropriate given the complexity of the topic and the diversity of the data. As assessments of forest sustainability are tied to the values society assigns to these resources, conclusions on what is sustainable will vary over time as will the factors influencing these trends.

Funding

This project was funded by the USDA Forest Service Northern and Southern Research Stations and through a grant from the USDA Forest Service Northern Research Station to the Family Forest Research Center at the University of Massachusetts Amherst (Grant no. 20-JV-11242305-074).

CRediT authorship contribution statement

Brett J. Butler: Conceptualization, Formal analysis, Writing – original draft. **Jesse Caputo:** Formal analysis, Writing – original draft. **Jesse D. Henderson:** Formal analysis, Writing – original draft. **Scott A. Pugh:** Methodology. **Kurt Riitters:** Formal analysis. **Emma M. Sass:** Formal analysis, Writing – original draft.

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.

Acknowledgements

We are thankful to the constructive feedback on earlier versions of this manuscript provided by Fred Cubbage, Puneet Dwivedi, Kathleen McGinley, Guy Robertson, and John Stanovick.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.forpol.2022.102783.

References

Alexander, S.J., Oswalt, S.N., Emery, M.R., 2011. Nontimber forest products in the United States: Montreal Process indicators as measures of current conditions and sustainability. In: General Technical Report PNW-GTR-851. United States Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, Oregon, United States. https://www.fs.usda.gov/treesearch/pubs/38393 (accessed on March 3, 2021).
Aust, W., Blinn, C., 2004. Forestry best management practices for timber harvesting and site preparation in the eastern United States: an overview of water quality and productivity research during the past 20 years (1982-2002). Water Air Soil Pollut. Focus 4, 5–36. https://doi.org/10.1023/B:WAFO.0000012828.33069.f6.
Bailey, C., Barlow, B., Dyer, J., 2019. Practical constraints to timber management among African American owners of heir property. Landsc. Urban Plan. 188, 180–187. https://doi.org/10.1016/j.landurbplan.2019.03.008.
Bechtold, W.A., Patterson, P.L., 2005. The enhanced Forest Inventory and Analysis program – national sampling design and estimation procedures. In: Gen. Tech. Rep. SRS-80. U.S. Department of Agriculture, Forest Service, Southern Research Station, Asheville, NC. https://doi.org/10.2737/srs-gtr-80, 85 p. (accessed on October 8, 2020).
Burrill, E.A., Wilson, A.M., Turner, J.A., Pugh, S.A., Menlove, J., Christensen, G., Conkling, B.L., Winnie, D., 2018. The Forest Inventory and Analysis Database: Database Description and User Guide for Phase 2 (Version 8.0). U.S. Department of Agriculture, Forest Service, 946 p. www.fia.fs.fed.us/library/database-documentation.
Butler, B.J., Ma, Z., Kittredge, D.B., Catanzaro, P., 2010. Social versus biological availability of woody biomass in the northern United States. North. J. Appl. For. 27 (4), 151–159. https://doi.org/10.1093/njaf/27.4.151.
Butler, S.M., Huff, E.S., Snyder, S.A., Butler, B.J., Tyrrell, M., 2018. The role of gender in management behaviors on family forest lands in the United States. J. For. 116 (1), 32–40. https://doi.org/10.5849/jof.2016-076R2.
Butler, S.M., Schelhas, J., Butler, B.J., 2020. Minority family forest owners in the United States. J. For. 118 (1), 70–85. https://doi.org/10.1093/jofore/fvz060.
Butler, B.J., Butler, S.M., Caputo, J., Dias, J., Robillard, A., Sass, E.M., 2021a. Family forest ownerships of the United States, 2018: results from the USDA Forest Service, National Woodland Owner Survey. In: Gen. Tech. Rep. NRS-199. USDA Forest Service, Northern Research Station, Madison, WI. https://doi.org/10.2737/NRS-GTR-199, 52 p.
Butler, B.J., Caputo, J., Robillard, A.L., Sass, E.M., Sutherland, C., 2021b. One size does not fit all: relationships between size of family forest holdings and landowner attitudes and behaviors. J. For. 119 (1), 28–44. https://doi.org/10.1093/jofore/fvaa045.
Butler, B.J.; Caputo, J.; Henderson, J.D.; Pugh, S.A.; Riitters, K.H.; Sass, E.M. In review. Cross-boundary sustainability: Assessment across forest ownership categories in the conterminous USA using the Montréal Process Criteria and Indicators framework.
Carpenter, S., 2012. The USDA discrimination cases: Pigford, In re black farmers, Keepseagle, Garcia, and Love. Drake J. Agric. Law 17 (1), 1–36.
Caputo, J.; Butler, B.J.; Brandeis, T.; Riitters, K. 2020. **Changes in land use, forest ownership, parcel size, and fragmentation in forests of the U.S. South**. e-Res. Pap. SRS–63. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 16 p. https://www.fs.usda.gov/treesearch/pubs/60404 (accessed on July 3, 2020).
Castello, J.D., Teale, S.A., 2011. Forest Health: An Integrated Perspective. Cambridge University Press.
Chandran, A., Innes, J.L., 2014. The state of the forest: reporting and communicating the state of forests by Montreal Process countries. Int. For. Rev. 16 (1), 103–111. https://doi.org/10.1505/146554814811031288.
Cristan, R., Aust, W.M., Bolding, M.C., Barrett, S.M., Munsell, J.F., Schilling, E., 2016. Effectiveness of forestry best management practices in the United States: literature review. For. Ecol. Manag. 360, 133–151. https://doi.org/10.1016/j.foreco.2015.10.025.
Cristan, R., Michael Aust, W., Chad Bolding, M., Barrett, S.M., Munsell, J.F., 2018. National status of state developed and implemented forestry best management practices for protecting water quality in the United States. For. Ecol. Manag. 418, 73–84. https://doi.org/10.1016/j.foreco.2017.07.002.
Cubbage, F.W., McGinley, K.A., Arbogast, T., 2020a. Taxation and other economic strategies that affect the sustainable management of forests (Indicator 47). In: McGinley, K.A., Cubbage, F.W. (Eds.), Legal, Institutional, and Economic Indicators of Forest Conservation and Sustainable Management in the United States: Analyzing Criterion 7 of the Montréal Process Criteria and Indicators Framework. General Technical Report IITF-GTR-52. U.S. Department of Agriculture, Forest Service, International Institute of Tropical Forestry, Rio Piedras, PR, pp. 59–88.
Cubbage, F.W., McGinley, K.A., O'Laughlin, J., 2020b. Legislation and policies supporting the sustainable management of forests (indicator 45). In: McGinley, K.A., Cubbage, F.W. (Eds.), Legal, Institutional, and Economic Indicators of Forest Conservation and Sustainable Management in the United States: Analyzing Criterion 7 of the Montréal Process Criteria and Indicators Framework. General Technical Report IITF-GTR-52. U.S. Department of Agriculture, Forest Service, International Institute of Tropical Forestry, Rio Piedras, PR, pp. 9–39.
Dai, A., 2017. Dai Global Palmer Drought Severity Index (PDSI). Research Data Archive at the National Center for Atmospheric Research, Computational and Information Systems Laboratory, Boulder, CO. https://rda.ucar.edu/datasets/ds299.0/.
Deaton, B.J., 2012. A review and assessment of the heirs' property issue in the United States. J. Econ. Issues 46 (3), 615–632. https://doi.org/10.2753/JEI0021-3624460302.
Defenders of Wildlife, 2000. State Forestry Laws. Defenders of Wildlife, Albuquerque, NM, 58 p. https://defenders.org/sites/default/files/publications/state_forestry_laws.pdf (accessed on April 14, 2021).
Dwivedi, P., Tumpach, C., Cook, C., Izlar, B., 2018. Effects of the sustainable forestry initiative fiber sourcing standard on the average implementation rate of forestry best management practices in Georgia, United States. Forest Policy Econ. 97, 51–58. https://doi.org/10.1016/j.forpol.2018.08.016.
Family Forest Research Center, 2021. FFO Lit DB. Available at. https://www.zotero.org/groups/526589/ffo_lit_db (accessed on September 22, 2021).
FAO, 2020. FRA Platform: Global Forest Resource Assessment, FRA 2020 – Data Export. Available at. https://fra-data.fao.org/WO/fra2020/dataDownload/ (accessed on April 27, 2021).
Frey, G.E., Alexander, S.J., Chamberlain, J.L., Blatner, K.A., Coffin, A.W., Barlow, R.J., 2019. Markets and market values of nontimber forest products in the United States: a review, synthesis, and identification of future research needs. J. For. Oxford Acad. 117 (6), 613–631. https://doi.org/10.1093/jofore/fvz051.
Fryer, J.L., 2007. Quercus kelloggii. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Fort Collins, CO. https://www.fs.fed.us/database/feis/plants/tree/quekel/all.html#REFERENCES (accessed on June 3, 2021).
Google, 2021. Google Scholar. Available at. https://scholar.google.com (accessed on September 22, 2021).
Goyke, N., Dwivedi, P., 2021. Twenty-five years of increasing inequality among family Forest landowners in the United States. Forest Policy Econ. 122, 102334 https://doi.org/10.1016/j.forpol.2020.102334.
Gutierrez Garzon, A.R., Bettinger, P., Siry, J., Mei, B., Abrams, J., 2020. The terms foresters and planners in the United States use to infer sustainability in forest management plans: a survey analysis. Sustainability 12 (1), 17. https://doi.org/10.3390/su12010017.
Hitchner, S., Schelhas, J., Gaither, C.J., 2017. "A privilege and a challenge": valuation of heirs' property by African American landowners and implications for forest management in the southeastern U.S. Small-scale For. 16 (3), 395–417. https://doi.org/10.1007/s11842-017-9362-5.
Homer, C., Dewitz, J., Jin, S., Xian, G., Costello, C., Danielson, P., Gass, L., et al., 2020. Conterminous United States land cover change patterns 2001–2016 from the 2016 National Land Cover Database. ISPRS J. Photogramm. Remote Sens. 162, 184–199. https://doi.org/10.1016/j.isprsjprs.2020.02.019.
Huff, E.S., 2017. A national perspective on women owning woodlands (WOW) networks. J. Ext. 55 (2), 2RIB6.
Ice, G.G., Schilling, E.G., Vowell, J.G., 2010. Trends for forestry best management practices implementation. J. For. 108 (6), 267–273. https://doi.org/10.1093/jof/108.6.267.
Johnson Gaither, C., 2016. Have Not our Weary Feet Come to the Place for which our Fathers Sighed? Heirs' Property in the Southern United States. U.S. Department of Agriculture Forest Service, Southern Research Station, Asheville, NC, 31 p. https://www.fs.usda.gov/treesearch/pubs/53186 (accessed on September 5, 2018).
Kilgore, M.A., Greene, J.L., Jacobson, M.G., Straka, T.J., Daniels, S.E., 2007. The influence of financial incentive programs in promoting sustainable forestry on the nation's family forests. J. For. 105 (4), 184–191. https://doi.org/10.1093/jof/105.4.184.
Kilgore, M.A., Ellefson, P.V., Funk, T.J., Frey, G.E., 2018. Private forest owners and property tax incentive programs in the United States: a national review and analysis of ecosystem services promoted, landowner participation, forestland area enrolled, and magnitude of tax benefits provided. Forest Policy Econ. 97, 33–40. https://doi.org/10.1016/j.forpol.2018.08.015.
Kueper, A.M., Sagor, E.S., Blinn, C.R., Becker, D.R., 2013. Extension forestry in the United States: master volunteer and other peer learning programs. J. For. 112 (1), 23–31. https://doi.org/10.5849/jof.13-008.
Lubowski, R.N., Plantinga, A.J., Stavins, R.N., 2008. What drives land-use change in the United States? A national analysis of landowner decisions. Land Econ. 84 (4), 529–550. https://doi.org/10.3368/le.84.4.529.

McGinley, K.A., Cubbage, F.W., 2017. Examining forest governance in the United States through the Montréal Process Criteria and Indicators Framework. Int. For. Rev. 19 (2), 192–208. https://doi.org/10.1505/146554817821255123.
McGinley, K., Cubbage, F.W., 2020. Legal, Institutional, and Economic Indicators of Forest Conservation and Sustainable Management in the United States: Analyzing Criterion 7 of the Montréal Process Criteria and Indicators Framework. General Technical Report IITF-GTR-52. U.S. Department of Agriculture, Forest Service, International Institute of Tropical Forestry, Rio Piedras, PR, 174 p. https://www.fs.usda.gov/treesearch/pubs/61113 (accessed on March 17, 2021).
McGinley, K.A., Robertson, G.C., Friday, K.S., 2019. Examining the sustainability of tropical island forests: advances and challenges in measurement, monitoring, and reporting in the U.S. Caribbean and Pacific. Forests 10 (11), 946. https://doi.org/10.3390/f10110946.
McRoberts, R.E., McWilliams, W.H., Reams, G.A., Schmidt, T.L., Jenkins, J.C., O'Neill, K. P., Miles, P.D., Brand, G.J., 2004. Assessing sustainability using data from the Forest Inventory and Analysis Program of the United States Forest Service. J. Sustain. For. 18 (1), 23–46. https://doi.org/10.1300/J091v18n01_02.
Michigan Department of Natural Resources, 2020. Forest Action Plan 2020, 55 p. https://www.michigan.gov/documents/dnr/ForestActionPlan_Forestry_2020_710948_7.pdf (accessed on April 28, 2021).
Miles, P.D., 2002. Using biological criteria and indicators to address forest inventory data at the state level. For. Ecol. Manag. 155 (1), 171–185. https://doi.org/10.1016/S0378-1127(01)00557-6.
Miner, J., Dwivedi, P., Izlar, R., Atkins, D., Kadam, P., 2021. Perspectives of four stakeholder groups about the participation of female forest landowners in forest management in Georgia, United States Atiqul Haq, S.M. ed. PLoS One 16 (8). https://doi.org/10.1371/journal.pone.0256654.
Murcia, C., 1995. Edge effects in fragmented forests: implications for conservation. Trends Ecol. Evol. 10, 58–62. https://doi.org/10.1016/S0169-5347(00)88977-6.
NatureServe, 2021. Map of Biodiversity Importance. https://www.natureserve.org/access-data (accessed on September 22, 2021).
Nelson, M., Robertson, G., Riitters, K., 2015. Conserving forest biological diversity: how the Montreal Process helps achieve sustainability. Wildl. Prof. 9 (2), 44–48.
Oswalt, S.N., Smith, W.B., Miles, P.D., Pugh, S.A., 2019. Forest resources of the United States, 2017: a technical document supporting the Forest Service update of the 2020 RPA assessment. In: Gen. Tech. Rep. WO-97. U.S. Department of Agriculture, Forest Service, Washington, DC. https://doi.org/10.2737/WO-GTR-97, 223 p. (accessed on October 8, 2020).
Ries, L., Fletcher Jr., R.J., Battin, J., Sisk, T.D., 2004. Ecological responses to habitat edges: mechanisms, models, and variability explained. Annu. Rev. Ecol. Evol. Syst. 35, 491–522. https://doi.org/10.1146/annurev.ecolsys.35.112202.130148.
Riitters, K., Costanza, J., 2019. The landscape context of family forests in the United States: anthropogenic interfaces and forest fragmentation from 2001 to 2011. Landsc. Urban Plan. 188, 64–71. https://doi.org/10.1016/j.landurbplan.2018.04.001.
Riitters, K., Robertson, G., 2021. The United States' implementation of the Montréal process indicator of forest fragmentation. Forests. 12 (6), 727. https://doi.org/10.3390/f12060727.
Riitters, K.H., Wickham, J.D., O'Neill, R.V., Jones, K.B., Smith, E.R., Coulston, J.W., Wade, T.G., Smith, J.H., 2002. Fragmentation of continental United States forests. Ecosystems 5 (8), 815–822. https://doi.org/10.1007/s10021002-0209-2.
Robertson, G., Gaulke, P., McWilliams, R., LaPlante, S., Guldin, R., 2011. National Report on Sustainable Forests–2010. FS-979. USDA Forest Service, Washington, DC, 212 p. https://www.fs.usda.gov/treesearch/pubs/54685 (accessed on January 21, 2021).
Schelhas, J., Hitchner, S.L., 2020. Integrating research and outreach for environmental justice: African American land ownership and forestry. Ann. Anthropol. Pract. 44 (1), 47–64. https://doi.org/10.1111/napa.12133.
Simpson, H., Thomas, T., Work, D., 2015. Voluntary implementation of forestry Best Management Practices in East Texas. Texas A&M Forest Service, 60 p. https://tfsweb.tamu.edu/uploadedFiles/TFSMain/Manage_Forest_and_Land/Water_Resources_and_BMPs/Stewardship(1)/Round%209%20BMP%20Implementation%20Report(2).pdf.
Slesak, R.A., Corcoran, J., Rossman, R., 2018. A holistic monitoring approach for water quality BMP and forest watershed risk assessment. J. For. 116 (3), 283–290. https://doi.org/10.1093/jofore/fvy005.
Smart Growth Network. What is the Smart Growth Network? - Smart Growth Online. Available at. https://smartgrowth.org/what-is-the-smart-growth-network/ (accessed on April 16, 2021).
The Montréal Process, 2015. Montréal Process: Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests. In: https://www.montrealprocess.org/documents/publications/techreports/MontrealProcessSeptember2015.pdf (accessed on January 21, 2021).
The Montréal Process, 2021. Montréal Process Country Reports. In: https://www.montrealprocess.org/Resources/Country_Reports/index.shtml (accessed on January 21, 2021).
The Montréal Process. Montréal Process Fact Sheet. In: https://www.montrealprocess.org/documents/publications/factsheets/MontrealProcess-WFC2015-FactSheet.pdf (accessed on April 28, 2021).
U.S. Bureau of Economic Analysis (BEA), 2021. Table 1.1.9. Implicit Price Deflators for Gross Domestic Product (1994-2019). U.S. Bureau of Economic Analysis, Washington, DC. https://apps.bea.gov/iTable/index_nipa.cfm (accessed on June 15, 2021).
U.S. Bureau of Labor Statistics (US-BLS), 2020. Quarterly Census of Employment and Wages Data Files. U.S. Bureau of Labor Statistics, Washington, DC. https://www.bls.gov/cew/downloadable-data-files.htm (accessed on June 15, 2021).
U.S. Department of Agriculture Forest Service, 2012. Future of America's forest and rangelands: Forest Service 2010 Resources Planning Act Assessment. In: Gen. Tech. Rep. WO-87. U.S. Department of Agriculture Forest Service, Washington Office, Washington, DC, 198 p. https://www.fs.usda.gov/treesearch/pubs/41976/ (accessed on September 8, 2021).
U.S. Environmental Protection Agency, 2016. EPA Healthy Watersheds Program: Integrating Watershed Assessment and Protection across EPA. U.S. Environmental Protection Agency, Washington, D.C., 2 p. https://www.epa.gov/sites/production/files/2015-10/documents/2009_08_05_nps_healthywatersheds_highquality_hwi.pdf
USDA Forest Service, 2015. Forest Legacy Program Briefing Paper. State and Private Forestry, Washington, D.C., 2 p.
USDA Forest Service, Forest Inventory and Analysis (USFS FIA), 2021. Custom Data Retrieval from the USDA Forest Service, Forest Inventory and Analysis Database (Queries and Results Available from B.J. Butler upon Request). USDA Forest Service, Forest Inventory and Analysis, Washington, DC.
USDA Forest Service, National Woodland Owner Survey (USFS NWOS), 2021. Custom Data Retrieval from the USDA Forest Service, National Woodland Owner Survey Database (Queries and Results Available from B.J. Butler upon Request). USDA Forest Service, Forest Inventory and Analysis, Washington, DC.
VanBrakle, J.D., Germain, R.H., Munsell, J.F., Stehman, S.V., 2013. Do forest management plans increase best management practices implementation on family forests? A formative evaluation in the New York City watershed. J. For. 111 (2), 108–114. https://doi.org/10.5849/jof.12-034.
Vizek, A., Nielsen-Pincus, M., 2017. Landowner attitudes toward conservation easements: balancing the private and public interest in land. Soc. Nat. Resour. 30 (9), 1080–1095. https://doi.org/10.1080/08941920.2017.1331486.
World Commission on Environment and Development, 1987. Our Common Future. Oxford University Press, Oxford, 400 p.