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2016 BILLION-TON REPORT
Advancing Domestic Resources for a Thriving Bioeconomy

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2016 BILLION-TON REPORT

Advancing Domestic Resources for a Thriving Bioeconomy

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Bioenergy Technologies Office

Volume 2:
Environmental Sustainability Effects of Select Scenarios from Volume 1

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Availability

This report, as well as supporting documentation, data, and analysis tools, can be found on the Bioenergy Knowledge Discovery Framework at bioenergykdf.net. Go to https://bioenergykdf.net/billionton2016/vol2reportinfo for the latest report information and metadata.

Additional Information

The U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy's Bioenergy Technologies Office and Oak Ridge National Laboratory provide access to information and publications on biomass availability and other topics. The following websites are available:

- energy.gov
- eere.energy.gov
- bioenergy.energy.gov
- web.ornl.gov/sci/transportation/research/bioenergy/

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DISCLAIMER

The authors have made every attempt to use the best information and data available, to provide transparency in the analysis, and to have experts provide input and review. However, the *2016 Billion-Ton Report* is a strategic assessment of potential biomass (volume 1) and a modeled assessment of potential environmental effects (volume 2). It alone is not sufficiently designed, developed, and validated to be a tactical planning and decision tool, and it should not be the sole source of information for supporting business decisions. *BT16* volume 2 is not a prediction of environmental effects of growing the bioeconomy, but rather, it evaluates specifically defined biomass-production scenarios to help researchers, industry, and other decision makers identify possible benefits, challenges, and research needs related to increasing biomass production. Users should refer to the chapters and associated information on the Bioenergy Knowledge Discovery Framework (bioenergykdf.net/billionton) to understand the assumptions and uncertainties of the analyses presented. The use of tradenames and brands are for reader convenience and are not an endorsement by the U.S. Department of Energy, Oak Ridge National Laboratory, or other contributors.

The foundation of the agricultural sector analysis is the USDA Agricultural Projections to 2024. From the report--"Projections cover agricultural commodities, agricultural trade, and aggregate indicators of the sector, such as farm income. The projections are based on specific assumptions about macroeconomic conditions, policy, weather, and international developments, with no domestic or external shocks to global agricultural markets." The *2016 Billion-Ton Report* agricultural simulations of energy crops and primary crop residues are introduced in alternative scenarios to the 2015 USDA Long Term Forecast. Only 2015-2024 Billion-Ton national level baseline scenario results of crop supply, price, and planted and harvested acres for eight major crops are considered to be consistent with the 2015 USDA Long Term Forecast. Projections for 2025–2040 in the *2016 Billion-Ton Report* baseline scenario and the resulting regional and county level data were generated through application of separate data, analysis, and technical assumptions led by Oak Ridge National Laboratory and do not represent nor imply U.S. Department of Agriculture or U.S. Department of Energy quantitative forecasts or policy. The forest scenarios were adapted from U.S. Forest Service models and developed explicitly for this report and do not reflect, imply, or represent U.S. Forest Service policy or findings. The Federal Government prohibits discrimination in all its programs and activities on the basis of race, color, national origin, age, disability, and, where applicable, sex, marital status, familial status, parental status, religion, sexual orientation, genetic information, political beliefs, reprisal, or because all or part of an individual's income is derived from any public assistance program.

11 | Forest Biodiversity and Woody Biomass Harvesting

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11.1 Background

With the expected increase in demand for woody biomass to help meet renewable energy needs, one principal sustainability question has been whether this material can be removed from forest stands while still conserving biological diversity and retaining ecosystem functioning (Hecht et al. 2009; Berch, Morris, and Malcolm 2011; Ridley et al. 2013). In general, biodiversity is the variety of life and can be considered at the genetic, population, species, community, and ecosystem levels (Berch, Morris, and Malcolm 2011). Biodiversity is often characterized as the number of species (or other taxonomic entity) and the relative abundance of each species in a defined space at a given time. A larger species pool is generally believed to indicate improved ecosystem functioning (i.e., health, resilience, goods, and services), especially in landscapes with intensified use (Loreau et al. 2001). Indices of species richness and evenness of their distribution (e.g., common or rare) are often used to measure local diversity and to compare the diversity across geographic areas. Relative abundance metrics, however, are not always good predictors of species importance for multiple reasons, but the scale of observation often dictates results (Godfray and Lawton 2001). More emphasis is being placed on understanding biodiversity through functional shifts in species assemblages in response to changing environments (i.e., ecosystem functioning) (Loreau et al. 2001; Hooper et al. 2005). Uncertainties exist on whether shifts in species assemblages, each with their own set of traits, influence ecosystem functioning even when biodiversity metrics may be similar.

Although seemingly simple in concept, the mechanisms driving variation and functional significance of biodiversity are complex, not well understood, and debated (Loreau et al. 2001; Hooper et al. 2005; Duffy et al. 2007; Berch, Morris, and Malcolm 2011). Besides human impacts on biodiversity that are often evaluated, abiotic factors, system variability, site productivity, and geographic location influence relationships between biodiversity and ecosystem function (Hooper et al. 2005; Verschuyl et al. 2011; Veech and Crist 2007). Biodiversity does not respond in a unidirectional manner to ecosystem changes. Spatial and temporal scale of observations and landscape context profoundly influence reported patterns of diversity and habitat relationships (Jonsell 2008; Efroymson et al. 2013; Gaudreault et al. 2016). Plus, few biodiversity studies span decades to understand temporal changes in communities (Magurran et al. 2010). Trophic-level interactions are also not incorporated often, but these interactions may have significant influence on local biodiversity (Duffy et al. 2007). For example, shifts in top predator species or an alteration to food chain length may have cascading effects across trophic levels. Thus, reporting and comparing commonly used metrics of biodiversity without considering functional components and the complexities mentioned above will not adequately provide information needed to evaluate ecosystem changes in biodiversity.

We take a coarse-filter approach in this chapter to assess effects of woody biomass harvesting on biodiversity within an ecological framework, rather than comparing biodiversity indices. We used the projected harvest acres output at the county level from the Forest Sustainable and Economic Analysis Model (ForSEAM; DOE 2016) in *2016 Billion-Ton Report* (*BT16*) volume 1 to describe changes in forest types producing feedstocks and forest age based on harvest type (i.e., thinning and clearcut) within ecoregion units that had the greatest projected harvest intensities compared to other ecoregions (see section 11.2). This approach examined forest changes within a habitat and ecological context to help identify species and areas that may be most affected by spatial variability in biomass sourcing. We used case studies of taxonomic groups or single species with life-history traits that rely functionally on dead and downed wood or changing canopy cover. This information may be used in conjunction with other biodiversity assessments completed at finer scales (e.g., state wildlife action plans, county project planning) to identify species that may be vulnerable to simulated changes and to help forest managers guide conservation of biodiversity at multiple spatial and temporal scales.

The primary mechanisms by which biomass harvesting may affect biodiversity are through (1) removal of fine woody debris (FWD) (tops and branches, diameter at breast height [dbh] <10 cm) and coarse woody debris (CWD) (generally defined as >10 cm dbh) and (2) alterations of other forest stand and landscape structural characteristics, such as reducing piles of forest residuals, expanding open-canopy coverage (i.e., young forest), and modifying landscape-scale forest age class distribution (Jonsell 2008; Riffell et al. 2011a; Verschuyl et al. 2011). Dead and decaying wood provides resources for a host of organisms dependent on this material (saproxylic) as a food or breeding substrate, and residue piles provide structure for many taxa as shelter, nesting, and foraging substrates, as well as other life history needs (Harmon et al. 1986; Aström et al. 2005; Jonsell 2008; Abbas et al. 2011). Organism responses to these changes are species specific and vary by forest type, geographic location, and spatial scale of observation.

Not much is known about importance of FWD to the conservation of biological diversity (Gunnarsson, Nittérus, and Wirdenäs 2004; Berch, Morris, and Malcolm 2011; Abbas et al. 2011). This material has been viewed as less critical for wildlife than CWD. Logging residues have been found to positively influence species richness because residues increase structural heterogeneity, cover, shelter, and food (Ecke, Löfgren, and Sörlin 2002). Residue piles can affect microhabitat complexity, especially after clearcutting (Ecke, Löfgren, and Sörlin 2002; Gunnarsson, Nittérus, and Wirdenäs 2002; Nordén et al. 2004; Aström et al. 2005), and have been shown to provide habitat for many small vertebrate species such as mice, voles (Aarhus and Moen 2005; Manning and Edge 2008), and arthropods (e.g., Coleoptera beetles) (Gunnarsson, Nittérus, and Wirdenäs 2004) at the local scale. Other species known to use residual slash include carnivores, meso-mammals, birds, reptiles, amphibians, and other invertebrates (Gunnarsson, Nittérus, and Wirdenäs 2004; Manning and Edge 2008). Less is known about the response of plants to FWD removal. Aström et al. (2005) note that species richness of mosses and liverworts that depend on dead wood can be reduced by removing logging residues in clearcuts, but residue removal effects on plant communities as a whole are most likely minimal and highly variable. Whole-tree harvesting may also impact the diversity of wood-inhabiting fungi (Nordén et al. 2004), especially on dry, nutrient-poor sites (Bråkenheim and Liu 1998).

Retaining CWD has been linked to conservation of biodiversity (Hura and Crow 2004; Aström et al. 2005; Franklin, Mitchell, and Palik 2007; McComb 2008). Species responses to CWD have been widely studied, and the abundance of some taxa has been linked to presence and amount of CWD, especially downed logs, in many regions of the United States (Loeb 1999; Maidens, Menzel, and Laerm 1998; McCay et al. 1998, Davis, Castleberry, and Kilgo 2010a). Results, however, differ among studies, and some have shown minimal response to CWD by some taxa (e.g., Mengak and Guynn 2003; McCay and Komoroski 2004; Davis, Castleberry, and Kilgo 2010b). As with FWD, response to CWD abundance appears to be species-, ecosystem-, and scale-dependent (Davis, Castleberry, and Kilgo 2010a, 2010b; Riffell et al. 2011a; Homyack et al. 2013; Otto, Kroll, and McKenny 2013), meaning that broad patterns of association between CWD, FWD, and biodiversity are complex. Additionally, results from recent studies of operational biomass-production practices in the southeastern United States suggest minimal or short-term species responses, potentially due to abundance of CWD retained on-site even after biomass harvests (Fritts 2014; Fritts, Moorman, et al. 2015; Fritts, Grodsky, et al. 2015b; Fritts et al. 2016), which reflected recommendations commonly found in some biomass-harvesting guidelines (Perschel, Evans, and DeBonis 2012).

Forest woody-biomass harvesting includes traditional forest-harvesting methods, such as thinning and clearcutting. Thinning decreases tree density, increases forest canopy gaps, and can alter abundance and diversity of mid-story trees (Artman 2003; Agee and Skinner 2005; Hayes, Weikel, and Huso 2003; Harrod et al. 2009). Thinnings can be conducted precommercially, commercially, or as a fuels treatment (Verschuyl et al. 2011). Because thinning reduces overstory stem density and increases light availability below the canopy, it can lead to the development of more complex understory vegetation (Doerr and Sandburg 1986; Bailey and Tappeiner 1998; Wilson and Carey 2000; Garman et al. 2001; Homyack et al. 2015). Verschuyl et al. (2011) used meta-analysis to evaluate relationships between forest-thinning treatments and forest biodiversity from 33 studies conducted across North America. They found that forest-thinning treatments had generally positive or neutral effects on diversity and abundance across all taxa, although thinning intensity and the type of thinning conducted may at least partially drive the magnitude of response.

Clearcutting associated with woody-biomass harvesting obviously changes forest stands to a state of early succession and also influences forest age distribution across a landscape. Although clearcutting negatively affects species associated with older forest structure, many species require early successional forest conditions. The extent of young forest has been declining across the United States, especially in eastern forest regions, as have population trends of birds associated with this habitat (see, e.g., Brooks 2003; King and Schlossberg 2014). Regenerating forest from clearcuts may improve habitat suitability for some declining forest interior birds (Ahlering and Faaborg 2006), and birds typically associated with mature forests seek out this early seral-stage post-fledging to take advantage of abundant fruits and seeds (Stoleson 2013).

Understanding variability of residual CWD and FWD left after clearcutting is critically important to understand how amounts may influence ecosystem processes. Many best management practices (BMPs) recommend leaving residue to provide microhabitat structure (Abbas et al. 2011). Recent studies in the southeastern United States have found that the amount of CWD left on sites after biomass harvests is higher than amounts commonly recommended in biomass-harvesting guidelines and removal effects on wildlife appear to be minimal or short term (Fritts 2014; Fritts, Moorman, et al. 2015; Fritts, Grodsky, et al. 2015; Fritts et al. 2016; Perschel, Evans, and DeBonis 2012).

This chapter describes potential forest changes and implications for biodiversity resulting from expanding U.S. national biomass production. Specifically, we assess and compare effects of potential forest biomass produced in the near term (2017) and in significantly expanded biomass-production scenarios (2040) generated in volume 1 of *BT16* at the national level. Volume 1 investigates the potential economic availability of biomass resources at the roadside using an economic supply curve approach, assuming latest-available yield and cost data. An important aspect to understand is that this assessment is evaluating potential additive effects of removing logging residues associated with conventional harvests as well as expanded whole-tree biomass harvests within the assumptions of ForSEAM (see section 11.2.2). We do not attempt to evaluate the effects of conventional harvest on biodiversity, nor do we attempt to determine landscape-level or cumulative effects due to the scale of these data (i.e., county-level) and the fact that only two points in time are being compared. However, in some cases, effects of forest woody biomass harvest may be similar to the effects of conventional harvests. Assessment results, however, can provide information to help prioritize future research needs for specific species and communities based on forest-change scenarios. Results can also foster more focused investigations on critical thresholds of biomass removal and interactions of woody biomass harvest with other anthropogenic and natural factors relative to conservation of biological diversity.

11.2 Methods

Given the geographic extent representing numerous ecological contexts contained within this assessment, it was not possible to investigate all species that rely on dead and downed wood or young forests. To refine our assessment, we used the USDA U.S. Forest Service's National Hierarchical Framework of Ecological Units developed for the contiguous United States (ECS; Cleland et al. 2007) to identify ecoregion units that are expected to supply the greatest quantities of feedstock. This hierarchical framework classifies ecological types and maps ecological units based on associations of climate, physiography, and biotic characteristics that distinguish a unit from neighboring ones. The framework incorporates energy, moisture, and nutrient gradients that regulate the structure and function of ecosystems. Within each selected ecoregion unit, we describe primary forest changes that may drive the responses of species to removing feedstock. We used the province ecoregion unit (fig. 11.1), which is at a scale of millions to tens of thousands of square kilometers; this is an appropriate scale for assessments and strategic planning. Next, based on information in the scientific literature, we discussed implications of the forest type and structure changes to biodiversity-indicator case-study species found within each selected province.

As with other chapters in this report, we used environmental indicators and, in particular, biodiversity indicators, suggested by McBride et al. (2011), which include presence and associated habitat area for taxa of special concern that may be directly affected by forest changes related to forest woody-biomass harvesting. Taxa of concern can be categorized into 6 groups: (1) rare (or could become rare) native species; (2) keystone species that have a disproportionately large impact relative to abundance; (3) bioindicator taxa that monitor the condition of the environment; (4) species of commercial value; (5) species of cultural importance, or (6) species of recreational value.

Text Box 11.1 | Definitions from *BT16* Volume 1

- Forestland—land at least 120 ft (36.6 m) wide and 1 acre in size with at least 10% cover by live trees of any size, including land that formerly had such tree cover and that will be naturally or artificially regenerated.
- Timberland—forestland that is producing, or is capable of producing, in excess of 20 ft^3 (0.57 m^3) per acre per year of industrial wood and not withdrawn from timber utilization by statute or administrative regulations.

We focused our attention on vertebrate species that depend on CWD or FWD (e.g., amphibians—bioindicators) or rely on structure of residue woody material (e.g., piles) for shelter, feeding, or foraging, such as ground nesting birds, small mammals, and furbearers (e.g., American marten); we also focused on those species that may respond to open-canopy conditions, such as reptiles (e.g., gopher tortoise—keystone species) and game species. Based on the potential forest change for each province, we selected several representative species within each of the categories above and species functional groups. By targeting species within these categories, we were better able to assess potential effects of additive biomass harvest and help identify species and ecosystems for further consideration in BMPs, strategic planning, and scientific investigations. Saproxylic organisms such as invertebrates and wood-inhabiting fungi would be the primary species impacted by biomass harvests, since they depend directly on dead wood during part of their life cycle. However, not much is known about these species, nor are there adequate data to determine their presence.

11.2.1 Scope of Assessment

For the purposes of this report, we assessed potential effects on biodiversity indicators from forest change resulting from biomass harvests on timberland (text box 11.1) under select scenarios from *BT16* volume 1. We used county-level data down-scaled from ForSEAM analysis units (see *BT16* volume 1, fig. 3.16, p. 73) to (1) summarize projected change in harvest acres between the near-term baseline (moderate housing–low wood energy scenario, ML 2017) and expanded production under baseline (ML 2040) and high-yield (high housing–high wood energy scenario, HH 2040) growth assumptions by 2040 (table 11.1); (2) spatially identify geographic areas expected to have greater harvest intensities; (3) describe forest-structure changes based on forest habitat-cover types that supply feedstock within those geographic areas; and (4) infer how these changes may affect selected biodiversity indicators using case studies of wildlife taxa that functionally depend on dead and downed wood, residue piles, or open forest canopy (i.e., young forests).

Table 11.1 | Description of Wood Energy and Housing Scenarios (modified from *BT16* volume 1, table 3.6)

Land type (million acres)	Baseline 2015	Extended Baseline 2040
Moderate housing–low wood energy (baseline), ML	Returns to long-term average by 2025	Increases by 26% by 2040
High housing–high wood energy, HH	Adds 10% to baseline in 2025	Increases by 150% by 2040

USDA, U.S. Forest Service, Forest Inventory and Analysis

The forest biomass feedstocks considered were forest residues (i.e., logging residues) and whole-tree biomass from harvests of smaller-diameter merchantable stands (i.e., biomass-only harvest). Logging residues were generated as a product from conventional harvests. Whole-tree biomass was generated from commercial and noncommercial trees of smaller-diameter merchantable stands or removal of excess biomass from fuel treatment and thinning operations designed to reduce risks from catastrophic fires and improve forest health. The harvest method, whether full-tree or cut-to-length, differed among ForSEAM analysis regions (see under each ForSEAM region below), which impacted whether logging residues stayed on-site. Under the cut-to-length harvest method, residues stayed on-site (i.e., trees are felled, delimbed, and bucked directly in the stump area and then log sections are transported to landing or roadside). Under full-tree method, the whole tree (aboveground portion) was brought to a landing for processing, and residue was recovered. Also, merchantable materials were assumed to be harvested as roundwood.

We used the center of each county to delineate whether it was included in the province ecoregion of interest. We used harvest acres as the response variable rather than volume of feedstock produced because the amount of habitat is a major metric for vertebrate species. The number of acres harvested was highly correlated with the volume of feedstock produced for logging residues ($r = 0.87$) and whole-tree biomass harvests ($r = 0.77$).

11.2.2 Relevant ForSEAM Assumptions

The following aspects of ForSEAM are important to understand because these assumptions influence spatial and temporal patterns of woody biomass-supply projections reported for each ForSEAM analysis region, which ultimately influences projections within each province ecoregion and forest type:

- As an economic model, ForSEAM compared the relative costs of raw material inputs and met demands using harvest (including stumpage) residues first, then the least expensive harvest of whole trees, and finally, higher-cost harvests of whole trees.
- The model first solved for conventional timber demands (i.e., sawtimber and pulpwood), which generated logging residues (i.e., integrated harvest). Whole-tree biomass harvests did not occur unless demand for woody biomass was not met by logging residues.
- Availability of biomass declined through time as the model captured how and when materials were harvested, meaning that a harvest in year T impacted output in year T + 1. The land category transitioned from "available" to "regenerating," and over the short duration of modeling (2017 to 2040), land was, at the most, available for harvest only one more time.
- Only timberland <0.5 miles (<0.8 km) from roads with ≤40% slope (except Inland West region) were considered available for harvest. For most counties, only up to 5% of forestland was available for harvest in the model.
- Forest cover type remained consistent, meaning there was no land-use or cover change (e.g., natural stands of softwood were not converted to plantations, and marginal agricultural lands were not converted to forest).
- Only 70% of available logging residues were recovered from clearcut full-tree harvests on timberland with ≤40% slope to incorporate BMPs (i.e., 30% residues retained on-site). No logging residues were removed on timberlands with ≥ 40% slope. During thinning operations associated with whole-tree biomass harvests, all residues were harvested under the assumption that tree breakage during harvest would result in some retention of residues.
- Only small- and mid-diameter stands were harvested as whole-tree biomass. Harvest of mature trees provided stand-regeneration opportunities (i.e., age-class distribution) and affected availability of the next generation of small- and mid-diameter removals for biomass (i.e., harvest with no thinning for the next 10–15 years following final harvest). All diameter classes (class 1, >11 inches for hardwood or >9 inches for softwood; class 2, diameter 5–11 inches for hardwood or 5–9 inches for softwood; class 3, diameter <5 inches) could be clearcut.

11.3 Results

We report projected forest change under each scenario and time at several scales, followed by potential biodiversity effects. We first report national-scale changes, followed by changes at the ForSEAM regional level, and then by the province ecoregion unit that encompasses the concentration of counties having greater harvest intensities (e.g., >5,000 acres harvested) (fig. 11.1). Within each of these scales, we report total acres harvested by each source feedstock as well as acres in young forest. We then discuss the biodiversity effects on particular taxonomic groups or individual species that could be affected by the described forest changes at each scale.

11.3.1 Conterminous United States

Overall, approximately 8.5 million total acres were harvested for forest woody-biomass under the ML 2017 scenario, with harvested acreages reduced by 51% and 61% under ML 2040 and HH 2040 scenarios, respectively. At the ForSEAM region level, total acres harvested declined under both 2040 scenarios from ML 2017 projections for all regions except the Inland West (IW), where ML 2040 totals increased by 9.6% (fig. 11.2a). Under all three scenarios, approximately half of the national woody biomass-feedstock supply was projected to be harvested on lands within the South (S) region of the United States, 51%–57% across all three scenarios (fig. 11.2a). This pattern is a result of logging residues entering the model first to meet region demands of an increasing pellet market (*BT16* volume 1, p. 43).

The counties with >5,000 acres harvested for woody biomass in the ML 2017 scenario were concentrated mostly throughout S forests, especially in Louisiana, Arkansas, Alabama, and South Carolina; in North Central (NC) forests, primarily in northern Minnesota, Michigan, and Wisconsin; in Northeast (NE) forests, primarily in Maine; in Pacific Northwest (PNW) forests, primarily in northern California and southern Oregon; and in IW forests, primarily in northern Idaho and western Montana (fig. 11.3).

Figure 11.1 | Delineation of ecoregion provinces overlaid on total potential acres harvested under the ML 2017 scenario, which had the greatest quantity of total acres harvested of all scenarios. Black letters indicate ForSEAM regions outlined by bold black lines; red numbers indicate province ecoregions. See text for descriptions.

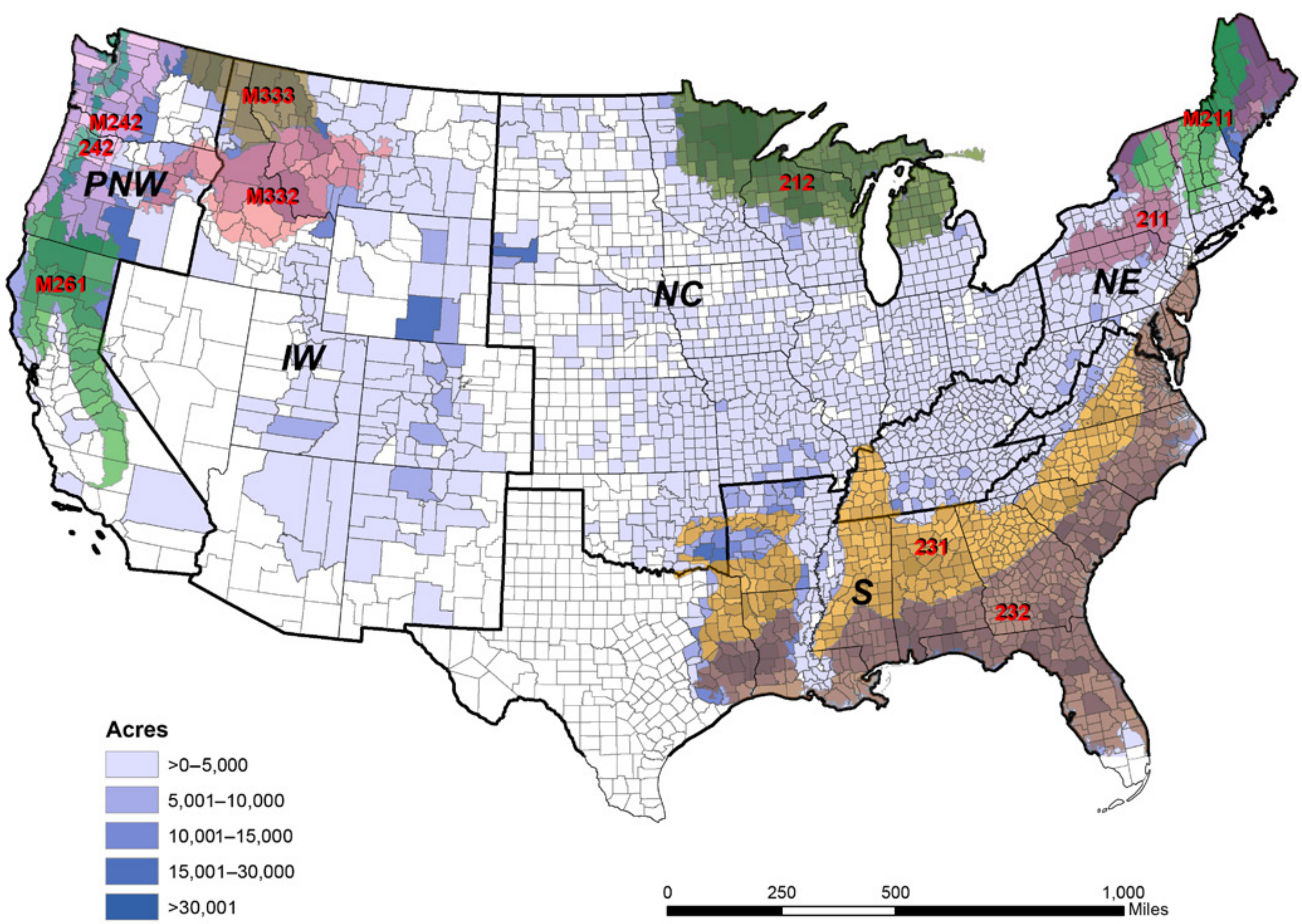


Figure 11.2 | Potential total acres harvested in each scenario—baseline (moderate housing–low wood energy) in the near term (ML 2017) and expanded production under baseline- and high-yield (high housing–high wood energy) in 2040 (ML 2040 and HH 2040, respectively)—in each ForSEAM region for (a) all feedstocks, (b) logging residues, and (c) whole-tree biomass harvests; note differences in scale.

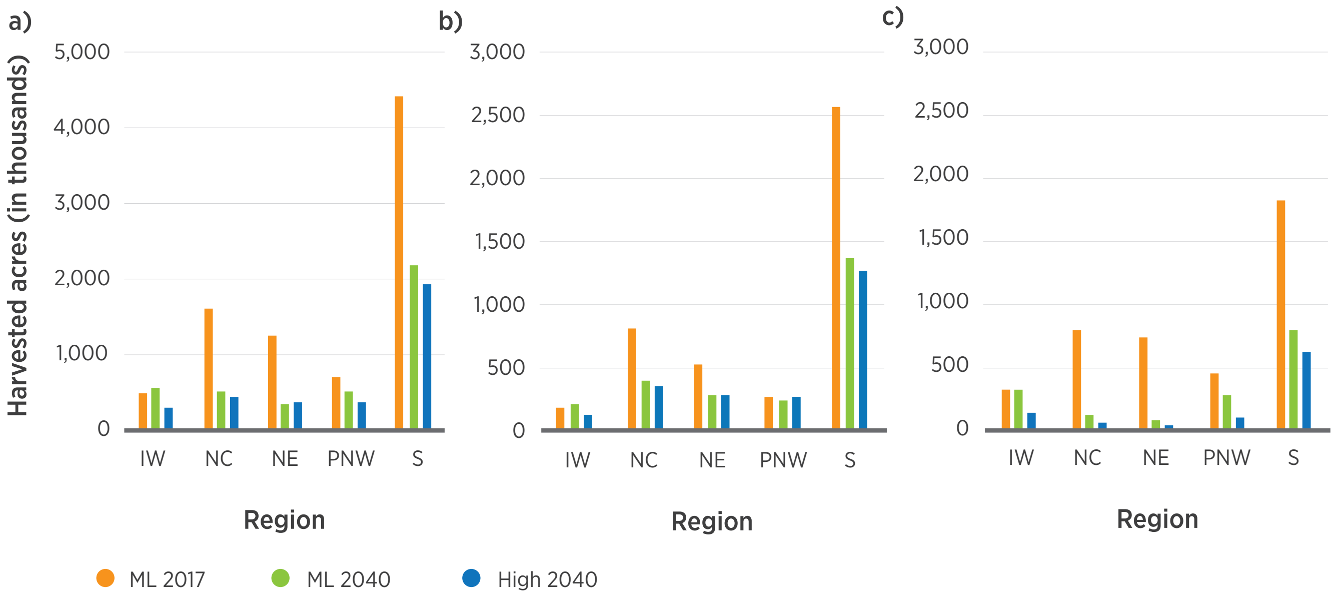
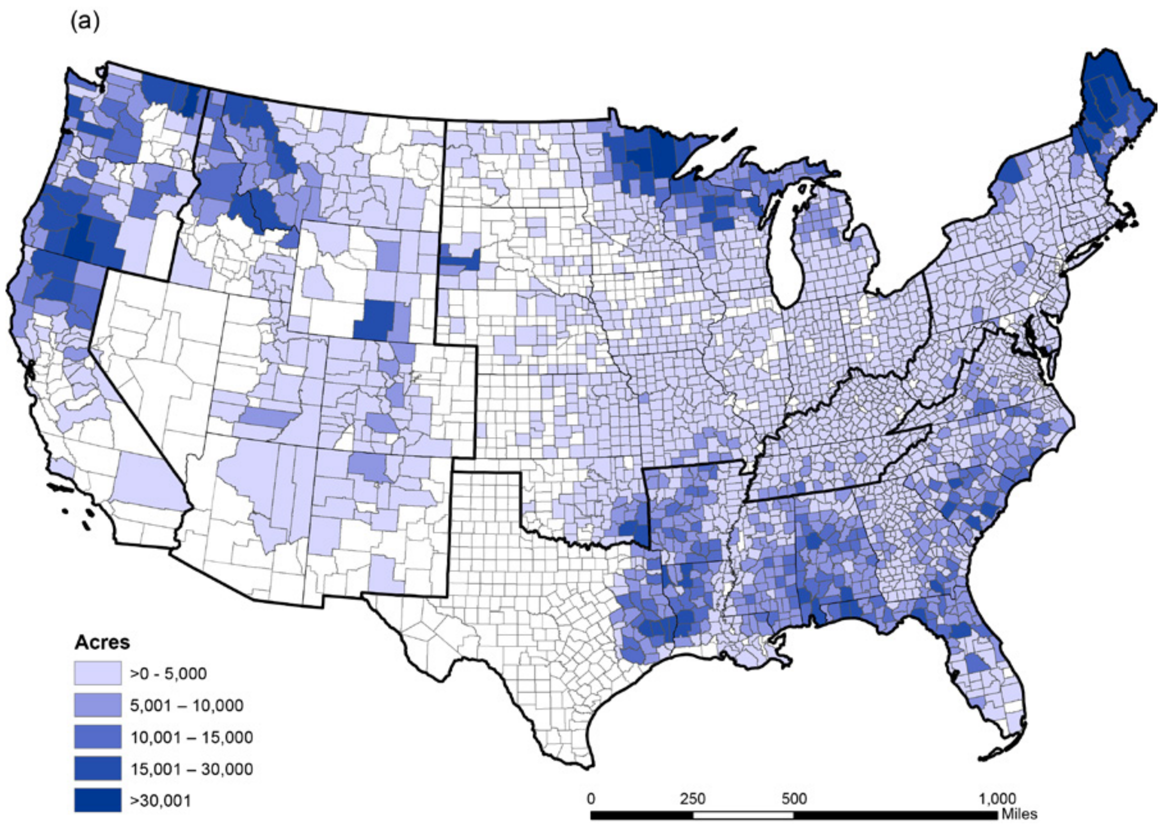
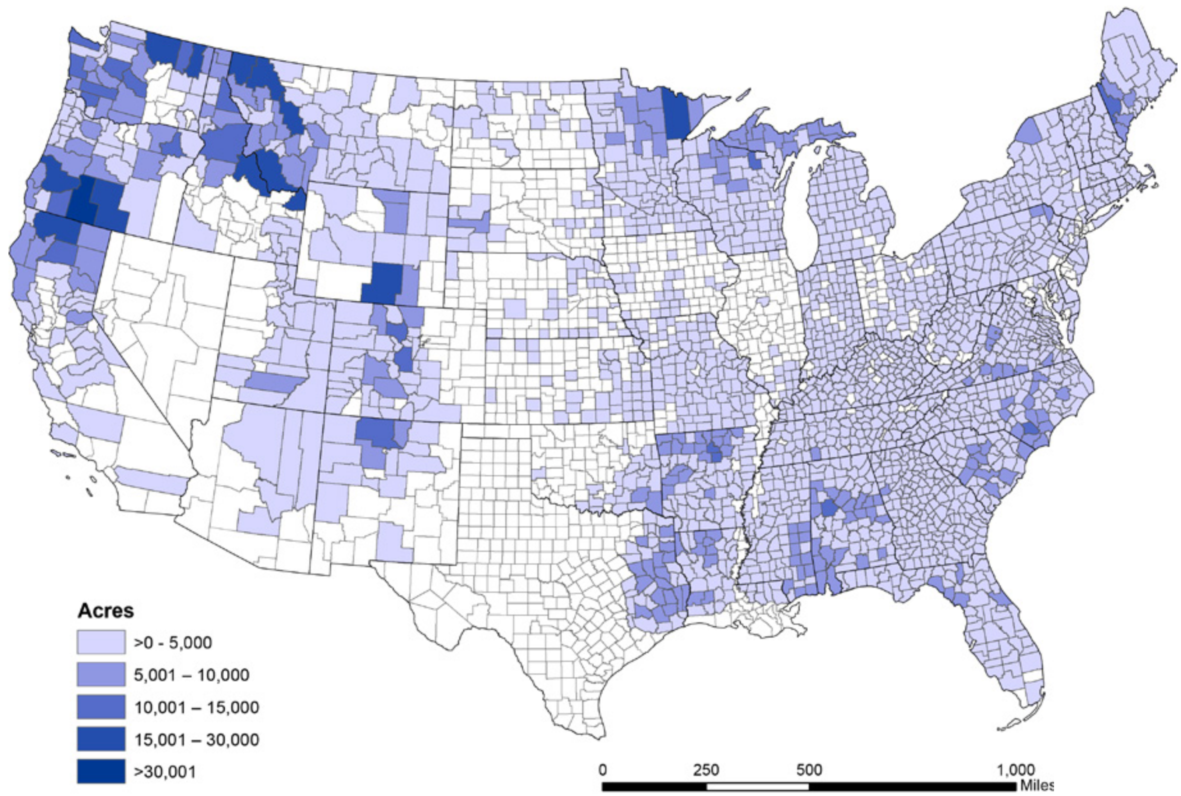


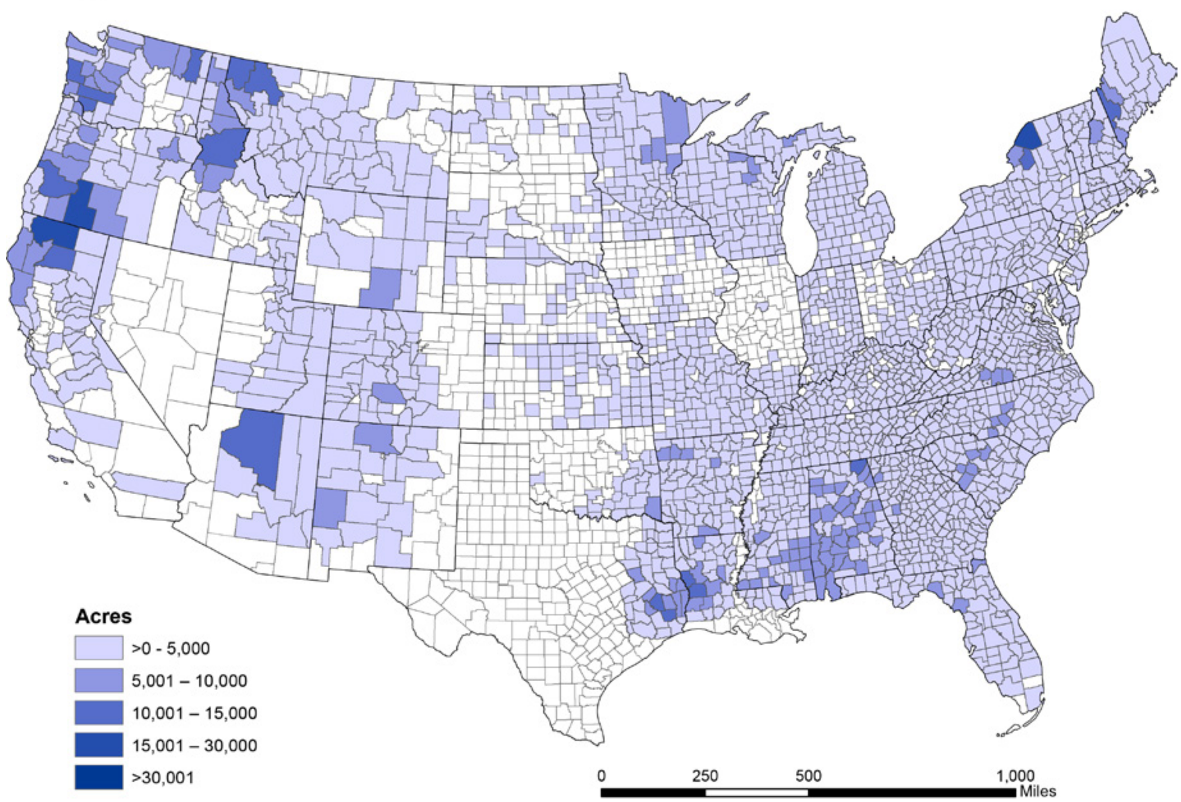
Figure 11.3 | Distribution of projected total acres from all feedstocks harvested by county under three biomass scenarios: (a) ML 2017, (b) ML 2040, and (c) HH 2040.



(b)


Acres
>0 - 5,000
5,001 – 10,000
10,001 – 15,000
15,001 – 30,000
>30,001
0
250
500
1,000
Miles

(c)


Acres
>0 - 5,000
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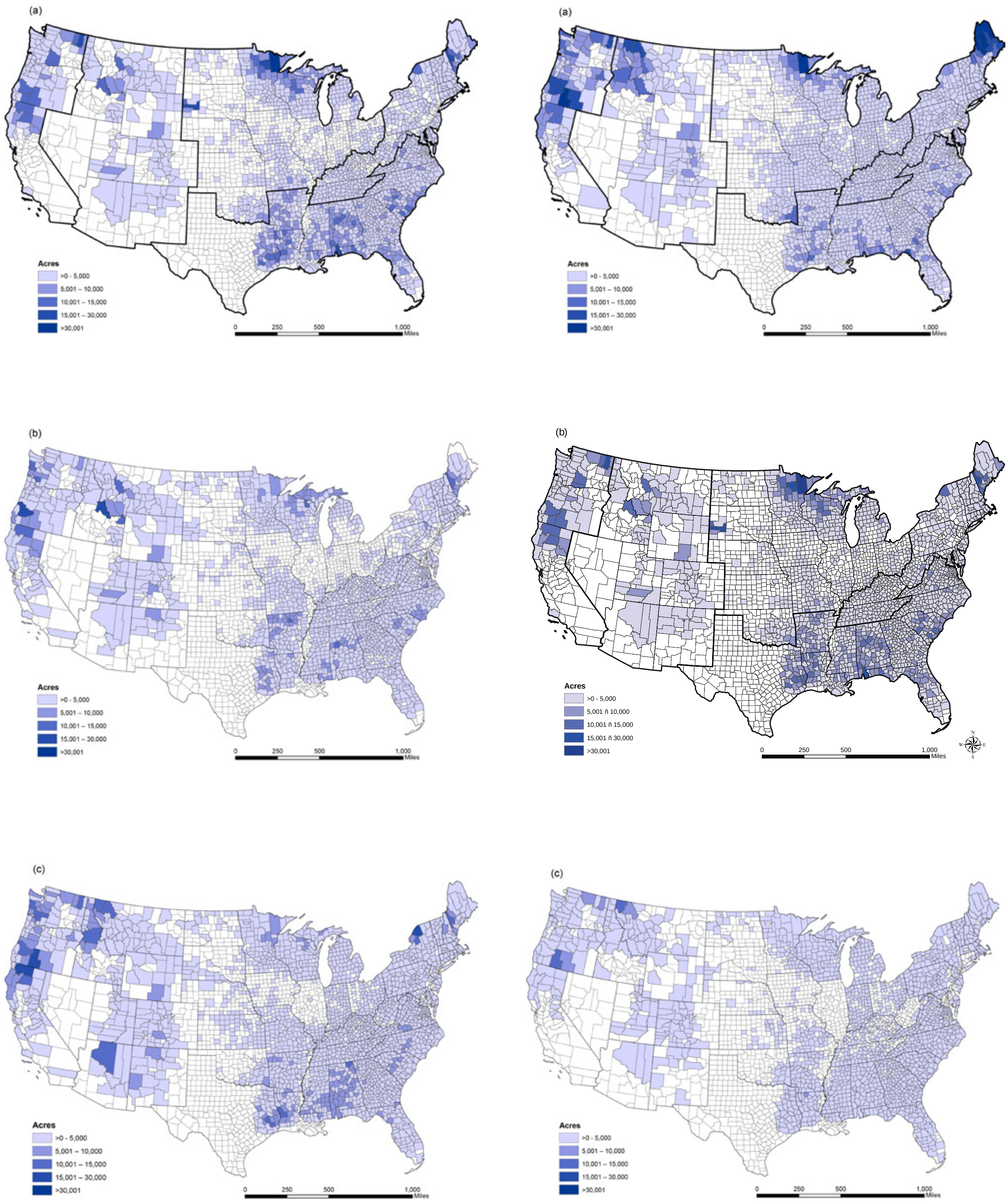
10,001 – 15,000
15,001 – 30,000
>30,001
0
250
500
1,000
Miles

Logging residues remained the primary feedstock under all scenarios in the S and NC regions, while whole-tree biomass remained the primary feedstock under all scenarios in the IW region (fig. 11.2b and 11.2c). Comparing the distribution of counties with >5,000 acres among feedstock type and ForSEAM regions also shows more counties with greater acres of logging residues than whole-tree biomass harvests (fig. 11.4). Logging residues under ML baseline scenarios decreased in all regions from 2017 to 2040, except in IW where it increased by 27% (fig. 11.2b). Comparing ML 2040 and HH 2040 scenarios, logging residues declined slightly in the S, NC, and IW, while increasing slightly in the NE and PNW regions (fig. 11.2b). The distribution of counties with >5,000 acres of harvest narrows to S, NC, and PNW primarily, with several counties also in NE and IW (fig. 11.4).

Harvested acres of whole-tree biomass declined in all regions between ML 2017 baseline and HH 2040 scenarios, except for IW where acreage was constant between ML 2017 and ML 2040 baseline scenarios (fig. 11.2c). This same pattern existed between ML 2040 and HH 2040 scenarios as well. Whole-tree biomass was the primary feedstock harvested in NE in near-term (ML 2017), but logging residues became the primary feedstock under ML 2040 and HH scenarios. For PNW, whole-tree biomass was the primary feedstock under ML 2017 and ML 2040 scenarios, but logging residues became the primary feedstock under HH 2040 scenario (fig. 11.2c). The distribution of counties with >5,000 acres narrows within PNW to the northwest with few counties in the remaining regions (fig. 11.4).

Figure 11.4 | Distribution of projected total acres harvested by county for logging residue feedstock (*left*) and whole-tree biomass feedstock (*right*) incorporating clearcut and thinning harvest types under scenarios (a) ML 2017, (b) ML 2040, and (c) HH 2040. Bold black lines in top panels delineate ecoregion provinces (see fig. 11.1).



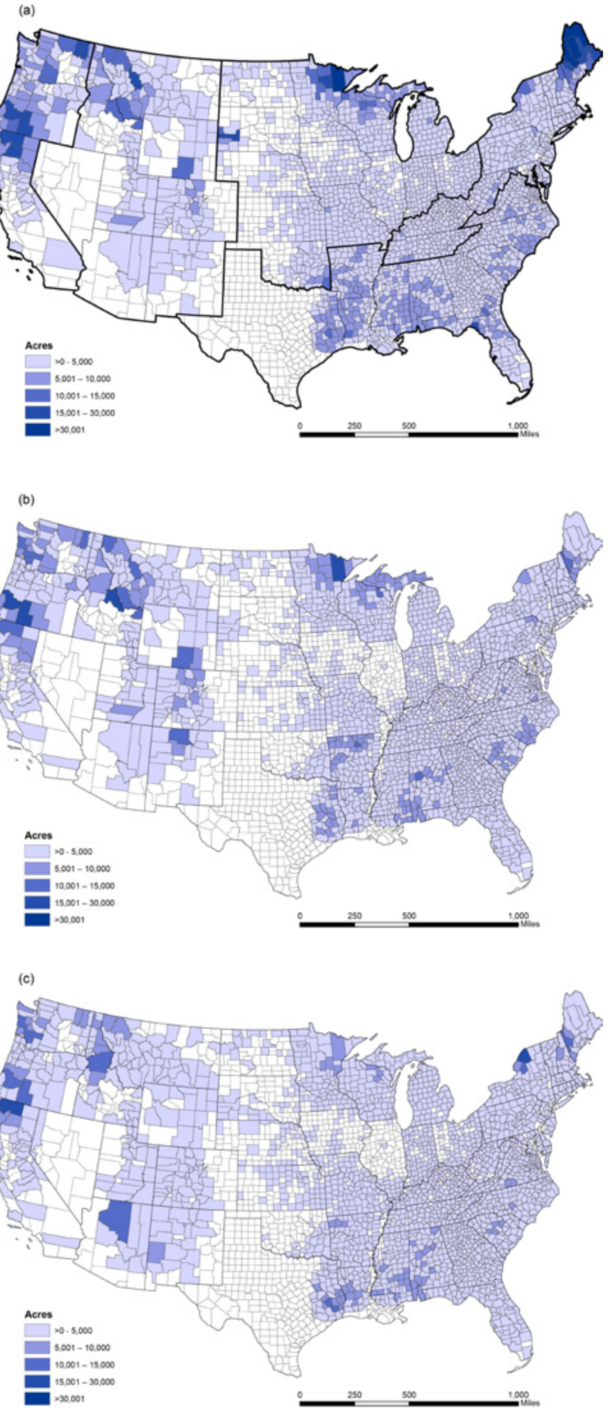
The distribution of young forests as a result of conventional and whole-tree harvest clearcutting was concentrated in the NE, upper NC, central PNW, and central S regions (fig. 11.5). However, under ML 2040 and especially HH 2040, the NE had fewer counties with large acres of clearcutting than did the Atlantic coast in the S, as well as the areas along the southern Rocky Mountains of Montana and Colorado.

11.3.1.1 Biodiversity Effects

Reduced biological diversity is caused by local extinctions, which can be a result of natural or human-induced factors. Habitat loss and fragmentation is identified as a significant driver of biodiversity loss (Reed 2004). Geographic distribution of species-endangerment patterns across the continental United States are typically unevenly distributed, concentrated into a few areas, separated along a land-cover gradient, and system-related (Dobson et al. 1997; Flather, Knowled, and Kendall 1998). Areas with greatest species endangerment have been found to be in the arid Southwest, Florida, southern Appalachia, and along the Atlantic, Gulf, and northern Pacific coastlines (Dobson et al. 1997; Flather, Knowled, and Kendall 1998). Because different factors have driven these patterns, endangered biota differ by area, with birds and reptiles driving trends in the eastern United States and aquatic vertebrates driving patterns in the western United States. Many imperiled species have faced face habitat loss associated with broad-scale processes such as urbanization, grazing, or altered natural disturbances (e.g., fire suppression), but local factors also contributed (Flather, Knowled, and Kendall 1998). By comparison, counties with greater harvest intensities in this assessment were also along the Gulf, Atlantic, and Pacific coasts, but were not concentrated in southern Appalachia, and there were only a few counties in the southwestern United States with high harvest intensities (fig. 11.5).

Because timberland area remained constant in ForSEAM, and other processes that may drive biodiversity patterns besides habitat area were not incorporated into ForSEAM, we mainly selected indicator species based on life-history characteristics and

Figure 11.5 | Distribution of projected young forest acres after logging residue and whole-tree harvests using clearcuts harvest type under (a) ML 2017, (b) ML 2040, and (c) HH 2040.



habitat associations for potential forest type changes within the ecoregion under consideration. In general, some characteristics of extinction-prone species are low reproductive rate; feeding at high trophic levels; large body size; limited or specialized nesting or breeding habitat; restricted or patchy distribution; poor dispersal ability; and low population densities but large individual ranges. Due to their life-history characteristics and occurrence in all regions of this assessment, amphibians may be a group of species that show biodiversity effects of woody biomass harvesting at national to local scales (see text box 11.2).

11.3.2 South Region

Overall, 51%–57% of the projected total acres harvested for woody biomass occurred in the S under ML 2017 and HH 2040 scenarios (fig. 11.2a). Total acres harvested declined approximately 50% from ML 2017 to ML 2040 and HH 2040, but the acres harvested were only 12% lower in HH 2040 than in ML 2040. Logging residues were the primary feedstock under all scenarios (fig. 11.2b and 11.2c), and were harvested from approximately the same proportion of land under ML and HH scenarios (58% and 63% in ML 2017 and ML 2040,

Text Box 11.2 | Case Study: Lungless Salamanders (Family Plethodontidae)—Bioindicators

Due to permeable skin, amphibians are considered environmental bioindicators. Amphibians are often abundant in ecosystems and play an important functional role as apex predators in detrital food webs (Davic and Welsh 2004). However, amphibians are declining across the nation at a projected rate of 3.79% per year, which may result in half of occupied sites becoming locally extinct within the next 19 years (Grant et al. 2016). No strong region-specific driver or single cause has been shown to account for this decline; local factors appear to have a stronger influence on viability (Grant et al. 2016). Reviews of field studies show amphibian numbers are positively correlated with dead wood, and retaining this material can reduce effects of forest harvest; however, results are also species- and system-specific and specific to the size of dead wood (Riffell et al. 2011a, 2011b; Otto, Kroll, and McKenny 2013). Conventional, partial-cut harvests affect amphibians less than clearcuts that open the canopy and increase desiccation risk, especially for young amphibians (Semlitsch et al. 2009). Lungless salamanders (Family Plethodontidae) may be more sensitive to woody-biomass harvests as many species are closely associated with forests that provide a moist environment with a large supply of invertebrate prey and dead wood that provides cover from predators and nesting substrate. Removing dead wood may increase risks of predation and desiccation, especially for those species with small home ranges and poor dispersal capabilities (see Petranka 2010).

Collectively, this taxonomic group contributes substantially to biodiversity at local to continental scales. For example, more than 40 species are found in the S, and 11 of these species are listed on the International Union for the Conservation of Nature (IUCN) red list, and all regions have these salamanders. The presence of lungless salamanders across the United States varies from locally common populations with restricted geographic distributions to patchy or continuous populations with broad geographic distributions (see Petranka 2010).

Concern for these species may be most relevant in areas of the nation expected to have greater intensities of clearcutting activities due to whole-tree biomass harvesting, such as the NE and IW, where extensive open areas with decreased residues may restrict movement enough to further isolate metapopulations. Another potential effect of harvesting residues concerns forest types that harbor high proportions of these species. Reduced retention of larger-diameter residues may lower availability of defendable nesting sites and foraging opportunities, causing a decline in local populations. However, few studies have separated the effects of residue removal from the effects of conventional harvest (Otto, Kroll, and McKenny 2013). Best management practices (e.g., buffers, minimum residue retention guides) for some of the more endemic species in the group (e.g., those found in Appalachia) may minimize any additive effects, but many common species with broad distributions, such as the red-backed salamander (*Plethodon cinereus*) common in northern forests, are not usually addressed specifically.

respectively, and 66% under HH 2040 scenario; fig. 11.2b and 11.2c). For the S region, 100% full-tree harvest type is defined under ForSEAM as felled trees taken to the landing to be processed and where either the whole tree or remaining waste could be chipped (i.e., no cut-to-length harvest type occurred in this region).

The greatest concentration of counties with >5,000 acres of potential total harvest occurred more often in the Gulf region than in the Atlantic region, with lower harvested acres in 2040 under both ML and HH scenarios (fig. 11.4a, b, and c). In the Gulf region, counties with >10,000 acres of potential harvest were in east Texas, Louisiana, Alabama, and the Florida panhandle, but few counties exceeded 10,000 acres of total biomass harvest in 2040 under ML and HH scenarios. In the Atlantic region, counties with >10,000 acres of potential harvest were primarily in South Carolina, coastal North Carolina, and south Georgia, but there were no such counties in both 2040 scenarios (fig. 11.4). These spatial patterns were mostly attributed to distribution of logging residue harvests (fig. 11.4b).

The majority of the land base that had greatest acreage of woody biomass harvesting was within the Southeastern Mixed Forest Province (231) (see text box 11.3) and the Outer Coastal Plain Mixed Forest Province (232) (see text box 11.4) under all scenarios, with approximately equal harvested acres in both (fig. 11.1). Within each province ecoregion, almost all counties had some woody biomass-harvest activity under all scenarios. Therefore, we limited our examination of forest change to these two ecoregions. However, it is worth mentioning that northern Arkansas had several counties with > 5,000 acres of potential woody biomass harvesting. This pattern is primarily a result of clearcutting, which created young forests in the 2040 baseline scenario (fig. 11.5b).

11.3.2.1 Province 231

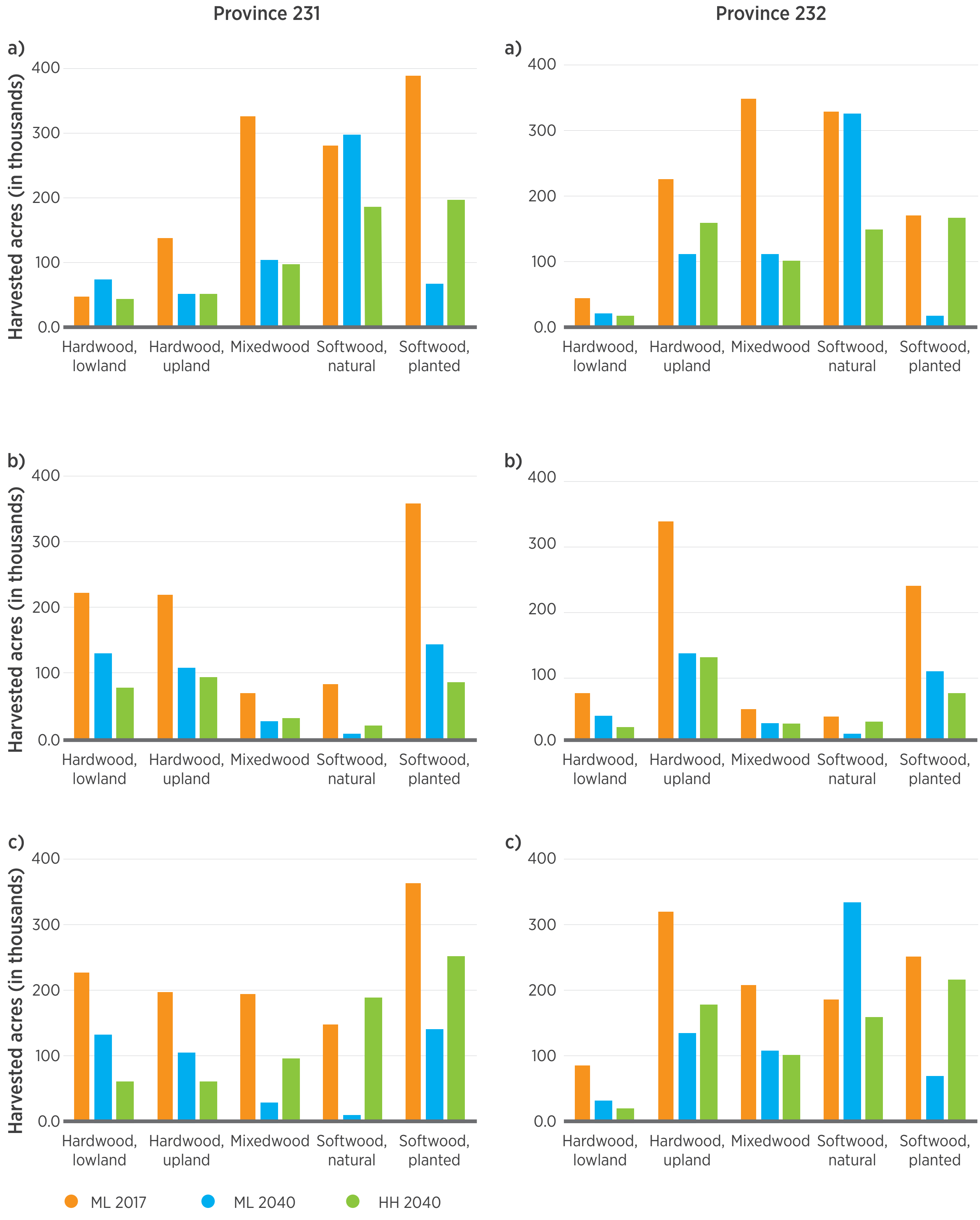
Province 231 covers 116.2 million acres (about 24.8% of the S). Under ML 2017, approximately 2 million acres were harvested (logging residues and whole-tree harvest), representing about 2% of the province. Harvested acres were reduced by half under both 2040 scenarios. Combined, planted, and natural softwoods produced approximately half of the feedstock under all scenarios (fig. 11.6). Planted softwood predominated in ML 2017 and HH 2040 scenarios (35.4% and 32.7%, respectively), but represented only 21.0% under ML 2040. Instead, natural softwood predominated under this scenario (30.9%).

All counties had some potential woody-biomass harvests under ML 2017, with the greatest concentration of counties having >5,000 acres harvested located in northeast Texas, northern Louisiana, southern Arkansas, eastward into northern Mississippi and Alabama, and northwest South Carolina and Virginia (fig. 11.1). This spatial pattern was driven by removal of logging residues for all scenarios (fig. 11.4b and 11.4c). Only three counties had >10,000 acres of potential whole-tree biomass harvest under ML and HH 2040 scenarios. Counties with greater areas of young forest as a result of whole-tree biomass harvests occurred in northern Arkansas primarily, followed by western South Carolina and West Virginia, but relatively few counties had harvests under the HH 2040 scenario (fig. 11.5).

Text Box 11.3 | Province 231: Southeastern Mixed Forest

- Maritime climate with mild winters and hot, humid summers; precipitation evenly distributed, but mid- to late-summer droughts may occur
- Hilly landscape with increasing relief farther inland
- Vegetation mixture of deciduous hardwoods and conifers
- Lowland hardwoods—primarily sweetgum/nuttall oak/willow oak and sugarberry/hackberry/elm/ green ash
- Upland hardwoods—primarily sweetgum/yellow-poplar and white oak/red oak/hickory
- Mixedwood—primarily loblolly and shortleaf pine with southern red oak
- Natural softwoods—primarily loblolly and shortleaf pine, as well as Virginia pine
- Planted softwoods—primarily loblolly and Virginia pine.

Figure 11.6 | Potential acres harvested by forest cover for the Southeastern Mixed Forest Province (231; left) and the Outer Coastal Plain Mixed Forest (232; right) within the southern region by (a) logging residue feedstock, (b) whole-tree biomass feedstock, and (c) open forest canopy condition (i.e., young forests).



For logging residues under both 2040 scenarios, primary forest change was a 51% reduction in acres producing this feedstock from the 1.16 million acres harvested under ML 2017. Planted and natural softwoods produced most logging residues under all scenarios, from 57% under ML 2014 to approximately two-thirds in both 2040 scenarios (fig. 11.6). Within these acres, planted softwood predominated under ML 2017 (58.2%) and HH 2040 (35.0%), but represented only 11.0% in ML 2040; natural softwoods predominated in ML 2040 (52.0%). Thinning all forest cover classes (diameter class 2) produced 78.0% of this feedstock under ML 2017, while clearcutting (diameter class 1) produced all logging residues under both 2040 scenarios. Specifically, by forest cover in ML 2017, most logging residues were harvested from planted softwood (33%) and mixedwood (28%) forests, followed by natural softwood forests (24%) through thinning and clearcutting. The lowest quantities of logging residues were projected to be harvested from lowland hardwoods (3%). Under ML 2040, natural softwood harvests produced 52% of logging residues while mixedwood yielded 17%, and upland hardwood generated the least (8%). Under HH 2040, planted and natural softwoods each produced approximately a third of logging residues, and mixedwood produced 16%. Lowland hardwoods remained lowest at 7%. The majority of counties with >5,000 acres producing logging residues were located in northern Alabama.

For whole-tree biomass, harvests occurred on fewer acres than logging residues (930,000 acres under ML 2017) and declined 57% under ML 2040 and 69% under HH 2040. Harvest of planted softwoods produced 38.2% of feedstock under ML 2017, 34.8% under ML 2040, and 28.2% under HH 2040. However, acres harvested declined 60.5% under ML 2040 and 76.7% under HH 2040 from ML 2017 levels (fig. 11.6b). Combined, upland and lowland hardwood harvests represented 46.5% of feedstock in ML 2017, 57.7% in ML 2040, and 56.8% in HH 2040. Natural softwoods produced the lowest fraction of feedstock in all 2040 scenarios. Under ML 2017, 92% of harvested acres for whole-tree biomass were produced by clearcutting diameter classes 2 and 3, but in 2040, acres harvested by clearcutting (class 2) under ML and HH scenarios were only 26.7% and 28.0%, respectively. Under the ML 2040 scenario, no counties had <5,000 acres harvested for whole-tree biomass.

For young forests, approximately 1.1 million acres were produced through clearcutting under ML 2017, primarily from planted softwood (32%), followed by lowland hardwoods (32%). Under ML 2040 scenario, acres in young forest were primarily produced from clearcutting of natural softwoods (42%). Natural and planted softwoods produced two-thirds of young forests under ML 2040 and HH 2040 scenarios, followed by mixedwood (14%) for both scenarios. This trend was similar to logging residues because clearcutting was the primary method of generating feedstocks. the few counties with <5,000 acres harvested were primarily in northern Alabama.

11.3.2.2 Province 232

This province covers 137.8 million acres (about 29.4% of the S). Under ML 2017, approximately 1.8 million acres were harvested (logging residuals and whole-tree harvest), representing nearly 2% of the province. Total acres harvested were slightly less than those in Province 231, but the same reduction by approximately half was modeled in ML and HH 2040 scenarios (fig. 11.6). In addition, planted and natural softwoods produced approximately half of total acres harvested for woody biomass under both 2040 scenarios but represented only 41.9% under the ML 2017 model. Upland hardwoods produced the greatest quantity of woody biomass in ML 2017 and HH 2040 scenarios (30.5% and 32.9%, respectively). Natural softwoods produced the most biomass in the ML 2040 line (37.2%), followed by upland hardwood (27.3%). Lowland hardwoods produced the least woody biomass under all scenarios.

Text Box 11.4 | Province 232: Outer Coastal Plain Mixed

This province is characterized by the following:

- Gentle topography and very low (<90 m) elevation
- Humid, maritime climate with mild winters, and warm summers with rare periods of summer drought
- Vegetation dominated by conifers with deciduous hardwoods along major floodplains
- Lowland hardwoods—primarily bald cypress, black gum, and overcup oak
- Upland hardwoods—primarily oak, hickory, cherry/white ash/yellow-poplar, sweetgum, and magnolia
- Mixedwood—primarily loblolly and longleaf pine mixed with oak and hickory
- Natural softwood—primarily loblolly and longleaf pine
- Planted softwood—primarily loblolly and longleaf pine.

All counties within this province had some potential woody-biomass harvests. The densest concentration of harvesting occurred in the Gulf region within Louisiana, Alabama, the Florida panhandle, and southeastern Texas. In the Atlantic region, biomass harvests occurred mostly in eastern South Carolina and Virginia (fig. 11.1, 11.3a, b, and c;). This spatial pattern was driven by counties with >5,000 acres removal of logging residues compared to whole-tree harvests for all scenarios (fig. 11.4). Only three counties had >5,000 acres of whole-tree biomass harvest in ML 2040 and HH 2040 scenarios (fig. 11.4b and 11.4c). The greatest density of counties with young forests occurred mostly in the Gulf region in eastern Texas, southern Alabama, and eastern South Carolina, but few counties had >5,000 acres harvested under HH 2040 (fig. 11.5).

For logging residues, the primary forest change was a reduction under both 2040 scenarios from 1.12 million acres harvested under ML 2017. However, the predominant forest cover harvested changed under each scenario. Under ML 2017, logging residues were a byproduct primarily from mixedwood (31.0%), followed by natural softwood (29.5%) and upland hardwood (20.6%). However, under ML 2040, natural softwood produced 56.1% of logging residues, followed by upland hardwood (19.1%) and mixedwood (18.8%). Under HH 2040, planted softwood predominated (28.2%) in the percentage of logging residues, followed by upland hardwood (26.7%) and natural softwood (25.5%). Nearly half of all logging residues, however, were a byproduct of softwoods under all scenarios. Logging residues from diameter class 1 comprised 27.8% of harvested acres under ML 2017 but were the only source for logging residues under both 2040 scenarios. The remaining source for logging residues was thinning of diameter class 2 (70.2%)—mostly upland hardwoods. The greatest concentration of counties with >5,000 acres of harvested logging residues occurred primarily in southern Alabama and Florida and in eastern South Carolina (fig. 11.4). Fewer than five counties had >5,000 acres of whole-tree biomass harvest under HH 2040 (fig. 11.5c and 11.5d).

For whole-tree biomass, harvests occurred on approximately 740,000 acres under ML 2017, and declined by 56.1% and 61.2% under ML and HH 2040 scenarios, respectively (fig. 11.6). Under ML 2017, upland hardwoods (45.7%), followed by planted softwoods (32.5%) and lowland hardwoods (10.1%), produced this feedstock. This pattern was consistent under both 2040 scenarios, except mixedwood was third under HH 2040 (10.8%). Relatively few whole-tree biomass harvests occurred in natural softwood forests—only 3%–10% of harvested acres across scenarios. Whole-tree biomass was a byproduct of thinning diameter class 2 (4.9%) under ML 2017, but this feedstock increased to approximately 70% under both 2040 scenarios, mostly from thinning upland hardwoods. Clearcutting produced the most feedstock under ML 2017, again primarily from upland hardwoods. Spatially, the greatest density of whole-tree harvest was in southern Alabama, the Florida panhandle, and southern South Carolina (fig. 11.4), but under HH 2040, no counties had >5,000 acres harvested for whole-tree biomass.

Young forests were generated after clearcutting approximately 1 million potential acres under ML 2017, which also generating logging residues and whole-tree biomass. Harvested acres declined to approximately 670,000–680,000 acres under both 2040 scenarios. In ML 2017, potential acres to be clearcut were greatest in upland hardwood forested systems, and similar acreage was projected for natural and planted softwoods and mixedwood. As a result of clearcutting, acres in open-canopy cover increased in natural softwoods under ML 2040; acres in planted softwoods also increased under HH 2040, while declining approximately by half in the upland hardwoods. Spatial distribution of counties with >5,000 acres was similar to patterns for logging residues produced by clearcutting—mostly in Gulf areas in southern Louisiana, Mississippi, and Alabama, and on the Atlantic coast, mostly in southeastern South Carolina and West Virginia.

11.3.2.3 Biodiversity Effects—Provinces 231 and 232

Before discussing potential effects of biomass harvest on biodiversity, it is important to put results of the harvest scenarios in context of the southern landscape. For both Provinces 231 and 232 (fig. 11.1), less than 2% of the province’s land area is potentially harvested by either whole-tree harvest or through the removal of forest residuals. Also in both provinces, logging residues were removed from approximately 1 million acres, and the whole-tree harvest was less than 1 million acres under ML 2017 that had the greatest potential harvested acres. Further, since acres of logging residuals are assumed to be a product of conventional harvest, it is not clear if potential harvests will have widespread, long-term effects on biodiversity in the S region. Given that harvested acres may be clumped in distribution, however, localized effects are possible. Additionally, as the most prominent result of biomass harvest will be changes in forest structure, it is important to understand how this may affect biodiversity in the S.

When comparing provinces, it appears that in general: (1) lowland hardwoods are projected to be the least affected by harvest in Province 232 but constitute a significant component of small-diameter whole-tree harvest in Province 231 (approximately 215,000 acres); (2) planted softwoods, natural softwoods, and upland hardwoods are projected to be the most affected by biomass harvest; (3) approximately 2.1 million acres of young, open forests are projected to be on the landscape under the ML 2017 scenario; (4) harvest of residuals may decline 51% between ML 2017 and both 2040 scenarios in Province 231; and (5) for Province 232, clearcutting is projected to be the most common harvest activity under ML 2017, with thinning as the dominant activity in both ML and HH 2040 scenarios. This summary is useful when considering potential biodiversity effects, given the initial caveat (biomass harvest in the context of total forest harvest in the S), which leads us to consider species and communities associated with upland forests more so than lowland forests.

One of the primary concerns associated with biomass harvest is removal of FWD and CWD due to the number of species dependent on, or associated with, these components of forest structure (see 11.1 Introduction). Removal of these materials may be prominent in both provinces because the primary sourcing feedstock is logging residues. However, it is not clear that the concern about forest structure loss extends as much to Province 232. The hot, humid conditions in the coastal plain of the southeastern United States lead to quick decomposition of downed wood. In fact, many species in the southeastern United States have shown minimal response to CWD (Mengak and Guynn 2003; McCay and Komoroski 2004; Davis, Castleberry, and Kilgo 2010b). Results from recent studies of operational biomass-production practices suggest minimal or short-term vertebrate species responses, potentially due to abundance of CWD retained on-site even after biomass harvests (Fritts 2014; Fritts, Moorman, et al. 2015; Fritts, Grodsky, et al. 2015; Fritts et al. 2016), which reflects recommendations commonly found in some biomass-harvesting guidelines (Perschel, Evans, and DeBonis 2012). Therefore, removal of CWD and FWD as part of biomass harvests may not be a strong driver of biodiversity response in these provinces.

Logging residues were a primary byproduct of planted and natural softwoods, but upland hardwoods and planted softwoods produced mostly whole-tree biomass. Lowland hardwoods are of conservation concern in the S, partly because of a perception that these forests are being extensively harvested for the wood-pellet market. As noted above, under all scenarios for Province 232 (Outer Coastal Plains), it appears that lowland hardwoods are minimally affected by biomass harvest using the parameters of this assessment, but this cover type is a primary source of whole-tree biomass harvests in Province 231 under all scenarios, meaning smaller-diameter classes are being harvested. However, the area that would be affected is, at most, approximately 215,000 hectares, which comprises less than 2% of a projected area of 12.15 million hectares of lowland hardwoods in the southeastern United States in 2010 (Wear and Greis 2012). Additionally, areas in bottomland hardwood forests remained relatively stable from 1970 to 1992, but slight declines in total acreage are expected between 1995 and 2040 (Wear and Greis 2002). Based on these scenarios, it does not appear that lowland hardwoods will be strongly or negatively affected by potential biomass harvest, although localized effects could be observed (see text box 11.5).

Under all scenarios, the amount of young forest created via biomass harvest is projected to decline dramatically between assessment periods, except for planted softwood in Province 232. Some of this change is due to potential conventional harvests of mature trees. However, the increasing amount of young forests generated from biomass harvests is a result of full-tree harvests. A suite of species requires early successional forests, and some of these species are in rapid decline in the eastern United States (see, e.g., King and Schlossberg 2014). There may be an influx of young forest conditions under

Text Box 11.5 | Case Study: Rafinesque's Big-Eared Bat—Rare Native

Rafinesque's big-eared bats (*Corynorhinus rafinesquii*) are a species of conservation concern across the southeastern United States. This species relies primarily on bottomland hardwood forests, roosting in tree cavities in larger hardwood trees, under bridges, and in buildings. Miller et al. (2011) estimated the potential roosting habitat for Rafinesque's big-eared bats by quantifying acres containing water tupelo (*Nyssa aquatic*) with greater than 50 cm diameter at breast height (dbh) based on U.S. Forest Service Forest Inventory and Analysis data. They found that there are approximately 308,000 hectares of bottomland hardwood forests with such trees in the southeastern United States (Miller et al. 2011). Given the relatively small area containing such potential roost trees, increased harvest of lowland hardwoods for biomass could have a localized, negative effect on this species if larger roost trees are removed or occupied habitat is harvested. However, given that most of the potential hardwood harvest for biomass is expected to be in smaller-diameter classes, it is not clear if such harvests will affect these more-mature lowland hardwood stands. Research is needed to further examine effects of potential biomass harvest in lowland hardwoods on the known distribution of this species and county-level (or more precise) potential harvest of lowland hardwoods for biomass.

the near-term ML 2017 scenario, but due to ForSEAM model assumptions, this pattern was not evident under both ML and HH 2040 scenarios. A decline in acres harvested by clearcutting, particularly in hardwood systems, may contribute to a strong trend of reduced oak regeneration, thereby changing forest composition and function in much of the eastern United States (McShea et al. 2007). Although the area affected by woody-biomass harvest appears relatively small compared to the total area of forested acres, even incremental changes in forest structure may have long-lasting effects on future forest composition.

Recently, an area of interest within the southern United States is creation and maintenance of open pine-canopy conditions (Greene et al. 2016). Historically, open-pine conditions on some site condition types were maintained by frequent fire, which suppressed hardwood encroachment, allowing herbaceous plant growth under a relatively open-pine canopy. Forest harvest can create these conditions in regenerating forests (see above) and also in older forest stands through thinning (Riffell et al. 2012). If there is a reduction in clearcut acres and thinning, as represented by changes from ML 2017 to both 2040 scenarios, biomass harvesting alone will likely not be able to help maintain open-pine conditions on the landscape (see text box 11.6). Therefore, planners need to consider the cumulative effects of conventional and biomass harvest when considering future distribution and amount of open-pine conditions in the southern landscape.

Text Box 11.6 | Case Study: Gopher Tortoise—Keystone Species

Based on the area of most change in Province 232, the gopher tortoise—a keystone species that is federally protected in the western portion of its range—is a species that could potentially be affected by biomass harvesting in this province. Gopher tortoises are associated with upland, sandy soils and require open-canopy pine forests with abundant herbaceous vegetation. Such open conditions can be created with clearcut harvests or thinning and can be maintained by prescribed fire and/or herbicide applications. The forest types associated with gopher tortoises in the assessment are natural and planted pine forests. The reduction in early successional forest stands and the relatively low level of potential thinning of natural and planted softwood stands under both ML and HH scenarios may result in less suitable habitat for gopher tortoises, assuming that other management activities do not ameliorate potential reductions. However, it must be recognized that the change would represent only a small portion of the projected occupied range for this species, which extends west from southern South Carolina and Florida through Georgia, Alabama, Mississippi, and eastern Louisiana. Also, a more precise spatial analysis is needed to understand location of potential harvest relative to appropriate soils (upland, deep sands) for gopher tortoises, which would help identify potential, localized effects of biomass harvest on gopher tortoises.

11.3.3 North Central Region

Overall, 19.4% of the total acres harvested for woody biomass occurred in the NC region under ML 2017, compared to 12% under both 2040 scenarios (fig. 11.2a). A total of 1.65 million acres were projected to be harvested under ML 2017, and acres declined 67.8% and 76.5% under ML and HH 2040 scenarios, respectively. Harvested acres were 27.2% lower under the HH 2040 scenario compared to the ML 2040 scenario. Logging residues and whole-tree biomass were produced from approximately the same amount of harvested acres under ML 2017 (approximately 800,000 acres), but logging residues were the primary feedstock under both ML 2040 and HH 2040, at 75.8% and 83.6%, respectively (fig. 11.2b and 11.2c). In this region, the assumption of ForSEAM was that the harvest method was 50% full-tree and 50% cut-to-length harvesting. Under the cut-to-length harvest method, trees are felled, delimbed, and bucked to length at the stump; then, logs are transported to landing (DOE 2016, p. 50). Residues stayed on the land, which also produced piles of residues (i.e., tops and limbs).

The densest concentration of counties with >5,000 acres of harvest would occur in northern Minnesota, Wisconsin, and the upper peninsula of Michigan (fig. 11.3). This area is encompassed by Province 212, Laurentian Mixed Forests (see text box 11.7; fig. 11.1). More than two-thirds of the counties within the NC region, however, had some forest woody-biomass harvest activity. Under HH 2040, only eight counties had >5,000 acres harvested (fig. 11.3c). It is worth noting that southern Missouri had eight counties under ML 2017 that experienced >5,000 acres harvested.

11.3.3.1 Province 212

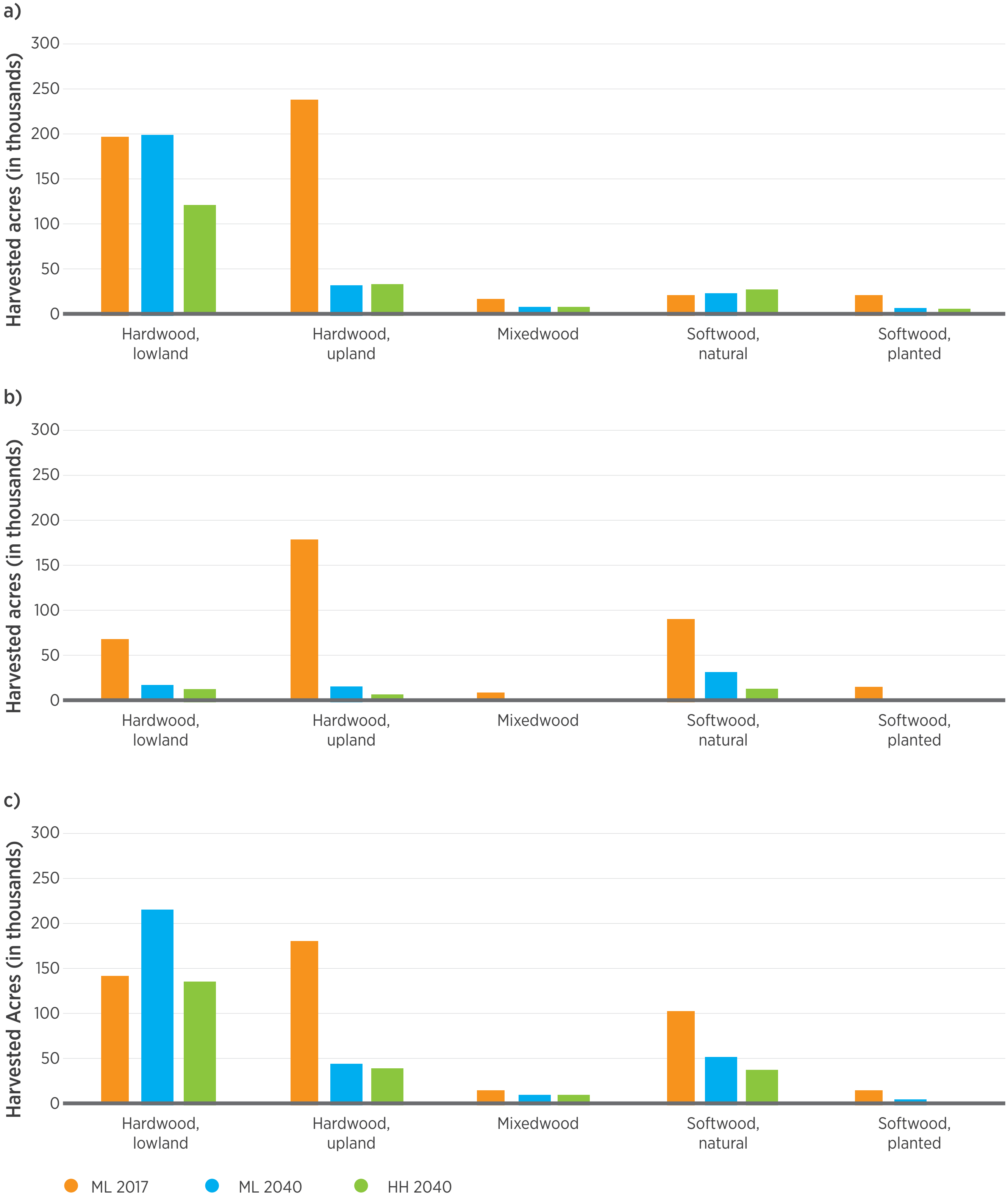
This province is 64.6 million acres, covering nearly 11% of the NC region. Under ML 2017, 838,080 acres were projected to be harvested, representing <1% of Province 212. The harvested land base for woody biomass declined by 61.0% and 73.7% under ML 2040 and HH 2040 scenarios, respectively; the HH 2040 scenario differed by 31.9% from the ML 2040 scenario. Under the ML 2017 scenario, counties with the greatest quantity of acres harvested were in northeast Minnesota and north-central Wisconsin, but under the HH 2040 scenario, only nine counties had >5,000 acres, and no counties had >10,000 acres (fig. 11.3).

Text Box 11.7 | Province 212: Laurentian Mixed Forest

This province is characterized by the following:

- Continental climatic regime with maritime influence along the Great Lakes; hilly landscapes with low relief and lakes, morainic hills, drumlins, eskers, outwash plains
- Ground continually snow-covered during the winter, with most precipitation occurring during summer
- Vegetation consisting of forests that are a transition between boreal and broadleaf deciduous zones
- Planted softwood—primarily red, jack, and white pine
- Natural softwood—primarily northern white cedar, balsam fir, tamarack, and black and white spruce
- Upland hardwoods—typically sugar maple-basswood mesic forests with red oak, American elm, red elm, green ash, and aspen-paper birch forests
- Lowland hardwoods—typically black ash with associated yellow birch, red maple, and beech
- Mixedwood—typically eastern white pine, northern red oak, and white ash mixed forests.

Figure 11.7 | Potential acres harvested by forest cover for the Laurentian Mixed Forest Province (212) by (a) logging residues, (b) whole-tree biomass feedstock, and (c) open forest canopy condition (i.e., young forest).



Logging residues were generated from 57.6% of potential harvested acres under ML 2017, and increased to 80.3% and 85.0% under ML and HH 2040 scenarios, respectively (fig. 11.7). Upland and lowland hardwood harvests produced 48.8% and 40.3% of this feedstock, respectively (89.1% combined), under ML 2017. However, under both ML and HH 2040 scenarios, lowland hardwoods were the predominant source of logging residues: 75.7% and 64.2%, respectively. Thinning of diameter class 2 produced 80.9% of logging residues under ML 2017, but only 1.2% and 1.4% under ML and HH 2040 scenarios, respectively. Instead, clearcutting of diameter class 1 produced 98.4% of logging residues under both 2040 scenarios. Harvest operation was full-tree conventional harvests for pulpwood under all scenarios. Only one county in northeastern Minnesota had >10,000 acres harvested under ML 2040; no counties under HH 2040 had >10,000 harvested acres. There were only four counties with >5,000 acres under the HH 2040 scenario—three in Wisconsin and one in Minnesota.

Whole-tree biomass was produced from harvest of upland hardwoods and natural softwoods at 49.9% and 25.0% of this feedstock, respectively, under ML 2017, but under the ML 2040 scenario, natural softwood produced 49.3% of feedstock, followed by lowland hardwood (25.7%) and upland hardwood (22.9%) (fig. 11.7). Under HH 2040, lowland hardwood comprised 39.2% of whole-tree biomass, followed by natural softwood (38.6%) and upland hardwood (20.3%). Under all scenarios, this feedstock was a byproduct of clearcutting diameter classes 2 and 3. The concentration of counties with >5,000-acre harvests was mainly in northern Minnesota under ML 2017; however, no counties had >5,000 acre harvests under HH 2040, and there was only one county in northern Minnesota that had >5,000 acres under the ML 2040 scenario (fig. 11.4).

Young forests were created through clearcutting on approximately half of the harvested acres under ML 2017, but accounted for >97% of total potential harvested acres under ML and HH 2040 scenarios. However, the potential harvested acres clearcut were 29.5% and 51.0% lower under ML and HH 2040 scenarios, respectively, than under ML 2017. Acres in young forests were 31.0% lower in the HH 2040 scenario than the ML 2040 scenario (fig. 11.7). Under ML 2017, clearcutting of upland and lowland hardwoods—and to some degree, natural softwoods—generated young forests, but under both 2040 scenarios, clearcutting of lowland hardwoods generated nearly two-thirds of young forest acreage. Whole-tree biomass harvesting accounted for 79.4% of clearcutting activities under ML 2017, but only 20.2% and 15.1% under ML and HH 2040 scenarios, respectively. Clearcutting associated with conventional harvests of lowland hardwood sawlogs produced most of the young forests under the 2040 scenarios. Only seven counties had >5,000 acres of potential harvest under the HH 2040 scenario (four in Minnesota and three in Wisconsin); there were no counties with >10,000 acres harvested under all scenarios (fig. 11.5).

11.3.3.2 Biodiversity Effects—Province 212

The primary forest change influencing biodiversity in this ecoregion is removal of logging residues from the forest floor under expanded biomass demand, as >80% of potential acres harvested produced residues under the 2040 scenarios. This forest change may have greater effects on biodiversity of species that rely on this material (see text box 11.8). Most of this feedstock was produced from harvests in lowland and upland hardwoods, especially lowland hardwoods under the 2040 scenarios. In the near term (ML 2017), logging residues were generated mostly through thinning harvests, but they were generated mostly through clearcut harvests under both 2040 scenarios. Upland and lowland hardwoods and natural softwoods generated most of the potential whole-tree harvests through clearcuts under ML 2017, but clearcuts of lowland hardwood sawlogs created most of the young forests under the 2040 scenarios. The total acres of lowland hardwoods clearcut was approximately the same between ML 2017 and HH 2040, but increased about half under ML 2040, meaning an influx of young forests in lowland hardwoods across all scenarios. However, lowland hardwoods on public lands in this region are not typically clearcut, so the effect on biodiversity is unclear as much of the land in Province 212 consists of public lands (see text box 11.9). The densest concentration of counties with >5,000 acres of total potential harvest occurred in northern areas of the province with a high proportion of public lands. With the reduction of potential harvest acres in 2040, the concentration of higher-intensity harvests was limited to northeast Minnesota and Wisconsin.

Text Box 11.8 | Case Study: American Marten—Species of Cultural Importance

Forest structural complexity is a critical habitat component for the American marten (*Martes Americana*). Dead wood, such as large snags, fallen trees, stumps and root mounts, and residual piles, provides den and resting sites; cover from fishers, lynx, and bobcat predators while traveling; forage areas for preferred small rodents, squirrels, and hares that also use residual piles; and access points to get to ground surface for foraging during snow cover (Corn and Raphael 1992). Marten have been found to prefer mature northern forest communities and avoid aspen-dominated systems, swamp conifer, and nonforested areas (Wright 1999). Within mature forests, tree-species composition is less important than the volume of downed woody debris and canopy closure (Buskirk and Ruggiero 1994; Buskirk 1994; Chapen, Harrison, and Phillips 1997). These two factors are often listed as major threats to marten viability in an area. Marten avoid recent clearcuts, and extensive clearcutting may lower local abundance (Hargis and McCullough 1984; Potvin and Breton 1997). Marten densities were found to be positively correlated with prey abundance in Maine (Soutiere 1979). Potential effects to marten in this province may be greater under the ML 2017 scenario, with more acres harvested producing logging residues in combination with increased whole-tree harvests by clearcutting in upland hardwoods. The loss of forest structure in combination with opening the canopy in preferred habitats may negatively affect this species. Furthermore, whole-tree harvesting in smaller-diameter trees rather than in the preferred mature forests may negatively affect this species in the long term if management practices result in significant reduction of mature forest. The southernmost distributional range of the American marten extends into the northern areas of the Northeast (NE) and Pacific Northwest (PNW) Forest Sustainable and Economic Analysis Model (ForSEAM) regions, so forest woody-biomass harvesting may affect this species in these regions as well and should be evaluated.

Text Box 11.9 | Case Study: Golden-Winged Warbler—Species of Concern

Young forests are an important habitat for the golden-winged warbler (*Vermivora chrysoptera*), a migratory bird found throughout the north-central and eastern United States. The golden-winged warbler population has declined range-wide, and the warbler is currently being considered for listing under the Endangered Species Act (Pruss et al. 2014). This decline has been attributed to loss of preferred breeding habitat caused by maturing forests. Regenerating upland and lowland habitat is used for breeding as dense foliage and shrubs provide cover for ground nests. Scattered trees or edges of forests provide singing perches. Dense foliage also lowers negative interactions with blue-winged warblers (*Vermivora cyanoptera*) and cowbirds (Molothrus spp.) (Pruss et al. 2014). Given the influx of young forests expected from clearcuts of mature lowland hardwoods under both 2040 scenarios, and from the same relative acreage in 2017 from whole-tree biomass harvesting, there may be opportunities in this ecoregion to contribute to the conservation of this warbler and other species that rely on young forests. Other birds associated with young forests showing range-wide declines are the chestnut-sided warbler (*Setophaga pensylvanica*), Bell's vireo (*Vireo belli*), alder flycatcher (*Empidonax alnorum*), American redstart (*Setophaga ruticilla*), and blue-winged warbler (*Vermivora cyanoptera*).

11.3.4 Northeast

Overall, 14.6% of potential total acres harvested for forest woody-biomass occurred in the NE under ML 2017 compared to 8.6% and 11.5% under ML 2040 and HH 2040 scenarios, respectively (fig. 11.2a). The total area harvested was 1.24 million acres under ML 2017. The total declined approximately 70% under both 2040 scenarios; projections for HH 2040 harvested acres were 7.3% greater than the projections for the ML 2040 scenario. Whole-tree biomass was harvested from 759,000 acres, while logging residues were harvested from 483,000 acres under ML 2017. However, logging residues dominated feedstock under both 2040 scenarios: 75.9% under ML 2040 and 86.1% under HH 2040 (fig. 11.2b and 11.2c). In this region, the assumption of ForSEAM was that the harvest method consisted of 100% full-tree harvest type, meaning felled trees were taken to the landing to be processed, and the full trees or remaining waste after processing could be chipped.

The densest concentration of counties with >5,000 acres of total potential harvest occurred in Maine and several counties in northern New York under all scenarios (fig. 11.3). However, almost all counties

Text Box 11.10 | Province 211: Northeastern Mixed Forest Province

This province is characterized by the following:

- Modified continental climatic regime with maritime influence along the Atlantic Ocean
- Summer peaks in annual precipitation, which is otherwise equally distributed throughout the year; winters with continual ground snow cover
- Vegetation transitions between boreal spruce-fir in the north and broadleaf deciduous forests to the south
- Planted softwood—primarily Eastern white and red pine
- Natural softwood—primarily red spruce/balsam fir, balsam fir, and black spruce
- Mixedwood—primarily Eastern white pine/ northern red oak/white ash
- Upland hardwood—primarily aspen and paper birch
- Lowland hardwood—primarily sugar maple/ beech/yellow birch and hard maple/basswood.

within the region would have some woody-biomass harvests. Under ML 2040, few counties had >5,000 acres projected to be harvested, mostly located in southern Maine; however, under HH 2040, three counties had >10,000 acres and four counties had >5,000 acres projected to be harvested (fig. 11.3c). Province 211 and M211 encompassed greatest concentration of counties with >5,000 acres of harvesting potential (see text boxes 11.10 and 11.11; fig. 11.1). Because the forest-change trends were similar between provinces, we reported combined total acres, but separated the provinces graphically (fig. 11.8).

11.3.4.1 Province 211 and M211

Province M211 is approximately 24.1 million acres, covering 10.6% of the NE Region, and Province 211 is approximately 33.7 million acres, covering 14.8% of the NE. Under the ML 2017 scenario, 216,290 acres were harvested in M212, and 277,720 acres were harvested in Province 212, representing about 2% and <1%, respectively. The harvested land base for woody biomass declined by 75.6% and 66.0% under ML 2040 and HH 2040 scenarios. The harvested land base is 39.6% higher under HH 2040 than under ML 2040. Under the 2040 scenarios, few counties had >5,000 acres harvested, mostly located in western New York and the southeastern corner of Maine.

Logging residues were the major feedstock only under ML and HH 2040 scenarios, comprising 72.1% and 87.7% of the total harvest, respectively. Logging residues were 46.0% lower under ML 2040 than under the ML 2017 scenario but were greater under HH 2040 than ML 2040. Much of this difference was due to greater logging residues produced after harvesting lowland hardwoods, which comprised 59.7% and 73.3% of harvested acres under ML 2040 and HH 2040, respectively (fig. 11.8a). Lowland hardwoods comprised 41.9% of harvested acres under ML 2017. Natural softwoods were the second largest forest type producing residues: 25.1% of acres harvested under ML 2017, 20.5% under ML 2040, and 16.2% under HH 2040 (fig. 11.8a). Thinning of diameter class 2 produced 66.6% of logging residues under ML 2017, but no logging residues were produced from thinning under either 2040 scenario. Instead, clearcutting of diameter class 1 produced 100% of logging residues. The harvest method was full-tree for pulpwood under ML 2017. The greatest concentration of counties with >5,000 acres was located in southeastern Maine and a few counties in upper New York.

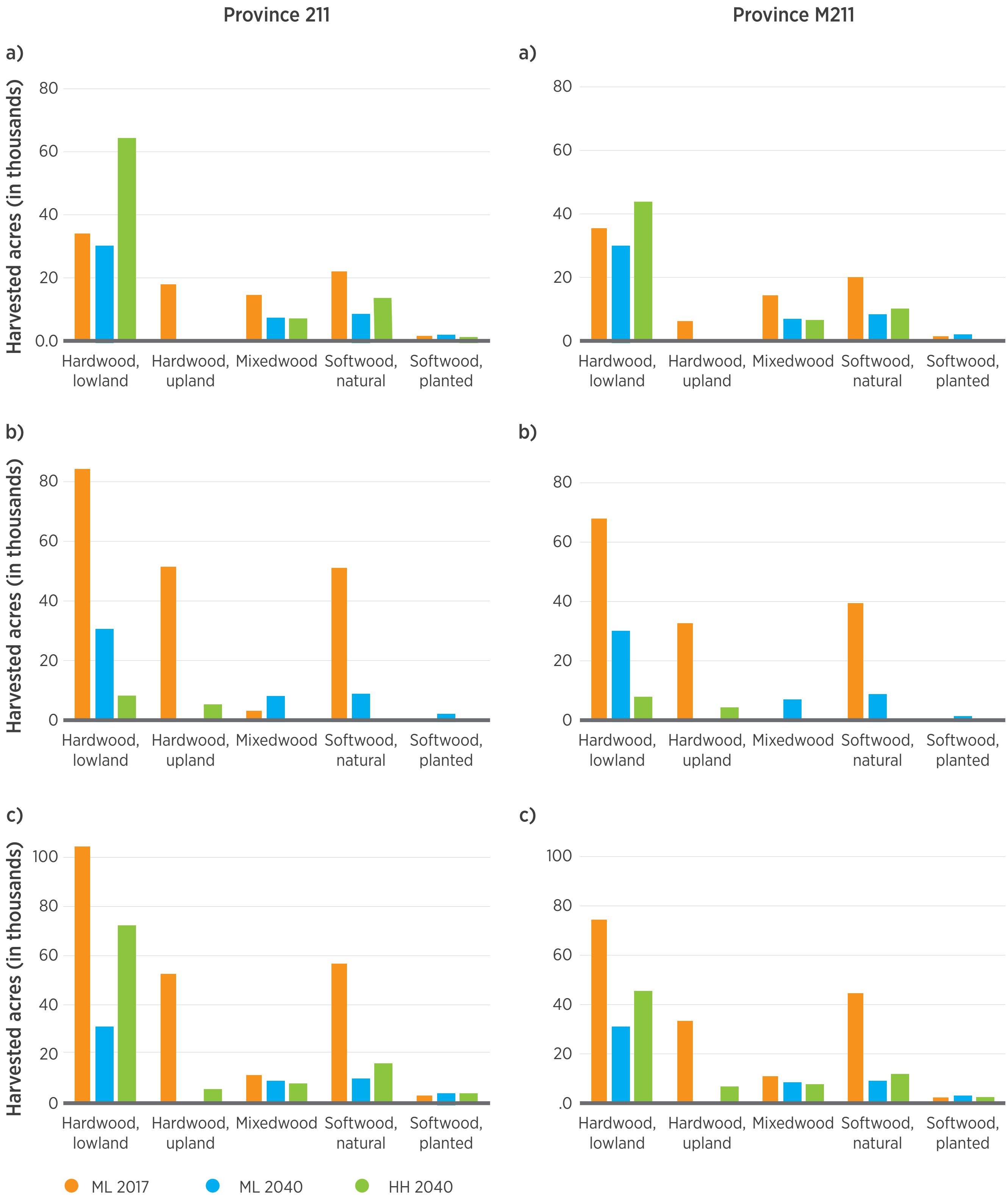
Whole-tree biomass was the primary feedstock in these provinces under ML 2017, comprising 66.5% of potential acres harvested, almost twice as much as logging residues (fig. 11.8b). However, this feedstock declined >90% under both 2040 scenarios from ML 2017. Lowland hardwoods produced 46.2% of the feedstock under ML 2017, followed by natural softwood (27.4%) and upland hardwoods (25.4%).

Text Box 11.11 | Province M211: Adirondack–New England Mixed Forest–Conifer Forest–Alpine Meadow Province

This province is characterized by the following:

- Continental climate regime with long winters and warm summers and annual precipitation evenly distributed across the year, distinguishing this climate from Province 211
- Mountainous landscape with dissected plateaus
- Vegetation transitions between boreal spruce-fir in the north and broadleaf deciduous forests in the south
- Planted softwood—primarily Eastern white and red pine
- Natural softwood—primarily red spruce, balsam fir, and black spruce
- Upland hardwoods—primarily aspen and paper birch
- Lowland hardwoods—primarily sugar maple/beech/yellow birch and red maple.

Figure 11.8 | Potential acres harvested by forest cover for Northeastern Mixed Forest Province (211; *left*) and Adirondack–New England Mixed Forest–Conifer Forest–Alpine Meadow Province (M211; *right*) by (a) logging residues, (b) whole-tree biomass feedstock, and (c) open forest canopy condition (i.e., young forest); note the difference in scale for young forests.



Upland and lowland hardwoods produced >90% of whole-tree biomass under both 2040 scenarios. Under ML 2017, whole-tree biomass was a byproduct of clearcutting diameter classes 2 and 3, but in the 2040 scenarios, only clearcutting diameter class 2 provided this feedstock. Much of this feedstock was from harvests in counties in western Maine, which is Province M212; these counties had >30,000 potential acres harvested under ML 2017. No counties had this level of harvest under the 2040 scenarios.

Text Box 11.12 | Case Study: American Woodcock—Recreational Species

American woodcock (*Scolopax minor*; hereafter, woodcock) breeds in northern states and provinces across eastern North America and winters from the Mid-Atlantic states south to the Gulf Coast, and west as far as eastern Texas. They use young hardwood forests as display areas and dense deciduous or mixed forests with closed canopy as diurnal feeding cover, and they nest in young open-canopy deciduous forests with well-drained soils (Keppie and Whiting 1994; Straw et al. 1994). Because of reduced availability of young forests in much of the eastern United States (King and Schlossberg 2014), woodcock populations have experienced significant declines since surveys were first implemented in the mid-1960s and thus is of conservation interest (Kelley et al. 2008). A conservation plan (Kelley, Williamson, and Cooper 2008) has suggested creating 20.8 million acres of new woodcock habitat if woodcock densities are to return to those observed during the early 1970s. Thus, increased harvest for woody biomass in the NE region is likely to enhance suitable habitat conditions for this species. Suitable habitat for woodcock is likely to be greater under ML 2017 than either ML or HH 2040 scenarios due to lower potential acres harvested in under these scenarios.

Text Box 11.13 | Case Study: Canada Lynx—Rare Native

Canada lynx (*Lynx Canadensis*; hereafter, lynx) is a federally threatened species; Maine is the only state in the northeastern United States known to support a resident population (Vashon et al. 2008a). It is a specialist predator of snowshoe hare (*Lepus americanus*) but also seeks alternative prey, such as red squirrels (*Tamiasciurus hudsonicus*) or Tetraonids (grouse) (Hoving et al. 2004). At the stand scale, prey abundance is a driving factor in lynx habitat selection. Male and female lynx in Maine strongly choose conifer-dominated sapling forests that contain high winter-hare densities and intermediate cover for hares (Fuller et al. 2007; Vashon et al. 2008a). Lynx selected tall (4.4–7.3 m) regenerating clearcuts (11–26-year post-harvest) and established partially harvested stands (11–21-year post-harvest) and selected against short (3.4–4.3 m) regenerating clearcuts, recent partially harvested stands (1–10-year), mature second-growth stands (>40-year), and roads and their edges (30 m on either side of roads) (Fuller, Harrison, and Vashon 2007). Vashon et al. (2008b), therefore, suggested that a mosaic of different-aged conifer stands would facilitate maintaining a component of regenerating conifer-dominated forest on the landscape. Lynx den sites in Maine were found primarily within conifer-dominated sapling and seedling stands, although lynx also did use dens in mature stands and in deciduous stands (Organ et al. 2008). However, coarse woody debris was not a useful predictor of lynx den-site selection despite its abundance. Rather, the combination of tip-up mounds of blown-down trees and visual obscurity from dense vegetation represented the within-stand characteristic predictive of lynx den sites (Organ et al. 2008). The authors recommended that managers in the northeast United States not focus on den habitat at the stand level. Similar to woodcock, potential suitable habitat for lynx is likely to be greater in the near term (ML 2017) rather than in the two scenarios for 2040 due to the lower potential acres harvested in the later time period.

Young forests were created through clearcutting from 77.7% of harvested acres under ML 2017; all acres under 2040 scenarios were clear-cut producing young forests. The harvested land base declined by 68.6% and 56.2% under ML 2040 and HH 2040, respectively. Young forests increased 39.6% under HH 2040 from ML 2040 levels (fig. 11.8c). Clearcutting of upland and lowland hardwoods accounted for >68% of the acres to be harvest under all scenarios. For HH2040, lowland hardwoods accounted for 69.6% of acres harvested. Given almost all acres were clearcut in these provinces, the location of large amounts of young forests tracked whole-tree biomass trends.

11.3.4.2 Biodiversity Effects—Provinces 211 and M211

The major forest change in the near term (ML 2017) was a major influx of young forests in the near term (ML 2017) from an increase in whole-tree biomass harvests through clearcutting smaller-diameter trees (see text boxes 11.12 and 11.13). The forest types contributing most to this feedstock were lowland and upland hardwoods, and natural softwoods of balsam fir and black and red spruce. Upland hardwoods were aspen and paper birch, and lowland hardwoods were primarily sugar maple/beech/yellow birch. Under the 2040 scenarios, the major feedstock switched to logging residues primarily from clearcutting mature, lowland hardwoods (diameter class 1). However, it is important to note that the land base with potential harvests declined three-quarters from ML 2017 to both 2040 scenarios, but the concentration of higher-intensity harvests remained in southern Maine and northwest New York. From a biodiversity perspective, Province M211 has some unique specialist species compared to Province 212 due to the alpine tundra such as long-tailed shrew, boreal (southern) redback vole (*Clethrionomys gapperi*), gray-cheeked thrush, and spruce grouse. Other species worth mentioning due to importance of structure or early successional forests are northern bog lemming (*Synaptomys borealis*) and New England cottontail (*Sylvilagus transitionalis*).

11.3.5 Pacific Northwest Region

Overall, 8.5% of potential total acres harvested for woody biomass occurred in the PNW region under ML 2017, compared to 12.6% and 11.6% under ML and HH 2040 scenarios, respectively (fig. 11.2a). Although proportion of total harvested acres increased in the PNW relative to other regions under both 2040 scenarios, total harvested acres in the PNW was lower by approximately 27.4% and 48.0% under ML and HH 2040 scenarios, respectively, from 720,253 acres under the ML 2017 scenario. The difference in potential harvested acres between ML 2040 and HH 2040 was 28.5%. Whole-tree biomass was the predominate feedstock harvested under ML 2017 and ML 2040: 457,676 acres compared to 262,577 acres producing logging residues; however, logging residues dominated feedstock under HH 2040, at 69.5% (fig. 11.2). In this region, the assumption of ForSEAM was that harvest method consisted of 100% full-tree harvest type, meaning no residues remained on the land except for any breakage that occurred during transfer to the landing.

The greatest concentration of counties with >5,000 acres of total potential harvest occurred in northern California, southwest Oregon, and western Washington (fig. 11.3). Many counties in southern California, Washington, and eastern Oregon had no potential harvests. The concentration of counties with >5,000 acres producing logging residues remained relatively consistent across scenarios, but the concentration of counties with >5,000 acres of whole-tree biomass harvests declined to four counties under HH 2040. Counties with >10,000 acres of young forests created through clearcutting were limited to six counties along California-Oregon state lines and several counties in northern Washington under ML 2017. This concentration of counties remained fairly consistent across scenarios (fig. 11.5). Provinces M261, M242 and 242 encompassed the greatest concentration of counties with total woody-biomass harvesting (see text boxes 11.14 and 11.15; fig. 11.1). Because Province 242 is narrower than many county boundaries, and we used county center points to designate the province in which each county was located, it is difficult to determine whether forest change is indicative for this province or an artifact of scale and methodology used. We therefore combined Province 242 with M242 into a Cascade province in the results. In addition, the counties in eastern Washington are encompassed under M333 (see the IW region).

Text Box 11.14 | Province M261: Sierran Steppe–Mixed Forest–Coniferous Forest–Alpine Meadow Province

This province is characterized by the following:

- Mountainous landscape with steep slopes crossed by many valleys with steep gradients
- Precipitation strongly influenced by altitude and direction of mountain ranges; hot and dry summers with most precipitation occurring in winter as snow
- Elevation-delineated vegetation with conifer and shrub associations at low elevations
- Higher elevations dominated by digger pine and blue oak; on western slopes, ponderosa pine, Jeffrey pine, Douglas-fir, sugar pine, white fir, and red fir predominate; on eastern slopes, Jeffrey pine replaces ponderosa pine and sagebrush-pinyon forest replace pine forests
- Lowland hardwoods—primarily red alder and Pacific madrone
- Upland hardwoods—primarily California black oak, Canyon live oak, and Oregon white oak
- Natural softwoods—primarily Ponderosa pine, white fir, lodgepole pine, and western juniper
- Planted softwoods—primarily Douglas-fir, Ponderosa pine, Jeffrey pine, and incense-cedar.

Text Box 11.15 | Provinces 242 (Pacific Lowland Mixed Forest Province) and M242 (Cascade Mixed Forest–Coniferous Forest–Alpine Meadow Province)

Both provinces are characterized by the following:

- Mild, modified marine climate with M242 having areas of cold-dry climate
- Province 242 occupying a north-south depression between the coastal and interior Cascade Mountains, characterized by level plains to low mountains with much of the natural forests replaced by agriculture
- Forests of western red cedar, western hemlock, and Douglas-fir; in the valleys, hardwoods of big-leaf maple, Oregon ash, and black cottonwood; prairies supporting Oregon white oak and Pacific madrone
- In Province M242, steep, rugged mountains along coast and several high-elevation peaks of volcanic origin with strong relief to foothills and plateaus
- Primarily montane vegetation, but at lowest elevations Douglas-fir predominates, but also western red cedar, western hemlock, grand fir, silver fir, Sitka spruce, and Alaska-cedar
- Ponderosa pine found along dry eastern slopes of the Cascades
- Lowland hardwoods—typically red alder and bigleaf maple
- Upland hardwoods—primarily Oregon white oak and paper birch
- Natural softwoods—primarily Douglas-fir, ponderosa pine, western hemlock, and white fir
- Planted softwoods—primarily Douglas-fir and ponderosa pine.

11.3.5.1 Province M261: Sierran Steppe-Mixed Forest-Coniferous Forest-Alpine Meadow

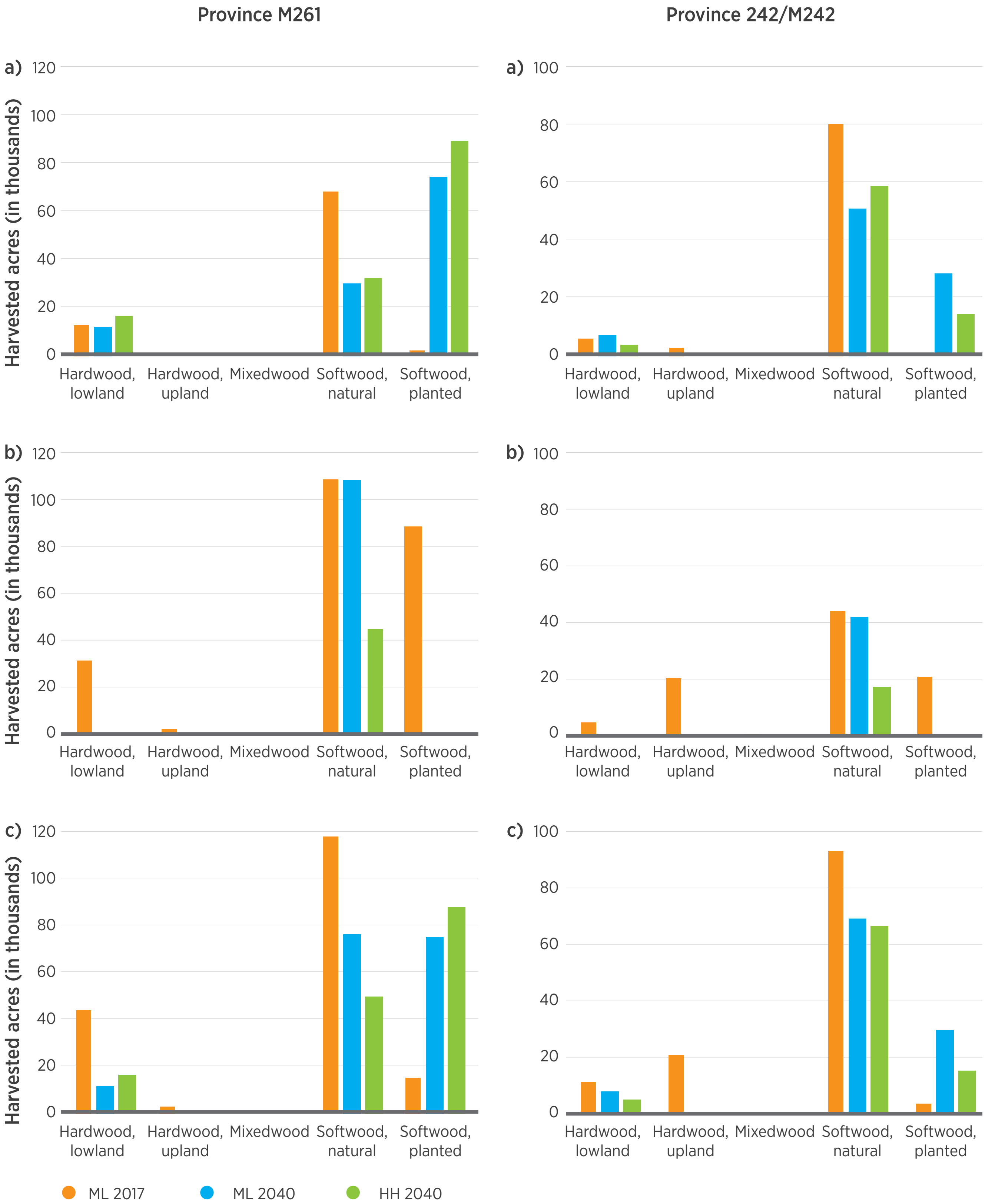
This province covers 43.0 million ac (21.1% of the PNW Region). Under ML 2017, 176,895 ac were harvested, representing less than 1% of Province M261. The projected harvested land base for wood biomass declined by 27.7% and 46.9% under 2040 baseline and high-yield scenarios; HH 2040 scenario decreased 26.5% from ML 2040 levels. Harvests with logging residues were approximately half of the feedstock under ML 2017, and increased to 67.7% and 81.6% under ML 2040 and HH 2040 with acres harvested ranging from 886,548 to 766,769, respectively. Under ML 2017, counties with the greatest potential acres harvested were in northern California and in southern Oregon, but under HH 2040, only three counties had >5,000 acres (fig. 11.3).

Logging residues were primarily a byproduct of natural softwood harvests, 90.1% under ML 2017, and 58.5% and 76.8% under ML and HH 2040 scenarios, respectively (fig. 11.9). Planted softwood harvests became the more prominent source of logging residues under ML and HH 2040 scenarios—33.1% and 18.3%, respectively, compared to only 0.4% under ML 2017. Nearly all logging residues were produced from clearcutting diameter class 1, natural softwoods under ML 2017 (86.8%). Logging residues from thinning operations (diameter class 2) contributed 6.6% under ML 2017 but provided no feedstock under ML and HH 2040 scenarios. Counties with >5,000 acres remained the same across all scenarios (fig. 11.4).

Whole-tree biomass was produced from harvest of natural softwoods (43.9%), planted softwoods (20.3%), upland hardwoods (19.6%), and lowland hardwoods (4.4%) under ML 2017, but under both 2040 scenarios, whole-tree biomass was only produced from harvests of natural softwoods. In addition, acres harvested declined by approximately half under ML 2040 and by 80.4% under HH 2040. Under all scenarios, approximately half of this feedstock was a byproduct of clearcutting diameter class 2, while the remaining half was a byproduct of thinning diameter class 2 operations. Counties with >5,000-acre potential harvests were mainly concentrated in southern Oregon in all scenarios, but only two counties under HH 2040 had greater harvesting commensurate with reduced total acres harvested (fig. 11.4).

Young forests were created by clearcutting 70.4% of the harvested acres under ML 2017, and this land base declined by 16.4% and 32.6% under ML 2040 and HH 2040, respectively. Between the 2040 scenarios, acres in young forests declined by 31.0% under HH 2040. Under ML 2017, clearcutting of natural softwoods was the primary source of young forests, but young forests were also created through clearcutting of upland and lowland hardwoods and, to some degree, planted softwoods (fig. 11.9c). But under ML and HH 2040 scenarios, young forests were created almost entirely through clearcutting of natural softwoods: 65.4% and 78.5%, respectively. Planted softwoods and lowland hardwoods also contributed to a much lesser degree. Spatially, counties with >5,000 potential acres harvested were located along California's and Oregon's borders under all scenarios.

Figure 11.9 | Potential acres harvested by forest cover for Province M261 (*left*) and Provinces 242/M242 (*right*) within the Pacific Northwest region by (a) logging residue feedstock, (b) whole-tree biomass feedstock, and (c) open forest canopy condition (i.e., young forest); note the different scales for each province.



11.3.5.2 Provinces 242 and M242: Cascade Provinces

These provinces cover 42.8 million acres, which is 21.0% of the PNW region. Under ML 2017, 311,083 potential acres were harvested, representing <1% of the province. Acres harvested for woody biomass were 28.3% and 42.3% lower under ML and HH 2040 than under ML 2017; HH 2040 was 19.6% lower than ML 2040. Whole-tree biomass harvests were the predominate feedstock under ML 2017 (74.2%), but harvests producing logging residues comprised greatest percentages under ML and HH 2040 scenarios (48.7% and 75.2% from 223,100 and 179,370 acres, respectively). Most counties in these provinces had >5,000 potential acres harvested, mostly concentrated in southern Oregon and northern Washington across all scenarios (fig. 11.3).

Similar to Province M261, in Provinces 242 and M242, logging residues were primarily a byproduct of natural softwood harvests (83.3% under ML 2017), but only represented 25.5% and 22.3% under ML and HH 2040 scenarios (fig. 11.9). Under ML and HH 2040 scenarios, two-thirds of logging residues were produced from planted softwood—64.6% and 65.5%, respectively—compared to only 2.0% under ML 2017. Eighty-three percent of clearcut acres generated logging residues from natural softwoods of diameter class 1 under ML 2017, but natural softwoods generated only 25.5% and 22.9% of logging residues under ML and HH 2040 scenarios, respectively. Instead, logging residues from planted softwood diameter class 1 generated approximately two-thirds of residues under both 2040 scenarios. Logging residues from thinning operations (diameter class 2) contributed 2.9% of total logging residues under ML 2017, but provided no feedstock under ML and HH 2040 scenarios. Counties with >5,000 potential acres harvested were concentrated in central Washington under ML 2017, but shifted to western Washington under both 2040 scenarios (fig. 11.4).

Whole-tree biomass was produced from potential harvests of natural softwoods (47.1%), planted softwoods (38.3%), upland hardwoods (13.6%), and lowland hardwoods (1.0%) under ML 2017; however, under both 2040 scenarios, >99% of whole-tree biomass was produced from harvests of natural softwoods. Similar to Province M261, in Provinces 242 and M242, acres harvested declined by approximately half under ML 2040 and by 80.7% under HH 2040. Under all scenarios, nearly half of whole-tree biomass feedstock was a byproduct of clearcutting diameter class 2, while the remaining half was a byproduct of thinning diameter class 2 operations. Counties with >5,000-acre potential harvests were concentrated throughout western Washington and Oregon under ML 2017, but these areas of high potential harvest were limited to a few counties in southern Oregon under both 2040 scenarios (fig. 11.4).

Young forests were generated after clearcutting 57.0% of harvested acres under ML 2017, and clearcutting 72.0% and 85.8% under ML and HH 2040 scenarios, respectively. Although the percentage of acres was greater than ML 2017 under both 2040 scenarios, total harvested acres were lower under ML 2040 and HH 2040 by 9.3% and 13.2%, respectively. Total acres of young forests differed by only 4.2% between ML and HH 2040 scenarios. Under ML 2017, clearcuts of natural softwoods generated the majority acres of young forest acres (66.8%), followed by lowland hardwoods (24.2%; fig. 11.9c). However, under ML 2040 and HH 2040 scenarios, young forests were created almost entirely after clearcutting natural and planted softwoods—92.8% and 89.7%, respectively. Few acres of lowland hardwoods were clearcut under both 2040 scenarios. Counties with >5,000 acres were concentrated in western Washington and southwest Oregon under all scenarios (fig. 11.5).

11.3.5.3 Biodiversity Effects—Provinces M242/242 and 261

When comparing provinces in the near term (ML 2017), logging residues were the major feedstock in northern California (M261), while whole-tree harvests were the major feedstock in western Washington and Oregon. However, under both 2040 scenarios, logging residues were the primary feedstock in both provinces. Natural softwoods produced the majority of each feedstock, mostly through clearcutting mature forests (diameter class 1), but in California, nearly half of residues were generated after clearcutting smaller-diameter trees. Natural softwoods were primarily Douglas-fir and ponderosa pine. To a much lesser degree, clearcutting smaller-diameter trees of upland and lowland hardwoods contributed to forest change under the ML 2017 scenario. Planted softwoods were the primary source of whole-tree biomass in the near term (ML 2017). Under all scenarios, potential acres for harvesting woody biomass comprise a small percentage of forests and decline under both 2040 scenarios, so it is unclear the effect these added harvests, especially whole-tree harvests, will have on biodiversity (see text box 11.16).

Text Box 11.16 | Case Study: Northern Flying Squirrel—Keystone Species

The Northern flying squirrel (*Glaucomys sabrinus*) is a forest-dwelling, arboreal rodent that inhabits boreal conifer and mixed forests with old-growth elements, such as substantial ground cover (Smith et al. 2005). This rodent travels by gliding and spends a lot of time on the forest floor foraging on fungus, lichens, and moss, which depend on an abundance of dead and downed wood, especially in moist, organic soils typical in older forests of western Washington and Oregon (Carey 1995; Weigl 2007). Conservation for this species focuses around its obligate symbiotic association with forest fungi (truffles) in which it feeds upon fruiting bodies and spreads mycorrhizal fungus through excreting pores. These fungi contribute to nutrient and water uptake of forests. Early successional stands have lower numbers of fungi, so large-scale clearcutting can be a threat to this species, especially in southern margins of its range, such as the Sierra Nevada, Rocky, and Appalachian mountains (Weigl 2007). The potential whole-tree harvests of conifers, especially in the near term, through clearcutting may affect the conservation of this species, but the effect is uncertain, given the degree of other aspects influencing their conservation, such as competition from the Southern flying squirrel (Weigl 2007). This squirrel is also an important prey species for the federally endangered spotted owl. Given the small contribution to national, potential woody-biomass harvests and the small potential area of lands with whole-tree harvests in the scenarios, the direct effects of woody-biomass removal on this squirrel are uncertain. However, their significance to forest-system productivity through their link with fungi and other trophic levels specific to the Pacific Northwest (PNW) should be considered. The importance of old growth versus successional forests to rare species in the PNW is often debated (Lehmkuhl et al. 2006). Whole-tree woody-biomass harvests may influence the canopy that this species requires, but removing residues may also lower the quality of habitat due to less dead and downed material that harbor fungus and lichen. Fungus and lichen are some of the most diverse communities associated with dead and downed wood. The southern part of this squirrel's distributional range covers the Inland West, North Central, and Northeast, which also have increases in whole-tree harvests for biomass, which increases stressors in the southern part of this species range.

Forest structure created by dead and downed wood is viewed as a positive characteristic in terms of wildlife and biodiversity (Bull 2002). However, in this region, retaining recent downed wood must be weighed against the risk of insect infestations as well. Storing this material in the forest before transport may attract saproxylic insects, some of which may be deleterious. Given that the majority of feedstock was generated from natural softwoods, fresh pine slash piles may increase the risk of spruce fir beetle, pin engraver, and California five-spined ips outbreaks. This interaction is beyond the scope of this chapter, but these risks should be weighed against the benefits of retaining forest residues for forest structure.

11.3.6 Inland West Region

Overall, the IW region had the lowest potential total acres harvested for woody biomass compared to the other regions under ML 2017—6.0%—but harvested total acres increased to 13.5% and 9.0% under ML and HH 2040 scenarios, respectively (fig. 11.2a). Within the IW region, there were a total of 512,134 potential acres harvested under ML 2017; under ML 2040, this increased 9.6%, but under HH 2040, total harvested acres declined to 301,013 (fig. 11.2). Whole-tree biomass was the predominate feedstock under all scenarios, comprising 65.1% of feedstock under ML 2017 and 59.6% and 51.3% under ML and HH 2040 scenarios, respectively (fig. 11.2). In this region, the harvest method assumption of ForSEAM was that harvests were 50% full-tree method and 50% cut-to-length; under cut-to-length, residues remained on the land.

The greatest concentration of counties with >5,000 acres of total potential harvest occurred in northern Idaho and western Montana, with several counties along the Rocky Mountains in Wyoming, Colorado, and New Mexico (fig. 11.3). Many counties in the southern IW region had few or no acres harvested. This pattern mostly contributed to predominate whole-tree biomass harvests across the scenarios, except for the HH 2040 scenario, where the counties with >5,000 acres were located in New Mexico and one county in Arizona that had predominately logging-residue feedstock (fig. 11.4). Counties with >5,000 acres of young forests created after clearcutting were concentrated in the same locations and also contributed to the large acreage in an Arizona county (i.e., logging residues were produced through clearcutting harvests) (fig. 11.5). Provinces M332 and M333 (fig. 11.1) encompassed the concentration of counties with >5,000 acres total woody-biomass harvesting. Province M333 actually covers counties in the PNW region, and we have included these counties in our results. Because forest-change trends were similar across provinces, total acres were combined and reported below, but were separated graphically (fig. 11.10).

11.3.6.1 Province M332 and M333

Province M332 is 48.8 million acres, and Province M333 is 24.0 million acres. Under ML 2017, 362,363 potential acres were harvested, representing about 0.5% of the land base. Acres harvested for woody biomass were 11.0% and 54.2% lower under ML and HH 2040 scenarios, respectively; the HH 2040 scenario had 48.6% fewer acres harvested compared to ML 2040. Whole-tree biomass harvests were the predominate feedstock under all scenarios: 67.1% under ML 2017 and 69.8% and 59.4% under ML and HH 2040 scenarios, respectively. All counties had >5,000 acres harvested for woody biomass in Province M333. In Province M332, nearly half of the counties that had >5,000 potential acres harvested were located in southwest Wyoming and along the Idaho state border (fig. 11.3).

Logging residues were a byproduct that was almost entirely generated from natural softwood harvests, 99.8% under all scenarios (fig. 11.10). Harvests of lowland hardwood produced remaining logging residues. Nearly all logging residues were generated from clearcut harvests of diameter class 1 under all scenarios. Logging residues from thinning operations (diameter class 2) contributed <0.3% under ML 2017, but no thinning operations occurred under both 2040 scenarios (fig. 11.10). Logging residues were primarily produced from potential harvests in the northeast corner of Washington and western Wyoming.

Text Box 11.17 | Province M332: Middle Rocky Mountain Steppe–Coniferous Forest–Alpine Meadow Province

This province is characterized by the following:

- Temperate desert with warm, dry summers and cool to cold, moist winters
- Precipitation mainly occurs in fall, winter, spring
- Mountainous landscape of moderate elevation or a basin-and-range area consisting of Blue and Salmon River Mountains with high altitudes, and floodplains draining valleys
- Lowland hardwoods—primarily cottonwoods
- Upland hardwoods—primarily aspen
- Natural softwoods—primarily Douglas-fir, lodgepole and ponderosa pine, and subalpine fir
- Planted softwoods—primarily ponderosa pine and Douglas-fir.

Whole-tree biomass was generated from harvest of natural softwoods (96.2%), planted softwoods (1.2%), upland hardwoods (2.5%), and lowland hardwoods (0.20%) under ML 2017, but under ML and HH 2040 scenarios, >99% was generated from harvests of natural softwoods. Acres harvested were 7.4% and 59.5% lower under ML 2040 and HH 2040 compared to ML 2017, respectively. Under ML 2017, 57.1% of feedstock was generated from thinning diameter class 2 natural softwoods; the remaining feedstock was produced from clearcut harvests of diameter classes 2 and 3 natural softwoods. Under ML and HH 2040 scenarios, approximately 58% of feedstock was produced by thinning natural softwood, similar to ML 2017; however, remaining feedstock was produced from clearcut harvests of diameter class 2 only. Only under the HH 2040 scenario did the counties with >5,000 potential acres harvested change significantly, and these counties were only found in northern Wyoming (fig. 11.4b).

Nearly all young forests were created by clearcut harvests of natural softwoods under all scenarios. Harvested acres were 14.4% and 48.4% lower than ML 2017 under ML 2040 and HH 2040, respectively. Total acres of young forest were 39.7% lower under HH 2040 compared to ML 2040. Clearcutting of lowland hardwoods generated remaining young forests under all scenarios (fig. 11.10). In Province M333, the distribution of young forests was in northeast Washington, northern Idaho, and northwestern Wyoming, and in Province M332, distribution of young forests was in southern Wyoming and northeast Idaho borders (fig. 11.5). Under HH 2040, new, young forests shifted to north-central Idaho (fig. 11.5).

11.3.6.2 Biodiversity Effects—Provinces M332 and M333

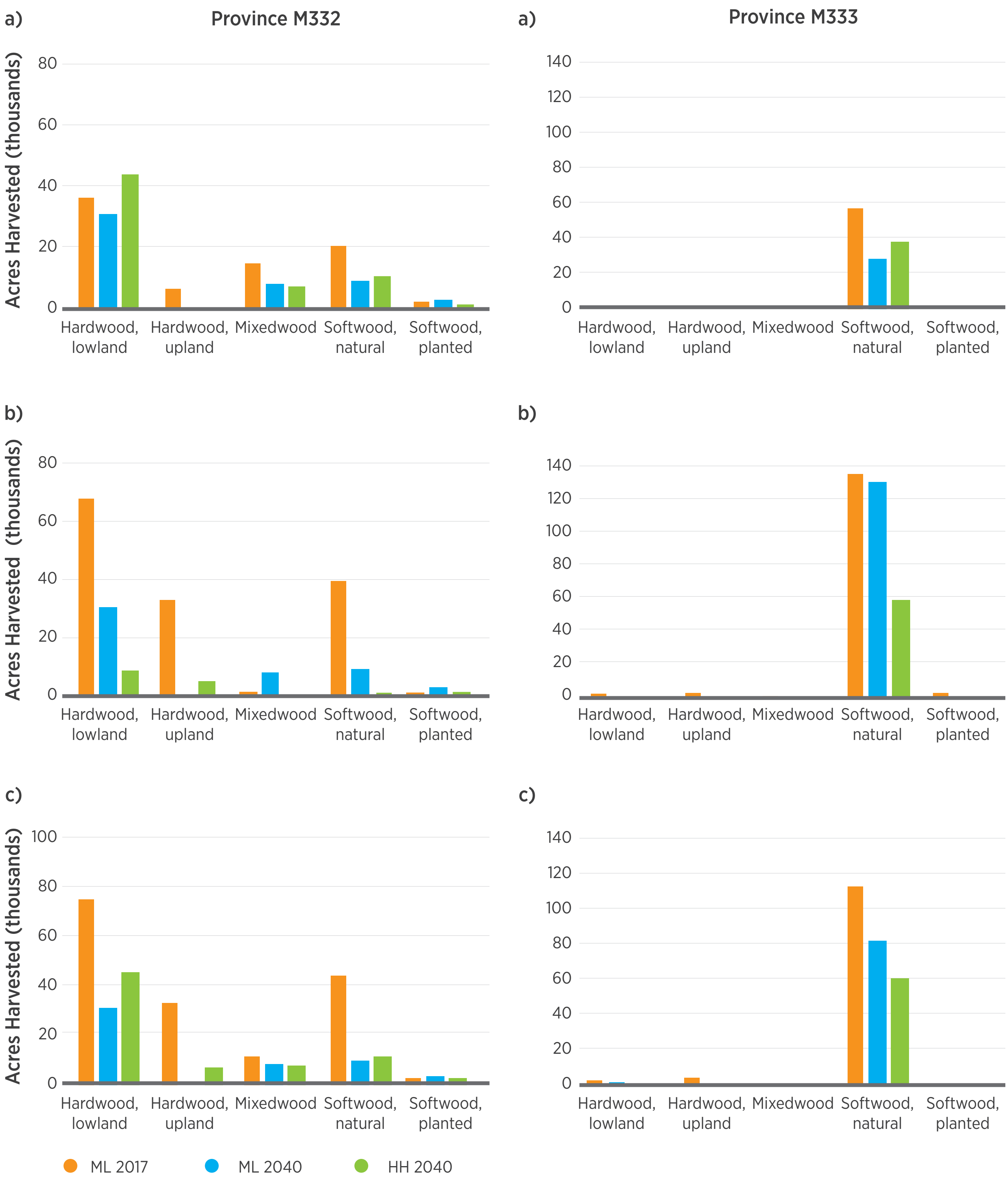
The IW region contributed the lowest quantity of feedstock to national woody-biomass harvests. Most of this contribution was from whole-tree harvests, primarily in natural softwoods, Douglas-fir, and ponderosa pine systems. The IW was the only region in which whole-tree biomass was the major source of feedstock compared to logging residues. About half of whole-tree harvests were generated through clearcutting in the northern Rocky Mountains that would result in young forests. The counties in the central and southern Rockies were predominately harvests with logging residues removed, presenting opportunities to examine effects on biodiversity at a smaller scale. Because relatively small woody-biomass harvests were simulated in this region, we did not present a case study. However, an important aspect of logging residues or effects of whole-tree harvest associated with woody-biomass harvesting in the dry coniferous forest types in this region (e.g., Douglas-fir or ponderosa pine) should be weighed within the context of fire risk in this region and the western United States. Many of the issues surrounding woody-biomass removal are similar to fuel-reduction treatments and biodiversity in these systems (Pilliod et al. 2006); whole-tree biomass harvests could be fuel-reduction harvests under the assumptions of the model.

Text Box 11.18 | Provinces M333: Northern Rocky Mountain Forest–Steppe–Coniferous Forest–Alpine Meadow Province

This high-elevation area is characterized by the following:

- Temperate climate with warm, dry summers and cold, moist winters with heavy snowfall; small glaciers in northern areas
- Mountainous landscape of high-relief; mixed conifer-deciduous forests predominant with major forest types being Douglas-fir and cedar-hemlock-Douglas-fir forests
- Subalpine dominated by Engelmann spruce and subalpine fir
- Montane belt dominated by Western red cedar and Western hemlock, and other common species include western white pine, western larch, grand fir, and western ponderosa pine
- Lowland hardwoods—primarily cottonwoods and red alder
- Upland hardwoods—primarily aspen and paper birch
- Natural softwoods—primarily Douglas-fir, lodgepole and ponderosa pines, western larch, grand fir, and western red cedar
- Planted softwoods—primarily Douglas-fir and ponderosa pine.

Figure 11.10 | Potential acres harvested by forest cover for Province M332 (*left*) and M333 (*right*) within the IW region by (a) logging residue feedstock, (b) whole-tree biomass feedstock, and (c) open forest canopy condition (i.e., young forest); note the different scales for each province.



11.4 Discussion

Overall, it appears that forest woody-biomass harvest, as modeled under the examined scenarios in *BT16* volume 1, will primarily affect biodiversity through changes in forest structure, both at the stand scale (e.g., CWD, FWD, canopy closure, etc.) and the landscape scale (e.g., distribution of stand ages). For all ForSEAM regions and scenarios we examined, effects of biomass removal on habitat conditions may not be a driver for biodiversity responses at broad spatial scales due to the small proportion of forested area harvested (generally <2% for most regions) and other potential broad-scale processes. However, the spatial distribution of potential harvests under all scenarios indicate that harvesting activities are concentrated in the same relative locations across the United States. Species could be negatively or positively affected at the province ecoregion unit scale based on species distributions, specific habitat requirements, and proportion of forest types affected by biomass harvest at the local scale. For example, potential biomass-harvesting activities were more intense in some forest systems that may be of concern in a given region, such as lowland hardwoods in the S region.

A primary concern with biomass harvest relative to biodiversity is the removal of dead and downed wood, and an increase in young forests from clearcutting smaller-diameter trees. However, as outlined in the introduction, it cannot be assumed that removal of this material due to biomass-only harvest will be a direct cause of local extirpations, especially as logging residues could be a product of conventional harvests under the integrated harvesting system of the ForSEAM model. In some cases, removal may lower habitat quality to such an extent that it reduces local numbers, thereby increasing vulnerability to other factors affecting the population, such as competition or fragmentation effects. In other cases, species associated with FWD and CWD may not actually be dependent on long-term presence of this material, or the creation of young forests may benefit other species. Economics of biomass harvest dictate that some material will be left on-site (i.e., material that is not economical to remove), meaning the amount retained after a biomass harvest may in fact be greater than retention rates recommended in existing biomass-harvest BMP guidelines for some forest systems (e.g., the S region). Recent studies in pine forests in the S indicate minimal response by vertebrate species to removal of FWD and CWD under current operational practices, even without application of biomass-harvest guidelines (see citations in the introduction). However, there is a general lack of studies that have examined potential causality between thresholds of woody debris amounts and biodiversity in forest systems and ecoregions across the United States, especially for relationships between biodiversity and FWD.

11.4.1 Implications of Results

Our results show that effects of woody-biomass potential varied regionally based on the forest systems sourcing feedstock. ForSEAM is an economic demand model that met analysis region demands first through logging residues associated with conventional harvests. Whole-tree biomass harvests increased use of smaller-diameter trees in those regions where demand was not met by logging residues, such as in the NE region in the near term (ML 2017) and the IW (all scenarios). An increase in young forests through clearcutting may be beneficial for NE species given the forest types present, but it also may be negative for a suite of species in temperate rainforests of the PNW that depend on closed canopies and moist conditions. Although harvests of logging residues in the model included a 30% retention rate to address BMPs, the modeled biomass harvests were not constrained further based on any certification or regulatory requirements. For example, most biomass harvests will be carried out under the auspices of a forest-certification program, biomass-certification program, or the Sustainable Forestry Initiative Fiber Sourcing

Standard, all of which mandate protection of known occurrences of Threatened and Endangered species, rare communities, and forest types of conservation concern. Additional state and federal forest-management regulations, federal rules (e.g., Endangered Species Act), state regulations for imperiled species, and forestry and biomass BMPs also govern specifics of any forest harvest, including biomass harvest. This provides an overarching structure of protection for imperiled species and communities that was not considered in the examined scenarios. Potential effects of biomass harvests, particularly on protected species or rare communities, should be assessed within the ecological context of these regulations as well as other driving factors influencing populations, such as competition.

As mentioned under the PNW and IW regions, the tradeoffs of retaining dead and downed material must be weighed within the broader context of other processes affecting forests regionally. Lowering habitat quality for some species by removing forest structure or smaller-diameter trees must be assessed against removing material to lower the risk of insect infestations and fire, decreasing old-growth characteristics in the western United States, and negatively impacting local economics. For example, in the eastern United States, urbanization is the greatest threat to forest cover, especially in the southeastern United States, as more than 80% of forested land in the region is privately owned (Wear and Greis 2012). As such, it is critically important that private landowners realize an economic return on their land so that it remains forested (Lubowski, Plantinga, and Stavins 2008). Biomass markets provide a potential revenue source for private landowners that may help provide these economic incentives (Abt et al. 2014). Therefore, when examining potential implications of biomass harvest on biodiversity, it is important to not only put effects in their ecological context, but also in the broader context of maintaining forest cover across the landscape.

11.4.2 Uncertainties and Limitations

The influence of model assumptions on results must be considered when interpreting reported patterns. The assumption that a stand could only be harvested once during the modeling time period contributed to the general decline of total potential acres harvested under 2040 scenarios. Given the two-decade time period between 2017 and 2040 model scenarios, some forest-type stands would at the very least be available for a thinning harvest after initial clearcuts, and stands could have been thinned one to two additional times during the scenario period. Therefore, the potential reductions in some habitat classifications (e.g., early successional conditions) may not be realistic. In addition, the order of entrance by cheapest forest type (hardwoods) into the ForSEAM model to meet supply demands may have shifted impact to forest systems not usually harvested through clearcuts, such as lowland hardwood. The potential expanded role of lowland hardwoods in providing feedstock in certain regions may not be realistic given regional and local management practices. In addition, harvested logging residues from other forest systems could be greater in some regions than what is reported here. Biomass harvesting intensities at smaller spatial scales should be assessed. Although logging residues were considered part of conventional harvests, a reality not captured by the model is that sawtimber harvest largely drives timber markets in the S region. As a result, biomass is, at best, a “come along” activity, and not a primary driver of forest harvest in a region that could provide half of woody-biomass feedstock. Therefore, potential effects described in this assessment could be viewed as not the primary causative factor for biodiversity response to forest management, especially when considering the much larger issue of forest conversion due to urbanization. The ForSEAM assumption of no forest conversion (loss), especially in the eastern United States, simplifies to some degree the effect of the biomass market;

however, as stated earlier, if private landowners are not able to make their land economically viable, the greater impact to biodiversity may be habitat loss rather than habitat quality issues in urbanizing areas of the United States.

Several other assumptions of the ForSEAM model or our approach limited our ability to assess effects of forest woody-biomass harvesting on biodiversity. Because we only compared harvest intensities between two points in time and under explicit assumptions, we were not able to assess cumulative effects of annual removal. In addition, the model constrained potential biomass harvests to within a small distance from roads. This limitation may provide an unrealistic estimation of potential biomass-harvest activities and restrict the modeling of potential landscape-scale changes to a smaller area than is likely truly available for harvest. Because data are presented at the county-level, we could not assess road density or widening of road effects (e.g., no cover) on biodiversity. This county-level resolution also compromised spatial interpretations of potential outcomes. Landscape pattern was not integrated, and we were unable to determine site-level impacts as harvested sites will be located in various landscape contexts. Managers can also implement harvests in various ways to influence residual stand structure to address occurrences of species of concern. By focusing our assessment on province ecoregions encompassing counties with greater potential harvests (i.e., >5,000 acres), we did not assess the effects of removing woody biomass or increasing whole-tree harvests (i.e., clearcuts) from landscapes that are predominantly agricultural or urban, rather than forest. Removing logging residues or increasing whole-tree harvests in these counties may have a proportionally greater impact on species assemblages (e.g., minimum patch sizes, increased isolation effects) than in the more continuously forested landscapes that we assessed.

11.5 Summary and Future Research

In *BT16* volume 1, the potential harvest intensity of woody-biomass harvests varied across the United States, but nearly half of potential harvests occurred in the southern ForSEAM region under all model scenarios. The NC and NE provided the next greatest quantities of biomass under the scenarios. The total potential acres harvested declined under both ML and HH 2040 scenarios, but the regional location of greatest harvest intensities remained primarily along the Atlantic, Gulf, and Pacific coasts, upper Midwest, northern Rocky Mountains, and upper Northeast regions of the country. Logging residues were the dominant potential source feedstock, except in the northern Rocky Mountains where whole-tree biomass harvests were the dominant source feedstock.

Feedstock and forest types producing this potential feedstock varied across the nation, contributing to the variability of biodiversity responses. For example, areas where increasing whole-tree biomass clearcuts were modeled may positively influence some species with the influx of early succession forest stands, but negatively influence other species that rely on moist forest floors. In other words, removing logging residues from some forest systems, especially dry forest types, may not be as negative as removing this structure from lowland hardwoods or forest systems in temperate rainforests of the PNW. This variability, coupled with broader processes, such as economics, urbanization, and insect and fire risk, make it difficult to generalize effects of woody-biomass harvesting.

Given the county-scale data generated by ForSEAM, we used a coarse-filter approach to characterize broad patterns in harvesting intensities. Ecoregion and county-level patterns can be coupled with biodiversity assessments completed at finer resolutions, such as the state level, that track large numbers of species (e.g., state wildlife actions plans) (Mawdsley, Humpert, and Pfaffko 2016).

As noted above, the exact relationships between woody-biomass harvest and biodiversity are not well understood in many regions and forest types due to a lack of empirical research; one exception may be the southeastern Coastal Plain (see 11.1 Introduction). Although general trends in biodiversity response and potential causal relationships can be addressed, the relationships discussed herein should be viewed as the basis for establishing testable hypotheses regarding biodiversity response to biomass harvest.

There is a need to conduct more manipulative studies that vary amounts of CWD and FWD retained across gradients in forest cover and forest types. By measuring the response of multiple species across trophic levels, results can improve understanding of these interactions and how they may influence local and landscape diversity. Manipulative studies can also help determine whether responses are due to the forest-harvest treatment itself or the additive effect of removing dead and downed wood.

Also, there is a need to continue established studies over longer time periods to better understand the effects of removing CWD and FWD during second- and third-rotation harvests. Despite many studies investigating the correlation between biodiversity and the amount of dead and downed material, outstanding questions remain on critical threshold amounts across a variety of forest types and regions to help determine resilience of forest systems to potential harvest intensification. For example, not much is known on the historical range of variability of CWD and FWD prior to fire suppression and other large-scale processes. Are U.S. forests within this historical range of variability in CWD and FWD amounts? Or, functionally, is CWD sufficient to provide the needed structure for many species, given more rapid decomposition of FWD?

Conservation of species amidst an increasing national demand for woody biomass will require taking a multi-scale approach and continued monitoring of species functionally dependent on the material to fulfill their life history requirements.

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