Pathways for Protecting Maine's Remaining Late-Successional and Old-Growth Forests

Property and Environment Research Center
May 2026

Jonathan R. Thompson,[*,1,2] Adam Daigneault,[*,3] Joshua Plisinski,[1] India Moon,[3] Julia Norton[1]

* Lone Mountain Fellow, Property and Environment Research Center, Bozeman, MT 59718

1 Harvard University, Harvard Forest, 324 N Main St, Petersham, MA 01366

2 Corresponding Author: jthomps@fas.harvard.edu

3 University of Maine, School of Forest Resources, 201A Nutting Hall, Orono, ME 04469

1. Introduction

The protection of old-growth forests has been a longstanding conservation priority (Thomas et al. 2006; Birdsey et al. 2024). Old-growth forests provide exceptional ecological and cultural value, storing disproportionately large amounts of carbon and supporting unique habitat structures and species assemblages not found in younger forests (Spies 2004). Globally, old-growth forests are rare, fragmented, and in decline (Watson et al. 2018; Peltz et al. 2025). In eastern North America, late-successional and old-growth (LSOG) forest ranks among the rarest of habitat types, a legacy of centuries of intensive land use and forest management (Davis 1996; Foster et al. 1996; Ducey et al. 2013). Although forests across the region have been aging, gains in northeastern old growth are nearly offset by losses in actively harvested areas (Birdsey et al. 2025).

Against this backdrop, Hagan and colleagues (2024) recently made a remarkable discovery: using LiDAR-based maps of forest structure, they identified more than 165,000 hectares of LSOG in northern and western Maine, forests largely unknown to the broader conservation community, though well known to the private timberland firms who own them. Extensive field verification confirms that these forests overwhelmingly exhibit LSOG conditions (Hagan et al. 2025). The discovery presents both a rare conservation opportunity and an urgent challenge.

Maine's conservation record illustrates the challenge. Despite having conservation easements on roughly 20% of its forestland, more than half of that protected land permits continued commercial timber harvest (Thompson et al. 2024; Kannel et al. 2023). Indeed, only about 3.3% of New England's land area is permanently protected as “Wildlands” free from extractive use (Foster et al. 2023). The forests identified by Hagan et al. (2024) represent a rare chance to meaningfully expand that fraction, but only if protection mechanisms are deployed that match the permanence and specificity that LSOG conservation requires. Because these forests contain disproportionately high timber volumes, they face elevated risk of near-term harvest, often the very characteristics that make them ecologically valuable also make them commercially valuable. As a result, LSOG forests are simultaneously among the most valuable to conserve and the most likely to be harvested. Unlike the iconic old-growth conservation efforts of the Pacific Northwest, such as the Northwest Forest Plan, Maine's newly identified old forests occur predominantly on privately owned commercial timberlands. Protecting them will require mechanisms that are both rapid and efficient, and that respect the property rights of landowners.

In 2025, the Maine Legislature recognized this challenge by passing LD 1529, directing the state to develop comprehensive strategies for LSOG conservation by November 2026. This report is intended to inform that effort. Here, we examine a broad range of conservation mechanisms, evaluate the most promising against alternative conservation criteria, and estimate protection costs for individual LSOG patches across the landscape. We close with recommendations for prioritizing conservation action under conditions of limited resources.

1.1 Maine's Forest Landscape

Maine's forests occupy a distinctive position within the regional context of forest conservation. The state is nearly 90 percent forested, with continuous forest cover extending across roughly 7.1 million hectares, including vast unorganized territories characterized by sparse settlement and few formal townships. More than half of Maine's forests are owned by private commercial timber interests and the age-class structure of Maine's forests reflects a long history of commercial forestry: across much of the boreal and northern hardwood forest, young- to mid-rotation stands predominate, and old forest remnants are scarce.

Approximately 95 percent of Maine's forestland is privately held (Butler 2018; Zhao et al. 2023). Ownership of this land has shifted dramatically in recent decades. Between 1990 and 2005, more than 10 million hectares of vertically integrated commercial timberland moved from traditional forest products companies to investment-oriented owners, principally Timber Investment Management Organizations (TIMOs) and Real Estate Investment Trusts (REITs; Hagan et al. 2005). These ownership transitions have had tangible consequences for harvest activity. Private landowners, and TIMOs and REITs in particular, account for the highest rates and intensities of harvesting in the state (Figure 1.1; Thompson et al. 2017; Gao et al. 2026). Between 4 and 6 percent of private forestland is subject to partial harvest annually (Brown et al. 2018), with typical harvest intensities removing 25 to 70 percent of standing biomass depending on owner class and management objectives. Landowner decisions about where and when to harvest are most strongly influenced by stand volume, stumpage prices, and site accessibility (Zhao et al. 2020; Brown et al. 2018; Thompson et al. 2017). LSOG forests are among the highest-volume stands and face systematically higher harvest pressure than the surrounding forest matrix. This reinforces a central challenge for conservation: protecting LSOG requires overcoming precisely the economic signals that make these stands most attractive to harvest.

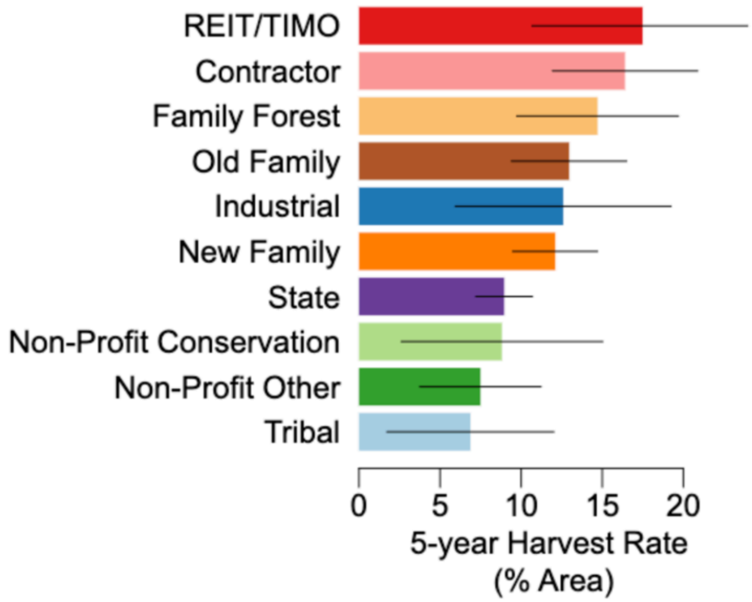


Figure 1.1 Harvest rates in Maine vary by landowner class. The above harvest frequencies are estimated from Forest Inventory and Analysis plots (taken from Gao et al. 2026). Appendix B includes a description of the ownerclasses. Harvesting in Maine typically occurs as partial harvests where, on average, < 50% of the biomass is removed from a site during a harvest operation (Thompson et al. 2017).

Over the same period of 1990 to 2005, conservation-designated lands expanded dramatically, from approximately 5 percent of the state in the 1980s to more than 20 percent today (Irland 2018; Zhao et al. 2020). Importantly, however, more than 85 percent of these conservation lands remain working forests open to regular harvesting (MLTN 2025; Thompson et al. 2024). This coexistence of conservation status and active management distinguishes Maine from many other heavily forested regions and strongly shapes both ecological outcomes and economic contributions (Figure 1.1). While permanent forest loss has historically been relatively low, approximately 2,000 hectares per year continue to be converted to other land uses (Daigneault et al. 2021).

Maine's forest policy framework reflects long-standing efforts to balance timber production, environmental protection, and landowner flexibility across this largely private landscape. The Tree Growth Tax Law, implemented in the 1970s, provides preferential property tax treatment by valuing forestland at current-use value rather than development value, and it currently applies to approximately 4.4 million hectares (Daigneault et al. 2024). The 1989 Forest Practices Act marked a pivotal regulatory shift by limiting most clearcut harvest units to 100 hectares or less, transforming harvesting practices from widespread clearcutting in the 1980s to a system dominated by partial harvesting, which now accounts for nearly 95 percent of harvest activity (Daigneault et al. 2024;

Simons-Legaard et al. 2021). While these regulations reduced the size of individual harvest openings, they also produced an unintended outcome: total harvest volume remained relatively constant, but the annual harvested area approximately doubled as harvest area spread across a larger footprint (Simons-Legaard et al. 2021). In the early 2000s, Maine introduced the Outcome-Based Forestry (OBF) program as an alternative regulatory pathway emphasizing demonstrated sustainability outcomes through third-party certification rather than prescriptive harvest rules. Together, these policies illustrate Maine's pragmatic approach to forest stewardship, in which working forests are expected to simultaneously meet economic, ecological, and social objectives. Approximately 1.17 million hectares of Maine's forest are currently managed under OBF (Maine Forest Service, 2024).

Forests are also central to Maine's economy and climate strategy. The forest products industry contributes more than $8 billion annually, representing approximately 4 percent of the state's gross domestic product (Maine Forest Products Council 2025). At the same time, Maine's forests sequestered nearly 15 million metric tons of CO_2 equivalent annually between 2017 and 2021, with an additional 1.6 million metric tons stored in harvested wood products (Hayes et al. 2024; Wei et al. 2023). Combined, forests and wood products sequester the equivalent of more than 90 percent of Maine's annual greenhouse gas emissions, reinforcing the forests' dual role as both economic engine and climate mitigation asset (Maine DEP, 2024).

Unlike regions dominated by federal or state ownership, conservation on private lands must account for property rights, economic constraints, and the diverse objectives of landowners ranging from industrial timber companies to family forest owners. Voluntary protection is therefore unlikely to occur at scale without external financial support, whether through private markets, philanthropy, or public policy, and in all cases requires substantial economic incentives to balance timber production with old forest protection.

Reflecting the attention brought by Hagan et al.'s (2024) maps, along with a growing recognition of the ecological and climate importance of LSOG forests, in 2025, the Maine Legislature passed An Act to Enhance the Protection of High-value Natural Resources Statewide (LD 1529). This legislation directs the Department of Agriculture, Conservation and Forestry to produce a comprehensive report by November 2026 outlining statewide strategies to enhance LSOG conservation, incorporating ecological values, carbon sequestration, and economic considerations informed by a broad range of stakeholders. Beginning in 2031, the Director of the Bureau of Forestry must also include information on the status of late-successional and old-growth forests in periodic reports on the state of Maine's forests.

1.2 The Ecology of Late Successional and Old Growth (LSOG) Forests in Maine

LSOG forests are characterized by distinctive structural complexity, including: multi-aged or multi-cohort age structures, multi-storied canopy layers, the presence of old trees, relatively undisturbed canopies where regeneration follows gap or small-scale patch disturbances, dead or dying trees in varying stages of decay, and abundant coarse woody debris including larger rotting logs (Mosseler et al. 2003, Burrascano et al. 2013). Structural complexity creates a unique physical environment defined by specific gradients of light, moisture, nutrients, organic matter, and the temporal stability of biomass structures. Importantly, eastern old-growth ecosystems are highly varied and dynamic in their structure, composition, and landscape pattern (Foster et al. 1996; Runkle 1982), reflecting the diverse disturbance regimes and ecological processes that have shaped northeastern forests.

LSOG forests serve critical ecological functions that distinguish them from younger, second-growth stands. For example, old-growth forests store significantly more carbon than younger forests (Birdsey et. al. 2025). They also contain significantly more down and standing dead wood compared to managed forests (McGarvey et al. 2013; Gunn et al. 2014), providing essential habitat structure for numerous organisms (D'Amato et al. 2009). Regionally, old growth supports different relative abundances of tree species compared to second-growth forests (Thompson et al. 2013), contributing to landscape-level biodiversity. LSOG forests also serve as ecological baselines that demonstrate how ecological processes operate without significant human influence, making them vital reference systems for ecological restoration and adaptive management strategies.

Empirical evidence underscores both the ecological value and vulnerability of Maine's remaining old forests. Ducey et al. (2013), examined LSOG forests statewide and documented substantially higher basal area, carbon stocks, and densities of large live and dead trees relative to other forest conditions, and carbon density was estimated to be 2.0 to 2.5 times the regional mean. This is consistent with broader studies showing that the largest 1 percent of trees globally store half of the aboveground forest carbon (Lutz et al. 2018). Despite forests aging across much of the region, increases in large-tree density have been largely offset by harvesting activity (Woodall et al. 2023). Further, because higher basal area is the strongest predictor of harvest likelihood, remaining old forests with their elevated basal area and biomass face a disproportionately high risk of loss (Canham et al. 2013; Thompson et al. 2017).

1.3 Purpose and Scope of This Report

This report evaluates alternative approaches for conserving the newly identified old forests in Maine, emphasizing forests occurring within private forest landscapes. Building directly on Hagan et al. (2024), we assess how different protection mechanisms might perform in safeguarding these forests under realistic ecological, economic, and institutional conditions. Because effective conservation of these lands will require strategies that extend beyond public land acquisition, we focus on market-based approaches. This focus reflects the underlying economic reality that LSOG conservation must directly address the opportunity costs associated with high-value timber stands; effective conservation strategies must compensate for or otherwise offset the foregone revenue.

This report synthesizes three complementary lines of inquiry: (1) insights from the literature on private land conservation mechanisms and incentives; (2) spatial and statistical analyses that characterize the distribution, risk, and conservation value of Maine's old forests; and (3) an integrated discussion of how alternative protection pathways might achieve the broader objective of conserving Maine's old forests.

Importantly, this report does not advocate a single, prescriptive solution. Instead, its objective is to provide a tiered, evidence-based framework for comparing alternative approaches, including fee acquisition, conservation easements, modified forest management, carbon-based finance, and other market-oriented mechanisms. Where possible, the analysis highlights trade-offs among approaches and identifies conditions under which particular strategies may be more or less appropriate.

The geographic focus of the study encompasses Maine's unorganized territories, with particular attention to regions where old forests are both ecologically significant and subject to high risk of loss, including areas dominated by private commercial ownership. While some findings may be transferable to other forested regions, the evaluation is grounded explicitly in Maine's biophysical conditions, land ownership patterns, and policy context.

The intended audiences for this report include conservation practitioners, land trusts, forest landowners, policymakers, and funders seeking to make informed decisions about LSOG forest protection in Maine. By clarifying the purpose, scope, and decision-relevance of alternative conservation pathways, this report aims to support more strategic, transparent, and effective efforts to retain late-successional and old-growth forest values within a working forest landscape.

The report is organized as follows: Chapter Two presents a systematic review of land protection mechanisms relevant to Maine's late-successional and old-growth forests, including a formal evaluation and ranking of these mechanisms. Chapter Three describes the data and methods used in the landscape analysis, including a summary of Hagan et al. (2024) old-growth mapping, an independent validation of those data, the analytical framework used here to evaluate alternative conservation criteria, and the methods used to estimate the costs of different protection strategies. Chapter Four presents the estimated costs associated with alternative prioritization approaches and conservation mechanisms. Chapter Five synthesizes the results and offers recommendations for a strategic, scalable approach to old-growth forest conservation in Maine. Chapter 6 concludes the report.

Overall, the report shows that protecting even the highest-priority LSOG forests (e.g., the top 50%) will require on the order of $200-300 million, reflecting the high timber value of these stands. The most effective strategy is a portfolio approach: targeted fee acquisition for the highest-value patches, complemented by strict no-harvest conservation easements across larger landscapes, and supported by carbon finance and other emerging funding mechanisms where they can offset a portion of these costs.

2. Instrument Evaluation

2.1 Policy Instrument Analysis

The effectiveness of any policy instrument for LSOG conservation depends on its ability to address a core economic asymmetry: LSOG forests generate high private returns through high timber volume but provide public benefits through carbon storage, biodiversity, and ecosystem function. We conducted a systematic literature review to identify and evaluate policy instruments that could incentivize the protection of late-successional and old-growth (LSOG) forests on private lands in Maine. The review proceeded in three stages: literature search and screening, policy instrument identification and categorization, and quantitative assessment.

The first stage involved conducting a literature search and initial screening. We searched Google Scholar and Web of Science databases from March to July 2025 using combinations of five primary keywords: 'old-growth', 'late-successional', 'forest conservation', 'policy instruments', and 'economic incentives' (Table 2.1). Articles containing any combination of these search terms were evaluated against three inclusion criteria: (a) the article addresses old-growth or late-successional forests, (b) the outcome variable relates to forest conservation, and (c) the article discusses policy instruments or economic incentives. The full set of literature identified for the review are summarized in Appendix B.

Table 2.1. Keywords Used for the Systematic Literature Review

Keyword	Description
Old Growth	A forest developed over a long period of time without disturbance
Late Successional	A forest in its mature stage, exhibiting characteristics including high diversity of tree species, multi-layered canopy, and large-diameter trees
Forest Conservation	The practice of protecting, managing, and restoring forests to ensure long-term health and sustainability
Policy Instruments	A mechanism that is used to achieve a specific policy objective
Economic Incentives	Tools used to influence economic behavior by offering a reward or penalty

The second stage focused on identifying and categorizing specific policy instruments. Articles meeting the inclusion criteria were analyzed to extract specific policy instruments applicable to LSOG conservation on private lands. For each instrument identified, we documented the conservation method, policy mechanism, advantages and disadvantages, and potential application to LSOG protection in Maine. We then organized these instruments into four high-level categories based on their primary approach: market-based, regulatory-based, property rights-based, and information-based mechanisms. Within each category, we identified more specific policy options such as taxes and subsidies, conservation easements, auctions, fee-simple purchase, and technical assistance programs. For each option, we qualitatively assessed its potential effectiveness for protecting LSOG forests in Maine.

The final stage developed a quantitative assessment framework. To systematically compare policy options, we developed a scoring rubric that evaluates each instrument across seven criteria: total implementation cost, transaction cost, monitoring and verification cost, landowner acceptance, capability for permanent LSOG protection, scalability, and additionality (Table 2.2). Each criterion is scored on a 0 to 5 scale, where higher scores indicate better performance. The current framework assigns equal weight to all criteria; however, weights could be adjusted to reflect specific project priorities such as cost-efficiency, ecological effectiveness, or social acceptance. For example, educational programs may score highly (5) on total cost due to minimal implementation expenses but score poorly (1) on permanent protection capability because they do not guarantee long-term conservation outcomes. Summing scores across all criteria provides an overall performance metric that facilitates comparison among policy options and can inform decision-making about which instruments may be most effective for LSOG protection in Maine's context.

Table 2.2. Policy Instrument Evaluation Scoring Rubric

Component	5 Points	4 Points	3 Points	2 Points	1 Points	0 Points
Total Cost (Program Implementation Cost)	Minimal direct costs (e.g., educational programs using volunteers, information dissemination)	Low costs with efficient resource use (e.g., property tax relief - revenue foregone rather than direct expenditure)	Moderate costs requiring sustained funding (e.g., PES payments, cost-share programs)	High costs requiring significant capital or ongoing payments (e.g., private protected areas with management costs)	Very high costs requiring major capital investment (e.g., fee-simple land purchase)	Prohibitively expensive for most organizations
Transaction Costs (Administrative Complexity)	Minimal paperwork, simple processes, self-implementing	Low administrative burden, streamlined processes (e.g., educational programs, property tax relief)	Moderate administrative requirements, established procedures (e.g., forest certification, auctions)	High administrative complexity, multiple stakeholders, lengthy processes (e.g., conservation easements, carbon offsets)	Very complex administrative requirements, multiple approvals needed (e.g., tradable development rights, habitat banking)	Extremely complex, requiring specialized legal/technical expertise
Monitoring and Verification Cost	Self-evident outcomes, minimal monitoring needed (e.g., fee-simple purchase - permanent ownership change)	Low monitoring costs, clear metrics (e.g., conservation easements with periodic site visits)	Moderate monitoring requirements (e.g., forest certification audits, cost-share compliance)	Regular monitoring needed, some technical complexity (e.g., PES outcome verification, carbon offset measurement)	Intensive monitoring required, complex verification (e.g., carbon offset programs, habitat banking credits)	Continuous monitoring required, very expensive verification systems
Landowner Acceptance	Very high acceptance, addresses landowner priorities (e.g., voluntary programs with flexible terms)	High acceptance, clear benefits to landowners (e.g., property tax relief, cost-share programs, fee-simple purchase)	Moderate acceptance, balanced benefits and constraints (e.g., conservation easements, private protected areas)	Low acceptance due to restrictions or complexity (e.g., forest certification requirements, carbon offset contracts)	Very low acceptance, significant constraints or uncertainty (e.g., tradable development rights, habitat banking)	Landowner resistance, perceived as unfavorable

Permanent LSOG Protection Capability	Permanent, legally binding protection (e.g., fee-simple purchase, conservation easements)	Long-term protection with strong legal backing (e.g., private protected areas with deed restrictions)	Medium-term protection, some legal mechanisms (e.g., forest certification, conservation banking)	Short to medium-term protection, renewable agreements (e.g., property tax programs, cost-share contracts)	Temporary protection, easily reversible (e.g., PES contracts, educational influence)	No long-term protection mechanism
Scalability	Highly scalable across many properties and regions (e.g., educational programs, property tax systems)	Good scalability with established frameworks (e.g., PES programs, carbon markets, agri-environmental programs)	Moderate scalability, some replication potential (e.g., forest certification, conservation banking, voluntary programs)	Limited scalability due to resource constraints or site-specificity (e.g., fee-simple purchase, small-scale auctions, tradable development rights)	Very limited scalability, highly site-specific (e.g., private protected areas)	Not scalable beyond individual cases
Additionality	Very high additionality, targets lands that would otherwise be developed/degraded (e.g., fee-simple purchase of threatened lands)	High additionality, creates new conservation incentives (e.g., PES payments, reverse auctions, conservation easements)	Moderate additionality, some new conservation behavior (e.g., carbon offsets, cost-share programs, policy mixes)	Low additionality, may reward existing conservation behavior (e.g., forest certification, educational programs)	Very low additionality, minimal change in landowner behavior (e.g., property tax relief for existing forests)	No additionality, payments for activities that would occur anyway

2.2 Policy Instrument Analysis

The literature review identified six major categories of policy instruments applicable to LSOG forest protection (Table 2.3, Figure 2.1). Each category employs distinct mechanisms to incentivize conservation behavior among private landowners, presenting unique advantages and challenges for implementation in Maine's context.

2.2.1 Tax Incentives and Subsidies

Tax incentives and subsidies serve as tools to influence sustainable forest management practices by reducing the financial burden of maintaining forest stands. Property tax reductions, carbon taxes and subsidies, and cost-share programs represent strategies that can enhance the protection of LSOG patches on private properties.

Property tax reductions assist in making land ownership and sustainable management economically viable in the face of high property taxes and development pressure, providing ongoing financial relief for forest conservation. These incentives have been implemented through numerous initiatives across the United States. Forest taxation programs currently exist in 47 states, collectively covering millions of forested hectares nationwide. Maine's Tree Growth Tax Law covers more than 4 million hectares of forest across the state (Maine Revenue Service, 2025).

The integration of carbon taxes and agri-environmental measures provides financial protection for LSOG forests on private lands. Carbon taxes disincentivize forest-damaging activities, while subsidies reward the provision of environmental services. Regionally, states such as Washington have implemented a carbon market that includes forest sector participation, requiring timber companies to account for carbon emissions from their forest management activities. At the federal level, the USDA Conservation Reserve Program (CRP) has enrolled about 1 million hectares of environmentally sensitive cropland into forest cover nationwide.

Cost-share programs reduce financial barriers to implementing conservation strategies by providing reimbursement for approved management practices, thereby creating positive financial incentives for LSOG protection. Several programs exemplify this approach: the USDA Environmental Quality Incentives Program (EQIP) provides forest practice cost-share funding nationwide; the Forest Stewardship Program assists more than 1.6 million private forest hectares; and the American Forest Foundation's family forest programs provide additional cost-share assistance to woodland owners. A potential limitation is that many of these programs only apply to ‘small’ forest landowners and thus may not be applicable to larger landowners that operate in the study area.

While tax incentives and subsidies prove effective at disincentivizing forest-damaging activities and encouraging the provision of environmental services, they require government authority to impose taxes and distribute subsidies through public agencies. This dependence on governmental action represents both a strength, in terms of institutional stability, and a limitation, in terms of political feasibility and administrative requirements. Enrolling in tax programs is typically voluntary and landowners are able to disenroll at their discretion, meaning the programs lack permanence.

2.2.2 Payments for Ecosystem Services

Payments for ecosystem services (PES) represent an effective mechanism for influencing private landowner behavior through direct compensation mechanisms, contractual arrangements, and results-based payment systems.

Direct payments compensate landowners for ecosystem services such as carbon storage and water purification provided by LSOG forests through voluntary contracts. This strategy has been implemented across the United States in various forms. New York City provides watershed payments to upstate forest landowners for water quality protection. California has established forest carbon offset protocols under its cap-and-trade program. The U.S. Forest Service's Forest Legacy Program provides ongoing payments for forest conservation across multiple states.

Contractual arrangements provide direct payments to landowners for maintaining their LSOG forest stands. These contracts are typically voluntary in nature and offer land users clearly defined payments for either the implementation of agreed-upon land use practices or achieved conservation results. These incremental payments typically span periods of 10 to 20 years. Payments for ecosystem services often perform well in economically disadvantaged areas with moderate conservation opportunity costs, where landowners face challenges to maintaining forest conservation without external support.

Results-based payment systems similarly provide direct payments to landowners but structure compensation around achieved outcomes rather than prescribed practices. These contracts compensate landowners based on measurable conservation results. Payments may be structured as incremental disbursements or as a single payment upon achievement of specified outcomes at the end of a defined period. Results-based payments require robust monitoring of enrolled forest stands to verify the desired conservation outcomes have been achieved.

While payments for ecosystem services can directly benefit LSOG protection on private lands, several limitations warrant consideration. Environmental benefits may cease immediately when payments stop, creating uncertainty about long-term conservation outcomes. Additionally, PES strategies often lack precise measurable indicators for robust environmental impact assessments and require ongoing monitoring and enforcement to ensure compliance. These challenges should be carefully considered when PES mechanisms are incorporated into forest management strategies.

2.2.3 Conservation Easements and Land Protection

Conservation easements are voluntarily negotiated between the landowner (grantor) and the easement holder (grantee) and their terms vary substantially. Conservation easements are typically less expensive than outright property acquisition while still providing meaningful conservation outcomes. Conservation easements represent a type of partial title transfer between a landowner and a government agency or nonprofit land trust that limits certain land uses permanently to preserve conservation qualities.

The legal agreements created through conservation easements provide long-term incentives through legal, financial, and tax-based benefits while allowing landowners to retain ownership of their property and to enjoy any lawful uses not proscribed by the terms of the easement. . These legal protections typically offer permanent protection from development and sometimes from extractive uses. They sometimes provide tax savings and other legal safeguards as well. Maine currently has more than 1.6 million hectares of forest under conservation easements, representing approximately 20 percent of the state's forestland. A majority of these are structured as permanent working forest easements that allow continued timber extraction while restricting development.

Nearly all conservation easements in the state are structured as ‘permanent’ due to the desire of the holder and added value associated with permanent preservation status. However, it is technically possible to structure an easement to be ‘temporary’ or ‘termed’ and thus expire after a specified period. The current threat to LSOG in Maine coupled with the relatively large area and amount of LSOG patches scattered across the state could enable ‘term easements’ to be a more desirable option to temporarily protect these areas while we are exploring more permanent protection opportunities.

Fee-simple acquisition involves the outright purchase of LSOG properties by conservation organizations or government entities, increasing the likelihood of permanent protection through complete ownership transfer at market value. Many organizations have employed this strategy successfully, although technically the LSOG is not formally protected from harvest without additional measures such as harvest prohibitions within conservation easements. For example, conservation landowners across Maine and the U.S. have protected several million hectares through fee purchases and almost 300,000 hectares with easements prohibiting harvest in Maine. Maine's Land for Maine's Future (LMF) program has acquired more than 240,000 hectares for conservation purposes. The Appalachian Mountain Club (AMC) has protected several thousand acres in the Hundred Mile Wilderness region of Maine through purchases from industrial timber owners. The Trust for Public Land purchases forest land for state forest expansion throughout the country. A notable early example is The Nature Conservancy's (TNC) acquisition of the approximately 2,000-ha Big Reed Forest Reserve (T8 R10 WELS) from the Pingree family in the 1980s, which protects one of the largest remaining tracts of LSOG forest in New England.

Transferable development rights (TDR) allow landowners to monetize conservation value by selling development rights while maintaining property ownership. This mechanism ensures land remains undeveloped while providing financial compensation to the landowner. The concept differs from a conservation easement which typically eliminates development rights, while a TDR formally redirects the rights somewhere else, typically in a target growth area. For example, the New Jersey Pinelands TDR program has protected more than 9,700 hectares, including significant forested areas, and King County, Washington utilizes TDRs for forest protection in rural areas adjacent to urban development pressures. This approach could be an option in the faster-growing areas of Maine that face high development pressure and land conversion to housing and commercial use, particularly in the southern areas of Cumberland and York counties.

2.2.4 Market-Based Auctions and Competitive Mechanisms

Market-based auctions and competitive mechanisms allocate limited conservation funding among competing landowners in an economically efficient manner. One option that falls under this category are "reverse auctions" also known as procurement auctions, which represent a contractual design whereby landowners submit bids specifying the compensation required for LSOG protection on their properties. Importantly, reverse auctions function as a delivery mechanism that can be combined with other conservation policy instruments described in this section, e.g., PES contracts, conservation easements, or cost-share agreements, to allocate funding more efficiently rather than serving solely as a standalone alternative

Auction mechanisms can generate significant cost-savings by identifying landowners with high private-benefit-to-opportunity-cost ratios for forest maintenance. The competitive bid selection procedure incentivizes participants to submit offers at or near the minimum price they are willing to accept, rather than inflated bids, because higher bids face greater risk of rejection by the conservation buyer. This competitive dynamic reveals true conservation costs and directs limited funding toward properties where conservation can be achieved most cost-effectively.

Several programs have successfully employed this conservation strategy. The USDA Conservation Reserve Program uses reverse auctions to allocate funding for forest conversion on agricultural lands. Oregon's Salmon Habitat Restoration Program conducts auctions for riparian forest conservation to protect salmon spawning habitat. The Conservation Resource Alliance in Michigan conducts forestland protection auctions to prioritize conservation investments across the northern Lower Peninsula.

The primary advantage of auction mechanisms lies in their ability to efficiently allocate scarce conservation resources. However, these approaches require sufficient landowner participation to generate meaningful competition, and they may be less effective in regions where few landowners are willing to participate or where conservation costs are relatively uniform across properties. They may also need to account for variable 'values' associated with the land that is being considered in the auction. That is, not all LSOG patches are created equal and thus should not necessarily be selected purely based on lowest-bid or cost to protect. Additionally, auction-based conservation contracts are most often temporary and thus share the impermanence limitations of term easements. Thus, auctions-based instruments may require a dedicated funding source to sustain LSOG protection payments over time.

Box 2.1. How Could a Reverse Auction Work for LSOG Protection in Maine?

A reverse auction is a competitive pricing mechanism in which a conservation buyer solicits sealed bids from landowners who specify the payment they would require to protect LSOG stands on their property. Unlike fixed-price programs, auctions harness competition to reveal true conservation costs and direct limited funding where it achieves the most impact (Pirard, 2012). Because auctions are a price revealing mechanism, they can be applied to a range of policy incentives and payment for ecosystem services schemes. Evidence from programs worldwide shows that auctions can deliver up to 30% more conservation per dollar than fixed-price alternatives (Schilizzi and Latacz-Lohmann, 2007).

The USDA's Conservation Reserve Program (CRP) is a good example of a conservation auction in practice (USDA FSA, 2026). Under its general signup, landowners bid to retire sensitive cropland in exchange for annual payments over 10 to 15 years. Bids are then ranked by price and a composite Environmental Benefits Index (EBI) that weighs ecological factors (e.g., wildlife habitat, water quality, erosion reduction) alongside the implementation cost. This ensures the program selects land offering the best overall value, not just the lowest bids.

In the context of Maine LSOG protection, a conservation organization or other 'buyer' group could administer an auction in which private landowners bid to protect specific LSOG forests. Each bid would specify the patch(es) offered, the proposed conservation action (e.g., harvest deferral, no-harvest easement), contract duration, and requested compensation. Bids could then be scored using a composite LSOG Benefits Index (LBI) modeled on the CRP's EBI:

LBI Component	Key Factors (higher value = higher score)
Ecological Value	LSOG classification, stand area, structural complexity (e.g., basal area, large trees, canopy layers)
Connectivity	Proximity to protected areas, wildlife corridors, contribution to landscape LSOG network
Threat Level	Documented harvest plans, active nearby operations, ownership type and harvest probability
Ecosystem Services	Carbon storage, habitat quality
Protection Durability	Contract length, legal strength of protection mechanism
Cost	Requested $/ha relative to other bids

After the enrollment window closes, bids are then ranked by LBI score and accepted in descending order until the budget is exhausted. Each winning landowner receives their bid amount (discriminatory pricing).

How This Fits the Maine LSOG Context

- Information asymmetry: Conservation buyers do not know individual landowners' true opportunity costs, which vary widely. Auctions elicit this private information through competition
- Heterogeneous parcels: LSOG stands differ in ecological quality, area, and threat. The LBI accounts for this variation rather than treating all hectares as equivalent.
- Landowner autonomy: Participation is voluntary and landowners set their own price, aligning with Maine's property-rights culture.
- Budget efficiency: Maximizes protected area per dollar, which is critical with limited funding.
- Compatibility: Auctions are a delivery mechanism that can be combined with PES contracts, easements, or fee-simple purchases to allocate funding across different protection levels.

2.2.5 Permits, Offsets, and Trading Systems

Permits, offsets, and trading systems represent conservation mechanisms that regulate forest management of LSOG stands on private forestland. These regulatory tools monitor and limit activities that reduce the natural ecosystem services provided by LSOG forests, including wildlife habitat, carbon sequestration, and climate mitigation benefits. Carbon offset markets and biodiversity banking allow for more sustainable forest management of LSOG stands by creating economic value for conservation.

Carbon offset markets work to reduce atmospheric carbon emissions by generating tradeable carbon credits based on the significant storage and sequestration capacity of LSOG forests. These programs provide ongoing payments to landowners who maintain or enhance forest carbon stocks. Carbon offset programs have been established across the United States at various scales. Currently, there are more than 4 million hectares of U.S. forests enrolled as carbon projects, and nearly 500,000 hectares in Maine, or about 6 percent of the state's total forest cover (Fastmarkets, 2025) .

Biodiversity banking operates through similar market mechanisms. Biodiversity banking creates markets for biodiversity credits, where LSOG protection generates tradable credits that developers can purchase to meet environmental offset requirements. While stream and wetland mitigation banking exists in most states, forest-specific biodiversity programs remain limited. For example, California is developing regional conservation investment strategies that include forest ecosystems (Grimm, 2020). Recently, Verra launched 'The Nature Framework,' a biodiversity crediting program that applies principles of additionality, leakage prevention, and permanence analogous to its carbon offset standards, though defining a standardized 'unit of biodiversity' remains a key methodological challenge (Verra, 2024).

While permits, offsets, and trading systems can effectively regulate destructive activities, implementation challenges exist with these mechanisms. Both carbon offset markets and biodiversity banking involve perceived high costs and regulatory complexity. Additionally, landowners may express skepticism about contract requirements that would limit their ability to harvest timber or do other active forest management activities, potentially reducing participation rates in these programs. Carbon markets partially address this tension by assigning financial value to the carbon stored in LSOG forests; however, they must compete directly with the often substantial timber value of these stands. The viability of carbon offsets contributing to LSOG conservation depends critically on whether carbon payments can match or exceed expected harvest revenues.

2.2.6 Information, Certification, and Voluntary Programs

Information, certification, and voluntary programs represent information-based instruments that encourage sustainable management through education about forest health and environmental stewardship. Forest certification systems, educational initiatives, and voluntary programs enable private forest owners to engage actively in maintaining the health and longevity of their forest stands.

Forest certification programs, including the Forest Stewardship Council (FSC) and Sustainable Forestry Initiative (SFI), Currently, over 40 million hectares carry FSC or SFI certification nationwide, and there are more than 3 million hectares of certified forest in Maine. Both programs already contain provisions relevant to LSOG conservation. FSC standards prohibit commercial harvesting in 'type 1 old-growth' forests, while SFI calls for the identification of old growth and management that maintains its conservation value. However, despite these written standards, certification has proven largely ineffective at conserving LSOG stands on certified timberlands in Maine. As Hagan et al. (2025) document, timberland owners in both certification systems in Maine are harvesting late-successional and old-growth forest, suggesting either that the standards should be revised to conform to practices on the ground, or that enforcement should be strengthened to bring practices into conformance with the written standards.

Educational initiatives, while less directly effective at incentivizing permanent protection compared to financial mechanisms, inspire LSOG protection through increased awareness and knowledge transfer. By increasing awareness of LSOG forests' ecological, economic, and cultural value, these programs empower landowners to make informed conservation decisions based on understanding of sustainable management practices. Cooperative extension forestry programs operate in nearly all 50 states, providing technical assistance and educational resources. The American Forest Foundation's family forest owner programs reach more than 100,000 landowners annually. Master Forest Owner programs are active in more than 15 states, including Maine, training volunteer landowners to provide peer-to-peer outreach and education.

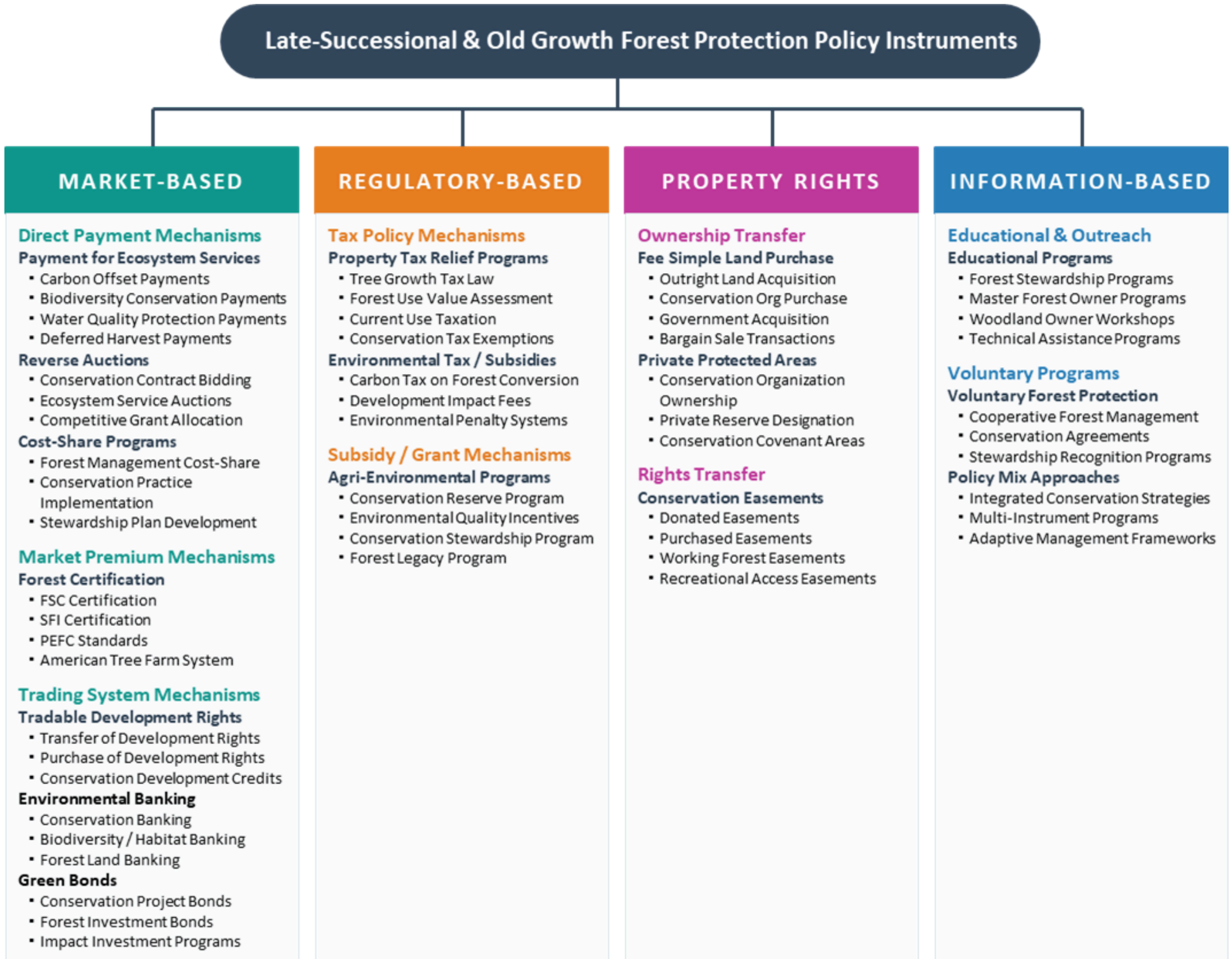
Voluntary programs offer a low-commitment opportunity for landowners to modify their current management strategies without the binding obligations of formal contracts or easements. Voluntary contracts allow for personalized tailoring to the specific circumstances of individual landowners and forest locations. This conservation strategy enables landowners and forest programs to develop more personalized connections, thereby improving trust and fostering long-term stewardship relationships that may lead to more formal conservation commitments over time.

Table 2.3: Potential Late-Successional and Old-Growth (LSOG) Conservation Policy Instruments

Instrument	**Key Characteristics**	**Example Instruments**	**Real World Applications**	**Potential Application for Maine LSOG Protection**
Tax Incentives and Subsidies	Reduces financial burden or provides direct financial support to make forest conservation economically viable	Property tax reductions, carbon taxes/subsidies, agri-environmental subsidies, cost-share programs	Maine's Tree Growth Tax Law covers 4+ million hectares; Forest taxation programs exist in 47 states covering millions of forested hectares.	Although Maine lacks an LSOG-specific tax credit, tax incentives and subsidies can create financial motivation and improve the feasibility for private landowners to conserve LSOG forests rather than harvesting them.
Payments for Ecosystem Services (PES)	Direct compensation for the environmental services that LSOG forests provide to society	Direct payments for carbon sequestration, water purification, biodiversity conservation; contractual agreements between landowners and beneficiaries; results-based payments	New York City watershed payments to upstate forest landowners for water quality protection; California's forest carbon offset protocols under cap-and-trade; the U.S. Forest Service's Forest Legacy Program provides ongoing payments for forest conservation. The USFS recently awarded NEFF $4+ million dollars to protect Maine's oldest forests.	Payments for ecosystem services align landowner incentives with long-term LSOG conservation goals by providing compensation for carbon storage, biodiversity, and clean water. Given Maine's active forestry industry, providing compensation for carbon sequestration and other ecosystem services helps counteract the strong financial incentive to harvest LSOG forests.
Conservation Easements and Land Protection	Legal mechanisms that permanently or long-term restrict development while allowing continued private ownership	Conservation easements (voluntary or purchased), private protected areas, fee-simple land acquisition, tradable development rights	Maine has 1.6+ million hectares of forest (~20%) under conservation easements, 80%+ of these are considered working forests allowing timber harvests.	Conservation easements and land protection mechanisms provide legal defense against future harvest pressures. By voluntarily agreeing to limit development and harvest in LSOG areas while retaining ownership, landowners receive tax benefits and conservation payments, making long-term sustainability more economically feasible.

Market-Based Auctions and Competitive Mechanisms	Uses market mechanisms to efficiently allocate conservation funding and reveal true conservation costs	Reverse auctions where landowners bid for conservation contracts, small-scale competitive bidding, competitive allocation of conservation resources	USDA Conservation Reserve Program uses reverse auctions for forest conversion.	Market-based auctions and competitive mechanisms support Maine's LSOG protection by incentivizing conservation of high-value forest stands in a cost-effective and voluntary manner. Competitive mechanisms increase cost efficiency by identifying the most effective allocation of limited conservation funds.
Permits, Offsets, and Trading Systems	Creates markets for environmental benefits, allowing conservation to generate revenue through trading mechanisms	Carbon offset credits, biodiversity banking and habitat credits, cap-and-trade systems, tradeable permits	More than 4 million hectares in U.S. forest are currently enrolled in forest carbon programs; 500,000 hectares are enrolled in Maine, 6% of the state's total land cover.	Permits, offsets, and trading systems limit activities that can degrade LSOG characteristics. While there is flexibility in how these regulations are met, they maintain regulatory oversight that is crucial for long-term sustainability of LSOG forests on private land.
Information, Certification, and Voluntary Programs	Relies on information, voluntary participation, and market premiums to incentivize conservation	Forest certification programs (FSC, SFI), educational initiatives, voluntary agreements, price premiums for certified products	Over 40 million hectares FSC/SFI certified in the US; 3 million ha certified in Maine. Most forested states have university of state forest service extension programs focused on landowner outreach.	Information, certification, and voluntary programs contribute to LSOG protection by encouraging awareness and market incentives rather than regulation. Educating landowners on the ecological importance of LSOG forests and best management practices fosters cooperation, flexibility, and landowner relationships that support long-term sustainability.

Figure 2.1: Late-Successional and Old-Growth Forest Protection Instrument Dendrogram



2.3 Instrument Multi-Criteria Assessment

To systematically compare policy instruments for LSOG forest protection, we applied the scoring rubric described in Section 2.1 to evaluate each instrument across multiple performance dimensions (Table 2.4). This assessment enables the identification of instruments best suited to Maine's specific context and implementation constraints.

We note that a key scope of this study is to focus on instruments that can be implemented by private conservation organizations and land trusts who are seeking near-term, actionable strategies that do not depend on legislative action or new government programs. This does not mean that government involvement is undesirable or unrealistic, as public funding and policy support has the potential to enhance the effectiveness of several instruments we investigated. In this case, the instruments are categorized by their feasibility for private implementation so that organizations can identify strategies deployable in the current policy environment while simultaneously advocating for supportive government action

2.3.1 Evaluation Criteria

The multi-criteria assessment evaluated each policy instrument across eight dimensions that capture both practical implementation considerations and conservation effectiveness:

1. Total Implementation Cost measures the direct financial resources required to establish and operate the instrument, including program administration, payments to landowners, and infrastructure development.
2. Transaction and Administrative Costs capture the complexity and expense of program processes, including legal requirements, paperwork burden, stakeholder coordination, and time required to complete transactions.
3. Monitoring and Verification Requirements assess the ongoing effort and expense needed to confirm compliance with program requirements and verify that conservation outcomes are being achieved.
4. Landowner Acceptance Likelihood evaluates how receptive private forest owners are likely to be toward participating in the program, considering factors such as flexibility, financial benefits, and restrictions on land use.
5. Permanence of Protection measures the duration and legal strength of conservation outcomes, ranging from temporary voluntary agreements to permanent legally binding protections.
6. Additionality Potential assesses whether the instrument generates new conservation outcomes beyond what would have occurred without intervention, rather than simply rewarding existing conservation behavior.
7. Scalability Across the Landscape evaluates the potential to expand the instrument across many properties and large geographic areas, considering resource requirements and replicability.
8. Non-Government Implementation Feasibility measures whether the instrument can be effectively implemented by private organizations, land trusts, or other non-governmental entities without requiring government authority or public funding.

Each category is given equal weighting for ease of comparison. Alternative weighting towards more important criteria (e.g., permanent protection) would yield alternative rankings.

Table 2.4. Policy Instrument Multi-Criteria Assessment Scores

Policy Instrument	Total Cost	Transaction Costs	Monitoring & Verification Costs	Landowner Acceptance	Permanent Protection	Additionality	Scalability	Non-Government Policy Applicability	Total Score	Average Score (out of 5)
Educational Programs	5	4	5	4	1	2	5	5	**31**	**3.9**
Conservation Easements	4	2	4	3	5	4	3	5	**30**	**3.8**
Fee Simple Land Purchase	1	3	5	4	5	5	2	4	**29**	**3.6**
Reverse Auction	4	2	3	3	2	4	3	5	**26**	**3.3**
Payment for Env. Services (PES)	3	3	2	4	1	4	4	5	**26**	**3.3**
Green Bonds	3	2	3	3	3	4	4	4	**26**	**3.3**
Private Protected Areas	2	4	3	3	4	3	2	5	**26**	**3.3**
Forest Certification	4	3	3	2	3	2	3	5	**25**	**3.1**
Forest Land Banking	2	3	4	3	4	4	2	3	**25**	**3.1**
Property Tax Relief Programs	4	4	4	4	2	2	4	0	**24**	**3.0**
Cost-Share Programs	3	2	3	4	2	3	4	2	**23**	**2.9**
Tradable Development Rights	3	1	4	2	4	3	2	2	**21**	**2.6**
Forest Carbon Offsets	3	2	1	2	2	3	4	3	**20**	**2.5**
Conservation Banking	3	2	2	2	3	3	3	2	**20**	**2.5**
Biodiversity/Habitat Banking	3	1	1	2	3	3	3	2	**18**	**2.3**

The multi-criteria assessment identified three instruments with the highest overall scores: Educational Programs, Conservation Easements, and Land Purchases. Each offers distinct advantages for LSOG forest protection in Maine, as discussed below. Instruments that scored lower could still be considered in specific circumstances, particularly those related to providing financial incentives.

Educational Programs (3.9/5.0 average score)

Educational programs emerged as the highest-scoring instrument overall, driven primarily by their low implementation costs, high scalability, and strong landowner acceptance. These programs can be delivered through existing cooperative extension networks and forestry outreach organizations at minimal marginal cost, reaching large numbers of landowners across diverse geographic areas. Landowners generally respond positively to educational approaches because they provide useful information without imposing restrictions on land use decisions.

However, educational programs exhibit significant limitations in two critical dimensions. They score poorly on permanence of protection because education alone does not create legally binding conservation commitments, and landowners may change management practices at any time. Moreover, additionality remains uncertain because it is difficult to verify whether educational programs actually change landowner behavior or simply provide information to landowners who would have conserved their forests regardless. It is also important to note that the multi-criteria assessment assigns equal weight to all evaluation criteria. If criteria related to permanent protection and additionality were weighted more heavily, reflecting their arguably greater importance for long-term LSOG conservation outcomes, educational programs would rank considerably lower. The high overall score for educational programs should therefore be interpreted cautiously and are best suited in this context as a complementary instrument that builds awareness and support for more permanent protection mechanisms.

Conservation Easements (3.8/5.0 average score)

Conservation easements ranked second overall, distinguished by their ability to provide permanent, legally binding protection while allowing landowners to retain property ownership. Maine's extensive experience with working forest conservation easements, covering approximately 1.6 million hectares statewide, demonstrates the viability and acceptance of this approach. The established legal and institutional framework for easement transactions reduces uncertainty and provides clear precedents for implementation.

The primary limitations of conservation easements relate to transaction complexity and costs. Negotiating easement terms, conducting legal review, completing appraisals, and securing funding requires substantial time and professional expertise. These high transaction costs can make easements impractical for small properties where the conservation value may not justify the administrative expense. Despite these challenges, conservation easements remain among the most effective instruments for achieving permanent LSOG protection on private lands. Notably, while no-harvest or limited-harvest easements will be more expensive than working forest easements, monitoring compliance is relatively straightforward. Periodic review of NAIP aerial imagery or other remote sensing data can readily detect harvest activity at fine spatial scales, significantly reducing ongoing monitoring costs compared to programs requiring field-based verification of management practices.

Fee-Simple Land Purchase (3.6/5.0 average score)

Fee-simple land purchase scored third overall, with the highest possible scores for permanence of protection and additionality. Outright acquisition by conservation organizations or public agencies provides the most certain and complete protection, eliminating virtually any risk that future landowners might alter management practices or seek to modify conservation restrictions. Purchased lands are typically managed explicitly for conservation purposes, ensuring that LSOG characteristics are maintained and enhanced over time.

The significant limitation of fee-simple purchase is its high cost, which constrains both the total acreage that can be protected and the ability to scale the approach across the landscape. At current forestland prices in Maine, fee-simple acquisition requires substantial capital that limits application to the highest-priority sites. Additionally, changing the landowner to a non-profit conservation group potentially eliminates property tax revenue for local governments and may face resistance in communities concerned about "public" land expansion. An exception is in cases where the non-profit owner compensates municipalities in the form of payments in lieu of taxes (PILOT), which is somewhat common in Maine (Bennett, 2023). Further, many fee-simple acquisitions by conservation organizations that maintain public access and engage with local stakeholders (e.g., Appalachian Mountain Club), potentially improving community relationships relative to prior corporate ownership. Fee-simple purchase is therefore best reserved for the most ecologically significant LSOG sites where permanent protection is essential and other mechanisms are insufficient. When evaluating the cost of fee-simple acquisition, it is also instructive to consider the cumulative public investment in working forest easements, tax reductions, and cost-share programs on lands where LSOG harvesting may continue. Fee-simple purchase, while expensive per transaction, provides permanent, guaranteed results without the recurring costs and uncertain outcomes associated with other incentive-based instruments.

2.3.2 Instruments Best Suited for Private Implementation

A key consideration for LSOG protection in Maine is the feasibility of implementation by private conservation organizations, land trusts, and other non-governmental entities. Many policy instruments require government authority to implement, limiting their applicability for private-sector conservation initiatives. The assessment evaluated each instrument's suitability for non-governmental implementation, categorizing instruments into three tiers of applicability. Importantly, the effectiveness of each instrument for LSOG protection depends not only on implementation feasibility but also on whether the instrument's design can accommodate the specific management restrictions necessary to maintain LSOG forest characteristics. The analysis also reflects the political economy of forest management in Maine, where many large landowners have strong property-rights traditions and are skeptical of direct government intervention in land management decisions. Instruments that respect landowner autonomy and provide clear financial incentives are therefore more likely to achieve participation than those perceived as regulatory or prescriptive (Irland 2000; Bell 2007).

High Applicability for Private Implementation

Several instruments can be effectively implemented by private organizations without requiring government authority or public funding, making them particularly attractive for organizations seeking to advance LSOG protection in Maine independent of government program cycles and funding constraints.

Private protected areas offer maximum flexibility for LSOG conservation, as conservation organizations can acquire and manage lands according to their own conservation priorities without regulatory constraints. Under this approach, organizations such as land trusts or conservation nonprofits purchase properties outright and manage them explicitly for LSOG development and protection. In Maine, this model has been successfully employed by organizations including TNC, Northeast Wilderness Trust (NEWT), and AMC, which manage several forest reserves with LSOG characteristics. The primary advantage for LSOG protection is that the acquiring organization maintains complete control over management decisions and can implement strict no-harvest policies necessary to allow forests to develop LSOG characteristics over time. However, the high capital costs of land acquisition limit the total acreage that can be protected through this mechanism, and the approach removes land from private ownership, which may face resistance in communities with strong traditions of private forest stewardship.

Payments for ecosystem services represent a highly flexible mechanism that can be structured as private contracts between landowners and beneficiaries such as water utilities, carbon credit buyers, or conservation organizations willing to pay for environmental outcomes. For LSOG protection in Maine, PES programs could compensate landowners for deferring harvest on stands with LSOG potential, with payments reflecting the foregone timber revenue and the value of ecosystem services including carbon sequestration, biodiversity habitat, and watershed protection. The New England Forestry Foundation's recent $4.3 million award from the U.S. Forest Service to purchase LSOG harvest deferrals in Maine demonstrates growing interest in PES approaches for LSOG conservation. Critically, existing LSOG stands already possess the structural and ecological characteristics that make them valuable. The primary objective of PES in this context is to prevent their loss rather than to incentivize their development. This distinction is important because LSOG characteristics that can take centuries to develop can be eliminated in a single harvest, creating a fundamental asymmetry between the time required for development and the speed of potential loss. Private PES programs can be tailored to specific LSOG protection objectives, including requirements for no-harvest reserves, extended rotation ages, or retention of legacy trees and coarse woody debris. However, the temporary nature of most PES contracts poses challenges for LSOG protection, as LSOG characteristics require decades to centuries to develop, far exceeding typical contract durations of 10 to 20 years. Achieving meaningful LSOG outcomes through PES may require innovative contract structures with longer terms, renewal provisions, or escalating payments that increase landowner commitment over time.

Reverse auctions can be administered by private foundations or conservation organizations to allocate philanthropic funding efficiently among competing landowner bids for LSOG protection contracts. This mechanism could work in the Maine context because it reveals the actual opportunity costs or willingness to accept for LSOG protection across diverse forest types and ownership classes, enabling conservation organizations to maximize the acreage protected per dollar invested. Auction-based approaches also feature a competitive price-discovery mechanism, in which landowners set their own bid prices, that can improve cost-effectiveness compared to fixed-price offerings. Like fee-simple purchases and conservation easements, participation in auctions is entirely voluntary, which may improve acceptance among Maine's independent-minded forest landowner community. For LSOG applications, auctions could be designed to prioritize bids from properties with existing late-successional characteristics, high potential for LSOG development, or strategic locations that connect existing protected areas. The competitive nature of auctions incentivizes landowners to request only the compensation necessary to make LSOG protection economically viable, rather than inflated payments that would reduce program cost-effectiveness.

Medium Applicability for Private Implementation

Conservation easements occupy a middle ground in implementation feasibility, as they require some governmental involvement through tax incentive programs and legal enforcement mechanisms, but are primarily transacted between private landowners and land trusts. Private organizations can lead easement negotiations, provide stewardship, and hold easements in perpetuity, though the tax benefits that make many easements financially viable depend on government policy.

For LSOG protection in Maine, conservation easements present both significant opportunities and important limitations that merit careful consideration. Maine has extensive experience with conservation easements, with approximately 1.6 million hectares of forestland currently under easement protection. However, the vast majority of these are structured as "working forest" easements that permit continued timber harvesting while restricting development and subdivision. However, to date, working forest easements in Maine have been applied to lands with little threat of conversion and because they do not tend to constrain harvesting, they do not protect or help develop LSOG characteristics (Thompson et al. 2024; Maine Audubon, 2025). However, it is entirely feasible to draft easement terms that include explicit LSOG harvest restrictions. Organizations such as NEWT and AMC already employ easements with strict forestry standards that prohibit or severely limit commercial harvesting. These existing models demonstrate that stronger protections can be incorporated into easement language as needed to protect LSOG stands. Under most working forest easements, landowners retain the right to harvest timber according to sustainable forestry standards, which generally involves periodic harvesting that could prevent forests from reaching the advanced successional stages characteristic of old-growth.

To effectively protect LSOG through conservation easements, a different easement model is required: the “ecological reserve,” “wildland” or “forever wild” easements (hereafter, collectively referred to as ecological reserve easements). These easements explicitly prohibit commercial timber harvesting and other extractive activities, allowing forests to develop naturally toward LSOG conditions over time. They may permit limited management activities such as trail maintenance, invasive species control, or ecological restoration, but prohibit the regular harvest entries that characterize working forest management. Ecological reserve easements in Maine are more common than often recognized and cover substantial acreage. Examples include portions of the Appalachian Trail corridor, reserves held by the NEWT, conservation lands managed by AMC, and numerous other parcels held by various NGO. Many of these are now owned by conservation organizations and include explicit no-harvest provisions.

While standalone ecological reserve easements conveyed by industrial timber owners are uncommon, a ‘nested’ model where ecological reserves are embedded within larger working forest conservation easements is a well-established approach in Maine. Forest Society of Maine, for example, holds thousands of hectares of ecological reserves, most of which is nested within larger industrial working forest easements. This combination model allows timber operations to continue on the majority of the landscape while permanently protecting ecologically significant areas within the larger parcel. Additionally, ecological reserve easements on conservation-owned fee land represent an equally important tool that should not be overlooked in a comprehensive LSOG protection strategy.

Another pathway that emerges from large easement transactions is the identification and fee-simple acquisition of sub-parcels with particularly high conservation value. The process of negotiating a no-development easement can create ‘packaged’ opportunities for more protective mechanisms, e.g., outright purchase, to be applied to the most ecologically significant areas within the larger easement. While this layered approach can increase the total cost, it achieves a higher level of protection for priority LSOG stands.

Forest certification similarly involves private certification bodies and market mechanisms, but achieving meaningful LSOG conservation outcomes through certification alone faces significant limitations. Current certification standards under both the FSC and SFI include provisions for protecting high conservation value forests and maintaining representative samples of native ecosystems, which can encompass LSOG stands. However, certification standards generally do not require the complete harvest cessation necessary to develop LSOG conditions from younger forests, and certified operations may continue harvesting in stands that would otherwise have potential to develop LSOG characteristics over extended timeframes. For LSOG protection, certification is best viewed as a complementary tool that raises awareness and establishes baseline protections, rather than a primary mechanism for achieving comprehensive LSOG conservation outcomes.

Low Applicability for Private Implementation

Property tax relief programs inherently require government action, as only governmental entities have the authority to modify tax assessments or provide tax exemptions. Maine's Tree Growth Tax Law (TGTL) provides reduced property tax assessments for forestland maintained for commercial timber production, but the program's structure actually creates disincentives for LSOG protection. Landowners enrolled in TGTL must demonstrate intent to harvest timber, and removing land from active timber management to allow LSOG development could jeopardize eligibility for the reduced tax assessment. Modifying Tree Growth to accommodate LSOG protection would require legislative action to create a new enrollment category for landowners committed to allowing forests to develop LSOG characteristics without regular harvest. Private conservation organizations can advocate for such policy changes but cannot implement property tax modifications directly. Proposed modifications to the TGTL can face significant political resistance from the timber industry, which has a strong financial and operational interest in maintaining existing harvest practices. The political sensitivity surrounding TGTL means that legislative changes, even modest ones, are likely to encounter substantial opposition.

Regulatory banking systems, including carbon offset registries and biodiversity credit programs, typically require government oversight to establish standards, verify credits, and enforce compliance. While private markets can develop around these mechanisms, their effectiveness depends on regulatory frameworks that only governments can establish. Carbon offset programs present particular challenges for LSOG protection because most forest carbon protocols emphasize additionality, requiring demonstration that carbon storage would not have occurred without the offset payment. Forests that already exhibit LSOG characteristics are sometimes assumed to be ‘baseline’ carbon stocks ineligible for offset credits. However, additionality can be demonstrated when landowners have documented plans to harvest LSOG stands within a near-term timeframe (e.g., 5 years), which is common in

Maine’s actively managed industrial forests. While this lowers the additionality barrier, it also creates a potential perverse incentive, as landowners could strategically threaten harvest to qualify for offset payments. Some emerging "improved forest management" protocols do allow credits for extending rotation ages or establishing no-harvest reserves, but the complex verification requirements and regulatory uncertainty in carbon markets create barriers for private implementation focused specifically on LSOG outcomes.

Cost-share programs similarly require government appropriations to fund landowner payments, limiting private organizations to advocacy roles rather than direct implementation. Federal programs such as EQIP and the Forest Stewardship Program could theoretically support LSOG protection activities, but current program priorities emphasize active forest management practices rather than the passive management approach that characterizes LSOG development: allowing natural succession without harvest intervention. Private organizations can work with government agencies to develop LSOG-specific practice standards and payment rates within existing cost-share frameworks, but they cannot directly fund landowner payments at the scale necessary for landscape-level LSOG protection.

Implications for Maine LSOG Conservation Strategy

This analysis suggests that private conservation organizations seeking to protect LSOG forests in Maine should prioritize instruments in the high- and medium-applicability categories, while advocating for supportive government policies that enhance the effectiveness of private conservation investments. A comprehensive LSOG conservation strategy would likely combine multiple instruments: fee-simple acquisition and private protected areas for the highest-priority sites with existing old-growth characteristics; ecological reserve easements for larger landscapes where landowners are willing to accept harvest restrictions; PES contracts and reverse auctions to engage landowners on a shorter-term basis while building relationships and new conservation instruments that may lead to more permanent protection; and educational programs to build broader awareness and support for LSOG conservation values among Maine's forest landowner community.

The relative scarcity of ecological reserve easements applied to previously harvested timberland represents both a challenge and an opportunity for LSOG conservation in Maine. For example, the incentive for a corporate owner to accept an ecological reserve easement on a portion of their holdings rather than selling outright may derive from the ability to receive compensation for the foregone timber value while retaining ownership and management control over the remaining (non-reserved) acreage. The easement payment effectively monetizes the conservation value of the LSOG stand while the landowner continues to operate commercially on the rest of the property. In cases where the landowner has no strategic interest in retaining the parcel, outright sale to a conservation buyer may indeed be the more straightforward and preferred transaction. Developing new easement models, financing mechanisms, and landowner engagement strategies specifically designed for LSOG protection could establish Maine as a leader in private-lands LSOG conservation and create templates that could be replicated in other forested regions facing similar conservation challenges.

3. Data and Methods

Until now, we have been vague with regard to exactly what we mean when we say old growth or old forests. Over the years, there have been many expert-led efforts to define and categorize exactly what is and is not "old growth" (e.g., Frelich and Reich. 2003; Wirth et al. 2009; Franklin and Spies 1989; Orwig et al. 2001). We hope to avoid issues of semantics here by focusing explicitly on the classes of older structurally complex forests mapped by Hagan et al. (2024), who describe their process for mapping and classifying forests throughout the 4.2 million hectares of unorganized territories of Maine (Figure 3.1).

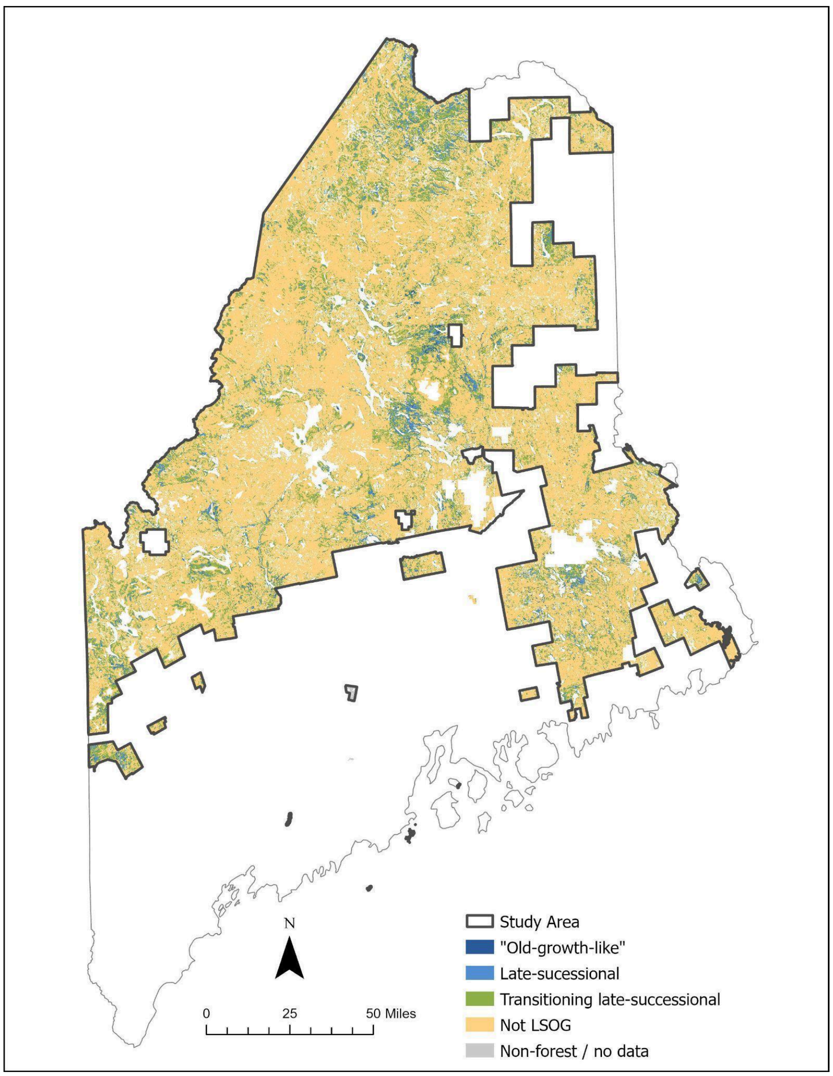


Figure 3.1. The study area is the unincorporated territories of Maine where Hagan et al. 2024 mapped three classes of older forests. Note: Old Growth forests are classified as "Old-Growth-Like" by Hagan et al. due to their mapping relying on modeling rather than ground verification.

Hagan et al. (2024) identify four classes of forest: Old-growth, Late-successional, Transitioning late-successional, and Not late-successional or old growth (Table 3.1). We compared the forest conditions among Hagan's forest classes using the U.S. Forest Service's Forest Inventory and Analysis (FIA) plots (Figure 3.2), which are distributed randomly throughout the state at a density of one plot per 2,428 ha. The precise location of the FIA plots are not public but were available for this analysis thanks to a data-use agreement between the Forest Service and the Harvard Forest (MOU #19-MU-11242305-016). Using FIA plots to summarize forest conditions removes the potential for selection bias to influence outcomes, but it also results in a small sample of rare landscape conditions, such as LSOG. Indeed, there are just 17 FIA plots in the Old Growth-like patches, 67 in the Late Successional category, 264 in Transitioning LS, and 1427 in the remaining Not LSOG area. Despite the sparse sample, the FIA data confirm that the old forest and late successional classes have greater live and dead basal area (and therefore carbon), more large trees, and more diversity of tree species. Contrary to conventional wisdom, there is no observable difference in annual growth (i.e., Basal Area Increment) between the LSOG forest and the younger forest.

Table 3.1. Late-successional and old-growth forest classification taken from Hagan et al. (2024).

<table>
<tr><th>Major Class</th><th>Class Name (code)</th><th>Description</th></tr>
<tr><td colspan="2">Not late-successional or old-growth classes (80%) 3,363,504 ha</td><td>Not late-successional (LSOG) forest. Includes clearcuts, mid-age forest (~30–60 years old), and economically mature commercial forest (~60–100 years old).</td></tr>
<tr><td rowspan="3">Late-successional and old-growth classes (LSOG) (20%) 824,577 ha</td><td>Transitioning late-successional (16%) 662,696 ha</td><td>Forest generally past economic maturity, with a higher density of large trees, large snags, and fallen logs than Not LSOG stands. Transitioning LS could be a late-successional forest stand that has been recently partially cut but still retains significant late-successional qualities, or a commercially overmature stand that could become LS within the next 25–50 years.</td></tr>
<tr><td>Late-successional (LS) (3%) 124,821 ha</td><td>Very high density of large trees and snags and large, downed logs, though not as many as true old-growth. Where harvesting evidence exists, stumps are highly decayed and few in number, suggesting a light harvest ~50 years ago or more, likely targeting large spruce. Cored trees indicate overstory ages generally 150–200 years, with occasional older individuals.</td></tr>
<tr><td>Old-growth (OG) (1%) 37,060 ha</td><td>True old-growth forest by our definition. No evidence or record of harvesting in sampled areas; no logging trails visible on 1960s aerial photographs. High density of large trees and especially large, downed logs. Forest dynamics consistent with steady-state conditions and small- to mid-sized canopy gaps. No recent fire history. Big Reed Reserve served as the primary source of OG training data.</td></tr>
</table>

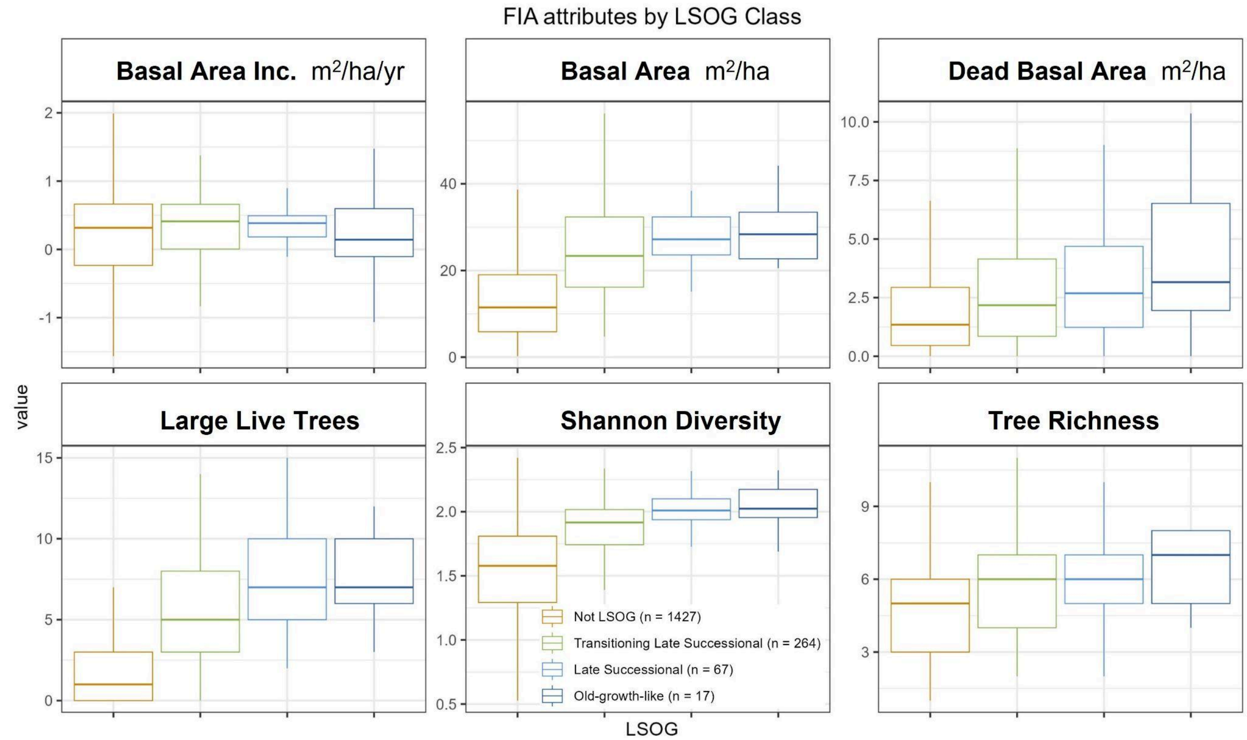


Figure 3.2. Forest structural attributes observed in U.S. Forest Service Inventory plots within the study area and delineated among forest classes of Hagan et al. (2024).

LSOG forests are not evenly distributed across the study area. There is generally more LSOG in the north. We evaluated patches of LSOG calculated using the native 100-m resolution LSOG raster from Hagan et al. (2024) and an eight-neighbor (queen's case) connectivity rule among the LSOG classified pixels to define contiguous LSOG patches. As originally shown in Hagan et al. (2024, 2025), most of the LSOG is in small patches (Figure 3.3). Indeed, more than 75 percent of the area in the OG class is in patches less than 5 ha; 75 percent of LS and OG combined are in patches less than 50 ha. The largest single patch of LSOG (excluding the transitioning class) is 957 ha, and the top-10 largest patches combined cover 5,172 ha. LSOG forests are more common near streams and rivers, away from roads, and on steeper slopes.

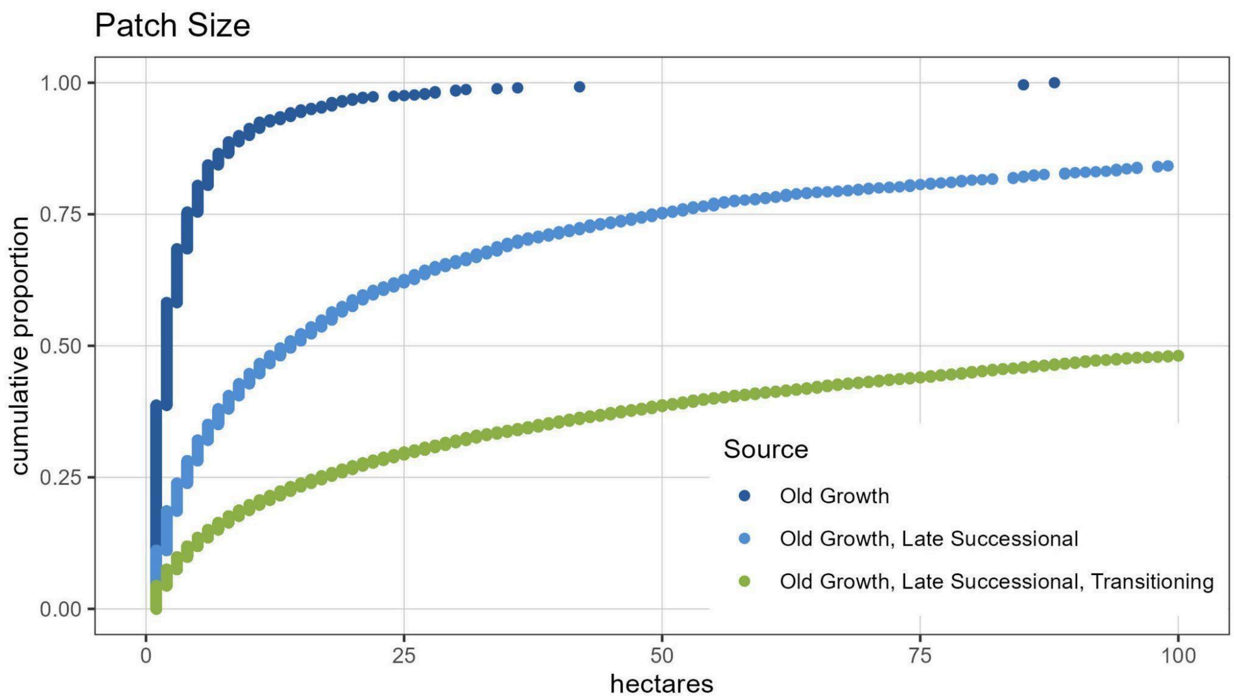


Figure 3.3 Cumulative distribution of patch sizes. For example, the figure shows that 75% of LS+OG (light blue) are in patches smaller than 75 hectares.

Of the 161,881 ha of LS and Old Growth-like, 14,992 ha (26 percent) is legally protected from conversion and harvest[1]. We determine this protection status from its GAP status, provided by The Nature Conservancy (Crist 1998, TNC 2024) or from Foster et al. (2023) in *Wildlands of New England Database.* The protected LSOG lands are primarily state-owned lands in wildland reserve status. With 6,717 ha of OG+LS+TLS and 1,407 ha of OG+LS, Baxter State park is the largest example. Private non-profit groups have fee-title ownership of another 32,684 ha of OG+LS+TLS and 10,040 ha of OG+LS, which have administrative protections against harvests.

[1] Note the Hagan et al. 2025 report similar but slightly different statistics. This is because we use the NEPOS (2025) conservation database while Hagan et al. used PADUS (USGS 2024).

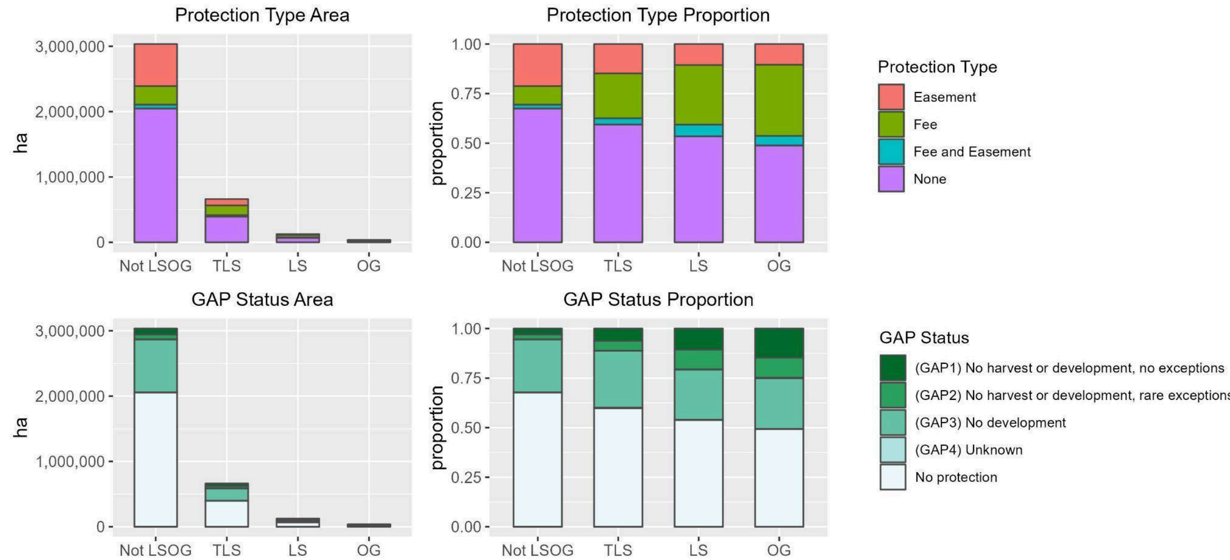


Figure 3.4. Existing land protections within the Study Area.

For the remainder of this study, we focus on the 125,922 ha that are not protected from harvest and are classed as Old Growth-like and Late Successional, hereafter unprotected LSOG (Table 3.2). Roughly two-thirds of that is privately owned by diverse timber interests (Figure 3.5). Note that 14,762 ha are in working forest easements (as defined by Thompson et al. 2024); however, these offer no protections from harvest and therefore remain in the Unprotected category.

Table 3.2. LSOG Area (ha) by Aggregate Ownership and Protection Status

Reporting Area	Hectares
Transitioning late-successional (TLS) + Late-successional (LS) + Old-growth (OG).	824,577
Late-successional (LS) + Old-growth (OG).	161,881
Protected LS + OG.	35,959
Unprotected LS + OG.	125,922
Unprotected (Private) LS + OG.	102,672
Unprotected (Public) LS + OG.	23,250

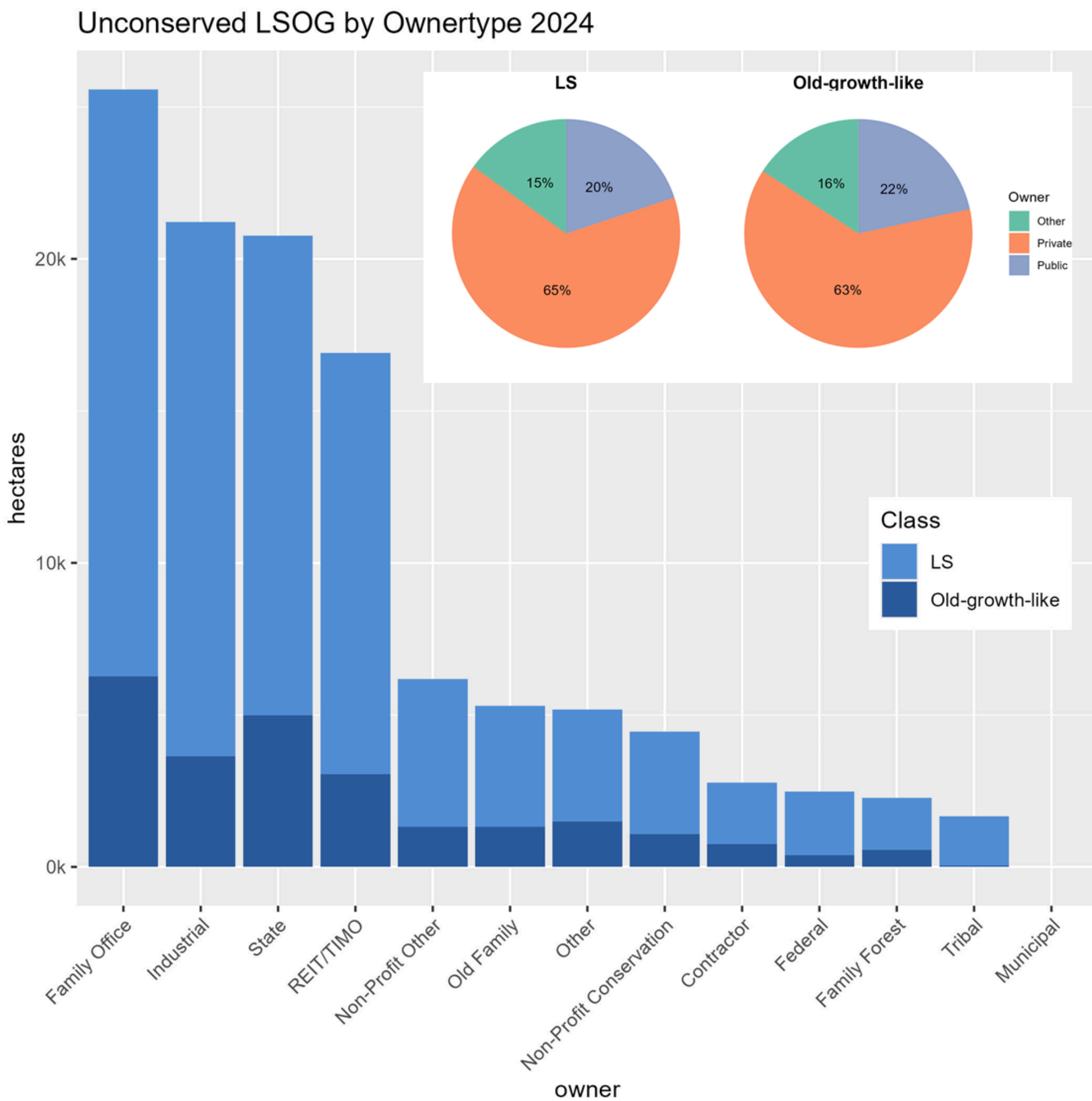


Figure 3.5. Area of unconserved Late Successional (LS) and Old-Growth-like forests (as classified by Hagan et al. 2024). Owner classes taken from Gao et al. (2026) please see Appendix A. for class definitions. Note: Old Growth forests are classified as "Old-Growth-Like" by Hagan et al. due to their mapping relying on modeling rather than ground verification.

3.1 Prioritization Criteria

Funding for old-growth protection in Maine is limited; therefore, conservation investments must be strategically prioritized among the newly mapped LSOG stands. Multiple prioritization frameworks are possible depending on which ecological, climate, or socio-economic objectives are emphasized (e.g., see Börner et al. 2020; Hagan et al. 2025). Here, we evaluate four complementary criteria that reflect widely recognized dimensions of conservation value and risk: patch size, carbon stocks, local connectedness, and harvest threat. These four criteria are uncorrelated (i.e., Pearson < 0.1) and, together, capture key differences among LSOG stands in terms of ecological function, climate mitigation potential, landscape context, and vulnerability to near-term loss. In practice, each of these metrics offers only a best estimate that would need to be validated in the field before any conservation investment is committed.

For each LSOG patch, we calculate a single score for each of the criteria. As discussed above, there are 12,493 OG patches and 22,429 OG+LS patches; they range in size from 1 to almost 1000 ha; and most of the patches are small (i.e., > 75 % of patches are < 50 ha) Patches exist within a matrix of forests of varying structural and conditions and ownerships. Approximately, 97 percent (21,635 patches) occur on a single ownership, 3 percent (746 patches) are split across two owners, and just 0.2 percent (43 patches) have three owners.

Patch Size is a foundational criterion in conservation planning because larger forest patches tend to support greater ecological resilience and diversity (Didham 2010). Large old forest patches are generally more resilient to disturbance, contain greater internal habitat heterogeneity, and experience reduced edge effects relative to smaller fragments (Spies and Franklin 1995). They are also more likely to sustain viable populations of area-sensitive species and to maintain ecological processes such as gap dynamics and natural disturbance regimes (Runkle 1982). From a landscape perspective, protecting large patches can enhance regional connectivity of intact forest. In addition, transaction costs for achieving land protection are lower on a per area basis when applied to larger patches.

We emphasize that prioritizing larger patches does not imply that small LSOG patches lack conservation value. Numerous studies demonstrate that small patches can function as important reservoirs of biodiversity (Lindenmayer 2019) and ecosystem services, including carbon storage (Blumstein and Thompson 2015), particularly in fragmented landscapes. Rather, patch size represents one plausible prioritization lens among several, useful for understanding trade-offs among alternative investment strategies.

Carbon Stocks: LSOG forests often contain disproportionately high aboveground carbon densities relative to younger forests, reflecting long periods of biomass accumulation and structural development (McGarvey et al. 2013; Gunn et al. 2014). Protecting these stands from harvest therefore represents a high-leverage opportunity for climate change mitigation by avoiding near-term carbon emissions and maintaining long-term carbon storage. In addition, intact LSOG forests may provide greater carbon stability through resistance to disturbance and slower turnover rates.

Estimates of aboveground live carbon stocks were derived from Gao et al. (2026), who produced a 10-m spatially explicit imputation of FIA data. This imputation integrates field observations with remotely sensed covariates using the AlphaEarth Embeddings developed by Google DeepMind (Brown et al. 2025). These data provide high-resolution, spatially continuous estimates of live aboveground carbon suitable for stand-level prioritization.

Local Connectedness: Local connectedness refers to the degree to which a landscape facilitates ecological movement, as influenced by fragmentation and barriers to movement. Highly connected landscapes promote ecological resilience by enabling species to move among habitat patches, track shifting climatic conditions, and access suitable microclimates. Connectivity is particularly important under climate change, as it supports adaptive responses across spatial scales.

We use The Nature Conservancy's Local Connectedness metric (TNC 2022), which characterizes landscape permeability, i.e., the degree to which the landscape is conductive to movement, dispersal, and the natural flow of ecological processes. Barriers that increase resistance to movement such as major roads, developed areas, energy infrastructure, and intensively managed agricultural and forestry lands contribute to low connectedness scores while continuous tracts of forest, low slopes, etc., facilitate local movement, range shifts, and the potential for the reorganization of species communities (TNC 2016). LSOG stands embedded within more connected landscapes are prioritized under this criterion because their conservation value extends beyond stand boundaries, contributing to broader landscape-scale resilience.

TNC provides the Local Connectedness measure as a 30-m resolution raster map with eight classes representing an ordinal ranking from Developed (0) to Most Connected (7). We treat the index as continuous by calculating the mean value for each patch, resulting in a patch-level Local Connectedness score ranging from 0 to 7.

Harvest Threat: Prioritization based on threat recognizes that conservation gains are greatest where the risk of loss is high. While it is impossible to predict with certainty which LSOG stands will be harvested in the future, the probability of harvest can be estimated based on observed patterns and site attributes associated with past harvesting activity.

We modeled harvest threat using observations of timber harvesting between 2010 and 2018 (Pasquerella et al. 2023). Harvest risk was estimated using the Dinamica EGO land-use change modeling platform (Soares-Filho et al. 2002, 2009), which applies a Bayesian Weights of Evidence (WoE) approach to quantify the influence of spatial predictors on the likelihood of land-use or land-cover change. Dinamica EGO is a cellular automata model that estimates the probability of harvesting at each location based on a suite of predictor variables previously shown to influence harvesting decisions (Thompson et al. 2017). Predictor variables include: distance to roads, distance to streams and rivers, forest type, land ownership, parcel size, and slope. LSOG stands with higher modeled probabilities of harvest are prioritized under this criterion due to their elevated risk of near-term loss.

Composite Score: We also prioritized the LSOG stands using a composite index that combined the four preceding conservation criteria (Patch Size + Carbon Stocks + Local Connectedness + Harvest Threat). Each of the individual criteria maps were rescaled using a 0 to 1 stretch before being averaged to create a composite score map. This stretch preserved the underlying distribution of each variable while aligning the minimum and maximum pixel values at 0 and 1. The resulting composite score map ranges from 0 to 1, with composite scores for each patch calculated using the mean value of all pixels within the patch (Figure 3.6).

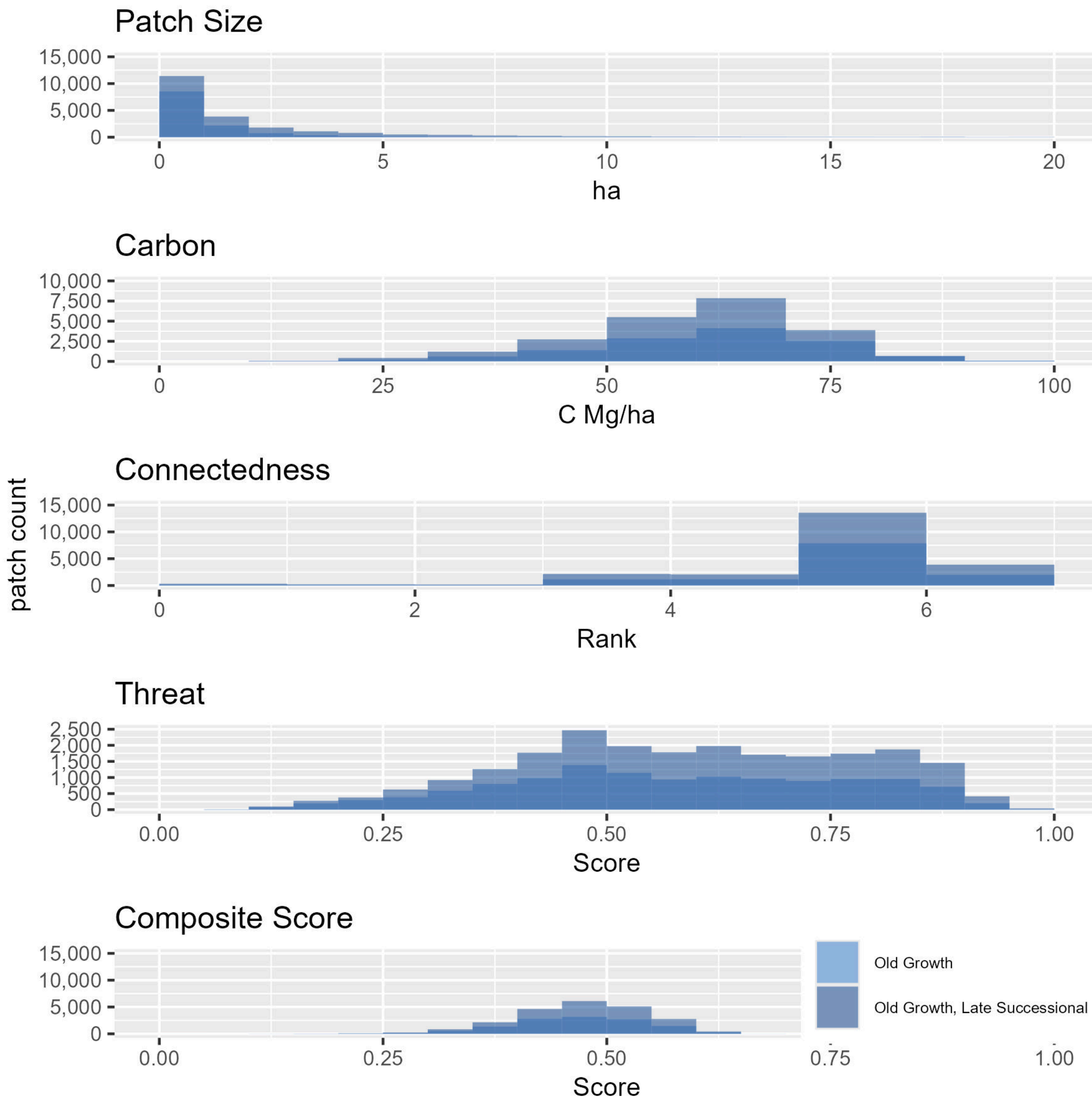


Figure 3.6. The distribution of prioritization scores for LSOG patches

3.2 Estimating the Costs of LSOG Protection

Based on our review of potential conservation instruments, we focus on three mechanisms for compensating private landowners for protecting LSOG that differ in both their permanence and the asset being valued. These mechanisms span a gradient from permanent to non-permanent protection and from valuation of land and timber to valuation of ecosystem services. Specifically, we estimate costs associated with (1) permanent fee-title acquisition, which compensates landowners for both land and standing timber; (2) forgone timber value, represented by stumpage values that would be realized under harvest; and (3) carbon value, representing compensation for avoided emissions and long-term carbon storage (Figure 4.1). Together, these approaches provide a standardized and comparable framework for evaluating the relative costs of alternative LSOG protection strategies at the LSOG patch scale, rather than a prediction of which mechanisms are feasible or optimal in practice.

Permanent Fee-Title Acquisition

To estimate the cost of permanent fee-title acquisition of LSOG forests (including both land and timber value) we relied on parcel-scale land value estimates from the Private-Land Conservation Evidence System (PLACES) geodatabase (Nolte 2020). PLACES provides spatially explicit estimates of private land values across the United States, derived from observed private land transactions and associated parcel characteristics.

PLACES land values were resampled to a 100-m resolution to match the spatial resolution of the LSOG dataset and adjusted to 2025 U.S. dollars using the Consumer Price Index. Because the private land transactions used to train the PLACES model implicitly reflect the expected value of standing timber on the parcel at the time of sale, directly adding LSOG stumpage values would result in double-counting timber value.

To address this, we first adjusted PLACES land values by subtracting the mean stumpage value associated with non-LSOG forest conditions (estimated at $1,875 ha^{-1}), representing the typical timber value embedded in baseline land prices. We then added the estimated LSOG-specific stumpage values derived from our timber valuation analysis. This adjustment yields an estimate of fee-title acquisition cost that reflects both underlying land value and the elevated timber value associated with LSOG conditions, while avoiding double-counting of timber already incorporated in market land prices.

Estimating the Value of LSOG Timber

To estimate the potential timber value of LSOG forests, we calculated stumpage value, defined as the price paid to a landowner for standing timber immediately prior to harvest, or in this case the current merchantable stock. As with carbon estimates, we relied on the spatial imputation of Forest Inventory and Analysis (FIA) plot data developed by Gao et al. (2026), which provides spatially explicit estimates of tree species composition and size structure across the study area.

For each imputed FIA plot, we assigned stumpage values to individual trees based on species and diameter class, following the methods described by Zhao et al. (2020). This approach applies regionally appropriate stumpage prices and explicitly differentiates between pulpwood and sawlog products based on tree size thresholds, allowing timber value to vary with stand structure and composition. Tree-level stumpage values were then aggregated to the plot level to estimate total stumpage value per unit area, which was subsequently mapped across LSOG stands.

This approach has some limitations. First, it does not attempt to identify or assign premiums for exceptionally high-value products such as veneer logs, which may be more abundant on LSOG stands due to the larger average tree size. Second, it does not account for access constraints or harvest costs, which may be higher on these remnant stands that may be disproportionately found on inoperable lands (thus explaining why they've not been previously harvested). As a result, estimated stumpage values should be interpreted as standardized, relative indicators of potential timber value rather than as predictions of realizable revenues from specific harvest operations.

Estimating the Value of LSOG Carbon

We estimated the potential economic value of carbon stored in LSOG forests by bracketing carbon prices using values observed in both the California compliance market and voluntary carbon markets. Standing aboveground live carbon stocks, expressed in units of megagrams of CO_2-equivalent (Mg CO_2e [2]), were estimated using spatially explicit data from Gao et al. (2026).

To approximate the number of market-eligible carbon credits under a compliance-market framework, we applied a simplified baseline-and-additionality approach consistent with forest carbon protocols. We defined a regional baseline as the mean aboveground live carbon stock (Mg CO_2e) of FIA plots within the corresponding U.S. Forest Service ecological region and FIA Forest Group Type. The difference between this baseline and the estimated carbon stock of each LSOG stand was interpreted as the amount of additional carbon attributable to LSOG conditions, and thus as the number of potential carbon credits. We estimated the monetary value of these credits by applying a price of $30 per Mg CO_2e, which approximates recent prices in the California compliance market.

For the voluntary carbon market, we assumed that all standing aboveground live carbon in LSOG forests would be treated as additional, but applied a substantially lower credit value of $7 per Mg CO_2e, reflecting typical prices observed in voluntary markets (Forest Trends' Ecosystem Marketplace 2023). Together, these two approaches provide lower- and upper-bound estimates of the potential economic value of LSOG carbon, rather than a prediction of realizable market revenues. Note, however, that these carbon value estimates are intended as an analytical metric for comparing relative conservation

[2] We convert to carbon dioxide equivalents by multiplying the mass of the aboveground forest carbon by 3.67. This ratio is derived from the molecular weight of CO_2.

priorities among LSOG stands and should not be interpreted as projections of market feasibility, project eligibility, or realizable revenues under existing carbon offset protocols.

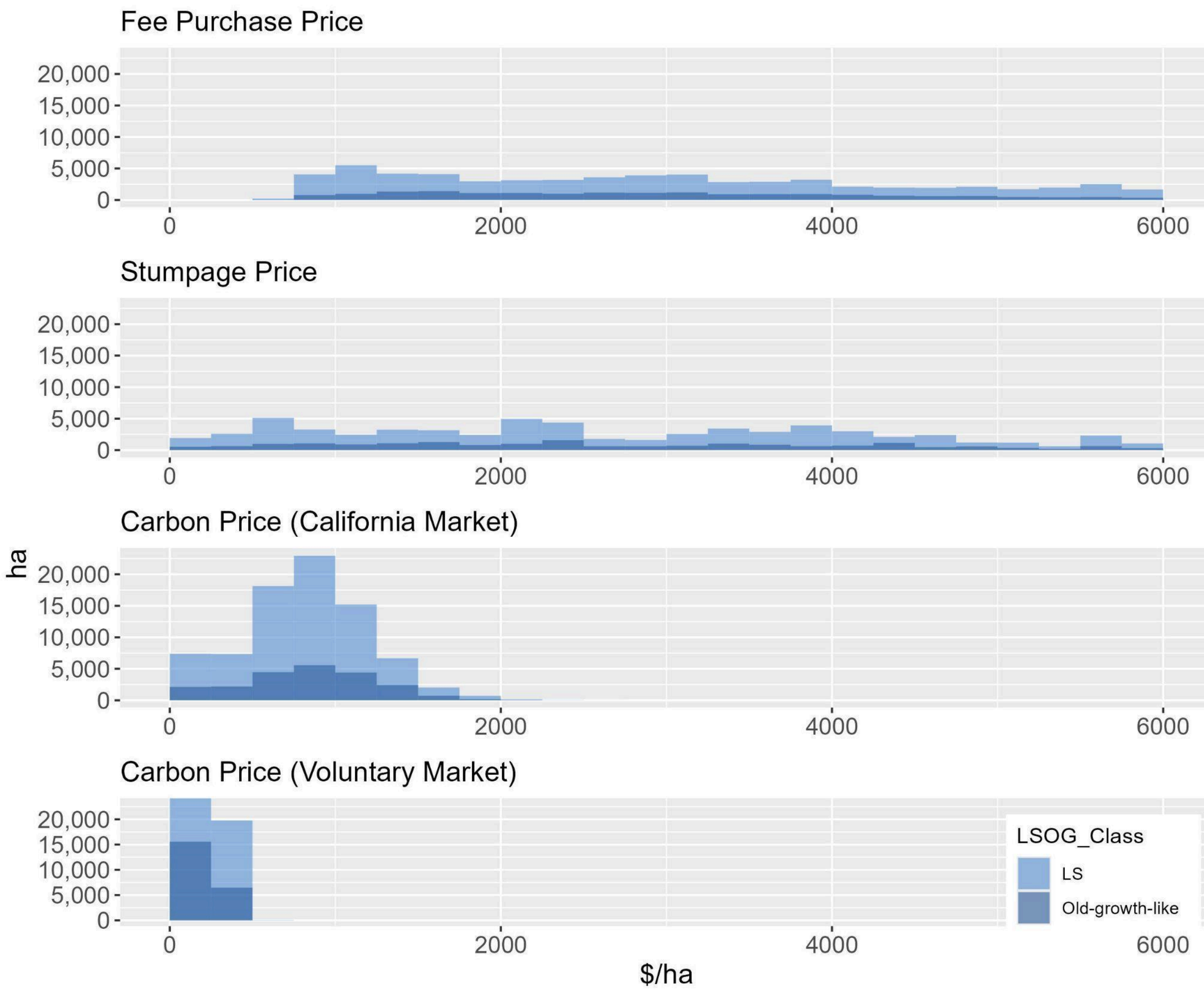


Figure 4.1 The distribution of costs estimated for multiple attributes of LSOG patches

4. LSOG Protection Options

Hagan et al. (2024) identified 124,821 ha of Late Successional and 37,060 ha of Old Growth-like forests (161,881 ha combined). Of these, 125,922 ha have no codified protections from future harvesting, with 80 percent on privately owned land. We estimate an average per hectare cost of privately held LSOG forestland at $3,799 (SD = $2,388), meaning that the cost to purchase all of the privately held LSOG would exceed $422 million (Figure 4.1).

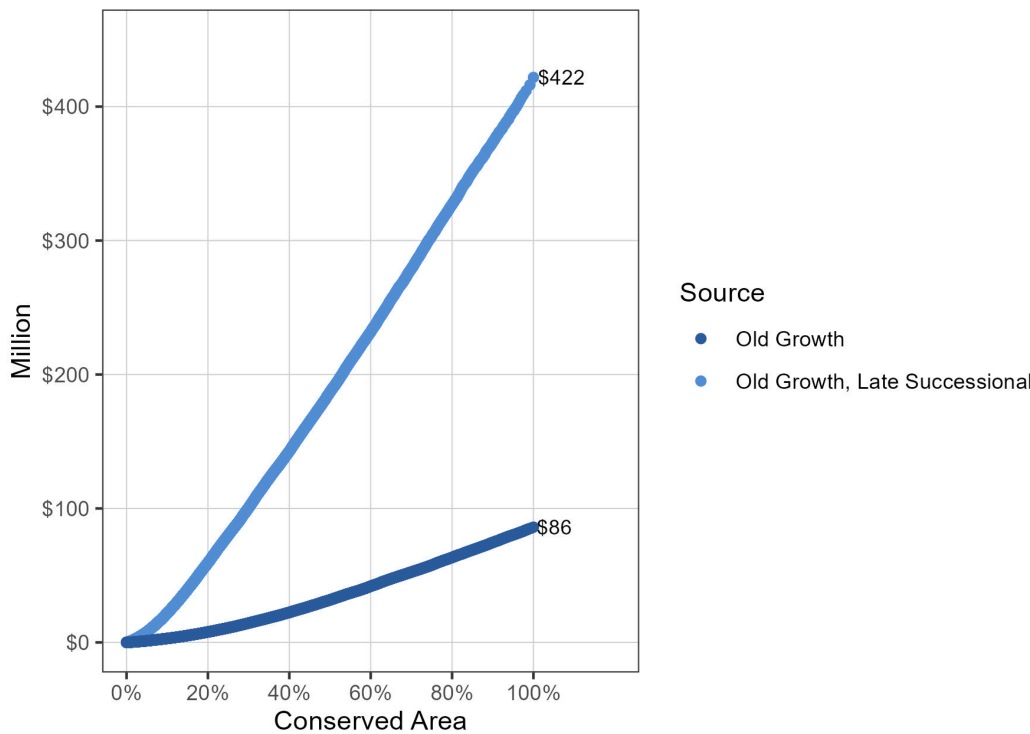
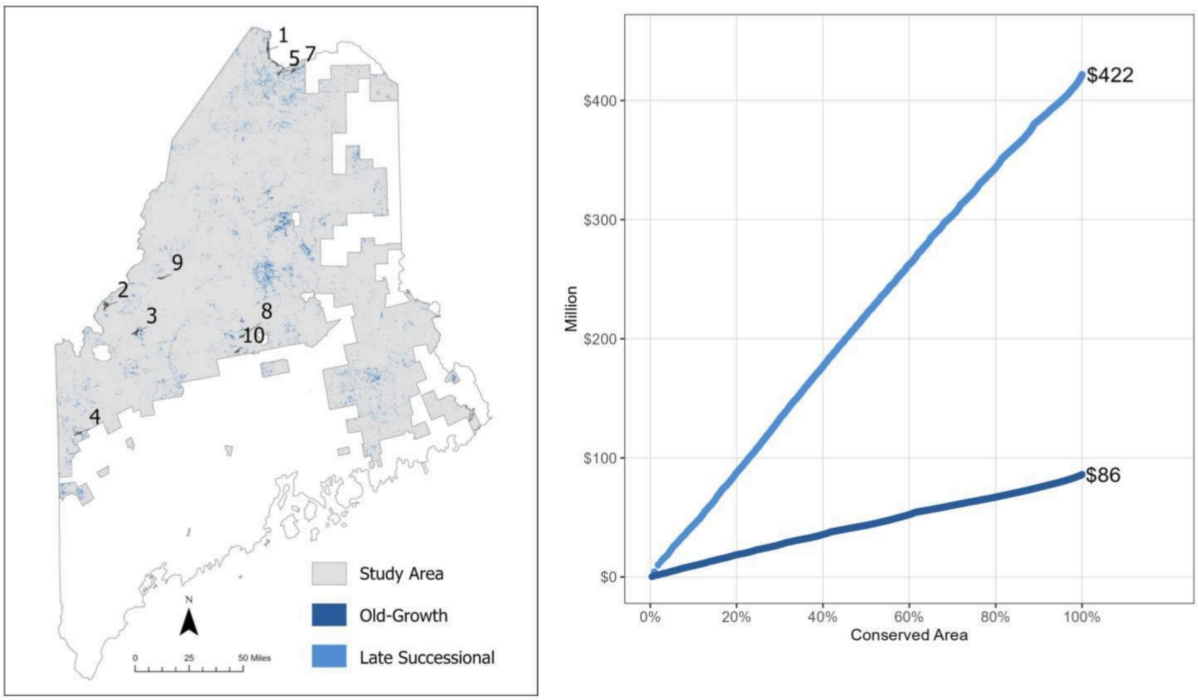


Figure 4.1 Estimated cost of fee title purchase of LSOG patches ordered from least to highest cost patches.

4.1 Prioritizing the largest LSOG patches

The largest patches of LSOG are clustered in the far north and in the Western Mountain Region (Figure 4.2) Eight of the 10 largest unprotected patches of LSOG are held by private timber owners, underscoring the importance of engaging large private landholders in any near-term protection strategy. A private Family Office with extensive land holding, owns three of the 10 largest patches, all in far northern Maine, including the single largest unprotected LSOG patch (just under 1,000 ha). The second-largest patch (886 ha) is Tribally owned, and the eighth-largest patch (355 ha) is owned by a regional conservation organization.

If conservation efforts were to prioritize protection of the largest remaining LSOG patches, and if transactions could be structured to parcel these areas out of larger private timber holdings (excluding Tribal and conservation-organization lands), we estimate the total acquisition cost of the 10 largest patches would be approximately $16 million to protect these 3,932 ha. While constituting just 4 percent of the total unprotected LSOG, this estimate suggests that protection of the very largest LSOG patches may be financially feasible at a scale commensurate with other regional conservation initiatives.



Map ID	Patch Size (ha)	Carbon (Mg/ha)	Connectedness	Threat	Stumpage ($/ha)	Composite Score	Fee Price $/ha	Total Fee Price	Owner Type
1	972	63.9	6.6	486.0	4,959	0.78	4,560	4,432,752	REIT/TIMO
2	886	66.8	7.0	589.1	4,228	0.82	6,348	5,624,381	Tribal
3	684	73.3	6.5	572.1	3,571	0.76	4,328	2,960,079	Family Office
4	500	73.5	6.9	570.3	3,700	0.72	4,367	2,183,271	Family Office
5	409	69.4	6.3	426.9	3,662	0.62	2,935	1,200,308	REIT/TIMO
6	388	72.6	6.5	445.7	4,338	0.63	3,656	1,418,648	REIT/TIMO
7	356	71.1	6.0	325.6	3,391	0.56	2,689	957,327	Industrial
8	355	66.4	6.8	648.1	2,413	0.69	5,774	2,049,778	Non-Profit Conservation
9	326	71.0	6.8	566.8	5,172	0.67	5,035	1,641,333	Old Family
10	296	77.2	5.9	525.6	4,503	0.63	5,200	1,539,129	Family Office

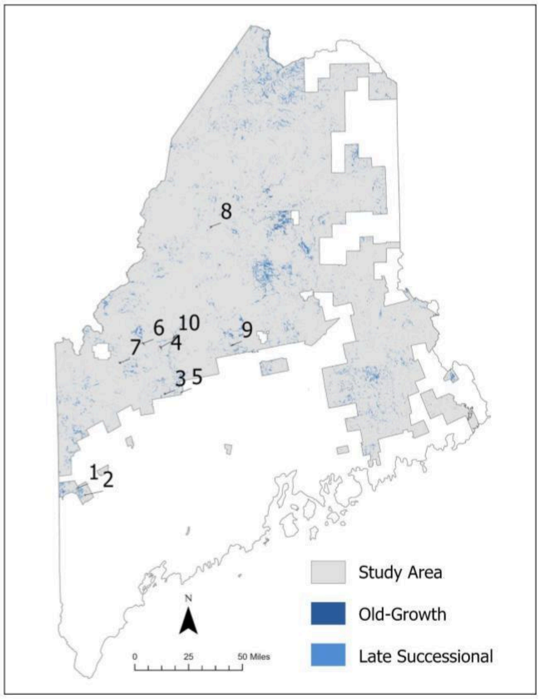
Figure 4.2: Location and cost of the largest patches of LSOG. The 10 largest patches are shown for illustrative purposes; the full list of all LSOG patches ranked by size are provided in supplemental data.

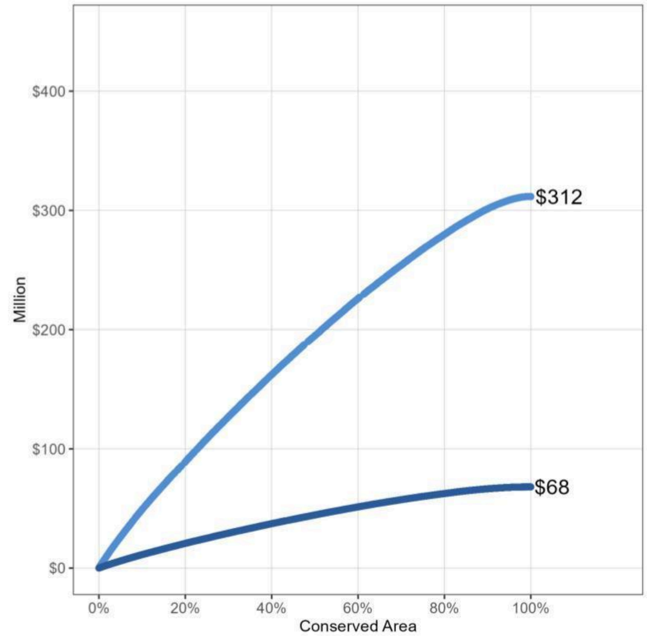
4.2 Prioritizing LSOG based on Carbon Density

Across all LSOG patches within the study area, including the public and protected LSOG, mean carbon density per patch ranges from 8.0 to 103.3 Mg C/ha, with an overall average of 61.5 (SD = 12.3). Figure 4.3 highlights the 10 most carbon-dense LSOG patches; however, this analysis is restricted to patches larger than 50 ha. Without this size threshold, the top 100 ranked patches are all less than 6 ha in size, reflecting small, highly carbon-dense fragments that are unlikely to be viable targets for conservation transactions. We therefore impose the 50 ha cutoff to focus on patches of a scale more appropriate for land protection, carbon offset projects, or other conservation instruments.

Among unprotected privately owned LSOG patches less than 50 ha, carbon density ranges from 40 to 93 Mg C/ha, with an average of 69 (SD). The most carbon-dense of these privately held patches are concentrated in the southern portion of the study area (Figure 4.3), suggesting a geographic clustering of high-carbon LSOG that likely reflects underlying gradients in forest composition, productivity, or management history. Notably, seven of the 10 most carbon-dense LSOG patches are owned by non-corporate landowners with relatively small holdings. This pattern may reflect less-intensive management histories typical of non-industrial private forest owners (e.g., Thompson et al. 2017), which can promote the accumulation and retention of forest carbon over time.

In aggregate, we estimate that privately held, unprotected LSOG contains approximately 25 million Mg of CO_2e, the equivalent to the annual emissions of approximately 5 million passenger vehicles. If a clear and credible mechanism existed to monetize this carbon through offset markets, the full pool of private unprotected LSOG could generate an estimated $311,594,671 under the California regulatory market or $72,393,828 under voluntary carbon markets. Restricting offset crediting to only the most carbon-dense patches, such as the 10 shown in Figure 4.3 would yield substantially higher returns, estimated at approximately $4,500 to $5,500 per hectare initial one-time payout on the California Market, or $1,000 to $1,300 on the voluntary market.



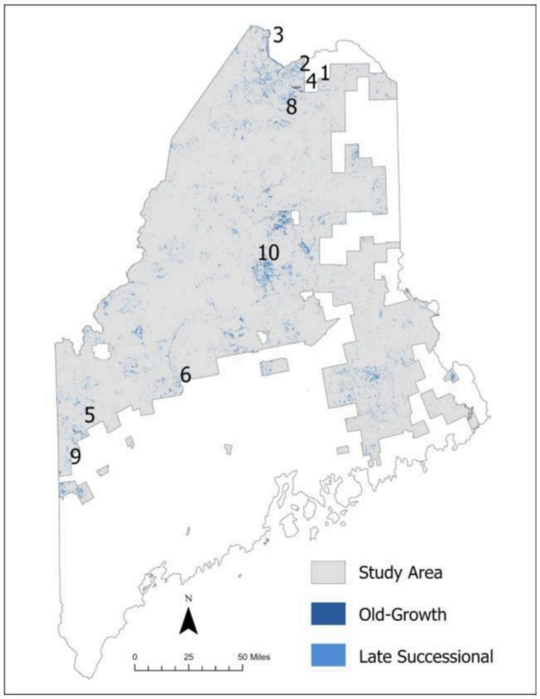


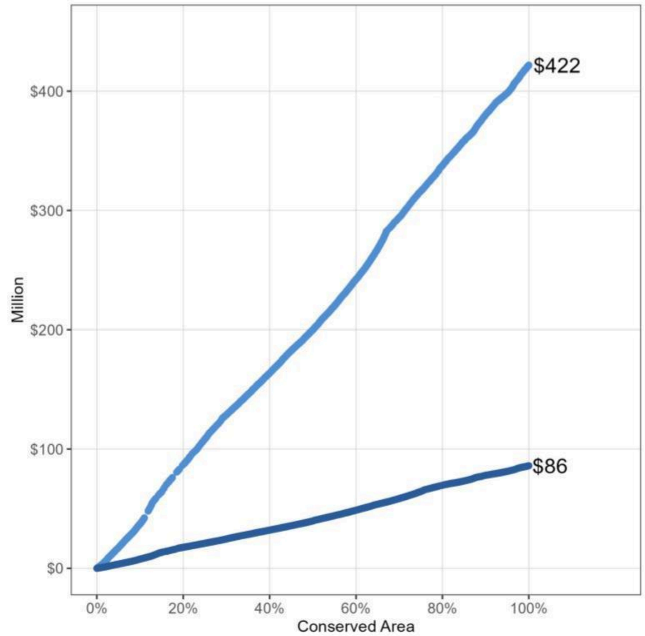
Map ID	Patch Size (ha)	Carbon (Mg/ha)	Connectedness	Threat	Stumpage ($/ha)	Composite Score	Fee Price $/ha	Total Fee Price	Owner Type
1	57	93.5	5.8	480.0	6,541	0.59	8,491	484,011	Unknown
2	52	87.7	5.8	471.6	4,325	0.57	7,141	371,354	Unknown
3	105	86.3	5.9	581.2	4,523	0.62	6,514	683,926	Unknown
4	125	85.0	6.8	453.2	4,878	0.61	6,791	848,816	Family Forest
5	59	83.8	4.8	518.2	3,755	0.54	7,214	425,621	Unknown
6	73	82.7	6.2	461.7	5,289	0.57	6,865	501,173	Family Office
7	96	82.2	3.2	304.0	5,278	0.41	10,051	964,939	Unknown
8	59	82.2	6.0	205.6	6,202	0.47	5,904	348,352	REIT/TIMO
9	107	81.9	5.9	588.4	4,079	0.61	4,580	490,053	Unknown
10	85	81.3	6.2	509.1	4,387	0.59	5,107	434,088	Unknown

Figure 4.3 Top 10 patches ranked by their average carbon density

4.3 Prioritizing based on Local Connectedness

We used The Nature Conservancy's Local Connectedness ranking system to assess the landscape context of unprotected private LSOG. This metric is based on a seven-point ordinal scale, which we averaged across each patch to derive a continuous 0 to 7 metric, with a score of seven indicating the highest level of local forest connectivity. We find that 12.8 percent of the unprotected private LSOG area receives the maximum score of seven. Many of the smaller LSOG patches also have an average connectedness score of seven, including all of the top 10 patches shown in Figure 4.4.





Map ID	Patch Size (ha)	Carbon (Mg/ha)	Connectedness	Threat	Stumpage ($/ha)	Composite Score	Fee Price $/ha	Total Fee Price	Owner Type
1	89	66.3	7.0	331.9	2,112	0.52	1,499	133,413	Industrial
2	191	55.9	7.0	309.1	3,031	0.51	2,509	479,193	Industrial
3	52	63.8	7.0	558.2	2,056	0.58	2,606	135,514	Other
4	56	62.2	7.0	335.6	3,239	0.50	2,691	150,672	Industrial
5	94	63.2	7.0	632.9	1,510	0.62	2,848	267,697	Family Office
6	86	67.7	7.0	495.5	3,250	0.58	3,179	273,383	Other
7	122	66.7	7.0	311.7	3,996	0.52	3,197	390,066	Industrial
8	55	69.9	7.0	622.2	3,997	0.62	3,223	177,285	Family Office
9	60	74.2	7.0	461.5	3,200	0.58	3,362	201,740	Family Forest
10	59	80.3	7.0	420.5	3,656	0.58	3,763	222,015	Old Family

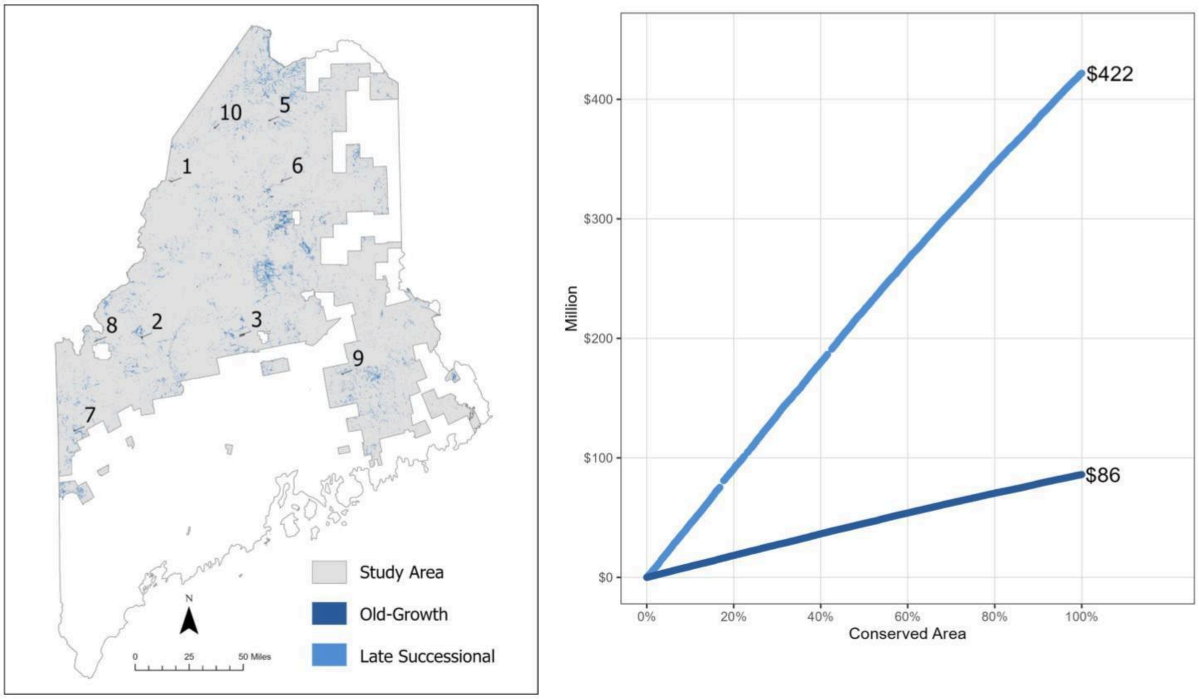
Figure 4.4 Top 10 patches ranked by their Local Connectedness scale

4.4 Prioritizing based on Harvest Threat

We estimate harvest risk using an empirical model that relates observed harvesting patterns to proximity to roads, streams, and rivers; forest type; ownership class; slope; and other site characteristics. These relationships are used to infer the relative likelihood that a given LSOG patch will be harvested. If conservation efforts were to prioritize LSOG protection based on near-term risk, these high-threat patches would be logical initial targets. However, important uncertainty remains. We have no direct information on whether or when individual LSOG patches will be harvested, and the presence of large standing timber volumes on these sites raises a key question: if LSOG patches are economically attractive to harvest, particularly on lands owned by industrial timber interests, why have they not already been cut? Possible explanations include access constraints, operational considerations, long-term management strategies, certification requirements, or intentional retention, but these factors cannot be resolved with available data. As a result, harvest-risk rankings should be interpreted as relative indicators of vulnerability rather than predictions of imminent harvest.

LSOG patches with the highest estimated harvest threat are broadly distributed across the study area and span a range of ownership types (Figure 4.5). These include lands held by conservation organizations, as well as large private timber owners. To the extent that landowners are willing to share harvest schedules or management plans, protection efforts could be more precisely targeted toward LSOG that is demonstrably at risk.

This targeted approach is exemplified by the strategy currently employed by New England Forestry Foundation (NEFF), which focuses on purchasing temporary harvest deferrals rather than acquiring land outright (Milakovsky 2025). Under this model, NEFF compensates landowners for postponing harvest for a defined period, typically by paying a negotiated portion of the estimated stumpage value of LSOG that is explicitly slated for harvest under an existing management plan. This approach is cost-effective insomuch as it succeeds in protecting the most imminently threatened LSOG. However, because these agreements are time-limited; once the deferral period expires, landowners are again free to harvest unless additional conservation measures are secured.



Map ID	Patch Size (ha)	Carbon (Mg/ha)	Connectedness	Threat	Stumpage ($/ha)	Composite Score	Fee Price $/ha	Total Fee Price	Owner Type
1	90	64.6	6.2	666.4	5,894	0.61	5,672	510,477	Non-Profit Conservation
2	108	77.1	7.0	651.8	3,758	0.66	5,302	572,669	Other
3	355	66.4	6.8	648.1	2,413	0.69	5,774	2,049,778	Non-Profit Conservation
4	74	72.8	5.9	640.9	6,232	0.60	5,518	408,311	Family Office
5	52	56.8	5.8	640.6	3,579	0.55	3,246	168,803	Family Office
6	96	70.5	5.9	634.9	6,222	0.60	7,163	687,647	Family Office
7	94	63.2	7.0	632.9	1,510	0.62	2,848	267,697	Family Office
8	55	73.3	6.0	630.5	4,157	0.60	4,307	236,859	Family Office
9	51	51.0	6.0	629.7	2,073	0.54	3,232	164,828	Family Office
10	70	72.3	5.9	625.6	4,270	0.59	3,582	250,735	Unknown

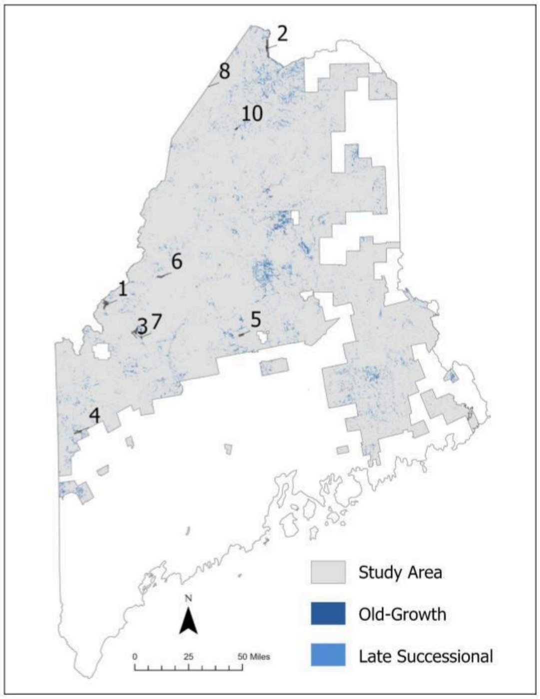
Figure 4.5 Top 10 patches ranked by their relative threat of timber harvest

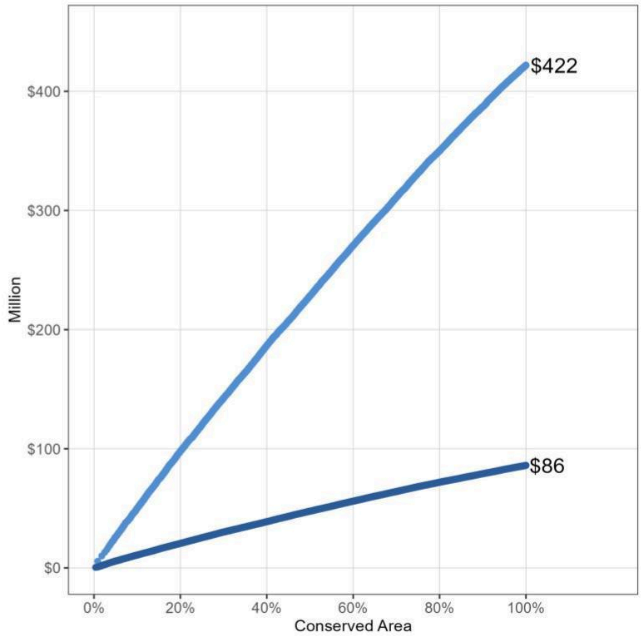
4.5 Prioritizing using a Multi-Criteria Approach

Our final prioritization integrates the four preceding criteria into a single composite index: patch size, carbon density, local connectedness, and harvest threat. Each criterion is weighted equally, reflecting an intentional choice to balance ecological value, climate significance, landscape context, and relative harvest threat, rather than elevating any single dimension. This composite score is designed to identify LSOG patches that perform consistently well across multiple conservation objectives, rather than those that excel on only one metric.

The highest-ranked LSOG patches under the composite index largely identify LSOG patches previously at the top of the individual rankings (Figure 4.6), indicating a high degree of concordance among criteria. The very highest-ranked patches are all larger than 300 hectares and also rank at or near the top of the patch-size criterion. Seven of the 10 highest composite scores also appear in at least one of the individual top-10 lists, suggesting that these sites represent robust "no-regrets" candidates for protection regardless of the specific conservation lens applied.

Importantly, the composite index also elevates several patches that do not rank at the very top for any single criterion but perform well across all four dimensions. These sites may be overlooked in single-metric prioritizations yet represent strong candidates for strategic investment, particularly where conservation goals include permanence, climate mitigation, and landscape-scale connectivity.





Map ID	Patch Size (ha)	Carbon (Mg/ha)	Connectedness	Threat	Stumpage ($/ha)	Composite Score	Fee Price $/ha	Total Fee Price	Owner Type
1	886	66.8	7.0	589.1	4,228	0.82	6,348	5,624,381	Tribal
2	972	63.9	6.6	486.0	4,959	0.78	4,560	4,432,752	REIT/TIMO
3	684	73.3	6.5	572.1	3,571	0.76	4,328	2,960,079	Family Office
4	500	73.5	6.9	570.3	3,700	0.72	4,367	2,183,271	Family Office
5	355	66.4	6.8	648.1	2,413	0.69	5,774	2,049,778	Non-Profit Conservation
6	326	71.0	6.8	566.8	5,172	0.67	5,035	1,641,333	Old Family
7	108	77.1	7.0	651.8	3,758	0.66	5,302	572,669	Other
8	6	78.3	7.0	711.7	4,152	0.66	4,298	25,790	Family Office
9	294	80.6	6.3	541.0	3,959	0.66	5,498	1,616,468	Other
10	156	71.2	7.0	620.8	4,716	0.65	4,068	634,595	Family Office

Figure 4.6 Top 10 patches ranked by the composite prioritization scale

4.6 Public Lands

Approximately 20 percent of currently unprotected late-successional and old-growth (LSOG) forest in Maine occurs on public lands, including state-owned lands managed by the Maine Bureau of Parks and Lands and federally owned lands within the White Mountain National Forest (WMNF). The publicly owned LSOG includes some of the largest remaining unprotected patches in the state (e.g., three patches exceeding 400 ha) as well as some of the most carbon-dense stands, including an 90-ha patch on state land with a mean carbon density of 88 Mg C ha^{-1} and a 480-ha patch on WMNF with a mean density of 86 Mg C ha^{-1} (Figure 4.7). From a public policy perspective, these lands represent a comparatively straightforward opportunity for LSOG protection, as existing management authorities could codify reserve designations without the need to compensate private landowners.

Designating LSOG on public lands as reserves would entail limited direct financial cost but would reduce timber harvest opportunities on those lands, with potential implications for agency objectives and for the forest products industry and local logging contractors. However, public lands in Maine already experience substantially lower harvest intensity than private industrial and non-industrial forestlands (Thompson et al. 2017), suggesting that the marginal reduction in timber supply from additional reserve designations would be modest at the regional scale. Moreover, both the Maine Bureau of Parks and Lands and the WMNF have demonstrated institutional capacity to manage lands with little or no timber harvest through existing ecological reserve and wilderness designations. Indeed, the two largest ecological reserves in New England are Baxter State Park and the wilderness areas of the White Mountain National Forest (Foster et al. 2023), illustrating that large, permanently protected forest landscapes are administratively feasible within existing governance structures. As a result, expanding reserve status on public lands may represent one of the lowest-cost and lowest-barrier pathways for increasing LSOG protection in Maine, particularly as an initial step while more complex private-land conservation strategies are developed.

Map ID	Patch Size (ha)	Carbon (Mg/ha)	Connectedness	Threat	Composite Score	Owner Type
1	459	79.3	5.8	548.6	0.82	Federal
2	417	87.2	5.7	458.3	0.78	Federal
3	505	68.4	6.0	436.0	0.77	State
4	1	79.0	7.0	702.0	0.69	State
5	1	94.0	6.0	656.0	0.68	Federal
6	3	92.3	6.0	656.0	0.68	Federal
7	1	96.0	7.0	524.0	0.67	State
8	291	67.0	5.8	484.9	0.67	State
9	4	90.5	6.0	656.0	0.67	Federal
10	85	65.5	6.8	670.1	0.67	State

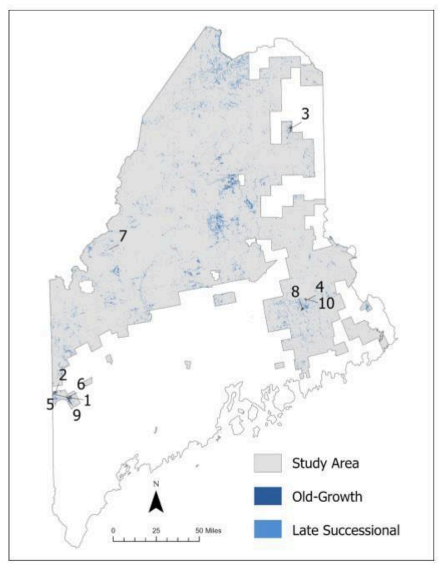


Figure 4.7 Highest scoring publicly owned patches.

5. Discussion

The protection of Maine's newly identified LSOG forests presents both an urgent conservation opportunity and a complex policy challenge. Our analysis identified roughly 126,000 hectares of LSOG that remain unprotected and vulnerable to harvest on predominantly private lands. These forests provide irreplaceable ecological values. However, their occurrence primarily on commercial timberlands creates trade-offs between conservation objectives and timber production.

In the preceding chapters, we mapped the spatial distribution of LSOG, characterized their ecological and carbon storage attributes, assessed harvest threats, and developed prioritization frameworks to identify which patches might offer the greatest conservation value. We also systematically evaluated alternative conservation mechanisms using multi-criteria assessment across dimensions of cost-effectiveness, permanence, scalability, and implementation feasibility. This analysis revealed that no single mechanism offers a complete solution, as each presents distinct trade-offs that make it more or less suitable for different contexts and conservation objectives.

The discussion that follows synthesizes these findings to develop practical recommendations for LSOG protection. We begin with fee-simple acquisition (Section 5.1), which provides the strongest permanence guarantees but faces enormous cost barriers that make exclusive reliance on this mechanism unrealistic. This cost constraint necessitates complementary approaches that can extend protection more affordably while maintaining conservation effectiveness. We therefore examine ecological reserve easements (Section 5.2) as a permanent protection mechanism that recovers partial costs through carbon markets (Section 5.3) as a revenue source that can help finance both acquisition and easements while delivering climate co-benefits.

Beyond these primary mechanisms, we assess the strategic role of harvest deferrals (Section 5.4) as temporary bridge protection while permanent solutions are arranged, forest certification (Section 5.5) as an existing but demonstrably insufficient voluntary measure, and regulatory policy approaches (Section 5.6) that, despite apparent appeal, create serious implementation challenges including perverse incentives and property rights conflicts. We conclude (Section 5.7) by integrating these mechanisms into a tiered portfolio strategy that matches each tool to the contexts where its comparative advantages are strongest, offering a realistic pathway to comprehensive LSOG protection within financial and political constraints.

Throughout this discussion, we use the simplifying assumption that landowners are willing to participate in the mechanisms we propose. This assumption is far from certain. Landowner acceptance will vary substantially based on individual circumstances, financial positions, conservation values, and the specific terms of protection agreements. Overcoming these social and behavioral barriers through outreach, relationship-building, and economic incentive design represents a major implementation challenge beyond the scope of our technical analysis. Nonetheless, the mechanisms we recommend are designed specifically to align landowner economic interests with conservation objectives through fair compensation rather than regulatory coercion, maximizing the likelihood of voluntary participation. Where participation proves limited despite adequate compensation, this would suggest either that our valuation of LSOG conservation benefits is insufficient to justify the costs we propose or that non-economic barriers require additional policy interventions we do not directly address here.

5.1 Fee-Simple Purchase

From a purely conservation perspective, fee-simple purchase offers unparalleled advantages: absolute permanence, complete management control, immediate protection, and elimination of virtually all future harvest risk. However, the fundamental constraint is cost. The estimated $422 million required to protect all unprotected LSOG through outright acquisition far exceeds available conservation funding, making fee purchase alone an unrealistic strategy. Effective LSOG conservation will therefore require sound prioritization and innovative approaches for integrating fee acquisition with complementary mechanisms that extend protection coverage while managing the financial burden.

Why Fee Acquisition is the Conservation Gold Standard

Outright ownership eliminates any uncertainty about long-term protection. Unlike temporary agreements (e.g., harvest deferrals, PES contracts), voluntary programs (e.g., certification, tax programs), or even conservation easements (which depend on holder enforcement), fee ownership provides complete control over management decisions in perpetuity. There is no contract expiration, no renegotiation risk, no dependence on landowner cooperation, and no vulnerability to ownership changes or financial pressures. That said, fee ownership alone does not provide a legally binding guarantee of perpetual protection, because future owners could alter management priorities. For LSOG forests that require centuries to develop their characteristic structural complexity and ecological functions, this permanence is essential. A five-year harvest deferral or 20-year PES contract provides protection for 2 to 10 percent of the timescale relevant to old-growth development. Fee ownership provides protection indefinitely. Our multi-criteria assessment assigned fee-simple acquisition the highest possible scores (5 out of 5) for both permanence of protection and additionality potential, reflecting these fundamental strengths. If cost were not constraining, and the landowners were willing to parcelize and sell these lands, fee acquisition would be the clear choice for comprehensive LSOG protection.

The Cost Barrier: Why Fee Acquisition Alone Is Unrealistic

The primary limitation of fee acquisition is cost. Our analysis estimates that protecting all 102,672 hectares of currently unprotected LSOG through fee purchase would cost approximately $422 million, with per hectare costs averaging $3,799 (SD = $2,388). This figure represents the combined value of land and standing timber, calculated using land value estimates from Nolte (2020) adjusted to 2025 dollars, and timber values based on species composition and size structure from spatially explicit FIA data (Gao et al. 2026; Zhao et al. 2020).

To contextualize this cost: $422 million is more than double the total funding that Maine's primary public conservation program has ever provided (LMF 2025). The Land for Maine's Future (LMF) program has authorized $174.25 million in total funding over its 38-year history from 1987 through 2022—an average of $4.6 million annually. Actual disbursements through 2025 total approximately $158 million. While LMF funding has been highly variable across years, ranging from nearly zero in some periods to peaks of $23 million (1991) and $17.6 million (2011), recent appropriations suggest renewed commitment, with a $40 million general fund appropriation in 2022 and projected disbursements of $19.7 million in 2027. However, these LMF funds support all conservation priorities statewide, including coastal access, working forest easements, farmland protection, wildlife habitat, and recreation lands. Even if the recent higher funding levels of $15 to $20 million annually are sustained, dedicating this entire amount to LSOG acquisition would require 22 to 28 years to reach $422 million while simultaneously eliminating funding any other land conservation in Maine.

Private land trusts and conservation organizations operating in Maine add significantly to available funding, collectively investing additional millions annually into land protection. Optimistic projections combining all public and private conservation funding suggest perhaps $50-75 million annually available for land acquisition across all priorities and geographies. For example, the The Magalloway Collaborative has raised over $49 million to permanently conserve forest The Magalloway Collaborative raised over $49 million in 2025 to permanently conserve ~30,000 ha of forest in western Maine; all but $6 million raised through private philanthropy (Charpentier 2026). If such rates could be sustained, protecting all LSOG through fee acquisition would consume 10 to 15 years of Maine's total conservation acquisition capacity.

The geographic distribution of LSOG further complicates cost-efficient acquisition. While some large patches (greater than 400 hectares) offer economies of scale where per hectare transaction costs are reasonable, over 75 percent of LSOG patches are under 50 hectares—too small for efficient individual acquisitions given legal, appraisal, survey, and closing costs that can be substantial per transaction regardless of acreage. Protecting numerous dispersed small patches through fee acquisition would incur prohibitive transaction costs relative to conservation value delivered. Conservationists may choose to acquire LSOG stands with buffers of second growth or Transitioning Late-successional Forests to protect the LSOG and to set a foundation for future LSOG over the long term.

Moreover, competition for conservation dollars extends beyond Maine. Regional and national land trusts, federal programs like the Forest Legacy Program, and private philanthropy direct funding to diverse conservation priorities, creating intense competition for limited conservation resources. A campaign to raise $422 million exclusively for Maine LSOG would compete against these priorities for philanthropic attention.

Chapter 4's spatial analysis identified that three of the ten largest private unprotected LSOG patches statewide, totaling 3,200 ha, are owned by a single entity REIT/TIMO and are concentrated in far northern Maine. These patches present an unusually favorable conservation scenario: consolidated ownership and large LSOG patch sizes (minimizing per-hectare transaction costs). Acquiring these three patches through fee purchase would cost approximately $12-15 million and would secure roughly 3 percent of the unprotected LSOG estate. Fee purchase becomes increasingly less tractable as patches get smaller; the remaining 120,000 hectares comprises thousands of smaller patches (75 percent under 50 hectares) scattered across Maine and owned by diverse commercial timber companies and non-industrial forest owners. Protecting this dispersed landscape through fee acquisition would be geographically and financially infeasible. This example illustrates both the opportunity and the limitation of fee-based strategies.

The Necessity of Complementary Approaches

Given the costs, effective LSOG conservation will require a portfolio strategy that combines fee acquisition for highest-priority lands with complementary mechanisms that extend protection at lower per hectare cost. Two mechanisms emerge as particularly promising complements: ecological reserve easements and carbon markets, which we discuss in the following sections.

5.2 Ecological Reserve Conservation Easements

Maine's conservation record illustrates both the promise and the limitation of this approach. Conservation easements account for more than half of all conserved land in the state (one of the highest proportions in the northeast) yet less than one-tenth of those easements prohibit timber harvest (Kannel et al. 2023). The majority are so-called "working forest easements" where timber harvest regimes resemble unprotected commercial timberlands, meaning that the scale of easement protection in Maine substantially overstates the degree to which forests are actually protected from harvest (Thompson et al. 2023). Land-use restrictions imposed by conservation easements are flexible and negotiated between the landowner and easement holder. Ecological reserve easements are a distinct class of easement that prohibit commercial timber harvesting and other extractive uses in perpetuity.

These easements would provide permanent LSOG protection while allowing land to remain in private ownership, and typically allow only low-impact recreational uses that permit conditions to develop unimpeded toward old-growth characteristics.

The Northeast Wilderness Trust Model

Because ecological reserve easements remove the owners' right to harvest timber, commercial timberland owners are unlikely to apply them to their lands. The more typical application of ecological reserve easements is exemplified by Northeast Wilderness Trust (NEWT), who have put these easements on more than 40,000 hectares throughout New England and New York, including 20,000 ha in Maine. NEWT's strategic model combines fee acquisition and application of a Wildland easement. On lands that it purchases in fee, it donates an ecological reserve conservation easement to a partner land trust, or when not possible, records an ecological reserve declaration of public trust. NEWT also holds ecological reserve conservation easements on other land trust owned fee lands.

A variation of this model, also used by NEWT, includes the sale of carbon offset credits at the same time as the easement. To address potential additionality concerns of pairing easements with carbon offsets, conservationists need to be transparent about the role of carbon revenue in their conservation financing, demonstrate that carbon income enables protection beyond what would occur with traditional funding alone, and structure projects to meet the specific additionality requirements of their chosen carbon protocol. The acquisition-easement-carbon offset reduces net conservation investment required. While initial acquisition requires paying full market value, which averages $3,799 per hectare average for LSOG, then placing an ecological reserve easement that prohibits commercial harvest in perpetuity, which effectively ensures that all their lands will eventually be LSOG. Where possible, the sale of carbon credits can reduce the effective purchase price by $705 to $3035 per hectare depending on the market (which are the average per hectare price of carbon stocks in the voluntary and California markets, respectively).

Ecological reserve easements work best for large patches (greater than 200 hectares) where transaction costs are justified by conservation value, where wilderness character is ecologically meaningful, and where recreation access and scenic values enhance appeal to conservation buyers. Properties attractive to individuals or organizations seeking low-impact forest ownership for legacy, recreation, or conservation purposes are most suitable for this model. (AMC TNC)

Transaction Costs and Monitoring

Ecological reserve easements have high transaction costs resulting from due diligence and contracting costs to establish the easement, including land appraisals, legal review, title searches, stewardship endowment funding, and extended negotiations with landowners (NEWT 2025). Our multi-criteria assessment (see section 2.2) assigned easements a score of 2 out of 5 on transaction cost efficiency, reflecting these substantial administrative burdens. Worth noting is that monitoring costs for these easements may be relatively low for LSOG where the conservation objective is simply to verify continued forest cover and absence of harvest, which can be determined using publicly available remote sensing data that is updated relatively frequently (Rose et al. 2015).

5.3 Carbon Offset Markets

Carbon offset markets represent a potentially significant application of payments for ecosystem services approach to LSOG protection. As discussed in Chapter 2, PES programs compensate landowners for providing ecological services that generate societal benefits but lack conventional markets. Maine's LSOG forest carbon markets could provide substantial revenue to offset protection costs while delivering climate mitigation co-benefits, particularly for parcels that are assessed to be at high risk of LSOG loss and thus considered additional.

Carbon Storage in Maine's LSOG

LSOG forests store significantly more carbon than typical managed forests. Across all LSOG patches, mean carbon density is 61.5 Mg C/ha (SD = 12.3). The highest-carbon-density patches are clustered in the southern portion of the study area and are often owned by non-industrial forest owners (See Chapter 4). The geographic clustering offers a strategic opportunity to pilot offset sales in these carbon hotspots where per-hectare carbon value ($4,500-$5,500 compliance market) often exceeds acquisition costs on non-industrial holdings. The most carbon-dense patches exceed 80 Mg C/ha, representing carbon stocks 40 to 60 percent higher than regional averages. In aggregate, across all privately held, unprotected LSOG, there is approximately 25 million Mg of CO_2e, the equivalent to the annual emissions of approximately 5 million passenger vehicles. This substantial carbon stock represents a significant climate mitigation opportunity if it can be protected and credibly monetized through offset markets.

To understand the scale of the opportunity, we estimated potential carbon revenue under two market scenarios. Under California compliance market prices ($30 per Mg CO_2e), using baseline-and-additionality approaches consistent with IFM forest carbon protocols, the full pool of private unprotected LSOG could generate approximately $312 million. Under voluntary carbon market prices ($7 per Mg CO_2e), the same LSOG could generate $72 million. For the most carbon-dense patches specifically, per hectare revenue would range from $4,500 to $5,500 under compliance markets or $1,000 to $1,300 under voluntary markets. These figures suggest that carbon markets could provide 15 to 75 percent of the estimated $422 million cost of protecting all private LSOG through fee acquisition, representing a substantial reduction in net conservation costs. Carbon revenue could enable protection at scales that would not be financially feasible through traditional conservation funding alone.

The Case for Carbon Offsets as LSOG Protection

The strongest argument for carbon-based LSOG protection is that it creates economically efficient payments for genuine ecosystem services while achieving permanent conservation outcomes. Unlike regulatory mandates that confiscate property rights without compensation, or philanthropic acquisition that depends on charitable donations insufficient to achieve landscape-scale protection, carbon markets create ongoing revenue streams that compensate landowners for the climate mitigation services their forests provide to society.

This payment structure addresses the fundamental market failure in forest conservation: Landowners cannot capture the social value of carbon storage, biodiversity, water quality, and other ecosystem services through timber markets alone, creating systematic underinvestment in conservation relative to its true social value. Carbon markets internalize these externalities by paying landowners for ecosystem services, better aligning incentives with societal values.

The permanence requirements of many carbon protocols also strengthen conservation outcomes. Most carbon standards, including California's compliance market and higher-quality voluntary standards (e.g., Verra's Verified Carbon Standard), require legally binding commitments to maintain carbon stocks for extended periods, typically 40 years or more. This ensures that carbon payments generate genuine long-term protection rather than temporary deferrals that merely postpone harvests.

Carbon markets also demonstrate potential for substantial scalability compared to traditional conservation funding. As corporate net-zero commitments drive demand for high-quality forest carbon offsets, Maine's LSOG could access capital from major corporations, institutional investors, and compliance buyers; these funding sources are largely unavailable to traditional conservation mechanisms like Land for Maine's Future appropriations or regional land trust budgets.

Integration with Fee Acquisition and Easements

Integrating offsets with fee acquisition strengthens the carbon market approach. As discussed in Sections 5.1 and 5.2, conservation organizations can acquire LSOG lands in fee simple, place permanent conservation easements, develop carbon projects to generate offset credits, and use carbon revenue to repay acquisition debt or fund additional purchases. This creates a revolving conservation fund where initial philanthropic capital is leveraged through carbon markets to achieve protection at multiples of the original investment.

The optimal implementation sequence combines acquisition and carbon development: Conservation organizations acquire LSOG in fee simple (ensuring immediate permanent protection), place conservation easements (meeting carbon protocol permanence requirements), develop carbon projects (generating offset credits), and sell credits (recovering partial acquisition costs). This creates a revolving conservation fund where carbon revenue enables additional purchases.

Targeting the most carbon-dense patches (greater than 80 Mg C/ha) for combined acquisition and carbon development could generate substantial offset revenue over time, meaningfully reducing net conservation costs. While carbon markets alone cannot protect all LSOG due to protocol constraints and market limitations, they provide valuable supplemental funding when integrated with fee acquisition.

Finally, carbon markets create positive incentives rather than adversarial relationships. Landowners who participate in carbon projects receive ongoing revenue for forest stewardship, fostering pro-conservation attitudes and long-term engagement. This contrasts sharply with regulatory approaches that impose restrictions without compensation, creating resentment and resistance that undermines future conservation efforts.

The Case Against Carbon Markets for LSOG Protection

Despite theoretical appeal, carbon markets face serious practical limitations that constrain their effectiveness for LSOG protection. The most fundamental barrier is the parcel-scale requirement.

Forest carbon protocols generally prohibit selective enrollment of high-carbon patches while excluding surrounding managed forest, a requirement designed to prevent adverse selection. In general, landowners cannot enroll fragmented or non-contiguous land to maximize credits. For LSOG protection, this may create an intractable problem. Most LSOG occurs as relatively small patches, distributed across large ownerships that also contain substantial areas of younger, actively managed forest. Over 75 percent of old-growth and late-successional patches are under 50 hectares. Typically, for example, a landowner could not enroll only a 20-hectare LSOG patch in a carbon project while continuing to harvest 200 hectares of productive timberland surrounding it. The protocol requires enrolling either the entire 220-hectare ownership or none of it.

A requirement that full ownership be enrolled would likely eliminate most private timber owners as potential carbon project participants. Industrial forest owners manage hundreds of thousands of hectares for sustained timber yield; enrolling entire ownerships in no-harvest carbon projects would fundamentally alter their business model. However, there are examples of carbon project areas being defined on partial ownership—for instance, Weyerhaeuser enrolled nearly 50,000 acres in its first carbon project in Maine in 2023 (Weyerhaeuser 2026), which is a fraction of the company's entire land holdings in the state. This suggests some flexibility may exist. However, even this example involves a substantial contiguous area rather than selective LSOG patches, and the specific accommodations that allowed partial enrollment remain unclear.

Transaction costs and timeline delays further constrain carbon market viability. Developing forest carbon projects involves substantial upfront investment in project design and documentation, third-party verification and validation, registration and listing fees, monitoring and reporting systems, and buffer pool contributions. These costs create economies of scale that require protecting large areas to achieve reasonable per hectare efficiency. The timeline from project initiation to first credit issuance typically spans 12 to 24 months, meaning carbon revenue cannot provide immediate acquisition funding but rather must be secured through bridge financing or deferred implementation. Conservation organizations acquiring LSOG for immediate protection cannot rely on carbon income for initial purchase capital.

Strategic Role of Carbon Markets

Carbon markets represent a promising but imperfect tool for LSOG protection. As a PES mechanism, they create economically efficient payments for genuine ecosystem services and could generate substantial conservation revenue. However, protocol constraints, transaction costs, market volatility, and implementation barriers prevent carbon markets from serving as the primary protection mechanism. Integrated strategically with fee acquisition and easements, carbon markets can meaningfully reduce net conservation costs while delivering climate co-benefits—a valuable but secondary role in comprehensive LSOG protection.

5.4 Harvest Deferrals

The New England Forestry Foundation's harvest deferral program is funded by a $4.3 million grant from the U.S. Forest Service The program compensates landowners for postponing harvest of stands explicitly scheduled for cutting in existing management plans, typically paying a negotiated portion of the estimated stumpage value for a five-to-fifteen year deferral, while also incentivizing landowners to improve silvicultural practices within younger forests (Milakovsky et al. 2025). To date, NEFF has engaged with only a handful of landowners affecting nearly 500 hectares. They intend to expand the program in coming years.

Strengths of the Deferral Approach

The primary advantage of harvest deferrals is their ability to target LSOG forests facing imminent threat. By focusing on stands scheduled for harvest, deferrals maximize additionality, ensuring that protections change landowner behavior rather than rewarding actions that would have occurred anyway. In addition, harvest deferrals provide an important entry point for engaging landowners and building relationships with industrial timber owners with strong organizational commitments to maintaining timber production. Conversely, the transaction costs associated with identifying truly threatened stands can be substantial. NEFF invests considerable effort in confirming the harvest intentions and trying to ensure additionality, which requires access to management plans, site visits, and negotiations with landowners. These costs reduce the efficiency that harvest deferrals might otherwise hold over more permanent mechanisms.

Limitations and Concerns

The harvest deferral approach suffers from a fundamental limitation: it postpones rather than prevents LSOG loss. Once the deferral period expires, typically after five to 10 years, landowners regain full harvest rights. For LSOG forests, this temporary protection may prove insufficient unless new conservation funding and mechanisms can be found to extend the protections. At their best, the deferrals will serve as a bridge to allow time to arrange permanent protections such as fee purchase and/or an ecological reserve easement. At worst, the deferral program could also create a "moral hazard." If landowners learn that conservation organizations will pay to defer scheduled harvests, they may strategically schedule more LSOG for cutting to create future payment opportunities, which is a perverse incentive that could accelerate rather than prevent LSOG loss over the long term.

Strategic Role as Bridge Mechanism

Despite the limitations, harvest deferrals have a valuable role as a bridge mechanism to protect high-value and highly threatened LSOG stands, until a more permanent solution is found. For harvest deferrals to contribute meaningfully to LSOG conservation, several conditions should be met: (1) deferral payments should be structured with renewal options or escalating terms that incentivize long-term commitment, (2) deferred stands should be prioritized for subsequent permanent protection through easements or acquisition, (3) the program should maintain rigorous verification that targeted stands face genuine near-term harvest threat, and (4) to maximize the chance that the “bridge” will lead to permanent LSOG protection, the deferral terms should include the right of first refusal for buying the land and/or timber, upon expiration of the deferral agreement.

5.5 Forest Certification

Maine has some of the highest rates of forest certification in the United States. Approximately three-million hectares, or roughly half of total forest cover, is certified under Forest Stewardship Council (FSC), Sustainable Forestry Initiative (SFI), or both (Sherwood et al. 2014). Both certification systems include provisions relevant to LSOG protection.

Certification Standards and LSOG

In the case of the FSC's certification requirements, there are 10 "Principles" that serve as the foundation of its forest management standards (FSC 2023). Principle Nine requires that "management activities in high conservation value forests maintain the attributes which define these forests," while Principle Six says that "management practices maintain the area, structure, composition, and processes of old-growth stands where they exist." Similarly, SFI Objective Four requires the protection of biological diversity, including "the conservation of forest plants and animals, aquatic species, threatened and endangered species, Forests with Exceptional Conservation Value, old-growth forests, and ecologically important sites" (SFI 2022).

Why Certification Is Insufficient

Both FSC and SFI allow considerable flexibility in how conservation objectives are achieved on certified land. Furthermore, LSOG is rare on the landscape, and until Hagan et al. (2024), there was no comprehensive map of regional LSOG. So it is plausible that certification audits have not encountered nor had to enforce these principles and standards. It is also possible that the remaining LSOG has not been previously harvested, at least in part, because it is protected by the certifications. Nonetheless, maintaining certification would seem to be dependent on maintaining the existing commitments not to harvest LSOG.

Certification is voluntary, and enforcement mechanisms for non-compliance are limited to suspension or revocation of certification status (Rametsteiner and Simula 2003) For large timber companies with diverse holdings, the loss of certification on one unit may not create sufficient incentive to forgo harvesting.

The evidence strongly suggests that certification alone is insufficient to ensure comprehensive LSOG protection in Maine. Hagan et al. (2025) documented the loss of some 15,000 hectares of LSOG since LiDAR was flown in 2016 to 2018. Most of this loss was on SFI or FSC certified lands. While certification may play a complementary role by raising awareness and establishing baseline expectations, more direct protection mechanisms—particularly fee acquisition, ecological reserve easements, and carbon markets—remain essential for ensuring permanent conservation outcomes.

5.6 Regulatory Policy

Maine Legislature's enactment of LD 1529, An Act to Enhance the Protection of High-value Natural Resources Statewide, signals growing public and political recognition that protection of LSOG forests are a social priority. This legislation directs the Maine Forest Service to produce a comprehensive report outlining statewide strategies for LSOG conservation and requires biennial reporting on LSOG status beginning in 2031. The bill stops short of imposing direct regulatory protections, leaving critical questions about the potential role of mandatory policy in LSOG conservation. Maine currently has a suite of regulatory policies designed to protect ecological features of the landscape, including the Maine Forest Practices Act and Maine Forest Service Rule Chapters (i.e, the Operational Standards). However, these regulations do not directly address LSOG protections.

Theoretical Advantages and Context

Regulatory protection of LSOG would have advantages, including: comprehensive coverage regardless of ownership, permanence across ownership transitions, no direct public acquisition costs, and clear legal enforcement mechanisms. These characteristics explain the appeal of regulatory approaches for other old-growth protections, such as the Northwest Forest Plan (FEMAT 1994). However, the Northwest Forest Plan addressed LSOG protection on only federally owned land, where government regulatory authority was unambiguous and property rights concerns were minimal. Implementation required resolving competing management mandates within federal agencies and addressing economic transitions in timber-dependent communities but did not confront issues of private property takings or require compensating private landowners for lost timber value (Thomas et al. 2006). In contrast, 80 percent of Maine's LSOG forests are situated on private commercial timberlands.

Property Rights and Constitutional Constraints

Harvest restrictions directly conflict with property rights and economic expectations of the landowner. While courts have upheld environmental regulations on private land under the police power doctrine, restrictions that deny all economically beneficial use typically constitute compensable takings (see Lucas v. South Carolina Coastal Council, 505 U.S. 1003). For industrial timber owners in Maine, regulatory LSOG protection would likely eliminate the primary economic value of affected parcels, at least as they are currently constructed.

Regulations to prohibit harvesting LSOG may also produce perverse incentives. If landowners anticipate future harvest prohibitions, rational economic behavior would be to accelerate LSOG cutting while it remains legal, precisely the opposite of the intended conservation outcome.

This risk is not merely theoretical. In New Zealand, for example, harvest restrictions as part of the Climate Change Act that established the country's Emissions Trading Scheme were announced in 2002 but didn't become active until 2008 (Carver et al. 2022). During the six-year gap between policy announcement and implementation, deforestation accelerated in New Zealand as landowners rushed to clear forests before restrictions took effect.

Given the property rights implications, perverse incentive risks, and distributional impacts of regulatory LSOG protections, conservation strategies should prioritize voluntary mechanisms—fee acquisition, easements, payments for ecosystem services, carbon markets—that achieve protection through compensation and cooperation rather than mandates. Regulatory approaches should be reserved for future consideration only if voluntary mechanisms with adequate funding demonstrably fail to achieve protection goals within relevant timeframes.

5.7 Integrated Strategy and Implementation

LSOG conservation in Maine is an economic problem as much as an ecological one. The stands that provide the greatest carbon storage, structural complexity, and biodiversity value are also those that generate the highest returns for the firms who own them. LSOG conservation strategies must explicitly confront this alignment between ecological value and economic incentive. Based on cost realities and complementary mechanism capabilities, we recommend a tiered strategy that deploys fee acquisition strategically while leveraging ecological reserve easements and carbon markets to extend protection:

A Tiered Protection Strategy

Tier 1: Identify late-successional and old-growth forest patches on public and conservation organization-owned lands. Approximately 32,000 hectares of LSOG are owned by conservation organizations and land trusts but lack ecological reserve easement protections, relying instead on administrative safeguards. Additionally, approximately 25,000 hectares of unprotected LSOG occur on public lands (state and federal). Our Tier 1 strategy suggests that: (1) public agencies formalize LSOG protection through reserve designations and legal protections that preclude timber harvest; and (2) conservation organizations strengthen their fee-owned LSOG through ecological reserve easements, ensuring durable legal permanence.

Tier 2: Protection of large LSOG patches (e.g., > 200 ha) through fee acquisition and ecological reserve easements tailored to conservation objectives and landscape context. For patches with the greatest ecological resilience, highest carbon density, and strategic locations adjacent to existing protected areas, prioritize fee acquisition—ideally embedded within larger projects that include a matrix of Transitioning Late-successional and/or other high-quality secondary forests. Where possible, particularly on the most carbon-dense lands that would otherwise be harvested, use the sale of carbon offset credits to help finance the purchase of these sites. New private conservation ownership and ecological reserve easements should prioritize sites with the maximum conservation value determined on the ground. Creative price revealing mechanisms such as reverse actions should be used to maximize efficient deployment of limited conservation funds.

Tier 3: Incentivize voluntary protections for small dispersed LSOG patches that are embedded within timberland owner properties. Many LSOG patches are small and geographically isolated, making them impractical for acquisition by external conservation organizations. In fact, approximately 75% of the mapped LSOG area is in patches smaller than 50 hectares. Request voluntary protection of small patches by timberland owners through: (1) continued compliance with their existing forest certification standards, and (2) in recognition of Maine's historical social contract for sustainable forestry.

Tier 4: Complementary and temporary mechanisms to provide bridge protection and reduce the harvest threat while permanent conservation solutions are developed. This includes temporary harvest deferrals with a right of first refusal upon deferral expiration for patches facing imminent threat (i.e., the NEFF model), and incentivizing markets for low-grade wood to reduce harvest pressure on LSOG forests.

Tier 5: Use near-real time remote sensing and public protection databases to monitor all LSOG forests and communicate their status on a publicly available website showcasing where, when, and by whom LSOG is protected as well as where, when, and by whom it is lost to timber harvest.

This integrated approach could protect the substantial majority of unprotected LSOG while managing total investment to levels more realistic than the $422 million required for fee acquisition alone. The strategy recognizes that different protection mechanisms have comparative advantages for different types of properties and conservation objectives, and that efficient resource allocation requires matching mechanisms to circumstances rather than relying exclusively on any single approach.

Acknowledgements

We are grateful for comments and suggestions from David Foster, Jon Leibowitz, Robert Perschel, Brian Milakovsky, John Hagan, Brian Shamgochian, Morten Moesswilde, Charles Gauvin, Lucy Lee, Steve Tatko, and Tate Watkins.

References

Bell, K. (2007). Houses in the woods: Lessons from the Plum Creek concept plan. *Maine Policy Review*, 16(2), 44-55.

Bennett, A. (2023). *The Impact of Conservation Land on Property Taxes and Municipal Budgets in Maine: a Mixed-methods Study*. Electronic Theses and Dissertations. 3918.https://digitalcommons.library.umaine.edu/etd/3918

Blumstein M. and J. R. Thompson. (2015). Land-use impacts on the quantity and configuration of ecosystem service provisioning in Massachusetts, USA. Journal of Applied Ecology. doi: 10.1111/1365-2664.12444

Birdsey, R.A., DellaSala D.A., Walker, W., and Gorelik, S. (2025). How much more carbon could be protected in mature and old-growth forests in the United States? *Biological Conservation* 306: 111114. https://doi.org/10.1016/j.biocon.2025.111114

Börner J., D. Schulz, S. Wunder, A. Pfaff. (2020). The Effectiveness of Forest Conservation Policies and Programs. Annual Review Resource Economics. 12:45-64. https://doi.org/10.1146/annurev-resource-110119-025703

Brown, M.L., Canham, C.D., Murphy, L., and Donovan, T.M. (2018). Timber harvest as the predominant disturbance regime in northeastern U.S. forests: effects of harvest intensification. *Ecosphere* 9(3): e02062. https://doi.org/10.1002/ecs2.2062

Brown, C.F., Kazmierski, M.R., Pasquarella, V.J., Rucklidge, W.J., Samsikova, M., Zhang, C., Shelhamer, E., Lahera, E., Wiles, O., Ilyushchenko, S., Gorelick, N., Zhang, L.L., Alj, S., Schechter, E., Askay, S., Guinan, O., Moore, R., Boukouvalas, A., and Kohli, P. (2025). AlphaEarth Foundations: An embedding field model for accurate and efficient global mapping from sparse label data [Preprint]. arXiv: 2507.22291. https://doi.org/10.48550/arXiv.2507.22291

Burrascano, S., W. S. Keeton, F. M.Sabatini, C. Blasi.. (2013). Commonality and variability in the structural attributes of moist temperate old-growth forests: A global review. *Forest Ecology and Management*, 291, 458-479.

Butler, B.J. (2018). Forests of Maine, 2017. Resource Update FS-160. U.S. Newtown Square, PA: Department of Agriculture, Forest Service, Northern Research Station. https://doi.org/10.2737/FS-RU-160

Canham, C.D., Rogers, N., and Buchholz, T. (2013). Regional variation in forest harvest regimes in the northeastern United States. *Ecological Applications* 23:515–522. https://doi.org/10.1890/12-0180.1

Carver, T., Dawson, P., O'Brien, S., Kotula, H., Kerr, S., & Leining, C. (2022). Including forestry in an emissions trading scheme: Lessons from New Zealand. Frontiers in Forests and Global Change, 5, 956196.

Charpentier (2026) Conservation groups near $62M goal for 78,000 acres in western Maine. Sun Journal. Accessed March 20 2026. https://www.sunjournal.com/2026/02/02/conservation-groups-near-62m-goal-for-78000-acres-in-western-maine/

Crist, P.J., B. Thompson, T. C. Edwards, C. G. Homer, S. D. Bassett. 1998. Mapping and Categorizing Land Stewardship. A Handbook for Conducting Gap Analysis.

D'Amato, A W., D A. Orwig, and D R. Foster. Understory vegetation in old-growth and second-growth Tsuga canadensis forests in western Massachusetts. (2009) *Forest Ecology and Management 257*.3 1043-1052.

Daigneault, A., Simons-Legaard, E., Birthisel, S., Carroll, J., Fernandez, I., and Weiskittel, A. (2021). Maine Forestry and Agriculture Natural Climate Solutions Mitigation Potential Final Report. Center for Research on Sustainable Forests, University of Maine.
https://crsf.umaine.edu/wp-content/uploads/sites/214/2021/08/UMaine-NCS-Final-Report_final_8.4.21.pdf

Daigneault, A., Simons-Legaard, E., and Weiskittel., A. (2024). Tradeoffs and synergies of optimized management for maximizing carbon sequestration across complex landscapes and diverse ecosystem services. *Forest Policy and Economics* 161: 103178. https://doi.org/10.1016/j.forpol.2024.103178

Davis, M. B. (Ed.). (1996). Eastern old-growth forests: prospects for rediscovery and recovery. Island Press, Chicago, Illinois, USA

Didham, R. K. (2010). Ecological consequences of habitat fragmentation. Encyclopedia of Life Sciences. https://doi.org/10.1002/9780470015902.a0021904

Ducey. M.J., Gunn, J.S., and Whitman, A.A. (2013). Late-successional and old-growth forests in the northeastern United States: structure, dynamics, and prospects for restoration. *Forests* 4(4): 1055-1086. https://doi.org/10.3390/f4041055

Fastmarkets. (2025). Resilient growth in US forest carbon markets. [Website]. Accessed on 2/9/26.https://www.fastmarkets.com/insights/resilient-growth-in-us-forest-carbon-markets/

Forest Trends' Ecosystem Marketplace. 2023. State of the Voluntary Carbon Markets 2023. Washington DC: Forest Trends Association.

Foster, D.R., Johnson, E.E., Hall, B.R., Leibowitz, J., Thompson, E.H., Donahue, B., Faison, E.K., Sayen, J., Publicover, D., Sferra, N., Ireland, L.C., Thompson, J.R., Perschel, R., Orwig, D.A., Keeton, W.S., Hunter Jr., M.C., Masino, S.A., and Howell, L. (2023). Wildlands in New England: Past, Present, and Future. Harvard Forest Paper 36. Harvard University.
https://wildlandsandwoodlands.org/wp-content/uploads/2023/07/Wildlands-in-New-England-Full-Report-20230705.pdf

Foster, D.R., Orwig, D.A., and McLachlan, J.S. (1996). Ecological and conservation insights from reconstructive studies of temperate old-growth forests. *Trends in Ecology and Evolution* 11(10): 419-424. https://doi.org/10.1016/0169-5347(96)10047-1

Franklin, J. F., & Spies, T. A. (1989). Ecological definitions of old-growth Douglas-fir forests. University of Washington Press.

Frelich, L E., P. Reich. (2003) Perspectives on development of definitions and values related to old-growth forests. *Environmental Reviews* S9-S22.

FSC 2023. Forest Stewardship Council FSC-STD-01-001 V5-3
https://open.fsc.org/entities/publication/6bb703f2-001d-481d-aa04-c9fc92e143fd

Gao, X,. Daignault, A. Leahey, J. Laflower, D., Abrams, J. Thompson, J. R. 2026 Forest Financialization Drives a Land-use Regime Shift. Preprint.

Gao, X., Pasquarella, V.J., Laflower, D., and Thompson, J.R. (2025). Mapping Forest Communities, Including Species Composition, Structure, and Carbon, at 10-m Resolution Using Geospatial Embeddings [Preprint]. Available at SSRN: https://ssrn.com/abstract=5936862

Grimm, M. (2020). Conserving biodiversity through offsets? Findings from an empirical study on conservation banking. *Journal for Nature Conservation* 57, 125871. https://doi.org/10.1016/j.jnc.2020.125871

Gunn, J.S., Ducey, M.J., and Whitman, A.A. (2014). Late-successional and old-growth forest carbon temporal dynamics in the Northern Forest (Northeastern USA). *Forest Ecology and Management* 312: 40-46. https://doi.org/10.1016/j.foreco.2013.10.023

Hagan, J.M., Irland, L.C. and Whitman, A.A., (2005). Changing timberland ownership in the Northern Forest and implications for biodiversity (p. 10). Manomet Center for Conservation Sciences, Forest Conservation Program.

Hagan, J., Shamgochian, B., Taylor, M., and Reed, M. (2024). Using LiDAR to Map, Quantify, and Conserve Late-successional Forest in Maine. Our Climate Common, Georgetown, Maine. 44p. https://ourclimatecommon.org/wp-content/uploads/2024/10/MAINE-LSOG-Report-Exec-Summary-2024b.pdf

Hagan, J., B. Shamgochian, M. Taylor, and M. Reed. (2025). Prioritizing LSOG Forest Conservation in Maine's Unorganized Territories. Our Climate Common Report, Georgetown, Maine. 23 pp. https://ourclimatecommon.org/wp-content/uploads/2025/12/PRIORITIZING-LSOG-CONSERVATION-MAINE.pdf

Harvard Forest. (2023). New England Protected Open Space v1.2 [Dataset]. DOI:10.5281/zenodo.7764284

Hayes, D., Brewer, A., Daigneault, A., Enterline, C., Fernandez, I., Frank, J., Johnson, B., Knapp, S., Legaard, K., Price, N., Puryear, K., Simons-Legaard, E., Stevens, A., Wei, X., and Weiskettel, A. (2024). The State of Maine's Carbon Budget Version 2, 2017-2021. Center for Research on Sustainable Forests, University of Maine. https://crsf.umaine.edu/carbon-budget/

Irland, L.C. (2000). Maine Forests: A Century of Change, 1900-2000… and elements of policy change for a new century. Maine Policy Review, 9(1), 66-67.

Irland, L.C. (2018). Maine's public estate and conservation lands: brief history and assessment. Maine Policy Review 27(2): 11-29.

Kannel, J., D. Publicover and H. Clish. (2023). State-level progress toward the "30 by 30" land conservation goal. Appalachian Mountain Club Conservation Research Report #2023-2. Boston, MA.

Keeton, W.S., Whitman, A.A., McGee, G.C., and Goodale, C.L. (2011). Late successional biomass development in northern hardwood-conifer forests of the northeastern United States. *Forest Science* 57(6): 489-505.

LMF 2026 LMF Funds Disbursed/Available 1987-2026 https://www.maine.gov/dacf/lmf/docs/LMF%20Funds%20In%20Out%20Data%20FY26.pdf

Lindenmayer, D. (2019). Small patches make critical contributions to biodiversity conservation. *Proceedings of the National Academy of Sciences*, 116(3), 717-719.

Lutz JA, Furniss TJ, Johnson DJ, et al. (2018) Global importance of large-diameter trees. *Global Ecology and Biogeography.* 27: 849–864.

Maine Audubon (2025). Forest Conservation Easements and Wildlife: A Review of Working Forest Conservation Easements, Their Potential for Conserving Wildlife and Habitat, and Recommendations for Improvements. Online: print.maineaudubon.org/forestconservationeasementsandwildlife

Maine Forest Products Council. (2025). 2024 Statewide Economic Contribution of Maine's Forest Products Sector. Online: https://maineforest.org/wp-content/uploads/2025/10/2024-Economic-Report-FINAL-for-printing-AK.pdf

Maine Department of Environmental Protection (2024). Tenth Biennial Report on Progress toward Greenhouse Gas Reduction Goal. Online: https://www.maine.gov/tools/whatsnew/attach.php?id=12796425&an=1

Maine Forest Service. (2024). Outcome Based Forestry [Website]. Accessed on 2/9/26. https://www.maine.gov/dacf/mfs/policy_management/outcome_based_forestry.html

Maine Land Trust Network (MLTN). (2025). Land trusts work for Maine [Website]. Accessed on 2/9/26. https://www.mltn.org/impacts-2025/

Maine Revenue Service. (2025). Municipal Valuation Return Statistical Summary [Website]. Accessed on 3/22/26. https://www.maine.gov/revenue/taxes/property-tax/municipal-services/valuation-return-statistical-summary

McGarvey JC, Thompson J.R., Epstein HE, Shugart HH. 2015. Carbon storage in old-growth forests of the Mid-Atlantic: toward better understanding the eastern forest carbon sink. Ecology 96:311–7.

Milakovsky B. (2025) Conserving Maine's Oldest Forests https://newenglandforestry.org/climate-initiatives/conserving-maines-oldest-forests/

Mosseler, A., J. A. Lynds, J.A., and Major, J.E. (2003). Old-growth forests of the Acadian Forest Region. Environmental Reviews 11.S1: S47-S77. https://doi.org/10.1139/a03-015

NEWT (2025) Northeast Wilderness Trust "How We Work" [Website]. Accessed on Feb 24 2026 https://newildernesstrust.org/wilderness-conservation/#how

Nolte, C. (2020). High-resolution land value maps reveal underestimation of conservation costs in the United States. *Proc. Natl. Acad. Sci. U.S.A.* 117(47): 29577-29583. https://doi.org/10.1073/pnas.2012865117

Orwig, D. A., Cogbill, C. V., Foster, D. R., & O'Keefe, J. F. (2001). Variations in old-growth structure and definitions: forest dynamics on Wachusett Mountain, Massachusetts. Ecological Applications, 11(2), 437-452.

Pasquarella, V.J., Morreale, L.L., Brown, C.F., Kilbride, J.B., and Thompson, J.R. (2023). Not-so-random forests: Comparing voting and decision tree ensembles for characterizing partial harvest events. *International Journal of Applied Earth Observation and Geoinformation* 125: 103561. https://doi.org/10.1016/j.jag.2023.103561

Pirard, R. (2012). Market-based instruments for biodiversity and ecosystem services: A lexicon. *Environmental Science & Policy*, 19, 59-68.

Pelz, K. A., G. Hayward, A.N. Gray, E.M. Berryman, C.W. Woodall, A. Nathanson, N.A. Morgan. (2023) Quantifying old-growth forest of United States Forest Service public lands, *Forest Ecology and Management*, Volume 549, 121437,

Rametsteiner, E., & Simula, M. (2003). Forest certification—an instrument to promote sustainable forest management?. Journal of environmental management, 67(1), 87-98.

Rose, R.A., Byler, D., Eastman, J.R., Fleishman, E., Geller, G., Goetz, S., Guild, L., Hamilton, H., Hansen, M., Headley, R. and Hewson, J., (2015). Ten ways remote sensing can contribute to conservation. *Conservation Biology,* 29(2), pp.350-359.

Runkle, J.R. (1982). Patterns of disturbance in some old-growth mesic forests of eastern North America. *Ecology* 63(5): 1533-1546. https://doi.org/10.2307/1938878

Schilizzi, S., & Latacz-Lohmann, U. (2007). Assessing the performance of conservation auctions: an experimental study. *Land Economics*, 83(4), 497-515.

Sherwood, D.F., (2014). *Assessing Maine's Certified Sustainable Harvest*. University of Maine Electronic Theses and Dissertations, 2724. https://digitalcommons.library.umaine.edu/etd/2724

Simons-Legaard, E., Legaard, K., Weiskittel, A. (2021). Projecting complex interactions between forest harvest and succession in the northern Acadian Forest Region. *Ecological Modelling* 456, 109657.

Soares-Filho, B. S., Pennachin, C. L., & Cerqueira, G. (2002). "DINAMICA—a stochastic cellular automata model designed to simulate the landscape dynamics." *Ecological Modelling*, 154(1-2), 117-135.

Soares-Filho, B. S., Rodrigues, H. O., & Costa, W. L. (2009). *Modeling Environmental Dynamics with Dinamica EGO*, Guidebook, Belo Horizonte, MG: https://csr.ufmg.br/dinamica/

Spies, T. A.(2004) "Ecological concepts and diversity of old-growth forests." Journal of forestry 102.3 14-20.

Spies, T.A. and Franklin, J.F. (1996). The diversity and maintenance of old-growth forests. In: Szaro, R.C. and D.W. Johnston eds. Biodiversity in Managed Landscapes: Theory and Practice. Oxford University Press. New York. 778 p.

SFI 2022 Sustainable Forest Initiative. Forest Management Standard https://forests.org/wp-content/uploads/2022_SFI_StandardsandRules_section2.pdf#page=4.06

The Nature Conservancy. 2024. Secured Areas by GAP Status and Type 2024. Accessed via The Nature Conservancy Geospatial Conservation Atlas.

The Nature Conservancy. (2022). Local Connectedness Index [Dataset]. Accessed on 10/16/2025. https://geospatial.tnc.org/maps/TNC::local-connectedness-1/about

Thomas, J.W., Franklin, J.F., Gordon, J. and Johnson, K.N. (2006), The Northwest Forest Plan: Origins, Components, Implementation Experience, and Suggestions for Change. Conservation Biology, 20: 277-287. https://doi.org/10.1111/j.1523-1739.2006.00385.x

Thompson, J. R., Canham, C.D., Morreale, L., Kittredge, D.B., and Butler, B. (2017). Social and biophysical variation in regional timber harvest regimes. Ecological Applications (27) 942-955. https://doi.org/10.1002/eap.1497

Thompson, J.R., Carpenter, D.N., Cogbill, C.V., and Foster, D.R. (2013). Four centuries of change in northeastern United States forests. *PLoS ONE* 8(9): e72540. https://doi.org/10.1371/journal.pone.0072540

Thompson, J.R., Kalinin, A., Lee, L.G., Pasquarella, V.J., Plisinski, J., and Sims, K.R.E. (2024). Do working forest easements work for conservation? *Environmental Research Letters* 19(11): 114033. https://doi.org/10.1088/1748-9326/ad7ed9

U.S. Department of Agriculture (USDA) Farm Service Agency (2026). Conservation Reserve Program (CRP). Online: https://www.fsa.usda.gov/resources/conservation/conservation-reserve-program

U.S. Geological Survey (USGS) Gap Analysis Project (GAP), (2024), Protected Areas Database of the United States (PAD-US) 4.1: U.S. Geological Survey data release, https://doi.org/10.5066/P96WBCHS

Verra (2024). Nature Framework. Online: https://verra.org/methodologies/nature-framework/

Watson, J. E. M., Evans, T., Venter, O., Williams, B., Tulloch, A., Stewart, C., et al. (2018). The exceptional value of intact forest ecosystems. Nat. Ecol. Evol. 2, 599–610. doi: 10.1038/s41559-018-0490-x

Weyerhaeuser 2026. Removing and storing carbon dioxide from the atmosphere. Online: https://www.weyerhaeuser.com/climate-solutions/forest-carbon/

Wei, X., Zhao, J., Hayes, D.J., Daigneault, A., and Zhu, H. (2023). A life cycle and product type based estimator for quantifying the carbon stored in wood products. *Carbon Balance and Management* 18: 1. https://doi.org/10.1186/s13021-022-00220-y

Wirth, C., Messier, C., Bergeron, Y., Frank, D. and Fankhänel, A., (2009). Old-growth forest definitions: a pragmatic view. In Old-growth forests: Function, fate and value (pp. 11-33). Berlin, Heidelberg: Springer Berlin Heidelberg.

Woodall, C. W., Kamoske, A. G., Hayward, G. D., Schuler, T. M., Hiemstra, C. A., Palmer, M., & Gray, A. N. (2023). Classifying mature federal forests in the United States: The forest inventory growth stage system. Forest Ecology and Management, 546, 121361.

Zhao, J., Daigneault, A., and Weiskittel, A. (2020). Forest landowner harvest decisions in a new era of conservation stewardship and changing markets in Maine, USA. *Forest Policy and Economics* 118: 102251. https://doi.org/10.1016/j.forpol.2020.102251

Zhao, J., Daigneault, A., Weiskittel, A., and Wei, X. (2023). Climate and socioeconomic impacts on Maine's forests under alternative future pathways. *Ecological Economics* 214: 107979. https://doi.org/10.1016/j.ecolecon.2023.107979

Appendices

Appendix A. Classification of Maine forest ownership types

Owner Type	**Definition**
Industrial	A forestland owner that also owns either a paper mill or pulp mill and/or sawmill.
REIT/TIMO	A single organization or a collection of individuals or organizations that purchase timberland as a financial investment. This owner type does not own mills (in our classification system).
Non-Profit Conservation	An organization with primarily an environmental conservation interest in the land (e.g., The Nature Conservancy, The Trust for Public Land, Appalachian Mountain Club), and private individuals with a clearly articulated conservation interest.
Non-Profit Other	A non-profit organization with neither conservation nor timber interests in their land. This category features scouting and church organizations that own land for youth camps.
Contractor	Landowner that is also a logging contractor; one who owns their own logging equipment and manages their own logging crews. Contractors acquire land primarily to provide a land base for their logging crews.
Old Family	Multiple generations, former timber baron families from the 1800s, sometimes contract with forest management companies.
Family Forest	<1000 acres, individuals or families, multiple objectives, likely not contracted with a forest management advisor
Family Office	First generation families, often owning greater than 1,000 acres, owning as a timberland investment, often have a forest management company advisor
Municipal	Town-owned land including community forests.
State	State-owned land. Forest could be a state park (e.g., Baxter State Park) or land managed for multiple uses including timber (e.g., Maine Bureau of Parks and Lands).
Federal	Federal forest owner (U.S. government). These include: Department of Defense, National Park Service, USDA Forest Service, etc.
Tribal	Native-American owners (e.g., Penobscot and Passamaquoddy tribes in Maine).
Other	Other landowners that do not fit cleanly into any category, such as ski areas and private companies that are not forestland (e.g., commercial blueberry lands).

Appendix B. Summary of studies identified in LSOG policy instrument literature review

Authors	**Publication Date**	**Title**	**Journal**	**Geographical Area**
Alix-Garcia, J. and Wolff, H.	2014	Payment for Ecosystem Services from Forests	*Annual Review of Resource Economics*	Global / Regional
Behnoosh Abbasnezhad and Jesse B. Abrams	2025	Are prevailing policy tools effective in conserving ecosystem services under individual private tenure? Challenges and policy gaps in a rapidly urbanizing region	*Trees, Forests and People*	Atlanta, Georgia (USA)
Carlos Carroll, Barry R. Noon, Susan A. Masino, and Reed F. Noss	2025	Coordinating old-growth conservation across scales of space, time, and biodiversity: lessons from the US policy debate	*Frontiers in Forests and Global Change*	United States
Börner, J.; Schulz, D.; Wunder, S.; and Pfaff, A.	2020	The Effectiveness of Forest Conservation Policies and Programs	*Annual Review of Resource Economics*	North America; Europe; Australia; Africa; Asia; and Brazil
Chizmar, S.; Cushing, T.; Baral, S.; and Ruseva, T.;	2025	How do landowners perceive and respond to incentives for sustainable forest management? A synthesis to inform discussions on programs for climate-smart forestry	*Trees, Forests and People*	United States; Montreal; Central America; and Rio De Janeiro
Cubbage, F.; Harou, P.; and Sillis, E.	2007	Policy instruments to enhance multi-functional forest management	*Forest Policy and Economics*	Global / Regional

Derek Kauneckis and Abigail M. York	2009	An Empirical Evaluation of Private Landowner Participation in Voluntary Forest Conservation Programs	*Environmental Management*	Southern Indiana
Francisco X. Aguilar, Matthew C. Kelly	2019	US family forest management coupling natural and human systems: Role of markets and public policy instruments	*Landscape and Urban Planning*	United States
Gregory E. Frey, Chalisa Kallayanamitra, Philadelphia Wilkens, and Natasha A. James	2021	Payments for forest-based ecosystem services in the United States: Magnitudes and trends	*Ecosystem Services*	United States
Irene Ring and David N. Barton	2015	Economic instruments in policy mixes for biodiversity conservation and ecosystem governance	*Handbook of Ecological Economics*	Europe
Katri Korhonen, Teppo Hujala, and Mikko Kurttila	2013	Diffusion of voluntary protection among family forest owners: Decision process and success factors	*Forest Policy and Economics*	Finland
L'Roe, A. and Rissman, A.	2017	Factors that influence working forest conservation and parcelization	*Landscape and Urban Planning*	Wisconsin
Ma, Z.; Butler, B.; Kittredge, D.; and Catanzaro, P.	2012	Factors associated with landowner involvement in forest conservation programs in the U.S.: Implications for policy design and outreach	*Land Use Policy*	United States
Maine Forest Service	2025	Tree Growth Tax Law Information	*Maine Forest Service*	Maine

Malin Tiebel, Andreas Mölder, and Tobias Plieninger	2022	Conservation perspectives of small-scale private forest owners in Europe: A systematic review	*Ambio*	Austria, Bulgaria, Czech Republic, Greece, Hungary, Romania, Slovenia, Spain, Sweden, and Finland
Matilda Miljand, Therese Bjärstig, Katarina Eckerberg, Eeva Primmer, Camilla Sandström	2021	Voluntary agreements to protect private forests – A realist review	*Forest Policy and Economics*	Finland, Norway and Sweden
Matthew C. Kelly, René H. Germain, Stacey A. Mack	2016	Forest conservation programs and the landowners who prefer them: Profiling family forest owners in the New York City watershed	*Land Use Policy*	Catskill Mountains region of New York
Mayer, A. and Tikka, P.	2006	Biodiversity conservation incentive programs for privately owned forests	*Environmental Science & Policy*	Southern Finland; Austria; Sweden; Vermont, USA; Indiana, USA; and Oregon, USA
Megan Jenkins and Harrison Naftel	2022	Making Private Lands Count for Conservation: Policy Improvements toward 30×30	*The Center for Growth and Opportunity*	United States
Michael A. Kilgore, Gregory E. Frey, Stephanie A. Snyder, and Christopher Mihiar	2025	Factors influencing a forest landowner's choice of incentive program commitment length	*Forest Policy and Economics*	Minnesota

Mindy Selman, Suzie Greenhalgh, Michael Taylor, and Jenny Guiling	2008	Paying for Environmental Performance: Potential Cost Savings Using a Reverse Auction in Program Sign-up	*World Resources Institute*	Conestoga watershed in Pennsylvania
Miriam Weber, Peter P.J. Driessen & Hens A.C. Runhaar	2014	Evaluating environmental policy instruments mixes; a methodology illustrated by noise policy in the Netherlands	*Journal of Environmental Planning and Management*	Netherlands
Mirzabaev, A. and Wuepper, D.	2023	Economics of Ecosystem Restoration	*Annual Review of Resource Economics*	Bonn, Germany; Zürich, Switzerland; Africa; Latin America; Caribbean; Pakistan; China; Ireland; France; Costa Rica; and Brazil
Pirard, R.	2012	Market-based instruments for biodiversity and ecosystem services: A lexicon	*Environmental Science & Policy*	France and Europe
Pirard, R. and Lapeyre, R.	2014	Classifying market-based instruments for ecosystem services: A guide to the literature jungle	*Ecosystem Services*	Global / Regional
Robert C. Brears	2022	Payments for Ecosystem Services Financing Nature-Based Solutions	*Financing Nature-Based Solutions*	Global / Regional
Schomers, S. and Matzdorf, B.	2013	Payments for ecosystem services: A review and comparison of developing and industrialized countries	*Ecosystem Services*	Global / Regional

Terhi Koskela and Heimo Karppinen	2024	Forest Owners’ Intention to Safeguard Forest Biodiversity: An Application of the Theory of Planned Behavior	*Forest Science*	Finland
Tina Simoncic; Thomas A. Spies; Robert L. Deal; and Andrej Boncina	2015	A Conceptual Framework for Characterizing Forest Areas with High Societal Values: Experiences from the Pacific Northwest of USA and Central Europe	*Environmental Management*	Pacific Northwest of USA (PNW) and Central Europe (CE)
Wunder, S.; Börner, J.; Ezzine-de-Blas, D.; Feder, S.; and Pagiola, S.	2020	Payments for Environmental Services: Past Performance and Pending Potentials	*Annual Review of Resource Economics*	Global / Regional
Wunder, S.; Brouwer, R.; Engel, S.; Ezzine-de-Blas, D.; Muradian, R.; Pascual, U.; and Pinto, R.;	2018	From principles to practice in paying for nature’s services	*Nature Sustainability*	Global / Regional
Yan, H.; Yang, H.; Guo, X.; Zhao, S.; and Jiang, Q.	2022	Payments for ecosystem services as an essential approach to improving ecosystem services: A review	*Ecological Economics*	Global / Regional

Appendix C. Detailed Policy Instrument Review Table

Instrument	# of Papers (% total)	Key Characteristics	Example Instruments	Strengths	Weaknesses
Tax Incentives and Subsidies	16 (25%)	Reduces financial burden or provides direct financial support to make forest conservation economically viable	Property tax reductions, carbon taxes/subsidies, agri-environmental subsidies, cost-share programs	Reduction in property taxes makes forest ownership more affordable; creates legal buffer against development pressures; opens access to certified sustainable forestry programs and green markets	Sometimes requires minimum acreage thresholds (e.g., 4 hectares); penalties for program withdrawal; may subsidize less ecologically valuable lands
Payments for Ecosystem Services (PES)	12 (19%)	Direct compensation for the environmental services that LSOG forests provide to society	Direct payments for carbon sequestration, water purification, biodiversity conservation; contractual agreements between landowners and beneficiaries; results-based payments	Novel and efficient market-based instruments; payments directly negotiated act as significant participation incentive; compensates opportunity costs of conservation	Environmental impacts may cease immediately when payments stop; lack of precise measurable indicators for robust testing of environmental outcomes
Conservation Easements and Land Protection	6 (9%)	Legal mechanisms that permanently or long-term restrict development while allowing continued private ownership	Conservation easements (voluntary or purchased), private protected areas, fee-simple land acquisition, tradable development rights	Can increase or maintain natural land cover and biodiversity intactness; provides permanent protection; property tax breaks and funding opportunities	Landowners may choose least valuable rather than most ecologically valuable land; high transaction costs; permanent restrictions may deter participation
Market-Based Auctions and Competitive Mechanisms	6 (9%)	Uses market mechanisms to efficiently allocate conservation funding and reveal true conservation costs	Reverse auctions where landowners bid for conservation contracts, small-scale competitive bidding, competitive allocation of conservation resources	Highly effective in revealing provider costs; efficient allocation of limited conservation funds; competitive process ensures value for money	Potentially complex and expensive to implement; may favor larger landowners with resources to participate in bidding processes

Information, Certification, and Voluntary Programs	5 (8%)	Relies on information, voluntary participation, and market premiums to incentivize conservation	Forest certification programs (FSC, SFI), educational initiatives, voluntary agreements, and price premiums for certified products	Market-based incentives for sustainable management; voluntary nature reduces regulatory burden; can provide access to premium markets	Still limited effectiveness due to relatively low consumer willingness to pay; relies on voluntary participation; market premiums may be insufficient to cover conservation costs
Permits, Offsets, and Trading Systems	4 (6%)	Creates markets for environmental benefits, allowing conservation to generate revenue through trading mechanisms	Carbon offset credits, biodiversity banking and habitat credits, cap-and-trade systems, tradeable permits	Provides regulatory framework for exchanging offsets; creates financial incentives through credit generation; allows developers to meet environmental requirements	Lack of consensus regarding positive and negative outcomes; complex regulatory frameworks; potential for perverse incentives or gaming