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Ecological Silviculture for Lowland Wet Conifer Forest Lake States

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7.1 Overview

The North American boreal forest spans over 600 million hectares and includes a diversity of ecosystems and forest communities [1]. The boreal forest reaches its southwestern range limit within the Great Lakes Region (GLR) in the United States (Michigan, Minnesota, and Wisconsin, USA) and Canada (Ontario). Within the GLR, one of the dominant southern boreal forest communities is the lowland conifer ecosystem, which has been variously referred to as lowland conifer ecosystem, swamp, bog, peatland, marsh, waabashkiki (Ojibwe), and mashkiig (Ojibwe) [2, 3]. From a European-American perspective, some of these names imply a negative relationship to these forests – they were viewed as places filled with biting insects, with limited potential for agriculture or homesteading and, as such, were seen to have little value [4]. However, lowland wet conifer forest ecosystems have numerous social, ecological, economic, and cultural benefits [1].

Within the GLR, lowland conifer ecosystems cover 35.5 million hectares and range from 1 to 2-ha pocketed features within upland ecosystems to expansive wetland complexes covering thousands of hectares [5, 6]. The lowland conifer forest ecosystems include open vegetation communities (non-forested systems), low productivity forests (defined as a site index less than 7m at 50 years), and closed canopy forest communities [3]. The closed canopy forest communities are dominated by three overstory species, black spruce (*Picea mariana* (Mill.) B.S.P.), eastern larch (*Larix laricina* (Du Roi) K. Koch), and northern white cedar (*Thuja occidentalis* L.). While eastern larch and northern white cedar have slightly more southerly distributions compared to black spruce, these species have their greatest dominance within the lowland conifer system because of their ability to tolerate the harsh, high moisture conditions associated with lowland conifer forests. These species may co-occur in mixed lowland conifer ecosystems or occur as more single-species communities based on disturbance history and site characteristics [6].

The extensive forest communities in the GLR have a generational history of management [7, 8]. Ojibwe tribes have been the stewards of these forests for generations and continue to steward these

important ecosystems. Black spruce has numerous traditional uses across its range including use of the roots to sew baskets and snowshoes. Within Ojibwe culture, both black spruce and eastern larch are used medicinally [9] and these ecosystems also contain many culturally important food sources, including blueberries and cranberries (*Vaccinium* spp.). These ecosystems provide habitat for numerous wildlife species such as moose (*Alces alces*), white-tail deer (*Odocoileus virginianus* Zimmermann), beaver (*Castor canadensis* Kuhl), grey wolves (*Canis lupus* Linnaeus), and the boreal chickadee (*Poecile hudsonicus* Forster) [10].

Eastern larch and black spruce are also managed for conventional forest products, but markets vary regionally and through time (e.g. black spruce is utilized heavily in Minnesota but lowland conifer species are currently less utilized for conventional markets in Wisconsin and Michigan; [11]). Northern white cedar is mostly unmanaged in this region because of concerns related to an inability to regenerate this species due to white-tail deer herbivory and other factors [12]. Forest harvesting is often limited to the winter under frozen ground conditions [13]; harvesting during nonfrozen conditions is difficult for equipment and can cause extensive damage to soils and hydrology. The combination of limited economic markets and seasonal access issues has resulted in less consistent and less overall silvicultural research in lowland conifer ecosystems than in more economically valuable upland forests in the GLR, such as red pine (*Pinus resinosa* Ait.) or aspen (*Populus* spp.) ecosystems (but see [14]).

This chapter will focus on the black spruce and eastern larch forest types since these forests are currently more likely to be actively managed using silvicultural systems. The vast majority of the chapter will be focused on closed canopy ecosystems, but low-productivity black spruce stands will also be discussed to provide context for the broader lowland conifer ecosystem. Additionally, since we are still learning foundational information about the growth, development, and stand dynamics of these ecosystems, the structure of our chapter will look a little different than others in this book. For some sections, we may have limited information (e.g. recovery period after a regeneration harvest) and include aspects that require additional investigation. In other sections, we will share preliminary findings; finally, in some cases, we will share potential directions or hypotheses which will require future study.

7.2 Glacial History

A major defining characteristic of lowland conifer forests in the GLR is the glacial history and its effects on associated soils [6]. The Wisconsinan glaciation, which occurred about 11,600 YBP, encompassed the entire boreal forest region and much of the GLR. Generally, it was the last lobe that left the surface materials and landforms that now influence the GLR landscape [15]. Given the variety of transport mechanisms associated with glacial activity, surface sediments in these forests are variable and include coarse outwash sands, lacustrine clays, and glacial till and moraine features that have variable textures. As the glaciers receded from the GLR, black spruce and eastern larch, which have pollen records of being present in modern-day Florida and Louisiana, respectively, migrated north and west [16].

Post glaciation, lowland conifer communities are generally derived from two processes, terrestri- alization, and paludification [5]. Terrestrialization occurs in small kettle lakes that formed from ice blocks that calved off glaciers, were subsequently buried, then melted following the retreat of glaciers. These shallow lakes were filled in with vegetation over time as plant productivity was slightly greater than decomposition, mainly because of the waterlogged and cool conditions. During paludification, expanses of relatively dense mineral soils (e.g. lake-derived clays), inhibit

the movement of water, leading to the accumulation of organic matter and the formation of peat, which further restricts the movement of water, promoting waterlogged conditions. Bogs are peatlands that usually form through the terrestrialization process and are acid in nature, low in nutrients, and disconnected from the regional water table (WT). Fens are peatlands that are typically formed by the paludification process and are generally higher in pH, more nutrient rich, and connected to regional WTs. In both types of peatlands, the depth of accumulated peat can be upwards of 10 m [17].

7.3 Plant Community Composition

The plant composition of lowland conifer forest ecosystems varies based on WT and soil acidity [6] (Table 7.1). Forested acid peatlands (i.e. bogs) are dominated by black spruce with eastern larch as a smaller component. In more nutrient-rich, higher pH conditions, the importance of eastern larch increases relative to black spruce, and the occurrence of other tree species including black ash (*Fraxinus nigra* Marsh), northern white cedar, American elm (*Ulmus americana* L.), red maple (*Acer rubrum* L.), and yellow birch (*Betula alleghaniensis* Britton) increases.

Table 7.1 Characteristic plant species of lowland conifer systems in the western Lake States.

Scientific name	Common name (English)	Common name (Ojibwe)	Growth form	Importance by forest type	
				Forested rich peatland	Forested acid peatland
<i>Larix laricina</i>	Eastern larch	Mashkiigwaatig	Tree	●●●	●●●
<i>Picea mariana</i>	Black spruce	Zesegaandag	Tree	●●	●●●
<i>Alnus incana</i>	Speckled alder	Wadoop	Shrub	●●	–
<i>Betula pumila</i>	Bog birch		Shrub	●●●	●●●
<i>Rhamnus alnifolia</i>	Dwarf alder		Shrub	●●	●●●
<i>Andromeda glaucophylla</i>	Bog rosemary		Ericaceous shrub	●	●●
<i>Chamaedaphne calyculata</i>	Leatherleaf		Ericaceous shrub	●	●●●
<i>Kalmia polifolia</i>	Bog laurel		Ericaceous shrub	●	●●
<i>Rhododendron groenlandicum</i>	Bog Labrador tea		Ericaceous shrub	●●	●●●
<i>Vaccinium angustifolium/ myrtilloides</i>	Lowbush and velvetleaf blueberry	Miinan	Ericaceous shrub	●	●●
<i>Vaccinium oxycoccos</i>	Small cranberry	Mashkiigimin	Ericaceous shrub	●●	●●●
<i>Caltha palustris</i>	Marsh marigold		Forb	●●	–

(Continued)

Table 7.1 (Continued)

Scientific name	Common name (English)	Common name (Ojibwe)	Growth form	Importance by forest type	
				Forested rich peatland	Forested acid peatland
<i>Campanula apariondes</i>	Marsh bellflower		Forb	●●	–
<i>Epilobium</i> spp.	Willow herbs		Forb	●	–
<i>Rumex orbiculatus</i>	Greater water dock		Forb	●●	–
<i>Sarracenia purpurea</i>	Purple pitcher plant		Forb	–	●
<i>Carex disperma</i>	Soft-leaved sedge		Graminoid	●●	●
<i>Carex leptalea</i>	Bristle-stalked sedge		Graminoid	●●	–
<i>Sphagnum</i> spp.	Sphagnum moss	Mashkiigwakamig	Moss	●●●	●●●

Importance is based on frequency and cover.

●●●, species with high importance; ●●, species with moderate importance; ●, somewhat important species; –, species generally not associated with the forest type.

Source: Ojibwe name sourced from the Ojibwe People's Dictionary <https://ojibwe.lib.umn.edu/>.

7.4 Historical Natural Disturbance Regime

7.4.1 Stand-Replacing Disturbance

Across eastern larch and black spruce forest communities, stand dynamics and disturbance processes are complex and include historically large stand-replacing fires, mixed severity fires, and small-scale gap dynamics due to insects, parasitic plants (dwarf mistletoe, *Arceuthobium pusillum* R. W. Smith), and wind throw [18, 19]. Historical fire return intervals for high-severity fires are extremely variable and range from as little as 120 years to over 1000 years depending on the specific forest community and the location on the landscape [20]. More frequent, low-severity fires were common in lowland conifer ecosystems that were in close proximity to more fire-prone or fire-dependent upland ecosystems [21]. Stand-replacing fires are hypothesized to have coincided with drought years, i.e. reduced moisture levels (Box 7.1) and previous fine-scale disturbance (windthrow or insects) that increased the amount of downed dead wood on the forest floor [22]. These fires likely burned at a landscape scale resulting in a mosaic of fire intensity including unburned patches.

Due to the relatively thin bark of eastern larch and black spruce, surviving fire-scarred individuals are rare, resulting in fewer dendrochronological studies of fire history compared to pine species in the region (but see [21]). Charcoal analysis from soils has been used to infer fire history, providing fire history for longer time periods (i.e. thousands of years) but at lower precision than dendrochronology [23]. Additional details on disturbance dynamics have been explored in Minnesota using the Public Land Survey (PLS) records between 1846 and 1908 to identify potential fire return intervals, which include using some fire-scarred trees [24]; this technique provides very broad estimates of fire return but has limitations including potential sampling bias. Given predicted increases in growing season drought in the region due to climate change and the connection between fire and drought in these systems, the fire dynamics of these systems may look very different in the future [25].

Box 7.1 Current and Future Impacts of Fire

As mentioned above, historically, stand-replacing fires likely occurred in lowland conifer forests in the GLR following extended periods of drought. Climate change is expected to increase the frequency and intensity of these droughts, and thus fire is also predicted to increase in frequency [25]. Recent and ongoing research on two fires in northern Minnesota may provide insight into this question. A study of the North Minnie fire in 2012 in northwest Minnesota found after two growing seasons that more nutrient-poor bogs dominated by black spruce were likely to recover quickly from low and moderate severity fire and regenerate to black spruce, while more nutrient-rich swamps dominated by eastern larch were not regenerating to larch and may shift away from forested conditions to open wet meadows [43]. However, fire severity and thus fire effects were varied and patchy across this landscape [43]. Observations of the 2021 Greenwood Fire after one growing season also support findings of heterogeneity in fire severity and impacts within lowland conifer forests (Figure 7.1). In areas where sphagnum was not completely consumed, recovery of understory vegetation was apparent even early in the first growing season after the fire (Figure 7.1). In areas with higher burn severity where more sphagnum and peat were consumed, recovery may be slower or the trajectory of the forest may be changed (Figure 7.1).



Figure 7.1 Early vegetation response of peatland forests to Greenwood fire in northeast Minnesota. The Greenwood fire burned in August and September of 2021, photos were taken in June 2022. In areas with lower burn severity, the ground-layer vegetation recovered rapidly (a, b), but areas of high burn severity showed minimal recovery of ground-layer vegetation early in the first growing season (c–e).

7.4.2 Gap Dynamics

Gaps dynamics are an understudied but critical component of stand dynamics within lowland conifer ecosystems. Due to high WTs and their shallowed-rooted nature, both eastern larch and black spruce are vulnerable to windthrow, which can create various-sized gaps [4]. Additionally, black spruce is susceptible to eastern spruce dwarf mistletoe (EDM), a parasitic plant that, unlike other mistletoes, kills 75% of infected host trees in 17 years creating a fine-scale pattern of disturbance [26, 27]. EDM seeds can be dispersed short distances (a few meters) by the plant itself or longer distances by wind or wildlife such as birds. It is likely that birds move the sticky seed around since EDM brooms can provide excellent nesting habitat. Once established, mistletoe spreads outward, creating mortality pockets [26, 27]. However, EDM presence and severity are difficult to predict [28]. In forests managed for maximum timber value, EDM is seen as a forest health threat, but at low to moderate levels, EDM creates opportunities for increased species and structural diversity within peatland forests [27, 29]. For example, eastern larch, balsam poplar, eastern white pine, and other species were found within EDM mortality centers, reflecting the potential for increased diversity when EDM-initiated gaps are formed [27, 29]. Alternatively, high levels of EDM can cause widespread overstory mortality and the ecosystem may shift toward more open forests or shrub-dominated communities such as willow or alder for a period of time [30]; the duration of this stage before eventual canopy closure is not well understood.

Another disturbance agent in gap dynamics within lowland conifer ecosystems is eastern larch beetle (*Dendrodoctonus simplex*, ELB) [31]. ELB is a native insect that historically fed on the phloem of recently dead or dying eastern larch, resulting in very limited mortality of living larch. Although ELB has always been a component of the disturbance dynamics of these systems, it did not historically result in large outbreaks like other *Dendrodoctonus* species (e.g. mountain pine beetle [*Dendroctonus ponderosae* Hopkins] or spruce beetle [*Dendroctonus rufipennis* Kirby]). However, since 2000, the GLR region has been experiencing unprecedented ELB population growth and subsequent widespread mortality of eastern larch [31]. As part of the ongoing outbreak in northern Minnesota, the impact of ELB has created a mosaic of severity across the landscape, including large areas that have widespread and extensive, stand-replacing mortality. Early in the outbreak, the beetle targeted larger-diameter, more productive stands [32], but has moved into smaller-diameter and higher-density stands as the outbreak continues [33]. Across the areas impacted by ELB, some eastern larch trees survive, but the reason(s) why are unclear. Unlike other *Dendrodoctonus* species [34], research on ELB has been limited, with most work focused on recent changes to the beetle's ecology and dynamics due to climate change [31]. There are currently no published management guidelines for ELB but recent work has highlighted similarities between ELB and other *Dendrodoctonus* species in terms of responses to host structure at stand and landscape scales [34].

7.5 Silvics of Black Spruce and Eastern Larch

Eastern larch and black spruce can both be considered early successional or seral species, able to regenerate under full light conditions such as those that may exist after a stand-replacing fire. Initial growth of both species can be rapid; however, given the same conditions eastern larch generally has faster initial growth than black spruce [2]. Eastern larch is conventionally classified

as an extremely shade-intolerant species with limited ability to survive under any shade. However, some studies have observed eastern larch's ability to establish under some level of shade, including after insect damage from larch sawfly (*Pristiphora erichsonii* Hartig) [35]. Recent work in northern Minnesota forests impacted by ELB has documented a wide range of ages for eastern larch saplings; some of these trees were small in diameter (2.5–5 cm) but upwards of 80 years old and were likely growing in shaded understory prior to release by ELB [33].

While black spruce is noted as an early successional species, it can also commonly establish as advance regeneration in the understory and in gaps [27]. Release of black spruce advance regeneration has been observed and can occur in individuals that are greater than 50 years old [36].

The ability of black spruce to self-replace under a range of disturbance severities creates many opportunities for multiple directions or pathways for stand development and stand dynamics. Currently, there is limited information on the dynamics of these systems in the GLR and past work has often relied on diameter as a proxy for age [24], which may overlook the ability of these species to survive extended periods of shade. For example, recent work indicates that 15 cm DBH black spruce and tamarack can be anywhere between 30 and 150+ years old (Figure 7.2). Growth of these tree species may be related to several factors including microsite conditions [37] (see Box 7.2), and a lack of a consistent relationship between diameter and age has commonly been documented in forests dominated by shade-tolerant species. Given the potential for multiple developmental pathways in these systems, lowland conifer ecosystems in the GLR would benefit from more stand dynamics research that included extensive tree cores and cross sections to better understand stand development processes, which may include multiple pathways within one single stand or management unit (see [38–40] for examples of dendrochronology in black spruce in Canada).

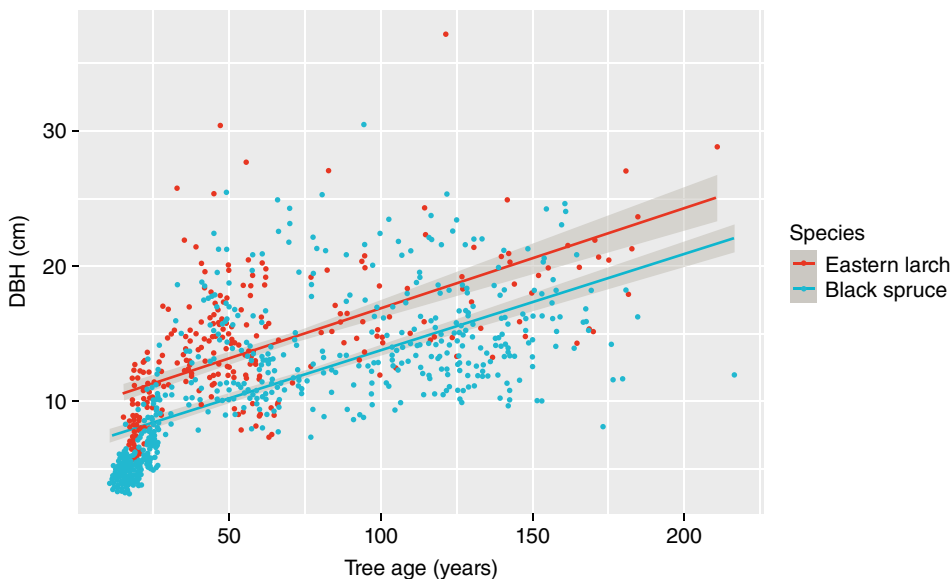


Figure 7.2 Tree age (based on tree core data) vs diameter at breast height (cm) for eastern larch and black spruce at 36 lowland conifer sites in northern Minnesota. Regression lines are based on linear regression with shading indicating 95% confidence intervals.

Box 7.2 Connection Between Hydrology and Silvicultural Treatments

Hydrology and its influence on the magnitude and duration of waterlogged or flooded conditions is a critical aspect affecting the ecosystem functions (e.g. plant productivity and carbon storage) of lowland conifer forests in the GLR. Hydrological processes in lowland conifer forests are strongly influenced by the degree of connectivity to regional water tables (WT) and the timing and amount of precipitation. Fens typically have a relatively stable WT throughout the year at a depth that is dependent on the degree of connectivity to regional groundwater. In contrast, WT in most other lowland conifer forests are more strongly influenced by precipitation. In drought years, WT drawdown occurs more quickly and to a greater depth than more typical years with average annual precipitation [48]. Forest disturbance can also alter WT dynamics, largely because loss of the forest canopy alters the accumulation and melting of snow and reduces water loss via transpiration. However, one study observed limited connection between the water table elevation and black spruce growth [47].

7.6 Current/Conventional Silvicultural Approaches

As mentioned above, both eastern larch and black spruce can act as pioneer species and regenerate well under high light conditions. Regeneration occurs relatively rapidly after a large-scale disturbance and conventional management has focused on production; The Manager's Handbook for Black Spruce in the North Central States emphasizes that silvicultural systems should *produce a high sustained yield of pulpwood and other forest values as efficiently as possible* [4]. This focus on maximizing productive potential is still captured in the current conventional management for lowland conifer species within the GLR. Commonly, lowland conifer stands are treated with the clearcut regeneration harvest system on rotations of 60–100 years depending on site index. Strip clearcutting is another common technique that has been recommended for these systems [4]. Eastern larch and black spruce are generally between 12 and 30 cm in diameter when harvested; a productive black spruce stand will produce roughly $270\text{--}450\text{ m}^3\text{ ha}^{-1}$ [41].

The regeneration harvest is often defined by the stand boundaries of the management organization. Common stand sizes range between 4 and 16 ha (but stand size maybe much greater than 40 ha) depending on the degree of intermixing within more upland forests [42]. However, lowland conifer ecosystems often occur in large complexes, which can be 100s if not 1000s of hectares in size.

After the regeneration harvest, regeneration can establish quickly, especially on the more productive sites. In clearcut regeneration harvests in Minnesota, average stem density of regeneration exceeded 1000 stems per hectare [4]. Species composition of regeneration is dependent on available seed source. Supplemental aerial seeding is a common management practice; recently seeding of black spruce has become more common than eastern larch due to both market demands and seed availability. Little tending or intermediate treatments occur within these systems. The final harvest occurs as the stands are within the stem exclusion stage of stand development; structural diversity and species diversity are limited [27]. While not commonly used, prescribed fire was a more common site preparation tool used during the early and mid-twentieth century to provide more favorable seedbed conditions for the semi-serotinous black spruce cones [4].

The conventional management of lowland conifer ecosystems is based on a relatively narrow window of stand development and a narrow interpretation of the disturbance dynamics of these forest ecosystems (i.e. frequent stand-replacing events). The gradient of the silvics of eastern larch and black

spruce and recognition of the influence of gap dynamics highlight the potential for these ecosystems to have a broader range of structural diversity and a greater potential for the use of multiple silvicultural strategies in managing lowland conifer ecosystems. Additionally, these forest ecosystems are experiencing rapid changes from the long-running ELB outbreak, fueled in part by the impacts of a warming climate on both beetle life cycles and below-ground processes. Increasing the potential silvicultural strategies within lowland conifer ecosystems can likely increase resistance and resilience to immediate forest health threats (i.e. ELB) and broader, longer-term climate-induced impacts [31].

7.7 Natural Development Model for Lowland Conifer Ecosystems

7.7.1 Disturbance and Legacy Creation

Large, stand-replacing disturbances that may include fire, windthrow, and currently wide-spread ELB mortality result in large areas with standing dead or dying trees intermixed with live tree legacies of similar diameter. Legacy trees are likely scattered, more likely to be in groups or clumps, and may be influenced by microsite characteristics.

7.7.2 Preforest Stage

Depending on the location of the landscape, the disturbance, and site history, length of the preforest stage may be highly variable [6]. In eastern larch stands that suffer heavy mortality from ELB, regeneration may be slower and the preforest stage may last more than a decade [33]. The species composition and the timing of regeneration have also been observed to be variable after fire within these systems ([43] – Box 7.1).

The variability in the preforest stage within this ecosystem is likely heavily influenced by microsite variability. Regeneration can be delayed even longer if a disturbance causes a stand to shift to open shrub or sedge, grass meadows [5]. Conventionally this is considered a “loss” of forest land, however, it is more likely representative of a large landscape pattern where forests move from closed canopy to open canopy across long periods and based on disturbances [6].

7.7.3 Young Forest Stage

The young forest stage within lowland conifer forests is rarely visited by forest managers due to the limited use of intermediate treatments. There is huge potential to increase our understanding of the range of variability between stand initiation and stem exclusion.

Under a natural development model, stand density would likely be highly variable. In areas where there was a good match between seed availability and microsite quality, stand density is likely high with limited structural diversity (e.g. moving from stand initiation to stem exclusion). However, in other portions of the stand, stand density would be lower and tree species density would be more evenly mixed with shrub species. Additionally, diseases like EDM could start the process of gap formation, creating heterogenous conditions and allowing for more continuous recruitment [30].

7.7.4 Mature Forest Stage and Old Forest Stage

We are grouping the mature and old forest stages together for lowland conifer ecosystems due to our current understanding of structural and composition variables paired with disturbance dynamics. Future research may support the need to decouple this grouping.

While there is an increase in tree size from the Young Forest to the Mature and Old Forest Stage, the biggest differences relate to the overstory structural characteristics due to the small to moderate scale disturbances dominating these stages [27, 29]. Disturbances like EDM create expanding mortality centers, which result in increased standing dead trees across the diameter distribution [27]. ELB mortality can result in both expansive areas of mortality or more pocketed features, again increasing the number of standing dead trees [33]. Windthrow can result in a shift from standing dead to down dead wood, which can be highly variable. Within the disturbed landscape, regeneration can be continuous, creating a flat-diameter distribution. Diameter is likely a poor surrogate for age since the majority of trees fall within a narrow range of diameters (10-30 cm dbh) [36].

7.8 Ecological Silviculture System

We will broadly discuss a potential model for an ecologically based silvicultural system within the lowland conifer ecosystem. With increased investment in applied research within these systems, there will likely be large gains in knowledge within the next decade or two that will allow us to expand and provide more detailed guidance (see [39] for shelterwood growth response study in black spruce in Canada). Thus, we provide a broadly based model here but acknowledge critical pieces are still being explored within the GRL. The overarching system we are proposing is an expanding gap irregular shelterwood with reserves (Table 7.2).

Table 7.2 Lowland conifer developed across different stages, years, actions, and scale.

Stage	Year	Description	Actions	Scale
Disturbance/ Legacy creation	0	Scattered residual trees that are tied to microsite	Including residual trees after a regeneration harvest	Can begin at the stand scale
Preforest	1–10+	Mix of trees, shrubs, and forbs. A stand may shift toward more open dominated by shrubs depending on disturbance intensity, site quality, and weather	Patience	Can begin at the stand scale
Young forest	3–50	Variable-density small pole trees intermixed with more open areas more dominated by shrubs and forbs	Gaps could be created to decrease time to attain mature forest	Can begin at the stand scale
Mature and old forest stage	50+ years	Trees have increased in size and gap dynamics are occurring; gap size will vary based on disturbances and will follow microsite features	Irregular shelterwood with reserves; reserves composing 40–70% and based on microsite features and location of stand within the landscape	Can begin at the stand scale
Old forest stage (cont.)	120+ years	Similar to above with regrowth providing opportunity for another entry to shift structural complexity	Moving from the stand to the landscape, the next entry should consider how residual patches will shift and gap expansion	Moving toward the landscape

7.8.1 Disturbance and Legacy Creation

Current conventional management in lowland conifer ecosystems focuses on even-aged silvicultural systems with limited legacy creation, which likely encompasses only a portion of the natural disturbance dynamics of these systems [4]. We recommend increasing the amount and distribution of residual trees. This can be a good first step if the current management is more “conventionally” focused. Residuals will provide structural complexity and seed source. Additionally, the difference in microsite, especially if residuals are clumped, can provide opportunities for habitat for more closed canopy species.

7.8.2 Preforest Stage and Young Forest Stages

We are grouping these two sections together. The vegetative response and length of time in these two stages can be highly variable based on factors related to the disturbance, weather patterns, and longer-term climatic trends. For stands with goals other than maximizing stand volume, we recommend little active management within these stages. Site occupancy by tree species may happen quite rapidly (within five years) or may be more prolonged.

If there is interest in moving a young forest stage to the mature or old forest stage of development, pre-commercial gap creation could be implemented but would be unlikely given economic and logistical constraints (e.g. winter harvest in a changing climate).

7.8.3 Mature Forest Stage and Old Forest Stages

As forests transition from the young forest stage to the mature and old forest stage, we recommend the use of an expanding gap irregular shelterwood system with reserves and managing at the landscape scale. This could another be a point of entry if starting with a mature or old forest stage and implementing ecological silviculture within this system.

The irregular shelterwood may more closely emulate the disturbance dynamics of fire, windthrow, and disease in lowland conifer systems. By varying the density, shape, and spacing of reserve trees, reserve trees may serve multiple purposes with scattered individual trees serving as future down dead wood and more clumped patches providing seed source and acting as refugia for plants and animals. Groups of reserves tree can vary in size between 0.2 and 4 ha; the placement of reserve trees should follow microsite characteristics. Leaving widely scattered individual trees or small groups (5–10 trees) within more open areas of the of the shelterwood can provide opportunity for snag creation and blow down for down dead wood. Reserves should compose between 40% and 70% of the initial stand area. The initial intensity of the shelterwood will depend on microsite features, the location of the stand within the landscape, and current species composition (e.g. more reserve trees may be left if there are higher components of rare features like northern white cedar groves or inclusions of paper birch).

As noted above, the exact prescription will be based on the individual site and the location on the landscape. The overarching goal would be to move from individual stand prescriptions to a broader landscape approach to create a complex mosaic of the different stages or natural development occurring across a lowland conifer complex. It would also still maintain a flow of economic services from these systems, but with more focus on microsite features and how disturbance may have influenced the landscape and less on stand boundaries.

While an irregular shelterwood system is more complex than a clearcut system, the implementation of irregular shelterwood cuts would be feasible given advances in technology, namely

handheld mapping platforms (e.g. Arc or Avenza) that can be shared with logging professionals. The primary time investment would be related to extra surveying of stands in the growing season to document the nuances in site conditions, slight changes in elevation, and note areas where reserves maybe placed; essentially the art of silviculture. The GRL does have recent examples of moving toward *more complicated* silvicultural systems. These systems were initially met with hesitancy but are now widely implemented and have resulted in increased ecological resilience and provided greater economic returns to loggers through increased quality of wood products [42].

7.9 Climate Changes Impact on Lowland Conifer Ecosystems

Lowland conifer ecosystems within the GLR have emerged as critical ecosystems, which are predicted to be drastically impacted by a changing climate [44]. Researchers and natural resource managers are actively considering climate change. There have been huge investments to understand the full ecosystem response to increasing temperatures and CO₂ in the Spruce and Peatlands Response Under Changing Environments (SPRUCE) Experiment in northern Minnesota (Figure 7.3). Some critical initial results indicate that warming causes lowland conifer peatlands to shift from carbon sinks to carbon sources, with rates of carbon loss ranging from 5 to nearly 20 times that of historical rates of accumulation [45]. The plant communities in this experiment have also experienced significant changes with warming, with longer growing seasons and more frequent false springs allowing shrubs like blueberries to overtake black spruce and eastern larch [46].

Warming winter temperatures are also predicted to shift the timing and length of frozen ground conditions, influencing both overall ecosystem dynamics and the logistics of management in these systems (Box 7.3). While these peatland communities in the GLR are vulnerable to climate change, the inherent complexity of the system and the duality of the two dominant overstory species (both shade intolerant and tolerant) can provide opportunities to increase ecological resistance and resilience.

7.10 Summary

- 1) Lowland conifer ecosystems within the GRL occur along the southern edge of the boreal forest within Michigan, Minnesota, and Wisconsin in the United States and Ontario in Canada.
- 2) These systems are more understudied compared to other forests in the region but are actively managed for conventional and nonconventional forest products.
- 3) Conventional management generally focuses on even-aged regeneration harvest using clearcuts with or without reserves on relatively long rotations (60–100 years) due to slower growth rates in peat soils and focused on stand development up to stem exclusion.
- 4) Disturbance dynamics are complex within lowland conifer ecosystems and include stand-replacing disturbance through mixed severity and stand-replacing fires. However, small to moderate disturbances that increase structural and species complexity are also common.
- 5) The pre and young forest stages can last variable amounts of time (less than one year to decades) depending on the disturbance (timing, frequency, intensity) and the site characteristics.
- 6) The mature and old forest stage include relatively small diameter trees (10–30 cm dbh) and currently are grouped together. However, as additional research occurs on stand development in these systems, these stages maybe pulled apart.



Figure 7.3 (a) Overhead of SPRUCE (Spruce and Peatlands Response Under Changing Environments) Experiment and (b) inside an enclosure. *Source:* Oak Ridge National Laboratory, U.S. Dept. of Energy.

Box 7.3 Lowland Conifer Management Under Shifting Winter Conditions

Given that lowland conifer forests in the GLR are at the southern edge of their range, they are likely to experience large impacts of climate change on ecosystem functions. Forest harvesting in these systems is generally constrained to winter when soils are frozen and have sufficient strength to support the weight of harvest machinery and limit the amount of soil disturbance that occurs. Climate models generally indicate that snowfall will decrease and air temperatures increase in the GLR – both of which have large influence on the rate of formation and total

depth to which frost develops. Recent research has shown that in peatlands the absence of snow causes frost to develop five times faster relative to when snow is present [13].

What does this mean for the timing of forest management in the future? As long as increased winter air temperatures remain below freezing, it is likely that frost will develop faster and to a greater depth given predicted decreases in snow accumulation. This will likely increase the times when suitable frost is present to conduct harvesting but may also alter other ecosystem functions that are controlled by soil temperature. For example, Friesen et al. [13] found frost as late as mid-July when snow was removed from lowland conifer forests. Depressed soil temperatures into the growing season may cause indirect effects on ecosystem functions such as site productivity. Of course, all of this depends on that rate of warming – if winter temperatures increase above freezing for prolonged periods, then frost is likely to decrease regardless how much snow cover occurs.

- 7) Shifting from a clearcut regeneration harvest, we propose the use of an expanding gap irregular shelterwood with reserve system that would incorporate the mixed severity disturbance dynamics of these systems and provide increased opportunities for structural and species complexity.
- 8) Natural resource managers could incorporate ecological silviculture principles by increasing legacy trees and shifting to natural regeneration after a conventional clearcut regeneration harvest or implementing irregular shelterwoods in a mature or old forest stand with the goal of shifting management from the stand to landscape.

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