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Economic and Spatial Impacts of a Wildlife Habitat Policy on Forest Management

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ECONOMIC AND SPATIAL IMPACTS OF A WILDLIFE HABITAT POLICY

ON FOREST MANAGEMENT

By

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Regulations protecting habitat of forest-dwelling species often impact forest management practices. Those impacts may be mutually beneficial to both wildlife and forestry or they may lead to unanticipated negative outcomes, such as an associated economic cost compared to management free from habitat regulations. One example of a regulation that impacts forest management is the zoning of winter habitat of white-tailed deer *(Odocoileus virginianus)* in Maine, where deer abundance has been consistently below socially desired levels in most areas of the State since the 1970s due in part to the heavy toll of severe winter weather. To mitigate winter-related mortality, the Maine Department of Inland Fisheries and Wildlife (MDIFW) sought to establish protected zones for winter deer habitat (or deeryards) in areas of dense softwood forest cover and traditional deer use. MDIFW also developed an approval process to ensure timber harvests maintained zoned habitat. While there are benefits to supporting the deer population, there are also potential drawbacks to managing for winter habitat on land used primarily for timber production. This thesis assessed both the stand-level economic and landscape-level habitat implications of this wildlife policy.

The first research component evaluated the economic implications of Maine's winter deer habitat zoning policy by quantifying the cost to landowners of managing deeryards on their land. Using the

Forest Vegetation Simulator, I modeled six silvicultural management scenarios and calculated the financial outcomes by wood product stumpage price. Results were dependent on site and the influence of landowner objectives on past forest management and ranged from lower harvest revenues inside deeryards because of less stand tending to higher revenues inside deeryards because of commercially favorable species composition. Adaptive implementation of novel silvicultural regimes holds opportunities for positive habitat-level outcomes with commercially viable timber management. Clearer habitat management guidelines based on standard forest inventory metrics may facilitate the harvest approval process and help foresters realize the potential of silvicultural management within deeryards.

In the face of persistently low deer numbers in northern Maine, MDIFW is reevaluating its guidelines regarding maintenance of habitat features within zoned deeryards and the biological basis of zone delineation. I used maps of tree species abundance and harvest history to evaluate and compare forest characteristics within existing zoned deeryards to areas that would be delineated based on a proposed new zoning method. This analysis of northern Maine led to identification of areas that currently exhibit the desirable characteristics of white-tailed deer winter habitat and a quantitative evaluation of that habitat's distribution. The original zoned deeryards effectively protected patches of softwood-dominated forest from intensive timber harvests. Many patches of potential wintering habitat persist across northern Maine and tend to be aggregated on the landscape. These findings provide new information to aid in revision and improvement of winter deer habitat regulations and guidelines and to mitigate their unintended side effects.

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LITERATURE REVIEW AND GUIDE TO CHAPTERS

Background in forest economics

Forestry and forest management are a balance of silvicultural choices, carefully timed tending operations, ranking of numerous potential outcomes, and financial considerations (Smith et al. 1997). Although there are various possible objectives in forest management, an investment in trees is rarely free of monetary concerns for industrial or small, private woodlot owners (Parks and Alig 1988). Even forests under conservation regulations such as easements are often utilized for and supported by production of marketable output. Thus trees are in many aspects a commodity, with product prices and returns to the investor being a function of supply and demand in a market economy (Healey et al. 2005, Zhang and Pearse 2011). Forests as sources of goods consumed by society – from lumber to recreation – are valued in the field of natural resource economics (Conrad 2010).

The economic value of forests can be analyzed from numerous perspectives. At the broadest scale, forests have both consumptive and non-consumptive value, with consumptive uses including the production of lumber, fuelwood, and non-timber products such as berries, mushrooms, and even forest-dwelling game species. Non-consumptive value stems from the unpriced goods forests provide, such as water and air purification or recreational opportunities, as well as from their preservation value, or the worth society places on the continued presence of forested ecosystems (Zhang and Pearse 2011). Some of these uses are more easily evaluated in monetary terms than others, but all contribute to the value of forests to society and therefore their economic worth.

In investment terms, forests are viewed as capital that can be liquidated when the trees are harvested for processing and subsequent sale (Zhang and Pearse 2011). A forest product with relatively straightforward pricing is timber, or trees grown for processing into products such as paper or lumber. Because those products are bought and sold on the open market, their market value is evident from prices paid (Healey et al. 2005). Timberland is a unique investment and is increasingly included in financial portfolios because, unlike other economic assets, the growth of a tree is always positive. Regardless of changes in demand and market prices, a live tree will never decrease in wood volume. Timber continues growing and can be harvested for income at regular intervals, producing relatively consistent returns (though the magnitude of harvest revenue depends on market prices for the final products) (Healey et al. 2005). Moreover, as a tree grows, it increases not only in quantity of salable material but also in quality of merchantable products. Young, small trees can be made into pulp for paper or pellets for burning, but once they reach a certain size, they can be used for solid lumber and beams. Eventually very high-quality mature trees may be sold as veneer for specialized wood products such as string instruments. Value of timberland thus increases faster than the rate of tree growth because of these "product class step-ups," making an investment in timber uniquely profitable through time as well as flexible in the asset's ability to respond to market demand for each product class (Newman 1987, Healey et al. 2005).

Stumpage

Timber is an expedient asset because of the reliability with which it can be appraised based on the clear market signals from derived wood product prices. Standing timber is appraised with a stumpage value, or what a buyer pays per unit for the trees ready to harvest (Klemperer 1987). This metric is used when a timberland owner is selling trees to a mill, for example, and can vary based on multiple market factors. The seller's reservation price, or lowest bid they are willing to accept, defines the lower limit of the stumpage value. The buyer's maximum bid determines the upper limit. The range of each of those values depends on the individual buyer and seller and how they value the timber. Their decisions are influenced by market prices of timber products as determined by derived demand: a mill will pay less for stumpage if demand, and therefore prices paid for lumber, is low (Klemperer 1996). The construction industry is the largest consumer of lumber products in the U.S., thus the housing market has a strong impact on timber stumpage prices (Healey et al. 2005). The cost of logging and hauling the timber must also be factored into what a buyer is willing to pay as stumpage price. Average annual stumpage values can be determined based on multiple timber sales within a given area and reflect regional timber market values (Maine Forest Service 2015b).

Stumpage values, as determined by forestland owners, mills, and ultimately demand for the derived products, influence forest management decision making concerning silvicultural system, timing of management actions, and target outcomes (Smith et al. 1997). The desired outcome may be old growth characteristics, which can be facilitated by single-tree selection silviculture at regular but infrequent intervals. If the objective is sawlog production for construction materials, selection systems or shelterwood might be employed with intermediate thinning. Pulpwood production for paper could be achieved with shelterwood or clearcutting and planting (Smith et al. 1997). Depending on market demand for each product, forest managers may alter their decisions and schedule to shift production toward higher value goods (Parks and Alig 1988). Some objectives, such as natural succession of afforested areas, may require no further management action and have little feedback relationship with stumpage prices. Other objectives such as wildlife habitat are more loosely linked to markets. Trees can be harvested to promote certain habitat types, and harvested timber can provide revenue, though returns may be a lower priority than achieving certain forest characteristics used by the wildlife species of interest (DeGraaf et al. 1992, Bettinger et al. 1997, Smith et al. 1997).

Other market valuation methods

Sometimes forests are appraised, bought, and sold on a basis other than the immediate harvest value of the standing timber. They may be evaluated on the overall rate of return the investment will provide the buyer, which typically should be greater than the market interest rate at the time to warrant choosing forestland over other investment options (Bentley and Teeguarden 1965). If a buyer is considering forested land without an immediate harvest, he or she might base their maximum bid on the value of a future harvest in terms of its net present value (NPV), or the market value of the future timber in terms of its current worth to the buyer. A forestland owner might consider selling at the liquidation value, or the income he or she would receive from clearcutting the trees and selling the bare land (Klemperer 1987). Similarly, there is a bare land or land expectation value (also called the soil expectation value or soil rent), which includes the value of the land and the present value of an infinite series of harvests (Zhang and Pearse 2011). This valuation method assumes the land will remain forest indefinitely. If it does not, the price of converting it to another use must be factored in (Zinkhan 1991). Alternatively, one might consider the cost that would be paid to provide the same goods a different way, or the replacement cost (Klemperer 1996). An example of this scenario is the analysis conducted by the State of New York to determine whether building a water filtration plant would be more economical than restoring the forests of the watershed for the same purpose (Pires 2004).

Discounting

When future harvests, stumpage, or even land value are considered in a financial context, we must account for the fact that much of the revenue will be acquired many years from now. We cannot simply sum the total expected returns, because there is a generally accepted time preference of investors. The time preference places greater value on income received now relative to future income, of which the latter is subject to greater risk (Conrad 2010). The time preference also reflects the fact that an investor has numerous investment options with associated rates of return that must be compared to that of leaving the land as forest. To account for time preference and compare timber investment rates of return with other potential investment options with differing time horizons, economists typically discount future income to its present value by applying a chosen rate, similar to the interest rate when compounding current sums into the future. Discounted values are reduced by that annual rate, which varies with the strength of the investor's preference for current revenue, willingness to undertake the risk of a long-term investment, and sense of uncertainty regarding changes in interest rates and future prices (Klemperer 1996, Conrad 2010). Greater uncertainty and preference for current income leads to a higher discount rate, thus reducing the value of future income to the present investor. Higher discount rates, when used in calculations to appraise timberland, may lead a purely financially-minded investor to favor earlier liquidation of forest capital (complete or partial) by harvesting (Berck 1979, Prestemon and Holmes 2000).

Discounting is a common practice in financial asset management, but it is problematic when applied to a class as necessarily long-term as forestry. Even when returns from harvests of multiple rotations are considered, they are often so far in the future that their present value is negligible (Conrad

2010). This situation makes an investment in forestland seem of lower value than it is likely to be in the long term. When comparing the value of the land itself for various uses, timber production is often at a disadvantage relative to other land uses. Its long-term returns are weighted lightly in the accounting compared to uses with earlier payoffs, such as agriculture with annual rotations, or residential development with immediate payout (Zinkhan 1991, Klemperer 1996). A deeper dilemma raised by the question of discount rates arises when forests are considered for uses other than production of merchantable goods. Consider an investment in forests that will remain unharvested for preservation of endangered species, recreation, or other ecosystem services, with no or very distant and infrequent anticipated revenue. The financially sensible choice would convert the forest to some other, more profitable use. However, society clearly places value on unharvested forest and the goods it provides. Assigning a value to such forests is essential to compare their output to market-priced commodities (Calish et al. 1978), and some methods that have been developed to estimate non-market values will be discussed in a later section. In the context of discounting, it is clear that some forest management decisions cannot be made on a purely financial basis. Nevertheless, those decisions are included in the economic sphere because the focus is on maximizing the value to society, be it in market terms or unpriced.

Rotation

Balancing the growth rate of trees with the financial elements of present and future value, the timing of harvest operations is determined by both biological and economic factors. The rotation, or interval in which trees reach the desired size or age (Smith et al. 1997), is the measurement unit between timber harvests. It varies in length according to the objectives of the landowner and the chosen valuation method (Calish et al. 1978, Berck 1979). Traditionally there have been two perspectives on the ideal rotation, termed the “biological rotation” and the “economic rotation” (Parks and Alig 1988, Smith et al. 1997). Both aim to grow trees until they reach maximum value, but that value is determined via different routes. If an investor chooses to maximize timber yield, the rotation ends when the volume added annually to the trees on the property peaks, or at maximum mean annual increment (MAI) (Berck 1979).

This biological rotation will generally be longer than the economic rotation, which ends when a harvest will maximize monetary returns on the capital invested in the trees. That point of profit maximization is decided by the chosen valuation method as described previously, and choice of rotation length depends on the priorities of the landowner. In accordance with the National Forest Management Act, the U.S. Forest Service allows tree growth in its public National Forests to continue until the maximum MAI is reached, whereas private landowners may choose to harvest earlier or later depending on their personal discount rate and objectives in owning forestland (Calish et al. 1978, Berck 1979, Smith et al. 1997). There is an opportunity cost of lost returns on capital associated with waiting to harvest until peak MAI, but on the other hand, some management objectives such as creating old growth habitat characteristics call for trees to be left well beyond peak growth (Calish et al. 1978).

Forest investment

Forestland ownership over the last century in Maine was a combination of small private woodlots and large-scale industrial production companies. In the late 1980s, there was a shift to fewer vertically integrated industrial landowners (which own forestland as well as the processing infrastructure) in favor of land held under institutional asset management (Clutter et al. 2005, Zhang et al. 2012). The transition was due in large part to economic factors including a change in tax policies that eliminated the tax advantage of industrial timberland ownership and the undervaluing of timberland inherent in accounting practices (Zhang et al. 2012, Li and Zhang 2014), as was previously discussed (See Discounting). Investors have become increasingly interested over the last 20 years in timber as an investment asset, but industrial firms have not been eliminated (Li and Zhang 2014). Advantages remain in both types of timber investment, and each lends itself to distinct forest management approaches.

Vertically integrated industrial landowners

The ownership strategy of vertical integration decreases the risk involved in timber ownership as compared to that of non-vertically integrated wood product companies, or those that own only the forestland or only the mill. Because the firm owns the supply chain from the primary resource (trees), to the processing equipment (mill) and the product output, it can better respond to changes in the market than can a company that owns only one of those components (Li and Zhang 2014). As prices for input or output change, the firm can alter its utilization of its timber versus production facilities and restrict how much timber reaches the market, as well as the proportion of output types produced (Prestemon and Holmes 2000, Zhang and Pearse 2011). With market shifts, a vertically integrated company can substitute products in greater demand (Newman 1987, Zhang and Pearse 2011). There is an additional advantage if the firm owns the land surrounding the mill. It can minimize transportation costs and generate land rent, according to the leverage theory of vertical integration (Li and Zhang 2014). Despite these advantages to vertical integration in industrial timberland company structure, not all firms are vertically integrated, and the trend since the mid-1980s has been toward timberland ownership under a different tax structure, primarily as an asset in timberland investment management organizations (TIMOs) (Clutter et al. 2005, Healey et al. 2005).

Institutional timberland investment

TIMOs invest capital on behalf of individuals, states, corporations, foundations, endowments, pension funds, insurance companies, and any other investor interested in asset management (Healey et al. 2005, Zhang et al. 2012). Timberland has become an attractive portfolio asset because of the unidirectional increase in wood volume quantity as well as quality with product class step-ups, the extensive research contributing to consistent growth and quality, the positive performance of timber investments in the face of inflation, the presence of both local and global markets for a variety of timber products, and the value of the land itself should an alternative use be more profitable (Healey et al. 2005). Timberland is a favorable asset class also because of its wide diversification options. TIMOs can compile a timber portfolio that incorporates variety in geographic location, tree species, management intensity, site quality, output produced, and age classes (Healey et al. 2005). Thus, the risk of failure from any specific ownership decreasing overall returns to the investor is low. Furthermore, institutional investment is impacted relatively little by short-term timber product market fluctuations (Yin et al. 1998). Due to the large amount of capital a TIMO invests and its freedom from the pressures of annual cash flow targets an industrial firm would experience, it can alter its buying and selling patterns depending on current markets.

Similar to how a vertically integrated company balances timber supply from its own land with product output from its own mill, TIMOs can restrict the amount of timber products on the market during economic downturns, driving up the price by decreasing supply. An industrial company can use such a tactic to a limited extent because it must still meet minimum return targets, but large TIMOs have much greater capital with which to increase their flexibility in the market (Yin et al. 1998).

Changes in forest management resulting from recent shifts to institutional timberland ownership will become evident in the coming years. Initial data suggest that both TIMOs and industrial landowners prioritize returns for their investors when making silvicultural decisions (Clutter et al. 2005). While vertically integrated companies historically may have concentrated more on long-term income, and thus invested more heavily in research, intermediate silvicultural treatments, and community involvement, they often made decisions based on what would increase final returns. TIMOs, especially those with geographically diverse landholdings that do not tie them to the surrounding community, may make fewer local investments and rely more heavily on final revenues alone to meet shareholder expectations. The ownership system of TIMOs operates on a much shorter time scale than industrial companies, allowing them to profit from their investment earlier but perhaps decreasing the quality (and therefore value) of timberland output in the long run. This as yet undocumented outcome would be the result of TIMOs' supposed tendency to harvest earlier than would a traditional industrial firm and to de-emphasize intensive forest management and assurance of future supply in the interest of returns on capital (Clutter et al. 2005, Zhang et al. 2012, Li and Zhang 2014). Although data on silvicultural viability of the TIMO forest management strategy are lacking, one study did find that non-industrial landowners (including TIMOs) are harvesting sustainably (cutting less than or equal to the volume that has grown since the last harvest) and replanting at a rate equal to that of industrial landowners (Zhang et al. 2012).

There is, however, a greater risk of land use change when timberland is converted from industrial to institutional ownership (Clutter et al. 2005). Because the priority is on returns rather than continued value of the timber resource itself, the institutional investor has no need to keep the land forested if an alternate use will increase returns. Depending on the location and quality of the land itself, demand for wood products relative to other commodities, and demographic variables such as population growth and concentration in metropolitan centers, forestland is most frequently converted to other uses such as housing development (Parks and Alig 1988, Clutter et al. 2005). Some land sales to TIMOs result in virtually no management change from the previous forest ownership, while others end in broad scale land use conversion (Clutter et al. 2005).

Multiple use

The above discussion has centered on forestland as a source of timber and its derived wood products as a market commodity. While still working within a market-priced framework, there are other uses of forestland apart from product-driven timber production. It can be used simultaneously for timber and other products such as fodder production in the understory, savannah-type rangeland for cattle, or habitat for game species that can be profitable to the landowner in the form of hunting leases sold for access to the property (Klemperer 1996). Sometimes these simultaneous uses are competitive, and an increase in one decreases the productivity of the other. In these cases a careful analysis must be done to determine the optimum balance of each alternative to maximize total revenue (Zhang and Pearse 2011). There is also the possibility of joint or complementary uses, which increase together as in the case of tree growth and carbon storage (Zhang and Pearse 2011). Sometimes it is more efficient to offer multiple uses in separate areas of one forest tract, such as providing hiking trails in one section and assigning the other to intensive timber production (Klemperer 1996). Additionally, there is an amenity value associated with any acre of forestland. This value includes the services that the forest provides regardless of other uses and outputs. Amenity values can consist of ecosystem services such as water purification; societal benefits such as scenic locations for recreation; and widely accepted ideals such as preservation of biodiversity (Berck 1979, Conrad 2010, Zhang and Pearse 2011). When deciding the balance of multiple uses in economic terms, it is useful to calculate the discounted net present value (NPV) to the landowner, or some other evaluation metric such as rate of return, of all the potential uses at varying intensities. However, when we include uses such as recreation and other amenity values that are not necessarily subject to direct market signals, identifying the ideal allocation is more complex (Klemperer 1996).

Non-market valuation

Valuation methods have been developed to assign value to products that are not well regulated by the market. These "non-market valuation methods" use financial signals outside market supply and demand to estimate the worth of a resource to society (Conover 1997). They include estimating a consumer's costs associated with an activity such as hunting or recreation (in gasoline, lodging, hunting licenses or entry fees, and related expenses) through travel cost analysis (Moser and Dunning 1986, Luzar et al. 1992); counting the number of times a user accesses a resource (Hussain et al. 2016); directly surveying a sample of a population with the contingent valuation method to estimate overall willingness to pay for a certain good or service such as protection of endangered species (Loomis and White 1996, Fix et al. 2005); combining multiple methods to account for the biases inherent in each, such as the union of travel cost and contingent valuation methods in conjoint analysis (Mackenzie 1990); observing changes in demand or willingness to pay in response to changes in site characteristics through the hedonic approach (Livengood 1983); and many other methods and combinations to estimate the value of unpriced goods (Conover 1997, Schwabe et al. 2001). Accounting for the unpriced preferences of society is subjective and approximate, and therefore must be applied carefully when determining total value of non-market goods. Yet any strategy is preferable to completely disregarding the value of the complete suite of forestland features, whether easily priced or not.

Market failure

Often unpriced goods are not efficiently regulated by market signals of supply and demand. It is likely in that circumstance that the benefits and costs of the resource are allocated inefficiently. This scenario is called a market failure, and a positive or negative externality is the result when the costs to society do not equal the benefits (Klemperer 1996). For example, amenity values rarely contribute to the revenue of a landowner invested in timber production, although production-focused forestry can provide many additional goods to society such as air purification and wildlife habitat. The value of these goods is infrequently weighed in the decision of most profitable land use, and thus forestland may be converted to other uses such as residential development without regard for the unpriced benefits society was experiencing (Conrad 2010). When the costs of an action are borne by those who are not receiving the benefits, such as in this land use conversion example of an externality, the market is not an efficient allocator of a resource's value. In order to allocate resources with greater equity, measures such as incentives or regulations must be taken to induce revenue-motivated firms to consider non-market goods (Quartuch and Beckley 2014). The most common source of intervention in a mixed capitalist system such as that of the U.S. is the government (Zhang and Pearse 2011). In situations such as excessive waste production by processing plants, for example, governments will implement caps on waste output or mandatory measures to decrease pollution (Montgomery 1972). Another situation often impacted by government regulation is in the case of habitat conservation. Despite the fact that game species have some market value derived from revenue associated with hunting, wildlife and associated habitats are generally non-market goods. To protect wildlife in the face of land use conversion and forest management that may be contrary to species' needs, government agencies may pass legislation that specifies certain habitat characteristics that must be present, limits harvest activity in sensitive areas, or requires approval procedures before allowing timber management and harvesting activity (Lavigne 1997).

Deeryard protection policy

One example of a regulation to protect wildlife habitat impacting forest management on private lands is the implementation of zoning to protect deer wintering areas, or deeryards, in the State of Maine. White-tailed deer (*Odocoileus virginianus*) are recognized by the public as having value as a source of hunting revenue and for unpriced viewing enjoyment, among other non-market values. However, the winter habitat deer depend on in the north of their range is often found on privately-owned land under intensive management for timber production, where provision of habitat is not a market-induced action. Even though individuals working for a forestry firm may highly value deer, the priorities guiding the company's forest management decisions are often revenue-focused. Thus, government action was undertaken to account for the societal value of deer. To increase the State's deer population, government agencies enacted measures to maintain the availability of critical areas of winter habitat.

Identification of deeryards in Maine began as early as the 1950s, although deeryard zoning legislation was not enacted until the 1970s (Lavigne 1997). Biologists in the Maine Department of Inland Fisheries and Wildlife (MDIFW) performed ground and aerial surveys to identify areas where white-tailed deer congregated under specific wintering conditions of 30.48 cm snow depth, 20.32 cm deer sinking depth, and average temperatures below 0 degrees C. Wintering conditions were defined for surveying purposes based on the Winter Severity Index (WSI), a scale of winter weather severity that was developed by MDIFW from literature and their own data of snow, temperature, and weather conditions in Maine (Maine Department of Inland Fisheries and Wildlife 1990a). Identified deeryards were originally protected through the formation of cooperative agreements between MDIFW and forestland owners, in which the landowner committed to protect the deeryard and surrounding area by maintaining forest characteristics important for deer during the late fall, winter, and early spring (Lavigne 1997). In 1973, the Maine State Legislature established the Land Use Regulation Commission (LURC), now the Land Use Planning Commission (LUPC), to protect Maine's natural resources and oversee the increasing development in the unorganized townships of northern Maine. LURC became the regulatory authority in identification and protection of deeryards and instituted the zoning of Protected Fish and Wildlife (PFW) areas, moving away from cooperative agreements in favor of more binding zone designation (Lavigne 1997; P-FW, Dept. of Conservation, Maine LURC 1997, LURC statute TITLE 12, M.R.S.A., Chapter 206-A LAND USE REGULATION, Chapter 10 Land Use Districts and Standards defines Fish and Wildlife Protection Subdistricts). LURC collaborated with MDIFW such that MDIFW would continue the process of identifying, delineating, and monitoring deeryards that were officially designated as PFWs through LURC (R. Robicheau, Maine Department of Inland Fisheries and Wildlife, personal communication). Official zoning of PFWs created alarm among forestland owners concerned about State regulation of their property; therefore, the extent of PFWs was limited to the most critical area of shelter for wintering deer and excluded the surrounding areas where deer lingered in late fall, early spring, and mild winter days (R. Robicheau, Maine Department of Inland Fisheries and Wildlife, personal communication; Maine Department of Inland Fisheries and Wildlife 1990a). PFWs were delineated after multiple surveys to confirm significant deer use during wintering conditions (at least 8 deer per km^2 when WSI>60 in at least 2 of the past 10 winters) (Maine Department of Inland Fisheries and Wildlife 1990a). No additional PFW zoning has been pursued since the early 1990s, although LURC retains the authority to do so as of August 2017 (R. Robicheau, Maine Department of Inland Fisheries and Wildlife, personal communication).

In organized townships, Maine's 1987 Natural Resources Protection Act (NRPA) assigned the Department of Environmental Protection (DEP) regulatory authority over significant wildlife habitat (Maine State Legislature 1987, Maine Department of Inland Fisheries and Wildlife 1990a). As in the unorganized townships, MDIFW had reached cooperative agreements with landowners in southern, organized townships to protect deeryards prior to the enactment of NRPA, but DEP provided a mechanism by which official zoning could occur. Original identification of those southern deeryards was based on remote identification of suitable forest types often used by wintering deer rather than surveys of deer presence, and official zoning by DEP would require formal surveys during wintering conditions, similar to the surveys performed during PFW delineation (R. Robicheau, Maine Department of Inland Fisheries and Wildlife, personal communication). Ultimately, no deeryards were zoned through DEP because of the infrequency of wintering conditions in which to perform the necessary surveys to verify deer use. Furthermore, winter deer shelter is relatively unimportant in the predominantly southern organized townships, where deer density is higher than the MDIFW target and does not warrant active habitat protection to support the deer population (R. Robicheau, Maine Department of Inland Fisheries and Wildlife, personal communication, Maine Department of Inland Fisheries and Wildlife 1990a). Nevertheless, the outlines of those remotely identified deeryards in organized townships, called Deer Wintering Areas (DWA) by MDIFW, are filed with DEP. Any extensive proposed development that infringes on a DWA boundary is referred to MDIFW for evaluation. The agency suggests adjustments to minimize or mitigate the potential impact on winter deer shelter quantity and quality (R. Robicheau, Maine Department of Inland Fisheries and Wildlife, personal communication).

Voluntary protection of additional forestland that may function as winter deer shelter occurs throughout the forested landscape of Maine. Many private landowners choose to maintain forest characteristics similar to those published as winter deer shelter by MDIFW (Maine Department of Inland Fisheries and Wildlife 2010b) on part of their property (R. Robicheau, Maine Department of Inland Fisheries and Wildlife, personal communication). Their motivation may be to increase their deer hunting success, to support the deer population for viewing enjoyment, existence value, or one of its other non-consumptive values to society, or to pursue alternative objectives such as promoting old growth forest, which shares many characteristics of winter deer shelter. Additionally, some owners of large tracts of commercial timberland have chosen to enroll part of their property in cooperative deeryard protection agreements with MDIFW (R. Robicheau, Maine Department of Inland Fisheries and Wildlife, personal communication). The additional area is often adjacent to existing PFWs and meets habitat needs of wintering deer such as additional shelter or winter browse. The increase in protected area allows forest managers greater flexibility in extent, timing, and intensity of timber harvests in the protected area while still meeting minimum requirements for core shelter (Maine private forester, personal communication). These agreements are similar to those that protected winter shelter for deer prior to official zoning through LURC. The landowner and MDIFW agree on the boundary and the monitoring procedure, which includes a visit by a company forester and an MDIFW biologist to the site of any proposed timber harvests to reach a plan agreement. Cooperative agreements are not binding if the land changes ownership, but are usually evaluated and renewed with the current owner every 5-10 years (R. Robicheau, Maine Department of Inland Fisheries and Wildlife, personal communication).

Focus of thesis

Under Maine's current legislation, most of the actively protected winter deer shelter is concentrated in PFWs and cooperative agreements in the State's northern, unorganized townships. The majority of Maine's commercial timberland is in unorganized townships, and thus, much of the cost of this habitat provision policy is borne by forestland-owning firms. The imbalance between public and private value allocation and the associated economic impacts in the context of this unique policy was the focus of the research described herein.

The research surrounding deeryard management has typically concentrated on identifying silvicultural actions that improve habitat quality for wintering deer. Rarely does a study report the impacts of those actions in metrics other than forest habitat characteristics. Any forest management decision has potentially far-reaching social effects, influencing land use, public opinion, and profits for forest landowners to loggers (Parks and Alig 1988, Weladji et al. 2003, McComb 2016). Study of these decisions requires a union of biological and social sciences (Smith et al. 1997). Evaluation of policies that affect forest management must extend beyond their direct impacts on forest characteristics to include impacts on society such as economics.

The policy in the State of Maine that protects certain forest areas as winter habitat for white-tailed deer through zoning has been subject to much discussion but relatively little research since its implementation. There is a notable lack of information other than stand-level forest characteristics within the zoned areas (Bryan 2007, Doty 2007, Stadler 2007, Maine Department of Inland Fisheries and Wildlife 2011, Harrison et al. 2013, Maine Department of Inland Fisheries and Wildlife 2013a). The following studies present two novel analyses of this habitat provision policy: its economic impacts on the landowning firms on whose land the habitat is located, and the long-term region-wide status of available habitat. These are necessary analyses at a critical point in the policy's history. It has recently received greater attention as MDIFW, charged with its practical oversight, has undertaken revision of the guidelines that direct forest management within the zoned habitat areas. Targeted research will inform policy discussions and clarify effects thus far, as well as provide practical information to those affected by the policy.

Guide to chapters

Chapter 1 includes an introduction to the relevant background in economic theory and literature as well as the history and current context of the habitat policy I focus on in this thesis. Forest management actions are regularly influenced by market feedback and in turn affect wildlife habitat, emphasizing the important role economics plays in both forest and habitat management. Chapter 2 specifically addresses the economic consequences of altered forest management due to deeryard zoning. The MDIFW management guidelines for zoned areas of winter deer habitat require that harvest operations maintain minimum standards of tree height, crown closure, and acreage (Maine Department of Inland Fisheries and Wildlife 2010b). I found during interviews with forest managers that they often need to adjust their silvicultural prescriptions to maintain those features by decreasing the intensity of a harvest or using an alternative silvicultural system than is typically used on non-zoned timberland. Maine private foresters asserted that these adjustments resulted in an economic loss compared to the revenues possible with more commonly applied harvest scenarios. If true, such a situation is a case of unequal allocation of costs and benefits. The use of zoning to protect deer wintering habitat was implemented to address the original externality of a public good (deer and their critical winter habitat) that was perceived as not being sufficiently provisioned by private landowners; as a result, the private landowners might be bearing the cost of a natural resource from which they do not receive compensatory benefits. To identify the true cost of deeryards on a commercial forest landowner’s property, I examined the stand-level financial returns of common silvicultural scenarios as applied both inside and outside of zoned deeryards based on inventory data from multiple sites in Maine. I included a novel silvicultural system, irregular group shelterwood with reserves, which has not been widely used but might be appropriate for implementation both inside deeryards and on non-zoned timberland. I parameterized a growth and yield model according to forester responses to interview questions regarding their typical management and compared both harvested and residual value of timber from inside and outside deeryards. My results will be available to the policy makers and those implementing deeryard guidelines on the ground in hopes that new information may improve planning and outcomes of forest management inside deeryards.

Economic factors are also at work on a scale larger than the individual deeryard. Regulations such as this habitat zoning policy or the Forest Practices Act (FPA) enacted in 1989 and most recently revised in 2013 (Maine Forest Service 2013a) may cause land management companies to alter their forest management decisions as a result of legislation that makes formerly profitable actions less cost effective. If companies expect lower returns due to harvest restrictions or the process necessary to receive approval for harvesting, they may change their plans to find greater revenue from harvests elsewhere. Changes in harvesting patterns over recent decades have altered the characteristics of the forest surrounding zoned deeryards, thus altering the landscape context of these habitat patches. They are often isolated from other similar patches by a matrix of non-winter habitat (Harrison et al. 2013). Chapter 3 provides descriptive spatial information regarding the current setting of deeryards across northern Maine. It includes tree species and harvest history information within zoned deeryards as well as within an alternative zoning strategy that MDIFW has recently considered. Furthermore, I analyzed the distribution of winter deer habitat across northern Maine to determine its availability apart from zoned areas. Results will be informative to other ongoing deer and forest typing studies in the Northeastern US and Canada.

My research is intended to be of practical use to researchers, policy makers, and those working in the field for both the forest industry and wildlife management. With this goal in mind, the work presented in Chapter 2 is in preparation for submission to Land Use Planning at the time of this document's submission to the University of Maine Graduate School. Any differences in writing style and tone between Chapter 2 and the rest of this document can be attributed to the input of the submitted manuscript's coauthors Dr. Mindy Crandall and Dr. Amber Roth and the author guidelines of the journal. The research presented in Chapter 3 is ongoing in conjunction with a regional deer research partnership that has incorporated university and industry effort across the Maine-New Brunswick border. This research will be included in publications after the submission of this thesis.

CHAPTER 2

ECONOMIC COST AND BENEFIT OF SILVICULTURAL SCENARIOS APPLIED IN DEERYARDS ON TWO FOREST PROPERTIES IN MAINE, USA

Abstract

In the northern Maine, severe winters lead to high deer mortality, but the toll of winter weather is mitigated when deer find shelter in mature softwood-dominated forest. Critical areas of this forest type, often found on private forestland managed for commercial timber production, are maintained through timber harvest plans that are agreed upon by the timber company forester and a state biologist. Yet there are persistent difficulties in the implementation of this policy, including a perceived economic loss to forestry companies due to restricted timber harvests within deeryards. I simulated common silvicultural management scenarios in a growth and yield program and calculated the associated revenues in order to address the economic concerns of timber companies managing winter deer habitat in Maine. Simulations included a suite of forest management scenarios that have been successfully applied in winter deer habitat management and included a novel scenario, irregular group shelterwood with reserves. Results of simulations using inventory data from diverse plots across central Maine indicated that there are opportunities for comparable revenues inside and outside of deeryards, although returns varied depending on the legacy of previous management and the current species composition of harvest sites. The irregular group shelterwood with reserves was competitive with other scenarios in terms of revenues, although modeling output could not verify its suitability as winter deer habitat. Improved habitat evaluation metrics that are easily understood by foresters and biologists and that are reliable in common growth and yield modeling programs could encourage active management inside deeryards, facilitating positive outcomes for both parties' objectives.

Introduction

Forest and wildlife management have long been intertwined in local, state, federal, and international policy (McComb 2016). New regulations in one sphere often impact the other and can stimulate a change in management approach and outcomes. The link between silviculture and wildlife habitat conservation has ripple effects through arenas as wide-ranging as hunter satisfaction, biologist-forester-sportsman interactions, harvest systems and machinery, operator contracts, species composition of both wildlife and sylvan communities, and economic markets (Brown et al. 1994, Conrad 1999, Weladji et al. 2003, McComb 2016). One such policy that has generated both intended and unforeseen outcomes is the protection of deeryards, also called winter cover or wintering areas, for white-tailed deer (*Odocoileus virginianus*) in the northern extent of its range. With input from forest managers and wildlife biologists in Maine, where deeryard regulation began as early as the 1950s (Lavigne 1997), I examine how the conservation policy has altered forest management and the financial implications of those changes.

Silvicultural management of deeryards has been the subject of discussion since the establishment of regulations guiding deeryard management (Boer 1978, Weber et al. 1983). The yarding behavior and preferred habitat of deer during the winter in northern New England, the Upper Peninsula of Michigan, New Brunswick, and southern Quebec have been well documented, but a consensus on best management of winter habitat for both sustained deer use and commercially viable timber harvests is elusive (Verme 1965, Telfer 1978, Euler and Thurston 1980, Sabine et al. 2002). In Maine, select sites of historical deer yarding have been designated as protected deeryards (PDs) and are managed by the landowner in conjunction with state biologists to maintain winter habitat quality while still allowing for harvest activity on private land. Management practices in these PDs vary widely, and there has not been any direct comparison or analysis of management outcomes. I used interviews, forest stand inventory data, and current economic information to model likely management activities in and outside of PDs and estimate the financial implications of this habitat provision policy. Economic returns presented here from a variety of management scenarios provide a reference point for evaluating silvicultural opportunities in deeryard management and estimating the cost of habitat management regulations.

Deer biological and behavioral response to severe winters

White-tailed deer are managed by the state as a public resource. The challenge for biologists in the north of the range is to maintain the population at a level sufficient to satisfy the public's desires despite the toll of harsh winter weather. Deer density relates inversely to winter severity, with deeper snow and colder temperatures resulting in higher deer mortality (Moen 1976). The browse selected by white-tailed deer during the winter consists largely of hardwood sapling twigs when the more nutritious ground plants and leaves they prefer are lacking or covered by snow, but such browse is limited in both quantity and nutritional value (Dumont et al. 2005). To meet their energy requirements through the winter until spring green-up, deer rely on fat stores accumulated throughout the fall (Potvin and Huot 1983). In areas with moderate winters, those energy stores sustain most deer through the cold season, but the long, cold winters across Canada and the northern United States can exhaust those reserves.

In response to the pressure of increased metabolic requirements to maintain body temperature and move through deep snow, white-tailed deer overwinter in sheltered areas rather than increase foraging effort (Moen 1976, Tierson et al. 1985). The energy expended foraging in snow is often greater than the calories taken in from winter browse. Rather than increase their movement in search of food, some deer migrate each fall to deeryards, or areas of low elevation, gentle topography, and dense softwood cover, which minimize snow accumulation and energy loss (Morrison et al. 2003). They often return to the same site over multiple generations (Boer 1992). Although browse is limited in these softwood-dominated areas, locomotion is less energetically costly because the softwood boughs block snow, and the high density of deer that overwinter in one location creates well-packed paths to ease movement (Lishawa et al. 2007).

Deeryard zoning

Due to the importance of deeryards to deer survival and impelled by public demand, the State of Maine’s Land Use Regulatory Commission (LURC, now the Land Use Planning Commission, LUPC) delineated many deeryards for official protection in the 1970s (Lavigne 1997). These zoned areas, called Protected Fish & Wildlife Zones (PFWs), were to be maintained as winter habitat for deer in perpetuity. Deeryards were selected for protection after wildlife biologists mapped sites of deer use based on aerial and ground surveys during severe winter weather (Maine Department of Inland Fisheries and Wildlife 2013a). Some landowners voluntarily designated an additional portion of their property as “cooperative deeryards" to be managed similarly to official PFWs (Lavigne 1997). Cooperative deeryards and PFWs are hereafter referred to together as "protected deeryards," or PDs. They span both public and private lands, many of which are commercially harvested for timber. To prevent habitat loss or degradation, deeryard management guidelines and a timber harvest approval system were created to ensure that PDs continue to exhibit features determined to be of value to wintering deer (Table 1; Maine Department of Inland Fisheries and Wildlife 2010a). Foresters planning to harvest timber from a PD must either file a Forest Operations Permit with LUPC or meet with a state wildlife biologist from the Maine Department of Inland Fisheries and Wildlife (MDIFW) to agree on a harvest prescription within the PD (Lavigne 1997). Any single timber harvest may decrease crown closure below the published desired percentage if at least 50% of the PD meets the stated minimum.

Table 1. Deer winter habitat management guidelines as described by the Maine Department of Inland Fisheries and Wildlife.

Habitat metric	Primary Winter Shelter	Nonconforming (not winter shelter)
Softwood crown closure	≥70%	<50%
Stand height	≥10.7 m	<10.7 m
Aspect	south	any
Shelter area	≥10 ha	<10 ha
Minimum shelter width	≥302 m	<302 m

Limited success of deeryard zoning

Despite these measures aimed at maintaining deeryard acreage and characteristics, recent findings indicate that adequate winter shelter within PDs has decreased from 10% to 5% of Maine's landscape from 1975-2007 (Harrison et al. 2013). This decrease is due to a variety of factors, including loss of softwoods to spruce budworm and natural stand deterioration through tree senescence without regeneration (Stadler 2007). Although forest within PDs is protected, the areas to which deer return each winter are becoming smaller and more fragmented because of intensive timber harvests surrounding PDs, rendering them less able to support the MDIFW's target deer population (Harrison et al. 2013). Since initiation of the zoning policy, estimates of deer abundance in Maine have not rebounded as desired back to their peak of about 4 deer per km^2 in the 1950s, instead remaining at 1-2 deer per km^2 in the northern and western regions of the state, where winters are typically more severe (Maine Department of Inland Fisheries and Wildlife 2013a).

Although timber harvesting is sometimes identified as a reason for the decline of deeryard quality, harvests themselves do not deter deer from returning to a site. In fact, the presence of cut hardwood tree tops around harvest sites often attracts deer short-term, as it provides an easily accessible food source (Tierson et al. 1985). Rather, declines in deeryard quality can occur when intense harvests outside of the deeryard extend to the PD boundary, essentially creating an island of winter shelter with sharp transitions to neighboring forest types (Maine Department of Inland Fisheries and Wildlife 2011, Harrison et al. 2013). Multiple foresters have communicated that harvesting within PDs is often avoided due to additional time and effort needed to design a prescription appropriate for maintaining the state-specified winter shelter characteristics and to obtain approval to harvest. That approval can come from LUPC through a Forest Operations Permit application process that is often lengthy or, more commonly, from MDIFW through a site visit and harvest agreement with a state wildlife biologist. There is a commonly held belief among foresters that harvests designed to maintain winter shelter in PDs are less profitable due to the "light touch" to which most prescriptions are restricted and the lower quality trees grown in the absence of typical intermediate treatments such as thinning. Maine private foresters often feel constrained in the type or intensity of harvest they are allowed to perform in PDs and therefore do not prioritize, and sometimes avoid, incorporating PDs into harvest plans. Additionally, the difficulty of finding a logging operator to agree to the anticipated low financial returns often associated with PD harvests can be prohibitive to management. Interviewed state biologists agree that more active management would be beneficial to sustained habitat quality but, because of the limited size of most PDs, they hesitate to approve intensive harvests for fear of losing the small amount of primary winter shelter that remains on the land base.

Justification: costs and benefits of PD management

Recognizing that silvicultural options are constrained when operating within PDs, there may yet be an advantage to seeking a percentage of harvested volume there in order to promote intentional management of PDs and achieve economic returns. Shared knowledge regarding the silvicultural systems acceptable within PDs may facilitate understanding between foresters and biologists in pursuit of that goal. By presenting feasible options that have been employed successfully by timber companies and clearly articulating the differences between "business as usual" and PD management, we may be able to decrease hesitancy of other landowners to harvest in PDs. Greater openness to collaboration with biologists could improve deer habitat quality by increasing the health and resilience of previously neglected stands and spreading the harvest more evenly across zoned and non-zoned areas. These results could lead to maintenance of acceptable winter habitat features across a larger area, as well as higher productivity within PDs. On a broader scale, examining the economic impacts of a habitat provision policy on forest industry will provide insight into the secondary effects of wildlife conservation regulations within forested habitats.

To identify viable silvicultural systems and their application to PDs, I interviewed landowners across northern Maine who pursue a variety of forest management objectives and analyzed their stated management regimes using the common reference frame of the resulting revenues. In order to capture a wide range of silvicultural options, including ones not commonly used currently in Maine, I also considered other silvicultural systems suggested by landowners and foresters. The cost that the landowner must bear, i.e. the loss of potential gain from harvesting inside a PD rather than on non-zoned timberland, is critical when considering any silvicultural recommendation. In order to address this financial trade-off, I generated stand-level volume outputs from growth and yield modeling applied to six silvicultural scenarios both inside and outside PDs. I estimated the value of the timber volume generated by each model and compared the economic returns inside and outside PDs.

Methods

Interviews with foresters and biologists

In order to identify timber management scenarios that are in use on the landscape, I interviewed a total of 17 employees of nine land management entities in Maine regarding their actual timber management activities, both within PDs and on the rest of their property. Interviewed employees included foresters, biometricians, supervisory staff, biologists, and an archivist. The entities represented had landholdings across central and northern Maine, and all managed for or had winter deer habitat on their property at the time of this study. They included a land trust, a public agency, a conservation organization, forest management companies for private clients, and vertically integrated commercial forest landowners. The areas of the properties ranged from 12,000 - 485,600 ha, with PDs comprising 3-58% of the individual landholdings. While specific management objectives differed between entities, all included both timber production and wildlife habitat priorities.

Participating interviewees agreed to discuss their approach to managing PDs, to provide details about the silvicultural systems and prescriptions applied both inside and outside PDs, and to describe the interactions between foresters and the state biologists who approve their harvest plan agreements (Institutional Review Board Approval # 2015-12-14). Questions in my semi-structured interviews (Appendix) focused on the specific silvicultural systems each company applied across their land base, whether there were differences in how they harvested inside PDs versus elsewhere, and if so, why and how they tailored prescriptions to PD management. I also asked for details on the process of acquiring approval from MDIFW for a harvest plan agreement, and the foresters' perspective on managing PDs. Interview responses are referenced in the text, although names are not disclosed to maintain confidentiality.

To better understand the history and rationale behind the state deer wintering area policy, I interviewed 5 state-employed biologists from 4 regions across the state as well as the section supervisor. These discussions, which dealt with the development of the policy, what biologists saw as its strengths and weaknesses, and their considerations when evaluating a PD and a proposed prescription, helped us to understand the actual limitations of harvesting in PDs and to select accurate silvicultural systems to model in this study.

Silvicultural scenarios

The silvicultural systems in use by the cooperating companies and modeled here were uniform shelterwood; clearcut; group selection; and single-tree selection. I modeled silvicultural scenarios on a per-hectare basis to approximate the stand-scale silvicultural decisions foresters make within PDs. A shelterwood or clearcut would never be implemented on an entire PD during one entry due to the necessity of maintaining crown closure across a majority of the PD, but those tools could be applied to individual stands within the PD when appropriate. These results can be multiplied or divided according to the acreage being treated with any of the modeled scenarios to estimate realistic revenues, but for consistency are modeled per hectare. Intermediate treatments were not modeled because they do not always contribute to revenue – the evaluation metric – and are not a consistent treatment used among all silvicultural systems. Accuracy of management scenarios to reality was reviewed by each interviewed forester as well as three School of Forest Resources faculty members at the University of Maine.

In addition to silvicultural systems identified in the interviews, I included two other systems from the study area: diameter-limit harvesting and "irregular group shelterwood with reserves," a *Femelschlag*-like treatment applied in the Penobscot Experimental Forest (PEF), a property managed by the University of Maine and the U.S. Department of Agriculture, Forest Service for silvicultural research. For the latter system, initial gaps are created as a percent of the total acreage, and subsequent harvests expand outward from the original gaps, protecting regeneration and leaving residual trees that will never be harvested (Seymour 2005). The gaps can be small or large (10% or 20% of total harvest block acreage, respectively). If small, 100% of the block will have been harvested by the end of a 100-year rotation with a 10-year entry interval; if large, 100% of the block will have been harvested within the first 50 years and no harvests occur in the second half of the rotation (Arseneault et al. 2011). It has been suggested by those involved in its experimental implementation that this system is appropriate for use in PDs, and so was included in my models to provide a point of reference for land managers who may consider applying it. Likewise, the diameter-limit harvest system was included due to its frequent application in the region, past and present.

Data description

Two companies among those interviewed, hereafter Company A and Company B, voluntarily provided inventory tree lists suitable for populating input for the Forest Vegetation Simulator (FVS), Northeast Variant (Dixon and Keyser 2008). That input, which included tree species and diameter at breast height (DBH, cm) of all stems greater than 2.54 cm in 15-BAF variable radius plots, was used to model all management scenarios. Inventory locations spanned multiple regions of Maine, and each location included stands inside and outside PDs to minimize differences in site conditions between inside- and outside-PD tree lists. Company A practiced typical commercial forest management for timber production, whereas Company B managed primarily for conservation and wildlife habitat priorities. The initial tree species composition and stocking varied among the inventory plot locations and between PDs and non-zoned timberland (Table 2), creating the potential for a range of harvest revenues and standing values during modeling. Due to proprietary concerns, company names and precise inventory plot locations are not disclosed.

Table 2. Summary of stand metrics of inventory tree lists used in modeling forest management scenarios in Maine. Quadratic mean diameter (QMD), basal area (BA) and trees per hectare (TPH) were exported from internally calculated FVS stand summaries.

Metric	Company A Outside Deeryard	Company A Inside Deeryard	Company B Outside Deeryard	Company B Inside Deeryard
Average stand QMD (cm)	14.0	13.0	21.5	13.9
Average stand BA (m^2 ha^{-1})	23.6	25.7	24.4	33.7
Average TPH	1713	1913	699	2691
Common species, percent presence	*Picea mariana*, 20 *Acer rubrum*, 18 *Abies balsamea*, 14	*Thuja occidentalis*, 29 *Abies balsamea*, 22 *Picea mariana*, 13	*Tsuga canadensis*, 27 *Fraxinus americana*, 18 *Thuja occidentalis*, 15	*Thuja occidentalis*, 26 *Tsuga canadensis*, 23 *Picea rubens*, 13
Number stands sampled	5	5	6	9
Number inventory plots	12	13	18	22
Imventory method	Variable radius BAF 15	Variable radius BAF 15	Variable radius BAF 15	Variable radius BAF 15
Site indices, m	*A. balsamea*, 17 *Picea mariana*, 15 *Fagus grandifolia*, 18	*A. balsamea*, 17 *Picea mariana*, 15 *Fagus grandifolia*, 18	*Pinus strobus*, 20	*Pinus strobus*, 20

Forest growth modeling

I modeled forest growth at the stand level under six silvicultural scenarios specific to either the regulated areas inside PDs or the "business as usual" scenarios outside PDs by adapting the actual management prescriptions described during forester interviews to FVS (Table 3). Forests inside and outside PD boundaries have been subject to different management practices in the 30-50 years since designation of zoning and often have differences in site quality that influenced tree growth even before deeryard zoning, resulting in distinct standing inventories at present. Avoidance of timber harvests inside PDs on many properties has allowed accumulation of tree volume that, if harvested according to business as usual scenarios, would yield high value for one rotation. Returns from mining this accumulated tree growth would not be sustained over subsequent rotations of business as usual management. Thus, inventory plots and associated tree lists from inside PDs were used to model inside-PD management, and likewise for outside-PD plots and management.

Table 3. Silvicultural scenarios and their Forest Vegetation Simulator (FVS) parameters for growth and yield modeling inside and outside protected deeryards in Maine. Scenarios were adjusted from actual silvicultural activities described by professional foresters in Maine.

<table>
<tr><th></th><th colspan="2">FVS Parameters</th></tr>
<tr><th>Silvicultural scenario</th><th>Inside zoned deeryard</th><th>Outside zoned deeryard</th></tr>
<tr><td>Uniform shelterwood</td><td>15-year entry interval: Establishment cut to 9 m^2 ha^{-1} BA; Overstory removal (OSR). Exclude T. occidentalis and T. canadensis from all harvests.</td><td>7-year entry interval: Establishment cut to 6.5 m^2 ha^{-1} BA; OSR.</td></tr>
<tr><td>Clearcut*</td><td colspan="2">Single entry: Removal of 95% of all stems at least 11.43 cm DBH.</td></tr>
<tr><td>Group selection</td><td>15-year entry interval: 20% of the harvest block in “Clearcut.” Exclude T. occidentalis and T. canadensis from all harvests.</td><td>10-year entry interval: 30% of the harvest block in “Clearcut.”</td></tr>
<tr><td>Single-tree selection</td><td>30 year entry interval: 20% removal 11.43-25.38 cm DBH using “Thin throughout a diameter range” function. Exclude T. occidentalis and T. canadensis from all harvests.</td><td>30 year entry interval: 30% removal 11.43-25.38 cm DBH using “Thin throughout a diameter range” function.</td></tr>
<tr><td>Diameter-limit</td><td>Removal of all but 5 trees per hectare 30.5 cm DBH and greater with 80% “cutting efficiency” setting. Exclude T. occidentalis and T. canadensis from all harvests.</td><td>Remove all but 5 trees per hectare 30.5 cm DBH and greater with 90% “cutting efficiency” setting.</td></tr>
<tr><td>Irregular group shelterwood with reserves*</td><td colspan="2">Small gap: 10 year entry interval: 10% of harvest block in “Clearcut” with 5 residual trees per hectare of at least 51 cm DBH.
Large gap: 10 year entry interval: 20% of harvest block in “Clearcut” with 5 residual trees per hectare of at least 51 cm DBH.</td></tr>
</table>

*Identical scenarios were applied inside and outside PDs. Using this set of parameters, simulations were run and results reported separately for inside- and outside-PD tree lists.

I parameterized models for each silvicultural system, approximating the harvests described during interviews, and ran 50-year projections with FVS forecasting per-hectare annual growth and mortality according to default settings of the Northeast Variant. Parameters identified the years of harvest entries, absolute or proportional basal area (BA, $m^2 ha^{-1}$) removed in each entry, diameter range of trees harvested, quantity and DBH of any residual trees to be left after an otherwise complete removal, and any species excluded from harvest. Excluded species during partial harvests within PDs were *T. occidentalis* and *T. canadensis*, as is common practice due to these species' high value to wintering deer (Euler and Thurston 1980, Potvin and Huot 1983, Morrison et al. 2003, Lishawa et al. 2007).

Financial analysis

Harvested volume of pulpwood and sawlogs for each silvicultural scenario, calculated with FVS internal equations, was tabulated by species, along with standing volume at 50 years. Including the final standing value of the stand when using an economic metric limits the potential to favor systems with short rotations or heavy early harvests, which would yield higher returns from harvests but not account for the high value of the residual stand in future rotations. FVS output was divided into product classes using the SPMCDBH function, which allows the user to specify the breakpoint DBH between product classes by species (Table 4; Crookston 1990). Breakpoints were determined by the Maine Forest Service based on stumpage utilization data (Ken Laustsen, Maine Forest Service, personal communication). Wood product output of simulated harvests was converted to financial returns using statewide average stumpage prices from the 2014 Maine Stumpage Price Report (Maine Forest Service 2015b). All revenues that were not acquired from a harvest at year 0 were discounted at a rate of 4% to better estimate the financial worth over time of each scenario to the landowner (Row et al. 1981). Total discounted per-hectare stumpage harvested from PDs on each property, combined with the discounted stumpage value of standing trees at the end of the 50-year time horizon, was compared to revenues from similar harvests outside of PDs. The monetary difference is the economic cost of management inside a PD relative to areas of the property that are not subject to timber harvest restrictions.

Table 4. Species-specific DBH input into Forest Vegetation Simulator parameters as the cutoff between pulpwood and sawlog products.

DBH at pulp-log cutoff (cm)	Species
20.32	*Abies balsamea* (L.) Mill, *Picea glauca* (Moench) Voss, *Picea rubens* Sarg., *Thuja occidentalis* L., *Tsuga canadensis* (L.) Carr
25.40	*Acer rubrum* (L.), *Acer saccharum* Marsh., *Betula alleghaniensis* Britton., *Betula papyrifera* Marsh., *Fagus grandifolia* Ehrh., *Fraxinus americana* L., *Pinus resinosa* Aiton, *Pinus strobus* L., *Populus grandidentata* Michx., *Quercus rubra* L.

Results

Responses to interview questions regarding management options revealed a set of silvicultural systems common among cooperating companies. Although forest stand entry interval and harvested basal area differed between companies, all interviewed foresters indicated that "business as usual" management typically consisted of the uniform shelterwood system or clearcuts with intermediate precommercial or commercial thinning treatments. Questions about management inside PDs elicited a greater variety of responses, including infrequent opportunistic harvests in which PDs were harvested if an outside-PD harvest was happening nearby; low intensity selection systems; group selection; and treatments similar to those applied outside of PDs. Results of modeled scenarios indicated that the partial harvest scenarios of single-tree and group selection leave a relatively greater proportion of their value as standing trees, whereas the others result in higher revenues from timber harvests within the 50-year simulation horizon (Figure 1). The small proportion of standing tree value left by the large gap irregular group shelterwood with reserves system is a feature of the system as it has been experimentally implemented: in my models, 100% of the harvest block was cut within the first half of the 100-year rotation, leaving only the reserve trees standing at the end of the 50-year simulation. The small gap system, in contrast, distributes harvest revenue across the entire rotation, resulting in a smaller ratio of harvested to standing trees at 50 years.

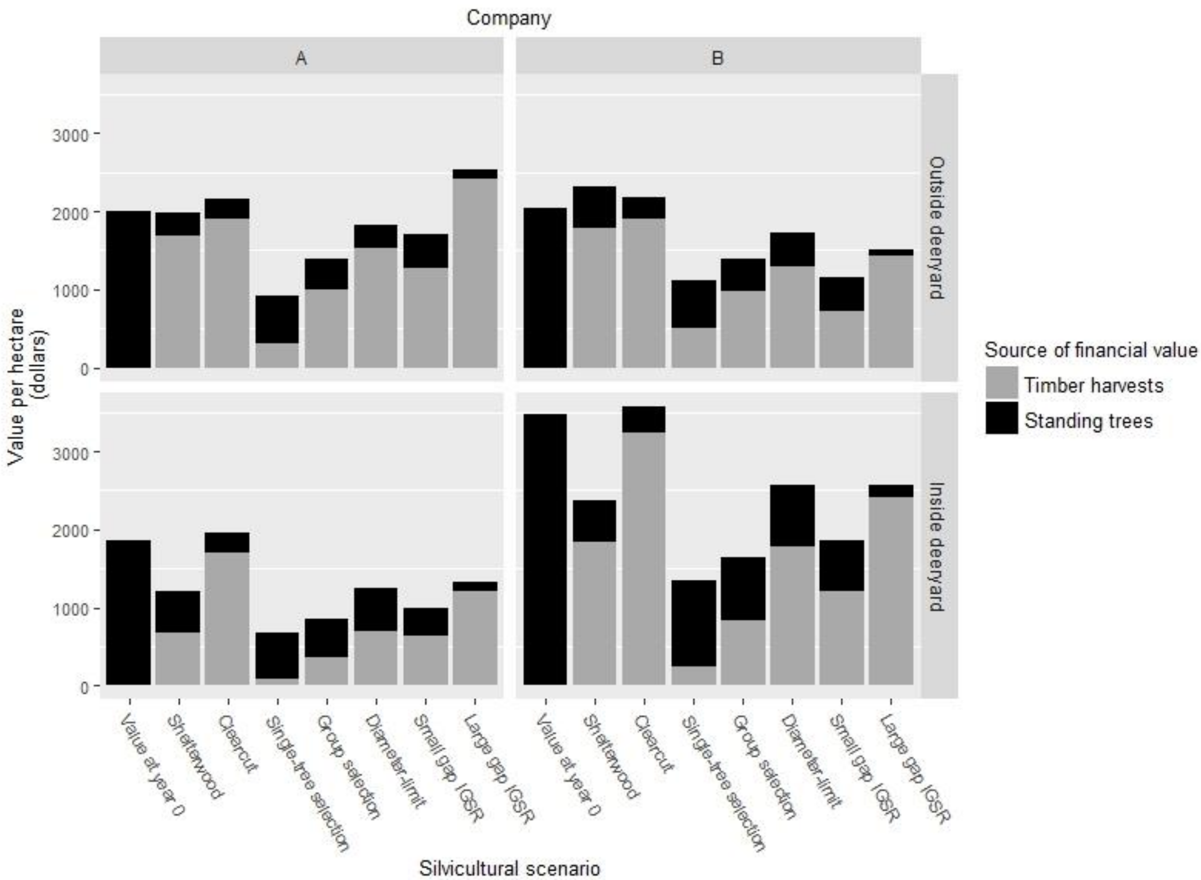

Figure 1. Economic returns per hectare of modeled management scenarios inside and outside of zoned deeryards of two companies. Harvest revenue is total returns from all entries within 50 years with the first entry at year 0; standing value is the stumpage value. “IGSR” represents the irregular group shelterwood with reserves system.

Differences between inside- and outside-PD revenues for each company are synthesized in Figure 2. These net values represent the economic loss or gain associated with inside-PD silvicultural scenarios when compared to “business as usual” management outside PDs. Modeling with Company A tree lists resulted in higher returns coming from harvests outside of PDs across all silvicultural scenarios. Revenues from modeled scenarios for Company B, in contrast, were not always lower inside PDs, as indicated by the negative values when revenue from PDs was subtracted from that of outside-PD scenarios (Figure 2). The only cases in which greater revenues resulted from “business as usual” management for Company B were single-tree and group selection harvests when final standing tree value was not considered. These two uneven-aged silvicultural systems, in which full overstory removal does not occur, produced lower harvest returns because of smaller percentage of stumpage extracted, but final standing tree value was greater inside PDs for all silvicultural scenarios in Company B.

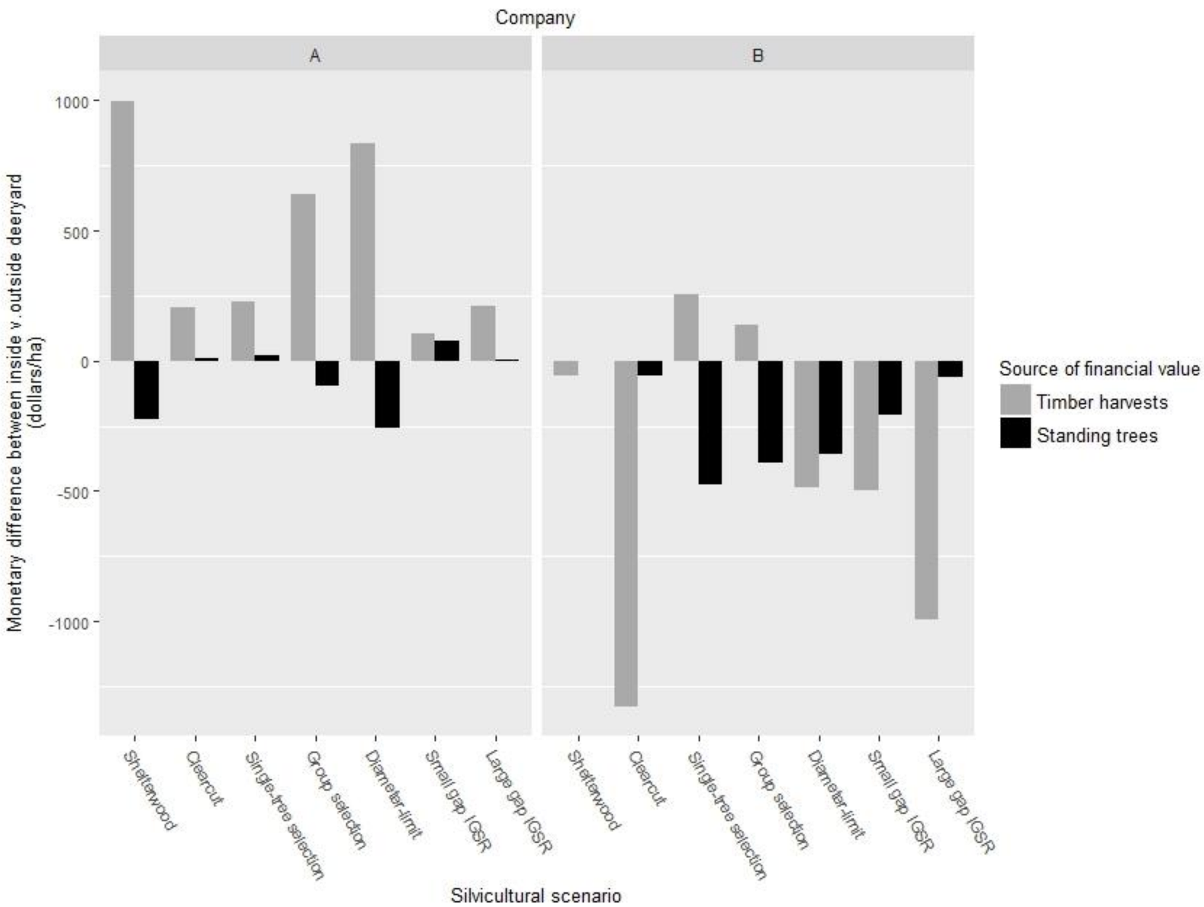

Figure 2. Difference in revenue per hectare between "business as usual" management scenarios and those applied within zoned deeryards of two companies. Positive values indicate greater revenue outside deeryards; negative indicates greater revenue inside. Harvest revenue is total returns from all entries within 50 years with the first entry at year 0; standing value is the stumpage value of standing timber at the end of the 50-year simulation. "IGSR" represents the irregular group shelterwood with reserves system.

Discussion

The difference in economic returns between Company A and Company B is largely due to stand-level variation. For Company A, the historically industrially managed land, the lower value found within PDs may be due to a lack of intermediate treatments. As interviewed foresters pointed out, longer rotations and uncertainty regarding harvest approval sometimes deter landowners from investments, and thinnings must be light to maintain a high percentage of crown closure. Without intermediate treatments, PDs on Company A property have a lower average quadratic mean diameter (QMD, cm) and higher TPH than stands outside PDs. These metrics indicate a high density of trees with a lower average DBH, and therefore lower merchantable volume.

Although Company B's inventory revealed even greater differences between inside- and outside PD stand metrics than Company A's inventory, species composition was a factor in Company B's greater revenue from inside PDs. Perhaps due to its history as conservation land, Company B property is dominated by *T. occidentalis* and *T. canadensis.* Outside of PDs, *Fagus grandifolia* Ehrh. is a major component alongside the dominant two conifer species. Inside PDs, the third most prevalent species is *Picea rubens* Sarg., with sawlogs worth more than double those of *F. grandifolia* at the time of analysis (Maine Forest Service 2015b). Thus, greater revenue was realized from harvests inside PDs because of their greater species-specific stumpage value.

The discrepancy in revenue patterns between the two companies allows us to conclude that stand characteristics and landowner objectives influencing past management have a strong impact on current value. Because of the difference in species composition between the two properties and variations in initial stand metrics, my models resulted in one company's experiencing an economic loss due to restrictions on harvests within PDs, whereas another gained an economic advantage despite the lower intensity harvests of those scenarios. These two properties, although different, are representative of forests found across the northeastern U.S. and southern Canada (Beyer Jr. et al. 1997, Loo and Ives 2003) and serve as examples of two common land management objectives: 1) conservation land on which the provisioning of wildlife habitat and recreational opportunities has been a higher priority than maximizing timber yield; and 2) production-focused commercial forestland that has been heavily harvested in the past (Jin and Sader 2006). The results of simulations on these representative properties provide a valuable reference point from which we can begin to examine the economic implications of PD regulations across regions in which they have been implemented (Russell et al. 2017), and make comparisons to other situations in which wildlife habitat and timber production objectives differ.

Analytical limitations

My ability to draw broad conclusions is limited by the small sample of landowners. I was unable to determine a consistent economic result for future management scenarios that will not vary between forest types. The variation within and among forest stands is great, and nearly impossible to capture without site-specific analyses for a large sample of landowners.

My FVS analysis was focused solely on timber value and did not incorporate operational factors with an economic impact when harvesting within PDs, such as the need for more widely spaced trails, smaller landings, and fewer roads, leading to higher transport costs. Interviewed foresters noted that sometimes specific, lower-impact machines are mandated by biologists, necessitating contracts with operators that may be more expensive or located farther from the harvest site. These considerations would compound the economic impact evident in my analysis. My FVS simulations may further overestimate the value of trees harvested from PDs because the companies did not include any indication of tree quality, or value of potential logs, in the data they shared with me. When tree value class codes are absent, FVS assumes no defect, or "desirable" trees (Dixon 2002). In these softwood-dominated, repeatedly harvested forests, sprouting hardwoods are often low quality, and because PDs receive few intermediate treatments to select for higher quality trees, they do not produce consistently merchantable hardwood logs (Schuler et al. 2016)**.** When the modeling program assumes all trees are sawlog quality, revenues are inflated in general, and particularly so when modeling PDs. The disparity in inside- versus outside-PD revenue evident in Company A results could therefore be greater in reality.

A challenge with interpretation of these results is the difficulty of comparing FVS outputs and forest inventory metrics to MDIFW deer wintering area management guidelines. The main characteristics that determine quality of a PD according to MDIFW are canopy closure and tree height (Maine Department of Inland Fisheries and Wildlife 2010a). Although there are keywords to estimate canopy closure within FVS, they are unreliable, and the base program is untrustworthy, especially when habitat decisions must be weighed using its outputs (Crookston and Stage 1999, Christopher and Goodburn 2008, Leites et al. 2009). Tree height, similarly, is predicted with internal growth equations (Dixon and Keyser

2008). They are calibrated to some extent by specifying site indices, but are nonetheless approximate and do not capture all regional variation (Crookston and Dixon 2005). Finally, FVS is distance-independent (Ray et al. 2009) and has no way of directly accounting for stand density and true crown conditions other than the user's inferring it based on other outputs (Christopher and Goodburn 2008). Therefore, it is nearly impossible to judge the quality of winter deer habitat by evaluating FVS outputs.

Even when FVS is not the chosen software, difficulties persist in equating stand metrics with habitat quality. In a study determining influential metrics in deer presence in New Hampshire, Weber et al. (1983) had the unexpected finding of BA being inversely related to occupancy. While such a relationship may indicate that some gaps are a favorable characteristic of PDs, as they provide areas for solar exposure and browse, it reinforces the difficulty of correlating BA with canopy closure and any prediction of deer presence. The MDIFW deer winter habitat guidelines specify a minimum desired tree height and percent canopy cover for forest managers to maintain within PDs. These metrics are two of the least accurately measured elements of forests (Husch et al. 2003a, 2003b, Iles 2003, Forest Inventory and Analysis Program 2004), and typical forest inventory metrics cannot be reconciled with the guidelines. I simulated basic scenarios that, through my interviews, I knew had been field-validated to preserve adequate winter shelter, but I would not be able to use FVS or most other growth and yield modeling software to simulate habitat quality after the modeled harvests. Were MDIFW to release revised guidelines based on standard inventory metrics, such as a desired stem diameter distribution and basal area, foresters would be better able to translate stand characteristics into habitat management goals prior to meeting with a biologist.

Conclusions

The first conclusion of this study is that there is a basis for the foresters' claim of lower revenues from harvests within PDs in forests typical of intensively managed areas, such as Company A. Modeled harvests within PDs for Company A garnered consistently lower revenues than harvests outside of regulated zones.

A second important conclusion when considering habitat regulations in conjunction with timber production is that revenues are site- and species-dependent. In the case of Company B, revenues were higher inside PDs, demonstrating that constrained harvests that maintain habitat do not necessarily result in financial loss. Company B showed more value from harvests within PDs because they contained a greater proportion of trees with higher stumpage prices. This finding indicates a larger-scale economic implication: that the results of any of these scenarios are also closely related to current timber markets. Were the price of *T. canadensis* to increase and that of *Pinus strobus* L. to plummet, the results would differ greatly from those presented here. The loss of the softwood pulp market in Maine is already shifting harvest strategies and revenues (Violo 2015).

Third, silvicultural systems such as the irregular group shelterwood with reserves have the potential to achieve comparable revenues to more common systems while maintaining necessary habitat. I found economic returns similar to other management scenarios both inside and outside PDs when I modeled the irregular group shelterwood with reserves. Theoretically, this system could be implemented across the entire PD, continuously regenerating patches while providing winter shelter in the matrix with access to regenerating browse in neighboring gaps (Arseneault et al. 2011). Local biologists would need to approve the system for application in PDs, and invariably its implementation would depend on individual stand characteristics. With some creativity and openness to novel silvicultural systems, foresters in conjunction with biologists could introduce effective, profitable strategies that would allow greater flexibility in management, provide more tools for tailoring silviculture to the specific needs of each PD, and perhaps achieve better habitat results when applied in the appropriate context. In contrast, diameter-limit harvesting of all stems above a specified DBH does not show promise for use in PDs due to its inherent tendency to reduce the mature component of a stand, leaving insufficient crown closure. It does not involve consideration of the future stand in terms of confirming advance regeneration, provisioning seed trees, or targeting desired residual species composition (Kenefic et al. 2005). Stand longevity and sustainability of harvests is critical in deeryards, which must meet the needs of wintering deer year after year. The diameter-limit scenario yields revenues competitive with the modeled silvicultural systems in the short term, but does not maintain habitat quality or consistent revenues in the long term (Nyland 2005).

Cost-benefit analysis of supporting deer populations

The intended outcome of PD regulations is a larger deer population. The benefit of such an outcome is difficult to quantify in economic terms similar to those used to assign value to timberlands. Deer, as a public resource and game animal, have a consumptive (e.g., hunting) and non-consumptive (e.g., viewing or knowing they are part of the ecosystem) value to society that is separate from the market system, and multiple strategies have been used in an attempt to assign them a monetary value (Luzar et al. 1992, Conover 1997, Schwabe et al. 2001, 2002). Their value varies between individual members of society and can be positive or negative (for example, if they cause damage to crops), but their total value to society is the sum of all individual evaluations (Conover 1997). To quantify their value, authors have used the monetary expenditures of deer hunters, losses attributed to damage in deer-vehicle collisions (DVC), and recreational travel costs (Mackenzie 1990, Conover 1997, Fix et al. 2005, Bissonette et al. 2008). Their resulting per-deer numbers ranged from $35 to $1468 depending on whether the authors were estimating with nonmarket valuation ($35-209, 1996 dollars), damage due to DVC ($35-1313, 2001 dollars) or hunting expenditures ($194-1468, 1996 dollars) (Loomis et al. 1991, Conover 1997, Bissonette et al. 2008). For the State of Maine, where the goal is primarily to support the hunting industry rather than to reduce DVC or crop damage, we can use an average value from the literature of $266 for what a hunter is willing to invest to harvest a deer (Keith and Lyon 1985, Loomis et al. 1991, Schwabe et al. 2001). Such an estimate does not include deer value to recreational wildlife viewers or their ecosystem value, so in fact deer are worth more than the number calculated based on their status as a game animal alone. Furthermore, the value of PDs is greater than the timber they contain and the deer they support. Other wildlife species such as the fisher (*Martes pennanti*), American marten (*Martes americana*), eastern red-backed salamander (*Plethodon cinereus*), pileated woodpecker (*Dryocopus pileatus*), and magnolia warbler (*Setophaga magnolia*) use habitat features similar to those maintained within PDs and can benefit from conservation of winter deer habitat (Titterington et al. 1979, Payer and Harrison 2003, Lemaître and

Villard 2005, Patrick et al. 2006, Zielinski et al. 2010). These animals have their own value to society that compounds the value of PDs where they overlap their ranges. The crucial question is whether the economic benefit the state receives for proportioning public goods such as game species and the intrinsic value to the public of those species balances the cost of maintaining their habitat. In the case of deer wintering habitat in Maine, that cost is borne primarily by private companies and individual landowners in forester hours and potential loss of harvest revenue. Results showed that PDs can be a net economic benefit for some landowners. Extensive cost-benefit analysis that incorporates the non-consumptive value of deer is necessary to determine whether the deeryard zoning policy overall has proven itself effective.

I have presented a set of silvicultural scenarios that have been applied to PDs in Maine in the context of their economic implications. With this baseline economic information, I conclude that implementation of a policy for provisioning wildlife habitat need not be an insurmountable obstacle to private landowners or timber companies seeking reasonable returns from harvests. Numerous other studies worldwide have reached similar conclusions, determining that intensive silviculture and habitat maintenance are not necessarily in opposition. Healthy populations of many small mammal species have been found in Eucalyptus (*Eucalyptus* spp.) plantations in Portugal (Teixeira et al. 2017). The fluctuating Canada lynx (*Lynx canadensis*) population is dependent on abundance of snowshoe hare (*Lepus americanus*), which are found in large patches of coniferous regeneration following harvests (Simons-Legaard et al. 2013). In a similar study to mine, contrasting management scenarios were modeled along with habitat quality for three species, with the finding that there are multiple approaches to maintaining essential habitat features while pursuing profitable forest management (Marzluff et al. 2002). It is important to realize that not all scenarios generate the same quality habitat and that further research is needed to determine a method of evaluating deer wintering habitat quality, both in terms of forest inventory metrics and growth and yield model output.

In Maine and elsewhere, a thorough knowledge of each forest stand is necessary before taking any management action to alter zoned habitat protection areas, and there is no guarantee that a stand will be a good candidate for any of the studied silvicultural systems. Clear standards that are understandable in terms of both the habitat characteristics and the stand features using common forest inventory metrics would facilitate development and execution of appropriate silvicultural prescriptions. Monitoring will determine whether, after conscientious implementation of appropriate silviculture, the deer population will respond to changes in habitat availability and quality across its northern range. The regulatory goal should be to develop an approach where the benefits society receives from deer are the same or greater than the costs borne to support desired numbers.

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CHAPTER 3

A SPATIAL EVALUATION OF MAINE FORESTS 40 YEARS AFTER DEERYARD ZONING

Abstract

The forest landscape of northern Maine changes frequently due to commercial timber harvests. These dynamic landscapes can present difficulties to wildlife species that depend upon a specific forest type for their survival. White-tailed deer (*Odocoileus virginianus*) in the north of their range rely on mature softwood-dominated forest that provides shelter from severe winter weather. The State of Maine protected critical areas of this forest type, or deeryards, in the 1970s using zoning to restrict timber harvesting. Since then, the forest surrounding protected deeryards has changed significantly and there is concern that deeryards are unable to meet the habitat needs of wintering deer. I described forest characteristics in deeryards and within areas recently delineated to address a wider range of wintering deer habitat needs. Using raster maps of northern Maine, I compared tree species composition and harvest history of the original zones and the newly delineated areas, Biological Deer Wintering Areas (BDWAs). I also reclassified the rasters and performed regional metric analyses with FRAGSTATS to evaluate the availability and distribution of suitable winter deer habitat across northern Maine. Deeryards had been well protected in zoned areas, maintaining characteristics of mature softwood-dominated forest. The BDWAs incorporated more diverse forest than the originally protected deeryards, with a greater percentage of hardwood tree species present and recent timber harvests on a greater percentage of the acreage in those areas. Winter shelter for deer is available across the region, though it is interspersed with mixedwood forest and may be irregularly distributed. These data will be most relevant in conjunction with studies of deer movement in the region, providing insight into deer habitat selection in the current context of forestland in northern Maine.

Introduction

As in the case of stand-level silviculture, it is common to study characteristics and use of specific habitat types known to be of importance to a species of interest at the patch scale, or at the level of individual sites (deMaynadier and Hunter 1999). However, it is necessary to examine the effects of a region-wide policy from a broader perspective. Results from stand-scale management are not the only outcomes we must consider when a policy affects forestry practices on a regional scale. Optimizing silvicultural outcomes for individual stands does not necessarily equate to meeting regional forest and habitat management objectives (Harvey et al. 2002, Lasch et al. 2005). Impacts of stand-level decisions must be researched and evaluated to determine whether detailed, site-specific management actions have accomplished the overall goal across a property and cumulatively across a landscape.

As habitat fragmentation has become a greater concern in wildlife management separate from the phenomenon of habitat loss alone (Fahrig 2003), interest in landscape-scale studies has increased (Felix et al. 2004, Mortelliti et al. 2011, Hurley et al. 2012). Methods have been developed to evaluate both the sensitivity of organisms to "non-habitat" being interspersed within historically larger matrices of habitat and the associated edge effects of the resulting landscape, as well as the degree to which populations suffer due to that fragmentation (Fahrig and Merriam 1985, Bright 1998). The spatial distribution of habitat and non-habitat is as important as the amount of each within an organism's range (Wiens 1995, Mortelliti et al. 2011). Whether patches of habitat are sufficiently connected to be accessible to an organism depends on the perspective of a species (With 1994, Girvetz and Greco 2007). For example, a vole would likely respond to a forest opening differently than a marten, whose movement is less restricted by such a feature (Wiens et al. 1993). Thus, when evaluating the quality of available habitat and its ability to support populations, it is essential to combine landscape-level perspective with patch-level analysis on a species-appropriate scale.

A system that exemplifies the need for multi-scale analyses is the management of white-tailed deer (*Odocoileus virginianus*) in the north of its range, where interspersion of browse and shelter is crucial for survival. In northern Maine, the northern Lake States, New Brunswick, and southern Quebec, severe winters with deep snow, low temperatures, and low browse availability deplete stored fat reserves of deer (Moen 1976, Dumont et al. 2005). Mortality is mitigated when deer migrate to areas of mature coniferous forest, where the canopy intercepts snow and wind, minimizing energy expenditure of wintering deer. These areas of winter shelter, or "deeryards," have been well studied in the tradition of patch-level analysis, providing a thorough description of necessary habitat metrics within deeryards (Wetzel et al. 1975, Euler and Thurston 1980, Weber et al. 1983, Morrison et al. 2002, 2003, Lishawa et al. 2007). On the landscape level, deer use additional habitat types including hardwood forest adjacent to a deeryard for late fall and winter browse and fields and forest edges that provide nutritious browse at green-up and through the summer (Sabine et al. 2001, Hurley et al. 2012). Because they use different habitat types at different times during the year, white-tailed deer habitat management requires a multifaceted approach (Walter et al. 2009a). Forest management plays a large role in both providing and altering available habitat (Telfer 1978, Vospernik and Reimoser 2008). Both stand-level silvicultural outcomes and landscape-level management patterns must be considered when evaluating availability and quality of deer habitat of all types, as interspersion of habitat types across the landscape has been shown to be critical in meeting deer needs for survival within a limited home range (Kie et al. 2002, Saïd and Servanty 2005, Felix et al. 2007).

Natural resource agencies in the State of Maine have attempted to manage each level of deer habitat use, in part, through regulations. The State's Land Use Regulation Commission (now the Land Use Planning Commission) responded to public demand for greater deer abundance in the 1970s by zoning areas of critical winter shelter for protection, referred to as Protected Fish and Wildlife zones (PFWs) based on deer presence during severe winter weather. These zoned deeryards were placed within the jurisdiction of the Maine Department of Inland Fisheries and Wildlife (MDIFW) for subsequent maintenance of essential habitat characteristics (Lavigne 1997). Much of northern Maine is privately-owned commercial timberland, and although timber harvesting is permitted within PFWs, an MDIFW wildlife biologist must visit the site with the forester to agree on the proposed harvest prescription and plan (Maine Department of Inland Fisheries and Wildlife 2010a). In order to minimize the extent of the harvesting restrictions, the State zoned only core areas of deeryards, or the most protective areas for winter shelter. With frequent timber harvests occurring throughout the landscape, it was hoped that deer needs for hardwood browse and open fields would be met without official zoning of those habitat types (Lavigne 1997). As a result, historical management of deeryards in Maine has been focused primarily on the patch-level characteristics for much of its history and has been implemented by adapting harvest plans to the maintenance of specific core areas of winter shelter. Within the last ten years, the scope of Maine's planning for deer habitat conservation has widened with the realization that zoning PFWs has been insufficient to meet stated goals of deer abundance (Maine Department of Inland Fisheries and Wildlife 2013a).

Winter deer shelter in Maine consists of mature coniferous forest, which also produces timber of relatively high market value (Maine Forest Service 2015b). Much of that forest type, which was widespread on the Maine landscape in the past, has been targeted and converted to younger forest by harvesting activity over the last 25 years (Jin and Sader 2006). Many areas that may have been used by wintering deer but were not designated as PFWs have been harvested, eliminating them as suitable shelter for wintering deer (Boer 1992, Harrison et al. 2013). Further, the size of individual patches may be influential in their use by wintering deer, with small patches being occupied less frequently despite the presence of suitable habitat (Boer 1992). In many locations in Maine, the forest surrounding PFWs that was historically a similar habitat type has now been harvested, leaving islands of protected winter shelter in a matrix of non-shelter habitat (Harrison et al. 2013). Thus, isolated PFWs may not be of use to deer despite the high-quality habitat they may contain, which may be a contributing factor to the lack of success in increasing regional deer abundance.

Because MDIFW has not seen the desired increase in the deer population despite PFW zoning and other population management strategies such as predator control, the agency is considering a revision of its approach to habitat management. In 2010, the agency delineated what it refers to as "biological deer wintering areas" (BDWAs) (R. Robicheau, Maine Department of Inland Fisheries and Wildlife, personal communication). The outlined BDWAs include mixedwood forested areas adjacent to existing PFWs; thus, BDWAs tend to be larger than PFWs. In concept, BDWAs will contribute to maintenance of the diverse habitat types deer require year round and lend increased flexibility to deeryard management, allowing timber harvesting that enhances habitat features with less restrictive area constraints than have often been an obstacle within the smaller PFWs (Bothwell et al. unpublished).

A drawback of the BDWAs is that they are based on the same deer surveys used to delineate forest patches for protection as PFWs, and Maine's landscape has since altered due to ownership and management changes (Jin and Sader 2006, Sader and Legaard 2008). Another complication in any study of deer habitat use in Maine is that consistent yarding behavior, in which deer often exhibit high seasonal range fidelity (Verme 1973, Tierson et al. 1985), has decreased due to supplemental feeding near human population centers (Maine Department of Inland Fisheries and Wildlife 2013b). Deer feeding has been implicated in other states as the cause of significant and sustained alterations in seasonal movement patterns of white-tailed deer (Felix et al. 2007, Walter et al. 2009b). Whether there is sufficient winter habitat of adequate quality present on the landscape of northern Maine or other factors are influencing deer habitat use and population viability is currently unknown.

In the face of these challenges to successful deeryard management, my objectives were 1) to compare forest characteristics within existing PFWs and the BDWAs under consideration and 2) to compare the extent and distribution of all likely winter shelter to that contained within PFWs. My research compared features of existing PFWs with the newly drafted BDWAs to determine the differences in forest characteristics between the two habitat classification types. I used Landsat-based raster data of tree species composition and harvest history to describe current forest conditions. I expected that BDWAs would incorporate a greater proportion of hardwood tree species and would have experienced stand-replacing harvests on a greater percentage of the area than PFWs. This baseline description of the forest characteristics within BDWA boundaries can be leveraged in policy-making to determine if any additional zoning should occur. The comparison with PFWs will be essential in any future evaluation of changes in habitat quality over time within areas under consideration for zoning. My research also aimed to identify suitable habitat available to wintering deer in northern Maine using the same raster data. This large-scale spatial analysis ignored zoning designations to identify forest areas deer may use in severe weather. I expected patches of winter shelter to be widespread but relatively small and isolated from each other. These analyses provide baseline information on the current state of deer winter shelter within protected areas and across the forested landscape of northern Maine.

Study area

This analysis spanned the northern half of the State of Maine, USA; specifically, the portions of Landsat scenes 11/28, 12/27, and 12/28 that are within the state boundaries (Figure 3). Maine is the most northeastern state in the USA, bordered primarily by the Atlantic Ocean and Canada. The study area is dominated by northeastern spruce-fir forest (Brissette 1996) and has a cool and humid climate similar to the Canadian maritimes (Sendak et al. 2003). Although many northern conifer and hardwood species are present, red spruce (*Picea rubens*) and balsam fir (*Abies balsamea*) are most prevalent (Sendak et al. 2003). The primary industry in this region is commercial timber production for pulpwood and sawlogs on private landholdings.

Because my analysis of PFWs and BDWAs included forest characteristics that could be proprietary, I limited it to the property boundaries of member companies in the Cooperative Forestry Research Unit (CFRU), which provided my funding and whose members therefore had cooperator status in this study (Figure 3). My analysis of winter deer habitat suitability across the study area was not limited by property boundaries due to the unlikelihood of releasing proprietary information at such large resolution.

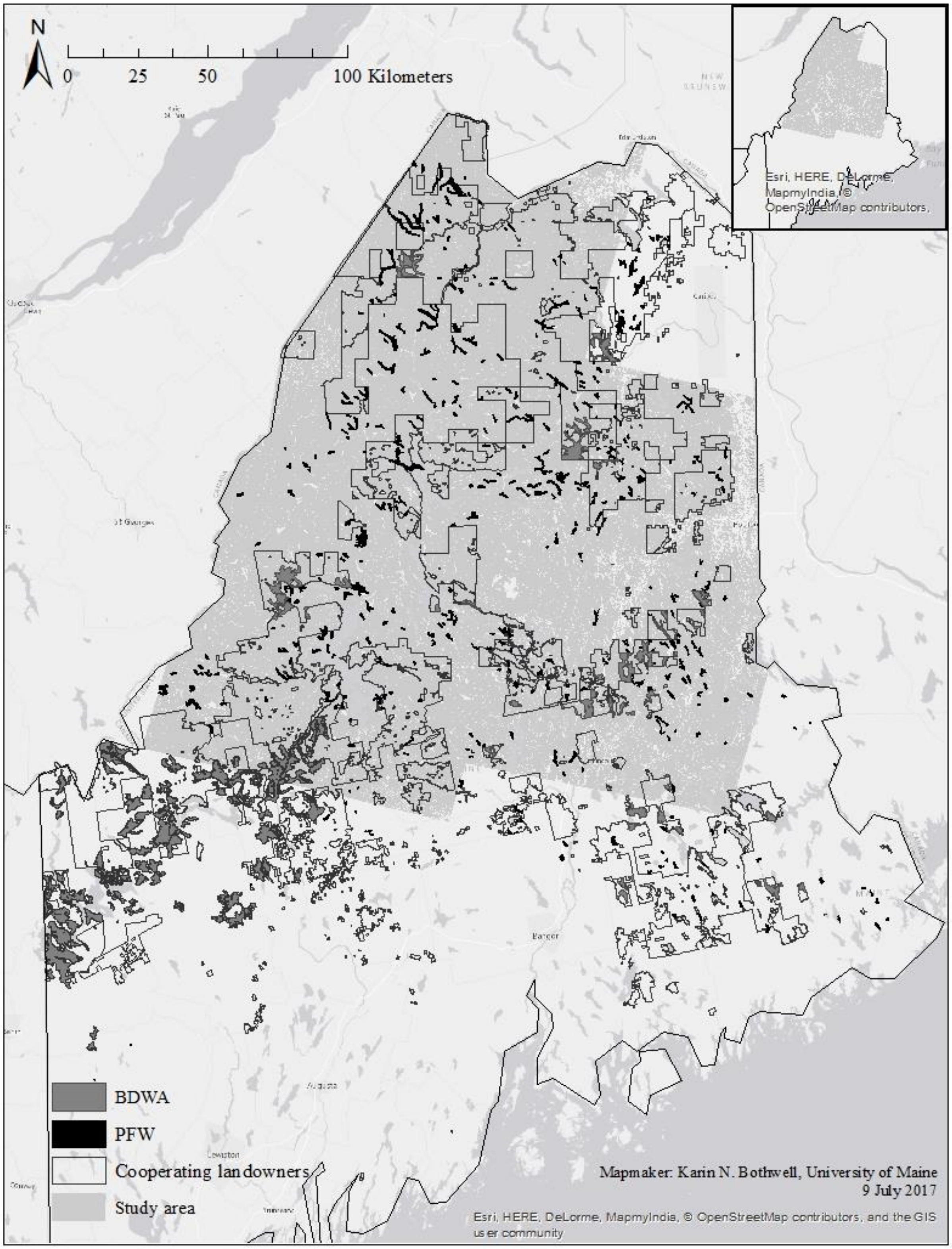


Figure 3. Map of study area within the State of Maine, USA.
Area of analysis is bound by Landsat scenes 11/28, 12/27, and 12/28 (shaded background).

Methods

Data description

I used ArcGIS version 10.3.1 (ESRI 2015) for spatial processing. MDIFW provided vector shapefiles of the PFW and BDWA boundaries, which were clipped to the footprint of land owned/managed by members of CFRU (Figure 3). To describe recent conditions (ca. 2010-2013) within PFWs and BDWAs, I used available raster maps (30 m resolution) of forest harvest history since 1970 (Legaard et al. *In Preparation[1]*) and relative abundance of 13 tree species based on 2013 imagery (Legaard et al. *In Preparation[2]*) developed for northern Maine. Tree species and harvest history maps were constructed using predictions from support vector machines. Reference data for modeling were obtained from U.S. Forest Service Forest Inventory and Analysis (FIA) plots, and predictors included spectral variables from Landsat Thematic Mapper imagery, as well as terrain and climatological variables. Harvest information was condensed for this study; classes included stand-replacing harvests classified by decade (1970-2010), partial harvests (1988-2010) as a single class, and the remaining "no-change forest" that had not experienced a harvest since 1970.

Spatial processing

To compare characteristics between PFWs and BDWAs, I first calculated the area of overlap between the two habitat classification types (PFW and BDWA) and each harvest disturbance class. I also estimated the percent presence of each of the 13 tree species within PFWs and BDWAs by calculating the zonal mean of each species' relative abundance within each polygon, normalizing to convert relative abundance to percent, and averaging those percentages for PFWs and BDWAs. For my analysis of extent and distribution of likely winter shelter, cooperating MDIFW biologists elected to define suitable winter shelter for deer based on the relative abundance of balsam fir (*A. balsamea*), white spruce (*P. glauca*), black spruce (*P. mariana*), red spruce (*P. rubens*), northern white-cedar (*T. occidentalis*), and eastern hemlock (*T. canadensis*) within PFWs. In addition, I determined with the input of local forestry experts (K. Kanoti, C. Koch, and E. Simons-Legaard, University of Maine, personal communication) that a stand age of at least 40 years would meet MDIFW guidelines for 10.7 m minimum tree height within a zoned deeryard (Maine Department of Inland Fisheries and Wildlife 2010b). I assumed forest that had not received a stand-replacing harvest since 1970 was at least 40 years old.

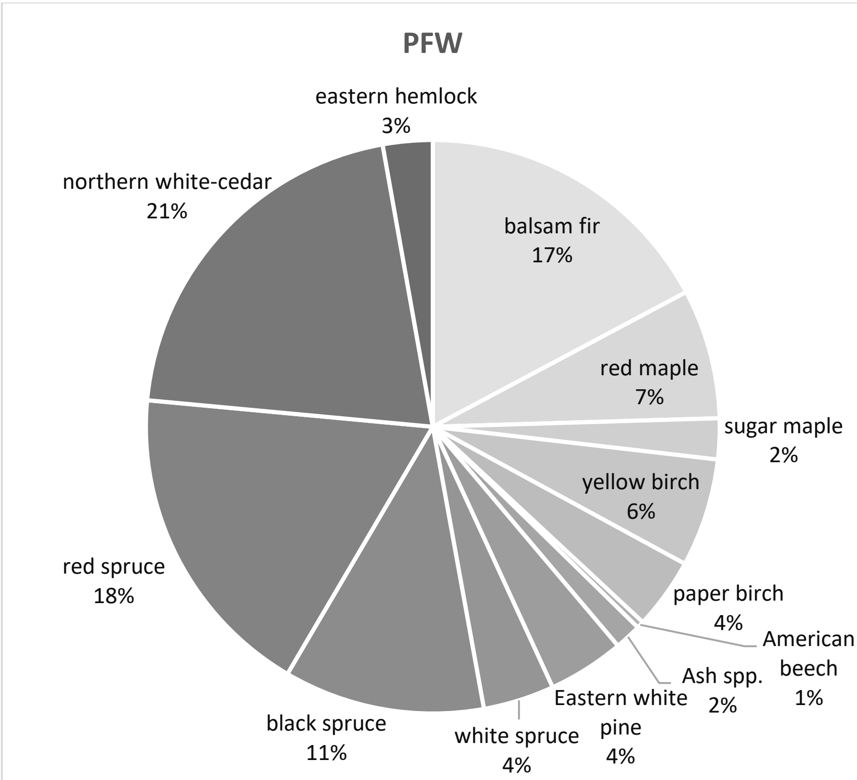
I created a Boolean raster identifying patches of forest that met the species composition and age requirements for further analyses. I then applied a minimum patch size rule by stipulating that adjacent cells meeting the specified requirements amount to at least 10 ha, which is the minimum size requirement of deeryards (Maine Department of Inland Fisheries and Wildlife 2010b). Landscape metrics were calculated with the program FRAGSTATS (McGarigal et al. 2012) for the resulting raster of likely winter shelter. At the class level, I calculated total area of the focal class (CA), percent it comprised of the total study area (PLAND), total number of patches of the focal class (NP) and number per 100 ha (PD), mean (AREA_MN) and area-weighted mean patch size (AREA_AM), mean (ENN_MN) and area-weighted mean Euclidean distance between each patch and its nearest neighbor (ENN_AM), and different measures of aggregation of like cells (CLUMPY, PLADJ and nLSI).

Results

Comparison of PFWs and BDWAs

Species composition

The composition of the 13 tree species of interest were different within PFW polygons as compared to BDWAs (Figure 4). Four species comprised greater than 10% of biomass within PFWs: northern white-cedar (20.7%), red spruce (18.0%), balsam fir (17.2%), and black spruce (11.3%). The hardwood species with greatest prevalence were red maple (7.3%) and yellow birch (6.1%). In BDWAs, balsam fir, red spruce, and northern white-cedar predominated (Figure 4), but their order of prevalence was reversed as compared to PFWs (16.0%, 13.5%, and 10.9% respectively), and the hardwood red maple was most dominant overall (18.3%). Presence of yellow (8.7%) and paper (7.1%) birch was also notable within BDWAs. Coniferous tree species of importance for winter shelter composed only 52% of biomass in BDWAs.



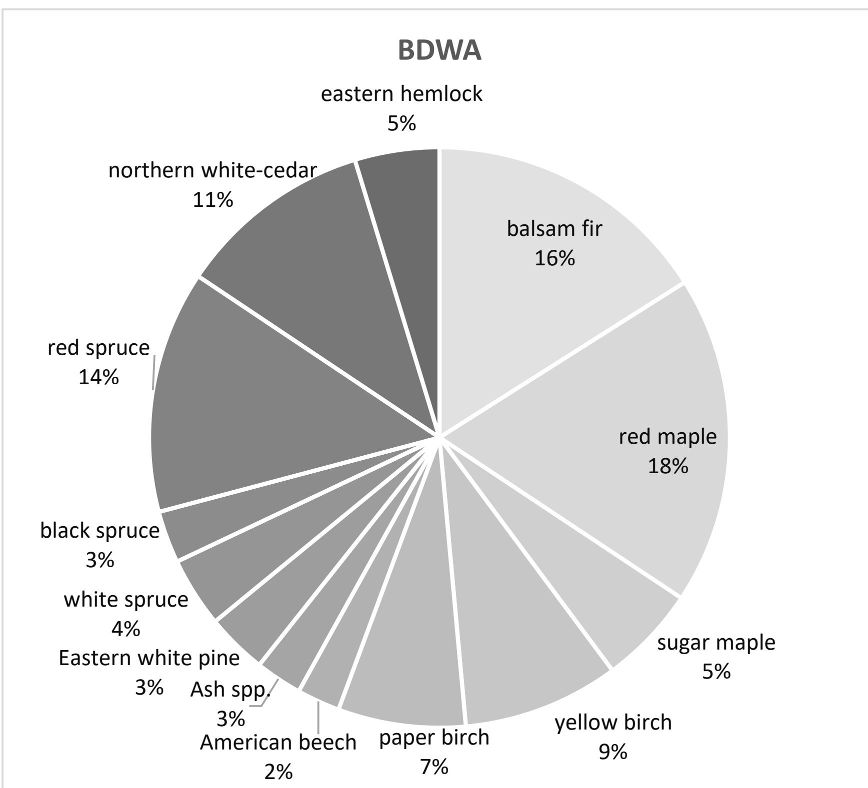
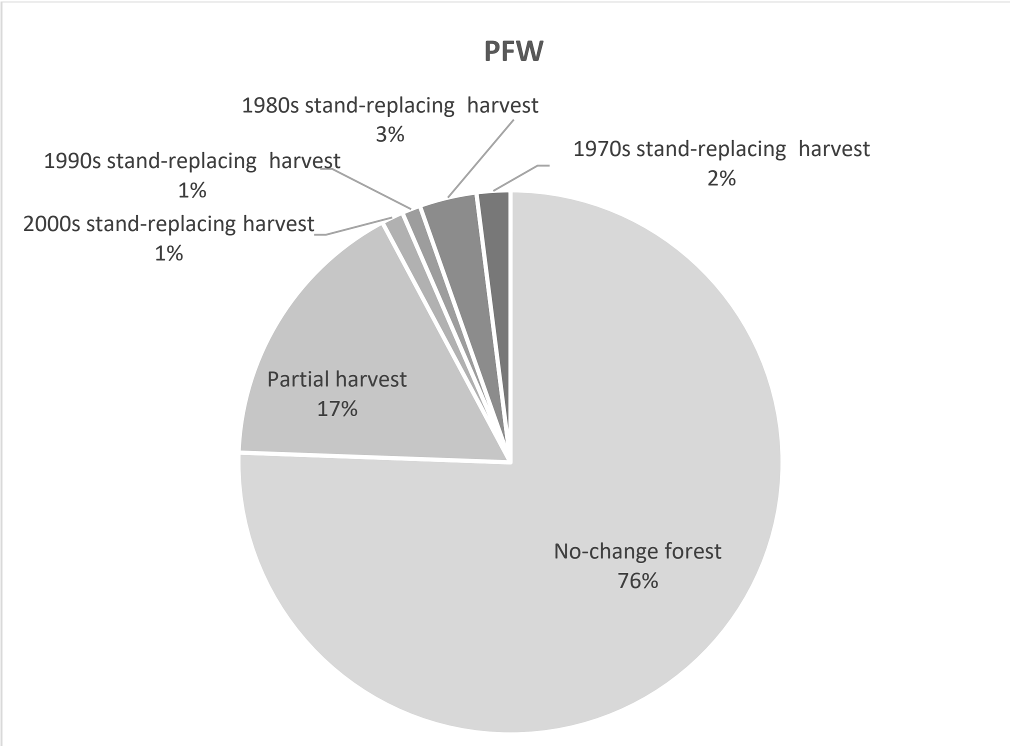


Figure 4. Average tree species composition (%) across all Protected Fish and Wildlife (PFW) zones and Biological Deer Wintering Area (BDWA) zones in northern Maine in 2013.

Harvest disturbance classes

PFWs and BDWAs also differed in their harvest history (Figure 5). “No-change forest” made up the largest percentage of area within both types of habitat classification, although it comprised 76% of PFW acreage but only 48% of area in BDWAs. “Partial harvest” was the second most common class for both deeryard zone types. The only other harvest class that comprised more than a negligible amount of land was “1980s stand-replacing harvest” in BDWAs (9%).



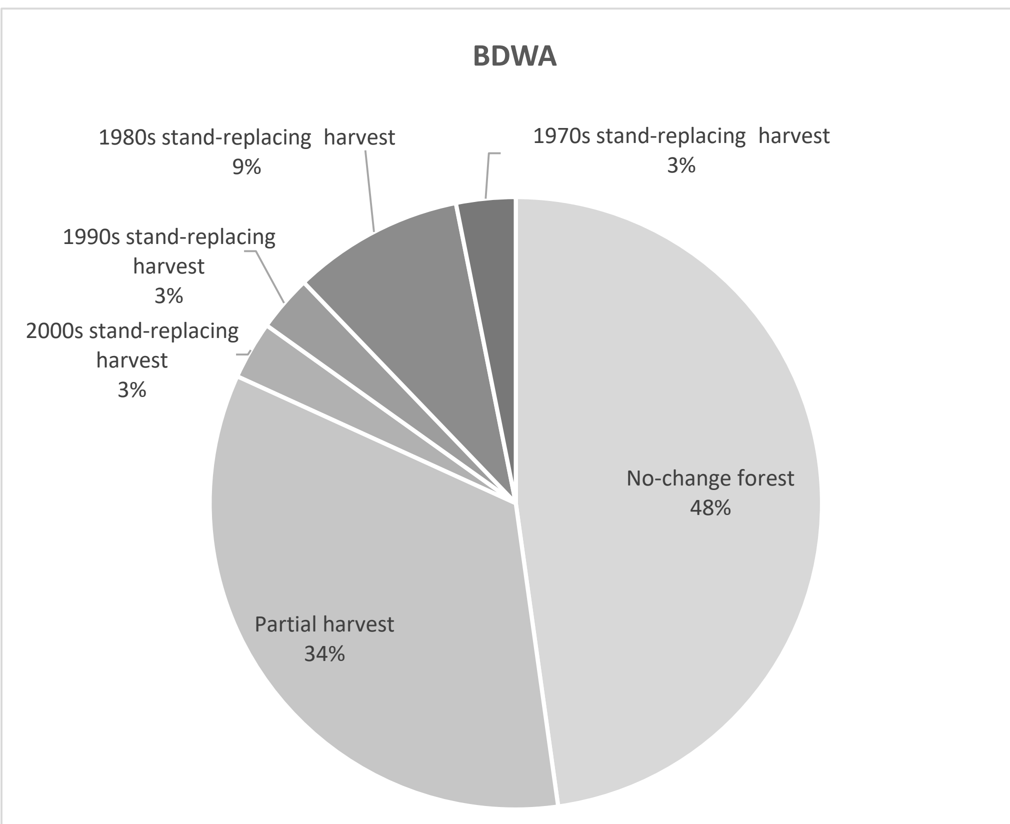


Figure 5. Area within Protected Fish and Wildlife (PFW) zones and Biological Deer Wintering Area (BDWA) zones in northern Maine by most recent harvest, 1970-2010.

Identification of suitable winter deer shelter

Tree species identified by MDIFW biologists as important for winter shelter (*A. balsamea*, *P. glauca*, *P. mariana*, *P. rubens*, *T. occidentalis,* and *T. canadensis*) composed 74% of total biomass within PFWs (Figure 4). Suitable winter shelter for wintering deer (i.e., greater than 40 years old with the combined relative abundance greater than or equal to 74% of the six species above and greater than or equal to 10 ha) was distributed throughout the study area (Figure 6). Landscape metrics of this habitat are reported in Table 5. There were forest patches with deeryard characteristics (i.e., greater than 40 years old with the combined relative abundance greater than or equal to 74% of the six species above) in the study area that were smaller than 10 ha and therefore not included in the final map of suitable winter deer habitat or calculation of landscape metrics. These 230,682 additional undersized patches amounted to 192,768.6 ha, or 2.7% of the study area.

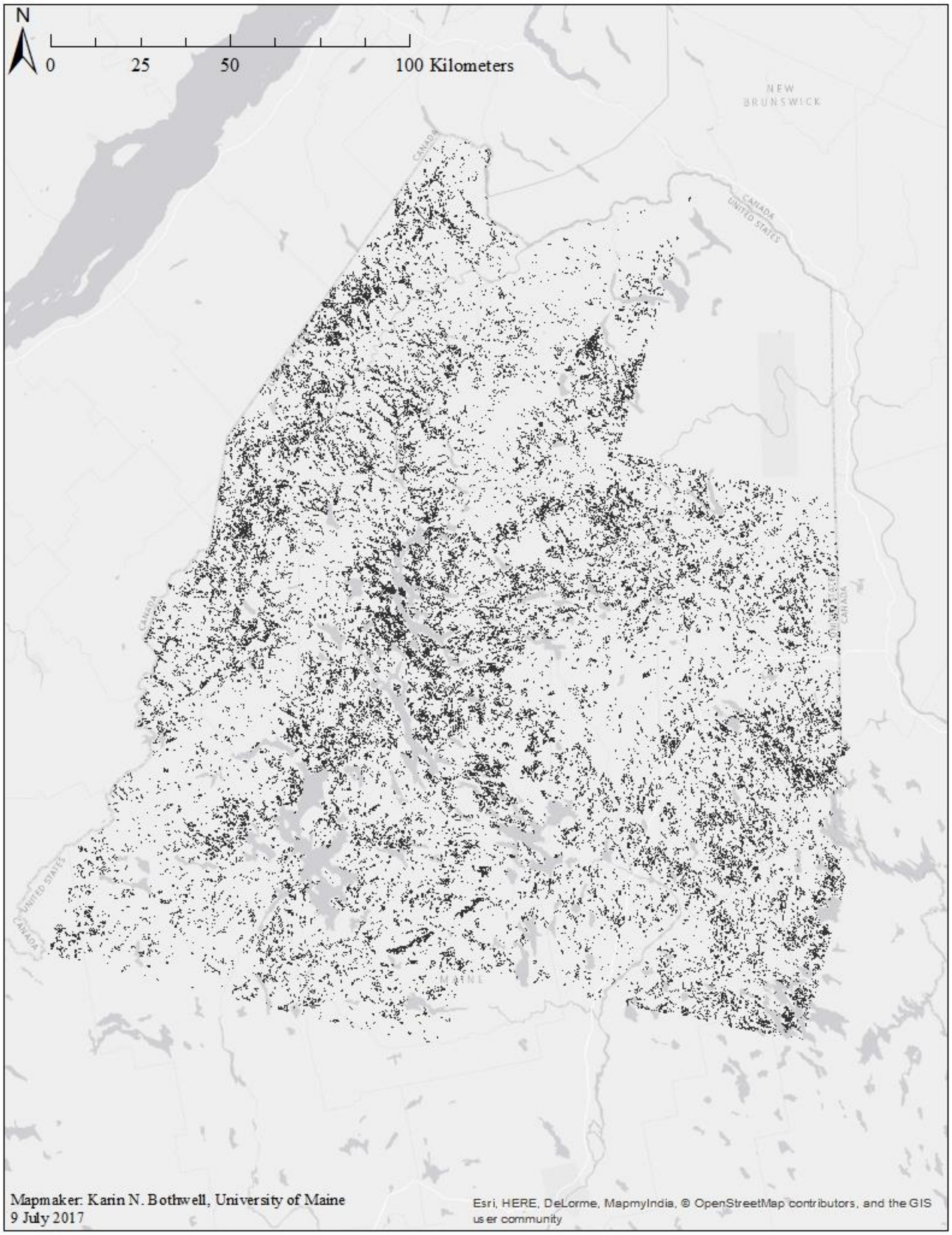


Figure 6. Winter deer habitat (dark grey) across the study area meeting chosen metrics of 74% softwood, no stand replacing disturbance within 40 years, and at least 10 contiguous hectares.

Other metrics described connectivity of suitable winter shelter for deer in the study area. The area-normalized landscape shape index (nLSI) indicated a high level of aggregation of winter shelter, with a value relatively close to the lower bound of dispersion (Table 5). Likewise, percent of like adjacency (PLADJ) and the clumping index (CLUMPY) were both on the upper end of their respective scales. Average Euclidean nearest neighbor distance (ENN_MN) between a patch and its closest neighbor was 231.6 m, although the standard deviation (ENN_SD) indicated a wide range of values for ENN (Table 5).

Table 5. FRAGSTATS analysis of suitable winter deer habitat patches of at least 10 ha in northern Maine, ca. 2010-2013.

Parameter	Name: description (range or units)	Value
CA	Class area: total area of focal class (ha)	516,459.2
PLAND	Percent landscape: percentage of the study area made up of the focal class (0-100)	7.0
NP	Number of patches	9,022
PD	Patch density: number of patches per 100 ha	0.12
AREA_MN	Mean area: average size of each patch of the focal class (ha)	57.2
AREA_AM	Area-weighted mean area: average patch size when weighted by total area of study area (ha)	793.9
AREA_SD	Standard deviation of patch sizes	205.4
ENN_MN	Mean Euclidean nearest neighbor: average distance between a patch and its nearest neighbor of the same focal class (m)	231.6
ENN_AM	Area-weighted mean Euclidean nearest neighbor: average distance between a patch and its nearest neighbor, weighted by total area of study area (m)	133.3
ENN_SD	Standard deviation of Euclidean nearest neighbor distances	301.7
CLUMPY	Clumpiness index: Deviation of like adjacencies from that expected under a spatially random distribution (−1-1, disaggregated-aggregated)	0.82
PLADJ	Percentage of like adjacencies: percent of cells adjacent to focal class cells that are of the same class (0-100)	82.8
nLSI	Normalized landscape shape index: measure of aggregation scaled to the range of values possible for the focal class area (0-1, single square patch-maximally disaggregated patches)	0.17

Discussion

Comparison of PFWs and BDWAs

The differences between PFWs and BDWAs in tree species composition and harvest history can be attributed to the distinct purposes for which they were delineated. PFWs, restricted to core areas of mature coniferous shelter, were dominated by northern white-cedar, spruce species, and balsam fir.

Previous research indicates that these tree species are common in areas where deer congregate during severe weather in this region (Boer 1978, Morrison et al. 2003), and, thus, it is not surprising that they were abundant in areas surveyed by MDIFW to support the delineation of PFWs. The majority of forest within PFWs had not experienced a harvest since the 1970s, which was likely a result of timber harvesting restrictions after implementation of PFW zoning beginning in that decade (Lavigne 1997, Harrison et al. 2013). In contrast, BDWAs with their greater abundance of hardwood tree species were representative of the heterogeneous mixedwood component of Maine's landscape. MDIFW staff delineated them intentionally to address a wider range of deer habitat needs, incorporating browse with winter shelter (R. Robicheau, Maine Department of Inland Fisheries and Wildlife, personal communication). Thus it is expected that they would have a lower proportion of coniferous trees and greater presence of hardwood species than PFWs. Similarly, canopy disturbance indicative of partial timber harvests was more common in BDWAs, which are not zoned areas in their entirety and, thus, do not have the same timber harvest restrictions as PFWs. The relative prevalence of stand-replacing harvest in the 1980s in BDWAs also has a historical explanation. Clearcuts to salvage timber were common in Maine during and after the spruce budworm (*Choristoneura occidentalis* Freeman) outbreak of the 1970s and 1980s and prior to clearcutting restrictions stemming from the Maine Forest Practices Act, which was passed in 1989 (Maine Forest Service 2013a). Portions of PFWs could also have been affected by stand-replacing harvests such as clearcuts because small-scale application of such silvicultural systems can be implemented when appropriate (Maine Department of Inland Fisheries and Wildlife 2010a), or harvest activity may have predated zone delineation in some cases.

Identification of suitable winter deer shelter

In order to transcend the framework of zoned deeryards, I analyzed the region-wide distribution of suitable winter deer habitat across northern Maine. Deer are known to migrate up to hundreds of kilometers between summer and winter ranges (Brinkman et al. 2005, Girvetz and Greco 2007, Walter et al. 2009a), and dispersal distance of juvenile deer is inversely related to the amount of forest cover (Long et al. 2005). Thus, it is important in the context of this species-specific management to consider habitat availability and distribution from a regional perspective, rather than restricting research to within the boundaries legislation has imposed. The regional metric analysis in FRAGSTATS suggested the availability of winter shelter across the study area (7.0%) is below the target of 10%, but patches were on average over five times (57.2 ha) the minimum size of 10 ha stated in the MDIFW guidelines (Maine Department of Inland Fisheries and Wildlife 2010b). Results of dispersion metrics (PLADJ, CLUMPY and nLSI) also indicated that patches of winter habitat tend to be aggregated, with on average 231.6 m of non-habitat separating neighboring patches. Previous research indicates heterogeneity and interspersion of habitat types on the landscape are associated with smaller home range area and may be a positive feature for a deer within its range (Kie et al. 2002, Saïd and Servanty 2005, Felix et al. 2007). Interspersion of non-shelter mixedwood forest into the aggregated patches of shelter could serve as a valuable source of winter browse, so in fact mixedwood or recently harvested gaps between patches of core shelter would not necessarily detract from habitat quality for wintering deer (Telfer 1974, Morrison et al. 2002). At a regional scale, however, high aggregation of the limited amount of winter shelter indicates areas providing core shelter are not evenly distributed across northern Maine. Forest patches with winter shelter characteristics that are less than 10 ha may serve as travel corridors between larger wintering areas depending on their accessibility to migrating deer and their spatial arrangement in relation to those larger patches.

A possible concern with the relevance of these results is that aggregation of habitat patches may not be highly important for wintering deer. They are known to travel great distances through seemingly suitable deeryards to reach a site to which they have fidelity (Rongstad and Tester 1969, Verme 1973, Tierson et al. 1985), so perhaps the protection of annually occupied deeryards is more important than estimating availability of other habitat patches in the region. Furthermore, the standard deviation of patch area and distance between patches is large relative to the average values of these two metrics. This variation in patch size and nearness to other suitable habitat patches leads to difficulty in applying these findings to management decisions on any scale smaller than the entire study area. Another concern is that this estimate of available winter deer shelter is limited to the time at which the maps and analysis were completed. In intensively managed forests like those across northern Maine, the amount and distribution of any forest type changes frequently (Sader and Legaard 2008). Annual timber harvests and subsequent forest regeneration inevitably alter connectivity and availability of winter shelter, making its landscape context dynamic and impossible to evaluate adequately with static maps. These results can provide only a temporally specific estimate of winter deer habitat subjectively defined by tree species abundance and harvest history within the study area.

Management implications

The intent of initial deeryard zoning was to protect and maintain those characteristics within deeryards identified by deer presence, but foresters report that many PFWs have been unoccupied for decades, leading wildlife and forest managers to question the efficacy of PFW management. My results suggest that PFWs have successfully protected areas of core protective shelter through deeryard zoning, and that were zoning expanded to encompass BDWAs, those areas would provide both shelter and browse. One task for future habitat management will be determining whether BDWA characteristics can be maintained without any zoning regulation beyond that which currently delineates PFWs. However, despite a positive habitat-based outcome after nearly 50 years of deeryard conservation measures, the deer population has not increased. Other factors influencing mortality, such as predation and vehicle collisions, and factors such as deer feeding that alter habitat use may have a larger impact on population size than does a lack of suitable winter habitat (Maine Department of Inland Fisheries and Wildlife 2011). Actions in response to those threats may need to be reevaluated and strengthened in order to enact a positive change in deer abundance.

The regional challenge in managing winter deer habitat is to ensure that both shelter and browse are sufficiently dispersed across the region. In districts of the study area that have isolated patches of winter shelter, surveys of deer use and population health will be especially useful to determine whether those patches are occupied in the winter and whether they are sufficient to support the local deer herd. However, the widespread practice of feeding deer and recent mild winters in Maine may complicate survey efforts. These factors will need to be addressed when assessing the implications of region-wide habitat dispersion for Maine's deer herd compared to other variables affecting deer wintering behavior. Balancing the patch-level and regional winter deer habitat patterns in regulatory decisions will be essential to ensure the quality of individual habitat patches as well as their region-wide accessibility to wintering deer.

Acknowledgements

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CHAPTER 4

CONCLUSIONS

<u>Related policies</u>

This research provides a multi-faceted, though far from comprehensive, case study of some of the forest management implications of a wildlife habitat provision policy that delineates protection zones of winter deer habitat in Maine. The policy's impacts are far-reaching, spanning forestry and social spheres with both positive and negative economic effects, only some of which could be included in this study. Alternatively, there are factors not directly impacted by the winter deer habitat policy that might affect the deer population. Altering these factors could leverage a positive outcome in deer abundance separate from the specific habitat protection that was the focus of this thesis. I have grouped the factors whose modification could decrease white-tailed deer mortality in Maine into three broad topics – interaction with other wildlife, interaction with humans, and forestry regulation – and have included my own suggestions relevant to their components.

Interaction with other wildlife

Deer encounters with other animal species and with other white-tailed deer are common, given the abundance of wildlife that is found in the Maine woods (DeGraaf and Yamasaki 2001). Predator as well as other prey species play a role in the health of the white-tailed deer population in Maine. Non-predatory species might negatively impact deer health through competition for scarce resources or through disease transmission. There is little evidence of inter- or intra-species competition limiting the health or abundance of deer in northern Maine. In southern Maine deer are numerous and impact vegetation through over-browsing in some areas of high deer concentration (Maine Department of Inland Fisheries and Wildlife 1990b, 2005). Even so, lack of forage, fawning sites, or other resources is not a notable cause of deer mortality anywhere in the State.

Transmission of parasites and diseases is a more likely mechanism through which interactions with deer and other species could negatively impact Maine deer herds. Parasites such as deer ticks (*Ixodes scapularis*) and the nematode *Parelaphostrongylus tenuis* are a common component of deer natural history (Kellogg et al. 1971, Gilbert 1973). While they may weaken infected individuals, they currently are not of great concern relating to mortality of white-tailed deer in Maine (Maine Department of Inland Fisheries and Wildlife 2005). Parasitism often increases with increased deer density (Gilbert 1973), and thus might act as a limiting factor on the population if deer were more numerous in the region. Mosquito-borne diseases such as Eastern Equine Encephalitis and West Nile Virus present an increasing threat to white-tailed deer elsewhere in the United States, but are not yet a problem in Maine (Tate et al. 2005, Schmitt et al. 2007). Regular monitoring of deer for symptoms and periodic laboratory testing of blood samples from dead deer, a practice MDIFW biologists have already adopted (Maine Department of Inland Fisheries and Wildlife 2014), will be sufficient until infection rates are much higher in the region. At that time, mosquito control measures such as spraying of insecticide might be considered, although it is unlikely that such broad spraying as would be necessary to protect deer would be feasible.

A more pertinent threat to deer in Maine is transmissible diseases such as bovine tuberculosis (*Mycobacterium bovis*, TB) and chronic wasting disease (CWD). At this time, TB is most common among farmed deer and is not present in Maine deer (Griffin and Mackintosh 2000). To minimize the likelihood and extent of a potential TB outbreak, I recommend consistent monitoring of wild deer by MDIFW staff and informed hunters for any signs of TB, testing of any deer that exhibits symptoms, and periodic testing of asymptomatic deer shot or found dead, along with the continued absence of deer farms in Maine. CWD, though not present in Maine at this time, is of much greater concern than TB (Maine Department of Inland Fisheries and Wildlife 2013c). It is a highly infectious and fatal neurological disorder found in North American cervids. It is caused by prions that are remarkably resistant to destruction in the environment and are spread via contact with an infected individual's urine, feces, saliva, eye fluid, blood, or muscle tissue, including through shared water, forage, and bedding locations (Johnson et al. 2006, Gilch et al. 2011). Its zoonotic potential is uncertain and MDIFW recommends thorough protective measures for anyone handling a deer (Gilch et al. 2011, Maine Department of Inland Fisheries and Wildlife 2013c). Once present in a region, CWD has been impossible to eradicate and can potentially be passed between moose, elk, deer, and some rodent species (Baeten et al. 2007, Heisey et al. 2010). It has been identified in 17 states and 2 Canadian provinces, with the closest location in New York (Gilch et al. 2011). MDIFW is actively monitoring for any signs of CWD in the region by performing the steps listed above in my recommendation for TB prevention, and prohibits importation of cervids killed anywhere except New Hampshire, New Brunswick, and Nova Scotia (Maine Department of Inland Fisheries and Wildlife 2013c).

Predation is a contributing factor to deer mortality and is a natural phenomenon in a healthy ecosystem. Any manipulation of predator-prey relationships should be approached with care to avoid creating an imbalance in other ecological associations. Predators of adult deer and fawns in Maine include eastern coyote (*Canis latrans* var.), black bear (*Ursus americanus* Pallas), and bobcat (*Lynx rufus gigas* Bangs). Packs of coyotes are the foremost predator of adult deer and fawns, with bear preying primarily on fawns after emerging from hibernation in the spring (Mathews and Porter 1988, Patterson and Messier 2000). Bobcats sometimes supplement their hare-dominated diet with fawns, and large males are able to kill adult deer, although deep snow limits their ability to hunt such large prey in the winter (Litvaitis and Harrison 1989). Furthermore, coyotes have been known to kill bobcats, so in general where coyote density is high, bobcat predation of deer is not a significant concern.

The coyote population in Maine is stable, well-distributed, and poses a significant threat to deer, especially during the winter (Maine Department of Inland Fisheries and Wildlife 2013d). By the end of a severe winter, deer energy stores are low and their ability to flee is compromised. Packs of coyotes use the trails deer have packed down through deeryards to prey on them while their movement is limited by deep snow (Patterson et al. 1998). However, it is unlikely that any measures to decrease the coyote population would benefit the deer population long-term (Jakubas 2001). Coyotes increase reproduction in response to high mortality the previous year and readily disperse to occupy vacant territory (Knowlton et al. 1999). Frequent and consistent trapping of coyotes from deeryards of high importance might mitigate deer mortality over the course of one winter, but such effort requires a high level of investment with no indication of any long-term benefit (Jakubas 1999). Where coyotes are present in high densities, distemper and mange combined with competition for space may decrease the population, but such high densities are not found in Maine (Pence 1995, Jakubas 1999). Surgical sterilization of territorial coyote packs could decrease overall regional reproduction while excluding reproducing individuals or packs from critical deer wintering areas (Bromley and Gese 2001). The process of trapping and sterilizing coyotes would be very expensive in terms of time, effort, and money, and would first require a thorough evaluation of the territoriality of Maine's coyotes to determine its potential effectiveness. Such an activity is not currently feasible for MDIFW but could be proposed should coyote predation be identified as a focus of active management. Reintroducing wolves would be another mechanism of lowering coyote abundance, but aside from the numerous biological, social, and political reasons such a decision is unlikely to be feasible in Maine, deer mortality would not decrease as a result (Paquet 1992). Moreover, predation generally culls the weakest members of prey species who are at greatest risk of mortality from other causes. In the specific case of coyote and deer in Maine, no MDIFW studies have indicated that predation decreases deer abundance exorbitantly (Jakubas 1999, Patterson and Messier 2003).

The last possibility for decreasing predation-related mortality in Maine deer is to lower the bear population. Bear abundance is high in Maine, especially in the north of the State (McLaughlin 1999). Areas of high bear density overlap with areas of high winter severity and corresponding deer mortality, so bear predation may disproportionately impact the most at-risk deer herds. Hunting is the most common mechanism for reducing bear abundance, but MDIFW reported in 2013 that hunter success rates were below stakeholder-defined objectives for controlling bear abundance (Maine Department of Inland Fisheries and Wildlife 2013e). One possible reason for the lack of efficiency of hunting to suppress current bear population growth, and one that is difficult to counteract, is that bear are concentrated far from population centers, making most hunting trips logistically difficult. Promoting bear hunting in the region is a possible solution to the insufficient numbers of participating sportsmen. A pro-bear-hunt advertising campaign could increase public interest, and public education about the numerous hunting strategies could increase success. Performing a survey of sportsmen who have held permits or been in lotteries for other game species regarding their interest in, knowledge of, and participation in bear hunting could inform the campaign and focus of education. It is possible that there is residual uncertainty and negative perceptions surrounding bear hunting following the controversial Maine bear referendum of 2014. This public education campaign must therefore be carefully targeted and implemented, and perhaps originate from a source other than MDIFW, with the goal of counteracting anti-bear-hunt sentiment. Extending the bear hunting season to include spring would increase the impact of hunting, although participation would likely be a limiting factor in the spring as it is in the fall. As a last recommendation, increasing the per-person bear limit per season would likely result in greater hunting-related bear mortality because those who are interested in and skilled at bear hunting would be able to kill more per year. Ultimately, the health of the bear population and the management objectives surrounding that goal must be of equal importance to the management of white-tailed deer. Decreasing bear abundance simply to increase that of deer is unwise and unsound, but it is possible that the desired outcomes of the two independent goals (to keep bear abundance at a stable, low level and to increase deer abundance) could align.

Interaction with humans

As a large mammal that is often found near population centers, deer have a high social value (Conover 1997, Maine Department of Inland Fisheries and Wildlife 2005). They receive attention from humans that can be beneficial or detrimental. Human actions such as protection of critical habitat, establishment of limited hunting seasons, and customization of hunting limits to the demographics of the regional deer population are intended to have positive outcomes such as improved deer body condition and a population that maintains a healthy and sustainable age and sex distribution (Maine Department of Inland Fisheries and Wildlife 1990a, 2013a). However, human actions can have negative effects on deer intentionally or unintentionally.

Hunting is a direct mechanism of negatively impacting individual deer that are killed by sportsmen. However, when properly monitored and bounded, annual hunting activity can be a tool to maintain a healthy population size and structure (Maine Department of Inland Fisheries and Wildlife 2013a). MDIFW uses multiple strategies to control hunting-related deer mortality including mandatory registration of hunter-killed deer, per-hunter limits of number of deer killed per open season, careful restriction of hunting of antlerless deer (doe and fawns), and recordkeeping of buck age (Maine Department of Inland Fisheries and Wildlife 2013f). By altering the number of permits distributed annually according to changes detected during population monitoring by MDIFW biologists, the agency is able to prevent hunting from causing unacceptable deer mortality. Were deer hunting prohibited, it is likely that deer abundance would increase; however, deer density in northern regions of their range where winters are severe would remain relatively low compared to southern Maine due to winter-related mortality (Maine Department of Inland Fisheries and Wildlife 1990a). Moreover, one of the components of the high value society associates with deer is the fact that they are game animals and provide hunting opportunity to sportsmen (Keith and Lyon 1985). Deer hunting is an activity with a long cultural legacy in Maine in particular. Deer are a popular game animal for both in-state and out-of-state sportsmen and associated revenue comprises a portion of the State budget (Maine Department of Inland Fisheries and Wildlife 2013g, 2014). Thus hunting within carefully determined parameters that ensure sustained population health should remain one of the ways humans can enjoy deer as a public resource.

One of the primary causes of deer mortality in Maine is deer-vehicle collisions, or DVCs (Maine Department of Inland Fisheries and Wildlife 2005). Minimizing DVCs is in the best interest not only of Maine's deer but also of drivers on Maine roads. Areas of high DVC frequency have been identified and marked with signage warning drivers to be alert to deer in the road, and the Maine Department of Transportation includes other advisory information on their website (Maine Department of Transportation n.d.). Some U.S. states attempt to decrease DVCs by lowering the deer population through hunting (Schwabe et al. 2002), but because our purpose in minimizing DVCs is to increase deer abundance, such a strategy is not viable in northern Maine. Wildlife crossing structures have provided a partial resolution to this issue in other states (Foster and Humphrey 1995, Donaldson 2007). Overpasses and underpasses crossing major roadways provide a corridor for traveling wildlife and minimize their likelihood of entering a roadway. There are many challenges involved in the design, construction, and use of such crossing structures (Foster and Humphrey 1995), but there is evidence that in terms of decreased vehicle damage and human injury, crossings are cost-effective (Donaldson 2007, Bissonette et al. 2008). Were

Maine to construct wildlife crossing structures, the probability of DVCs would decrease along with associated rates of deer mortality.

In addition to roadways, the human infrastructure of fencing provides a potentially hazardous obstacle to travelling deer (Maine Department of Inland Fisheries and Wildlife 2013a). Adult deer and fawns become entangled in wire fencing, facilitating predation or causing death as a result of stress or injury while struggling to escape. Recommendations in MDIFW online resources include appropriate fence construction to keep deer out of sensitive areas and avoid entanglement (Maine Department of Inland Fisheries and Wildlife 2005). Deer will crawl under fences before attempting to jump them, so if a fence is necessary on a property but not intended to obstruct deer travel, the lowest board or wire should be 17 inches above the ground. The top of a fence allowing deer passage should be less than 4 feet high (Maine Department of Inland Fisheries and Wildlife 2005). To further mitigate fence-related mortality through public awareness, MDIFW could collaborate with fence supply companies that distribute their merchandise to locations in Maine. The agency could request that the companies provide the above recommendations on their websites and with any shipment of their materials to Maine addresses. Fence sales and installation employees should also be asked to make customers aware of the risks to deer before finalizing a sale or installation.

Another manner in which humans unintentionally harm deer is by taking fawns from the woods. Fawns spend entire days curled in sheltered areas, relying on camouflage to protect them from predation (White et al. 1972). Does will avoid their fawns between feedings to minimize the risk of attracting predators. Humans often incorrectly assume fawns found alone during the day have been abandoned and take them home or to a wildlife rehabilitation facility to provide care. If a fawn has been mistaken for an orphan, MDIFW recommends rubbing an old towel in grass and then wiping the fawn to remove human scent, replacing the fawn in the exact location it was found, and checking on it from a distance to be sure the mother returns and accepts her fawn. The agency makes clear in its online resources that fawns should be left alone by humans unless no doe has been seen in eight hours (Maine Department of Inland Fisheries and Wildlife 2005).

Finally, humans often unintentionally harm the deer population by providing supplemental food during the winter. Many individuals who participate in supplemental deer feeding believe they are providing necessary sustenance to deer suffering from winter weather, while other people enjoy seeing deer on their property and are unaware of the negative effects of supplemental feeding. In fact, supplemental food causes numerous ill effects in individual deer, the population as a whole, deer-human interactions, and effectiveness of management effort (Maine Department of Inland Fisheries and Wildlife 2013b). These effects include malnutrition because of the inappropriate food offered, increased aggression between deer at feeders, rapid spread of disease such as CWD, and increased predation of deer found at feeders rather than in the protection of their traditional habitat. MDIFW has attempted to decrease supplemental feeding through public awareness, but the effort needs to be much greater and a penalty needs to be implemented to deter those who are determined to continue feeding. MDIFW lacks the resources to address the many instances of supplemental feeding, but with enough pressure, the Maine Legislature may be able to transfer enforcement authority to local police. Fines, and even the threat of fines, may be sufficient to decrease the prevalence of feeding stations. However, it is unlikely that enough support for such a measure would ever be generated from Maine residents. MDIFW would need to carefully investigate its options in terms of making a request of Legislature that inevitably would spark public opposition.

Forestry legislation

Regulations (such as the provision of winter shelter) that affect forest management can be employed to provide for and improve conditions for deer. Regulations not intended to support the deer population directly can nevertheless impact it indirectly by altering forest conditions within the ranges of white-tailed deer across Maine. Legislation influencing forest management practices has the potential to alter the characteristics of Maine's forested landscape, resulting in associated changes in the availability and quality of habitat types deer use at different times during the year. For example, the Forest Practices Act (FPA) was passed in 1989 primarily to reduce liquidation harvesting by placing restrictions on clearcutting practices (Maine Forest Service 2013a). However, the forest products sector (particularly mills) continued to require the same amount of wood. Many companies responded to this challenging supply and demand scenario by decreasing the intensity of harvest activity and increasing the extent. Such practices avoided the FPA-mandated process of obtaining approval for large clearcuts while still meeting wood demand (Maine Forest Service 2015a). The new predominance of partial harvests over clearcutting resulted in a patchwork landscape of smaller, more numerous forest openings. Such an alteration in the spatial pattern of harvested forest stands, regenerating tree age classes, and even species composition altered the availability of the corresponding habitat types for deer, among other unanticipated effects including unnatural timber harvest boundaries and economic costs to timberland owners (Maine Forest Service 2015a, Bothwell et al. unpublished). Although strong support remains for the FPA, there is also notable dissent among foresters who feel constrained by the regulations (professor, University of Maine, personal communication; Maine private forester, personal communication). This contingent does not want unrestricted harvesting activity but rather feels limited in its ability to achieve desirable outcomes because of the inflexible FPA requirements of clearcut size, timing, and spacing (Maine Forest Service 2013a, 2015a). Sometimes the habitat needs of deer would be better served by timber harvests of higher intensity that would allow other forest stands to mature longer before being harvested and provide higher quality shelter for wintering deer. Now that the impacts of the FPA have become evident, the Maine Forest Service and State Legislature may be convinced to revisit the Act and ease the approval process and penalties for clearcutting. However, such revision would inevitably encounter strong opposition from the public as well as many stakeholders in the forest management sector (professor, University of Maine, personal communication).

In 2001, Outcome Based Forestry was introduced as an alternative to forest management constrained by the FPA (Denico 2017). Under this legislation, timberland owners can enroll a portion of their property to be evaluated according to a set of standards that allow more flexibility in the extent, timing, and type of timber harvest, provided that forest management meets demanding criteria designed to ensure responsible utilization of the forest resource (Maine State Legislature 2014). Three land management entities in Maine have enrolled land in Outcome Based Forestry and have experienced greater freedom to pursue more site- and objective- specific forest management with improved forest stand and financial outcomes (Denico 2017). The application process to enroll in Outcome Based Forestry is extensive and subsequent audits are rigorous, but its advantages are many (Maine Forest Service 2015a). There are provisions to protect sensitive areas such as wildlife habitat, including winter deer shelter (Maine Forest Service 2015a), and the decreased fragmentation of mature forest patches due to more natural harvest boundaries and more concentrated harvest activity results in greater connectivity and accessibility of winter deer shelter. Outcome Based Forestry serves as a precedent of legislative alternatives to existing policy that allow greater flexibility with compliance assurance procedures and previously demonstrated responsible stewardship.

Cooperative deeryard agreements, or “co-ops,” are an opportunity for equivalent regulatory leniency in the winter deer habitat provision policy. In this scenario, forestland owners can enroll a portion of their property as winter deer habitat to be subject to similar monitoring procedures as official PFWs (Lavigne 1997). Because they provide additional area under protection as winter deer shelter, co-ops allow landowners greater flexibility in the extent, location, and intensity of timber harvests, provided their actions will improve winter deer habitat quality in the future and they maintain sufficient areas of winter shelter elsewhere in the co-op. Many landowners in Maine have designated co-ops on their property, and they report improved ability to perform site- and objective-specific timber harvests that are more operationally feasible because of their larger size, greater intensity, or ease of combination with an already planned harvest located outside the co-op (Maine private foresters from three timber companies, personal communication).

Forest certification under accepted standards such as the Forest Stewardship Council (FSC) or Sustainable Forestry Initiative (SFI) is another mechanism that can be leveraged to address deer habitat needs. Enrollment in forest certification is voluntary, non-regulatory, and intended to assure the public of responsible forest stewardship by timber-producing entities (Maine Forest Service 2013b). Certification requirements for protection of sensitive areas and old growth forest can benefit deer by protecting forest areas that provide winter shelter separate from official deeryard zoning (The Speaker’s Advisory Council on Forest Certification 2002). Additionally, maintenance of existing deeryards on the property is an advantage to the entity seeking certification, so the promotion and continuation of certification among forest landowners in Maine will fortify their incentive to maintain many habitat needs of deer.

Summary

The practice of supporting deer in northern Maine is a complex network of natural population dynamics, human desires and perceptions, and various regulatory mechanisms. The previous discussion illustrates some of the numerous management levers influencing deer abundance, once of which is the effort to provide sufficient shelter for wintering deer in the north of their range. This single policy demonstrates abstract economic principles as it affects and is affected by nearly all levels of the market, linking stumpage prices, wood product output, forest management objectives and practices, silvicultural and harvest systems, and timber harvest prescriptions. The PFW regulatory guidelines directly or indirectly touch on most aspects of forest management, from industry market decisions to stand-level silvicultural decisions and regional harvest patterns. The impacts of the wildlife policy are compounded by other legislation, such as the Forest Practices Act. Needless to say, one unexpected though subjective finding of this study is that regulatory policies and their ripple effects are fascinating. They reveal the interconnectedness of multiple fields of study and numerous individual roles of the people involved in their implementation. It would be foolish to approach a regulation such as this one with a sense of having all the answers, although I may have been guilty of such a thought for an initial brief moment. Studying the tangled elements of this policy can be nothing other than a continuous learning process, in which any information gained brings with it an increased understanding of the subject’s complexity.

It would be impossible for any project to encompass or even identify every manner in which a policy affects actions or outcomes. Nevertheless, there are discernible positive aspects within this habitat provision regulation. One that was addressed at the conclusion of Chapter 2 is the ecological transferability of winter habitat for deer to the needs of other forest species. The topics covered in this thesis focus on the deer-specific components of the policy, but other animal, plant and fungi species inevitably profit from the protection of mature coniferous forest. These benefits are enhanced when we remember that deer wintering areas on private property in Maine have been zoned and managed in conjunction with other regulated areas in many cases, such as riparian, late successional forest, rare plant, historic site, and sensitive area protection zones. Combining regulatory objectives can be mutually beneficial when expanding and reinforcing the value of the connected acreage within each designation furthers the goals of both. In a financial context, layering regulations on the same area saves timber firms money by minimizing the amount of land on which timber production is a secondary priority to conservation.

Policy implementation challenges

There are negative effects of this policy felt by both wildlife and forest managers involved in its implementation. I will present in generalities some the personal responses of interviewees and experts in the field with whom I spoke over the course of my research. These perspectives could not be incorporated into economic and silvicultural modeling but are no less valid data for their subjectivity. They describe the experience of the people most intimately connected to deeryard management. A first point of note is that initial zoning of deeryards, which was based on deer presence during severe winters, is likely to have favored (or penalized, according to the common opinion of deeryards as an economic disadvantage) forestland properties whose management was disposed to deeryard-type forests, or mature coniferous tracts with closed canopies. It is possible that deer preferred those areas for wintering, leading the biologists conducting the zoning surveys to designate and restrict harvests on a greater percentage of those firms' land relative to others where there were fewer deer due to lower quality habitat following a history of management unfavorable to closed canopy coniferous forest. Now the delineated areas are static zones within an ever-changing landscape of timber harvests and transitioning ownership. One forestry company analyst estimated that his employer had more primary shelter outside of deeryards than inside, and it does not seem to be an uncommon occurrence that some zoned deeryards are not used by deer for decades at a time. Yet any suggestion of changing the location, shape, or size of existing zones immediately sparks resistance. Revising delineation would penalize those companies that now have a greater acreage of quality habitat. It is unlikely that MDIFW would officially zone the delineated BDWAs because it is aware of the opposition it would face from forestland owners. Biologists also realize that practical details of deeryard management are imperfect and that deeryard management alones is unlikely to achieve the public's desired deer abundance. One state wildlife biologist speculated that it is time to ask the taxpaying residents of Maine what should be done and who should pay for it since biologists, foresters, legislators and researchers have been unable to identify a perfect solution to the present challenges of deer management in northern Maine. There have been many suggestions to ensure continued habitat provision, including buying land from private companies, offering tax allowances or other incentives for those who voluntarily set aside deer habitat, or using grants, public funding, or general State funds for more intensive habitat management. All have been rejected for various reasons of infeasibility. It is clear that one serious limitation to adequate attention being given to deeryards is financial, expressed as insufficient staffing within MDIFW; there are too few state wildlife biologists with too many diverse tasks to be able to monitor deeryard use as needed to inform policy. Forest managers complain that they cannot schedule a biologist for an on-site visit to review a harvest plan from September to December because they are preoccupied with responsibilities related to the hunting season. Biologists are frustrated with their limited time. They are opposed to human feeding of deer but have no way to prevent it other than posting informative signs. They act as both research biologist and game warden, unable to perform either role as well as they would like.

These ongoing tensions have led to antagonism between foresters and biologists in some cases. It was a common statement in interviews that effectiveness of deeryard management was closely linked to the quality of the relationship between the forester seeking a harvest agreement and the regional biologist overseeing the process. It seemed that those companies who were able to designate one forester as the point person for contact with the regional biologist experienced greater success in being granted the harvest plans and flexibility in prescriptions they thought appropriate for the forest stand. Those companies for which many foresters communicated with the regional MDIFW office seemed more frustrated with the long process they had to go through to meet with a biologist and the rigidity with which the biologist would reject many of their silvicultural suggestions. Some foresters found that by the time they reached an agreement with the biologist, the harvest would be too limited with expected revenues too low for any harvest machinery operator to accept the contract. They also encountered difficulties when their property spanned multiple wildlife management regions within the state. Each regional biologist had unique philosophies and approaches regarding deeryard management, creating confusion among foresters working across regions. Occasionally when the forestry bottom line and the needs of wintering deer conflicted, a third party mediated the agreement. It became clear during interviews that a level of trust and respect between the parties was very helpful in assuring a measure of leniency and economic practicality in granting harvest agreements. This situation emphasizes the specialized nature of deeryard management in Maine. Implementation of this policy is both site-dependent and person-dependent. Interpersonal relationships are as significant in its implementation as any legislation or boundary line. It is unclear how to circumvent this interpersonal obstacle since forest management, like wildlife habitat, is extremely site-specific. It is impossible to prescribe a blanket approach that will maintain deer habitat, and it seems that site visits are necessary. Silviculture is both an art and a science and is constantly changing with new information, and personal opinions of the correct course of action will inevitably conflict at times. A solution to this most basic challenge of on-the-ground deeryard management has been elusive.

A compounding factor in the pressures of forester-biologist interactions is the involvement of the public. Both sides of the previously described divide agreed that the public was a difficult force to handle. Harvests within deeryards are unpopular with deer viewers, who are afraid the deer will be negatively affected by or relocate due to the change in forest structure. Similarly, sportsmen fear that their hunting success will be decreased if deer movement patterns change in response to harvest activity. Many timber companies have found that the most effective strategy in dealing with public opinion is to be proactive by holding town hall meetings with stakeholders, explaining their intent prior to each harvest, and contacting the press before news of a harvest can be portrayed negatively. Biologists and foresters agree that forest management through timber harvests within deeryards is preferable to no management, but their impression is that the public expresses consistent opposition to harvesting activity in winter deer habitat.

Forest managers widely acknowledge the cost of deeryards, if not in financial losses, then in time and effort required to build credibility with state wildlife biologists and the public. Foresters successful in deeryard management have found that they must plan harvests multiple years in advance to ensure that a sufficient portion of a deeryard maintains the minimum percentage of crown closure through a harvest; build a relationship with the regional biologist to know how he (at the time of these interviews, there were no female regional wildlife biologists in MDIFW) prefers to be approached and see a harvest plan presented; proactively provide information and seek public input prior to scheduled harvests; survey for deer use that will affect the harvest plan they present; spend greater than average time laying out a harvest block to ensure that no errors are made on the part of the operator; employ a reliable and skilled contractor willing to take on a highly detailed and sensitive task; and check in frequently as the harvest is underway. Many land managers accept these requirements philosophically, stating either that there is no use complaining about these non-negotiable regulations or that this is simply the cost of social responsibility. They assert that they have been entrusted with maintaining a public good, and whether it were for deer or some other good, they would be held responsible for their management decisions by an outside authority and the public regardless.

Foresters and biologists have regularly confronted and adapted to changes in forest and wildlife management. There will always be new challenges to policy implementation. These include the recent transitions in timberland ownership to institutional investment firms, under which land is frequently bought and sold, presenting a novel difficulty in necessarily long-term deeryard maintenance. A current struggle is maintaining habitat across numerous stands that have simultaneously reached maturity since regenerating after the last cycle of the spruce budworm outbreak in the early 1980s. The fundamental difficulties of this deeryard zoning policy are persistently problematic. No complete solution has been developed in the years since the beginning of deeryard zoning in Maine, but neither have those invested in it stopped searching for one. Research as well as technological and strategic advances continue. It is my hope that this research will prove practical and applicable in both management and policymaking surrounding deer wintering habitat. One certainty is that I have thoroughly enjoyed familiarizing myself with the intricacies of this contentious legislation and the people involved in its implementation. It combines wildlife biology, silviculture, the constraints of imperfect regulations, and a human element of earnest and practical managers that make its application simultaneously unpredictable and extremely enlightening to someone studying policy at any scale.

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APPENDIX

INTERVIEW QUESTIONS

What is your current management plan for your PDs?

How would you manage that land if it were not in a zoned PD?

Are you satisfied with the production of your stands in PDs? Do you have any plans to increase it?

Are you satisfied with the returns brought in by stands in PDs?   Do you have any plans to increase them?

What is your estimate of the cost *in time* of managing PDs – including making a specific management plan and meeting with a state biologist?   What other steps are involved?

Are you willing to make your inventory and harvest data available to this project for more accurate computer modeling?

Have you made any changes to your PD management? What were the results?

Do your foresters notice deer in your PDs? Elsewhere on your property?

Are you interested in managing for any other species?

Would research on the range and habitat needs of any other species be of interest to you?

Would you find a similar economic analysis of larger-scale PDs of value?

BIOGRAPHY OF THE AUTHOR

Karin Noel Bothwell was born and raised in Roxbury, an urban neighborhood of Boston, Massachusetts. She had the privilege of graduating from The Winsor School with the Class of 2006 and earning her Bachelor of Science in Biology with a Spanish minor from Georgetown University in 2010. She enjoyed a surprising variety of subsequent roles, including employment as an outdoor educator of urban youth, a children's ski instructor, a ranch wrangler, a veterinary surgical technician, and a field technician in wildlife research. She has united her interest in wildlife conservation and natural resource management through her studies at The University of Maine School of Forest Resources. She is a member of the Spanish Honor Society and the Society of American Foresters and will begin an internship as the first National Society of American Foresters Mollie Beattie Visiting Scholar in Washington, D.C. after graduation. She is a candidate for the Master of Science degree in Forest Resources from The University of Maine in August 2017.