

Best Management Practices

For the New England Cottontail

New York



Specific challenges

- Invasive shrubs
- Heathlands
- Canopy Retention
- Eastern cottontails

Statement of Purpose

Populations of species residing at the edge of their range are exposed to novel environments and stressors that may affect their response to management. The impacts of eastern cottontails and the prevalence of invasive shrubs have been recognized as factors limiting New England cottontail populations at the edge of their range in New York State. Here, canopy closure, heathlands, and invasive shrubs may also play a large role in providing habitat and mitigating the negative impacts of competition with the eastern cottontail.

This document is meant to serve as a technical guide for managers working to restore or create New England cottontail habitat in the face of these challenges. Recent work suggests current management practices may be ineffective or even harmful when the impacts of invasive shrubs and eastern cottontails are not considered in forest management decision-making. These guidelines provide background information and updated recommendations derived from recent and ongoing research on New England cottontails for use in developing site specific forest management plans.

While we use New York specific examples, many of these challenges we discuss, such as management of New England cottontails in the presence of eastern cottontails, are rapidly becoming a range-wide concern. The guidance outlined herein is adaptable to similar habitat in New England.

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Cover photo: New England cottontail resting under red cedar felled as part of management to open canopy gaps. Credit: Amanda Cheeseman

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Introduction

Over 300 species use resources provided by northeastern young forests². Among these are at least 20 mammal species, including the imperiled New England cottontail³, a shrubland obligate rabbit that relies on successional shrublands. New England cottontails were once common throughout New England and eastern New York, but due to natural forest succession and anthropogenic development, over 86% of the historic range is no longer occupied (Figure 1)⁴⁻⁶. The New England cottontail is now state listed as a species of greatest conservation need, threatened, or endangered within every state in its current range.

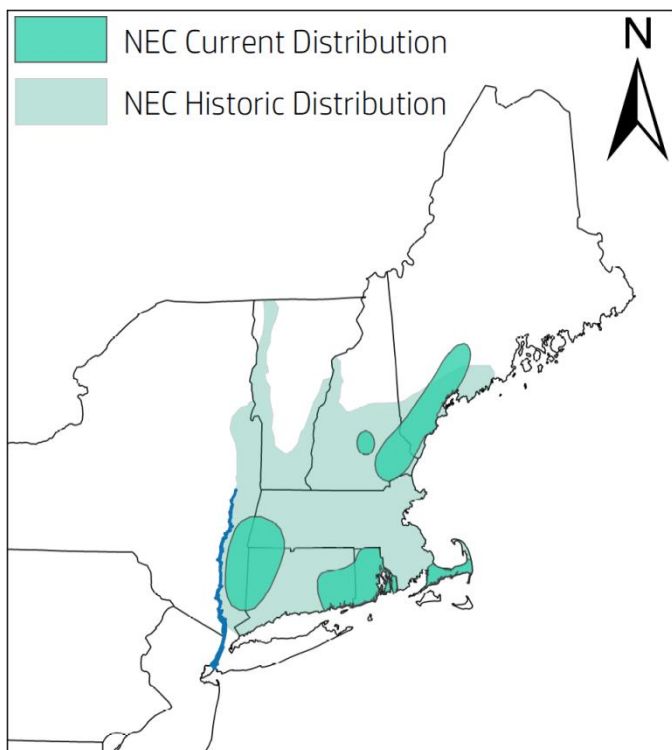


Figure 1. Map of historic and current distribution of New England cottontails (NEC) detailing range loss (IUCN 2015), range contractions have continued and present ranges are smaller than shown here.

Historically, beaver and wildfire maintained tracts of successional shrublands; however, decades-long suppression of these natural disturbances means that today's shrublands are primarily the result of anthropogenic disturbance. As a consequence, one of the largest challenges for New England cottontail recovery is the ephemeral nature of the successional shrublands upon which they rely combined with a fragmented landscape that severely limits connectivity (Figure 2). The successful recovery of the New England cottontail hinges on long-term management to create and maintain networks of connected suitable shrublands at a higher rate than they are lost due to natural succession. To aid recovery of the New England cottontail, a region-wide coalition of managers established a goal of creating 50,000 acres of suitable shrubland, including 10,000 acres within New

York State to be met by 2020⁷. This goal was intended to be met through existing shrubland, combined with management on public and private lands and is critical for establishing sustainable populations of New England cottontails⁷.

While the primary threat to New England cottontails is still considered to be habitat loss, within portions of their range competition with the eastern cottontail, the proliferation of invasive shrubs within existing habitat, and low survival at some locations alter what constitutes suitable habitat. Within these areas, targeted habitat management that considers these variables should be employed to maximize habitat quality for New England cottontails.

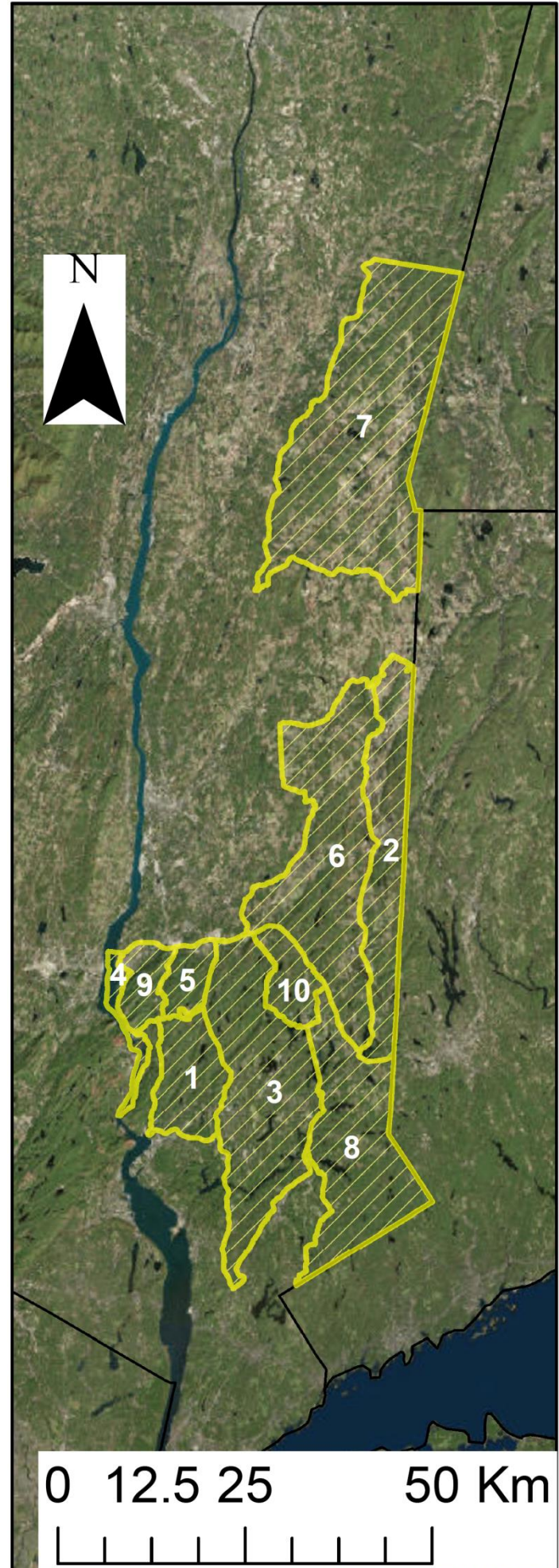


Figure 2. Map of the 10 identified genetically distinct populations of New England cottontail in New York identified by Cheeseman et al. In Review. 1: South FSP, 2: Cranberry, 3:East FSP; 4:Highlands, 5: North FSP, 6: Pawling, 7:Taconic, 8:Weschester, 9: West FSP, 10: Carmel

Invasive Shrubs

Invasive shrubs are common in early successional forests in the northeastern United States. These shrubs regenerate rapidly and may arrest succession for a time, extending the longevity of successional shrublands. However, many invasive shrubs reduce the diversity of native plants, and provide low quality forage for wildlife like white-tailed deer and passerines⁸. When at low to moderate densities, invasive shrubs provide habitat for New England cottontails (Figure 3; Figure 4)^{1; 9}; however, at high densities they may have detrimental impacts on the survival of New England cottontails.

Furthermore, in patches of certain invasive shrubs, such as Japanese Barberry (*Berberis thunbergii*) and multiflora rose (*Rosa multiflora*), the abundance of black-legged ticks and their associated pathogens such as Lyme disease are increased, and pose health risks to wildlife, including New England cottontails and humans¹⁰.

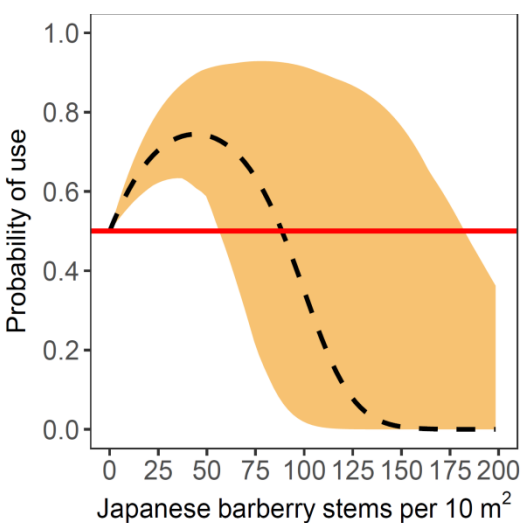


Figure 4. Probability that a New England cottontail will use Japanese barberry densities where eastern cottontails are prevalent. Probabilities > 0.5 indicate selection, < 0.5 indicate avoidance where 95% confidence bounds do not overlap y = 0.5. There was no selection for barberry where eastern cottontails were not prevalent.



Figure 3. Shrubland dominated by invasive Japanese barberry. Here Japanese barberry outcompetes other shrubs, resulting in low shrub diversity. While Japanese barberry may provide poor quality habitat, where prevalent wholesale removal would leave little understory and may result in local extirpation of New England cottontails.

Where invasive shrubs are over abundant to the point where they severely limit native shrub diversity, management to remove invasive shrubs will be beneficial.

- Wholesale removal of invasive shrubs where they dominate the understory may severely diminish habitat quality for New England cottontails to the point of site-level extinctions for this species (Figure 3).
- Where New England cottontails may be present, invasive shrub removal should be conducted in plots with a rotational schedule. Allow native shrub regeneration within areas where invasive shrubs have been removed before proceeding to the next section.

- Invasive shrub removal in 50 m x 50 m plots arranged in a checkerboard pattern may balance cover needs for resident New England cottontails with invasive removal goals (Figure 5).
- Create brush piles from invasive shrub cuttings to augment cover for New England cottontails where re-sprouting from cut stems is not a concern (Figure 6).
- Hand felling and leaving downed canopy trees in invasive removal plots may reduce possible negative impacts of shrub removal by augmenting food and cover and may open canopy gaps to encourage shrub regeneration and protect native saplings from deer browse (Figure 6). See recommendations for canopy retention for additional details.
- Depending on site conditions, ongoing

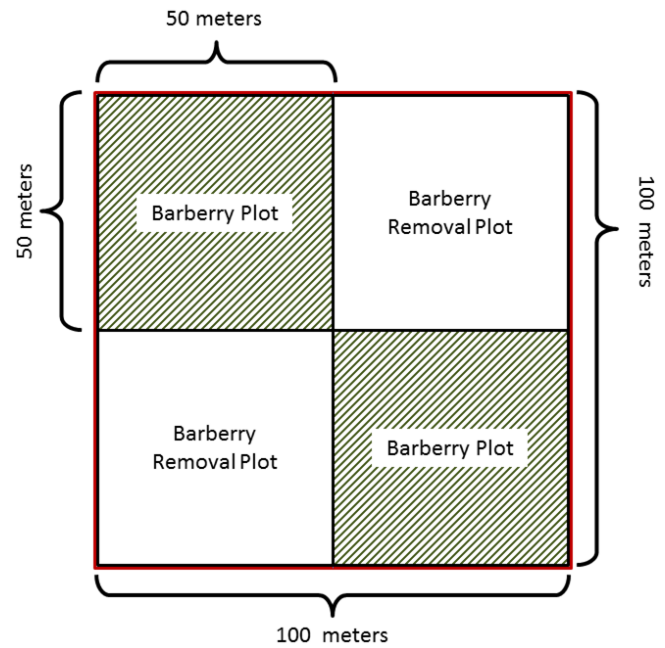


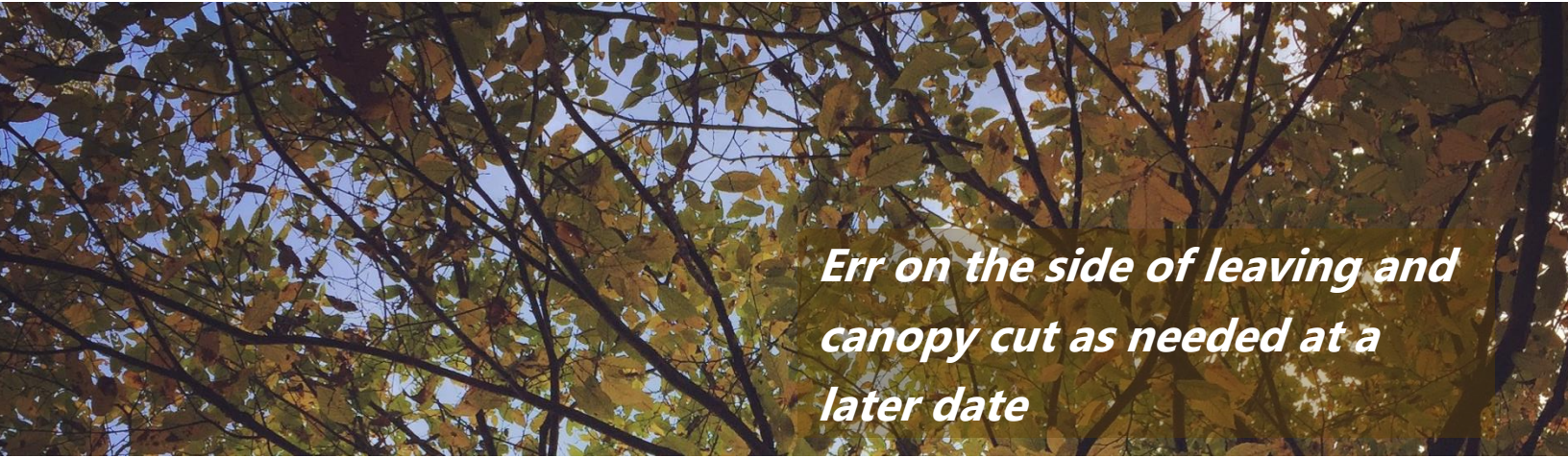
Figure 5. Example of recommended rotational prescription for a dominate shrub, Japanese barberry, at a site where New England cottontail is present. Plots with barberry left intact should be treated once shrub regeneration in the barberry removal plots has progressed to the point that it is now suitable for New England cottontails.

invasive shrub management and/or native shrub plantings may be necessary to encourage native understory recruitment after invasive shrub removal.



Figure 6. Example of managed site pre management (May 2018, left), after invasive shrub removal with brush piles created from removed shrubs (July 2018, center), and after canopy was thinned (November 2018, right). Site had documented New England cottontail occupancy within the last 5 years; however, New England cottontails were not detected in the summer preceding the management efforts. New England cottontails were again detected using the managed area in post-cut in November 2018.

Canopy Retention



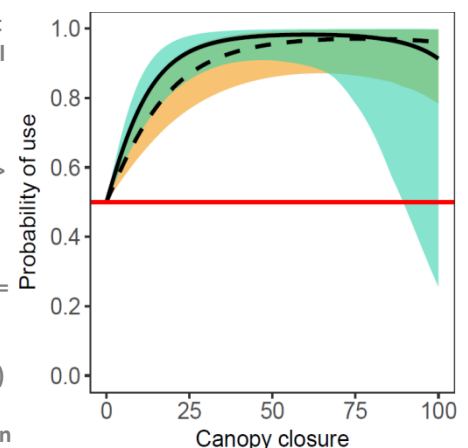
Err on the side of leaving and canopy cut as needed at a later date

The New England cottontail was historically known as the 'Woods Rabbit' due to its association with forested shrublands. Today, they are more commonly considered an early successional species; however, canopy closure remains an important habitat component for New England cottontails.

- Persistent canopy closure¹ should be managed between 25-75% (Figure 7) to maximize use by New England cottontails.
- At most sites there will be a tradeoff between canopy closure and shrub density and regeneration.
- Managers should consider site conditions and balance canopy retention with expected shrub regeneration, leaving as much canopy standing as possible while still meeting shrub regeneration targets.

- Some invasive shrubs such as Japanese barberry are good competitors under low-light conditions, while invasive shrubs such as multi-flora rose are better competitors under high-light conditions.
- Managers should consider the invasive shrub species present and nearby, and the anticipated response of these shrubs to canopy thinning.
- Invasive removal and/or native shrub plantings in addition to canopy removal may be necessary to achieve shrub regeneration targets.

Figure 7. Probability that a New England cottontail will use levels of canopy closure where eastern cottontails are not prevalent. Probabilities > 0.5 indicate selection, < 0.5 indicate avoidance where 95% confidence bounds do not overlap $y=0.5$. Use of persistent canopy closure during the leaf-off season (blue) and seasonal canopy closure during the leaf-on season (orange) shown.



¹ Persistent canopy closure is assessed using a spherical densitometer held at a height of 1 m. Woody plant material and evergreen vegetation is counted as canopy closure if it covers $> \frac{1}{2}$ of a square. This is summed for all 96 squares. See Vegetation Sampling Methods in Appendix 5.



Heathlands

Heathlands, otherwise known as ericaceous shrublands, are dominated in southern NY by mountain laurel (*Kalmia latifolia*) and blueberry (*Vaccinium* spp.; Figure 8). These shrublands often have a high degree of canopy closure, usually oak (*Quercus* spp.) dominated, may span large areas, and have a highly variable understory density (Figure 9). These shrublands have been recognized as important habitat for Appalachian cottontail across their range and for New England cottontail in New York.

- New England cottontails focus use in heathlands where understory density is high.
- Opening a series of small canopy gaps within heathlands may allow for dense understory regeneration within the canopy gaps. These areas may act as refugia for New England cottontails.
- Gaps that would allow small (less than ~30 m diameter) patches of herbaceous cover may enhance summer forage availability.
- Mountain laurel does not appear to be a palatable food source. Managers should encourage regeneration of other native shrub and saplings such as blueberry and oak.
- Shrub height may be a limiting factor within these shrublands. Where low bush blueberry dominates, forage may be plentiful but cover, especially during winter, will be lacking. In areas of tall mountain laurel,

Figure 8. Top: Example of heathland density during winter when cover and forage provided by short plants such as low bush blueberry is under snowpack. Bottom: Natural canopy opening resulting from hemlock die off in heathland. Dense regeneration of white pine and high bush blueberry is apparent.

forage may be lacking but cover abundant. Maintaining a mosaic of cover and forage sources should be a focus of heathland management.

- Where understory density is low, heathlands may still facilitate movement between patches.
- Creation of suitable shrublands (see throughout) >7.5 ha and adjacent to large spans of heathland may improve

connectivity between populations of New England cottontail.

- The density of New England cottontails within heathlands may be lower than other shrubland types, and heathlands may be associated with larger home ranges.
- As eastern cottontails do not appear to select heavily for heathlands, these shrublands may provide a refugia from competition.



Figure 9. Photo of New England cottontail taken by trail camera in heathland patch dominated by mountain laurel and low bush blueberry. Site had oak dominated canopy

Eastern Cottontails

As a habitat generalist, the eastern cottontail is able to capably exploit a wide range of habitat types. They can be abundant in agricultural hedgerows, residential landscaping, regenerating old fields, and successional shrublands, though they show a preference for areas with high stem densities. As such, eastern cottontails are able to colonize early successional shrublands at an earlier seral stage age than is suitable for New England cottontails, and their occupancy may limit the success of future colonization efforts by New England cottontails.

Table 1. Average vegetation in patches defined as early, mid, and late successional shrublands in New York. Values defined by mean \pm 95% confidence intervals.

	Early	Mid	Late
Persistent canopy closure^a	13-21%	37-57%	51-71%
Seasonal canopy closure^a	29-57%	57-69%	85-93%
Forb height^b	36-56	18-42	6-14
Forb cover^c	18-46%	10-38%	2-14%
Graminoid cover^c	13-41%	1-17%	2-10%

^a Assessed using spherical densitometer at a height of 1 m

^b Assessed as average maximum height of vegetation in cm

^c Assessed as the proportion of each cover type in a 1 m plot at each point

Within co-occupied shrublands (Table 1), the eastern cottontail appears to compete with the New England cottontail displacing New England cottontails into later successional

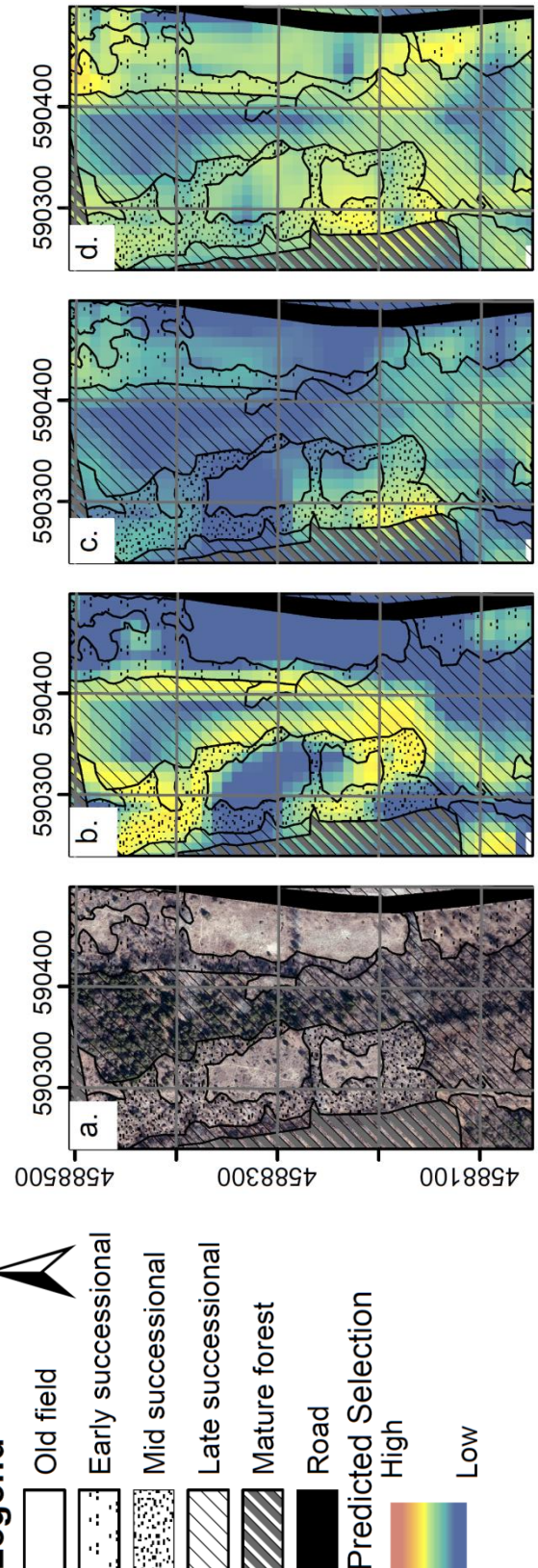


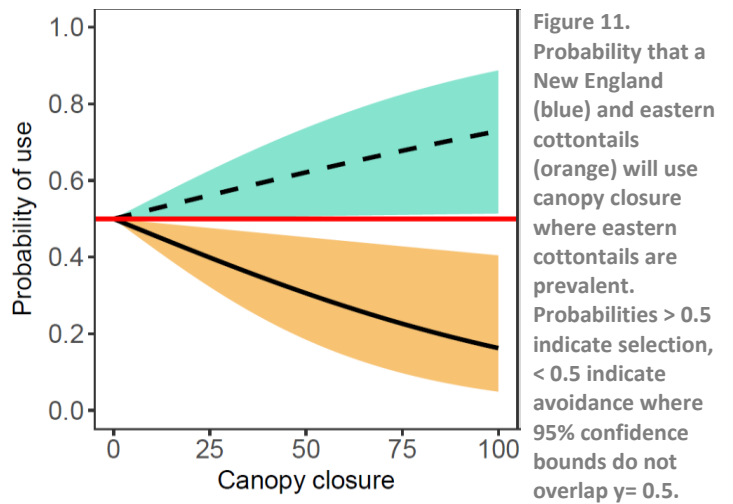
Figure 10. Habitat classifications (a) and predicted resource selection of those shrublands for (b) New England cottontails (NEC) when eastern cottontails (EC) are not prevalent, (c) NEC when EC are prevalent, and (d) EC when they are prevalent. Note shifts from mid-successional shrublands and edge habitats when EC are not prevalent to interior late successional shrublands when EC are prevalent. Data shown for leaf-off season. From Cheeseman *et al.* (2018)

shrublands. Eastern cottontails in turn avoid these same late successional shrublands (Figure 10)¹.

These interactions present a challenge for the management of New England cottontails in the presence of eastern cottontails.

Management that mimics the conditions of mid-late successional shrublands or enhances the quality of late successional shrublands while still providing necessary resources, such as dense understory vegetation, may benefit New England cottontails without encouraging use by eastern cottontails.

Management strategies that can selectively promote New England cottontails over eastern cottontails should be employed within New England cottontail focus areas wherever possible.



Canopy Closure

Canopy closure, which typically increases as shrubland succession progresses, appears to play a large role in determining use by New England and eastern cottontails, with eastern cottontails avoiding shrublands with high canopy closure and New England cottontails successfully using these areas (Figure 11; Figure 13). This use also reflects the survival probabilities of New England and eastern cottontails at varying levels of canopy closure;

Management strategies that completely reset succession give eastern cottontails an advantage

Management strategies to promote New England cottontails over eastern cottontails should be employed wherever possible



Figure 13. Despite the low understory density in many areas of this site, New England cottontails persist at apparently high densities. Herbaceous forb and grass cover are common across the site and the low red cedar canopy may prevent snowpack over this herbaceous forage.

New England cottontail survival is highest at high levels of canopy closure, whereas eastern cottontail survival is lowest at these same high levels of canopy closure (Figure 12).

Management to promote high canopy closure within shrublands may be an effective strategy to selectively manage for New England cottontail without encouraging habitat use by eastern cottontails⁹ and may improve New England cottontail survival.

- Management plans should consider variable seasonal resource needs of New England cottontails. Intermixed with dense shrub cover, encourage small patches (<30 m diameter) dominated by herbaceous plants, which provide valuable leaf-on forage and cover.

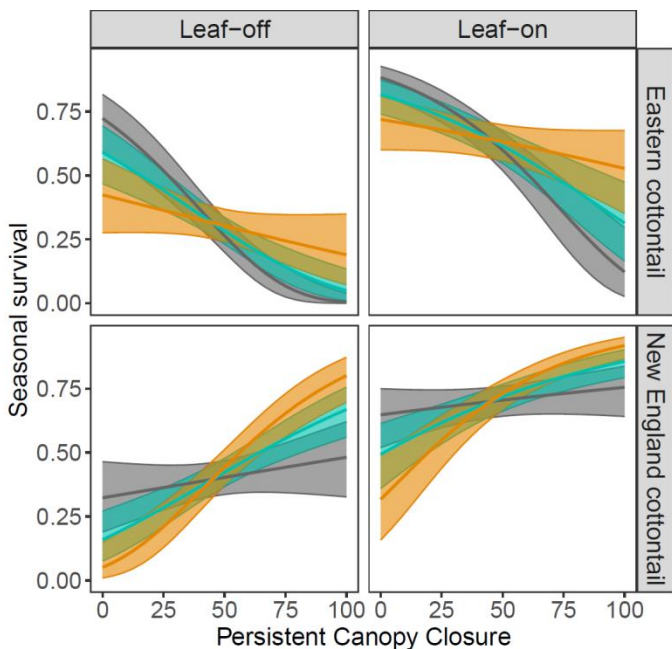


Figure 12. Probability of an individual cottontail surviving the season under different levels of canopy closure and at low (gray) moderate (blue) and high (orange) stem densities. Predictions and standard errors shown.

- At many sites there will be a trade-off managing for high canopy closure while still maintaining a dense, diverse shrub layer.
- Seed-tree cuts, shelterwood cuts, or canopy and mature shrub thinning to create forest openings or prolong shrubland suitability may achieve a beneficial landscape for New England cottontails, though techniques should be selected that will provide the greatest canopy closure while encouraging shrub regeneration and providing patches of leaf-on herbaceous forage (Figure 14).
- Small-scale patch thinning to create a series of adjoined canopy gap-phase processes may also be effective.
- At invasive shrub-dominated sites there may be a tradeoff between canopy retention and native shrub recruitment. Japanese barberry has a wide range of light tolerances and early spring leaf-emergence allows it to outcompete many native shrub species^{11; 12}.
- Heavier canopy tree thinning, coupled with invasive shrub management, may be necessary where shade-tolerant invasive shrubs are common.
- Where management plans for New England cottontail target closed canopy forests with low understory densities, consider implemented a network of patchy rotational canopy thinning at a small scale (i.e. individual cuts ~1 ha or smaller)



Figure 14. Site managed for moderate residual canopy to promote New England cottontail over eastern cottontail.

isolated by at least 100 m. Corridors with very light canopy thinning between patches may also be beneficial. Individual cuts may not be of sufficient size to support eastern cottontails, but the network of patches, high canopy closure edges, and high canopy corridors may be sufficient for New England cottontail. Adjacent cuts to increase patch size and improve habitat quality can be completed once higher stem densities are achieved within initial cuts, following recommendations to selectively benefit New England cottontails over eastern cottontails.

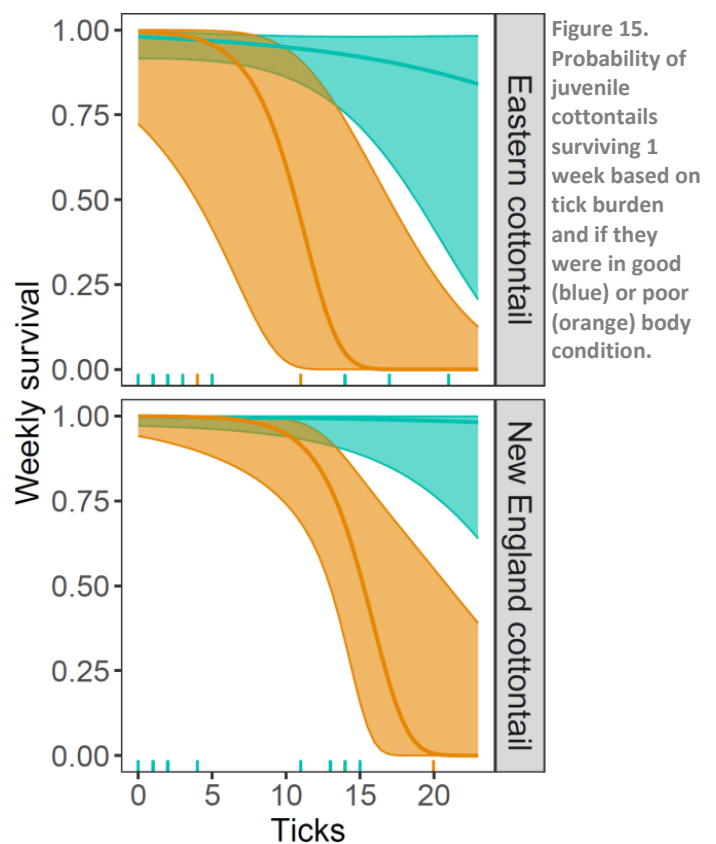
Invasive Shrubs

Eastern cottontails may displace New England cottontails into areas of dense barberry within closed canopy forests (Figure 4). While these areas likely provide cover for New England cottontails, as Japanese barberry outcompetes other, potentially more palatable plant species, forage may be lacking. Furthermore, displacement into these dense stands of invasive shrubs by eastern cottontails appears to increase tick burdens which have been associated with dramatically reduced survival of juvenile cottontails (Figure 15). Given competitive interactions between New England and eastern cottontails and resulting habitat use, areas of high barberry density are likely to confer disproportionately negative impacts on New England cottontail populations.

- Where New England cottontails may occupy dense barberry stands or stands dominated by other invasive shrubs, invasive plant management should be considered to improve habitat for New England cottontail.
- Invasive shrubs should not be simultaneously removed across large areas, but instead removed rotationally.
- When considering translocations or reintroductions of New England cottontails, avoid areas where invasive shrubs dominate the plant community or manage these areas for invasive plants

prior to release of translocated or captive bred animals.

- Canopy removal may be needed to facilitate shrub regeneration after barberry removal. Felling trees and leaving them in place is recommended to provide a temporary source of forage and refuge.
- Shrub plantings and continued removal or treatment of invasive shrubs, and additional canopy removal may be necessary to encourage native shrub regeneration after Japanese barberry removal.



Connectivity

Dispersal of New England and eastern cottontails is limited, rarely exceeding 1 km. However, eastern cottontails are more prevalent and capably exploit more of the landscape than do New England cottontails. As a result, any managed patch is likely to be within dispersal distance of a greater number and closer eastern cottontail populations than New England cottontail populations, which will confer a colonization advantage to eastern cottontails (Figure 16). Consideration of the landscape and probable source populations for both New England and eastern cottontails is thus warranted when planning management.

- Where the proximity of eastern cottontails is unknown, managers should assume there are resident eastern cottontails within dispersal distance.
- For sites where known eastern cottontail populations are within 1 km, shrublands should be managed with higher canopy closure to reduce the suitability to eastern cottontails.
- For sites where known eastern cottontail populations are >5 km, and New England cottontails are within adjacent patches, shrublands may be managed with lower residual canopy; however residual canopy should still be greater than 25% to maximize use by New England cottontails.



Figure 16. Hypothetical landscape of patches suitable to both New England and eastern cottontails (Background vegetation) and patches that are suitable for only eastern cottontails (yellow; i.e. residential landscaping, hedgerows, regenerating old fields). Patches suitable for only eastern cottontails are abundant on the landscape, suggesting that eastern cottontails are more likely to be in close proximity, and therefore more likely to colonize any shrubland suitable for both New England and eastern cottontails than New England cottontails whose suitable patches are more fragmented.

- For sites where New England cottontails are not within 1 km or New England cottontail residency is unknown, sites should be closely monitored for New England cottontail colonization. Translocations or reintroductions of New England cottontails may need to be considered if no colonization is detected. These sites should be managed to limit competition and increase survival (i.e. with high canopy closure and low barberry density) to maximize the potential success of translocation and reintroduction efforts.

General Considerations

Minimizing disturbance

A high level of disturbance to vegetation and soil can retard succession, facilitate site invasion by exotic species, and dramatically lower short-term site suitability for New England cottontails.

- Where possible, practices that minimize disturbance to soil and surrounding vegetation, such as hand felling canopy trees instead of using heavy machinery should be used.
- To encourage rapid regeneration of native shrubs and saplings, care should be taken to avoid disrupting and damaging native shrubs and saplings during management activities.
- Where New England cottontails are present at management sites, low disturbance practices should always be employed. If not feasible, and habitat will be removed as part of the management strategy, managers should consider trapping New England cottontails off the site prior to management activities. These cottontails should be entered into ongoing captive breeding, reintroduction, or translocation efforts.

Forage

New England cottontail appear to forage in areas with abundant forbs and grasses

during summer but are unlikely to fully exploit large patches of forbs or grasses.

- Managing for small interspersed patches (< 15 m radius) within shrubland would likely be beneficial for New England cottontail.
- Large open shrubland forb areas may encourage use by eastern cottontail and increase competition between New England and eastern cottontails.
- Felling canopy trees and leaving crowns within cottontail habitat will augment short-term forage. Cuttings should be completed during winter to maximize benefit.
- Forage and cover is limiting during winter, and cottontails experience reduced survival during this season. During winters with a high level of snowpack, felling 1-3 canopy trees/ acre in New England cottontails sites may supplement forage and cover and may have positive impacts on overwinter survival. Implementing this within long-term management plans may also facilitate long-term maintenance of suitable shrublands.
- Native shrub and tree plantings may encourage native species recruitment and enhance the quality of young forest for New England cottontails and other wildlife.

- Palatable native shrubs and saplings include: High and low bush blueberry (*Vaccinium* spp.), raspberry and blackberry (*Rubus* spp.), dogwoods (*Cornus* spp.), *Viburnum* spp., and sumac (*Rhus* spp.) and saplings of birch (*Betula* spp.), maple (*Acer* spp.), oak (*Quercus* spp.), American elm (*Ulmus americana*), American beech (*Fagus grandifolia*), black cherry (*Prunus serotina*) (Table 2)¹³.

Supplementary cover

Supplementary cover in the form of brush piles, tree crowns, and rock walls or rock piles may improve habitat for New England cottontail and other wildlife.

- Cut and drop tree felling (without removing the fallen tree from the site) to create canopy openings will provide additional cover and forage. During winters with a high level of snowpack, felling 1-3 canopy trees/ acre in New England cottontails sites may supplement forage and cover and may have positive impacts on overwinter survival. Implementing this within long-term management plans may also facilitate long-term maintenance of suitable shrublands.
- Creation of brush piles from invasive removal projects may augment cover in the absence of invasive shrubs. Brush piles should not be created for species that may re-sprout from cut stems.

Table 2 List of plant species deemed palatable by feeding trails or comprising >5% of feeding observations or stomach contents for New England cottontails in the leaf-on season

Red maple (<i>Acer rubrum</i>) ¹⁴
Sugar maple (<i>Acer saccharum</i>) ¹³
Wood anemone (<i>Anemone quinquefolia</i>) ¹³
Wild Sarsaparilla (<i>Aralia nudicaulis</i>) ¹³
Gray birch (<i>Betula populifolia</i>) ¹⁴
Toothwort (<i>Cardamine diphylla</i>) ¹³
Chicory (<i>Cichorium intybus</i>) ¹³
Bunchberry (<i>Cornus canadensis</i>) ¹³
Crab grass (<i>Digitaria sanguinalis</i>) ¹⁴
Horsetail (<i>Equisetum arvense</i>) ¹³
Wild strawberry (<i>Fragaria virginiana</i>) ^{13; 14}
Wintergreen (<i>Gaultheria procumbens</i>) ¹³
Wild geranium (<i>Geranium maculatum</i>) ¹³
Lettuce (<i>Lactuca sativa</i>) ¹³
Canada mayflower (<i>Maianthemum canadense</i>) ¹³
Partridge berry (<i>Mitchella repens</i>) ¹³
Plantain (<i>Plantago lanceolata</i>) ¹⁴
Common plantain (<i>Plantago major</i>) ¹³
Grasses (Poaceae) ^{13; 14}
Fringed Polygala (<i>Polygala paucifolia</i>) ¹³
Solomon's seal (<i>Polygonatum biflorum</i>) ¹³
Black cherry (<i>Prunus serotina</i>) ¹⁴
Choke cherry (<i>Prunus virginiana</i>) ¹⁴
Pear (<i>Pyrus communis</i>) ¹⁴
White oak (<i>Quercus alba</i>) ¹⁴
Red oak (<i>Quercus rubra</i>) ¹³
Staghorn sumac (<i>Rhus typhina</i>) ¹³
Rose family (Rosaceae) ¹⁴
Blackberry (<i>Rubus allegheniensis</i>) ¹⁴
Red raspberry (<i>Rubus strigosus</i>) ¹³
Sheep sorrel (<i>Rumex acetosella</i>) ¹⁴
Willow (<i>Salix</i> spp.) ¹⁴
False Solomon's seal (<i>Smilacina racemosa</i>) ¹³
Goldenrod (<i>Solidago</i> spp.) ^{13; 14}
Spiraea (<i>Spiraea salicifolia</i>) ¹⁴
Chickweed (<i>Stellaria</i> spp.) ¹⁴
Marsh fern (<i>Thelypteris palustris</i>) ¹³
Clovers (<i>Trifolium</i> spp.) ^{13; 14}
American elm (<i>Ulmus americana</i>) ¹³
Low bush blueberry (<i>Vaccinium angustifolium</i>) ¹³
High bush blueberry (<i>Vaccinium corymbosum</i>) ¹⁴
Maple-leaved viburnum (<i>Viburnum acerifolium</i>) ^{13; 14}
Witch-hobble (<i>Viburnum alnifolium</i>) ¹³
Woods violet (<i>Viola</i> sp.) ¹³
Wild grape (<i>Vitis</i> spp.) ^{13; 14}
Barren strawberry (<i>Waldsteinia fragarioides</i>) ¹⁰



Figure 17. Unknown cottontail using brush pile created from invasive shrub cuttings

Table 3. List of plant species deemed palatable by feeding trails or comprising >5% of feeding observations or stomach contents for New England cottontails in the leaf-off season. * indicates plants where published results are conflicting and plant species may be more beneficial to eastern cottontails than New England cottontails.

Striped maple (*Acer pensylvanicum*)¹³
 Red maple (*Acer rubrum*)^{13; 14}
 Sugar maple (*Acer saccharum*)¹³
 Yellow birch (*Betula alleghaniensis*)¹³
 Black birch (*Betula lenta*)¹³
 White birch (*Betula papyrifera*)¹³
 Gray birch (*Betula populifolia*)^{13; 14}
 Red osier dogwood (*Cornus stolonifera*)¹³
 Beech (*Fagus grandifolia*)¹³
 Winterberry (*Ilex verticillata*)^{14*}
 Maleberry (*Lyonia ligustrina*)¹⁴
 Apple (*Malus spp.*)¹⁴
 Aspen (*Populus tremuloides*)^{14*}
 Black cherry (*Prunus serotina*)^{13; 14}
 Choke cherry (*Prunus virginiana*)¹⁴
 Oaks (*Quercus spp.*)¹³
 Blackberry (*Rubus allegheniensis*)¹⁴
 Dewberry (*Rubus flagellaris*)¹⁴
 Raspberry (*Rubus sp.*)¹³
 Willow (*Salix spp.*)¹⁴
 American elm (*Ulmus americana*)¹³
 High bush blueberry (*Vaccinium corymbosum*)^{13; 14}
 Lowbush blueberry (*Vaccinium sp.*)¹⁴

Deer browse

Overabundant deer may slow shrubland regeneration, increase the abundance of invasive species, and decrease the availability of forage for New England cottontail.

- While felling canopy trees, dropping and aimed stacking of tree trunks and crowns may deter deer from using the area and provide protection for regenerating native plants. Crowns from fallen trees may also provide supplementary cover for New England cottontails.
- Blackberry and raspberry (*Rubus*) plantings may also protect other valuable native shrubs, such as maple seedlings, from deer browse.

Patch Size

Patch size is an important determinant of patch suitability and population stability at a site.

- Individual patches or closely linked networks of patches should be at least 7.5 ha, patches >25 ha are preferred.
- Closely-linked networks of patches should be no further than 50 meters apart to ensure maximum connectivity.
- Survival is linked to patch size, patches <2.5 ha may be population sinks. However, when placed strategically on the landscape small patches may provide important corridors or stepping stones between populations.
- Larger patches will have higher stability and may be important source populations for nearby areas. Long term management plans should be made to retain large patches in perpetuity.
- Larger patches may be more easily colonized than smaller patches.

Patch distance

Dispersal of New England cottontails is infrequent and rarely exceeds 1 km.

- Management should focus on expanding and improving current habitat or creating habitat in close proximity to New England cottontail-occupied patches.
- Where possible, young forest creation should be focused away from eastern cottontail-occupied patches. Where managing habitat away from eastern cottontail populations is infeasible, altering management strategies to promote New England cottontail use and discourage eastern cottontail use may be a way to selectively manage for New England cottontails.
- When managing patches >1 km from known New England cottontail populations or where nearby New England cottontail residency is unknown, patches should be closely monitored for New England cottontail colonization. If colonization is not detected, reintroductions or translocations may need to be considered.

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Site Specific Example 1: State Forest

Site goals: Manage for healthy forests, improve and increase habitat for New England cottontails

Four areas were identified as ideal management sites for young forest / New England cottontail (Figure S 1).

Area 1 – This area is comprised of mature forest with little to no understory (Figure S 2). Existing understory is primarily Japanese barberry (Figure S 3). The patch is not frequently used by New England cottontail but is immediately adjacent to used areas. This patch may act as a barrier to movement between existing shrubland patches. Recommendations to create New England cottontail habitat and provide connectivity between New England cottontail habitat patches provided.

Primary needs: Increase shrub and herbaceous cover, reduce prevalence of Japanese barberry

- Thin to no less than 25% canopy closure to permit shrub regeneration.
- Establishing four, 50 m x 50 m plots within the canopy removal area where barberry and other invasive shrubs will be targeted for rotational removal. Only remove barberry from every other plot initially, removal of the remaining plots should be completed after cover has begun to regenerate in the removal plots. This rotation will facilitate growth of native shrubs and high quality forage for New England cottontails while still preserving some valuable invasive shrub cover for use by New England cottontails.

Area 2 – This area is primarily larch forest currently used by both New England and eastern cottontails, and appeared to be dominated by New England cottontails as of fall 2016. Variable amounts of understory cover from sparse to thick are present (Figure S 2). Invasive shrubs such as Japanese barberry are common (Figure S 3). *Primary needs: Increase shrub and herbaceous cover and reduce shrub height.*

- Thin to 75% and no less than 25% in 100 m x 100 m plots. This would improve habitat and allow adaptive management to test the response of both cottontails to variable levels of canopy thinning.

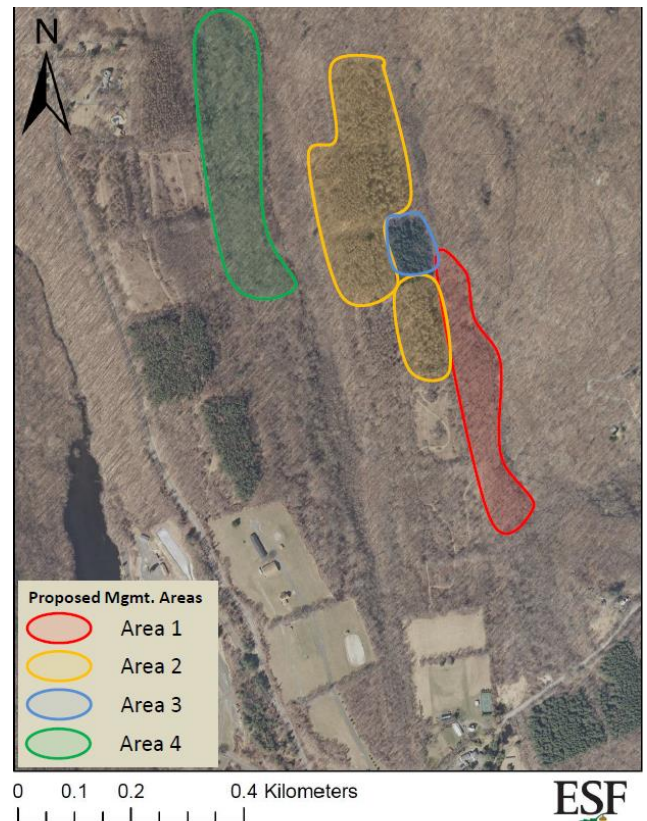


Figure S 1. Proposed areas for habitat management targeting New England cottontail

- Establishing four, 50 m x 50 m plots within each canopy plot area (above) where Japanese barberry and other invasive shrubs will be targeted for rotational removal. This should facilitate growth of native shrubs and high quality forage for New England cottontails while still preserving some Japanese barberry for use by New England cottontails.
- Manual tree cutting is recommended to reduce disturbance to existing habitat. Short shrubs should be left intact to provide forage and cover for cottontails in the canopy cut areas. Leaving intact tree crowns, downed trunks, and the creation of brush piles is recommended to augment cover for New England cottontail, and may protect regenerating shrubs and saplings from deer browse.

Area 3 – This area is dominated by a spruce canopy with little to no understory and is generally unoccupied by both cottontail species (Figure S 2; Figure S 3); however, occasional use has been observed. This patch likely acts a barrier to movement between shrubland patches. Recommendations to thin canopy and create New England cottontail habitat and increase connectivity between New England cottontail occupied patches is provided. *Primary needs: Increase shrub and herbaceous cover.*

- Propose thinning to no less than 25% canopy closure to allow for shrub and herbaceous cover regeneration.
- Establishing four, 50 m x 50 m plots within each canopy plot area (above) where Japanese barberry is targeted for rotational removal. This should facilitate growth of native shrubs and high quality forage for New England cottontails while still preserving some valuable invasive shrub cover for use by New England cottontails.

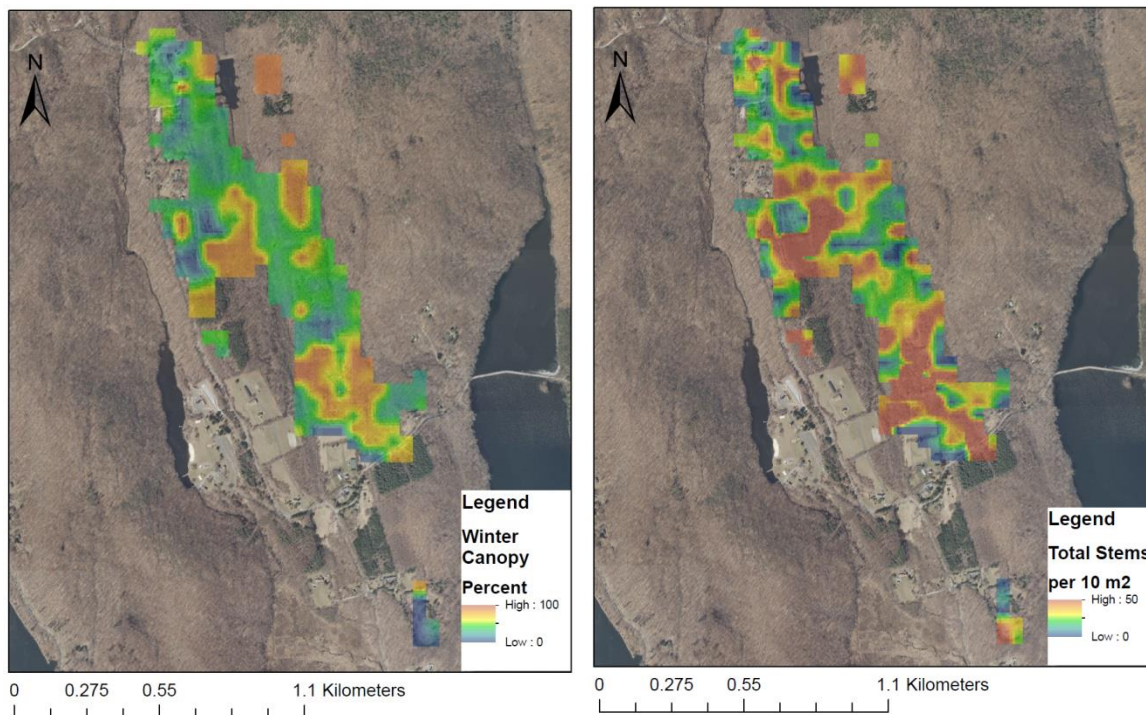


Figure S 2. Left: Percent winter canopy cover. Green to yellow colors represents the target range for New England cottontails (25 – 75 % canopy). Right: Stem density per 10 m². Red represents the target range for New England cottontails (> 50 stems/ 10 m²).

- Manual tree cutting is recommended to reduce disturbance to existing habitat. Short shrubs should be left intact to provide forage and cover for cottontails in the canopy cut areas. Leaving intact tree crowns, downed trunks, and the creation of brush piles is recommended to augment cover for New England cottontail, and may protect regenerating shrubs and saplings from deer browse.

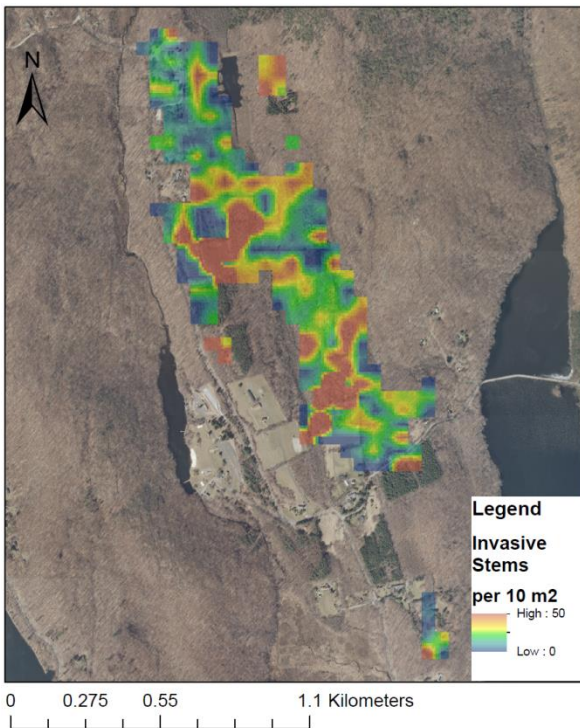


Figure S 3. Invasive stems per 10 m². Warm colors indicate areas with abundant dense invasive shrubs, often characterized by dense multiflora rose and Japanese barberry.

Area 4 – This area is comprised of mature forest, with moderate to sparse understory dominated by invasive shrubs (Figure S 2; Figure S 3). It is occupied by both New England and eastern cottontails. It is typically eastern cottontail dominated. This area could be opened up to encourage shrub regeneration and improve habitat and connectivity. *Primary needs: Reduce quality of habitat to eastern cottontail, increase shrub density, and reduce prevalence of Japanese barberry.*

- Propose thinning to 75% and no less than 25% in 100 m x 100 m plots. This would allow for evaluating the response of both cottontails, and regenerative vegetation to varying levels of canopy closure.
 - Establishing a checkerboard of 50 m x 50 m plots within each canopy plot area where barberry is targeted for rotational removal. This should facilitate growth of native shrubs and high quality forage for New England cottontails while still preserving some invasive shrub cover for use by New England cottontails.
- Manual tree cutting is recommended to reduce disturbance to existing habitat. Short shrubs should be left intact to provide forage and cover for cottontails in the canopy cut areas. Leaving intact tree crowns, downed trunks, and the creation of brush piles is recommended to augment cover for New England cottontail, and may protect regenerating shrubs and saplings from deer browse.

Site Specific Example 2: State Park

Site goals: Improve habitat for New England cottontails, discourage use of site by resident eastern cottontails, reduce the abundance of invasive species, and balance increasing connectivity between New England cottontail populations with reducing road mortality of New England cottontails. Site surveys in 2018-2019 detected no New England cottontail occupancy; however the site was occupied 2013-2016.

Four areas (Figure S 4) have been identified within the site to improve young forest for New England cottontails.

Area 1 – *Not regularly used by cottontails.* High canopy cover, this area is dominated by red cedar with little to no shrub understory (Figure S 6).

Common invasive plants include Oriental bittersweet and Japanese barberry (Figure S 7).

Primary need to improve habitat for New England cottontails: Increase shrub cover.

- Recommend thinning to 75% canopy cover, a level that will not encourage eastern cottontail use. A single 100 m x 100 m section could be accommodated to assess the response of New England cottontails to this management strategy. Given proximity to existing New England cottontail habitat, manual cutting (including chainsaw use) of trees is recommended over heavy machinery to reduce disturbance to existing shrubs.
- Invasive shrubs should be removed within two of four, 50 m x 50 m quadrats in the 100 m x 100 m plot (Figure S 4). Invasive shrub removal within managed quadrats would leave cover for New England cottontails in nearby areas, while native shrub regeneration occurs within managed quadrats. Invasive shrub management could later occur within previously unmanaged quadrats once managed quadrats reach desired shrub density.

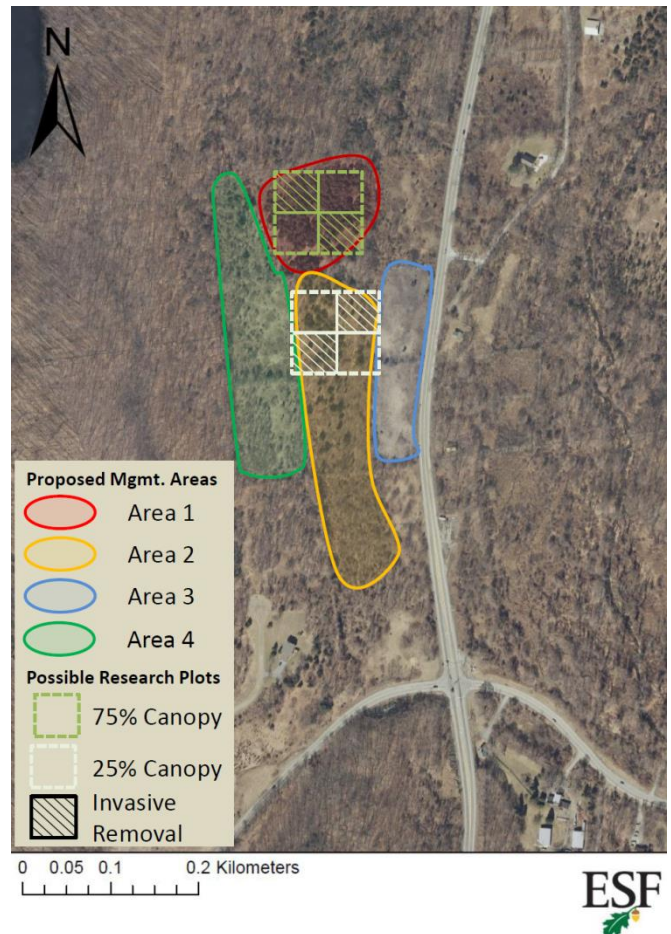


Figure S 4. Areas identified for possible management to improve young forest value for New England cottontails. Dashed lines represent proposed areas that could be managed to improve New England cottontail habitat and monitored to inform future management efforts targeting young forest and New England cottontail.

- All native shrubs should be left intact to provide forage and cover for cottontails in this area. Leaving intact tree crowns, downed trunks, and the creation of brush piles is recommended to augment cover for New England cottontails.

Area 2 – *Has been heavily used by New England cottontails.* This area has moderate to high canopy cover and low to moderate stem density (Figure S 6; Figure S 7). Oriental bittersweet is a dominant invasive in this area. *Primary needs: Increase shrub cover, lower abundance of invasive shrubs*

- Recommend thinning to 25% - 75% canopy cover across Area 2. A single 100 m x 100 m plot, managed at no less than 25% canopy cover would be beneficial and could be accommodated to assess the response of New England cottontails to this management strategy. Cuts could focus on trees with bittersweet damage.
- Bittersweet could be removed across Area 2 to facilitate native plant regeneration.
- Invasive shrubs should be removed within 50 m x 50 m quadrats on a rotational basis (Figure S 4). Invasive shrub removal within smaller managed quadrats would leave cover for New England cottontails in nearby areas, while native shrub regeneration occurs within managed quadrats. Invasive shrub management could later occur within previously unmanaged quadrats once managed quadrats reach desired shrub density.
- All native shrubs should be left intact to provide forage and cover for cottontails in this area. Leaving intact tree crowns, downed trunks, and the creation of brush piles is recommended to augment cover for New England cottontail.



Figure S 5. Area 1 pre-management conditions. Area has high canopy closure and low stem density throughout. New England cottontails do not regularly use the area but have occupied adjacent shrubland within the last 5 years.

Area 3 – *Not used by cottontails*. This area is a regenerating old field. Many native young shrubs and trees are beginning to grow. Oriental bittersweet is also common and may hinder native shrub regeneration. Some large barberry shrubs are located near field edges. *Primary needs: Increase shrub cover and lower abundance of invasive shrubs.*

Recommendation A: Manage for Young Forest

- Managing this area for young forest will provide additional habitat for New England cottontails, may improve connectivity between this site and other populations of New England cottontails in the area, but may increase road mortality.
- Area 3 may naturally transition into young forest within the next 5-10 years. Although native shrub saplings are abundant, common invasive shrubs at the site including Oriental bittersweet, Japanese barberry, and multiflora rose are common.
- Shrub plantings may accelerate the transition to young forest, but white-tailed deer and competition with invasive plants including oriental bittersweet will present challenges for the survival of plantings. Planting shrubs within several small dense patches may facilitate regeneration. Fencing patches and targeted invasive removal within planting areas may also facilitate native regeneration. We recommend plantings include combinations of high and low bush blueberry (*Vaccinium* spp.), raspberry and blackberry (*Rubus* spp.), dogwoods (*Cornus* spp.),

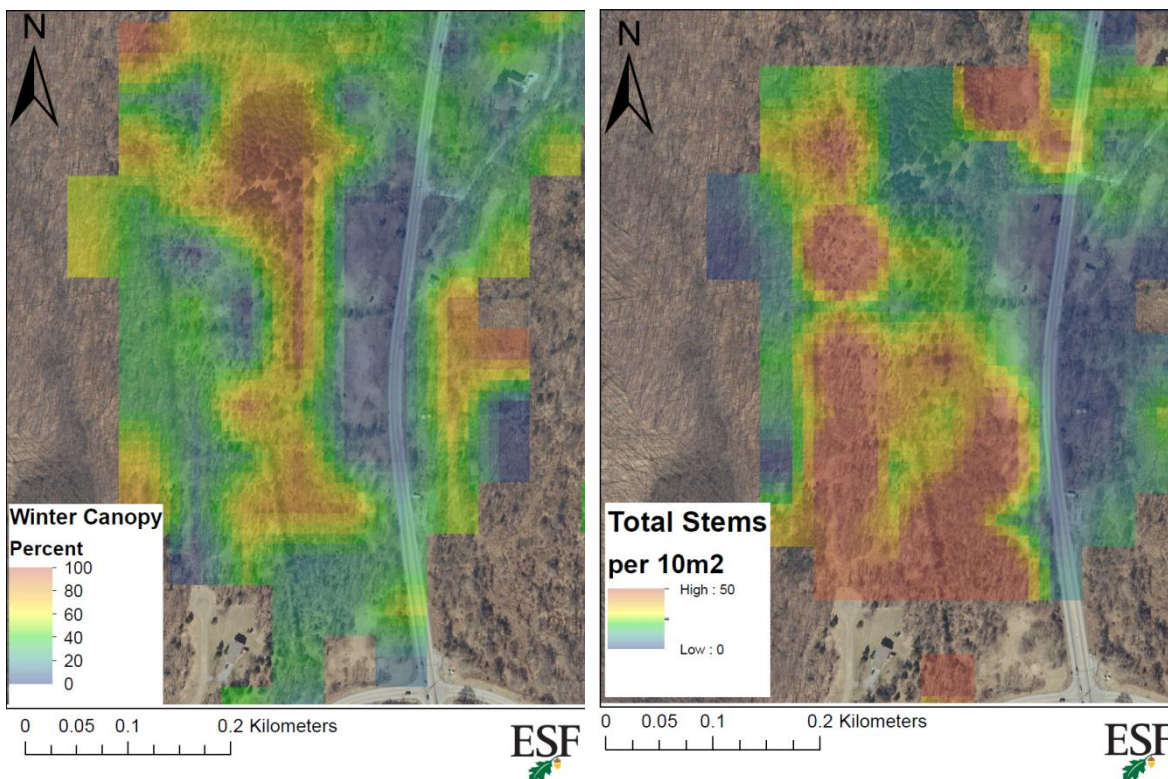


Figure S 6. Left: Percent winter canopy cover. Green to yellow colors represents the target range for New England cottontails (25 – 75% canopy). Right: Stem density per 10 m². Red represents the target range for New England cottontails (> 50 stems/10 m²).

Viburnum spp., serviceberry (*Amelanchier* spp.), and /or sumac (*Rhus* spp.) which provide valuable native forage.

Recommendation B: Manage as regenerating old field

- Managing area 3 as old field and grassland may reduce road mortality by New England cottontails but will not provide habitat and may encourage colonization by eastern cottontail.
- Fields should be mowed on a rotational basis not to exceed 10 years between mowing events for each section.
- Continued treatment of invasive plants, particularly black swallowwort and oriental bittersweet may be needed.

Area 4 – *Used heavily by New England and eastern cottontails.* This area is in the early stages of shrubland succession. Shrubs are primarily invasive Japanese barberry and multiflora rose (Figure S 7), and some small stands of *Rubus* spp. occur at the southern end. Low to moderate canopy cover, canopy is higher on the western end and near rock walls (Figure S 6). *Primary needs: lower abundance of invasive shrubs*

- These areas are naturally entering shrubland succession but shrub recruitment is dominated by invasive species (Figure 4). Management to remove some invasive shrubs within patches on a

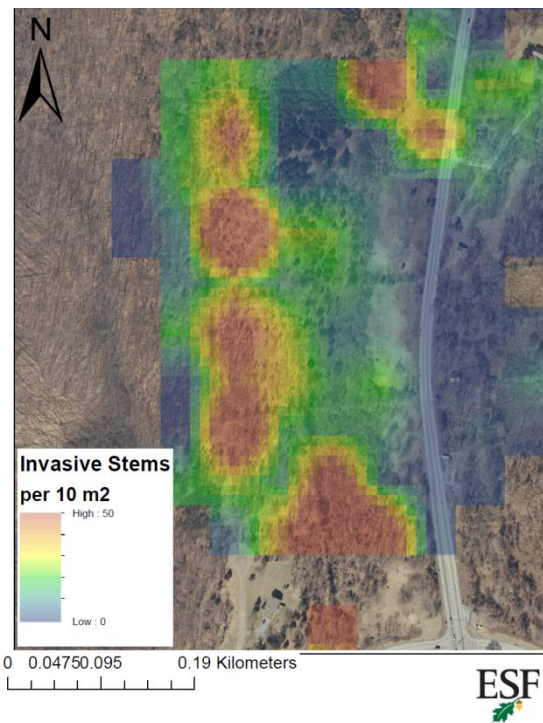


Figure S 7. Invasive stems per 10 m². Warm colors indicate areas with abundant dense invasive shrubs, often characterized by dense multiflora rose and Japanese barberry.

rotational basis may improve habitat quality for wildlife and promote native shrubs and sapling regeneration. We advise against removing all invasive shrubs in a given period and instead recommend invasive removal be conducted in no larger than 50 m x 50 m areas.

- Shrub plantings may accelerate the transition to young forest and encourage native shrub growth, but white-tailed deer and competition with invasive plants including oriental bittersweet will present challenges for the survival of plantings. Planting shrubs within several small dense patches may facilitate regeneration. Fencing patches and targeted invasive removal within planting areas may also facilitate native regeneration. We recommend plantings include combinations of high and low bush blueberry (*Vaccinium* spp.), raspberry and blackberry (*Rubus* spp.), dogwoods (*Cornus* spp.), *Viburnum* spp., serviceberry (*Amelanchier* spp.), and /or sumac (*Rhus* spp.) which are valuable native forage species for New England cottontail.

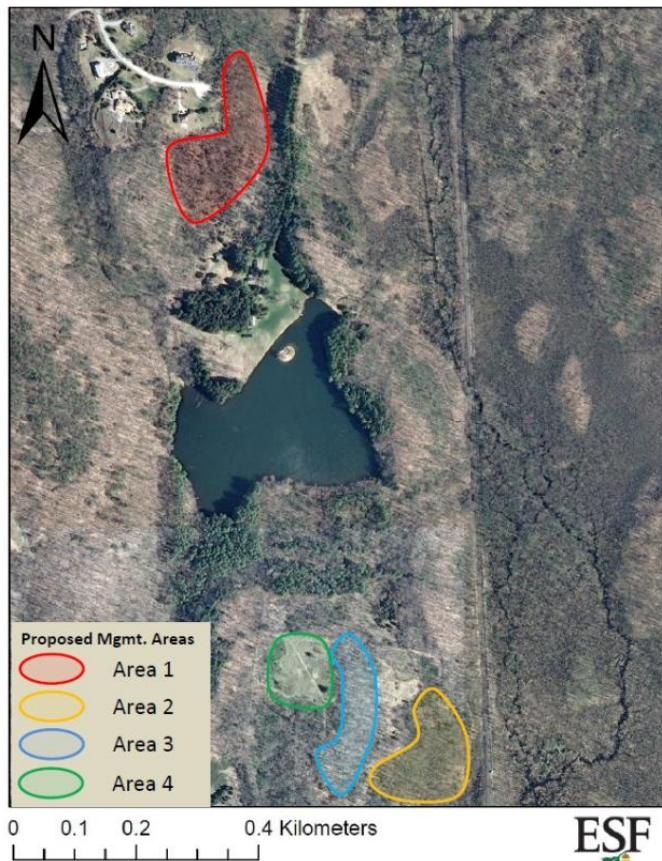


Figure S 8. Proposed areas for habitat management targeting New England cottontail on property

Site Specific Example 3: Private Landowner

Site goals: Improve extent and quality of New England cottontail habitat and discourage use of area by eastern cottontails

Four areas were identified as possible management sites for young forest / New England cottontail (Figure S 8).

Area 1 – Mix of New England and eastern cottontails in this area. Dense to sparse understory shrub cover. Mature trees and tall invasive shrubs make up canopy. Open powerline corridor runs along eastern edge of patch.

- Recommend thinning to 75% canopy cover, a level that will not encourage eastern cottontail use. A single 100 m x 100 m section could be accommodated to assess the response of New England cottontails to this management strategy. Tall invasive shrubs could be cut to augment tree

thinning for canopy removal.

- Additional thinning to no less than 25% canopy cover along power line corridor could make use of existing canopy openings. This treatment would allow for scientific testing of whether eastern cottontail would use areas of lower canopy cover more than New England cottontails.
- We recommend establishing four, 50 m x 50 m plots within each canopy plot area (above) where barberry is targeted for rotational removal. This should facilitate growth of native shrubs and high quality forage for New England cottontails in the removal plots while still preserving some Japanese barberry in nearby areas for use by New England cottontails.
- Low shrubs should be left intact to provide forage and cover for cottontails in this area. Leaving intact tree crowns, downed trunks, and the creation of brush piles is recommended to augment cover for New England cottontail.

Area 2 – Only New England cottontails have been detected here to date and eastern cottontails have not been detected in adjacent patches. Patch is comprised of mature trees and tall invasive shrubs.

- Recommend thinning to no less than 25% canopy in the absence of eastern cottontails. A single 100 m x 100 m section could be accommodated to assess the response of New England

cottontails to this management strategy. Tall invasive shrubs could be cut to augment tree thinning for canopy removal.

- We recommend establishing 2, 50 m x 50 m plots within the canopy plot area (above) where barberry is targeted for removal. This should facilitate growth of native shrubs and high quality forage for New England cottontails while still preserving some Japanese barberry for use by New England cottontails.
- Low shrubs should be left intact to provide forage and cover for cottontails in this area. Leaving intact tree crowns, downed trunks, and the creation of brush piles is recommended to augment cover for New England cottontail.

Area 3 – This area is currently unoccupied by cottontails and is comprised of mature trees with limited understory cover. This patch provides a significant barrier to movement between shrubland patches and inhibits use of high quality old field habitat by New England cottontails.

- Thin to 75% canopy cover. This should facilitate shrub growth and allow shrubland to regenerate between patches, providing connectivity. A single 200 m x 50 m plot could be accommodated to assess the response of New England cottontails to this management strategy.
- We recommend establishing four, 50 m x 50 m plots within the canopy plot area (above) where Japanese barberry and other invasive plants are targeted for rotational removal. This should facilitate growth of native shrubs and high quality forage for New England cottontails while still preserving some Japanese barberry for use by New England cottontails.
- Low cover shrubs should be left intact to provide forage and cover for cottontails in this area. Leaving intact tree crowns, downed trunks, and the creation of brush piles is recommended to augment cover for New England cottontail.

Area 4 – This area is generally unoccupied by eastern cottontail with occasional use by New England cottontail. It is an old field with abundant and diverse young native shrubs and trees regenerating. This patch is managed for grassland associated birds and some young forest wildlife and would be high quality New England cottontail habitat within a few years. Recommendations given to retain old field while not promoting eastern cottontail colonization

- Section the field into 4 smaller quadrants; rotationally mow one quadrant every 4-7 years. This will reduce the size of patches that might only be suitable for eastern cottontail while increasing the area suitable for New England cottontail, thereby augmenting the area of nearby habitat patches.
- The field has a high diversity of native shrubs; however, frequent disturbance such as mowing combined with the proximity to nearby invasive dominated forests, may facilitate invasion of this field by exotic shrubs. Treatment for invasive plants should be included on a rotational basis within the field.

Site Specific Example 4: Nonprofit Organization

Site Goals: Improve habitat for New England cottontail, discourage use of habitat by eastern cottontails at the site. Other species of conservation interest are present which require small canopy gaps and meadows. Management prescriptions for New England cottontail need to balance management goals for other species of conservation interest.

Unit 1- Regenerating old field (Figure S 9). This area contains narrow strips of forb vegetation with dense shrub edges. *Rubus* spp. and gray dogwood are common in the field. Old fields provide summer forage to cottontails and habitat to many other species. The regenerating old fields are already narrow and surrounded by shrub vegetation, which will maximize the use of the field by cottontails.

Recommendations are to section the field into 2-3 portions and instate a rotational mowing schedule such that field portions are mowed every 3-5 years, or as shrub regeneration begins to become apparent to retain the regenerating old fields while minimizing disturbance to occupant species.

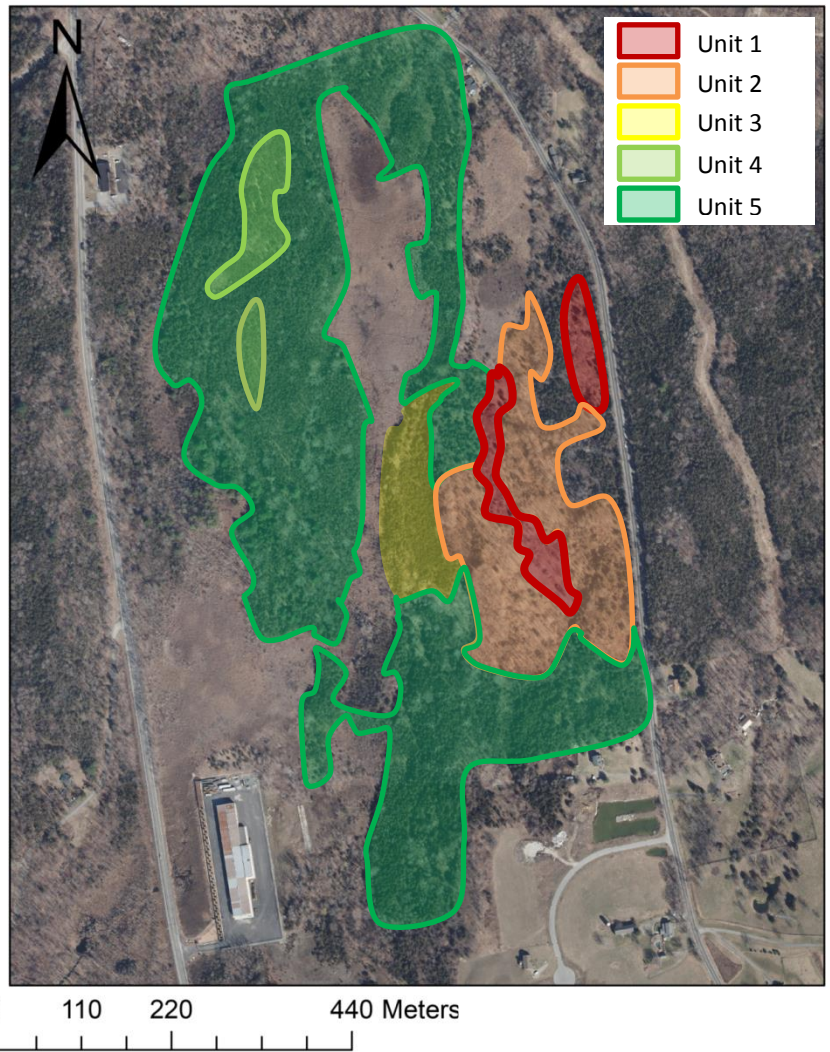
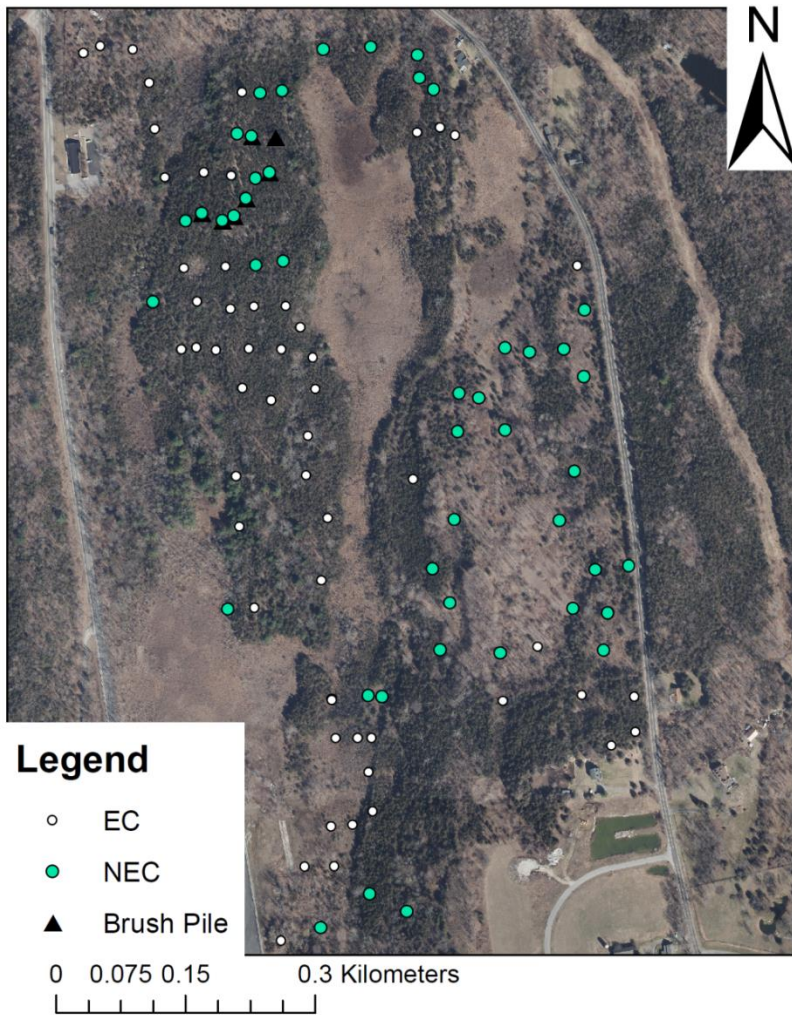


Figure S 9. Identified habitat units comprised of similar vegetation or forest age stand. Management recommendations are provided for units 1-5



Unit 2-Late successional shrubland- Ash Canopy (Figure S 9). This area has a sparse to moderately dense shrub layer with mid-canopy prickly ash and dense ash canopy common throughout. Autumn olive is common, and low densities of Japanese barberry and multiflora rose are present. This area appears to be predominately occupied by New England cottontails (Figure S 10). Maintenance of this area as a mid-late successional shrubland into the future may help retain New England cottontail occupancy without increasing the use of this area by eastern cottontails. Stem densities within much of this area meet the suggested density for New England cottontails (50 stems/ 10 m²). Where stem densities are lower than 50 stems/10 m² due to a high degree of canopy cover, felling of individual or small groupings of trees within this area to provide canopy gaps and increase forage and shrub density within regenerating gaps is recommended to improve and retain this

Figure S 10. Pellet identified as New England (green) or eastern cottontail (white) from collections in early 2018. Collections from brush piles are marked with an additional black triangle.

area as mid-late successional shrubland. Conducting small cuts during winter may provide additional forage to cottontails during this food limiting season.

Unit 3- Mature Forest, sparse understory, cedar canopy (Figure S 9). This area is on the side of a hill with steep terrain and very little understory.

Significant tree thinning would be required to bring this area into suitability for New England cottontails. If managers desire to bring this area into suitability, 25% canopy thinning (leaving approximately 75% standing canopy) or felling of individual trees or small patches to create a series of small canopy gaps is recommended over clear-cutting or more intensive thinning, which might favor eastern cottontails. However, care should be taken to minimize erosion following cutting. Invasive shrub treatment is recommended post-thinning to encourage native shrub recruitment. Nearby areas have an abundance of native ash, dogwood, and *Rubus* spp., so native shrub plantings may not be required to ensure native shrub recruitment post cutting. Monitoring of vegetation response post cutting and adapting management plans as necessary is recommended to ensure desired response.

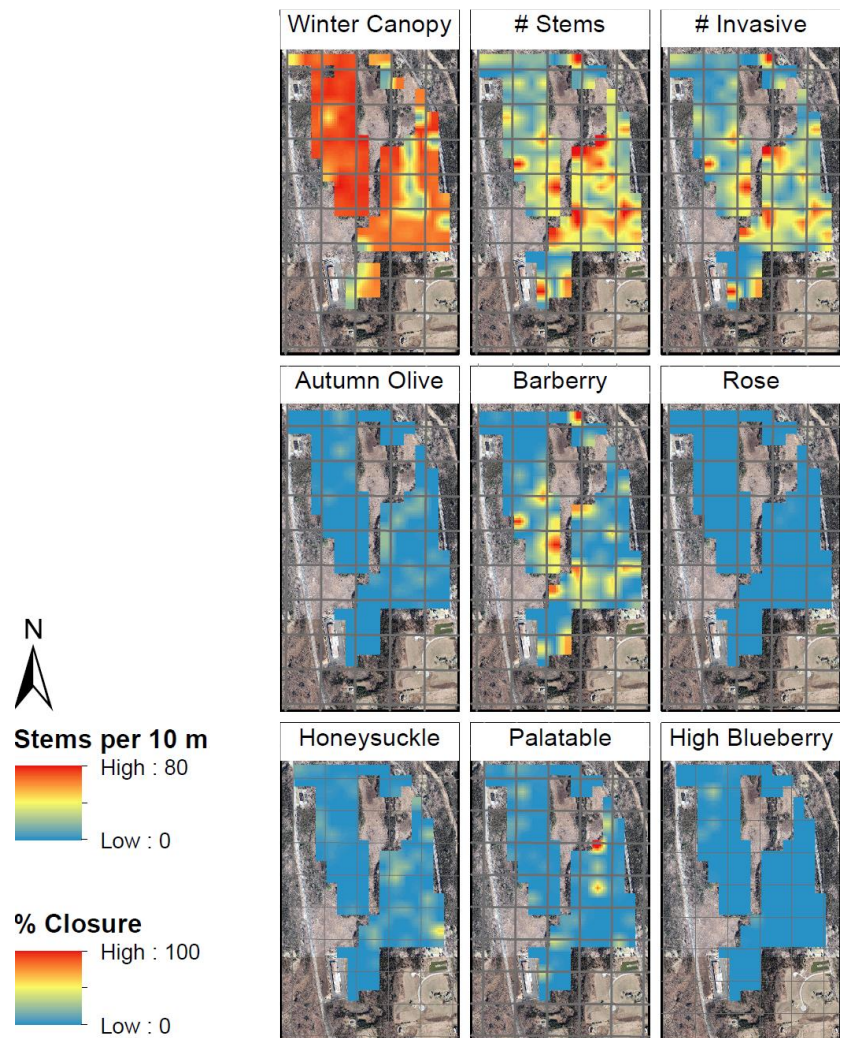


Figure S 11. Maps of vegetation characteristics including percent of woody canopy closure, the total number of stems per 10 m², and the number of each pooled invasive, autumn olive, Japanese barberry, multiflora rose, honeysuckle, palatable native stems, and high bush blueberry stems per 10 m².

Unit 4-Grassy knolls (Figure S 9). Higher elevation areas with grasses and forbs. Autumn olive and cedar provide mid-canopy. Autumn olive removal was

conducted prior in 2017 and brush piles created to provide refugia for New England cottontails. Management to remove autumn olive and red cedar removal to create a series of canopy gaps along the higher elevation grassy knolls was conducted during the spring and summer 2018 (Figure S 12)

Grassy knolls with cedar canopy. Autumn olive removal has been conducted throughout the area and red cedar thinning has been implemented in small patches to create canopy gaps and encourage forb and native shrub regeneration. Knolls have abundant summer forage for cottontails but very low stem densities. Brush piles of autumn olive and cedar have been created to provide

refugia for cottontails and may partially substitute for low stem density. Creating a series of small canopy gaps (<30 m wide) is recommended to benefit New England cottontail in the presence of eastern cottontail. Where possible canopy gaps should be within 25 – 50 m and brush piles placed in between gaps to improve habitat.

Autumn olive remains the most common invasive shrub on these knolls and is re-sprouting following removal. Continued removal of autumn olive and other invasive shrubs is recommended. Low stem densities suggest that winter cover and forage are lacking in these areas. Conducting small cuts during winter is recommended in this area and may provide additional forage and cover to cottontails during this food limiting season. Encouraging native shrub recruitment is recommended to increase winter cover and forage for New England cottontails. As native shrubs are not abundant in the vicinity, native shrub plantings are recommended. Native *Rubus* spp. and blueberry species are growing nearby and would likely do well under the unit conditions. Both species provide preferred cover and forage to New England cottontails. Deer appear to be prevalent at the site as well. Deer fencing to limit browse on native shrub saplings may be necessary to limit browse. Leaving felled trees may also discourage deer browse and thus facilitate native shrub regeneration.

Unit 5-Late successional shrubland- Coniferous Canopy (Figure S 9). Late successional shrubland dominated by Japanese barberry. Red cedar canopy with white pine and hemlock at lower elevations. Some autumn olive present. Autumn olive removal was conducted prior in 2017 and brush piles created to provide refugia for New England cottontails.

This area has a high coniferous canopy and a dense understory dominated by Japanese barberry. Tree thinning combined with intensive invasive shrub removal is recommended across unit 5 to reduce the prevalence of invasive Japanese barberry and improve habitat for New England cottontail. Thinning to approximately 75% canopy or the creation of a series of small canopy gaps is recommended to encourage New England cottontail use without encouraging use by eastern cottontail. Vegetation response to canopy removal should be monitored and additional trees felled if native shrub recruitment appears to be limited by light conditions. Conducting small cuts during winter is recommended in this area and may provide additional forage and cover to cottontails during this food limiting season.

Invasive shrubs provide refugia to cottontails; however they may not provide adequate nutrition or forage. As a result, where invasive shrubs are dense, they may act as an ecological trap to New England cottontails and removal of highly dense patches is recommended. Any invasive shrub removal should occur on a rotational basis over small areas to minimize detrimental impacts to New England cottontail. Removal within 50 x 50 m grids may allow New England cottontails to adjust their habitat use without altering their home range. Removal of remaining invasive shrubs is recommended

once a high density of native shrubs has been retained (ideally 50 stems/ 10 m²) within the initial removal plots.

Native shrub plantings may be necessary to encourage native shrub regeneration in areas where Japanese barberry dominates. In upland areas, native *Rubus* spp. and blueberry species are actively growing at the site and may respond well to planting. At lower elevations, dogwoods and willows are common at the site and plantings of these species may respond well. Leaving any felled trees may also discourage deer browse and thus facilitate native shrub regeneration.

The creation of brush piles from removed invasive shrubs or felled trees is recommended in areas where invasive shrub removal has been conducted or where stem densities are lower than 50 stems/ 10 m².



Figure S 12. Unmanaged (left) and managed (right) area of site. New England cottontails present throughout managed and unmanaged areas both prior and after management occurred. New England cottontails were observed to frequently use brush piles created from autumn olive and cedar cuts.

Supplies:

- GPS units
- Compass
- DBH tape
- Densiometer
- Measuring tape
- Datasheet
- Writing Utensil
- Flags
- Tree/shrub ID guide
- 1 m² Quadrat
- 1 m rod with 10m of string attached

Creating Plots

1. Prior to conducting measurements, visit site
2. Set GPS unit to create trail
3. Walk along edge of patch, patch edges defined by border or a 15 m gap in shrubland vegetation
 - a. It may help to have one person scout and the other map edges of habitat patch
4. Import trail into ArcMap, and establish grid points:
 - a. Create grid of points spaced 50 m apart (Create Fishnet tool) and clip to the shrubland boundaries established in step 3.

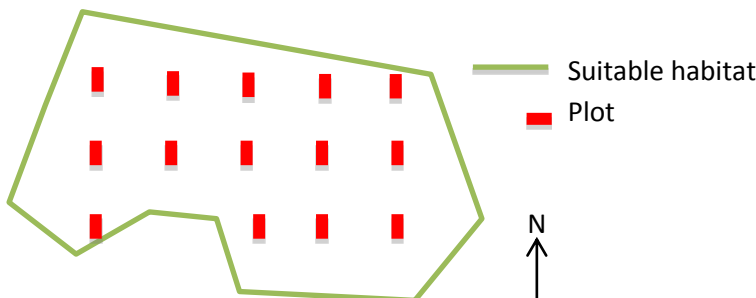


Figure S 13. Diagram of plot layout within site. Plots (red) are spaced every 50 m within the site boundaries (green).

Creating Plots – *In field*

1. Navigate to predetermined coordinate on transect using a GPS programed with the plot locations
2. At each plot 1, 10m² plot will be established for stem counts and shrub species ID. The point location for each plot will serve as the location for collecting herbaceous cover and canopy closure.

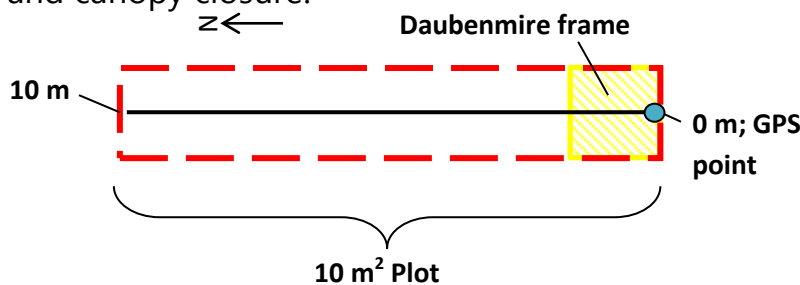


Figure S 14. Vegetation sampling plot layout. At each 50 m plot referenced by a GPS point, a 10 m² plot is established facing North and herbaceous cover and height is estimated within the first 1 m²

Herbaceous Cover

1. Herbaceous cover should be estimated during leaf-on season
2. At each plot point (0 m) place the 1m² Daubenmire quadrat facing North (see Fig. 2).
3. Examine each square (totaling 100 squares) (Fig. 3). Count the number of squares (out of 100 total) that are at least ½ covered by forb vegetation. Record this number- this is your percent forb cover.
4. Repeat for graminoids (grasses, sedges, and rushes) and shrubs
5. Make sure you look at all levels of the vegetation to find any that might be hidden by other types, for example there may be grass under a tall shrub. The combined total of graminoids, forbs, and shrubs may exceed 100%
6. Record dominant species present.
7. Estimate average height of herbaceous cover to the nearest 5 cm.
8. Ensure all measurements are recorded
9. Repeat for all plots

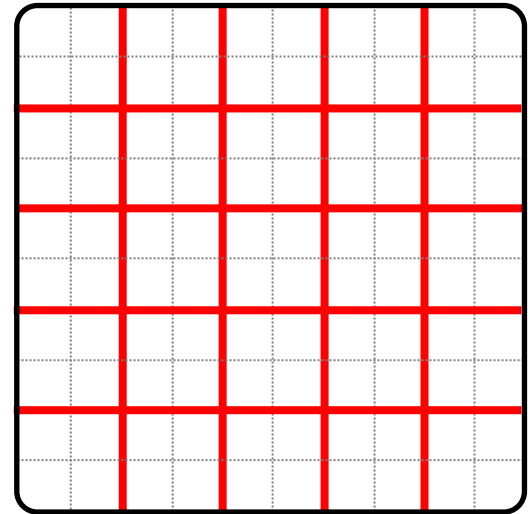


Figure S 15. Daubenmire frame- The black edges are each 1 m, creating a 1m² plot. Affix string every 20 cm to assist cover estimation. Within each red square imagine 4 smaller squares (gray dotted lines) to complete counts.

Note that vegetation must originate from inside the plot for it to be counted as cover.

Canopy Closure

1. Canopy closure should be estimated during both leaf-on (seasonal canopy closure) and leaf-off (persistent canopy closure) seasons
2. For each plot decide if you will count canopy or sky. Record this in a datasheet.
3. Facing north, hold a spherical densitometer away from the body at a height of 1 m.
4. Ensure the densitometer is level by tilting it until the air bubble in the level is in the center of the circle
5. Within each marked square, imagine 4 smaller squares.
6. **Persistent canopy closure**- Count the number of small squares (adding to 96) that are at least ½ covered by woody or evergreen vegetation (i.e. sticks, branches, trunks, mountain laurel leaves, pine needles).
7. **Seasonal Canopy Closure**- Count the number of small squares (adding to 96) that are at least ½ covered by tree or tall shrub canopy.
8. Record measurements
9. Repeat facing South, West, then East
10. Ensure all measurements are recorded

11. Repeat for all plots

Stem Density

1. Stem density assessment should be conducted during the leaf-off period.
2. Beginning at the start of each 10 m² plot, have someone hold the string attached to the 1m rod. Alternatively you can clip it in a clipboard or tie to a heavy object.
3. Hold the rod parallel with the ground at a height of 0.5 m and begin walking north.
4. Count the number of stems for each plant species that are less than < 7.5 cm dbh and intersect the rod
 - a. *****Stems must originate from inside the plot *****
5. Count each stem only once, if stems branch then number of individual branching stems intersecting the rod at 0.5 m should be counted.
6. Ensure all data are recorded
7. Repeat for each plot

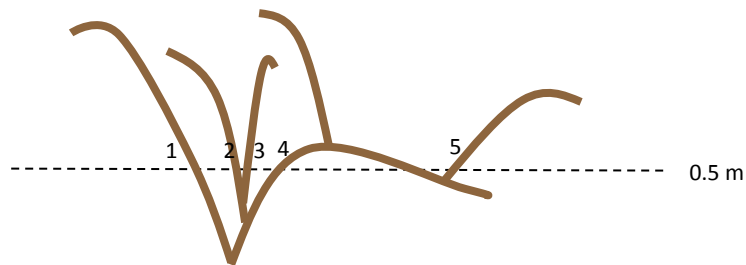


Figure S 16. Transect showing how stems of a branching and bending plant might be counted. Line marks the 0.5 m height and the numbers indicate which stems should be counted