



Influence of repeated fertilization on forage production for native mammalian herbivores in young lodgepole pine forests

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ABSTRACT

Stand thinning and fertilization are silvicultural practices designed to enhance wood and biomass production. Applications of nitrogen-based fertilizers make nutrients potentially available to all trees, plants, and wildlife in a given forest ecosystem, and therefore may affect productivity of forage plants for native mammalian herbivores. Species associated with areas of forest fertilization in temperate and boreal zones of North America include mule deer (*Odocoileus hemionus*), elk (*Cervus elaphus*), moose (*Alces alces*), and woodland caribou (*Rangifer tarandus*), snowshoe hare (*Lepus americanus*), and several species of voles. Impacts of fertilization on forest plant species may have important consequences for the nutrition, cover, and consequent survival of these herbivores, particularly in winter. This study tested the hypothesis (H_1) that large-scale repeated fertilization, up to 20 years after the onset of treatments, would enhance the biomass production of forage plants, particularly grass, forb, shrub and tree species for native mammalian herbivores. A secondary hypothesis (H_2) predicted that mosses and terrestrial lichens would decline as part of the ground vegetation in fertilized stands. Study areas were located in lodgepole pine (*Pinus contorta* var. *latifolia*) stands near Summerland, Kelowna, and Williams Lake in south-central British Columbia, Canada. Each study area had eight replicate stands: four unfertilized, and four fertilized five times at 2-year intervals.

Mean biomass of total grasses responded dramatically starting in the first year after fertilization. Total forbs and herbs also followed this pattern, although not to a significant degree until after the second and third applications of fertilizer. All of the dominant grasses and forbs serve as summer forage for mule deer, moose, elk, and woodland caribou. Fireweed (*Epilobium angustifolium*), a preferred forage for mule deer, increased in fertilized stands. Grasses and dominant herbs in fertilized stands provide excellent forage and cover habitat for snowshoe hares and *Microtus* voles.

Mean biomass of total shrubs was not affected by fertilization. However, saskatoon berry (*Amelanchier alnifolia*), prickly rose (*Rosa acicularis*), and red raspberry (*Rubus idaeus*) increased significantly in biomass in fertilized stands. Willow (*Salix* spp.) also increased in biomass, but was variable across treatment stands. Snowshoe hares respond favourably to enhanced shrub growth for food and cover in fertilized stands. All of these shrubs are readily eaten by deer, moose, and elk, and their structural attributes provide security and thermal cover. Mean biomass of understory Douglas-fir (*Pseudotsuga menziesii*) responded positively to fertilization, but sub-alpine fir (*Abies lasiocarpa*) and the three deciduous tree species did not. Dwarf shrubs such as kinnikinnick (*Arctostaphylos uva-ursi*), twinflower (*Linnaea borealis*), and dwarf blueberry (*Vaccinium caespitosum*) declined in fertilized stands. Thus, H_1 was partially supported for some species. Increasing cover of grasses and nitrophilous herbs, and canopy cover from rapidly growing crop trees, in fertilized stands may have contributed to the decline of some dwarf shrubs. Mean crown volume index of total mosses and terrestrial lichens declined significantly in fertilized stands, thereby supporting H_2 .

Mean biomass of total grasses (increase), *R. acicularis* (increase), and *V. caespitosum* (decline) were significantly affected after one application of fertilizer. Repeated applications of fertilizer may enhance biomass of some additional forage forbs and shrubs, but reduce biomass of some dwarf shrubs, mosses, and lichens.

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1. Introduction

Stand thinning and fertilization are silvicultural practices designed to sustain wood and biomass production on a shrinking forest landbase while concurrently creating a diversity of forest habitat conditions to meet the goals of biodiversity conservation (Moore and Allen, 1999; Hartley, 2002; Monkkonen et al., 2014). In particular, nitrogen fertilization is a major way to improve the future timber supply and potentially mitigate impacts on other values from the loss of forests (Fox et al., 2007; Sullivan et al., 2013). Addition of nutrients reduces the time required for target stands to reach a harvestable size, and thus increase supplies of wood fibre (Albaugh et al., 2004; Jokela et al., 2004). In addition, fertilization increases the size of individual trees without sacrificing stand volume, and hence may be particularly useful for addressing age-class imbalances and for increasing long-term harvest levels (Brockley, 2005; Lindgren and Sullivan, 2013a). Fertilization and thinning have increased biomass production in second-growth forests across northern Europe (Nabuurs et al., 2007; Bergh et al., 2008), the southeastern United States (USA) (Albaugh et al., 2004; Fox et al., 2007), and coastal and interior forests of British Columbia (BC) (Weetman et al., 1992; Brockley, 2007a; Lindgren and Sullivan, 2013a), and other parts of North America (Demarais et al., 2017).

Aerial and land-based applications of nitrogen-based fertilizers to enhance forest growth makes nutrients potentially available to all trees, plants, and wildlife in a given ecosystem, and therefore may have direct and indirect effects on wildlife and biodiversity (see review by Sullivan and Sullivan, 2017a). Native species of mammalian herbivores include mule deer (*Odocoileus hemionus*), elk (*Cervus elaphus*), moose (*Alces alces*), and woodland caribou (*Rangifer tarandus*) which are often located in, or near, areas of forest fertilization. Another major mammalian herbivore, the snowshoe hare (*Lepus americanus*), is widespread in boreal, sub-boreal, and western montane forests of North America. This leporid is a major prey species for a wide variety of carnivores and birds of prey and is a keystone species in these forest ecosystems (Boutin et al., 1995; Boutin et al., 2003). Similarly, another group of forest mammals that are ubiquitous and also forage on various vascular and non-vascular plants include the meadow vole (*Microtus pennsylvanicus*), long-tailed vole (*M. longicaudus*), heather vole (*Phenacomys intermedius*), and southern red-backed vole (*Myodes gapperi*). All of these mammals rely on a wide range of herbaceous (summer range) and tree-shrub (winter range) plant species as their major forage and cover resources.

Mule deer and elk forage on a wide variety of grasses and forbs during summer months (Kufeld et al., 1973; Cook, 2002). In areas of relatively high snowpacks, mule deer seem to require mature and old-growth forest stands with high levels of canopy closure for snow interception during winter months (Armleder et al., 1994). These old forests have characteristics that intercept snow and supply forage via herbs, shrubs, arboreal lichen, and Douglas fir (*Pseudotsuga menziesii*) litterfall (Dawson et al., 1990; Nyberg, 1990). Shrub forage species include trembling aspen (*Populus tremuloides*), paper birch (*Betula papyrifera*), willows (*Salix* spp.), saskatoon berry (*Amelanchier alnifolia*), and high-bush cranberry (*Viburnum edule*) (Hodder et al., 2013). Moose follow a similar forage selection pattern in summer with the addition of sedges from riparian areas. In winter, moose may also utilize mature and old-growth forests for snow interception cover (Balsom et al., 1996), and they prefer similar trees and shrubs as mule deer, including subalpine fir (*Abies lasiocarpa*), black cottonwood (*Populus trichocarpa*), alder (*Alnus* spp.), and rose (*Rosa* spp.) (Pierce, 1984; Hodder et al., 2013). Woodland caribou forage on a variety of herbs similar to the other ungulates, as well as terrestrial and arboreal lichens in summer, and shrubs and arboreal lichens in winter (Thomas et al., 1994).

Snowshoe hares occupy dense stands of conifers, or deciduous tree species, which provide the necessary food and cover (Koehler, 1990; Mowat and Slough, 2003). Hares also need early seral vegetation to feed on a variety of grasses, sedges, and forbs in summer (Koehler and

Brittall, 1990; Hodges, 2000). Trembling aspen, paper birch, willows, alders, maples, and *Vaccinium* spp., as well as conifers such as Douglas-fir, pines, and spruces are eaten in winter (Nagorsen, 2005).

Microtus voles occupy early successional (herb and shrub stages) forest habitats after disturbance and also naturally occurring meadows and riparian areas. They readily consume most available species of grasses, sedges, and herbaceous plants, as well as the bark and cambium of shrubs and trees in winter (Reich, 1981; Smolen and Keller, 1987). The heather vole occupies these same habitats, as well as upland coniferous and mixed forests. Food habits of heather voles include foliage and fruits of willow, kinnikinnick (*Arctostaphylos uva-ursi*), *Vaccinium* spp., soapberry (*Shepherdia canadensis*), and *Rosa* spp. (McAllister and Hoffman, 1988). The red-backed vole commonly inhabits late successional coniferous and deciduous forests across temperate and boreal North America. This vole feeds on vegetative parts of plants, nuts, seeds, berries, mosses, lichens, ferns, and fungi as well as roots and bark of deciduous trees (Merritt, 1981).

Impacts of fertilization on forest vascular plant species may have important consequences for the nutrition and survival of herbivores, particularly in winter. As reviewed by Sullivan and Sullivan (2017a), the majority of responses of understory herbs to nitrogen fertilization showed an increase in abundance, whereas some shrubs in repeatedly fertilized stands eventually increased in abundance in long-term studies. However, abundance of dwarf shrubs declined (Turkington et al., 1998; Lindgren and Sullivan, 2013b), as did the non-vascular bryophytes and terrestrial lichens in fertilized stands. In the few studies that have been conducted with mammalian herbivores, relative abundance of mule deer, moose, hares, voles and the quantity and quality of vascular plant forage were usually increased by forest fertilization (Edenius, 1993; Nams et al., 1996; Ball et al., 2000; Sinclair et al., 2001; Sullivan et al., 2006a; Sullivan et al., 2006b; Månsson et al., 2009; Sullivan and Sullivan, 2014).

Although these results suggest that fertilized vegetation may be beneficial for mammalian herbivores, a detailed examination of the biomass response of individual species of forage plants to consecutive nutrient additions, designed to enhance timber growth and yield, has not been done. Thus, this study tested the hypothesis (H₁) that large-scale repeated fertilization, up to 20 years after the onset of treatments, would enhance the biomass production of forage plants, particularly grass, forb, shrub, and tree species for native mammalian herbivores. A secondary hypothesis (H₂) predicted that the non-vascular mosses and terrestrial lichens, as part of the ground-layer vegetation, would decline in fertilized stands in response to enhanced biomass of herb and shrub layers. This paper is one of several periodic publications reporting on long-term responses of tree and stand growth (Lindgren et al., 2007; Lindgren and Sullivan, 2013a, Sullivan and Sullivan, 2017b), mammals (Sullivan et al., 2012), cattle and range management (Lindgren and Sullivan, 2014a,b; Lindgren et al., 2017), and biodiversity (Sullivan et al., 2009) to fertilization. The current paper reports specifically on biomass production (quantity) of forage plant species, on an annual basis, and its relationship to native mammalian herbivores in these experimental stands.

2. Methods

2.1. Study areas

Three study areas (Summerland, Kelowna, and Cariboo) were located in southern British Columbia (BC), Canada, where candidate stands of young (12–14 year old) lodgepole pine (*Pinus contorta* var. *latifolia*) had relatively uniform tree cover, comparable diameter, height, and density of trees prior to stand treatments. Location, proximity (boundaries), and size of candidate stands were determined by a balance between adequate interspersed of experimental units (Hurlbert, 1984) and the logistics and access for conducting the operational-scale treatments of pre-commercial thinning (PCT) and

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