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Survival, persistence, and regeneration of the reindeer lichens, *Cladina stellaris, C. rangiferina*, and *C. mitis* following clearcut logging and forest fire in northwestern Ontario

Abstract: The responses of the reindeer lichens (*Cladina stellaris, C. rangiferina,* and *C. mitis*) to logging and fire were compared in lichen-rich forest stands in northwestern Ontario. In the summer of 1992, reindeer lichen cover, in total and by species, was visually estimated and detailed notes were taken on reindeer lichen conditions, modes of reproduction, and substrate use on 34 undisturbed, burned, or logged sites. While virtually no reindeer lichens survived forest fire, much of the reindeer lichen cover remained after logging. Reindeer lichen cover increased with time since fire. Total reindeer lichen cover was not correlated with time since logging. Fragment growth was found to be an important mode of reproduction on logged sites, and occurred with greater frequency on logged sites than on burned sites. Colonization of organic substrates by reindeer lichens was observed on both logged and burned sites.

Key words: woodland caribou, timber harvest, reindeer lichens, *Cladina* spp., forest fire, terrestrial lichens.

Introduction

Fire-produced reindeer lichen-rich forest communities serve as late winter habitat for woodland caribou (*Rangifer tarandus caribou*), and the reindeer lichens, *Cladina stellaris* (Opiz) Brodo, *C. rangiferina* (L.) Harm, and *C. mitis* (Sandst.) Hale and Culb., are their primary late winter fodder (Simkin, 1965; Darby & Pruitt, 1984; Cumming & Beange, 1987; Morash & Racey, 1990; Schaeffer & Pruitt 1991). Reindeer lichens are adapted to recurrent forest fire, and reindeer lichen-rich stands in northwestern Ontario are almost exclusively of fire origin (Ahti & Hepburn, 1967). Where logging has replaced forest fire as the most prevalent type of large-scale disturbance, an understanding of the effects of logging on reindeer lichen ecology is relevant to issues of timber and woodland caribou management.

Post-fire ground cover succession in reindeer lichen-rich stands is well documented. Although the effects of fire vary depending largely on the intensity of the fire, in reindeer lichen-rich communities, forest fire almost always consumes the ground cover (Viereck, 1983; Morneau & Payette, 1989; Schaeffer & Pruitt, 1991). Post-fire lichen and bryophyte succession follows a general progression, first described by Ahti (1959) and documented throughout the boreal forest in Canada (Maikawa & Kershaw, 1976; Carroll & Bliss, 1982; Clayden & Bouchard, 1983; Foster, 1985; Morneau & Payette, 1989). Domination of the ground cover is first by crustose lichens, then cup lichens (*Cladonia* spp.), and finally, reindeer lichens: first *Cladina mitis,* then *C. rangiferina,* and ultimately *C. stellaris.*

Until recently there has been little documentation of reindeer lichen survival and regrowth on logged sites. Speculation on the fate of reindeer lichens in the complex process of vegetation regeneration on logged sites has often been contradictory. Ahti & Oksanen (1990) predict that drier, more extreme soil-level microclimates after logging may produce a lichen-rich successional stage in normally bryophyte-dominated forests. Darby *et al.* (1989) note that deciduous trees and shrubs often increase after logging, and reindeer lichens may be replaced by

vascular plants. Racey *et al.* (1992) suggest that clearcut logging, like fire, acts as an ecosystem renewal mechanism, allowing young vigorous vegetation, including reindeer lichens, to replace older forests. Recent studies have documented that reindeer lichens are abundant for more than 40 years after logging in some forest stands in northwestern Ontario (Harris, 1996; Racey *et al.,* 1996) and that some of these stands are being used by woodland caribou as winter habitat (Racey *et al.,* 1996).

Observations on reproductive modes and substrate use were made in an attempt to understand the reasons behind trends in reindeer lichen abundance. Lichens are known to reproduce through fragment growth, specialized reproductive structures containing both fungal and algal cells, and the conjunction of the fungal and algal components in situ. Lichen regeneration in natural settings has been rarely observed, and the relative importance of each mode of reproduction in various settings is not known.

Methods

In the summer of 1992, 34 stands near Armstrong and Sioux Lookout, Ontario were surveyed: 12 undisturbed sites, 8 sites burned 3-16 years prior to observation, and 14 sites logged 2-16 years prior to observation. The study sites were identified from aerial photographs as lichen-rich or lichen-rich prior to disturbance. The times since logging and fires were calculated from Ontario Ministry of Natural Resources records. Stand boundaries as defined on Ontario Ministry of Natural Resources Forest Resource Inventory maps were used as stand boundaries in this study.

Reindeer lichen-rich jack pine (*Pinus banksiana*) and/or black spruce (*Picea mariana*) stands occur on dry, nutrient-poor sites in this region, most commonly on shallow soils over bedrock or deep sand dunes or outwash deposits (Sims *et al.,* 1989). Both shallow soil and deep soil sites were included.

At each site the percent cover of each species of reindeer lichen was visually estimated in 20 50 X 100 cm quadrats randomly distributed along a 100 m transect. Each transect began 10 m from a stand boundary and its direction was determined by random number. Six uneven percent cover classes were used: <2%, 2-5%, 5-25%, 25-50%, 50-75%, and >75%. The midpoints of the percent cover categories were used for statistical analysis. The data points in the figures in this paper represent the ave-

rage reindeer lichen percent cover for each study site, since the category nature of the data does not lend itself to graphical representation of quadrat percent cover values.

Detailed notes on the ground cover of each quadrat were taken, and photographs were taken at most sites. Reindeer lichens were placed in 3 categories: 1) undisturbed, 2) fragment, or 3) new. The presence or absence of each reindeer lichen species in each category was noted for each quadrat at all but the first four sites. Reindeer lichens which had established prior to logging or fire and remained in their pre-disturbance orientation were classified as "undisturbed". Reindeer lichens grew either in a continuous carpet of 1 or more species or as individual podetia interspersed among moss. The "fragment" category included reindeer lichens which had established prior to logging or fire but were no longer intact. The fragments ranged in size from < 1 mm to several centimeters in diameter. Some fragments had only live tissue; some had both live and dead tissue. This category also included pieces of carpet that had shifted from their original locations and were no longer anchored to the substrate. Reindeer lichens in the "new" category had established since disturbance from propagules too small to be seen by eye. The new reindeer lichens had fewer annual branches than there were years since disturbance. Although there were no visible lichen fragments, the mode of dispersal was unclear. Dispersal may have occurred through thallus fragments too small to be observed, specialized reproductive structures, or the conjunction of the fungal and algal components *in situ.* Undifferentiated primary thallus was apparent at the bases of many of the newer podetia. The new reindeer lichens had fewer annual branches than there were years since disturbance. Collected reindeer lichens were examined under a dissecting microscope for further observations on fragment growth and establishment of new podetia.

Results

Reindeer lichen abundance
No undisturbed reindeer lichens were found on burned sites. *Cladina rangiferina, C. mitis* and total reindeer lichen cover increased with time since forest fire (Table 1, Fig. 1). *C. stellaris* was present in small amounts (average of 0.05% cover) on only two of the three sites burned 15 or more years prior to observation. The average total reindeer lichen percent cover for the three sites burned 15-16 years

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Table 1. Correlation coefficients and P values for reindeer lichen percenr covers and years since disturbance.

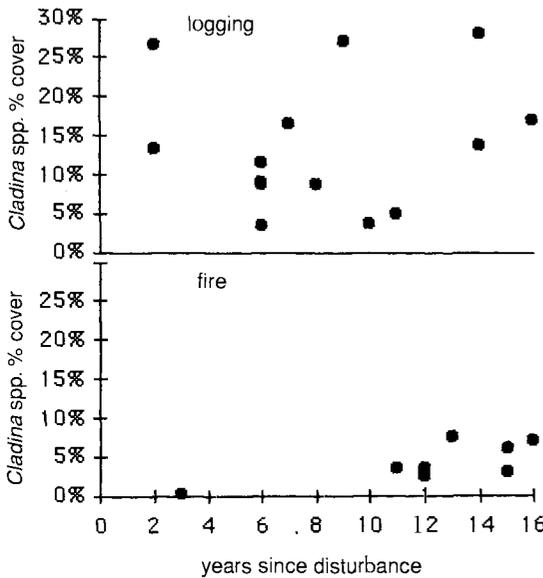| Reindeer lichen species	Pearson's correlation coefficient	$P=$
burned sites		
all *Cladina* spp.	0.301	0.0001
C. rangiferina	0.183	0.0212
C. mitis	0.299	0.0001
logged sites		
C. rangiferina	0.203	0.0006
C. stellaris	-0.151	0.0116

Fig. 1. Total reindeer lichen percent cover for logged and burned sires versus rime since logging or fire. Each point represents the mean of 20 percent cover measurements at each site.

While total reindeer lichen cover was found to be uncorrelated with time since logging, in contrast to time since fire (Fig. 1), *Cladina rangiferina* cover increased with time since logging, *C. stellaris* cover decreased, and *C. mitis* cover was uncorrelated (Fig. 2, Table 1). If the high *C. mitis* percent cover of site 4 (logged 2 years before observation) is considered to be an outlier and removed from analysis, then *C. mitis* cover also is found to be positively correlated with time since logging (Pearson's correlation coefficient 0.254, $P \leq 0.0001$).

Undisturbed reindeer lichens on logged sites

On logged sites, reindeer lichens that had established prior to logging were either: 1) undisturbed, 2) fragmented, or 3) buried beneath overturned soil or deadfall. The buried reindeer lichens, in every case, were dead. Virtually all of the mosses in the ground cover died within the first two years after logging.

With the exception of heavily shaded reindeer lichens and some unshaded *Cladina stellaris,* the
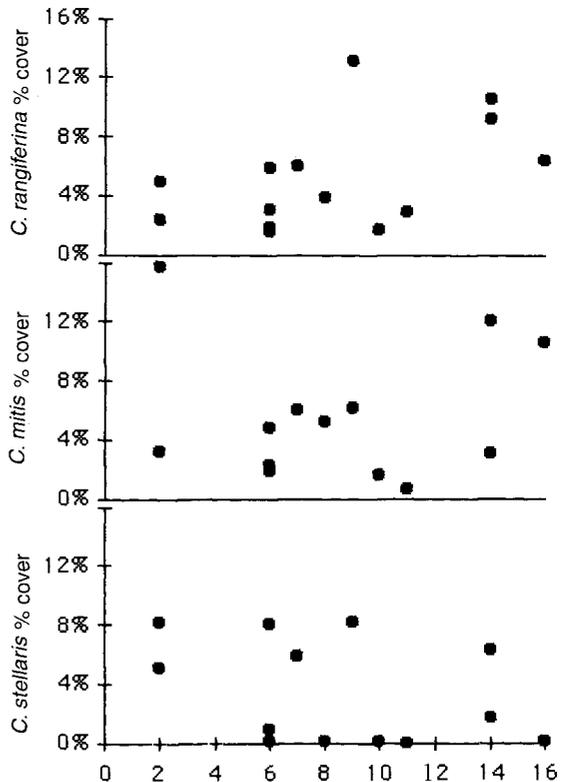

Fig. 2. Reindeer lichen percent cover by species versus rime since logging. Each poinr represents the mean of 20 percent cover measurements at each site.

prior to observation was 5.3% as compared to 25.2% for all undisturbed sites and 19.7% for the three sites logged 14-16 years prior to observation.

Logging, unlike forest fire, spares much of the ground cover. All three *Cladina* species were present on 13 of the 14 logged sites. The average total reindeer lichen percent cover of the two sites logged 2 years prior to observation was 37.7% of the average reindeer lichen cover on unlogged portions of the same stands. Undisturbed and/or fragmented reindeer lichens which predated logging were present on all logged study sites.

growth rate of living tissue and rate of death of basal portions appeared unaffected by logging. Although the surfaces of *C. rangiferina* which received the most insolation after timber harvest changed in color from ash gray to a darker gray-brown, the tissues remained firm and appeared healthy, and the annual growth rate did not appear to be reduced. The death rate of the basal portions of some undisturbed *C. stellaris* appeared accelerated, and the annual growth increments appeared shortened when compared to *C. stellaris* on adjacent unlogged sites.

Scarification by barrels and chains produced a distinctive pattern of disturbance to the ground cover on several of the deep soil sites studied. The ground cover on the ridges between the scarification trenches was generally undisturbed. In the trenches was exposed mineral soil. The ground cover removed to create the trenches was overturned on the sides of the ridges; the overturned ground cover, including reindeer lichens, was dead. Scarification ridges and trenches were well defined and relatively clear of debris 2 years after logging. Over time the scarification ridges settled. Mineral soil shifted down slope undercutting and fragmenting the ground cover mats on the ridge tops. Pieces of the ground cover mats and windblown reindeer lichen fragments and organic debris collected in the trenches. Undisturbed reindeer lichens persisted on the tops of scarification ridges. The effects of scarification were still discernable 14 years later. Rows of reindeer lichen carpet as well as microtopography indicated scarification ridge tops. Observations of resettling and fragmenting of carpet suggest decline in the abundance of undisturbed reindeer lichens over time.

Most of the shallow soil sites surveyed were not scarified. Because of the lack of scarification and the uneven topography typical of these bedrock outcrops, the patterns of ground cover disturbance were not as simple as on the scarified deep soil sites. On shallow soil sites there appeared to be less undisturbed reindeer lichen. The shortest interval between logging and observation on shallow soil sites was 6 years. It is possible that much of the ground cover survived logging intact and succumbed to erosion subsequently. In some areas with steep slopes reindeer lichen mats had slid down the underlying rock until they were caught in the branches of *Vaccinium* spp. and other dwarf shrubs at the bases of the slopes.

Colonization

New *Cladina mitis* and *C. rangiferina,* those colonizing by means of propagules too small to be seen, were observed on all sites burned or logged 6 or more years prior to observation. New *C. stellaris* were observed, less often: on two sites burned 15 or more years before observation and on three sites logged 6, 8, and 14 years before observation. The frequency of new reindeer lichen occurrence on logged sites was not significantly different from that on burned sites (Table 2).

New reindeer lichens were observed almost exclusively on organic substrates, including conifer needles, conifer cone scales, bark pieces, and wood ranging in size from small twigs to logs and stumps. There were some organic substrates colonized on logged sites which were not present on burned sites including: dead moss; overturned ground cover; very fine windblown organic matter collected in some scarification trenches; and organic soil on shallow soil sites exposed when dead ground cover or reindeer lichens shifted down slope. Reindeer lichens established directly on organic substrates or on crustose lichens on organic substrates. Smaller pieces of organic litter on which new reindeer lichens were established were often caught among mosses or other lichens, especially on shallow soil sites. Reindeer lichens were not observed colonizing mineral soil. A few cases of *C. rangiferina* colonizing coarsely textured rock faces were observed.

Fragment growth

Reproduction by fragment growth was observed on all disturbed sites except the most recent burn, but occurred on logged sites significantly more frequently than it did on burned sites ($t=5.787$, $P\leq0.0001$) (Table 2). Three types of fragment growth were observed: 1) continued growth of the apical tissues, 2) formation of new branches in the

Table 2. Mean frequency per sire by site disturbance category of reindeer lichen reproductive modes. The presence or absence of each reproductive mode for each of 3 species in each of 20 quadrars was noted (maximum possible score = 60).

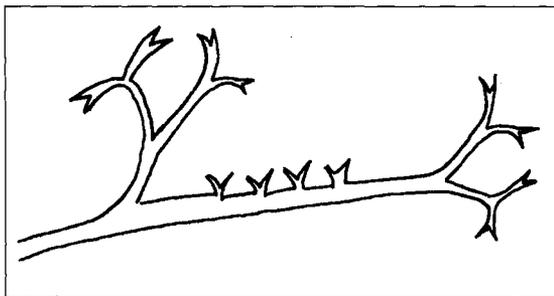| disturbance (n)	undisturbed lichen	fragmented lichen	new lichen
fire (8)	0	3.1	23.1
logging (12)	5.0	30.0	17.5
undisturbed (10)	26.6	0.7	0.4

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Fig. 3. New branches form on the internode between pre-disturbance branches on the surface which receives the most insolation in the post-disturbance orientation of the lichen fragment.
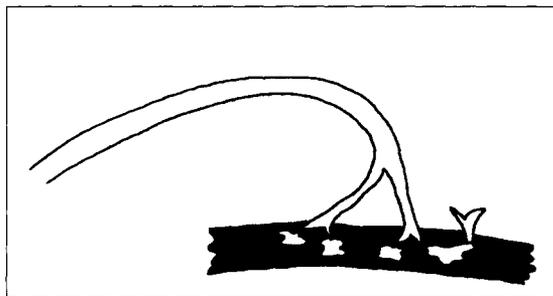

Fig. 4. Undifferentiated thallus spreads from rhe points of contact of the reindeer lichen fragment and the organic substrate. New podetia form from the undifferenriared thallus.

internodes between pre-disturbance branches, and 3) growth of new podetia from undifferentiated thallus that spread from the point of contact of a reindeer lichen fragment and organic litter.

Reindeer lichen fragments continued to grow from those apical tissues that were oriented toward the sun in the post-disturbance position. Accelerated death of tissues, including apical tissues, which received less insolation in their post-disturbance positions was observed.

Many fragments which were on their sides following logging formed new branches in the internodes between pre-disturbance annual branches on the surface of the internode which received the greatest insolation (Fig. 3). On older fragments the tissue of the original fragment was dead, in some cases making it difficult to distinguish between "new" and "fragment" reproduction. Thickening of the internodal tissue was the earliest indication of the branch formation. This thickening was most noticeable on tissue that was in the transitional zone between live and dead tissue. The formation of new branches in this zone suggests that lack of insolation as well as the age of the tissue, may explain the death of the basal portions of reindeer lichen podetia.

The spread of undifferentiated thallus from reindeer lichen fragments to organic substrate at the points of contact of the fragments and the substrate was observed. This occurred when a fragment was lying on an organic substrate as well as when small pieces of organic matter were caught within a lichen fragment. By 10 years post-logging, new podetia had differentiated from the tissue that spread from fragments (Fig. 4). Adhesion to a substrate seems to diminish the likelihood of further fragmentation and determine the pattern of growth by fixing the orientation of the fragment. Adhesion of fragments

also seems to promote the lateral spread of lichen growth, since new podetia grow from the undifferentiated thallus that spreads from the points of contact between the fragment and the substrate.

Discussion

This study found that when reindeer lichen-rich stands are logged, much of the reindeer lichen survives logging and continues to grow, and that reproduction by fragment growth and colonization of organic substrates occurs, but that total reindeer lichen cover is not correlated with time since logging. The different responses of the 3 reindeer lichen species to logging likely accounted for the lack of correlation between total reindeer lichen abundance and time since logging. The decline in *Cladina stellaris* suggests that the *C. stellaris* which survives logging is reduced over time by erosion and/or accelerated death of *C. stellaris* tissue and is not replaced through colonization or fragment growth. The decline in *C. stellaris* is likely due to the increase in insolation at the ground level as a result of logging. *C. stellaris* tolerates a relatively narrow range of light conditions, and is less abundant where excessive light is available such as in arctic and alpine regions (Ahti, 1961). *C. stellaris* is the slowest growing of the reindeer lichens and the last to regenerate on burned sites (Ahti, 1961). Increase in *C. rangiferina* cover could be attributed to continued growth of undisturbed or fragmented *C. rangiferina* and to colonization of the disturbed site. As with *C. stellaris,* the abundance of *C. rangiferina* is also reduced, but not as sharply, in habitats with intense light (Ahti, 1961). *C. rangiferina* is fast growing and is the most successful of the reindeer lichens on humus-rich soils (Ahti, 1961). The relationship of *C. mitis* cover and time since logging

was unclear. *C. mitis* is more successful earlier in the successional sequence than *C. rangiferina* or *C. stellaris,* but later its growth rate slows relative to other reindeer lichens suggesting that *C. mitis* is ecologically suited to disturbed sites (Ahti, 1961). Site 4 (logged 2 years prior to study) was the only logged site with well defined, relatively unstable sand dunes which may have led to *C. mitis* cover that was uncharacteristically high before logging for this set of sites and hence a relatively high *C. mitis* cover after logging. When site 4 was eliminated from statistical analysis, then *C. mitis* cover was positively correlated with time since disturbance as would be expected.

None of the relationships between reindeer lichen cover and time since disturbance in this study were strong. Much of the variability likely comes from: 1) differences between the sites compared other than type of disturbance and time since disturbance, and 2) a quadrat size too small to accurately capture reindeer lichen abundance. Type of disturbance and time since disturbance are only two of many factors such as slope, aspect, soil moisture, and canopy closure that influence reindeer lichen abundance. Logging adds variables such as time of year of logging, weather at time of harvest, seeding, method and timing of site treatment, and others, which affect reindeer lichen competitors as well as reindeer lichens themselves. It was not possible to control for or even identify all of these factors. Soil depth (deep sand or organic mat over bedrock) did not explain the variation in reindeer lichen abundance. The quadrat size, 50 X 100 cm, was small relative to the size of the patches in which mosses and reindeer lichens grow; therefore, there was high variability in estimated reindeer lichen percent covers among quadrats within sites.

Reindeer lichen fragment growth was found to be an important mode of reproduction on logged sites. Reproduction by fragment growth was more prevalent on logged sites than on burned sites, probably because of the greater abundance of lichen fragments on logged sites. Fragments on logged sites presumably result from the mechanical break-up of existing reindeer lichens by timber harvesting and site preparation activities (Harris, 1996). This study and Harris (1996) found that reindeer lichens which were undisturbed by timber harvest and site preparation persisted and were still evident on the oldest logged sites.

Colonization of organic substrates by propagules too small to be seen occurred on logged sites as it did on burned sites. This study, like Harris (1996) and Racey *et al.* (1996), found that reindeer lichens grow on substrates created by logging activities including stumps, slash, and haul roads. The persistence of undisturbed reindeer lichens and growth of reindeer lichen fragments, however, likely accounted for the higher cover of reindeer lichens on burned sites than on logged sites of the same age since disturbance. Harris (1996) found that microsites where mineral soil had been exposed during site preparation had significantly fewer reindeer lichens than where the ground cover had not been disturbed, suggesting that minimal disturbance to the ground cover of reindeer lichen-rich communities during harvest and site preparation will promote reindeer lichen persistence after logging. Similar observations were made in this study.

Racey *et al.* (1996), however, found in a 40 year old cutover near Nakina, Ontario, that reindeer lichen abundance was highest where the majority of the organic material had been removed from the mineral soil, for example on haul roads. Racey *et al.* (1996) argue that while severe fire removes the feather mosses and much of the humus layer, the humus, feather moss, and slash left after logging create a wetter, more nutrient-rich ground-level microenvironment which allows the feather mosses to continue growing and overtake the reindeer lichens. On the most recently logged sites observed in this study (logged 2 years before observation), however, virtually all of the feather mosses had died. It is seems likely that the sites observed in this study and by Harris (1996) were drier than those observed by Racey *et al.* (1996).

There is concern among wildlife managers, foresters, and others that logged sites may not produce sufficient abundance of reindeer lichens to support woodland caribou in the winter (Racey *et al.,* 1996). Although some trends in reindeer lichen cover with respect to time since logging were found, the long term fate of reindeer lichens on logged sites cannot be predicted from this study, nor is it possible to suggest silvilcultural treatments which will uniformly increase reindeer lichen abundance on logged sites. It is important to note that the trends observed were only for reindeer lichen cover which is not necessarily equivalent to reindeer lichen abundance. It is clear that even in areas which were lichen-rich before logging there is no simple relationship between reindeer lichen abundance and time since logging.

Acknowledgements

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