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RESEARCH ARTICLE

Terrestrial lichen caribou forage transplant success: year 5 and 6 results

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The southern mountain caribou—a subpopulation of caribou found in British Columbia—is listed on Schedule 1 of the Federal Species at Risk Act as Threatened. Woodland caribou are diet specialists, relying on *Cladonia* subgenus *Cladina* lichen as a primary food source during winter months. Lichens are burned along with trees and other vegetation during stand-replacing wildfire events, a natural disturbance in caribou ranges. In an attempt to accelerate the return of post-fire forests to productive caribou winter terrestrial lichen habitat, this study examined the survival and cover of three species of transplanted lichens in a post-wildfire environment in north central British Columbia, Canada, both with and without forest litter amendments. Chlorophyll fluorescence was used to evaluate lichen survival by measuring potential photosynthetic activity. The results of this study demonstrate that transplanted fragments and mats of *Cladonia* subgenus *Cladina* had survived 5 and 6 years after being transplanted within a post-wildfire environment, and had significantly greater percent cover when compared to the controls. The Fv/Fm results indicated that transplanted lichens survived, regardless of species, propagule type, or whether amendments were applied.

Key words: ***Cladina***, ***Cladonia***, **reindeer lichen, restoration, winter habitat**

> **Implications for Practice**
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> - This study used chlorophyll fluorescence, as a measure of potential photosynthetic activity, to confirm that transplanted terrestrial lichens had survived 5 and 6 years after being transplanted to a post-wildfire environment.
> - The literature indicated that transplanting terrestrial lichen is biologically feasible, but the health and long-term survival of the lichen remained a key uncertainty.
> - In this study, the data indicate that the lichens had survived, but also exhibited no or low stress in the specimens at the time of monitoring.
> - Based on these results, and other studies, terrestrial lichen transplants can be considered as novel tool that can be incorporated into caribou winter habitat restoration programs, as a means of reintroducing important winter lichen forage species.

Introduction

Historically, the woodland caribou (*Rangifer tarandus caribou*) was found across Canada, from Newfoundland to Haida Gwaii (Festa-Bianchet et al. 2011). The southern mountain caribou, a subpopulation found in British Columbia (BC), is listed on Schedule 1 of the Federal Species at Risk Act as Threatened (Environment Canada 2014). The decline of southern mountain caribou has mirrored the sharp decline of woodland caribou populations across Canada (Festa-Bianchet et al. 2011). The reason for the decline of woodland caribou is complex, but is linked to predation (Seip 1992; Environment Canada 2014; Johnson et al. 2019) as well as both anthropogenic and natural habitat alteration (Environment Canada 2014; Fryxell et al. 2020; Nagy-Reis et al. 2021). The federal recovery strategy for the southern mountain population of woodland caribou identifies habitat restoration as a management tool to be considered in recovery planning (Environment Canada 2014). A component of this may include the reintroduction or transplanting of important caribou food sources, such as terrestrial lichen.

Woodland caribou are diet specialists, with the central and northern groups in British Columbia relying on *Cladonia* subgenus *Cladina* lichen as a primary food source during winter months (Cichowski 1993; Thomas & Gray 2002; Thompson et al. 2015), and to a lesser extent in summer and autumn (Denryter et al. 2017). *Cladonia* subgenus *Cladina* lichens have a fruticose growth habit (Brodo et al. 2001), and are slow

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growing, with mean linear growth rates of 4.7 mm/year and 5.1 mm/year for *Cladonia arbuscula* ssp. *mitis* and *Cladonia rangiferina*, respectively (McMullin & Rapai 2020). *Cladonia* subgenus *Cladina* reproduces asexually through fragmentation, and the fragments are then distributed by wind, rain, and wildlife (Brodo et al. 2001). During dry periods, when terrestrial lichen readily desiccate, they also become susceptible to fire (Green et al. 2011). While post-fire lichen recolonization can vary as a result of these factors, studies from post-fire environments in BC suggest that forage lichens will establish in suitable stands following fires within 50–70 years (Coxson & Marsh 2001; Sulyma & Coxson 2001).

Forest management in BC uses a classification system based on climax vegetation, site environmental conditions, and climate to categorize similar forests (Mackinnon et al. 1992; MacKenzie & Meidinger 2018). This Biogeoclimatic Ecosystem Classification (BEC) system (Pojar et al. 1987) is used to further group forests in the central interior of BC. BEC zones are combined—based on forest patch size, seral stage, and assumed disturbance—into merged biogeoclimatic ecosystem units (mBEC; Delong 2011) and natural disturbance units (NDUs) which are used to classify areas into natural disturbance types (NDT; MOF 1995). The study area is assumed to be disturbed by stand-replacing fire on a frequent basis, NDT 3, with a modeled mean fire return interval of between 100 and 125 years (MOF 1995). Fire in NDT 3 trends toward stand initiating with fire-consuming living and dead trees, shrub and herb layers, and the forest floor, including terrestrial lichen.

To accelerate the return of post-fire forests to productive pine lichen winter range, transplantation of mat forming lichen thalli may be considered. In instances of stand-replacing fire, however, fragments of *Cladonia* subgenus *Cladina* are thought to be dispersal limited, and not necessarily limited by the post-fire conditions. Most notably, Crittenden (2000) reported that, in northern Finland in 1971, P. Kallio spread 200 g of crushed lichen thalli within areas cleared of vegetation on the floor of an open stand of *Pinus sylvestris* (Scots pine) and noted that, "monocultures of *Cl*[*adonia*]. *stellaris*, *Cl. rangiferina*, *Ce* [*Flavocetraria*] *nivalis* and *S*[*tereocaulon*] *paschale* had developed by 1978 and in 1998 most species were present as luxurious mats." Enns (1998) reported on monitoring data from 1997 from a hand sowing and aerial helicopter transplanting trial established in 1989–1990 within open, clearcut logged, and scarified areas on the Chilcotin Plateau, BC. Enns (1998) concluded that lichen transplanted through both methods had established, but that hand transplants were believed to be more successful, when compared to helicopter transplants which had greater break up [of thalli] and mortality.

Since this time, several studies have examined the feasibility of transplanting lichen fragments and mats to restore caribou winter forage habitat. *Cladonia* subgenus *Cladina* transplant studies have been conducted in regenerating boreal forests of Sweden (Roturier et al. 2007; Roturier & Bergsten 2009; Roturier et al. 2017) and Canada (Enns 1998; Duncan 2011; Ronalds & Grant 2018), as well as quarries and other mined landscapes in boreal regions (Campeau & Blanchard 2010; Hugron et al. 2013; Rapai et al. 2018), and also in alpine areas (Duncan 2015). Research has also been conducted to understand the impact of soil amendments and substrates (Roturier & Bergsten 2009; Duncan 2011; Hugron et al. 2013), lichen fragment size (Roturier et al. 2007; Duncan 2011; Ronalds & Grant 2018), transplant technique (Enns 1998; Krekula 2007; Ronalds & Grant 2018), seasonality (Huss-Danell 1977; Boudreault et al. 2013; Roturier et al. 2017), and microclimate attributes (Boudreault et al. 2013) on lichen establishment.

Multiple studies suggest fragmentation of the lichen thallus as the most appropriate method for transplanting terrestrial lichen (Crittenden 2000; Roturier et al. 2007; Rapai et al. 2017). In Sweden, Roturier and Bergsten (2009) found that *Cladonia stellaris* planted in patches/mats were grazed by reindeer; however, lichen seeded as fragments remained and grew similarly to naturally established lichen thalli in the area. On gravel-capped forestry roads in boreal Ontario both fragments and mats were able to establish (Rapai et al. 2018), indicating mats or large clump transplants could still be effective in areas where caribou are not overgrazing (Duncan 2011, 2015). As lichen growth is limited by the time a thallus is hydrated, combined with the level of irradiance during the hydration event (Gauslaa et al. 2007; Nash 2008), substrates that absorb and retain moisture may also benefit transplanted lichen propagule and diaspore establishment (Roturier & Bergsten 2009; Campeau & Blanchard 2010; Hugron et al. 2013). However, there are reports of transplanted *Cladonia* subgenus *Cladina* lichens establishing on bare mineral soil (Roturier & Bergsten 2009) and gravel-capped forestry roads (Rapai et al. 2018). Despite these transplant successes, it remains challenging to conclusively determine accurate survival and growth of transplanted lichen through ocular assessments in outdoor transplant trials, due to the fruticose growth pattern of lichens and their extremophilic nature with desiccation tolerance (Veerman et al. 2007; Komura et al. 2010; Singh et al. 2013).

To determine lichen survival, we measured the potential photosynthetic activity of transplanted lichens. Chlorophyll fluorescence is a technique for measuring potential photosynthetic activity in plants, as well as lichens. In lichens, the fluorescence is emitted by the photobiont (algae or cyanobacteria). Because photosynthetic activity is integral to most plants and is essential to metabolic processes, it can be used to assess environmental stress (Adams & Demmig-Adams 2004) and is often used as a proxy for health in lichen studies. Chlorophyll *a* fluorescence is used to detect potential photosynthetic activity or the viability of photosynthetic pathways, where light is absorbed by chlorophyll molecules, which allows the process of photosynthesis to occur. Light can then also be re-emitted as fluorescence, or heat. Fv/Fm is a parameter used to understand plant stress, as it provides insight into the maximum quantum yield of photosystem II (PSII) chemistry and therefore, lichen viability (Butler 1978; Genty et al. 1992).

A threshold of viability for the Fv/Fm ratio has been previously investigated: in a study investigating numerous Himalayan lichens, Fv/Fm values in the range of 0.5–0.76 were determined to be normal, with values less than 0.5 determined to be moderately stressed, and severe stress indicated by values in the 0.01–0.29 range (Nayaka et al. 2009). Values in the 0.2–0.3 range indicate irreversible changes to the PSII (Angelini et al. 2001; Dzubaj et al. 2008). Baseline values of Fv/Fm in foliose lichen *Parmelia sulcata* before stress from SO_2 exposure were 0.721–0.733 (Fernandez-Salegui et al. 2006). Research suggests that lichen thalli with Fv/Fm values greater than 0.7 are not exhibiting stress and can be a threshold for understanding lichen health (Fernandez-Salegui et al. 2006; Nayaka et al. 2009; Králiková et al. 2016).

While the literature indicates that successfully transplanting terrestrial lichen thalli is biologically feasible and can result in an increase in percent cover over time (Enns 1998), the health and long-term survival of these transplanted lichens remains a key uncertainty in the literature. The goal of this study was to evaluate the success of *Cladonia* subgenus *Cladina* and *Cladonia uncialis* lichen transplants within a post-burn environment after 5 and 6 years. The specific objectives of this study were to: (1) determine if lichen transplants result in increased lichen percent cover, (2) determine if the transplanted lichens survived, (3) compare survival between lichen species, and (4) examine the role of amendments with forest floor litter and varying treatments on lichen establishment and survival. The results of this study will aid in determining if transplanting *Cladonia* subgenus *Cladina* can be considered as a tool for restoring caribou winter forage in post-wildfire environments.

Methods

Two field trials were established in July 2015 and 2016 to evaluate the effectiveness of terrestrial lichen transplants in establishing lichen communities in a post-wildfire environment. Each of the field trials was established in north central British Columbia, approximately 160 km northwest of MacKenzie, within the Mesilinka River drainage. This area is considered Caribou Ungulate Winter Range under the British Columbia Forests and Range Practice Act. Prior to the 2014 fire, the area consisted of pine (*Pinus contorta*) lichen (*Cladonia* subgenus *Cladina*) open canopy forest with coarse, well drained and nutrient poor soils, in an area known to provide winter forage to the local chase subpopulation of Southern Mountain Caribou.

Experimental Field Trial Design

The experimental field trial was established in July 2015, into three blocks, which were representative of a combination of post-fire conditions and topography. The blocks were categorized as (A) intense burn and hillcrest, (B) intense burn and flat, and (C) partial burn and flat. Figure 1 provides photos of these block locations.

Lichen fragments and mats were transplanted in this study, specifically: *Cladonia rangiferina*, *Cladonia arbuscula* ssp. *mitis*, and *Cladonia uncialis*. The trial was arranged in a randomized block design with three blocks and six treatment combinations. Each treatment had approximately 10 replicates within each of the three blocks (Table 1), for a total of 180 1-m^2 experimental units. Block transects were oriented in an east to west direction to reduce wind transport of lichen thalli between treatments, with 1 m^2 between each experimental unit. Treatments were then applied within a 75 × 75 cm area in the center of each experimental unit. Three levels of lichen treatment (no lichen, fragments, entire mat) and two levels of amendment (no amendment, forest floor litter) were applied. The ground surface was not manipulated or altered prior to transplanting the fragment treatment (i.e. ground not roughened). The lichen were not prepared trimmed or modified in any way The entire thalli was transplanted, and not arranged. During collection, if thalli were in observably poor health, they were not collected. Further, during transplanting, thalli that were in poor health were not transplanted, and discared. The mat treatment received substrate roughening and soil pulling to plant the mat. A summary of the treatments applied in the experimental field trial is provided in Table 1, and photographs of the lichen fragment and mat treatments are provided in Figures 2 and 3.

Operational Field Trial

The operational field trial was established in July 2016. Twenty 100-m^2 replicates of each treatment were established using transplants of *Cladonia arbuscula* ssp. *mitis*, *Cladonia stygia*, and *Cladonia uncialis*, for a total of 80 experimental units. A treatment summary is provided in Table 2, and a complete description of the operational field trial transplant methods and experimental design is provided by Rapai et al. (2017). In July 2021, a wildfire burned through the project area, removing nine replicates of each treatment from the 2021 monitoring efforts of

Figure 1. Photos of experimental field trial block locations in July 2016 (1 year following establishment) at (A) intense burn hillcrest, (B) intense burn and flat, and (C) partial burn and flat.

Table 1. Summary of treatment combinations applied in the experimental field trial.

Treatment	*1-m²* *Replicates* (n)	*Hydrated Weight of Lichen* (g)	*Weight of Litter* (g)
Control (plot empty)	27	0	0
Control + forest floor litter	30	0	100
Lichen fragments (1–5 cm)	31	100	0
Lichen fragments + forest floor litter	32	100	100
Lichen mat	30	100	0
Lichen mat + forest floor litter	30	100	100

the operational field trial. As a result, the replicates available for monitoring in 2021 were reduced from 20 to 11.

Field Data Collection

Within the experimental field trial, field data collection was carried out on 6 and 7 July 2021. Technicians estimated ocular percent cover of *Cladonia* subgenus *Cladina* within each 1-m^2 experimental unit, using a 20 × 20–cm clear plastic grid. Estimates of percent cover were recorded as less than 1%, in 1% increments from 1 to 10%, and in 5% increments from 10 to 100%. A maximum of five samples of each of *Cladonia rangiferina* and *Cladonia arbuscula* ssp. *mitis* were then collected for fluorometry analysis. The preferred sample size for collection was a 3–5 cm thalli, but this was not always possible. *Cladonia arbuscula* ssp. *mitis* was absent from, or did not exist, in high enough abundance to be collected within all experimental units. During field collection, thalli were stored in paper bags, labeled, placed in plastic storage totes, and stored in the shade. The totes were then stored under a silvicool tarp before and during transportation to the laboratory.

Within the operational field trial, field data collection was carried out on 4 and 5 October 2021. Technicians estimated the percent cover of *C. arbuscula* ssp. mitis, *C. rangiferina*, *C. stellaris*, *C. stygia*, and *C. uncialis* within each plot, using a 20 × 20–cm and 1 × 1–m grids to assist in calibrating estimates. Ocular estimates of percent cover were collected as less than 1%, in 1% increments from 1 to 10%, and in 5% increments from 10 to 100%. Technicians then collected five subsamples, when available, of each of *C. arbuscula* ssp. mitis, *C. rangiferina*, and *C. uncialis* for fluorometry analysis. Lichen thalli were collected and stored in the same manner as the experimental field trial above.

Laboratory Analysis

The assessment of thallus viability in the collected lichens was assessed using chlorophyll fluorescence. All thalli were dried and preconditioned to allow relaxation of the short-term down-regulation of PSII. This was performed by wetting thalli with deionized water and keeping them hydrated at 100 μmol photons m^{-2} second^{-1} at room temperature (20°C) for 24 hours. Immediately after the preconditioning Fv/Fm was recorded with a portable fluorimeter (Plant Efficiency Analyzer; Hansatech, King's Lynn, U.K.) after a 5 minute period of dark adaptation following the methods of Gauslaa et al. (2012). Thalli whose Fv/Fm values fell above 0.7 were assessed as not demonstrating signs of stress (Fernandez-Salegui et al. 2006; Nayaka et al. 2009; Králiková et al. 2016).

Statistical Analysis

All statistical analysis was conducted using "R" software (version 4.1.3; R Development Core Team 2013). A series of analysis of variance (ANOVA) models fit using the "aov" function in base R were used to evaluate differences in percent cover between treatments within the experimental and operational field trials. For the experimental field trial, the percent cover in each experimental unit was modeled against block, treatment (control, fragments, mat), and litter (yes/no) factor effects along with a treatment:litter interaction. The percent cover in each experimental unit was modeled against block and treatment (control, fragments, mat) factor effects. For the operational field trial, the percent cover in each experimental unit was modeled against block and treatment (control, fragments, mat, hybrid) factor effects. Pairwise comparisons between the treatments

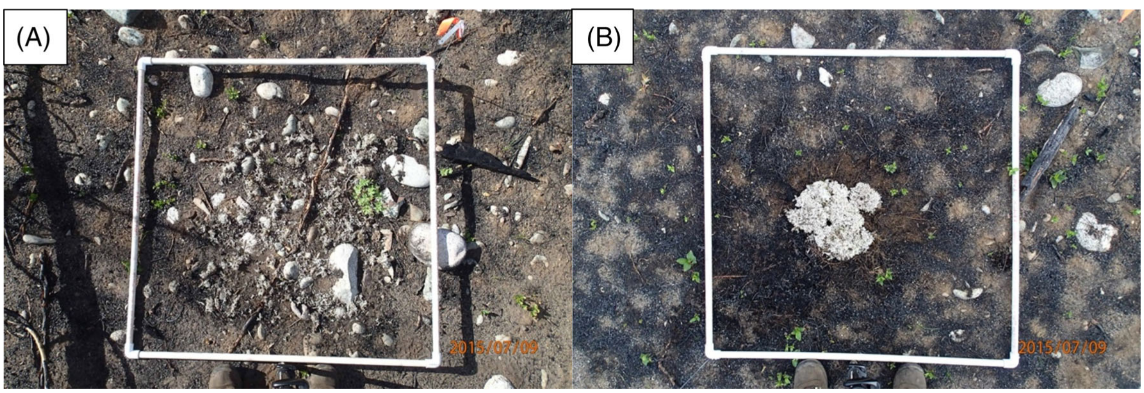

Figure 2. Examples of experimental units on 9 July 2015 after receiving the lichen (A) fragment and (B) mat treatments within the experimental field trial.

Figure 3. (A) Example of a lichen experimental unit containing lichen fragments on 6 July 2021, and (B) a lichen fragment thalli collected for analysis with chlorophyll fluorescence.

Table 2. Summary of treatment combinations applied in the operational field trial.

Treatment	*100-m² Replicates Monitored in 2021*	*Volume of Lichen (L)*
Control (plot empty)	11	0
Lichen fragments (2–7 cm)	11	100
Lichen mat	11	100
Hybrid (mat and fragments)	11	50/50

were conducted for each model using Tukey's honestly significant difference (HSD) method. Letter codes indicating significant difference in groupings for the pairwise tests were automatically assigned using the "cld" function from the R package "multcomp."

Differences in chlorophyll fluorescence (Fv/Fm) between treatments within the experimental and operational field trials were analyzed using a series of ANOVA models fit using the "aov" function in base R. Some plots did not contain enough lichen tissue to sample and were excluded from this analysis. A separate model was fit for each species (*C. arbuscula* ssp. *mitis* and *C. rangiferina* in the experimental field trial; *C. arbuscula* ssp. *mitis*, *C. rangiferina*, and *C. uncialis* in the operational field trial). Within the experimental field trial, percent cover in each experimental unit was modeled against block, treatment (control, fragments, mat), and litter (yes/no) factor effects along with a treatment:litter interaction. Within the operational field trial, the percent cover in each experimental unit was modeled against block and treatment (control, fragments, mat, hybrid) factor effects. Pairwise comparisons between the treatments were conducted for each model using Tukey's HSD method. Letter codes indicating significant difference in groupings for the pairwise tests were automatically assigned using the "cld" function from the R package "multcomp."

Differences in stress status (unstressed = Fv/Fm > 0.7) between treatments within the experimental field trial were analyzed using a series of logistic regression models fit using the "glm" function in base R. Some plots did not contain enough lichen tissue to sample and were excluded from this analysis. A separate model was fit for each species (*C. arbuscula* ssp. *mitis* and *C. rangiferina*). The stress status (1 if Fv/Fm > 0.7, 0 otherwise) in each experimental unit was modeled against block, treatment (control, fragments, mat), and litter (yes/no) factor effects along with a treatment:litter interaction. Pairwise comparisons between the treatments were conducted for each model using Tukey's HSD method. Letter codes indicating significant difference groupings for the pairwise tests were automatically assigned using the "cld" function from the R package "multcomp." There was no variance in stress status between treatments in the operational field trial, as the Fv/Fm values exceeded the stress threshold (unstressed = Fv/Fm > 0.7) for all species (*C. arbuscula* ssp. *mitis*, *C. rangiferina*, and *C. uncialis*) in all plots. The lack of variance in stress status between treatments in the operational trial precluded any further statistical analysis.

Results

For the experimental field trial, after 6 years, the ANOVA results showed a significant effect of treatment on lichen percent cover ($p < 0.0001$), but no significant effect for litter ($p > 0.05$) or the litter: treatment interaction ($p > 0.05$). The

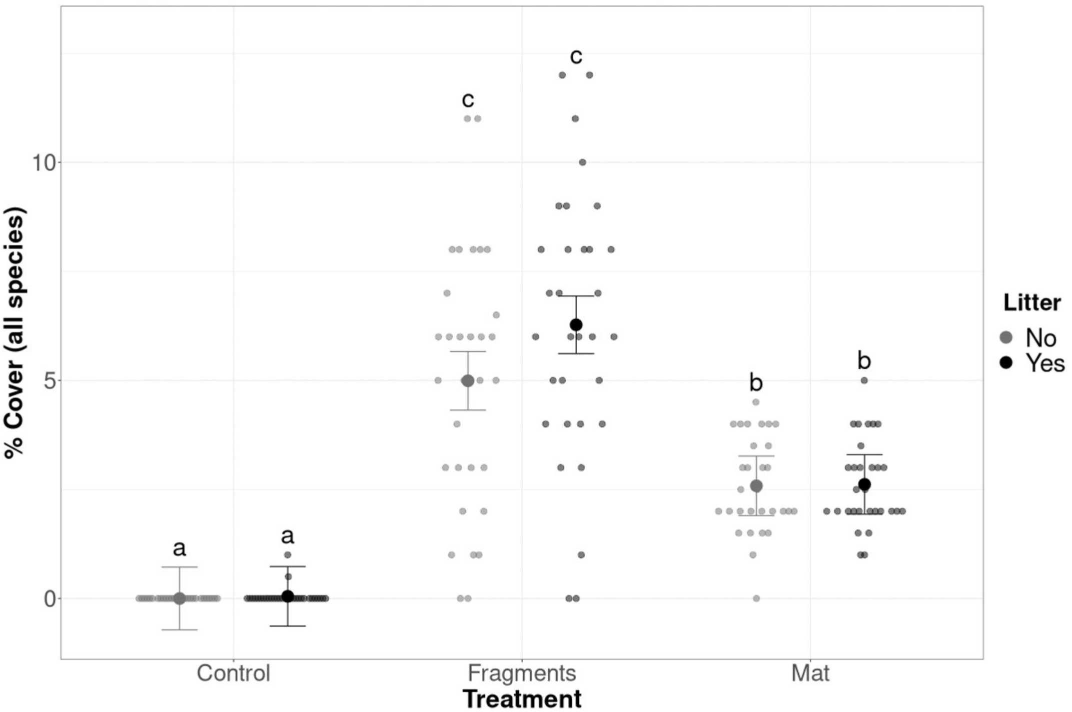

Figure 4. Mean lichen total percent cover by treatment in the experimental field trial. Treatments with the same letter code are not significantly different. The horizontal bars indicate ± SE.

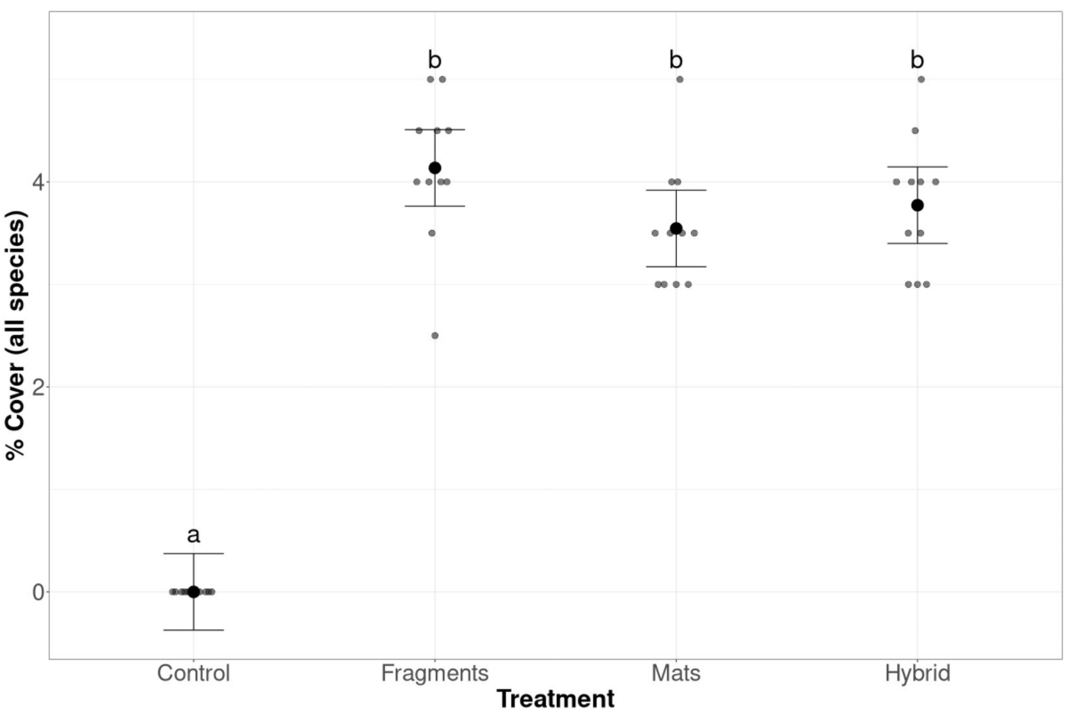

Figure 5. Mean lichen total percent cover by treatment within the operational field trial. Treatments with the same letter code are not significantly different. The horizontal bars indicate ± SE.

results of the pairwise comparisons are presented in Figure 4. The Control treatment had significantly lower (negligible; $p < 0.001$) lichen percent cover, on average, when compared to the fragment and mat treatments. The fragment treatment had significantly greater ($p < 0.05$) lichen cover, on average, than the mat treatment.

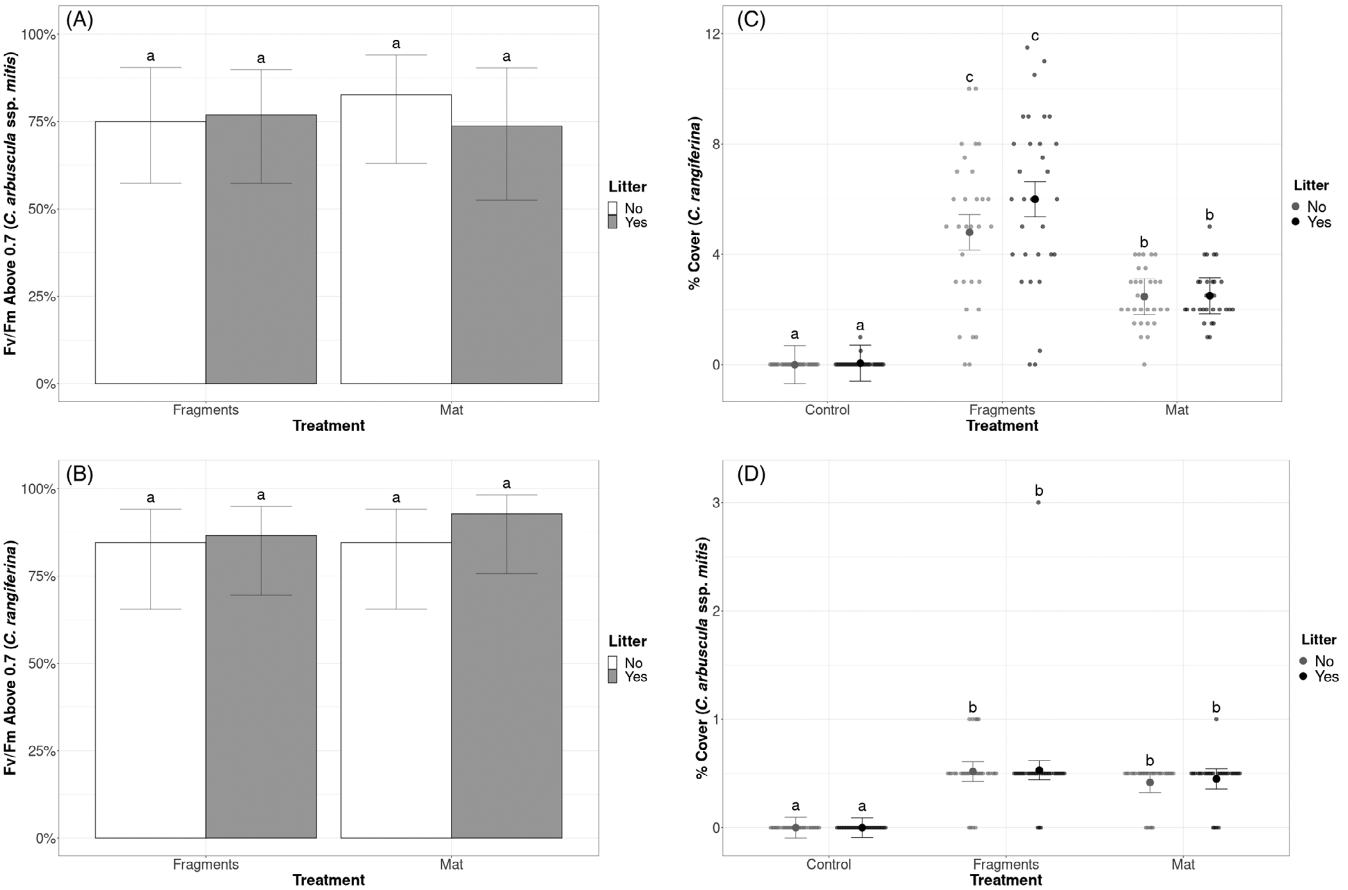

Figure 6. Fv/Fm values with the experimental field trial for *Cladonia arbuscula* ssp. *mitis* and *Cladonia rangiferina*. The horizontal bars indicate ± SE.

For the operational field trial, after 5 years, treatment was similarly found to have a significant effect on lichen percent cover ($p < 0.0001$). The results of the pairwise comparisons are presented in Figure 5. Control treatment plots had significantly lower total percent cover (mean = 0 for control treatments) on average compared to the fragment, mat, and hybrid treatment plots. However, there was no significant difference ($p > 0.05$) in total percent cover between the fragment, mat, and hybrid treatments.

When examining the results of the fluorometry analysis within the experimental field trial, there was no significant effect of treatment ($p > 0.05$), litter ($p > 0.05$), or a treatment:litter interaction ($p > 0.05$) on lichen stress (unstressed = Fv/Fm > 0.7) for *Cladonia arbuscula* ssp. *mitis* and *Cladonia rangiferina*. The results indicate that approximately 77% of *C. arbuscula* ssp. *mitis* thalli, and 87% of *C. rangiferina* thalli, exceeded the 0.7 Fv/Fm threshold (Fig. 6A & 6B), 6 years after transplanting. There was no significant difference ($p < 0.05$) in the mean Fv/Fm value between the fragment and mat treatments for either species (Fig. 6C & 6D).

Within the operational field trial, there was no variance in stress status between treatments (Fig. 7A). The Fv/Fm values exceeded the stress threshold (unstressed = Fv/Fm > 0.7) for all species (*C. arbuscula* ssp. *mitis*, *C. rangiferina*, and *C. uncialis*) in all plots, for 100% of the lichen thalli collected. Five years after being transplanted, there was no significant difference ($p < 0.05$) between fragment, mat, or hybrid treatments, on the mean Fv/Fm value, for any species of lichen (Fig. 7B–7D).

Discussion

The results of this study demonstrate that transplanted fragments and mats of *Cladonia* subgenus *Cladina* had survived 5 and 6 years after being transplanted within a post-wildfire environment. The lichens not only survived, but they had Fv/Fm values that suggest no or low stress in the specimens, at the time of monitoring in 2021. Transplantation of lichen was found to increase lichen percent cover over the time period of this study, as compared to 0% cover in the control plots. Further, the transplanted lichens survived regardless of species (*Cladonia arbuscula* ssp. *mitis*, *Cladonia rangiferina*, and *Cladonia uncialis*), propagule type (mat or fragment), or whether amendments with forest litter were applied. This suggests that *Cladonia* subgenus *Cladina* is dispersal limited, and not limited by the substrate or environmental conditions of the post-wildfire environment, as hypothesized by Roturier et al. (2017). Further, we conclude that transplanting *Cladonia* subgenus *Cladina* lichen is a viable tool to be considered by practitioners looking to restore caribou winter habitat by introducing forage.

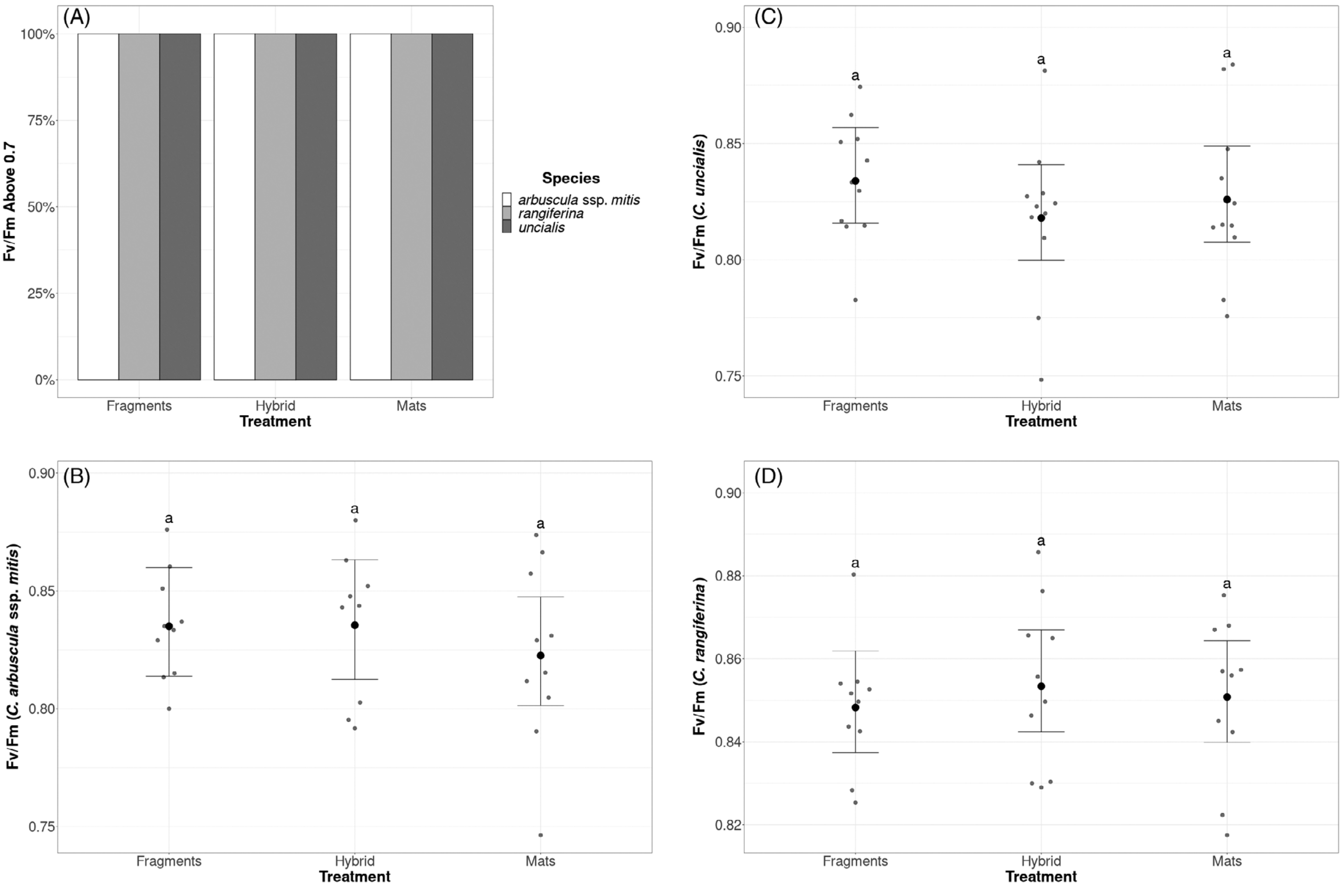

Figure 7. Fv/Fm values within the operational field trial for *Cladonia arbuscula ssp. mitis*, *Cladonia rangiferina* and *Cladonia uncialis*. The horizontal bars indicated ± SE.

However, there are several operational considerations that should be considered before incorporating lichen transplants into a caribou winter habitat restoration project. These include questions around where to collect the lichen so that it does not impact local caribou populations, and what volume of lichen can be considered sustainable to collect and remove from an area. These questions represent key uncertainties that have yet to be fully addressed in the literature, but are discussed in more detail by Duncan (2015) and Rapai et al. (2017).

Stand successional processes represent another source of uncertainty when evaluating the long-term success of lichen transplants. The natural recovery of caribou forage lichens after fire typically occurs some 50–60 years after fire, when self-thinning of dense early successional stands provides conditions which allow forage lichens to survive (Coxson & Marsh 2001). The fate of caribou forage lichen trying to establish naturally in early successional stands, that is inadequate growth due to low light levels and burial of lichen mats by high litterfall loading, may equally befall lichen transplants within the following decades, as natural processes of stand succession proceed. Additionally, caribou will generally avoid stands with dense canopy closure due to their preference for open lines of sight so that they can maintain predator avoidance (Serrouya et al. 2011). The success and utility of lichen transplant studies must therefore be evaluated in context of stand silvicultural treatments. Lichen transplants may only provide a brief period of enhanced forage availability (and caribou access into stands) as natural processes of stand succession occur.

While the results of this study are clear with respect to survival and cover occupancy in the immediate post-fire period, we did not examine the growth rate of the transplanted lichens in this study. A review by McMullin and Rapai (2020) indicate that the average linear growth rate of *Cladonia arbuscula* ssp. *mitis* and *Cladonia rangiferina* is 4.7 and 5.1 mm/year, respectively. Future studies, and monitoring of these trials, will consider methods for evaluating mean annual growth of the transplanted fragments and mats. This would provide greater insight into whether the growth rate is likely to produce sufficient caribou forage habitat. Another variable that was not assessed in this study was seasonal changes in chlorophyll fluorescence. Many chlorolichens from north temperate environments show higher Fv/Fm values at the end of the summer growth period (Králiková et al. 2016). Our use of a relatively conservative threshold for assessing viability (Fv/Fm < 0.7), however, should provide a reliable assessment of thallus viability across the growing season, falling below that of these previous measurements at different seasons.

Lastly, this study did not assess wildlife use of the transplanted lichens. Roturier and Bergsten (2009) reported foraging by reindeer in 14 of 40 plots within their transplant trial, which may have influenced the reduction of lichen cover measured in select plots in their study. Anecdotal observations from these trials suggest there may be some dispersal of transplanted lichens by wildlife. While the influence of wildlife on lichen dispersal may not be significant in this trial, the dispersal of *Cladonia* subgenus *Cladina* by wildlife, particularly caribou, is discussed in the literature (Brodo et al. 2001). Future monitoring of these trials will explore the role that wildlife is playing in the fragmentation and distribution of transplanted lichens. Like with the evaluation of lichen growth rate, more time and monitoring are required before any conclusions can be drawn.

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