Monitoring recovery of overgrazed lichen communities on Hagemeister Island, southwestern Alaska

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Abstract: Understanding the recovery rate of overgrazed lichen communities has value to mangers of lands in northern regions. We describe lichen community composition and present recovery rate measurements for a 12-year period following overgrazing by reindeer (*Rangifer tarandus*) on Hagemeister Island, Alaska. Reindeer were removed from the island in 1993 following overgrazing and average total lichen biomass increased from 504.2 kg/ha (SD 205.4) in 2003 to 795.3 (SD 489.6) in 2015. We estimate time to recovery with three competing growth curves which estimate grazeable biomass may be reached in 34-41 years. However, estimates of full recovery to climax biomass varied among the models, ranging from 71 to 400 years. In 2015, lichen communities were composed of various mixtures of at least 78 lichen taxa, and were dominated by *Cladina stygia* and other important reindeer forage species. While reindeer overgrazing diminished forage quantity, it did not extirpate preferred forage taxa.

Key words: Range recovery; *Rangifer tarandus*; grazing management.

Introduction

Hagemeister Island, located in Bristol Bay of the Bering Sea, is characterized by various shrub and tundra plant and lichen communities (Fig. 1, Swanson & LaPlant, 1987). These communities developed in the absence of ungulate grazers until 1965, at which time reindeer were introduced. The reindeer population grew from an initial introduction of 71 animals to over 1,000. Overgrazing was evident by 1973, at which time a recommendation was made to the U.S. Bureau of Land Management to reduce the reindeer population from 1,000 to 450 (Swanson & LaPlant, 1987). The reindeer population was not reduced, and a 1987 survey found damage to lichen sites but little impact to vascular plant-dominated sites (Swanson & LaPlant, 1987). In 1992, Swanson and Barker (1993) reported virtual depletion of lichens on the primary lichen-dominated sites and significant ecological damage on the remaining vascular-plant dominated sites. A die-off of approximately 300 reindeer occurred in 1992 and the

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remaining animals were removed in 1992-1993 by the U.S. Fish and Wildlife Service (which had been delegated management authority in 1980) in order to end the ecological effects caused by overgrazing (Swanson & Barker, 1993).

Lichens are important in reindeer and caribou (both *R. tarandus*) diets, particularly during winter (Klein, 1968; Pegau, 1968; Skoog, 1968; Thompson *et al.,* 1981; Boertje, 1984; Joly *et al.,* 2007; Joly & Cameron, 2018). Lichen taxa that have been determined to be particularly important forage species to reindeer and caribou include members of the principally ground-dwelling genera *Cladonia, Cladina, Cetraria* and *Stereocaulon* and the arboreal genera *Alectoria, Evernia,* and *Usnea* (Skoog, 1968; Sveinbjornsson, 1990). Lichens are characterized by extremely low rates of growth relative to vascular plants (Pegau, 1968; Sveinbjornsson, 1990). Lichen abundance can be reduced by overgrazing, as in the Hagemeister Island case or by fire, which tends to be a more destructive process generally requiring longer recovery times than that required by overgrazing, given that recovery post-fire is often dependent upon primary succession over large areas (Collins *et al.,* 2011). There have been numerous investigations of lichen recovery post-burning, given that much of the range of caribou occurs in the boreal north where fire is a regular ecosystem process (Collins *et al.,* 2011; Black & Bliss, 1978; Kumpula *et al.,* 2000; Maikawa & Kershaw, 1976; Morneau & Payette, 1989; Scotter, 1964). These studies are in agreement that recovery takes 100 years or longer. Klein (1968 and 1987) and Klein and Shulski (2009) studied lichen community recovery on St. Matthew Island, Alaska following overgrazing by reindeer that was followed by a complete die-off. Twenty-two years after the die-off, lichens had recovered to only 6% of the standing crop of living lichen biomass occurring on adjacent Hall Island with no grazing. At 41 years after the die-off, lichens had recovered to 12% of that on Hall Island, suggesting that in this example, post-grazing recovery may require a similar amount of time as that following fire. Swanson estimated that it would take 75 – 100 years for the depleted lichen communities on Hagemeister Island to recover in the complete absence of reindeer grazing (letter to Togiak National Wildlife Refuge manager in Swanson and Barker, 1993). However, other investigators have suggested that recovery following overgrazing can occur more rapidly. Henry and Gunn (1991) reported that essentially all macrolichen biomass had been eliminated in a single summer grazing event on an island in Northwest Territories and suggested that recovery could take 20 years or longer. Collins *et al.,* (2011) evaluated the impacts of caribou grazing on lichen abundance and subsequent use in interior Alaska, reported that caribou selected for habitat with >1,250 kg/ha forage lichen biomass, and hypothesized that substantial recovery following overgrazing may only require 20 years. Our goals are to document the rate of recovery of lichens on Hagemeister Island following the removal of reindeer and present alternative recovery scenarios, determine the relationship between biomass and visual estimates of lichen cover, and describe lichen community composition.

Study area

Hagemeister Island (58° 29' N, 160° 54' W) is approximately 39 km in length, approximately 31,200 ha in area, and is located approximately 31 km south of the village of Togiak in Bristol Bay (Fig. 1, Bailey, 1983). The climate on Hagemeister Island is subarctic maritime. Annual precipitation averages 94 cm and temperatures range from average daily low and high of –11 and –7 °C in February, the coldest month, to 8 and 12° C in August, the warmest month at the nearest weather station, Cape Newenham, Alaska (climate data averaged 1981-2010, National Oceanic and Atmospheric Administra-

tion, 2019). The island surficial geology ranges from relatively recent flood plain alluvium, colluvial deposits, and glacial drift of sand, gravel, and boulders to Paleozoic siltstone, limestone, and argillaceous rocks (Hoare & Coonrad, 1961). Intermediate in age are extensive carboniferous to cretaceous volcanic deposits. The island ranges from rolling hills up to 150 m elevation in the east to steep mountains up to 500 m in the west.

Hagemeister Island is treeless, composed of 12 landcover types, and is dominated by various shrub types ranging from tall to dwarf shrub (Collins, 2003; Winfree, 2009). Low elevation sites beginning at the beaches are forb and graminoid-dominated, and graminoid-dominated communities also occur above coastal cliffs and on elevated benches. Extensive alder (*Alnus)* thickets occur on mountain slopes protected from the wind. Lichens occur primarily on exposed upland dwarf shrub lichen sites, which by definition include >20% lichen cover (Viereck, 1992). Hagemeister Island supports diverse faunal communities, but in the absence of reindeer includes no lichen grazers (Bailey, 1983; Stimmelmayr, 1994).

Methods
We randomly selected 27 study sites from dwarf shrub lichen sites >4 ha to minimize the probability of sampling in the ecotone of other cover types (Fig. 1). At each site, we collected 4 samples at 3.05-m intervals along a randomly-oriented transect originating at the approximate sample site center. Samples consisted of lichens occurring in 0.125 m^2 rectangular sampling frames. We visually estimated ground cover of lichens and other land cover classes including mosses, crowberry (*Empetrum nigrum*), willow (*Salix* spp.), graminoid, other vascular plants, and non-living (e.g., soil, rock, detritus) within each sampling frame to the nearest percentage. Although observers all had experience from other studies in visually estimating cover, no

training or other efforts were made to attempt to standardize estimates. We then plucked all fruticose and foliose lichen from each sampling frame and did not separate living from non-living lichen. We oven dried the samples at 40° C, sorted them into like taxa and then weighed them to the nearest 0.001 g using an AND GX 400® balance (mass range: 0.001g to 410g). All lichen identifications were performed by T. Goward using a dissecting microscope and chemical reagents as needed (Brodo *et al.,* 2001).

We totaled lichen biomass of the 4 subsamples taken at each site and considered the total biomass by taxa for each site as replicates. We tested for change in biomass and cover between sampling periods using unequal-variance T-tests when Kolmogorov-Smirnov tests indicated data were not normally distributed or demonstrated unequal variance. When normally distributed, we made comparisons with equal-variance T-tests. Estimated lichen cover was averaged among plots at each site and sites were considered replicates. Average cover values were related to total biomass of all lichens per site using ordinary least squares regression. Statistical tests were performed at an alpha level of 0.05 using NCSS 10 Statistical Software (2015).

We calculated the rate of lichen recovery using 3 different models: linear and exponential growth functions and a growth curve specifically developed for woodland lichens in Scandinavia (Pekkarinen *et al.,* 2015). Linear growth was calculated as the average yearly increase in average lichen biomass between 2 points in time. For example, if average lichen biomass increased from 100 to 110 kg/ha in a 10-year period, the growth is assumed to continue to increase at 1 kg/ha annually. Exponential growth was calculated as the percent increase in average lichen biomass (kg/ha) between 2 points in time. For example, if average lichen biomass increased from 100 to 110 kg/ha in a
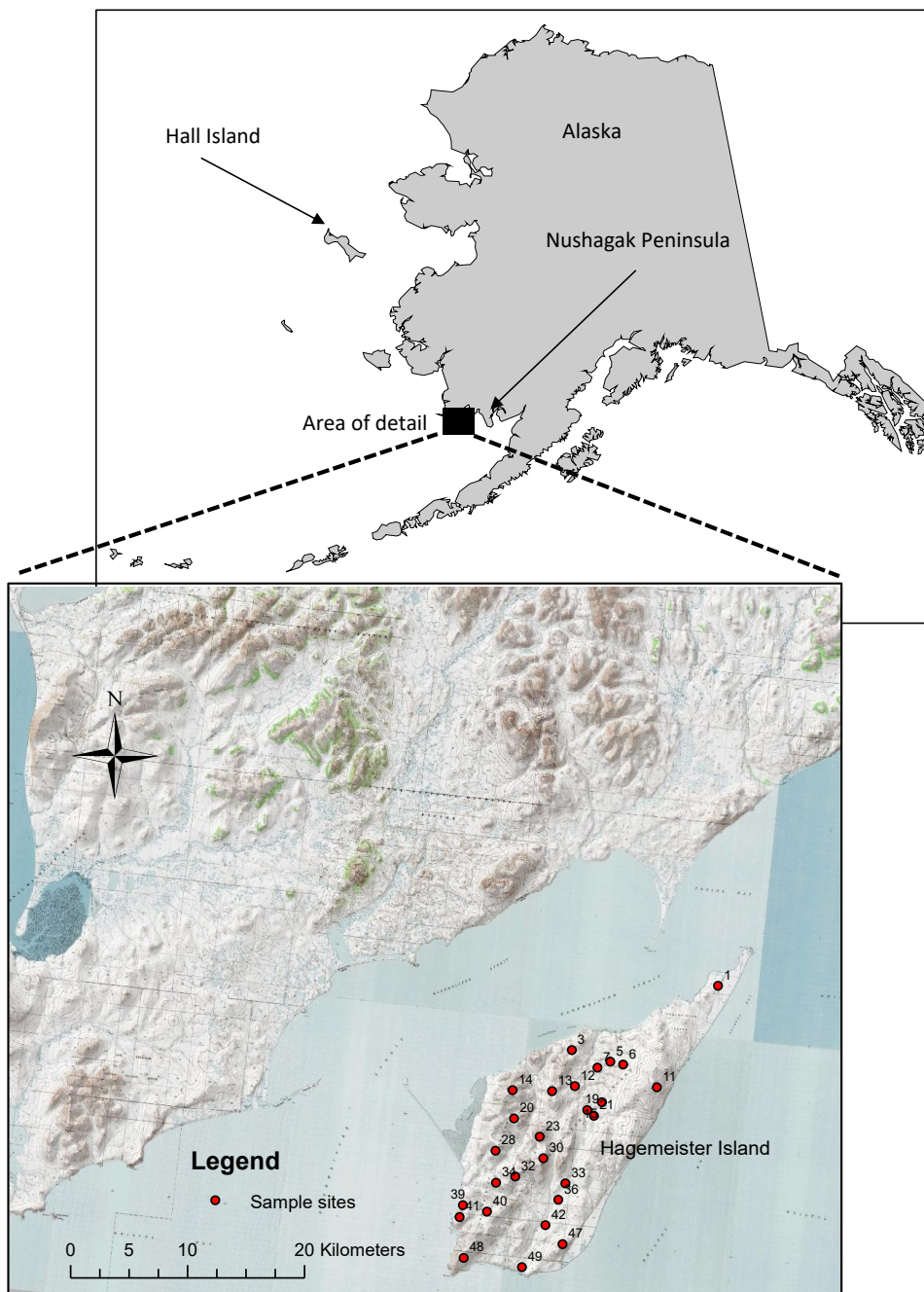
Figure 1. Sites sampled for lichen and other ground cover in 2003 and 2015 on Hagemeister Island and comparison study sites on Hall Island and Nushagak Peninsula, Alaska.

10-year period, growth is assumed to continue to increase at 10% every 10 years. The Pekkarinen *et al.,* model is expressed as

Annual lichen growth = g [-0.7008 * z + z (1 + z/100.5832)^{-0.0853}]

where parameter *g* is a habitat specific factor dependent upon the site potential to produce lichen varying from 0 to 1 where 1 is the growth rate in mature and old pine (*Pinus*) forests in Finland based on Kumpula *et al.,* 2000 and new data collected at Kaamanen Field Station, Finland (Kumpula *et al.,* unpublished). We calculated *g* in a simulation model by adjusting values of *g* until modeled annual biomass changed from a measured value taken at one point in time to a measured value taken at a later point in time. Parameter *z* is the dry weight of lichen at the beginning of the annual growing cycle.

We defined full recovery as the point in time when average biomass gain ceases following uninterrupted lichen growth and assumed this will occur on Hagemeister Island at some point within a range of approximately 5,070 – 6,658 kg/ha of lichen. Our basis for this range is taken from climax community lichen biomass measured at similar study sites, including:

1. <u>Nushagak Peninsula</u> (58° 60' N, 159° 02' W, Fig. 1), a mainland peninsula extending 40 km into the Bering Sea approximately 100 km east of Hagemeister Island. After more than 100 years absence of caribou grazing, caribou were reintroduced in 1988 (Hinkes & Van Daele, 1994). In 1993, Johnson (1994) reported that evidence of grazing remained negligible and performed a lichen assessment using a double-observer method relying on visual estimates that are corrected by a subset of clipped, dried, and weighed samples (Soil Conservation Service, 1972; Swanson *et al.,* 1983). Johnson estimated lichen biomass of 6,658 kg/ha (SD 1,708).

2. <u>Hall Island</u> (58° 60' N, 159° 02' W, Fig. 1), an island with no history of caribou grazing located approximately 700 km northwest of Hagemeister Island in the Bering Sea. Klein and Shulski (2009) reported lichen biomass from lichen-dominated communities from 2 times: 1985: 5,500 kg/ha (SD 1,440) and 2005: 5,070 kg/ha (SD 860).

We recognize that caribou range is useful for grazing well before full recovery, as reported in Collins *et al.,* 2011. Using their value of 1,250 kg/ha lichen biomass as the point at which caribou select habitat for grazing, we used the three models above to calculate the time required to reach this point.

Results
We sampled lichens on Hagemeister Island during the period 16-21 June 2003 and 16-19 June 2015. We collected 1,419 specimens in 2003 and 1,806 in 2015 (Supplemental materials Table 1). We recorded a total of 65 individual species or subspecies in 2003 and recorded an additional 13 taxa in 2015, for a cumulative total of 78 species or subspecies (Fig. 2, Supplemental materials Table 2). Total biomass of lichens per site averaged 504.2 (SD 205.4) kg/ha in 2003 and 795.3 (SD 489.6) in 2015. Average 2015 lichen biomass was significantly heavier than in 2003 (t = -2.847, d.f. = 34.88, P < 0.004), increasing linearly by approximately 24 kg/year. If growth progresses at this rate, recovery will occur in 200 – 267 years (Fig. 3). Under the exponential growth model, lichen biomass increased 57% in 12 years, and at this rate will reach recovery in 71 – 79 years. Under the Pekkarinen *et al.,* model, the lower recovery range will be reached in 160 years, but the model saturates at approximately 6,500 kg/ha in approximately 400 years (Fig. 3), not quite reaching the assumed recovery upper limit. Additionally, lichen biomass was estimated to reach 1,250 kg/ha (the point at which caribou select grazing habitat, Collins *et al.,* 2011) in
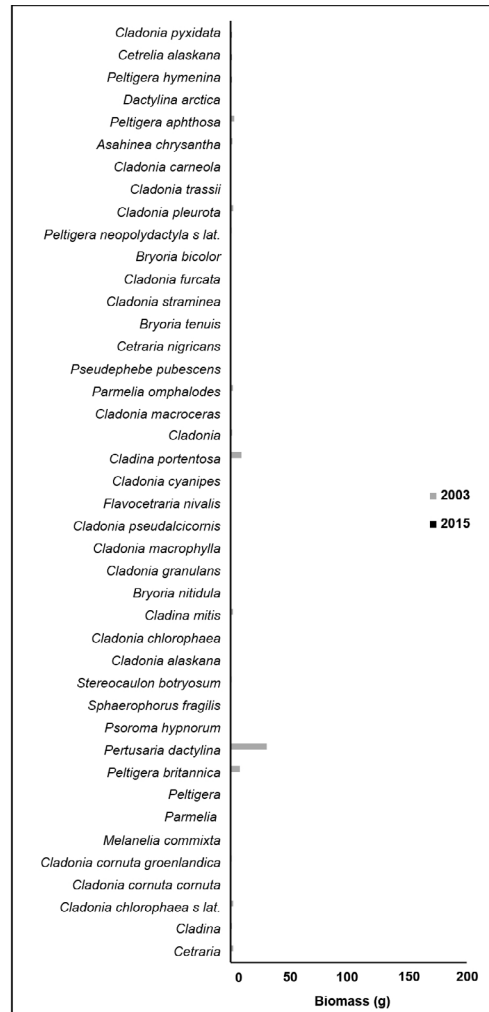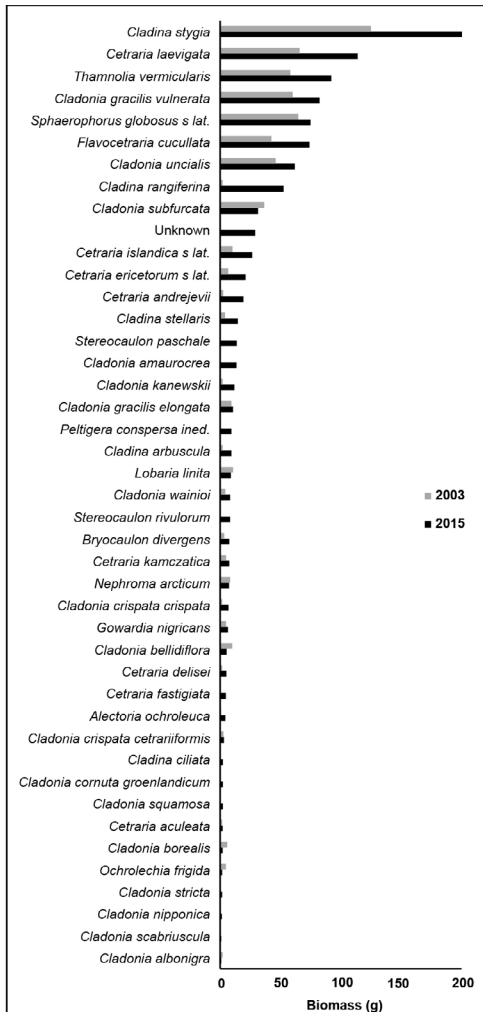
Figure 2. Comparison of total dry biomass of lichen taxa at all sample locations combined in 2003 and 2015 at Hagemeister Island, Alaska, ordered by 2015 dominance. Trace quantity measurements are not visible.

41 years according to the linear model; in 34 years using the exponential model; and in 37 years as stated by the Pekkarinen *et al.,* model.

Lichen cover estimates averaged 22.2% (range 1.8-50) in 2003 and 28.2% (range 3.8-57.5) in 2015 (Supplemental mMaterials Table 3). There was no detectable difference in percent cover between the two time periods (T = -1.5055, d.f. = 52, P < 0.070). There was a moderately strong relationship (r^2 = 0.498) between visually estimated cover and measured

biomass (Fig. 4). Frequency of occurrence of lichen taxa among sites ranged from a single site (n = 14 taxa) to 100% of sites (n = 6 taxa). Taxa that occurred within the upper 90th percentile of sites included *Flavocetraria cucullata, Cladonia subfurcata, Cladina stygia, Certraria laevigata, Thamnolia vermicularis, Sphaerophorus globosus* and *Cladonia uncialias*. These taxa total >60% of lichen biomass at all sites combined (Fig. 2). Dominance, or the influence of an individual taxon within its community,
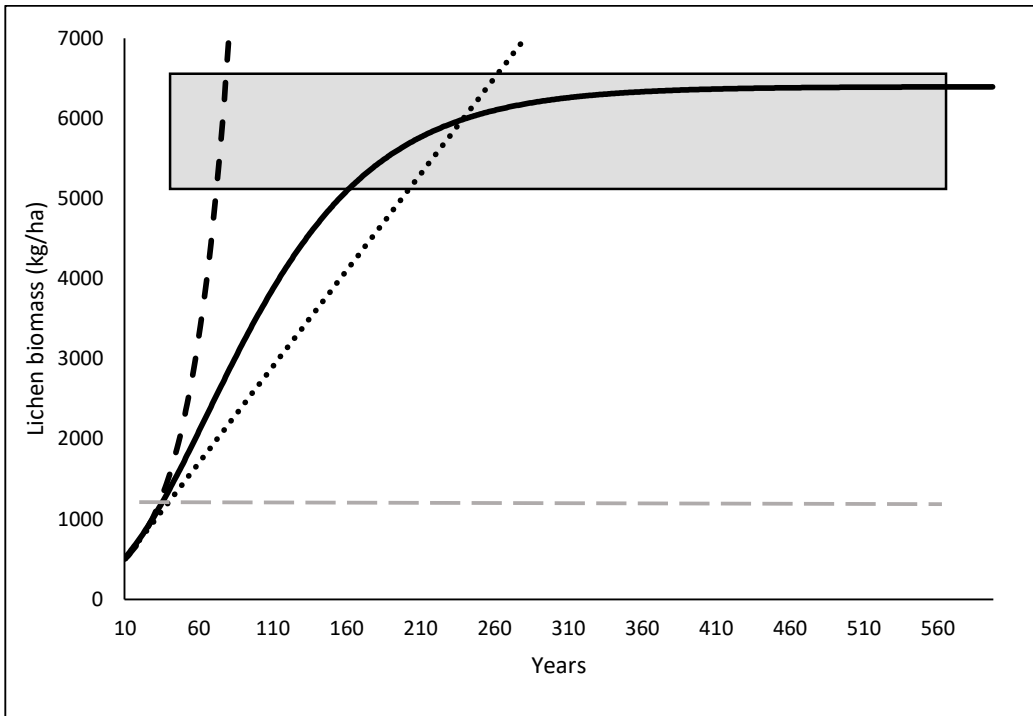
Figure 3. Pekkarinen *et al.,* (black line) and exponential (dashed line) and linear (dotted line) growth models of lichen biomass on Hagemeister Island, Alaska beginning in 2003 (year 10). Gray box defines assumed recovery range of 5,070 – 6,685 kg/ha lichen biomass. Dashed gray line defines the point at which growth reaches a graze-able biomass of 1,250 kg/ha.

can be reported as biomass per unit area. In this regard, *C. stygia* was clearly the dominant lichen species, followed by *C. laevigata, T. vermicularis, C. gracilis ssp. vulnerata, S. globosus, F. cucullata, C. uncialis, Cladina rangiferina* and *C. subfurcata* respectively. (Note: C. *stygia* is part of the *C. rangiferina* group, and is similar to *C. rangiferina* in form, color, and chemistry, but is distinguished by its dark brown to black stereome expressed at the basal portion of the thallus (Brodo *et al.,* 2001). Bases were broken or missing in many specimens collected in this study, so positive identification was not possible. However, as the majority of the specimens that could be identified with certainty were *C. stygia*, it is assumed that the remainder was *C. stygia* as well.)

Discussion

The St. Matthew Island example (Klein & Shulski, 2009) is the most similar study against which to compare the history of lichen recovery on Hagemeister Island and provides lessons valuable to management. An important difference between the St. Matthew and Hagemeister Island case studies is that reindeer on St. Matthew overgrazed the lichen communities to the point of starvation for virtually the entire population, while the reindeer on Hagemeister Island were removed by managers prior to total population starvation. Klein and Shulski (2009) reported evidence of the almost complete absence of forage lichen species (predominantly *Cladina* spp.) 22 years after the die-off, while we found that forage species dominated
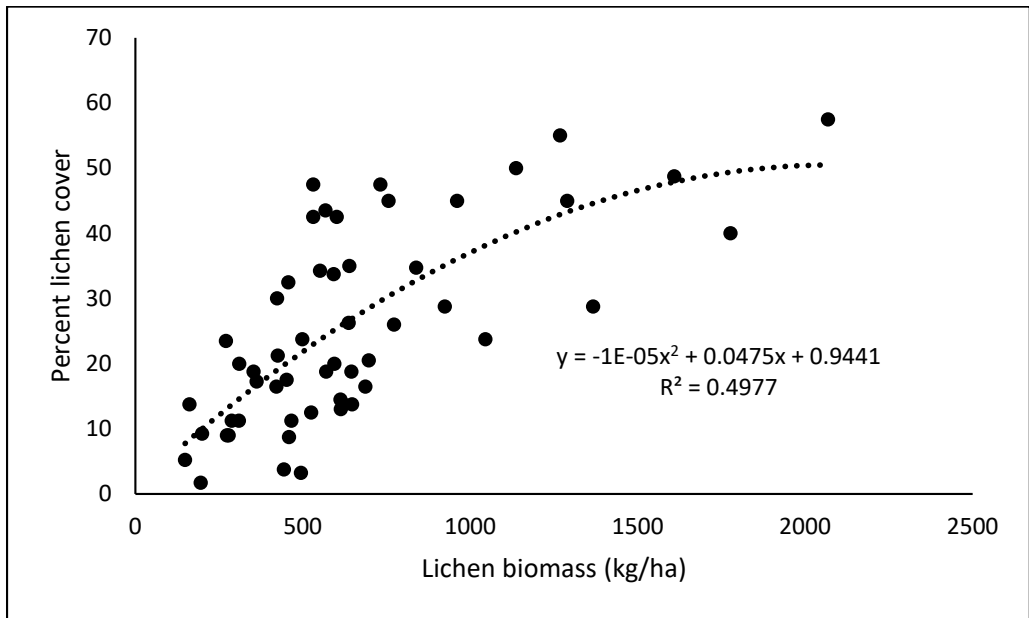
Figure 4. Relationship of visually-estimated percent lichen cover and weighed measurements at 27 study sites in 2003 and 2015 at Hagemeister Island, southwestern Alaska.

The equation shown on the figure:

$$y = -1\text{E}{-}05x^2 + 0.0475x + 0.9441$$
$$R^2 = 0.4977$$

Hagemeister Island lichen sites 10 years after reindeer removal. Thus, it seems apparent that reindeer removal from Hagemeister Island averted the more drastic ecological damage that St. Matthew Island sustained.

Given that measurements in this study occurred at only 2 points in time, the recovery rates measured here cannot be extrapolated with confidence, and thus we make no assumption on when full recovery will occur. Of the three growth models considered, the Pekkarinen *et al.* (2015) model is most realistic in that it accounts for the inevitable end in growth, while the linear and exponential models increase indefinitely, and thus cannot be considered useful beyond estimating when they reach a given biomass. However, the exponential model provided an estimated recovery time (71 – 79 years) more consistent with other investigator estimates, while the other models provided estimates of far longer recovery periods. We assume that the timing of full recovery of

caribou range is of less interest to grazing managers than the intermediate point in recovery at which lichen biomass reaches a grazeable level. Although the three models presented here provide substantially different estimates of full recovery, they provide quite similar estimates of when the range becomes useful for caribou grazing. If correct, that point will be reached on Hagemeister Island by 2027 – 2034. Future sampling can support, refute, or refine these models.

Visual estimates of percent cover are commonly used to monitor change in lichen communities over time (Soil Conservation Service, 1972; Henry & Gunn, 1991; Webb, 1998), although there are few published assessments of how well visual estimates perform. Dethier *et al.,* (1994) compared visual estimates of percent cover of sessile marine organisms against a probabilistic method and found that visual estimates were more accurate, and although they suggested that observer training could further

improve accuracy, did not detect differences among observers with varying degrees of experience. They concluded that visual estimates of percent cover can produce accurate and repeatable results among the same or different observers. Rosso *et al.,* (2014) argued that visual cover estimates are poor predictors of lichen biomass and recommended using volume (a combination of cover and height). Moen *et al.,* (2007) found that volume explained 0.88 – 0.96 of variation in lichen biomass. Here, we found that visual estimates directly related to weighed measurements but explained only half the variation. Additionally, our results demonstrate a saturation of the relationship suggesting that visual cover estimates are a better surrogate for weighed measurements at relatively low biomass levels and decrease in value as biomass increases. We conclude that in some cases, visual estimates may be sensitive enough for management, and in other cases managers should use more quantitative measures.

Note: Supplementary materials tables are available at: https://doi.org/10.5061/dryad.2v6wwpzm2

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