ISSN 1067-4136, Russian Journal of Ecology, 2023, Vol. 54, No. 2, pp. 77–87. © Pleiades Publishing, Ltd., 2023.
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Changing the Reserves of Green and Lichen Forage Stocks in the Southern Tundra Communities of Yamal from the 1930s to 2017–2019

A. M. Gorbunova[a], *, L. S. Gorbunov[a], and D. V. Veselkin[a]

[a] *Institute of Plant and Animal Ecology, Ural Branch, Russian Academy of Sciences, Yekaterinburg, 620144 Russia*

**e-mail: anastasiya_psu1991@mail.ru*

Received October 31, 2022; revised November 25, 2022; accepted November 29, 2022

Abstract—We compared the reindeer forage stocks at two landfills in the southern part of the Yamal Peninsula for the period from the early 1930s to 2017–2019. Data from [30] was used to characterize the feedstock in the 1930s. Feedstocks in the 1930s and 2017–2019 in plant communities in the basins of the the Erkatayakha and Baidaratayakha rivers were compared in the following vegetation divisions: lichen and shrub tundras; moss and grass tundras; shrub tundra; meadow communities; and bogs. The following hypotheses were tested: (1) the total supply of feed in Yamal decreased since the 1930s; (2) the decrease in stocks affected the lichen component to the greatest extent. Both hypotheses were confirmed. The general changes in the stocks and structure of food in the plant communities of South Yamal over the 85–87 years include delichenization, a decrease in the mass of lichens and the proportion of lichen food. The average stock of lichen fodder from the 1930s to 2017–2019 decreased by 5 times in the communities at the Erkatayakha test site and by 2 times at the Baidaratayakha test site. The mass of green fodder for 85–87 years has not changed. Thus, the change in the masses of economically important components of tundra vegetation over a uniquely long period, almost 90 years, has been characterized.

Keywords: Yamal, southern tundra, reindeer, pastures, overgrazing, delichenization, herbification, feed reserves, community productivity

DOI: 10.1134/S1067413623020066

INTRODUCTION

Different aspects of the dynamics of Arctic ecosystems attract great attention [1–4]. The amplitude of climatic changes in the Arctic is greater than in low latitudes [5–8]. The northern ecosystems are sensitive to climatic and direct anthropogenic influences [9] due to extreme conditions [10–12] and low species and functional diversity [13, 14].

The average duration of the observation periods of the vegetation of the Arctic is 20 ± 5 years (±95% confidence interval) using remote probing of the Earth [3, 5, 15–26] and 15 ± 10 years using the ground assessment of vegetation [18, 27–29]. The longest rows vary by about a quarter to a third of a century [3, 6, 16, 18, 21, 23, 29]. A unique opportunity to consider a change in the state of vegetation over 80–90 years is given by data published in 1934 in [30]. A comparison with data from this study made it possible to discuss changes in vegetation for a period of about 60 years [31].

The aim of the study was to compare the values of the reindeer feedstocks at two landfills in the south of the Yamal Peninsula from the beginning of the 1930s to 2017–2019. We checked two hypotheses: the first hypothesis suggested that the general supply of feed on Yamal decreased for the period since the 1930s; the second hypothesis suggested that the greatest reduction in stocks affected the lichen component, and the reserves of plant feed either decreased to a lesser extent, or did not decrease or, possibly, even increased.

These hypotheses are formulated on the basis of published data on the dynamics of the productivity of the ecosystems of the Arctic and taking into account information about the specificity of the dynamics of ecosystems on the Yamal Peninsula. Most researchers state that, at present, ecosystem productivity is increasing in the Arctic as a whole, which is described by the terms "herbification," "prairiefication," and "bushing" [2, 32, 33]. It is recognized that a general increase in the productivity of Arctic ecosystems is accompanied or caused by the advanced development of vascular plants and communities with their predominance. The results indicating a decrease in phytoma in Arctic ecosystems are rare [34]. Apparently, such a decrease is usually manifested at local and regional levels, as, for example, on Yamal. The situation on the Yamal Peninsula shows that reindeer grazing can affect the ecosystems more than climate

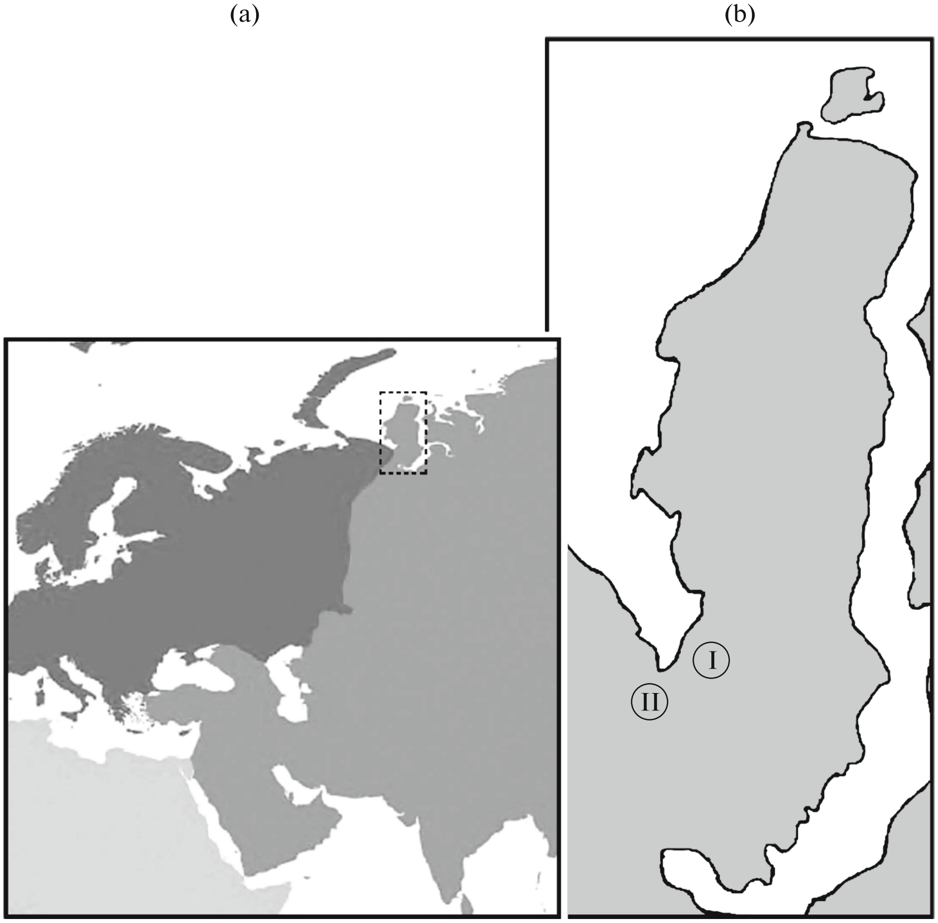

Fig. 1. (a) Geographic location of the Yamal Peninsula (dotted rectangle) and (b) location of test sites on the territory of Yamal (I, Erkatayakha; II, Baidaratayakha).

changes [9, 35]. In Yamal, intensive grazing of a large number of deer in a limited territory resulted in destruction, degradation, or a decrease in phytomass of certain types of vegetation [1, 36–40]. Grazing not only destroyed lichen cover, but it also reduced the stocks of herbs and shrubs [1, 36, 38, 40].

MATERIALS AND METHODS

We are discussing data related to the southern (shrub) tundra band of the subarctic tundra subzone of Yamal. The topography of the region is flat, hilly, and ridged. Absolute heights range from 1–3 m a.s.l. along the seacoasts and up to 85–90 m a.s.l. on the heights of central Yamal [41]. The distribution of permafrost is continuous. The watersheds are mainly occupied by shrub tundra in combination with grass–moss, shrub–moss, and shrub–lichen–moss tundras [27]. Meadow communities and shrub thickets are widespread in the floodplains of the rivers.

The climate has long and severe winters (average January temperature –23.5°C; duration of snow cover 240–260 days), short cool summers (average July temperature +15.2°C), late spring and early autumn frosts (frost-free period duration from 50 to 92–96 days). According to the Salekhard meteorological station, the increase in the average annual air temperature from 2001 to 2018 was +1.1°C/10 years [42], mainly due to the warming of the spring months.

In the 1930s, the number of domestic reindeer in the Yamalo-Nenets Autonomous Okrug was estimated at 350000–360000 individuals, including 100000–130000 individuals in Yamal [30]. In 2015–2016, there were 670000–765000 individuals in the territory of the district [43, 44], and 200000–330000 individuals in Yamal in 2001–2018 [42].

Test sites. In 2017–2019, field studies were carried out at two test sites in the lower reaches of the Erkatayakha and Baidaratayakha rivers (hereinafter, polygons are designated by the names of the rivers): the Erkatayakha test site is located in the southern part of the South Yamal (Yurebey) region [30]; the Baidaratayakha test site is in the northern part of the Ural region (Fig. 1).

The test site in the lower reaches of the Erkatayakha river is located on the territory of the Erkut research station of the Institute of Economics and Life, Ural Branch, Russian Academy of Sciences (68°13′38.30″ N, 69°9′2.20″ E). The topography is a gently sloping marshy plain. The watersheds are low (11–17 m a.s.l.). Soil-forming rocks are sandy and sandy loamy [41]; tundra soils are illuvial–humus, bog–frozen, bog humus–peaty–gley. Pastures are used mainly during the snowless period, during the transition of deer to winter pastures located to the north.

The test site in the lower reaches of the Baydaratayakha river is located on the southern coast of Baidaratayakha Bay (68°05′41.75″ N, 68°16′56.24″ E). The topography is flat, slightly undulating [37]. Absolute heights range from 4 to 10 m a.s.l. Humidification is excessive; soils are marsh, marsh frozen peat, or residual peat. Summer pastures, floodplain, mostly forb–grass–sedge [41]. The landfill also includes reindeer crossing routes to winter pastures.

Assessing feedstocks. Evaluation of deer feed in the 1930s is given in [30]. The origin and authorship of specific assessments in [30] are not indicated; therefore, all the characteristics of the reserves are dated to 1932. V.N. Andreev used cuttings of 1 m^2 in the air-dry state to determine the feedstocks. He separately cited data for lichen and green feed; he analyzed the leaves of shrubs, sedge, cereals, heels, and shrubs in green feeds. However, it is not indicated in which months the cuttings were taken, but there is a clarification that "... is given productivity ... slightly lower than the maximum size at the end of summer" [30, p. 124]. We used information from this work as follows: we took estimates only for the South Yamal (Yureby) and Urals districts; we brought all the fractions of feed reserves to two fractions: lichens and greens; we considered all information as independent observations. In total, there were 25 assessments for the Erkatayakha landfill and 20 assessments for the Baidaratayakha training ground.

Reindeer feedstocks were explored in July–August, 2017–2019. Geobotanical descriptions were carried out on test plots of 10 × 10 m and the stocks of aboveground phytomass were determined by the cutting method. On each square, three cuttings were taken from sites of 25 × 25 cm [45], the data on which was averaged up to one estimate on the square. Grassy plants and shrubs were cut at the level of the green and brown parts of the mosses. Cuttings in the air-dry state were disassembled by fractions: lichens, grasses, sedges, cereals, eaten parts of shrubs, and dwarf shrubs (*Dryas octopetala* L., *Salix nummularia* Andersson, *Salix polaris* Wahlenb., *Vaccinium uliginosum* L., *Vaccinium vitis-idaea* L.). The masses of the green part of the mosses, litter, dead grass, and stipitates of shrubs were taken into account. Bushy lichens were collected; crustaceous and foliose lichens were not taken into account. In total, we used: 80 independent assessments for the Erkatayakha test site (2017, 15 squares; 2018, 5 squares; 2019, 60 squares) and 8 assessments for the Baidaratayakha test site (2019, 8 squares).

Major divisions of vegetation. Stocks and ratios of forage fractions vary greatly in different plant communities. To correctly take into account this variability, we compared the vegetation subdivisions studied by Andreev [30] and us (Table 1). According to the ecological–phytocenotic (dominant) classification, the communities of the studied territories belong to three types of vegetation: tundra, meadows, and bogs. In the tundra vegetation, which is predominant in the study area, the following formations were distinguished: moss tundra, grass tundra, lichen tundra, dwarf shrub tundra, and shrub tundra. Within the formations of tundra vegetation and types of meadow and marsh vegetation, groups of associations were distinguished. At the analysis stage, five divisions of vegetation were used: (1) lichen and dwarf shrub tundras; (2) moss and grass tundras; (3) shrub tundras; (4) meadow communities; and (5) bogs, since the data on stocks for shrub tundra for the 1930s are not given, and they are few for herbaceous tundras [30].

For data analysis, general linear models (GLMs) were used with discrete predictors and calculation of only two-factor interactions between factors. In GLMs, the values of stocks of all fractions were analyzed after the logarithm, and the values of the characteristic "share of lichen forages" were analyzed after arcsine transformation. The figures and text use untransformed values. The calculations were made in the STATISTICA 8.0 package (StatSoft, United States, 1984–2007).

RESULTS

Feed stock values in the 1930s and 2017–2019 at different sites. Stocks of green fodder at the Erkatayakha test site, average for vegetation subdivisions, varied in the range of 1.4–25.0 c/ha in the 1930s and in 5.7–11.1 cq/ha in 2017–2019 (Figs. 2a and 2b); stocks at the Baidaratayakha training ground were 8.8–25.0 c/ha in the 1930s and 9.5–22.3 c/ha in 2017–2019. In general, the lowest amount of green fodder was found in lichen and shrub tundras, moss and grass tundras, and the highest amount of green fodder was found in shrub tundras and bogs.

The average reserves of lichen fodder (Figs. 2c and 2d) at both polygons differed greatly between vegetation subdivisions in the 1930s and slightly in 2017–2019. Average stocks for vegetation subdivisions at the Erkatayakha test site in the 1930s varied in the range of 0–34.6 c/ha; in 2017–2019 the reserves of lichen fodder were lower here and varied from 0 to 2.5 c/ha. There were fewer lichens at the Baidaratayakha test site than at the first test site: 0–2.7 c/ha in the 1930s and 0–0.4 c/ha in 2017–2019; lichens did not form a food reserve in the meadows, and most of them were in lichen and shrub tundra.

Table 1. Comparison and brief description of vegetation divisions studied in the 1930s and in 2017–2019.

<table>
<tr><th colspan="2">Major divisions of vegetation</th></tr>
<tr><th>1930s [30]</th><th>2017–2019</th></tr>
<tr><td colspan="2">Lichen tundra: mostly on plains; soils are sandy and sandy loam; dominants Vaccinium uliginosum L., Diapensia lapponica L., Carex bigelowii subsp. arctisibirica (Jurtzev) Á.Löve & D.Löve; Rhytidium rugosum (Hedw.) Kindb., Pleurozium schreberi (Brid.) Mitt., Aulacomnium sp.; Flavocetraria sp., Ochrolechia sp., Cladonia sp. Cover: total, 30–99%; mosses, 5–40%; lichens, 10–98%</td></tr>
<tr><td>Moss-lichen
Herbaceous-moss-lichen
Herbaceous-lichen
Dwarf shrub-lichen</td><td>Dwarf shrub-moss-lichen
Grass-moss-lichen
Grass-dwarf shrub-lichen
Moss-shrub-lichen
Moss-dwarf shrub-lichen</td></tr>
<tr><td colspan="2">Dwarf shrub tundra: mainly on the upper parts of the slopes; soils are sandy; dominants Empetrum nigrum L., Vaccinium vitis-idaea L., Rhododendron tomentosum Harmaja, Arctous alpina (L.) Nied., Equisetum arvense L.; Oncophorus sp., Aulacomnium sp.; Ochrolechia sp., Cladonia sp., Thamnolia vermicularis var. subuliformis (Ehrh.) Schaer. Cover: total, 30–100%; mosses, 1–50%; lichens, 0–85%.</td></tr>
<tr><td>The community type “dwarf shrub tundra” is absent in the report [30].</td><td>Moss-dwarf shrub
Grass-moss-dwarf shrub
Grass-dwarf shrub
Moss-grass-dwarf shrub
Lichen-grass-dwarf shrub
Moss-lichen-dwarf shrub
Shrub-lichen-dwarf shrub</td></tr>
<tr><td colspan="2">Moss tundra: mostly on terraces; clayey and sandy loamy soils; dominants V. vitis-idaea, V. uliginosum, Rubus chamaemorus L.; Polytrichum sp., Dicranum sp., Racomitrium lanuginosum (Hedw.) Brid.; Peltigera sp., Thamnolia vermicularis var. subuliformis (Ehrh.) Schaer., Cladonia sp. Cover: total, 40–100%; mosses, 25–100%; lichens, 1–50%.</td></tr>
<tr><td>Lichen-moss
Shrub-grass-moss
Shrub-moss</td><td>Lichen-grass-moss
Dwarf shrub-grass-moss
Shrub-grass-moss
Dwarf shrub-lichen-moss
Grass-dwarf shrub-moss
Grass-shrub-moss
Dwarf shrub-shrub-moss
Shrub-moss</td></tr>
<tr><td colspan="2">Grass tundra: mainly in the lower parts of gentle slopes; clayey and loamy soils; dominants V. vitis-idaea, C. bigelowii subsp. arctisibirica, Eriophorum vaginatum L., Eriophorum angustifolium Honck.; Polytrichum sp., Aulacomnium sp., Sphagnum sp.; Cladonia sp., Thamnolia vermicularis var. subuliformis (Ehrh.) Schaer. Cover: total, 80–100%; mosses, 10–85%; lichens, 1–20%.</td></tr>
<tr><td>Moss-grass</td><td>Lichen-moss-grass
Dwarf shrub-moss-grass
Lichen-shrub-herbaceous</td></tr>
<tr><td colspan="2">Shrub tundra: in floodplains; soils are sandy and clayey; dominants – Salix glauca L., Betula nana L., Andromeda polifolia L., V. uliginosum, Carex aquatilis Wahlenb.; Polytrichum sp., Dicranum sp.; Peltigera sp. Cover: total, 45–98%; mosses, 5–60%; lichens, 0–2%.</td></tr>
<tr><td>Willow moss
Willow forb
Willow grass
Willow moss-grass
Birch moss-lichen
Birch grass-moss</td><td>Willow shrub-moss
Willow grass
Birch dwarf-moss</td></tr>
</table>

Table 1. (Contd.)

Major divisions of vegetation	
1930s [30]	2017–2019
Meadow communities: mainly in floodplains; soils are sandy, less often clayey; dominants *E. arvense*, *Calamagrostis purpurea* (Trin.) Trin., *C. aquatilis*, *Eriophorum scheuchzeri* Hoppe, *Rubus arcticus* L.; *Polytrichum* sp., *Aulacomnium* sp.; *Nephroma arcticum* (L.) Torss. Cover: total , 40–100%; mosses, 0–30%; lichens, 0–1%.	
Grass meadow	Moss-grass meadow
Grass floodplain meadow	Grass meadow
	Moss-grass meadow
	Grass meadow
Bogs: mostly on the plains; dominants *V. vitis-idaea*, *R. tomentosum*, *E. vaginatum*, *Carex rariflora* (Wahlenb.) Sm., *Comarum palustre* L.; *Sphagnum* sp., *Polytrichum* sp.; *Cladonia* sp., *Ochrolechia* sp. Cover: total, 95–100%; mosses, 50–100%; lichens, 0–90%.	
Grass moss	Grass moss
Lichen-grass-moss	Shrub-grass-moss
Shrub-lichen-grass-moss	Shrub-grass-moss
Grass	Grass-lichen-moss
Lichen-grass	Shrub-lichen-moss
Grass-lichen	Grass-shrub-moss
	Shrub-moss-grass
	Shrub-moss-lichen
	Lichen-moss-shrub

The total supply of food is the sum of green and lichen (Figs. 2e and 2f). The total supply of fodder at the Erkatayakha test site in the 1930s varied in the range of 12.3–36.0 c/ha. In 2017–2019, it was lower: 7.0–12.1 c/ha. The largest feedstock at the Erkatayakha test site was in shrub tundra, lichen, and dwarf shrub tundra; in 2017–2019, it was the largest in meadow communities, moss, and grass tundras. At the Baidaratayakha test site, the variability of average reserves over time is not expressed: 10.0–26.3 c/ha in the 1930s and 9.8–22.7 c/ha in 2017–2019, with the largest stock in shrub tundra or bogs, and the smallest stock in moss and grass tundra.

The proportion of lichen feed varied greatly between test sites, over time, and between vegetation subdivisions (Fig. 3). At the Erkatayakha test site, average values for vegetation subdivisions varied in the range of 0–95% in the 1930s and in the range of 0–28% in 2017–2019. At the Baidaratayakha test site, the share of lichens in the total food supply was approximately 2–4 times lower: 0–22% in the 1930s and 0–6% in 2017–2019. The strongest decrease in the participation of lichens from the 1930s to 2017–2019 was observed in those communities, where they dominated in the 1930s.

Statistical assessment of the variability of feedstocks in different years of research on different polygons. For the Baidaratayakha polygon, there are no estimates of feedstocks in lichen and shrub tundra for the 1930s. Therefore, when conducting a statistical analysis, a GLM was used with an assessment of only the main effects: "years of research," "polygon," "vegetation subdivision," and two-factor interactions between them (Table 2). The stock of green fodder varied significantly only between different vegetation subdivisions. The main effects characterizing the differences between the years of research and polygons were not significant. The stock of lichen and their share in the total stock were more variable and at high significance levels differed between the years of research, polygons, and subdivisions. The total food supply unexpectedly turned out to be dependent only on the year of research. None of the indicators found a significant interaction between the factors "years of research" and "polygon." This means that stock changes from the 1930s to 2017–2019 had the same direction at both ranges.

General directions of changes in feedstocks. For a generalized idea of changes in feedstocks, they were analyzed without taking into account vegetation subdivisions (Fig. 4). Although the stock of green fodder based on statistical estimates has not changed over 85–87 years, a trend of its decrease in the communities of both polygons is visible. The average stock of lichen fodder from the 1930s to 2017–2019 decreased by 5 times at the Erkatayakha test site and by 2 times at the Baidaratayakha test site. The total supply of fodder over the period of 85–87 years also significantly decreased: by 2.3 times at the Erkatayakha test site and by 1.5 times at the Baidaratayakha test site. The decrease at the Erkatayakha test site is mainly explained by a decrease in lichen stocks, and the

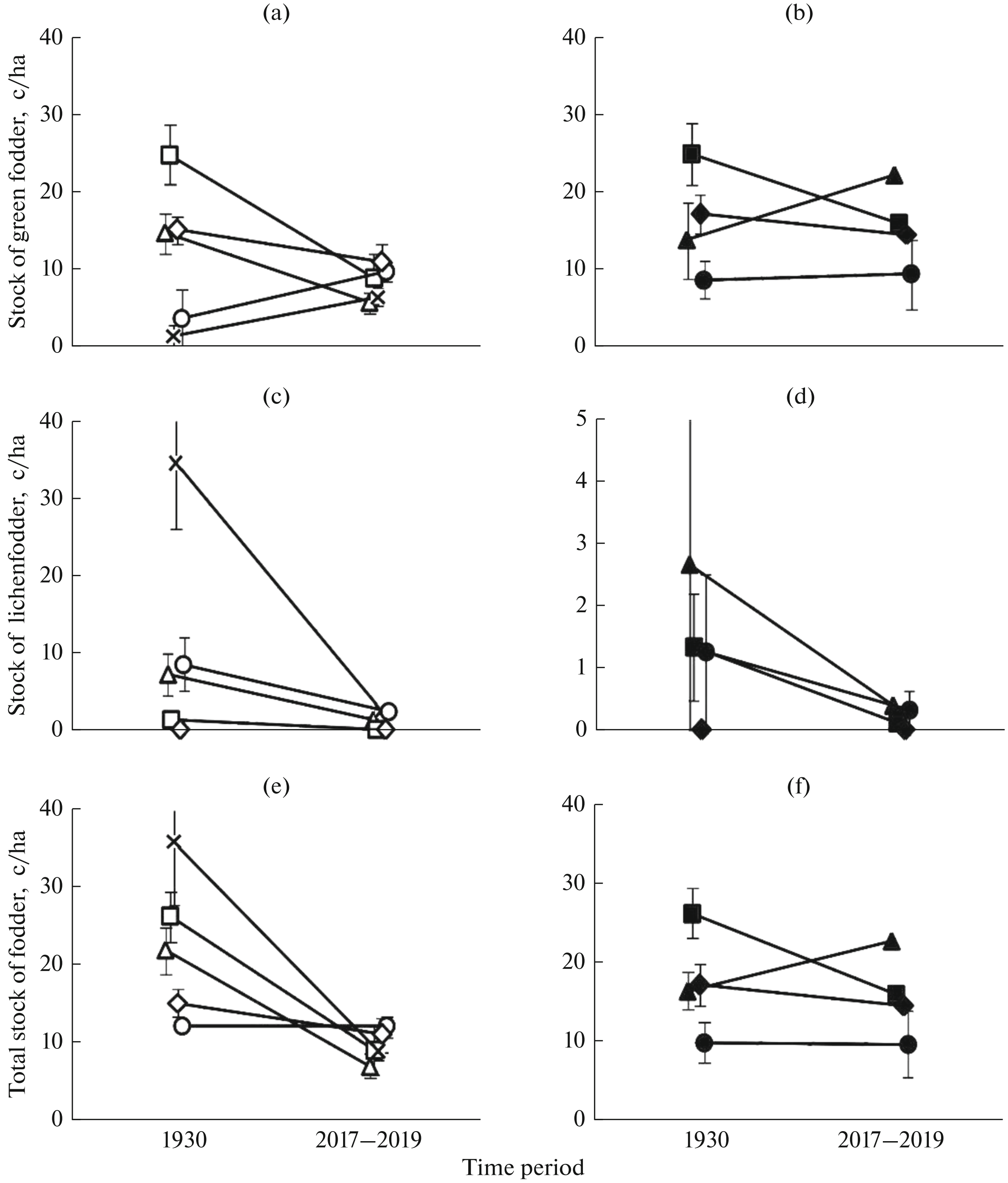

Fig. 2. Feedstocks of different fractions in the 1930s and 2017–2019 on polygons in the basins of the Erkatayakha (a, c, e) and Baidaratayakha (b, d, f) rivers: (a, b) green fodder; (c, d) lichen food; and (e, f) total stock. Here, and in Fig. 3, different symbols denote different divisions of vegetation: (oblique crosses) lichen and dwarf shrub tundra, (squares) shrub tundra, (circles) moss and grass tundra, (triangles) bogs, (diamonds) meadows, (vertical lines) standard error.

decrease at the Baidaratayakha test site is caused by an approximately equal change in the stocks of both green and lichen fodder. This is evidenced by the fact that the share of lichens in the total feedstock at the Erkatayakha test site decreased over time at a faster pace compared to green fodder, and the ratio between green and lichen feedstocks at the Baidaratayakha test site was stable.

DISCUSSION OF RESULTS

In South Yamal, over the 85–87 year period since 1932, the reserves of green deer feed did not change, and the reserves of lichen feed decreased. Due to the decrease in the reserves of lichens, the general feedstocks decreased and the ratio between the fractions changed towards the strengthening of the predominance of green feed. These changes are observed at

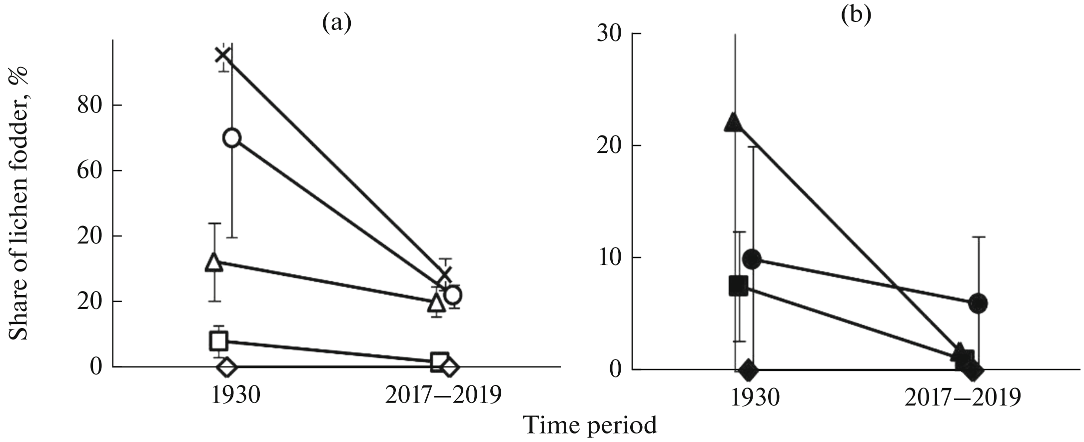

Fig. 3. Share of lichen fodder in the 1930s and 2017–2019 at landfills in the basins of the Erkatayakha (a) and Baidaratayakha (b) rivers.

both studied training grounds. Thus, both hypotheses were confirmed: the general supply of feed decreased due to a decrease in the fraction of lichen feed, i.e., one main phenomenon is established, which is described by the term division of communities.

Reliability of estimates of the change in feedstocks. Our study is an example of an analysis where the statistical reliability of comparisons is not sufficient and final confirmation of the objectivity of the result. The main doubts boil down to the question of how reasonable it is to compare food stocks for the 1930s and 2017–2019.

We believe that a comparison of modern estimates with those published for the 1930s is justified. Such confidence is due to the methodological clarity of the estimates published by Andreev [30]. First, this summary presents the data obtained in an understandable and reproducible way, which made it possible to repeat the measurements using not completely identical, but close methodology. Secondly, a clear classification of vegetation subdivisions was used in [30], which made it possible to take into account the variability due to the heterogeneity of the vegetation cover. Thirdly, Andreev [30] indicated geographic references for his data, and this made it possible to take into account geographic variability. Fourthly, Andreev [30] provided the initial empirical measurements, which made it possible to use standard methods of statistical analysis.

Part of stock that existed in the 1930s in the report [30] are apparently not taken into account. This is explained by the fact that “for the lands of the summer season ... only the productivity of green mass is given ... In the lands of the winter, spring, and autumn seasons ... productivity indicators are given only for lichens” [30, p. 124]. Lichen fodder is the main fodder fraction in the snow period, and green fodder is the main fodder fraction, respectively, in the snowless period [40, 46]. Therefore, estimates for the 1930s to some extent underestimate the reserves that existed at that time in the tundra of Yamal. But we took into account the reserves of both green fodder and lichens with equal accuracy in each community. Therefore, if we make a mistake when comparing past and present

Table 2. Significance of different factors of variability of fractions of food stocks and their ratio (GLM results, including the assessment of two-factor interactions between factors; dF, number of degrees of freedom; *F*, Fisher’s test; *P*, significance level)

Sources of variability	dF	Feedstocks						Share of lichen fodder	
		green		lichen		total			
		F	*P*	*F*	*P*	*F*	*P*	*F*	*P*
Years of research [1]	1	0.37	0.5456	17.69	0.0001	12.2	0.0007	10.98	0.0012
Test site [2]	1	2.70	0.1029	7.89	0.0058	0.34	0.5629	7.42	0.0074
Vegetation division [3]	4	8.10	<0.0001	9.64	<0.0001	1.10	0.3579	11.85	<0.0001
[1] × [2]	1	0.42	0.5162	1.02	0.3140	3.16	0.0783	1.19	0.2780
[1] × [3]	4	7.84	<0.0001	7.07	<0.0001	2.49	0.0468	7.05	<0.0001
[2] × [3]	4	0.22	0.9284	2.34	0.0594	0.85	0.4947	2.77	0.0303

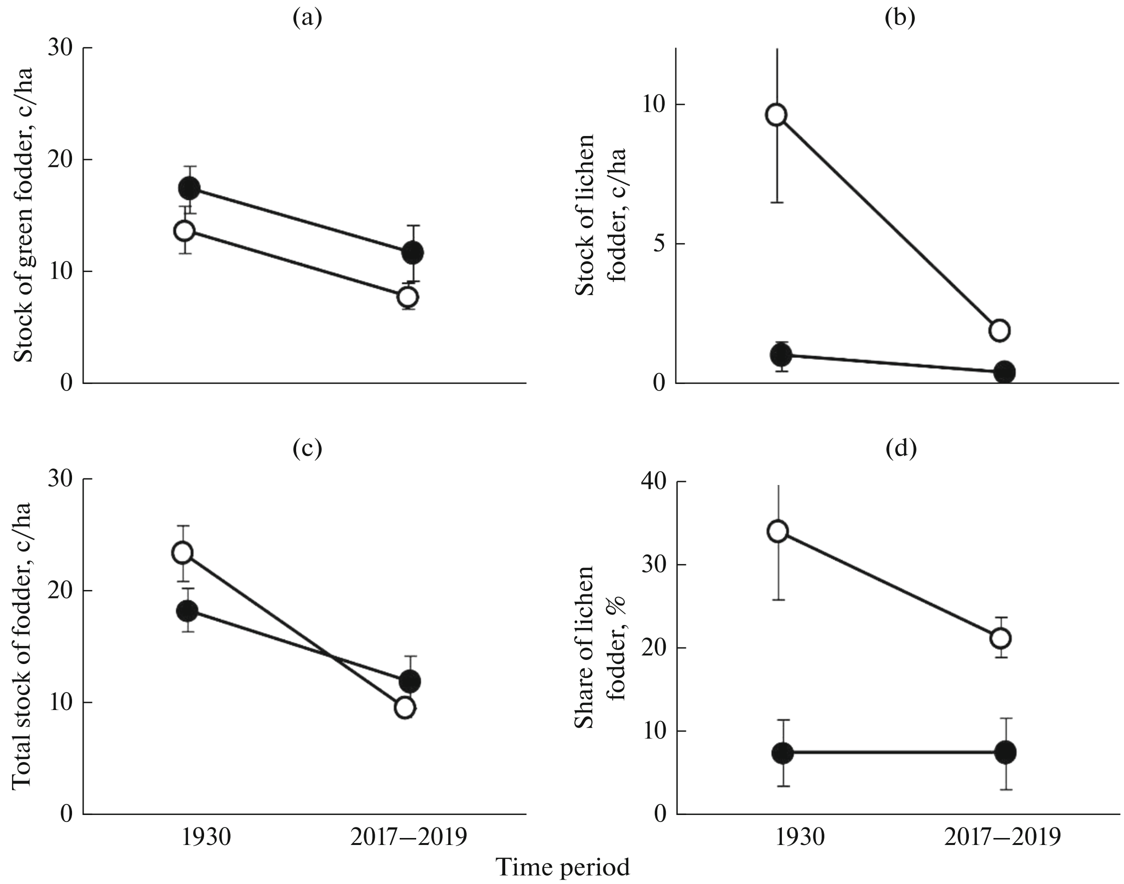

Fig. 4. Stocks and ratio of feed of different fractions in the 1930s and 2017–2019 at test sites in the basins of the Erkatayakha (○) and Baidaratayakha (●) rivers: (a) green fodder; (b) lichen fodder; (c) total stock; (d) the share of lichen stock; (verical lines) standard error.

food stocks, it is only in the direction of underestimating probable temporal differences.

There is uncertainty in the estimates associated with the inclusion or non-inclusion of dead grass, which is food for the reindeer in the feed stocks [30], but it is usually separated from green fodder as a separate fraction [46]. In [30, p. 123] there is a single mention that dead grass can serve as food for reindeer, but there is no explicit indication whether it was included in the feed supply or not. Apparently, Andreev did not include dead grass in green fodder. We recorded the mass of dead grass, but also did not take into account the composition of green fodder. According to our data, the mass of dead grass on average is about 60% of the stock of green fodder. It turns out that the estimates for 2017–2019 underestimate the stock of vegetable feed per mass of dead grass, i.e., by about 30–40%, although it is unlikely that Andreev indicated the stocks of green fodder, including dead grass in it. In any case, the uncertainty of the estimates associated with the inclusion or exclusion of dead grass could affect the amount of green, but not lichen fodder.

Feedstocks, biomass, and community productivity. Changes in the values of feedstocks can be interpreted as environmentally friendly, but with important restrictions. Different fractions of feed are parts of plant biomass, phytomass, and communities, but they are not directly converted into biomass, phytomass, and products. Green feed is a characteristic close to the annual aboveground products of plants. Pure annual products of the aboveground part of the communities include, in addition to feedstocks, the unaccounted parts of all plants located close to the surface of the Earth, and unknown components (mosses, plans, *Veratrum lobelianum* bernh., wood of shrubs, and dwarf shrubs *Rhododendron tomentosum* Harmaja, *Empetrum nigrum* L., *Arctous alpina* (L.) Nied., *Diapensia lapponica* L., and *Andromeda polifolia* L.). Thus, the supply of green feed is a correlation characteristic of plant biomass and phytomass. Green feeds make up 38–76% in different units of vegetation according to our data and 18–88% of aerobatic biomass according to [47]. Despite such a significant scatter, it will not be erroneous to believe that a change in the size of green feed can be interpreted as evidence of the same in the direction and close in terms of changes in the biomass of plants, their products, and phytomass of communities. Lichen feed is a perennial formation and a characteristic of the total mass, but not the annual products of bushy lichens.

Possible reasons for the change in feedstocks. Our results point to delichenization as the leading process of vegetation transformation in the southern subarctic tundras of Yamal. For 85–87 years, only a decrease in the mass of lichens is actually noticeable and a change in the mass of food formed by vascular plants is not noticeable. This result confirms the phenomena associated with pasture transformation described for Yamal [1, 32, 36–40] established at shorter time intervals. A strong overgrazing is a sufficient explanation for the decline in lichen stocks [9, 36, 40]. The decrease in the abundance of lichens due to anthropogenic disturbances, in particular due to overgrazing, is well known [30, 32]. Already in the 1930s, the number of deer in the areas of our study was considered close to the maximum possible [30]. A further increase in the number of deer in Yamal [3, 42] could lead to a progressive decrease in the proportion of lichens in the total food supply.

Changes in the stocks of green fodder in the plant communities of the tundra for 85–87 years have not been found. The data that we have do not allow us to confirm neither their increase (which could be expected based on the results of studies on leading climatogenic trends) nor decrease. A decrease in the stocks of grasses and shrubs has been described in other areas of Yamal [1, 36, 38, 40], which the authors also explain by the consequences of overgrazing. Phenomena described as herbification, prairiefication, and bushing [2, 32, 33] were not confirmed at the level of the biomass structure in specific communities in the areas of our study, if an increase in the absolute masses of fractions formed by vascular plants is meant. Our estimates allow us to speak of "greening" only in the sense that the share of vascular plants in the total amount of feed or biomass increases. However, such changes are caused by the delichenization of communities.

When interpreting the above results, it is necessary to take into account their strict attachment to the studied vegetation subdivisions. We did not analyze the ratio of areas occupied by different departments. Meanwhile, climatogenic changes in Arctic vegetation can primarily be reflected in changes in the ratio of areas occupied by different formations. The change in the ratio of the areas of landscapes and communities with different states is central in program generalizations regarding the climatogenic and anthropogenic dynamics of Arctic vegetation [2, 32]. Our results are more specific: they characterize changes in the structure of plant components only within individual subdivisions of tundra vegetation.

CONCLUSIONS

A comparison of the assessments of the feed reserves of the northern deer obtained at two landfills in South Yamal: in the basins of the Erkatayakha and Baidaratayakha river, in the 1930s [30] and in 2017–2019, showed that the patterns of the variability of the two main fractions of the feedstocks, green and lichen, have both common moments for both test sites and a pronounced specificity. The general direction of the change in the structure of the feed over 85–87 years is division, a decrease in the absolute mass of bushy lichens, and the share of lichen feed. The average supply of lichen feed from the 1930s to 2017–2019 reduced 5 times at the Erkatayakha test site and 2 times at the Baidaratayakha test site. The mass of green feed over 85–87 years has not decreased, but it also did not increase. In general, a change in the masses of economic components of tundra vegetation for the long period of almost 90 years was characterized. Apparently, the state of vegetation in southern Yamal is more determined by the local effects associated with the high density of ungulative phytophages than climatogenic causes.

FUNDING

The study was carried out as part of the topic of the state assignment of the Institute of Ecology of Plants and Animals, Ural Branch, Russian Academy of Sciences no. 122021000092-9.

COMPLIANCE WITH ETHICAL STANDARDS

Conflict of interest. The authors declare that they have no conflicts of interest.

Statement of the welfare of humans or animals. The article does not contain any studies involving humans or animals in experiments performed by any of the authors.

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Translated by M. Shulskaya