Soininen et al. Environ Evid (2018) 7:23
https://doi.org/10.1186/s13750-018-0135-1

Environmental Evidence

SYSTEMATIC MAP PROTOCOL

Evidence of effects of herbivory on Arctic vegetation: a systematic map protocol

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Abstract

Background: Along with climate change, herbivory is considered a main driver of ecosystem change in terrestrial Arctic environments. Understanding how herbivory influences the resilience of Arctic ecosystems to ongoing environmental changes is essential to inform policy and guide sustainable management practices. However, many studies indicate that the effects of herbivores on plants and ecosystem functioning depend on the abiotic and biotic conditions where the interaction takes place, i.e. the ecological context. Yet, the range of ecological contexts in which herbivory has been studied in the Arctic has not been systematically assessed. A lack of such evaluation prevents understanding the robustness and generalizability of our knowledge of Arctic herbivore effects on vegetation and ecosystems. The main objective of our systematic map is to identify the ecological contexts where herbivory is studied in the Arctic. Hence, this systematic map will enable us to assess our ability to make generalizable and robust conclusions regarding the impacts of Arctic herbivory.

Methods: We will search academic and grey literature using databases, search engines and specialist websites, and select studies addressing the response of the plant(s) to herbivory, deemed relevant in terms of (i) population (terrestrial Arctic plants and plant communities), (ii) exposure (herbivory, including disturbance and fertilization effects of herbivores), and (iii) modifier (ecological context being in the terrestrial Arctic including forest-tundra). We will synthesize the results using systematic mapping approaches.

Keywords: Browsing, Grazing, Grubbing, Defoliation, Tundra, Oro-Arctic, Forest-tundra, Vegetation, Plant–herbivore interaction

Background

Herbivory is a biotic interaction in tundra ecosystems that strongly influences the structure and dynamics of plant communities [1]. Herbivory interacts with climate change and has the potential to buffer some of the effects of warming in tundra, like increases in shrub cover [2] or advances in the tree line [3, 4]. Furthermore, the distribution and abundance of herbivores in the Arctic are also strongly modified by climate change [5, 6] and land use changes outside the Arctic [7, 8], but also by management within the Arctic [9, 10]. Herbivore management has repeatedly been suggested to counteract impacts of climate change [1, 11–13].

Many vertebrate herbivores have a central role in the livelihoods and culture of northern communities, through herding (e.g. reindeer) or hunting (e.g. geese and ptarmigan) [10, 14]. Herbivory by invertebrates is widespread in tundra but occurs at low intensity [15]. However, outbreaks of invertebrate herbivores are frequent in the forest-tundra ecotone [5, 16] and occasionally in tundra [13, 17]. Such outbreaks can cause dramatic vegetation state changes [18] which may also affect reindeer grazing grounds [16], and hence the livelihood of herder communities [9]. Understanding how herbivory influences the sensitivity of these systems to ongoing environmental changes is thus needed to guide appropriate adaptive strategies to preserve their natural values and related ecosystem services [1]. Indeed, robust and generalizable conclusions about herbivore effects on plants are essential for giving sound management advice.

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In essence, herbivory is a local ecological process that happens when animals eat plants. However, it can have consequences to the functioning of the entire ecosystem through its effects on nutrient cycling, vegetation structure and composition and climate feedbacks. For example, changes in shrub cover and vegetation structure driven by summer grazing by reindeer can lead to increases in surface albedo and decreases in ground heating, delaying snowmelt date, and ultimately affecting the yearly energy balance of tundra ecosystems [19].

In general, the effects of herbivores on plants and ecosystem functioning depend on the ecological context where the interaction takes place [20, 21]. For example, plants can respond to herbivory differently depending on local soil fertility [22, 23], salinity [24], or temperature [2]. Such context-dependency has been recently described in a systematic review for a widespread herbivore species in the Arctic, the reindeer (*Rangifer tarandus*) [25]. The impact of reindeer herbivory on vegetation was highly heterogeneous and seemed to depend on the local characteristics of the studies, making generalizations difficult. Overall, the effect of reindeer herbivory was partly related to temperature, with greater impacts in colder regions [25]. The effects of herbivores on plants can thus be expected to differ along climatic gradients within the Arctic (due to for instance differences in primary production and vegetation). Other ecological contexts which can be important for plant–herbivore interactions in the Arctic are for example the geographical position relative to the coast line (i.e. coastal vs. continental areas, due to marine subsidies of energy to the food web), the distance to the tree-line (due to overspill of boreal herbivores), and the extent of recent warming. Furthermore, plant responses to herbivory depend on herbivore guild composition [26]. Regions with high herbivore diversity [27] can be expected to show different responses to herbivory than those with low herbivore diversity.

Research on herbivory in tundra environments has, until recently, been mainly local in extent. The conclusions of local studies on herbivory are thus inevitably affected by the ecological context of the study. Hence, to what extent the current literature on herbivory in the Arctic covers the range of possible ecological contexts is an essential determinant of the conclusions that can be drawn about the role of herbivory for Arctic ecosystems change. Furthermore, the robustness of such conclusions is also pending on the coverage of the underlying ecological contexts.

Even though studies on plant–herbivore interactions have been conducted at a range of localities across the Arctic, we lack a systematic overview of which ecological contexts these localities cover. We therefore set out to improve this state of affairs, and present here a protocol for a systematic map of the coverage of ecological contexts in which herbivory is studied in the Arctic.

Objective of the review

The main objective of our systematic map is to identify the ecological contexts where herbivory has been studied in the Arctic. Individual studies, conducted at a specific location and within a specific ecological context, can be seen as replicates within the circumpolar Arctic. To assess the ability of studies spread in the circumpolar north without an a priori common study design to produce generalizable conclusions, it is crucial to have information on the number of replicates and how well they cover the underlying ecological gradients. Hence, this systematic map will enable us to assess our ability to make generalizable and robust conclusions on Arctic herbivory.

Primary question What are the effects of herbivory on Arctic vegetation?

Components of the primary question The primary study question can be broken down into the following study components:

- *Population* Terrestrial Arctic plants and plant communities
- *Exposure* Herbivory (including disturbance and fertilization effects of herbivores)
- *Comparator* No herbivory or alternative level of herbivory
- *Outcome* Response of the plant(s) to herbivory.

Our primary question reflects the question that needs to be addressed by each individual study in order to be included in our systematic map. Thus, its formulation differs from our main objective, that is, to assess the ecological contexts within which this question has been addressed.

Searching for articles

We will only include studies that we find using databases, search engines and specialist websites, not studies that are referenced in these studies. We will include academic and grey literature that provides primary data. As accessibility of grey literature is likely to vary greatly between the Arctic countries we will include an assessment of the potential bias in the systematic map. For example, MSc-theses from Russia are usually not available online, whereas MSc-theses from Norway and Iceland are routinely deposited in institutional and national online portals (e.g. Norway: bora.uib.no, nora.openaccess.no; Iceland: skemman.is).

Search terms

The search string that will be used in the systematic map was optimized during scoping exercises, and comprises two substrings. One substring is targeted at delimiting the study region and system, and the other targeted at the exposure element of the systematic map topic. The two substrings are combined using the Boolean AND operator, and the elements within each substring are combined using the Boolean OR operator.

The region/system specific substring is specified as (*Arctic OR subarctic OR tundra*) in order to find studies undertaken in Arctic or subarctic regions, or in tundra ecosystems, excluding studies conducted in the Antarctic. The exposure substring is specified to locate all types of vertebrate or invertebrate herbivory occurring in the Arctic study region. These include grazing, browsing, grubbing, defoliation, galling and mining, as well as impacts through trampling. To prevent the selection of studies relating to mining or galling outside of the context of herbivory (i.e. industrial mineral extraction and medical applications) we will combine galling and mining search terms (using the Boolean AND operator) with the herbivore taxa involved in these herbivore interactions i.e. invertebrates or insects. The exposure substring element of the search term is thus specified as (*herbivor* OR graz* OR browser OR browsing OR grubb* OR trampl* OR defolia* OR* ((*invertebrate OR insect*) *AND* (*gall* OR mining OR miner*))). We opted for *browser OR browsing* instead of *brows** as Scopus identifies the latter as *brow** thus broadening the search unnecessarily.

Our full search string (formatted for Web of Science) is thus: (arctic OR subarctic OR tundra) AND (herbivor* OR graz* OR browser OR browsing OR grubb* OR trampl* OR defolia* OR ((invertebrate OR insect) AND (gall* OR mining OR miner))).

Search languages

We will include the following languages: English, Russian, French, Finnish, Swedish, Norwegian, Icelandic, and Danish. We will use English in global search sources, and English together with relevant local languages in searches from local/regional sources. We will include studies in any of the above languages.

Our full search string in different languages are:

In Russian: (травояд* OR дефолиа* OR ощип* OR галлообраз* OR топт* OR выпас OR перевыпас OR паст* OR выби*) AND (аркти* OR тундр* OR субаркти*)

In French: (arctique OR subarctique OR toundra) AND (herbivore OR pâtur* OR paître OR brout* OR fouill* OR pietin* OR defoli* OR ((invertébré OR insecte) AND (galle* OR mineu*)))

In Finnish: (arkti* OR subarkti* OR *tundra) AND (herbivor* OR kasvinsyöj* OR laidun* OR tall* polk* OR ((selkärangat* OR hyöntei*) AND (äkäm* OR syömäkuvio* OR *tuho)))

In Swedish: (arktisk OR subarktisk OR tundra) AND (herbivor* OR bet* OR tramp* OR defolie* OR ((invertebrat* OR insekt) AND (gall* OR borr*)))

In Norwegian: (arktisk OR subarktisk OR tundra) AND (herbivor* OR planteete* OR plantespise* OR beit* OR gressing OR tramp* OR defolie* OR ((invertebrat* OR insekt) AND (gall* OR miner*)))

In Icelandic: (arktísk* OR subarktísk* OR norðurslóð* OR túndr* OR freðmýr*) AND (grasæt* OR beit* OR beitardýr OR bíta OR lirfa* OR traðk* OR aflaufgun* OR ((hryggleysing* OR skordýr*) AND (kýli* OR bora)))

In Danish: (arktisk OR subarktisk OR tundra) AND (herbivor* OR planteæde* OR plantespise* OR græs* OR tramp* OR defolie* OR ((invertebrat* OR insekt) AND (gal* OR miner*)))

The full search strings may be simplified to correspond some of the search sources.

Search sources

We will search publications from the following databases/search sources (Details of institutional subscriptions for the final searches will be reported):

- Web of Science Core Collection, specifically: all years search within Topic (Science Citation Index Expanded (SCI-EXPANDED)—1945-present, Social Sciences Citation Index (SSCI)—1956-present, Arts & Humanities Citation Index (A&HCI)—1975-present, Emerging Sources Citation Index (ESCI)—2015-present).
- Scopus (article title, abstract and keyword search) with no further limitations applied.
- Google Scholar, specifically: title search, standardized so that search history is not taken into account. We will only include the first 300 search results from this search source as recommended by Haddaway et al. [28].

We will also search the following local and specialist databases/sources for links or references to relevant publications, including grey literature. Potentially useful documents that are not already found using publication databases or search engines will be recorded.

Alaska Department of Fish and Game (http://www.adfg.alaska.gov).

Alaska Department of Natural Resources (http://www.dnr.alaska.gov).

Arctic Biodiversity Data Centre (https://www.abds.is/).

Arctic Centre (University of Lapland) (http://www.arcticcentre.org).

Arctic Council (http://www.arctic-council.org).

Arctic Institute of North America (https://arctic.ucalgary.ca/databases).

Arctic Portal (http://library.arcticportal.org/).

Bureau of Land Management, US Dept. of the Interior (http://www.blm.gov).

Current Research Information System in Norway (http://www.cristin.no).

Doria (National Library of Finland) (http://www.doria.fi).

disserCat (Russian Electronic Scientific Catalogue of Dissertations) (http://www.dissercat.com/).

Environment Canada (http://www.ec.gc.ca).

European Commission Joint Research Centre (ec.europa.eu/dgs/jrc).

European Environment Agency (http://www.eea.europa.eu).

Finland's environmental administration (http://www.environment.fi).

Food and Agriculture Organization of the United Nations (http://www.fao.org).

Greenland Ecosystem Monitoring (http://www.g-e-m.dk).

Greenland Institute of Natural Resources (http://www.natur.gl).

GRID Arendal (http://www.grida.no).

International Union for Conservation of Nature (http://www.iucn.org).

Landbunadur (Icelandic Repository for Agricultural Sciences) (http://landbunadur.is).

Ministry of Natural Resources of the Russian Federation (http://www.mnr.gov.ru).

Natural Resources Canada (http://www.nrcan.gc.ca).

Natural Resources Institute Finland (http://www.luke.fi).

Nordic Council of Ministers (http://www.norden.org).

Northern Research Institute (NORUT) (http://www.norut.no).

Norwegian Agriculture Agency (http://www.landbruksdirektoratet.no).

Norwegian Environment Agency (http://www.miljødirektoratet.no).

Norwegian Institute of Bioeconomy Research (http://www.nibio.no).

Norwegian Institute for Nature Research (NINA) (http://www.nina.no).

NORA (Norwegian Open Access Publication Archive) (nora.openaccess.no).

Norwegian Polar Institute (http://www.npolar.no).

Russian Science Citation Index (elibrary.ru).

Russian Regional Environmental Centre (http://www.rusrec.ru).

Royal Danish Library's publication portal (https://tidsskrift.dk/).

Skemman (Icelandic Academic Repository) (https://skemman.is/?locale=en).

Swedish Environmental Protection Agency (http://www.naturvardsverket.se).

United Nations Environment Programme (http://www.unep.org).

United States Environmental Protection Agency (http://www.epa.gov).

United States Fish and Wildlife Service (http://www.fws.gov).

University of Alaska Anchorage (http://www.uaa.alaska.edu).

Publication retrieval strategy

We will exclude publications for which we cannot access full text, as we will need the full text to be able to assign each publication to an ecological context. When we do not have access to an electronic version of the publication, we will attempt to acquire paper copies by ordering through institutional libraries or contacting the authors by e-mail once.

Assessing the specificity and sensitivity of the search

Systematic map search terms should be assessed for both specificity (minimizing the proportion of irrelevant studies returned by the search; [29]) and sensitivity (finding all relevant studies). We undertook scoping exercises during October 2017 for the search of peer-reviewed literature, as this search was the one likely to produce most results; this search string returned 1766 hits in the Scopus database (title, abstract keyword search), 2022 within the Web of Science Core collection (topic search), 'about 2940' hits on Google Scholar, and 245 hits in the Russian Science Index (February 2018). The 1766 records retrieved by Scopus were checked for specificity. Among a subsample of 500 records (first 500 alphabetically by first author name), 40% were excluded on the basis of title screening. The majority of these were excluded as they were conducted in aquatic environments. However, researchers of terrestrial systems tend not to specify that they work in terrestrial systems, and no appropriate keyword could screen away the aquatic studies. We therefore deemed the specificity of the search string adequate.

To assess the sensitivity of the search string we selected records obtained using two broader search strings (i.e. each of the region/system specific and the exposure specific substrings) that were not included in the results of the narrower full search (combined substrings) on the Scopus database. A total of 87,002 records were identified by the region-specific search string but not the combined search string, while 183,935 records were identified with the exposure-specific search string and not the combined search string. A sample of 1000 records from each of these were selected for screening by selecting the first 1000 records when listed alphabetically by first author name. These samples were first screened for title relevance. Potentially relevant publications were thereafter screened based on abstract and full text, in order to identify potentially relevant records that were missed by the full search string. In the set of records identified by the region-only search, one record out of the 1000 screened records was deemed potentially relevant, while in the set of records identified by the exposure-only search none of the 1000 screened records were deemed potentially relevant. Our search string was therefore deemed to be adequately sensitive.

Eligibility criteria

Relevant population (Arctic plants and plant communities)

We will exclude studies that do not focus on Arctic terrestrial vegetation. We define the Arctic as tundra habitats, including forest-tundra and ecotone habitats. To define these areas unambiguously, we will use the delimitation given in CAFF map no. 11 [30]. However, we will exclude from this map the areas defined as middle boreal, based on CAFF vegetation zone map [31]. While this delimitation will still include some boreal forest habitats, we will exclude these based on additional information (i.e. habitat description in the publication). We will include studies that report data from several sites, but consider only the sites that are within the Arctic. Thus, we will exclude studies where:

- The habitat is described as non-Arctic (e.g. boreal forest, temperate grassland). If the authors' description is ambiguous, we will inspect images of the study location from Google Earth to assess the extent of canopy cover and proximity to open tundra. If the study localities are clearly not in a tundra-forest ecotone (defined as very open forest, close proximity to tundra) the study will be excluded.
- The location can be recognized to be outside the Arctic (e.g. based on country or coordinates extracted from the publication). If we are unable to extract coordinates/study locality from the information given in the main publication or its appendices, we cannot allocate the study to a given ecological context and will therefore exclude it.
- The climate does not correspond to the current climatic context of the Arctic (e.g. paleo-ecological studies). Nevertheless, we will not include any time limitations for the publication year of the studies.

We will exclude studies if we are unable to find central information needed to be able to assess the identity and biological organization level of the plant/vegetation type. Thus, studies need to report on which plant/vegetation type they collected data on, and whether they measured the outcome of herbivory on plant individuals, species, populations, or communities.

Relevant exposure (herbivory)

We will include studies that look at various types of effects of herbivores on plants (i.e. herbivory, trampling and other types of disturbance, fertilizing). We will include studies that measure herbivore presence in direct and indirect ways (e.g. biting marks, galls). We will exclude studies that:

- Address trampling or fertilization effects by non-herbivorous animals (e.g. fertilization of cliffs by seabird colonies).

The studies are not required to report on the herbivores' taxonomic identity (for example in studies simulating herbivory).

Relevant comparator (level of herbivory)

We will include studies that assess the effect of herbivores by comparing a given level of herbivory (or another herbivore related effect) to either no herbivory or another level(s) of herbivory. For example, studies may contrast different intensities of herbivory or higher vs. lower densities of herbivores. We will place no restrictions on the type of comparison (e.g. factor levels of experimental treatments, continuous variable changing across spatial or temporal gradients) or the intensity of the comparison (e.g. number of herbivory levels, magnitude of difference of herbivory along a gradient). Further, we will not require a specific comparator parameter to be included in modeling studies, as long as they relate a change in vegetation to a given herbivory phenomenon.

Relevant outcome (herbivore effect on plants)

We will include studies that assess the effects of herbivory on Arctic terrestrial plants (as defined under the relevant population). We will exclude studies for which we fail to fill in information on the measured response variable (i.e. all studies need to report an outcome). We will further exclude studies that:

- Assess the effects of herbivory on ecosystem components other than plants (e.g. soil properties, fungi,

symbiotic organisms of plants, such as endophytes or mycorrhiza). We will include studies on lichen.
- Address different processes than herbivory (e.g. mutualistic plant–herbivore interactions such as pollination, mining in the sense of mineral extraction).
- Focus either on a plant or an animal, but not an interaction between them.
- Present no quantitatively analyzable (numbers, presence-absence, categorical variables…) primary data. We will therefore exclude reviews and book chapters, unless they contain primary data.

Relevant study designs

As a general principle, we will only include studies in which herbivory can be assigned to an ecological context. Hence, we will include field experiments, such as exclosure experiments and simulated herbivory/herbivore effect (e.g. clipping, feces addition, trampling). We will further include observational studies and quasi-experimental studies, such as field studies, remote sensing studies, and before-after studies, as long as the observed pattern of vegetation change is related to a given herbivory phenomenon, such as a herbivore population density change. We will only include modeling studies and greenhouse experiments if they attempt to address herbivore effects on plants in a given existing ecological context within the Arctic. Study designs that cannot be assigned to an Arctic ecological context, for example greenhouse studies that do not replicate Arctic growing conditions, will be excluded.

Redundancy

We will exclude studies that report data that has already been reported in a previous study. We will assess this first by checking the references cited in the methods section (excluding references that are clearly related to statistical analysis or specific methodologies only). We will also assess this by checking which studies were conducted at the same location.

Screening process

We will screen the studies in four stages; (i) title screening, (ii) abstract screening, (iii) locality screening, and (iv) screening during data coding from full text. As a general rule, whenever we are uncertain whether a study should pass to the next stage of screening, we will be inclusive. For the locality screening, we will use coordinates given in the text whenever possible and extracted coordinates from maps if they are not given in the text. We will provide a list of studies excluded at full text stage with reasons for exclusion.

The reviewers conducting the screening will not take part in the critical appraisal of their own work, i.e. if they have authored studies that are considered to be included in the systematic map. In these cases, an additional reviewer would assess these studies.

Evaluating observer error and repeatability of the screening process

We will include an assessment of the repeatability of our results in the systematic map. The assessment to include/exclude studies will be made by a single reviewer. At both the title and abstract screening stage, a subset consisting of 10% of the studies will be assessed by at least two reviewers. Similarly, data from 10% of the studies will be extracted by at least two reviewers. A kappa statistic relating to the assessments will be calculated to check for consistency among reviewers. If this statistic indicates that the reviewers are inconsistent in their assessment ($\kappa < 0.6$), discrepancies will be discussed and the inclusion criteria/data coding strategy will be clarified or modified. In addition, at the full-text screening stage, all studies considered doubtful by the main reviewer will be checked by at least one more reviewer.

Assessment of the repeatability of the screening process during the protocol development

To test the repeatability of our inclusion criteria, five of the authors screened the abstracts of 100 studies. These were the first 100 studies on an alphabetically ordered list of a full search string from Scopus, after one author had screened the list based on titles. This test did not encompass exclusion based on geographic coordinates, as it has no scope for observer error. The observers unequivocally agreed on the inclusion or exclusion of 66 out of 100 studies. Of these 66 studies, 16 were consistently deemed to be included. The excluded studies focused mainly either only on the herbivore or only on the plant (43 out of 50 excluded publications). The remaining unambiguously excluded studies (7) were either conducted outside the Arctic (3), lacked primary data (2), data were collected from aquatic environment (2), or herbivory was not studied (2).

Of the studies that the authors disagreed in inclusion/exclusion, 9 had issues with the delimitation of the Arctic region, 7 were reviews or paleo-ecological studies were it was unclear whether they included primary data on herbivory, 4 had issues with the interpretation of the type of responses and predictors, 3 were greenhouse experiments, 2 were conducted in ecosystems that may have been defined as forest or tundra-forest ecotone, while the remaining 9 had various study-specific issues. The disagreement was often related to where the information was found within the study, i.e. in the abstract vs. in the main body of the text. The authors discussed these disagreements and refined search criteria, as well as the extent to which exclusion criteria were to be applied while screening the abstract/main body of the study. The criteria presented above correspond to the refined criteria.

Study validity assessment

As we aim to identify the ecological contexts where herbivory is studied, the quality of a given study is not of paramount importance and we will therefore not exclude any study based on quality criteria. We will however assess the quality of the studies based on study design, grouping studies that have clear or unclear definition of the study design. We will also group studies based on spatial and temporal extent and resolution (e.g. short vs long term, local vs regional). Yet, the exact definitions of these groupings will be based on the range of studies retrieved by our search. We will cross tabulate study quality by other variables to highlight which ecological contexts are studied more superficially (e.g. only local and short-term studies, or only studies with unclear study design) as compared to those that are more thoroughly studied (e.g. studies using several types of spatial and temporal setup).

Data coding strategy

For each study that passes the screening stages of title, abstract and location, we will extract information on the variables described in Table 1. Additional information per variable (potential values, examples, specification) is given in Additional file 1. We will also exclude studies at this stage, if they fail to fulfill the inclusion criteria.

Information about the variables is recorded as it was reported in the study. One study can contain several evidence points, and in such case information is recorded for each evidence point separately. Separate evidence points are recorded when separate parts of the study differ from each other in terms of study design (i.e. different datasets of plant–herbivore pairs) or in terms of environmental context (i.e. dataset compiled from various locations for which environmental contexts are described separately). Evidence points also often differ in terms of study question, study length, methodological approach etc.

Assessment of the repeatability of the data coding strategy during the protocol development

We tested our data coding strategy to evaluate whether it was possible to extract the proposed variables. This test also assessed whether our coding strategy for the variables took into account the variability present in the studies (e.g. if we had excluded some necessary categories). First, all six of the authors coded ten studies each. A subset of five studies was coded by all observers to test for consistency in coding between observers. The other five studies differed between the authors, and were used to identify more issues where the data coding strategy should be refined. The studies were picked among those that passed the abstract screening test. While most of the variables coded by all authors were consistent, we identified several minor issues. We revised categories of several variables (e.g. management status, conservation status, study design variables), and split some variables into two or more (e.g. study design and methodological approach were separated, as were the spatial resolution at which the outcome was measured (recorded) and at which it was reported). We refined in particular the variables addressing study design and spatial and temporal aspects of the study.

Finally, we created an Excel sheet with drop-down menus for the refined data coding and tested this. This second test was done by the six authors, all of whom coded the same five papers. The papers for this second test were selected to represent different types of study designs and approaches to check that our data coding strategy accommodated them all. The test identified some ambiguity in defining study designs, biological organization types, and distinction between different evidence points from the same study. All of these issues were clarified in the data coding sheet and examples added to the template to facilitate future data coding.

The data coding strategy described in Table 1 corresponds to the refined coding.

Study mapping and presentation

In the final systematic map, we will describe the review process and the evidence base, focusing on the coverage of ecological contexts within the Arctic. We will discuss the implications of this coverage to the robustness of our current knowledge on herbivory in the Arctic, and to which extent we can generalize the results of different studies. We will provide statistics on the number of studies excluded during the screening process.

We will present the results using the following illustrations:

- A flow diagram illustrating the inclusion/exclusion process incl. the number of papers retained at each stage of the process.
- Barplots showing the distribution of studies across time
- A geographic map showing where in the Arctic studies on herbivory are conducted highlighting the distribution of studies across countries/terrestrial ecoregions. The size of points will reflect the number of evidence points.

Table 1 Variables extracted from the publications for the systematic map of arctic herbivory

Topic	Coding variable	Variable description	Source
Study ID	author_list	List of authors	P
	title	Title of the publication	P
	journal	Journal or publishing house	P
	year	Year of publication	P
	language	Language	P
	evidence_point_ID	ID number that separates the different evidence points within the same publication	P
Study location	country	Country name, as specified by the authors	P
	locality	Site name describing the locality, as specified in the study	P
	coordinates_N and coordinates_E	Geographic coordinates as reported in the study. If needed, these can be obtained from figures or inferred from maps	P
	year_start	Year when the study started, measuring both the plant and the herbivore parts	P
	year_end	Year when the study finished, measuring both the plant and the herbivore parts. For studies spanning 1 year or less, start and end year will be the same	P
	elevation	Elevation (meters above sea level) as reported by the authors	P
	elevation_DEM	Elevation as extracted from a digital elevation model	D
Study type	study_design	Study design type; experimental, quasi-experimental/natural experiment, observational or modeling	C
	experimental_design	For experimental, quasi-experimental, and some observational studies; how were the treatments and controls implemented? Before-after, control-impact, before-after-control-impact	C
	study_method	Methodological approach; e.g. field, greenhouse, remote sensing	C
	exposure_quantification	Approach used to create or assess the difference in herbivory (i.e. how are differences in exposure quantified). For example, exclosure, simulated herbivory, spatial contrast/gradient of herbivore abundance	C
	additional_exposures	The other factor, if any, with which herbivory was contrasted/analysed. E.g. warming, snow manipulation	P
	extent_of_spatial_scale	Size of the study area, i.e. the polygon that encompasses all the plots measuring a particular outcome	C
	spatial_resolution_recorded	Spatial scale at which the outcome was measured	C
	spatial_resolution_reported	Spatial scale at which the outcome is reported	C
	extent_of_temporal_scale	Length of study	P
	temporal_resolution	Interval between measurements, if regular and how long	C
	redundancy	Is the data already reported in another study?	C
Population: plant	biological_organizational_level_recorded	Biological organization level at which the outcome was measured. Individual, population/species, group of species, or community	C
	biological_organizational_level_reported	Biological organization level at which the outcome was reported. Individual, population/species, group of species, or community	C
	Identity_of_biological_organization_unit	For individual and population categories in the biological organization level a species list, for groups of species and communities identity as reported by authors (e.g. tall shrub heath, deciduous shrubs)	P
	management_plant	Management status of the targeted plant(s); e.g. fertilizing, managed grazing	P
	conservation_plant	Conservation status of the targeted plant(s); e.g. red listed, no concern	P
Outcome: the outcome of herbivory on plant(s)	measured_response_variable	What was measured on the plants following exposure to herbivory? E.g. biomass, cover diversity	P/C

Table 1 (continued)

Topic	Coding variable	Variable description	Source
Exposure: herbivory	herbivore_identity	A species name or a species list, or other definition as given by the authors	P
	herbivore_type	Herbivore functional group	C
	herbivory_season	When herbivory happens (not when the measurement happens)	P
	effect_type	Type of effect the herbivore has on target plants, as reported by authors. E.g. removal of plant parts, fertilizing	C
	management_herbivore	Management status of the targeted herbivore(s); e.g. hunted, semi-domesticated	P/C
	conservation_ herbivore	Conservation status of the targeted herbivore(s); e.g. red listed, no concern	C
Modifier: ecological context	management	Do the authors report any managed herbivores (including target herbivores) or managed plants being present?	C
	management_study_area	Management status of the study area, e.g. historical, current	C
	conservation_study_area	Conservation status of the study area, e.g. protected area, common habitat	
	distance_to_treeline	Distance to southern border of arctic subzone E	D
	temperature_P	Temperature as reported in the study	P
	temperature_measure	Type of temperature measure reported, e.g. mean annual temperature, average temperature of the warmest month…	P
	precipitation_P	Precipitation (mm) as reported in the study	P
	precipitation_measure	Type of precipitation measurement given, e.g. annual sum	P
	climate_axis_1	First PCA axis describing climate based on WorldClim bioclimatic variables (mainly temperature)	D
	climate_axis_2	Second PCA axis describing climate based on WorldClim bioclimatic variables (mainly precipitation)	D
	climate_axis_3	Third PCA axis describing climate based on WorldClim bioclimatic variables (mainly variability)	D
	growing_season_	Duration of growing season (days)	D
	distance_from_coast	Distance from the coast (km)	D
	bioclimatic_zone	Bioclimatic zone A to E, or outside the arctic as defined by the bioclimatic zonation	D
	soil_type	Soil type class	D
	productivity	Value of NDVI (vegetation greenness)	D
	productivity_P	Productivity description as reported by the authors (e.g. high productivity habitats)	P
	extent_of_recent_warming	Extent of last decades change in temperature	D
	extent_of_recent_greening	Extent of last decades change in NDVI.	D
	extent_of_recent_growing_season_change	Extent of last decades change in growing season length	
	herbivore_diversity	species richness of vertebrate herbivores	D
	habitat_type_P	Habitat type as reported by the authors	P
	habitat_type_C	Habitat type, collapsed to fewer categories after the habitat categories by authors have been recorded	C
	disturbance	Disturbance that occurs in the study system and could impact the results/is discussed by the authors. E.g. fire, flooding, ice/winter damage	C
	permafrost	Presence of permafrost	D
Additional information	food_web_context_other_herbivores	Is the presence of other herbivores in the study area described?	C
	food_web_context_predators	Is the presence of predators in the study area described?	C
	conservation_focus	Is the study framed within a conservation context (i.e. conservation aims are mentioned or not)?	C

The coding variables are grouped into eight broader topics. Values in column "source" describe where the data is extracted from: P for publication (i.e. data explicitly available in the published document), D for digital spatial data layers (i.e. data extracted from a data layer based on the spatial coordinates given in the publication), and C classified by the reviewers based on information available in the publication. Additional information on (i) references for digital data layers and categories, (ii) possible values for each variable, (iii) more detailed variable description, and (iv) examples and specifications of the possible values are given in the extended table in Additional file 1

- A map of ecological contexts (see an example in Figure 2 in [32]).
- A contingency plot (studied plant types vs studied herbivore types) where evidence points are colored/symbolled based on ecological context.

We see two major challenges when communicating the results of a systematic mapping exercise. Firstly, making the results accessible in an appealing format that invites exploration, and hence hopefully increase the impact of the systematic map. Secondly, keeping the results up to date. A systematic map represents a substantial investment in terms of time spent writing the protocol, searching and summarizing and communicating results. Yet, with the ever increasing number of new studies, systematic maps tend to be fairly quickly out of date. We will explore two possibilities for remedy:

- We will publish the final dataset in full on an interactive map server, in which readers can explore and filter the results and automatically get access to updated versions of the key graphics described above depending on filter settings.
- We will attempt to design a system by which new studies can be submitted to the dataset both by us, and by readers, following the original protocol. Submission of studies to the database will be encouraged through relevant research networks, such as the Herbivory Network (http://herbivory.biology.ualberta.ca). In doing so we will distinguish between studies which were part of the original published systematic map, and new studies submitted post publication. We believe this can increase the longevity and relevance of the map significantly.

Additional file

Additional file 1. Additional information on variables that are to be extracted from the included studies is provided this file and it includes specifications, examples and potential values per variable, and drop-down menus to be used for the data coding.

Authors' contributions

EMS, VTR and JDMS developed the original idea, all authors participated in discussions defining the search criteria and data coding strategy, as well testing these. All authors contributed to testing the search criteria and data coding strategy, and the test results were collated by EMS. EMS had the lead of writing the manuscript, with contributions from all authors. ICB assembled and edited the data coding table. All authors read and approved the final manuscript.

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Acknowledgements

We thank the participants of the Herbivory Network workshop "Identification of data gaps in tundra herbivory" in Iceland (16.9.2016), and an anonymous reviewer whose comments improved the manuscript. K. Svavarsdóttir, I. S. Jónsdóttir and G. Halldórsson helped with the selection of relevant search terms in Icelandic.

Competing interests

The authors declare that they have no competing interests.

Availability of data and materials

Not applicable.

Consent for publication

Not applicable.

Ethics approval and consent to participate

Not applicable.

Funding

FRAM—High North Research Centre for Climate and the Environment supported this work with funding for two workshops (project name: "The status of evidence for herbivory in Arctic tundra ecosystems—A protocol for a systematic map"). Funding from the Terrestrial Working Group of the International Arctic Science Committee (IASC) was received to organize the Herbivory Network workshop in Iceland, where some of the initial ideas were discussed.

Publisher's Note

Received: 9 May 2018 Accepted: 20 September 2018
Published online: 27 September 2018

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