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Environmental Evidence

SYSTEMATIC MAP PROTOCOL

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What are the effects of climate variability and change on ungulate life-histories, population dynamics, and migration in North America? A systematic map protocol

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Abstract

Background: Climate is an important driver of ungulate life-histories, population dynamics, and migratory behaviors, and can affect the growth, development, fecundity, dispersal, and demographic trends of populations. Changes in temperature and precipitation, and resulting shifts in plant phenology, winter severity, drought and wildfire conditions, invasive species distribution and abundance, predation, and disease have the potential to directly or indirectly affect ungulates. However, ungulate responses to climate variability and change are not uniform and vary by species and geography. Here, we present a systematic map protocol aiming to describe the abundance and distribution of evidence on the effects of climate variability and change on ungulate life-histories, population dynamics, and migration in North America. This map will help to identify knowledge gaps and clusters of evidence, and can be used to inform future research directions and adaptive management strategies.

Methods: We will catalogue evidence on how climate variability and change affect the life-histories, population dynamics, and migration patterns of the fifteen ungulate species native to North America. We will search both academic and grey literature, using academic journal databases and specialist websites. Articles will be screened for inclusion at the title/abstract and full-text levels, and data will be extracted from articles that pass the full-text review. These data will be summarized quantitatively, visually, and with a narrative review to describe the distribution and abundance of evidence on the effects of climate variability and change on ungulates in North America.

Keywords: Global change, Climate impacts, Weather, Ungulate management, Ungulate ecology

Background

Native ungulate species occupy a diversity of habitats across North America, from Canada's high arctic to the deserts of Mexico [1]. Through their herbivory, wild ungulates play an important ecological role, regulating processes such as nutrient cycling in temperate forests [2] and plant productivity and habitat heterogeneity in grasslands [3, 4]. Ungulates are also economically and culturally important in North America, providing recreational and subsistence hunting opportunities and non-consumptive, aesthetic values. For example, in 2016, 8.1 million people hunted deer (*Odocoileus* spp.) in the United States, and 0.7 million hunted elk (*Cervus canadensis*) [5]. However, the management of sustainable and robust ungulate populations in North America is challenged by a number of anthropogenic and environmental threats that have the potential to impact individuals, populations, and the ability of ungulates to move across the landscape [6]. Changes in habitat [7], climate

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conditions [8, 9], and predator communities [8] are of increasing concern to ungulate managers [10]. Of these, an improved understanding of the effects of changing climate conditions has been highlighted as a key information need [11–13]. Climatic variation occurs across multiple spatial and temporal scales, and understanding the impacts of both short- and long-term changes will provide valuable information to wildlife and land managers. Climate is an important driver of ungulate life-history characteristics, population dynamics, and migratory behaviors and changes in climate can directly or indirectly affect the growth, development, fecundity, dispersal, demographic trends, and long-term viability of populations [9, 13] as well as the timing and locations of migratory movements [14, 15]. Here, we use the term "climate variability" to refer to interannual or interdecadal fluctuations in temperature and precipitation, and the term "climate change" to refer to persistent, multi-decadal deviations from long-term averages [16].

Understanding the direct and indirect effects of climate variability and change on ungulates will be an important consideration for effective ungulate management and conservation in North America [13, 17], and a number of studies have begun to document these impacts. Direct impacts can include changes in the costs of thermoregulation or locomotion [18], while indirect impacts can include shifts in forage quality and quantity [8]. Studies have documented, for example, that winter temperatures can directly affect juvenile survival [19] and have population-level effects. For example, extreme winter temperatures, increased snowfall, and more frequent winter storms led to elk population reductions in Canada [20]. Precipitation and temperature, through their effects on plant production and nutritional quality, can also directly and indirectly affect ungulate life-history characteristics [21–23]. In Idaho, a longer autumn growing season increased mule deer (*O. hemionus*) fawn overwinter survival [24], while summer drought increased mortality among Sonoran pronghorn (*Antilocapra americana sonoriensis*) in New Mexico [25].

The effects of changes in the timing of spring green-up and winter severity, two key drivers of ungulate migration in North America, have also been documented. Elk in the Greater Yellowstone Ecosystem delayed departure from winter range habitat when spring green-up occurred later [15], mule deer in the Sierra Nevada migrated earlier in years with earlier green-up and low snow depth [14], and mule deer in Wyoming altered their use of stopover sites based on changes in plant phenology [26]. Lastly, there have been efforts to project the potential future impacts of climate change on ungulates. For example, studies have modeled the effects of climate change on population growth of pronghorn [27], mountain goat (*Oreamnos americanus*) [28], and desert bighorn sheep (*Ovis canadensis nelsoni*) [29] in the western U.S.

The response of ungulates to climate variability and change is not uniform and is likely mediated by local processes and species-specific traits [17], and the evidence is not equally distributed among species and geographies. Synthesizing the existing science on this topic will facilitate the identification of the range of climate-related impacts across ungulate species, populations, and geographies, and highlight knowledge gaps and clusters that can support management decision-making. Here, we propose a systematic map of evidence relating to the effects of climate variability and change on ungulate life-histories, population dynamics, and migration in North America. This review aims to bolster our understanding of how changes in climate conditions, whether occurring over short or long timescales, have already or could potentially impact ungulates. This goal will be achieved by cataloguing the evidence on how changes in climate and climate-related variables affect ungulate life-histories, population dynamics, and migration across the continent.

Stakeholder engagement

We began our process of identifying stakeholder needs by reviewing a series of state wildlife management agency plans that outline key threats and priority research areas related to ungulate management. These plans were developed by 11 western U.S. states in 2018, following the signing of Secretarial Order 3362,*"Improving Habitat Quality in Western Big-Game Winter Range and Migration Corridors"*. This order, which focuses on elk, mule deer, and pronghorn in 11 states, directs the U.S. Department of the Interior's land management bureaus to work in partnership with state wildlife agencies to improve ungulate winter range and migration corridor habitats. As part of this effort, each participating state developed a State Action Plan outlining major threats and priorities related to ungulate migration corridors and winter range habitat. In addition to commonly-cited challenges such as wildlife-vehicle collisions and physical barriers to movement such as fences, many plans listed drought, wildfire, disease, and habitat conversion due to the spread of invasive species as key threats to ungulates, and outlined a clear need for information that will enhance the understanding and protection of ungulate migration and use of range habitat.

In addition, we contacted big game and habitat managers from several state wildlife management agencies to better understand their priorities and information needs related to ungulate management. As part of these discussions, we inquired about their current understanding of how climate variability and change affect ungulates, and whether additional information on this topic would support management planning. We also spoke to federal scientists to identify relevant ongoing science activities, and to receive input on the science needs related to ungulates and climate change. This stakeholder input contributed to the initial conceptualization of this study and helped define the scope of the systematic map.

Objective of the review

This systematic map will focus on the fifteen ungulate species of the Order Artiodactyla native to North America [11]. We will describe the abundance and distribution of evidence relating to the impacts of climate variability and change on the life-history characteristics, population dynamics, and migratory behaviors of these species by gathering evidence on the topic from across the continent. First, we will map the evidence on the effects of seasonal, interannual, and interdecadal changes in temperature and precipitation (hereafter referred to as "direct climate variables") and their derivatives, such as drought, winter severity, and snow depth, on ungulate ecology. Changes in direct climate variables can also affect ungulates via changes in plant phenology [15, 30], wildfire [17, 31], invasive species [17], disease [32], and predation [20]. Therefore, we will describe the evidence on how changes in these "secondary variables" affect ungulates in cases where they are linked to changes in direct climate variables. We will also identify studies that project how future changes in climate could potentially impact ungulates in North America. Together, these tiers of evidence will enable the identification of knowledge gaps and clusters on the topic of ungulates, climate variability, and climate change to inform future primary research directions and targeted systematic reviews.

The primary question for this systematic map is as follows: *What evidence exists on the effects of climate variability and change on ungulate life-histories, population dynamics, and migration in North America?*

Our research question can be broken down into the following key elements, based on the PECO (Population, Exposure, Comparator, Outcome) question framework:

Population

All subspecies and populations of wild pronghorn, elk, mule deer, moose (*Alces alces*), bighorn sheep, white-tailed deer (*Odocoileus virginianus*), American bison (*Bison bison*), mountain goat, Dall sheep (*Ovis dalli*), muskox (*Ovibos moschatus*), caribou (*Rangifer tarandus*), collared peccaries (*Pecari tajacu*), white-lipped peccaries *(Tayassu pecari)*, brown brocket deer (*Mazama gouazoupira*), and red brocket deer (*M. americana*) in the U.S., Canada, or Mexico. The state of Hawai'i, the U.S. territories of Puerto Rico, the U.S. Virgin Islands, Guam, the Northern Mariana Islands, and American Samoa, and the Canadian province of Prince Edward Island will be excluded from the review. The fifteen ungulate species are either not present on these islands or were introduced and are non-native [33].

Exposure

Temporal changes in direct climate variables (i.e. temperature, precipitation) and their derivatives (e.g. snow, winter severity, drought); temporal, climate-related changes in secondary variables (i.e. plant phenology, wildfire, invasive species, disease, predation).

Comparator

A comparison of at least two different time points, over which there is a quantified, inferred, or projected change in a direct climate or secondary variable.

Outcome

Effect on individual life-history characteristics; population dynamics; migratory behavior; spatial location or quality of migration corridor, winter range, or summer range habitat.

Methods

The review will follow the Collaboration for Environmental Evidence Guidelines and Standards for Evidence Synthesis in Environmental Management [34], and conform to the ROSES reporting standards [35] (Additional file 1).

Searching for articles

We will conduct this review using Web of Science and Scopus, both of which are made available to the authors via the U.S. Geological Survey's subscriptions with the services. In Web of Science, the Science Citation Index Expanded (SCI-EXPANDED), part of the Web of Science Core Collection, will be searched. SCI-EXPANDED (1985-present) is the Core Collection citation index available to the authors via the U.S. Geological Survey. The search will be run based on the "topic" field, which includes article titles, abstracts, keywords, and "KeyWords Plus" (automatically generated terms pulled from the titles of cited articles). Our subscription service does not enable us to access articles published prior to 1985, so the timespan "all years (1985–2020)" will be selected. In Scopus, article titles, abstracts, and keywords will be searched using the search string outlined below, and all years of data will be searched. All searches will be conducted in English, and only English-language publications will be included in the review since this is the primary language of the reviewers. Search results will be exported into both an Excel spreadsheet and a reference management software, and duplicates will be removed.

Search terms

The final Boolean search string is structured to capture articles that pertain to the population variables and exposure to direct climate variables (and their derivatives) or to climate-related changes in secondary variables. The scientific and common names of each ungulate species were included as search terms. The terms "climat*" and "global warming" were included to capture articles specifically focused on the impacts of climate variability and change on ungulates. The term "weather" was also included, both because climate can be defined as the average weather in a location, and because extreme climate events such as severe icing or heat waves can also be characterized as extreme weather events and are relevant to this review [16]. Terms for the direct climate variables (e.g. temperature, precipitation), as well as relevant derivatives, were also added. These terms include snow, rain, ice, drought, heat, cold, freez*, and winter severity. While numerous additional derivatives of temperature and precipitation exist, such as daily snowfall, total rainfall, or average daily temperature, these variables will be captured by the existing terms in the search string and do not need to be individually added as terms.

We also included one of the secondary variables, phenology, as a search term. Plant phenology is a known driver of ungulate migration in North America [36, 37] and is inherently linked to climate, in particular to temperature [38, 39]. Due to this inherent link, our direct climate variable terms may not be present in the title or abstract of relevant articles addressing ungulates and plant phenology, and as such could be missed by our search string if phenology were not included as a term. We did not include the additional secondary variables as search terms, based on the results of the scoping exercises outlined in the following section.

The final search string, to be used in Web of Science and Scopus, is as follows (in a Web of Science format):

TS = (("mule deer" OR "black-tailed deer" OR "Odocoileus hemionus" OR "white-tailed deer" OR "whitetail" OR "Odocoileus virginianus" OR "elk" OR "wapiti" OR "Cervus canadensis" OR "pronghorn" OR "antelope" OR "Antilocapra americana" OR "bighorn sheep" OR "mountain sheep" OR "Ovis canadensis" OR "moose" OR "Alces a*" OR "bison" OR "Bison bison" OR "Dall sheep" OR "Dall's sheep" OR "thinhorn sheep" OR "Ovis dalli" OR "mountain goat" OR "Oreamnos americanus" OR "muskox*" OR "musk-ox*" OR "musk ox*" OR "Ovibos moschatus" OR "caribou" OR "Rangifer tarandus" OR "collared peccar*" OR "javelina*" OR "musk hog*" OR "musk-hog*" OR "Pecari tajacu" OR "white-lipped peccar*" OR "Tayassu pecari" OR "brocket*" OR "brown brocket*" OR "Mazama gouazoupira" OR "red brocket*" OR "Mazama americana") AND ("climat*" OR "global warming" OR "weather" OR "temperature" OR "precipitation" OR "snow*" OR "rain*" OR "ice" OR "icing" OR "drought" OR "heat" OR "cold" OR "freez*" OR "winter severity" OR "phenology")).*

Assessing retrieval performance

With the exception of phenology, the remaining secondary variables – wildfire, invasives, disease, and predation – were not included as search terms. For the secondary variables, we are concerned only with studies that attribute changes in a secondary variable (e.g. increased disease transmission) to a direct climate variable (e.g. temperature), and examine the effects on ungulates (e.g. mortality). The structure of our final search string inherently captures such articles, as the string is designed to return any article that uses a population term and a direct climate variable term. For example, an article describing the impacts of a temperature-driven change in disease transmission on mule deer would be captured by the final search string, due to the presence of the terms "mule deer" and "temperature".

To test this assumption, we ran separate searches that included all population variables, direct climate variables, and each of the four remaining secondary variables, one at a time (Additional file 2). We screened the titles and abstracts of the first 100 articles returned by each search, sorted by relevance in Web of Science, and identified any relevant articles based on our study eligibility criteria (Table 1). We then checked if these articles were returned by Web of Science when our final search string was run. The overall performance against the test list was 100% for each variable tested, demonstrating that relevant articles on these topics will be captured by our search string, and these variables do not need to be included as search terms.

The search string was also tested for overall sensitivity by identifying a set of 30 articles known to be relevant to the authors (Additional file 3), and checking if these articles were returned by Web of Science and Scopus. The overall performance against the test list was 100% for Web of Science and 93% for Scopus.

Additional search methods

Grey literature Grey literature will be identified through a combination of a Scopus search and hand-searches of relevant organizational websites. We are using Scopus to identify both academic and grey literature and therefore will use the same search string as in Web of Science. No additional search strings will be used to identify grey literature in Scopus. In addition to Scopus, the website of

Table 1 Study eligibility criteria

PECO component	Include	Exclude
Population: Pronghorn, elk, mule deer, moose, bighorn sheep, white-tailed deer, American bison, mountain goat, Dall sheep, muskox, caribou, collared peccaries, white-lipped peccaries, brown brocket deer, and red brocket deer in North America	Articles on any wild population of native ungulates in North America	1) Articles on populations of ungulates located outside of North America (e.g. moose in northern Europe) 2) Articles on domestic or non-native populations of ungulates
Exposure: 1. *Direct climate variables* (temperature, precipitation) and their derivatives 2. *Secondary variables* (plant phenology, wildfire, invasive species, disease, predation)	1) Articles on the effects of temporal changes in direct climate variables on ungulates in North America 2) Articles on the effects of temporal changes in secondary variables on ungulates, if the changes in secondary variables are linked to changes in a direct climate variable	1) Articles that describe space-for-time time comparisons and do not describe a temporal change in variables 2) Articles exploring the effects of changes in secondary variables on ungulates, but do not link those changes in secondary variables to changes in a direct climate variable
Comparator: A comparison of at least two different time points, over which there is a quantified, inferred, or projected change in a direct climate or secondary variable	Articles that use empirical analyses or projections to describe (1) the effects of temporal changes in direct climate variables on ungulates, or (2) the effects of climate-related changes in secondary variables on ungulates	Articles that only use data from a single point in time or those that do not specify the temporal scale of the study
Outcome: Life-history characteristics; population dynamics; migratory behavior; spatial location or quality of migration corridor, winter range, or summer range habitat	Articles that document (1) the effects of changes in direct climate variables or (2) the effects of climate-related changes in secondary variables on any aspect of ungulate life-history characteristics, population dynamics, migration, or range habitats in North America	

each state, provincial, and territorial wildlife management agency in Canada and the U.S. will be searched to locate available technical reports on our focal species (Additional file 4). Because our searches will be English-language only, we will not search the websites of Mexican wildlife management agencies as part of our grey literature search. While this may introduce geographical bias in our grey literature search results, the review team does not have the resources needed to conduct Spanish-language searches and to translate these articles.

If available, the built-in search functions of the organization websites will be used and separate searches will be run for each relevant ungulate species. For example, the website for Montana Fish, Wildlife & Parks will be searched using the terms "bighorn sheep", "bison", "caribou", "elk", "moose", "mountain goat", "mule deer", "pronghorn", and "white-tailed deer", as each of these species is currently or has historically been found in the state. The terms used to search each website will be recorded. The websites will also be hand-searched to locate pages containing agency reports and publications. Articles acquired during this process will be downloaded and included in the list of articles subject to the full-text review.

Review articles Relevant review articles will not be accepted directly into the review. Instead, we will examine the primary sources cited in review articles and ensure that any appropriate sources are captured and subjected to the title and abstract review.

Article screening and study eligibility criteria

A two-stage screening process will be implemented to identify relevant articles from the deduplicated set of search results. The first phase will involve a review of the article titles and abstracts. This phase will be completed using the open access web-based platform Colandr, a machine-learning tool that allows for iterative sorting of relevant and irrelevant articles [40]. All articles deemed relevant during this phase will then be subjected to a full-text review. In cases of uncertainty, the reviewers will include the paper. Data will be coded and extracted from all articles deemed relevant during the full-text review phase. At each stage, the number of excluded articles, and the reason for exclusion, will be documented. A list of articles excluded during the full-text review, with reasons for exclusion, will be provided as an additional file.

At the onset of the title and abstract review stage, each reviewer will assess the eligibility of a random subset of 100 articles and the level of agreement, or interrater reliability, will be tested using the Fleiss Kappa statistic [41]. A kappa result of ≥ 0.61 indicates a substantial level of agreement between reviewers [42] and will be considered acceptable. In cases where the kappa result is less than 0.61, the reviewers will discuss any differences to ensure that screening criteria are being consistently applied. Consistency checking will be repeated until a kappa result of 0.61 is achieved. If needed, the definitions of the eligibility criteria (Table 1) will be updated to improve consistency among reviewers. The remaining articles will be divided for review amongst all but one co-author. The remaining co-author will serve as a second screener on all articles. Any inconsistencies among screeners, or questions about whether an article meets screening criteria, will be reviewed between co-authors. Reviewers that have authored an article under consideration will be recused from decisions regarding the eligibility of the article.

Study validity assessment

A formal study validity assessment will not be carried out as part of this effort.

Data coding strategy

During the full-text review process, information on each relevant article will be extracted and entered into an Excel spreadsheet database. In addition to documenting basic bibliographic information for each article, we will record information on the species and population studied, the geographic location of the study, and the temporal scale over which the analysis was completed. We will document any relevant direct climate or secondary variables to which the study population was exposed, and the outcome variables that were analyzed. If information is missing or unclear in an article, we will email the authors to request the additional information. If the authors do not respond, or do not provide clarification, the article will be excluded from the analysis. Information extracted will include:

- Bibliographic information
  - Study ID (unique numeric ID assigned to each article)
  - Coder ID (unique ID assigned to each reviewer)
  - Citation information
  - Literature type (academic, grey)
- Study design
- Temporal scale
  - Study start and end dates
  - Study duration
- Population information

   - Study location (country, state/province, site name and location, habitat type, climate zone)
   - Species and subspecies
   - Demographic information (age and sex class)

- Exposure variables

   - Direct climate variables (temperature, precipitation)
   - Direct climate variable derivatives
   - Secondary variables (plant phenology, wildfire, invasive species, disease, predation)

- Comparator (type, temporal scale)
- Outcome components and subcomponents measured
   - Individual life-history characteristics
     Subcomponents: individual growth (e.g. body mass, nutritional condition), reproduction
   - Population dynamics
     Subcomponents: abundance, population growth, long-term viability, survival, distribution, structure, density, productivity, recruitment
   - Migration
     Subcomponents: behavior and movement patterns; range, corridor, and stopover habitat location and quality

We will employ several mechanisms to ensure repeatability and consistency in data coding. First, each data field will have a clear definition of the information intended for that field and the required format for data entry. Wherever possible, drop-down lists will be used to improve consistency in data entry. Additionally, at the onset of the data entry phase, each team member will independently review and enter data for the same 10 articles. Any differences in data entry will be discussed and reconciled, and the database fields will be updated if needed. Lastly, a second reviewer will independently review and enter data for a subset of 10% of all articles that pass the title and abstract phase. Any inconsistencies in the extracted information will be discussed and reconciled, and the extraction methodology will be refined if needed.

Study mapping and presentation

The final systematic map will be synthesized in a narrative review. The synthesis will include summary tables and figures of the study characteristics and select variables will be cross-tabulated in a series of heat maps [e.g. [43]]. These heat maps will display the distribution and frequency of occurrences of evidence on ungulate exposure to changes in direct climate and secondary variables by population (i.e. species) and outcome (i.e. life-history characteristics vs. population dynamics vs. migration). An evidence atlas showing the spatial location of each study containing discrete location information will also be produced.

Together, the narrative, tables, and figures will serve as a mechanism for recognizing knowledge gaps and knowledge clusters on the effects of climate variability and change on ungulates in North America. Identified knowledge gaps may represent topics for future primary research, while knowledge clusters may represent areas ripe for targeted systematic reviews. The full database containing the information extracted from each study will be made available for download.

Supplementary information

Supplementary information accompanies this paper at https://doi.org/10.1186/s13750-020-00204-w.

Additional file 1. ROSES form.

Additional file 2. Scoping exercises completed to determine inclusion/exclusion of secondary variable terms in final search string.

Additional file 3. Results of the sensitivity testing of the final search string and the list of articles used to test the sensitivity of the search string.

Additional file 4. List of management agency websites to be hand-searched for grey literature.

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Authors' contributions
KM conceived of the original research question, wrote the first draft of this paper, and led the research team. All authors contributed to refining the research question and study design and edited subsequent drafts. All authors read and approved the final manuscript.

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Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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