MONTANA
STATE LIBRARY
NATURAL HERITAGE PROGRAM mtnhp.mt.gov
1201 11th Ave ▫ P.O. Box 201800 ▫ Helena, MT 59620-1800 ▫ fax 406-444-0266 ▫ phone 406-444-3989

COMPREHENSIVE REPORT

Northern Bog Lemming - *Synaptomys borealis*

© 1997–2026 Montana State Library. All Rights Reserved.
By downloading this report, you are accepting our Data Use Terms and Conditions
Suggested Citation Format: Comprehensive Report for Northern Bog Lemming (Synaptomys *borealis*) from https://fieldguide.mt.gov/speciesDetail.aspx?elcode=AMAFF17020). Retrieved on 10/7/2026.

The Montana Natural Heritage Program is part of the Montana State Library's Natural Resource Information System. Since 1985, it has served as a neutral and non-regulatory provider of easily accessible information on Montana's species and biological communities to inform all stakeholders in environmental review, permitting, and planning processes. The program is part of the NatureServe network that is composed of over 60 member programs across North America that work to provide current and comprehensive distribution and status information on species and biological communities.

MONTANA STATE LIBRARY NATURAL HERITAGE PROGRAM

NATURESERVE

COMPREHENSIVE REPORT

MONTANA
STATE LIBRARY
NATURAL HERITAGE PROGRAM mtnhp.mt.gov
1201 11th Ave ▫ P.O. Box 201800 ▫ Helena, MT 59620-1800 ▫ fax 406-444-0266 ▫ phone 406-444-3989

MONTANA FIELD GUIDE™

Northern Bog Lemming - Synaptomys borealis

MONTANA FIELD GUIDE™

The Montana Natural Heritage Program is part of the Montana State Library's Natural Resource Information System. Since 1985, it has served as a neutral and non-regulatory provider of easily accessible information on Montana's species and biological communities to inform all stakeholders in environmental review, permitting, and planning processes. The program is part of the NatureServe network that is composed of over 60 member programs across North America that work to provide current and comprehensive distribution and status information on species and biological communities.

MONTANA STATE LIBRARY NATURAL HERITAGE PROGRAM

NATURESERVE

Northern Bog Lemming

Synaptomys borealis

© 1997–2026 Montana State Library. All Rights Reserved.

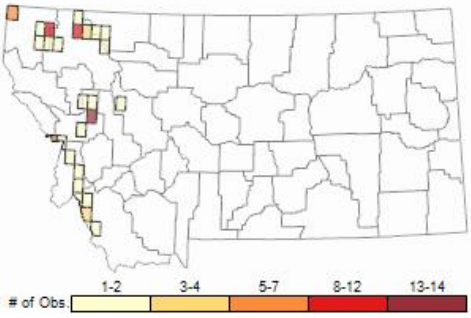
View in MONTANA FIELD GUIDE™



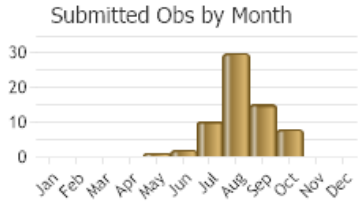
Species of Concern
Native Species
Global Rank: G5
State Rank: S2

Agency Status
USFWS:
USFS: Sensitive - Known in Forests (BD, BRT, KOOT, LOLO)
BLM:
FWP SWAP: SGCN





 # Observations: 76



General Description

The Northern Bog Lemming has a grizzled reddish-brown coat on the back that grades to gray on the belly; the coat is relatively long and loose. The ears extend noticeably beyond the body fur and are sparsely haired on the edge. The tail is extremely short. There are 16 teeth in the skull (dental formula: I 1/1, C 0/0, P 0/0, M 3/3), with the upper incisors broadly grooved. Body measurements are: total length 120 millimeters, tail 21 to 23 millimeters, hind foot 18 to 19 millimeters, and mass 22 to 25 grams (Foresman 2012).

Diagnostic Characteristics

The Northern Bog Lemming can be distinguished from all other mice and voles in Montana by a combination of a very short tail (equal to or only slightly longer than the hind foot), broad shallow grooves on the outer surface of the upper incisors, and the deep reentrant angles on the outer side of the upper cheek teeth and the inner side of the lower cheek teeth (Foresman 2012, 2001).

Habitat

Northern Bog Lemmings in Montana have been found in at least nine community types, including Engelmann spruce, subalpine fir, birch, willow, sedge (*Carex*), spikerush (*Eleocharis*), or combinations of the above, often occurring in wet meadows, fens, or bog-like environments. Wright (1950) captured lemmings in a swampy area containing spruce trees, timothy, alder and other moist-site plants (Wright 1950). The Upper Rattlesnake Creek specimen was captured in a wet-sedge/bluejoint meadow near subalpine fir (Adelman 1979). Areas with extensive moss mats, primarily sphagnum, are the most likely sites in which to find new populations (Wright 1950, Reichel and Beckstrom 1994, Reichel and Corn 1997, Pearson 1999, Foresman 2012).

Throughout their range a variety of habitats are occupied, especially near the southern edge of the global distribution, and include sphagnum bogs, wet meadows, moist mixed and coniferous forests, montane sedge meadows, krummholz spruce-fir forest with dense herbaceous and mossy understory, alpine tundra, mossy streamsides, and even sagebrush slopes in the case of *S. b. artemisiae* in British Columbia (Clough and Albright 1987, West 1999). Typically, occupied habitat has high moisture levels. The Northern Bog Lemming occupies burrow systems up to a foot deep, and also surface runways. Young are born in nests that may be underground or on the surface in concealing vegetation.

MONTANA STATE LIBRARY
NATURAL HERITAGE PROGRAM mtnhp.mt.gov
1201 11th Ave ▫ P.O. Box 201800 ▫ Helena, MT 59620-1800 ▫ fax 406-444-0266 ▫ phone 406-444-3989

CONSERVATION STATUS SUMMARY

Northern Bog Lemming - Synaptomys borealis

CONSERVATION STATUS SUMMARY

The Montana Natural Heritage Program is part of the Montana State Library's Natural Resource Information System. Since 1985, it has served as a neutral and non-regulatory provider of easily accessible information on Montana's species and biological communities to inform all stakeholders in environmental review, permitting, and planning processes. The program is part of the NatureServe network that is composed of over 60 member programs across North America that work to provide current and comprehensive distribution and status information on species and biological communities.

MONTANA STATE LIBRARY NATURAL HERITAGE PROGRAM
NATURESERVE

Northern Bog Lemming (*Synaptomys borealis*)
Conservation Status Rank Summary

Date Published: April 23, 2026

For details on assessment and ranking methodology, see: *Conservation Status Assessment Definitions, Process, Rank Factors, and Calculation of State Ranks for Montana Species*

Rarity and Trends

Rank Factor	Date Assessed	Value Factor Rating	Score	Data Source	Comments
Rarity					
Range Extent	2024-09-12	60690.7 km² F = 20,000-200,000 km²	3.930	MTNHP Range Maps	None
Area of Occupancy	2024-09-12	248 | 4km² cells F = 126-500 4-km² grid cells	3.440	MTNHP Modeling	None
Number of Occurrences	2024-09-12	33 C = 21 - 80	2.750	MTNHP Databases	None
Population Size			-		**Factor not used in ranking.**
# of Occurrences in Good Condition	2024-09-12	0 A = No occurrences with excellent or good (A or B) viability or ecological integrity	0.000	Expert Opinion	The montane wetlands used by the species are highly threatened by drought, fire, and other symptoms of our changing climate
% of Area Occupied in Good Condition			-		**Factor not used in ranking.**
Environmental Specificity	2018-09-26	Very narrow A = Very narrow; specialist or community with key requirements scarce	-	MTNHP Species Rank Data Table	**Factor not used in ranking.** Found only in bogs and fens with a sphagnum moss component | Methodology: NS (2003) | Original Score: A
Rarity is calculated by averaging weighted factor scores: **((3.93 × 1) + (3.44 × 2) + (2.75 × 1) + (0.00 × 2)) / 6 = 2.26**					
Trends					
Short-term Trend	2018-09-26	* U = Unknown	-	MTNHP Species Rank Data Table	**Factor not used in ranking.** No data on trends available. Although sites have been revisited, given the variety of survey methods used and low capture rates, it is difficult to assess trend with confidence | Methodology: NS (2003) | Original Score: U
Long-term Trend	2018-09-26	* U = Unknown	-	MTNHP Species Rank Data Table	**Factor not used in ranking.** Species has been captured so infrequently, it is difficult to say what the long-term trend in population is. | Methodology: NS (2003) | Original Score: U

No trend data used in this rank

*Values may be absent if not precisely estimated; factors may still be assessed for rank if a Factor Rating can be assigned.

Threats

Rank Factor	Date Assessed	Value / Factor Rating	Score	Data Source	Comments
Threats					
Overall Threat Impact		Very High - High / AB = Very High - High	[0.000, 1.830]		None
Intrinsic Vulnerability	2018-09-26	Highly vulnerable / A = Highly vulnerable	-	MTNHP Species Rank Data Table	**Factor not used in ranking.** Although the species has high fecundity, it has specific habitat requirements and fragmentation could make dispersal difficult and recovery of locally extirpated populations impossible. | Methodology: NS (2003) | Original Score: A
Threat score is calculated from Overall Threat Impact when available or Intrinsic Vulnerability if not: **([0.00, 1.83]) = [0.00, 1.83]**					

Individual Threats Data

Threat Category	Date Assessed	Impact Score	Scope	Severity	Immediacy	Comments
Agriculture & Aquaculture	2026-04-22	Medium - Low	Large-Restricted	Moderate-Slight	High	Grazing in peatlands can introduce/favor non-native plant species, change water chemistry (i.e., nutrient loading) that alters native plant communities, and result in soil compaction, all of which degrade habitat.
Biological Resource Use	2026-04-23	Low	Restricted	Moderate	Moderate	Timber harvest operations can change groundwater flow pathways that feed peatlands through soil compaction, road building, and other soil disturbance, leading to habitat loss and/or degradation. Timber harvest too close to peatlands can reduce, remove, or alter vegetated buffers that help reduce infestations of invasive plant species and capture sediment and pollutant runoff from timber harvest operations and associated roads.
Human Intrusions & Disturbance	2026-04-23	Low	Restricted	Moderate	High	Snowmobile use in peatlands can lead to snow compaction which may compact soils and vegetation and may collapse small mammal tunnel networks. -Jarvinen and Schmid (1971) determined that a decrease in subnivean air space, a change in temperature, and accumulation of toxic air under the snow occurs from snow compaction by snowmobiles. Through controlled experiments, researchers have demonstrated that compaction due to snowmobile use reduced rodent and shrew use of subnivean habitats to near zero â€“ a

						decline attributed to direct mortality, not outmigration.
Natural System Modifications	2026-04-23	Medium	Large	Moderate	High	Uncharacteristically dense stands of trees surrounding peatlands or encroaching into peatlands can lead to extreme fire events that cause direct destruction of peatlands or lead to excess sediment delivery to peatlands after fires. Severe fires can change water delivery to peatlands, either by altering flow leading to less water delivery or dramatically increasing water delivery through removal of trees that uptake from shallow groundwater.
Invasive & Other Problematic Species, Genes & Diseases	2026-04-23	Medium - Low	Large-Restricted	Moderate	High	Invasive plant species can invade peatlands and change/reduce structural and forage resources for NBLs. Invasion by exotic plant species is apparent in some peatlands. Reed canary grass (Phalaris arundinacea) is a commonly observed exotic species in peatlands, and is able to aggressively spread by rhizomes. Canada thistle (Cirsium arvense) may also invade peatlands following disturbances such as wheel ruts or fire (Chadde et al. 1998).
Climate Change & Severe Weather	2024-09-12	High	Pervasive	Serious	High	As a glacial relic, species faces significant threats from habitat loss due to ongoing climate change and impacts to montane wetlands
Threat Tally: 0 - Very High, 1 - High, [1,3] - Medium, [2,4] - Low Overall Threat Impact* = Very High - High						

*See Conservation Status Assessment Definitions, Process, Rank Factors, and Calculation of State Ranks for Montana Species for calculation of Overall Threat Impact based on the number and impact of individual threats.

Conservation Status Rank Calculation

Raw score

Rarity: (2.26 × 70%) + Threats: ([0.00, 1.83] × 30%) + Trends: (0.00) = [1.58, 2.13]

Calculated Rank: S2

Accepted Rank	S2
Author(s)	Dan Bachen
Rank Approved By	Montana Species of Concern Committee
State Rank Reason	Although populations of this species exist across much of western Montana, most appear isolated due to the species-specific habitat requirements and total area occupied is relatively small. Species faces significant threats to persistence from degradation of wetland habitats and isolation of populations that increase risk of local extirpation.

Supplementary Information

Montana Natural Heritage Program. 2021. Conservation Status Assessment Definitions, Process, Rank Factors, and Calculation of State Ranks for Montana Species. 18 p.
https://mtnhp.mt.gov/docs/Montana_State_Rank_Criteria_20211201.pdf

Montana Field Guide Species Account:
https://fieldguide.mt.gov/speciesDetail.aspx?elcode=AMAFF17020

Predicted Suitable Habitat Model:
https://mtnhp.mt.gov/resources/models/?elcode=AMAFF17020

Information Needs

Information needs are assessed by considering the availability of factors used to assess species status as well as the quality of these assessments. Current information availability and quality to inform Conservation Status Rank for this species are highlighted.

Rank Factor	Assessment Category	Value	Criteria
General Status	Status Quality	Adequate	Calculated rank has low uncertainty and is represented by a single rank (e.g. S3); accepted rank may be adjusted to a range rank (e.g. S2S3)
		Poor	Rank assessed as SU or calculated rank has notable uncertainty and corresponds to a range rank with 2 or more values (e.g. S2?, S1S3, or S4S5)
Rarity	Range Quality	Adequate	Range polygon adequately represents area of probable occupancy and does not include substantial unoccupied areas; range may be adequately defined and still include areas of unsuitable habitat (e.g. mountain ranges for plains species)
		Marginal	Range polygon defined, but may include or exclude notable areas where the species may or may not occur on the landscape
		Poor	Range polygon not defined
	Habitat Quality	Adequate	Species-habitat relationship is well-defined (e.g. relevant literature or robust habitat model available)
		Marginal	Understanding of species-habitat relationship is adequate among some but not all habitats (e.g. literature covers similar habitats outside of Montana or habitat model performance is only somewhat adequate)
		Poor	Species-habitat relationship is not well understood
Threats	Threat Quality	Adequate	Threat Impact is a single value (including "Unthreatened")
		Marginal	Threat Impact assessed at more than one value (e.g. "High - Medium")
		Poor	Threat Impact is Unknown but Intrinsic Vulnerability is assessed
		Unknown	Threat Impact is Unknown and Intrinsic Vulnerability is not assessed
Trends	Recency	Current	Short-term Trend assessment date less than 10 years old
		Out of Date but Adequate	Short-term Trend assessment date is more than 10 years old or Unknown, but species is Unthreatened
		Out of Date	Short-term Trend assessment date more than 10 years old
		Not Available	Short-term Trend data are not available
	Trend Quality	Sufficient	Short-term Trend assessed at a single value or multiple values with a minimum trend greater than -10% (stable or increasing)
		Unknown but Sufficient	Short-term Trend is Unknown, but species is Unthreatened
		Poor	Short-term Trend is less than -10% (in decline) with two or more values selected
		Unknown	Short-term Trend is Unknown

Summary of Information Availability

Species had a defined range polygon and is monitored at known sites. Presence at sites outside of the current range boundary and in other habitats is poorly studied. No data on trend exist.

Summary of Information Needs

Continued monitoring of historically occupied sites is needed to establish trend in the core of the species range. Exploration of potentially suitable habitat within and in areas adjacent to the species range will provide more certainty on range boundaries and habitat associations.

Additional Threat Details

The table below contains the complete threats assessment for this species. While the Conservation Status Rank Calculation is based on cumulative, broadly categorized (Level 1) threats data, threats are assessed and tracked for more specifically categorized (Level 2) threats when available.

Threat Category	Date Assessed	Assessed By	Data Source	Scope	Severity	Imme-diacy	Comments
Agriculture & Aquaculture - 2.3 - Livestock Farming & Ranching	2026-04-22	Dan Bachen	SWAP Assessment	Large-Restricted	Moderate-Slight	High	Grazing in peatlands can introduce/favor non-native plant species, change water chemistry (i.e., nutrient loading) that alters native plant communities, and result in soil compaction, all of which degrade habitat.
Biological Resource Use - 5.3 - Logging & Wood Harvesting	2026-04-23	Dan Bachen	SWAP Assessment	Restricted	Moderate	Moderate	Timber harvest operations can change groundwater flow pathways that feed peatlands through soil compaction, road building, and other soil disturbance, leading to habitat loss and/or degradation. Timber harvest too close to peatlands can reduce, remove, or alter vegetated buffers that help reduce infestations of invasive plant species and capture sediment and pollutant runoff from timber harvest operations and associated roads.
Human Intrusions & Disturbance - 6.1 - Recreational Activities	2026-04-23	Dan Bachen	SWAP Assessment	Restricted	Moderate	High	Snowmobile use in peatlands can lead to snow compaction which may compact soils and vegetation and may collapse small mammal tunnel networks. -Jarvinen and Schmid (1971) determined that a decrease in subnivean air space, a change in temperature, and accumulation of toxic air under the snow occurs from snow compaction by snowmobiles. Through controlled experiments, researchers have demonstrated that compaction due to snowmobile use reduced rodent and shrew use of subnivean habitats to near zero â€“ a decline attributed to direct mortality, not outmigration.
Natural System Modifications - 7.1 - Fire & Fire Suppression	2026-04-23	Dan Bachen	SWAP Assessment	Large	Moderate	High	Uncharacteristically dense stands of trees surrounding peatlands or encroaching into peatlands can lead to extreme fire events that cause direct destruction of peatlands or lead to excess sediment delivery to peatlands after fires. Severe fires can change water delivery to peatlands, either by altering flow leading to less water delivery or dramatically increasing water delivery through removal of trees that uptake from shallow groundwater.
Invasive & Other Problematic Species, Genes & Diseases - 8.1 - Invasive Non-Native/Alien Species/Diseases	2026-04-23	Dan Bachen	SWAP Assessment	Large-Restricted	Moderate	High	Invasive plant species can invade peatlands and change/reduce structural and forage resources for NBLs. Invasion by exotic plant species is apparent in some peatlands. Reed canary grass (Phalaris arundinacea) is a commonly observed exotic species in peatlands, and is able to aggressively spread by rhizomes. Canada thistle (Cirsium arvense) may also invade peatlands

							following disturbances such as wheel ruts or fire (Chadde et al. 1998).
Climate Change & Severe Weather - 11.1 - Habitat Shifting & Alteration	2024-09-12	Dan Bachen	None	Pervasive	Serious	High	As a glacial relic, species faces significant threats from habitat loss due to ongoing climate change and impacts to montane wetlands

MONTANA
STATE LIBRARY
NATURAL HERITAGE PROGRAM mtnhp.mt.gov
1201 11th Ave ▫ P.O. Box 201800 ▫ Helena, MT 59620-1800 ▫ fax 406-444-0266 ▫ phone 406-444-3989

ADAPTIVE CAPACITY

ADAPTIVE CAPACITY

Northern Bog Lemming - Synaptomys borealis

The Montana Natural Heritage Program is part of the Montana State Library's Natural Resource Information System. Since 1985, it has served as a neutral and non-regulatory provider of easily accessible information on Montana's species and biological communities to inform all stakeholders in environmental review, permitting, and planning processes. The program is part of the NatureServe network that is composed of over 60 member programs across North America that work to provide current and comprehensive distribution and status information on species and biological communities.

MONTANA STATE LIBRARY NATURAL HERITAGE PROGRAM

NATURESERVE

Adaptive Capacity of Northern Bog Lemming (*Synaptomys borealis*)

Adaptive Capacity refers to the intrinsic ability of a species to adapt to changes in its environment. This assessment scores species across seven categories representing the species habitat and distribution in Montana, life history attributes, behavior, and interactions between individuals and the environment they live in. This assessment was developed to assess Climate Change Vulnerability and Adaptive Capacity of species by Nature Serve in partnership with the US Geological Survey. Please review Guidelines for Using the NatureServe Climate Change Vulnerability Index for further details on the scoring process and factor definitions. Note this scoring criteria was developed to assess species vulnerability to changing climate and applicability of adaptive capacity scores to assess other landscape level changes on species are untested.

Contents

Adaptive Capacity Assessment Categories 2
- Distribution 2
- Movement 3
- Evolutionary Potential 4
- Ecological Role 5
- Abiotic Niche 5
- Life History 7
- Demography 8

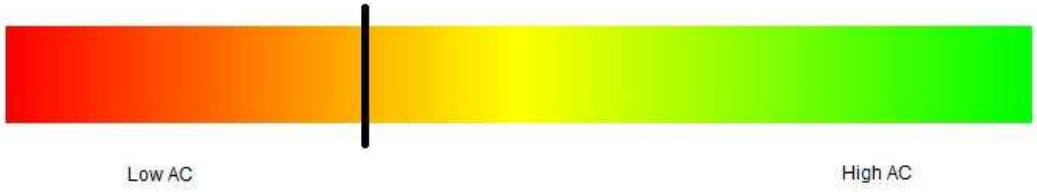
Calculation of Adaptive Capacity 9

Climate Change Vulnerability 10
- Species Exposure 10
- Threat Multipliers 11
- Response to Climate Change 12
- Climate Change Vulnerability and Adaptive Capacity Score 13
  - Adjusted Adaptive Capacity Score (AC_{adj}) 13
  - Vulnerability Score 13
- CCVIAC Calculation 13

Adaptive Capacity Assessment Categories

Distribution

Factor	Score	Numeric	Comments
Extent of Occurrence	High	0	60690.7 km² from NHP Range Maps
Area of Occupancy	Moderate-High	1	992 km² from NHP predicted habitat models
Habitat Specialization	Low	4	Species is found exclusively within bogs, fens, and wet meadows within conifer forests.
Commensalism with Humans	Low	4	Species is not found in habitat with extensive human development
Geographic Rarity	Low	4	Populations appear isolated and are relatively rare across the landscape
13 total points/20 possible points = 0.65			



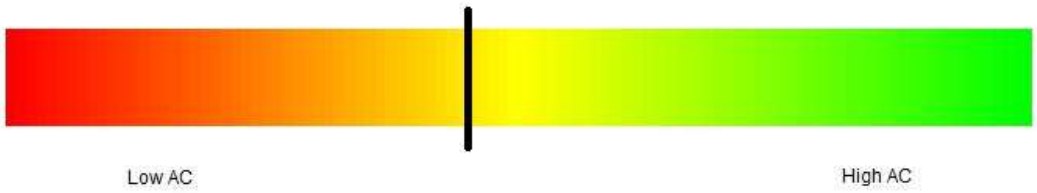
Movement

Factor	Score	Numeric	Comments
Dispersal Syndrome	High	0	Not well documented but species can disperse in both terrestrial and aquatic environments. Dispersal is unlikely to rely on fixed cues.
Dispersal Distance	Moderate-low	3	Habita patches are isolated and dispersal between patches appears unlikely based on current understanding of the species
Dispersal Phase	Low	4	Dispersal is primarily by juveniles
Site Fidelity	Low	4	Species shows strong site fidelity
Migration Frequency			Species is non-migratory. Factor not assessed
Migration Demography			Species is non-migratory. Factor not assessed
Migration Timing			Species is non-migratory. Factor not assessed
Migration Distance			Species is non-migratory. Factor not assessed
11 total points / 16 possible points = 0.5625			



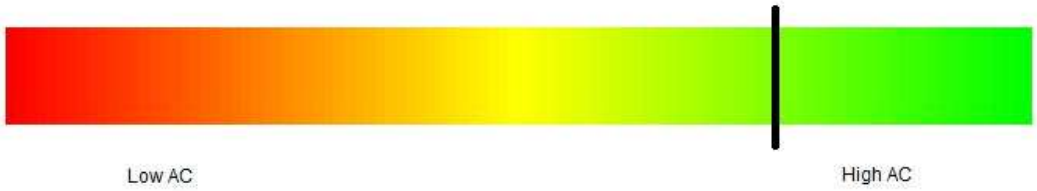
Evolutionary Potential

Factor	Score	Numeric	Comments
Genetic Diversity	Unknown		
Population Size	Moderate-High	1	No population estimates are available but given the limited habitat less than 10,000 individuals seems plausible.
Hybridization Potential	Low	4	Species is not known to hybridize with other species
5 total points / 8 possible points = 0.625			



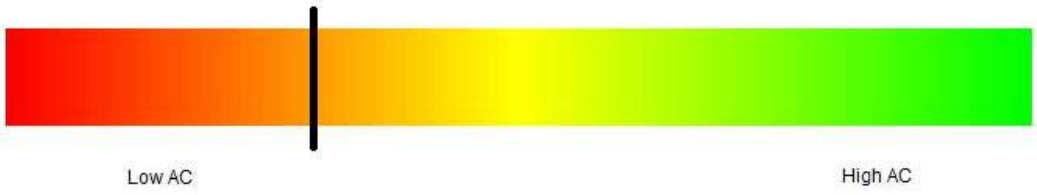
Ecological Role

Factor	Score	Numeric	Comments
Enemies	Unknown		
Diet Breadth	High	0	Species' diet is flexible
Diversity of Obligate Species	Moderate	2	Reliant on wetlands and similar communities for habitat
2 points/ 8 possible points = 0.25			



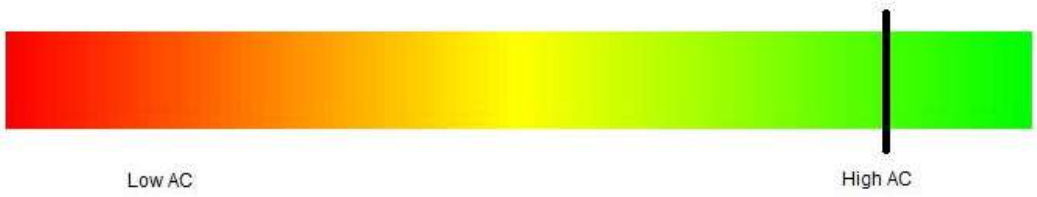
Abiotic Niche

Factor	Score	Numeric	Comments
Seasonal Phenology	High	0	Species is not dependent on environmental cues
Climate Niche Breadth	Low	4	Species is only found within a relatively narrow range climatic conditions
Physiological Tolerances	Low	4	Species associated with wetlands. Which will not provide refugia.
Behavioral Regulation of Physiology	Moderate	2	Species may be able to mitigate warming through behavior to some degree but sublethal effects are likely,
Disturbance Tolerance	Low	4	Changes in the intensity, frequency, or severity of disturbance events due to climate change are likely to have significant impacts to the hydrology of occupied systems
14 total points / 20 possible points = 1.0			



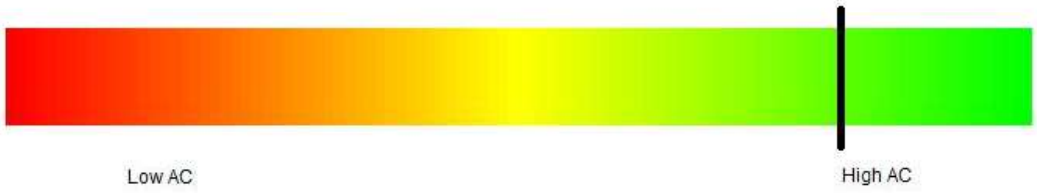
Life History

Factor	Score	Numeric	Comments
Reproductive Phenology	High	0	Reproduction is unlikely to be impacted by environmental cues
Reproductive Mode	High	0	Species is viviparous
Mating System	High	0	Species is promiscuous
Fecundity	High	0	Individuals likely produce more than 10 offspring within their lifetime
Parity	High	0	Iteroparous
Sex Ratio	Unknown		
Sex Determination	High	0	Chromosomal sex determination
Parental Investment	Low	4	Young are altricial
4 total points / 28 possible points = 0.1429			



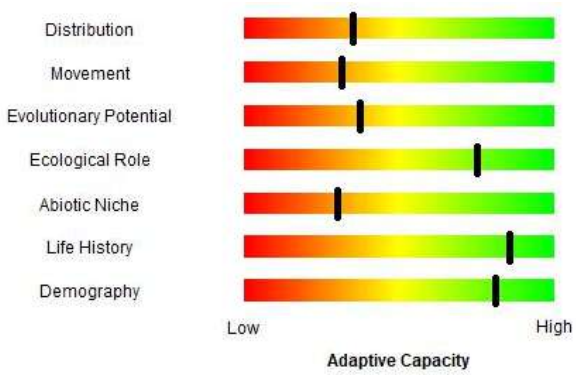
Demography

Factor	Score	Numeric	Comments
Life Span	Moderate-High	1	Species may live 1-3 years
Generation Time	High	0	Less than 1 year
Age of Sexual Maturity	Moderate	2	Species matures in several months
Age Structure	High	0	Biased toward younger individuals
Recruitment	Unknown		
3 total points/ 16 possible points = 0.1875			



Calculation of Adaptive Capacity

The adaptive capacity score of a species is calculated as the sum of each module score.



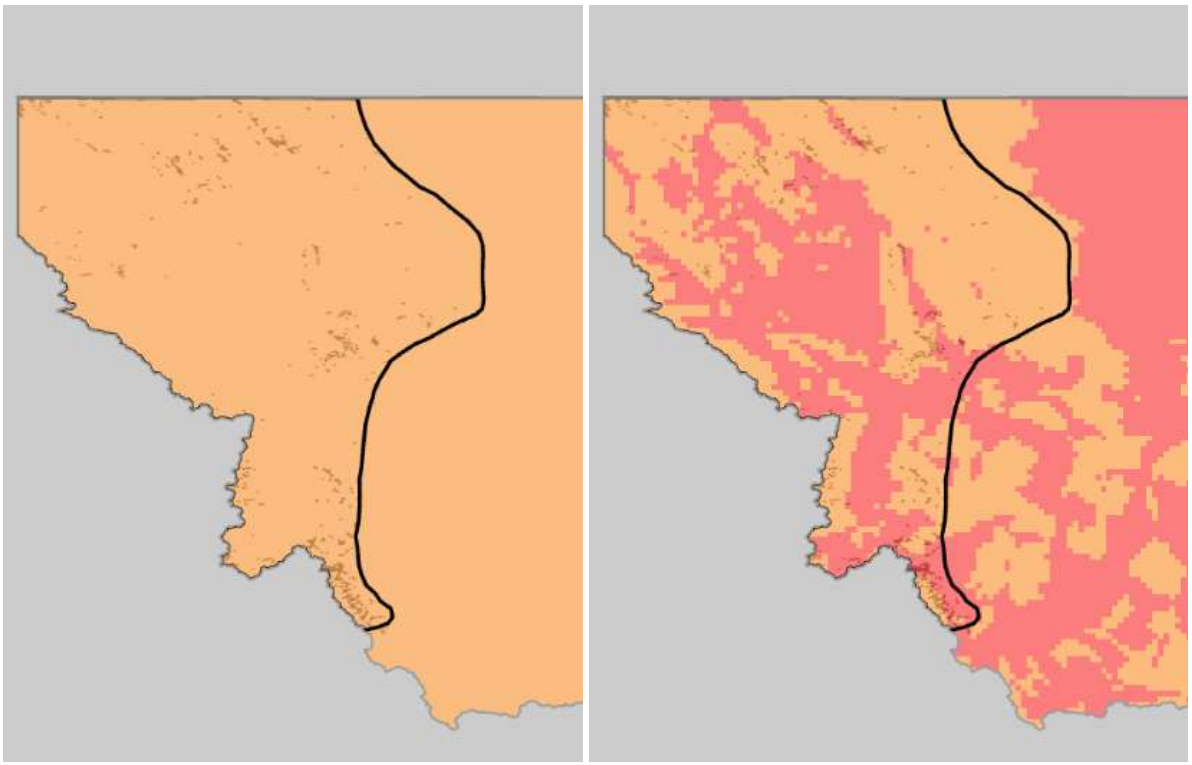
Module	Score
Distribution	0.65
Movement	0.688
Evolutionary Potential	0.625
Ecological Role	0.25
Abiotic Niche	0.7
Life History	0.143
Demography	0.188
Sum = 3.243	

Northern Bog Lemming has a score of **Moderately Low Adaptive Capacity** indicating that it may be impacted by climate change and may struggle to adapt to some threats it faces in Montana.

Climate Change Vulnerability

Species Exposure

Exposure to predicted change in predicted daily mean temperature and climactic water deficit, the evaporative demand not met by available water are scored across the species range under potential future climate scenarios: RCP4.5 representing moderate warming (~50 years) and RCP8.5 representing high warming (~100 years).



Climate Exposure under 4.5C warming (left) and 8.5C warming(right). Yellow areas show lower than average risk, orange shows average risk, and red shows higher than average risk. Species range is shown by the black polygon. Areas predicted as suitable habitat within range are displayed with exposure, with moderate and optimal categories displayed as dark hexes. Area with suitable habitat shown in red have a higher likelihood of climate related impact under these warming scenarios.

Warming scenario	Value
Moderate (RCP4.5)	1.50 (Moderate Exposure)
High (RCP8.5)	1.69 (High Exposure)

Threat Multipliers

Threat Multipliers Account for the interaction between a warming climate and other threats the species may face that could exacerbate impacts. Barriers to dispersal to other more suitable habitat are included.

Factor	Score	Numeric	Comments
Topographic Barriers to Movement	Somewhat increase	2	Warming may have moderate impacts topographic barriers by degreasing the already sparse connectivity between populations
Anthropogenic Barriers to Movement	Neutral	0	Warming scenarios are unlikely to increase anthropogenic barriers
Land Use Change	Neutral	0	Land use change exacerbated by warming is unlikely to impact the species
Other Anthropogenic Threats	Neutral	0	Anthropogenic threats are unlikely to increase under warming
Biological Threats	Neutral	0	Biological threats are unlikely to increase under warming
2 total points / 15 possible points = 0.1333			

Response to Climate Change

Documented or modeled response to climate change accounts for research and predicted response of the species to warming. This allows incorporation of external data to moderate or increase the vulnerability of the species.

Factor	Score	Numeric	Comments
Documented Response to climate change	Unknown	0	
Modeled Future (mid-century) Change in Population or Range Size	Unknown	0	
Overlap with Modeled Future (mid-century) Range with Current Range	Unknown	0	
Occurrence of Protected Areas in Future Distribution	Unknown	0	
-			

Climate Change Vulnerability and Adaptive Capacity Score

Adjusted Adaptive Capacity Score (AC_{adj})

The calculated Adaptive Capacity Score (AC) is adjusted using the Threats Multiplier Score (J_T) with the following equation:

$$AC_{adj} = AC * (1 + 0.5 * J_T)$$

Adaptive Capacity Score = 3.243

Threat Multipliers = 0.1333

Adjusted Adaptive Capacity = (3.24 * (1+0.5 *0.1333) = 3.46 Moderately Low

Vulnerability Score

To calculate the vulnerability score Adjusted Adaptive Capacity (AC_{adj}) is multiplied by Exposure under each warming scenario.

Moderate (RCP4.5) = 3.46 * 1.50 = 5.18 (Moderate Vulnerability)

High (RCP8.5) = 3.46 * 1.69 = 5.85 (Highly Vulnerability)

CCVIAC Calculation

To calculate the final Climate Change Vulnerability and Adaptive Capacity Score, the Vulnerability score derived from the exposure

		Vulnerability (AAC * Exposure)				
		Extreme	High	Moderate	Low	IE
Response to Climate Change	Extreme	Extreme	Extreme	High	High	Extreme
	High	**Extreme**	High	High	Moderate	High
	Moderate	High	High	**Moderate**	Low	Moderate
	Low	High	Moderate	Moderate	Low	Low
	IE	Extreme	High	Moderate	Low	IE

CCVIAC Moderate Warming: Moderate Vulnerability * High Response = Less Vulnerability

CCVIAC High Warming: High Vulnerability * High Response = Moderately Vulnerability

MONTANA
STATE LIBRARY
NATURAL HERITAGE PROGRAM mtnhp.mt.gov
1201 11th Ave ▫ P.O. Box 201800 ▫ Helena, MT 59620-1800 ▫ fax 406-444-0266 ▫ phone 406-444-3989

PREDICTED SUITABLE HABITAT

Northern Bog Lemming - Synaptomys borealis

PREDICTED SUITABLE HABITAT

The Montana Natural Heritage Program is part of the Montana State Library's Natural Resource Information System. Since 1985, it has served as a neutral and non-regulatory provider of easily accessible information on Montana's species and biological communities to inform all stakeholders in environmental review, permitting, and planning processes. The program is part of the NatureServe network that is composed of over 60 member programs across North America that work to provide current and comprehensive distribution and status information on species and biological communities.

MONTANA STATE LIBRARY NATURAL HERITAGE PROGRAM

NATURESERVE

Northern Bog Lemming (*Synaptomys borealis*)
Predicted Suitable Habitat Modeling

Distribution Status: Resident Year Round
State Rank: S2 (Species of Concern)
Global Rank: G5



Modeling Overview

Created by: Braden Burkholder
Creation Date: June 28, 2022
Evaluator: Dan Bachen
Evaluation Date: June 30, 2022

Inductive Model Goal: To predict the current distribution and relative suitability of general year-round habitat for Northern Bog Lemming at large spatial scales across its presumed current range in Montana.
Inductive Model Performance: The model appears to adequately reflect the current distribution and relative suitability of general year-round habitat for Northern Bog Lemming at larger spatial scales across its presumed current range in Montana. Evaluation metrics indicate an acceptable model fit and the delineation of habitat suitability classes is well supported by the data.
Inductive Model Output:
http://mtnhp.org/models/files/Northern_Bog_Lemming_AMAFF17020_20220628_modelHex.lpk

Deductive Model Goal: To represent the ecological systems commonly and occasionally associated with Northern Bog Lemming year-round, across its presumed current range in Montana.
Deductive Model Performance: Ecological systems that Northern Bog Lemming is commonly and occasionally associated with seem to overpredict the amount of suitable habitat across its presumed current range in Montana.

Suggested Citation: Montana Natural Heritage Program. 2022. Northern Bog Lemming (*Synaptomys borealis*) predicted suitable habitat models created on June 28, 2022. Montana Natural Heritage Program, Helena, MT. 20 pp.

Montana Field Guide Species Account: http://fieldguide.mt.gov/speciesDetail.aspx?elcode=AMAFF17020

Species Model Page: http://mtnhp.org/models/?elcode=AMAFF17020

Inductive Modeling

Model Limitations and Suggested Uses

This model is based on statewide biotic and abiotic environmental layers originally mapped at a variety of spatial scales and standardized to 90×90-meter raster pixels. The spatial accuracy of the training and testing data are varied (typically 20-400 meters) and may result in additional statistical noise in the model. As a result, model outputs may not be appropriate for use on smaller areas or at fine spatial scales. **Model outputs should not typically be used for planning efforts on land areas smaller than one quarter of a public land survey system (PLSS) section (<64 hectares)** and model outputs for some species may only be appropriate for broader regional level planning efforts. Models should be interpreted as landscape-level habitat suitability (fundamental niche) and not as estimated distributions of the species (realized niche) since suitable habitat may be unoccupied (Pulliam 2000). **Consequently, model outputs should not be used in place of on-the-ground surveys for species**, and wildlife and land management agency biologists should be consulted about the value of using model output to guide habitat management decisions for regional planning efforts or local projects. See Suggested Contacts for Natural Resource Agencies listed at the end of this report or on our website. In general, we have found across a large number of species representing a wide variety of plant and animal taxa that experts believe optimal and moderate suitability classes represent landscapes where suitable habitat is often more continuous while the low suitability class represents landscapes where suitable habitat is often less continuous, scattered, or patchy (see definitions in the Model Outputs and Evaluation section below). We encourage use of these classes for management, planning, permitting, survey, and other decisions accordingly.

Inductive Model Methods

Modeling Process

Presence-only data were extracted from Montana Natural Heritage Program Databases, which serve as a clearinghouse for animal and plant observation data in Montana. These data were then filtered to ensure spatial and temporal accuracy and to reduce spatial autocorrelation (summarized in Table 1). The spatial extent of this model was limited to the presumed geographic range of the species, by season when applicable, in order to accurately assess potentially available habitat.

We then used these data and 22 statewide biotic and abiotic environmental layers at a 90×90-meter pixel scale (Table 2) to construct the model using a maximum entropy algorithm employed in the modeling program Maxent (Phillips et al. 2006, Phillips et al. 2017). Entropy maximization modeling functions by calculating constraint distributions and then applies those constraints to the environmental layers to estimate a predicted suitable habitat distribution. The mean and variance of the environmental layer values (environmental variables) at the training data locations are used to estimate the constraint distributions. Maxent requires that the final predicted distribution fulfills these constraints. Maxent avoids overfitting models to the training data by “regularizing” or relaxing the constraints so that modeled distributions only have to be close to, rather than exactly equal to, the constraint distributions (Elith et al. 2011). The default regularization multiplier of 1.0 was used since species-specific tuning was impractical given the diversity and volume of species modeled in this effort (Merow et al. 2013, Radosavljevic and Anderson 2014). Additionally, we did not use hinge or threshold features at any sample size to minimize potential overfitting by overly complex models (Syfert et al. 2013, De Marco and Nóberga 2018). The Maxent algorithm can successfully train models even when collinearity exists between environmental variables and the practices of removing collinear variables and/or reducing variables results in limited improvement in Maxent model performance (De Marco and Nóberga 2018, Feng et al. 2019); neither method was employed here.

Maxent fits a model by assuming the predicted distribution is uniform in geographic space and moves away from this distribution only to the extent that it is forced to by the constraints of the training data. To do this, Maxent successively modifies the coefficients for each environmental variable via random walk, accepting the modified coefficient if it increases the gain. Gain is a measure of the closeness of the model concentration around the presence samples that is similar to goodness of fit in generalized linear models. The random walk of coefficients continues until either the increase in the gain falls below a set convergence threshold (0.00001) or a set maximum number of iterations are performed (50,000). The gain value at the end of a model run indicates the likelihood of suitability of the presence samples relative to the likelihood for random background points.

We employed a k-folds cross validation methodology, in this case using ten folds for model training and validation (Elith et al. 2011). Each fold consists of 90% of the data designated for training and 10% of the data reserved for testing. Each record is used for training nine times and testing once. Ten models are estimated and averaged to produce the final model presented here.

Model Outputs and Evaluation

The overall gain associated with individual environmental variables (Table 3) can be used as a measure of the relative importance of each variable (Merow et al. 2013). However, the importance of individual environmental variables should be interpreted with caution due to collinearity between variables. The jackknife assessment of contribution by individual environmental variables to training gain (Figure 1) may be more useful in interpreting the relative importance of individual variables. The response curves for the top four contributing environmental variables are shown for reference (Figure 2). These response curves should also be interpreted cautiously because the observation data used to train the models was not gathered under a probabilistic sampling scheme. If enough observations were available to train and evaluate the model, thresholds are estimated for low, moderate, and optimal habitat suitability; details of this process are presented in Table 4 and Figure 3.

The initial model output is a spatial dataset of continuous logistic values that ranges from 0-1 with lower values representing areas predicted to be less suitable habitat and higher values representing areas predicted to be more suitable habitat (Figures 4 & 5). The standard deviation in the model output across the averaged models is also calculated and plotted as a map to examine spatial variance of model output (Figure 6). The continuous output is reclassified into suitability classes and aggregated within 259-hectare hexagons (Figures 7-9).

In addition to the map of spatial variance in model output, we also evaluated the output of the Maxent model with absolute validation index (AVI) (Hirzel et al. 2006) and deviance (Phillips and Dudik 2008). These metrics are described below in the results (Table 5). True skill statistic (TSS) (Allouche et al. 2006), symmetric extremal dependence index (SEDI) (Wunderlich et al. 2019), and Area Under the Curve (AUC) values are also displayed for reference but are not used for evaluation (Lobo et al. 2008). Finally, a deviance value was calculated for each test data observation as a measure of how well model output matched what the model predicted for the location of test observations and this was plotted with larger symbols indicating larger deviance (see Figure 5). In practice, we have found large deviance values to be associated with records that are incorrectly or imprecisely mapped, problematic areas in underlying environmental layers, regions where species have few observations outside of the core portion of their range, or insufficient models with poor performance.

Table 1: Model Data Selection Criteria and Summary

Location Data Source	Montana Natural Heritage Program Databases
Total Number of Records	73
Location Data Selection Rule 1 – Valid and Accurate Records	Records with <= 400 meters of locational uncertainty
Number of Locations Meeting Selection Rule 1	66
Location Data Selection Rule 2 – Spatially Unique Records	No overlap in locations within 1600 meters in order to avoid spatial autocorrelation
Observation Records used in Model (Locations Meeting Selection Rules 1 & 2)	29
Season Modeled	Year-round
Number of Model Background Locations[a]	9,568

[a] Background locations are chosen at random and in proportion to the percent of the state covered by a species' geographic range, with a maximum of 60,000 locations. Although these locations only represent ~0.1% of the pixels in any modeled area, this level of sampling is sufficient to estimated distributions of environmental conditions present (Phillips and Dudik 2008).

Table 2: Environmental Layers and Corresponding Variables[a]

Layer Name	Variable		Layer Name	Variable
LC_AgDry_97	Developed - Dry Agriculture		NED_AspectEW	Aspect (East-West)
LC_AgIrr_97	Developed - Irrigated Lands		NED_AspectNS	Aspect (North-South)
LC_Alpine_97	Alpine		NED_Elevation	Elevation
LC_Barren_97	Sparse and Barren		NED_Ruggedness	Ruggedness
LC_Developed_97	Developed - All Other		NED_Slope	Slope
LC_ForestBurn_97	Forest - Burned		NED_SRISummer	Summer Solar Radiation
LC_ForestConif_97	Forest - Conifer		NED_SRIWinter	Winter Solar Radiation
LC_ForestDecid_97	Forest - Deciduous		NED_TPI	Topographic Position Index
LC_ForestHarv_97	Forest - Harvested		NHD_Dist2WaterEdge	Distance to Water Edge
LC_ForestInsct_97	Forest - Insect Killed		NHP_AnthroInfl	Anthropogenic Influence
LC_Grassland_97	Grasslands		NRCS_FrostFreeDays	Frost Free Days
LC_IntroVeg_97	Introduced Vegetation		NRCS_REAP	Relative Effective Annual Precipitation
LC_ShrubBurn_97	Shrublands - Burned		PRISM_Precipitation	Annual Precipitation
LC_Shrubland_97	Shrublands		PRISM_WinPrecip	Percent Winter Precipitation
LC_WetRip_97	Wetland & Riparian		SoilGrid_BD	Bulk Density
LC_Dist2Forest	Distance to Forest		SoilGrid_Clay	Percent Clay
MCO_DegreeDays	Degree Days		SoilGrid_EC	Electric Conductivity
MCO_MaxSumTemp	Maximum Summer Temp		SoilGrid_OrgC	Organic Carbon
MCO_MinWinTemp	Minimum Winter Temp		SoilGrid_pH	Soil pH
MCO_NDVI	Normalized Difference Vegetation Index		SoilGrid_Sand	Percent Sand
MTGeol_Dist2Alluv	Distance to Alluvium		SoilGrid_Silt	Percent Silt
MTGeol_Dist2C03	Distance to Carbonate Rock		SoilGrid_TotN	Total Nitrogen

[a] Additional details and sources available in Appendix.

Inductive Model Results

Table 3: Top Ten Contributing Environmental Variables to Model Fit

Variable	Percent Contribution[a]	Variable	Percent Contribution[a]
Wetland Riparian	28.6%	Aspect (East-West)	3.5%
Slope	26.1%	Frost Free Days	3.4%
Degree Days	7.6%	Topographic Position Index	3.3%
Anthropogenic Influence	5.7%	Soil pH	3.2%
Forest - Insect Killed	3.7%	% Winter Precipitation	2.7%

[a] Relative contributions of the variables to the model based on changes in fit (gain) during iterations of the training algorithm.

Table 4: Habitat Suitability Thresholds and Areas of Suitable Habitat

Measure	Value
Optimal Logistic Threshold[a]	0.234
Moderate Logistic Threshold[b]	**0.082**
Low Logistic Threshold[c]	0.007
Area of predicted optimal habitat within modeled range	593.4 km^2
Area of predicted moderate suitability habitat within modeled range	**721.3 km^2**
Area of predicted low suitability habitat within modeled range	3,517.8 km^2
Total area of predicted suitable habitat within modeled range	4,832.5 km^2
Area of entire modeled range (percent of Montana)	60,682.2 km^2 (15.9%)

[a] The logistic threshold where the percentage of test observations above the threshold is 10 or more times higher than would be expected if the observations were randomly distributed across logistic value classes (Hirzel et al. 2006) (see Figure 3). When sample sizes are small, it may be undetermined.

[b] **This is the cutoff recommended for use in management decisions.** The logistic threshold value where the percentage of test observations above the threshold is greater then what would be expected if the observations were randomly distributed across logistic value classes - in other words, when the modeled habitat is used more often than expected from its proportional availability on the landscape (Hirzel et al. 2006). When sample sizes are small, it may be undetermined.

[c] The logistic threshold between unsuitable and low suitability as determined by Maxent which balances data omission error with minimizing predicted suitable area (Phillips et al. 2017). This is a conservative threshold that should encompass nearly all potentially suitable habitat for a species. In practice, habitat with low suitability may represent landscapes of marginal or discontinuous habitat where suitable habitat patches of various sizes are isolated by unsuitable habitat.

Table 5: Evaluation Metrics

Metric	Value
Low AVI[a]	89.7%
Moderate AVI[a]	69.0%
Optimal AVI[a]	65.5%
Average Testing Deviance ($\bar{x}$ ± sd)[b]	3.541 ± 4.395
TSS (Sensitivity + Specificity - 1)[c]	0.6655 (0.6897 + 0.9759 -1)
SEDI[c]	0.8503
Training AUC[d]	0.991
Test AUC[e]	0.977

[a] Absolute Validation Index: The proportion of test locations that fall above the low, moderate, or optimal logistic threshold (see Table 4).

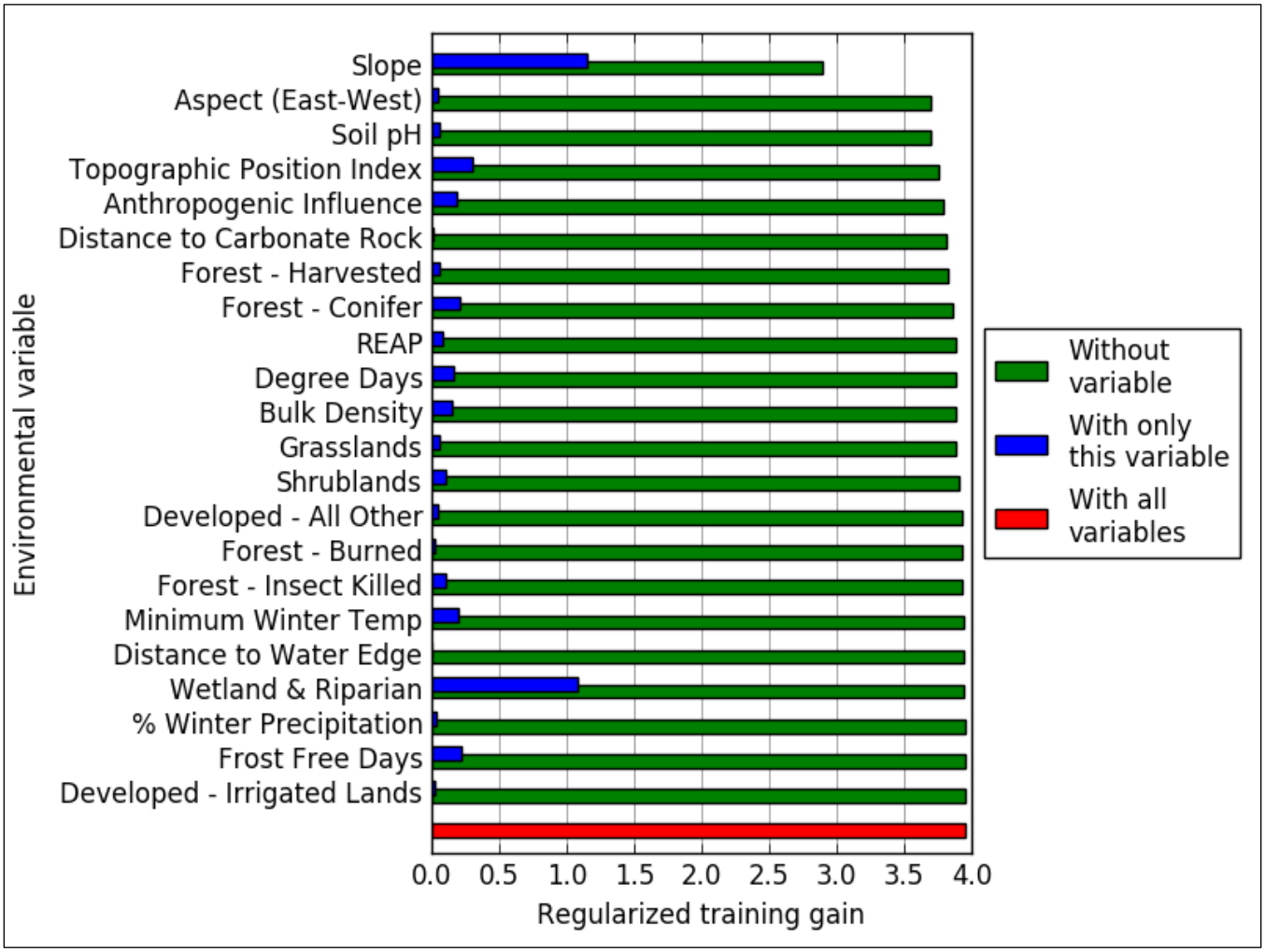
[b] A measure of how well model output matched the location of test observations. In theory, everywhere a test location was located, the logistic value should have been 1.0. The deviance value for each test location is calculated as -2 times the natural log of the associated logistic output value. For example, the equivalent deviance values for the low, moderate and optimal logistic thresholds of this model would be 9.924, 4.992 and 2.909, respectively. Deviances for individual test locations are plotted in Figure 5. Average Testing Deviance less than the Moderate Deviance typically indicates good model performance.

[c] Ranges from -1 to 1, with a random or null model performing at a value of 0 and values 0.65 indicating moderate performance (0.8 generally good performance). The moderate threshold (0.082) is used to develop the confusion matrix for Sensitivity and Specificity metrics. Note that Specificity is calculated based on pseudo-absences (not true absences) and may be biased when large areas are modeled as moderate or optimal suitable habitat.

[d] The area under a curve obtained by plotting the true positive rate against 1 minus the false positive rate for model training observations (averaged over 10 folds). Values range from 0 to 1 with a random or null model performing at a value of 0.5.

[e] The same metric described in [d], but calculated for test observations.

Figure 1. Jackknife assessment of contribution by individual environmental variables to training gain. Variables are ordered by reduction in gain without that variable (green), from greatest to least impact. Only the 25 most influential variables[a] are shown.



[a] Interpretation of individual environmental variables should be approached cautiously and may be inappropriate due to covariance between variables.

Figure 2. Response curves for the top four contributing environmental variables, mean value in red, +/- one standard deviation in blue. Response curves for additional environmental variables are available upon request.

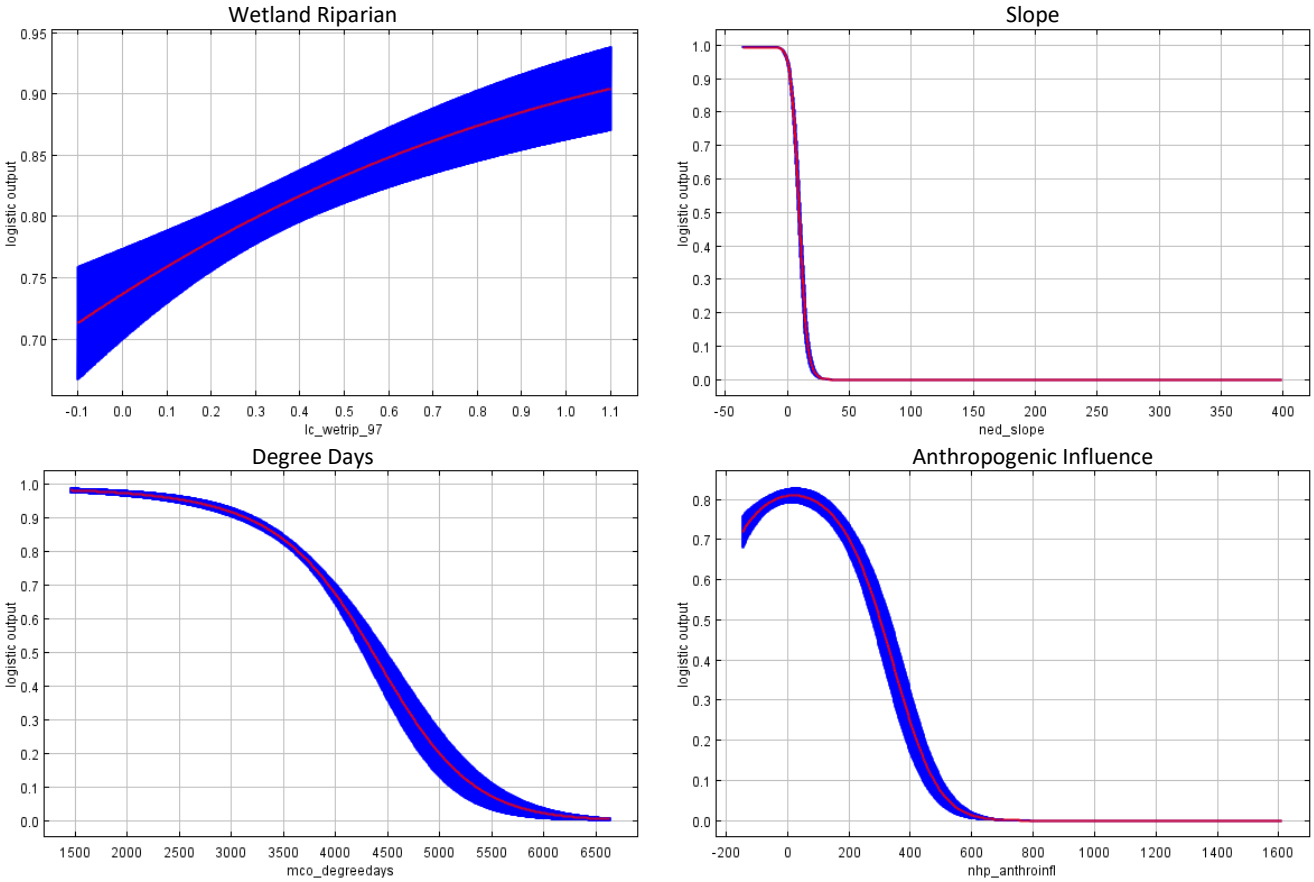
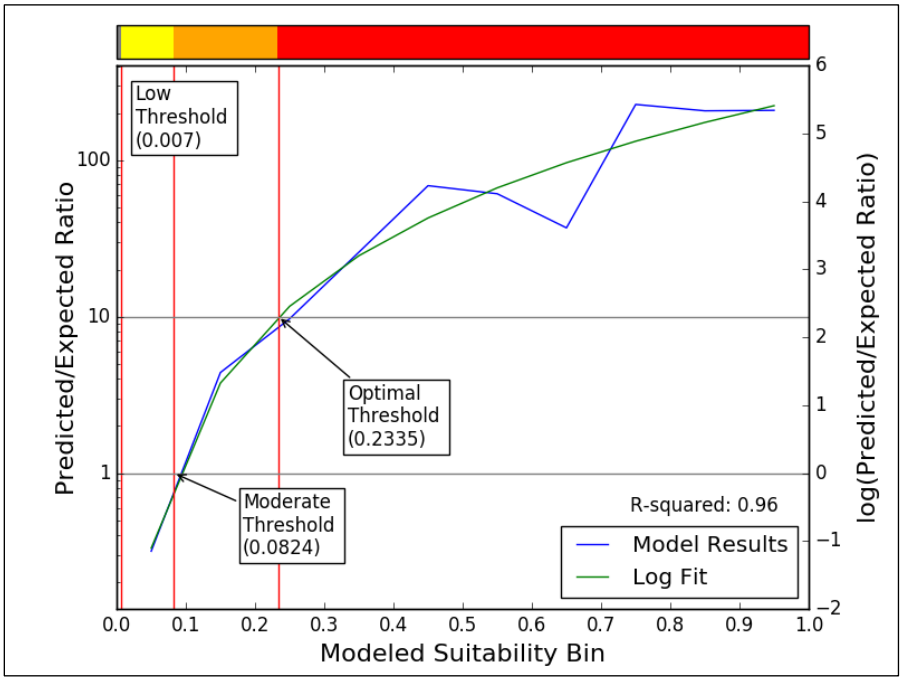


Figure 3. Thresholds for moderate and optimal suitability classes as determined by logarithmic fit.



Inductive Model Map Outputs

Figure 4. Continuous habitat suitability model logistic output (90-meter pixels); white area is not modeled.

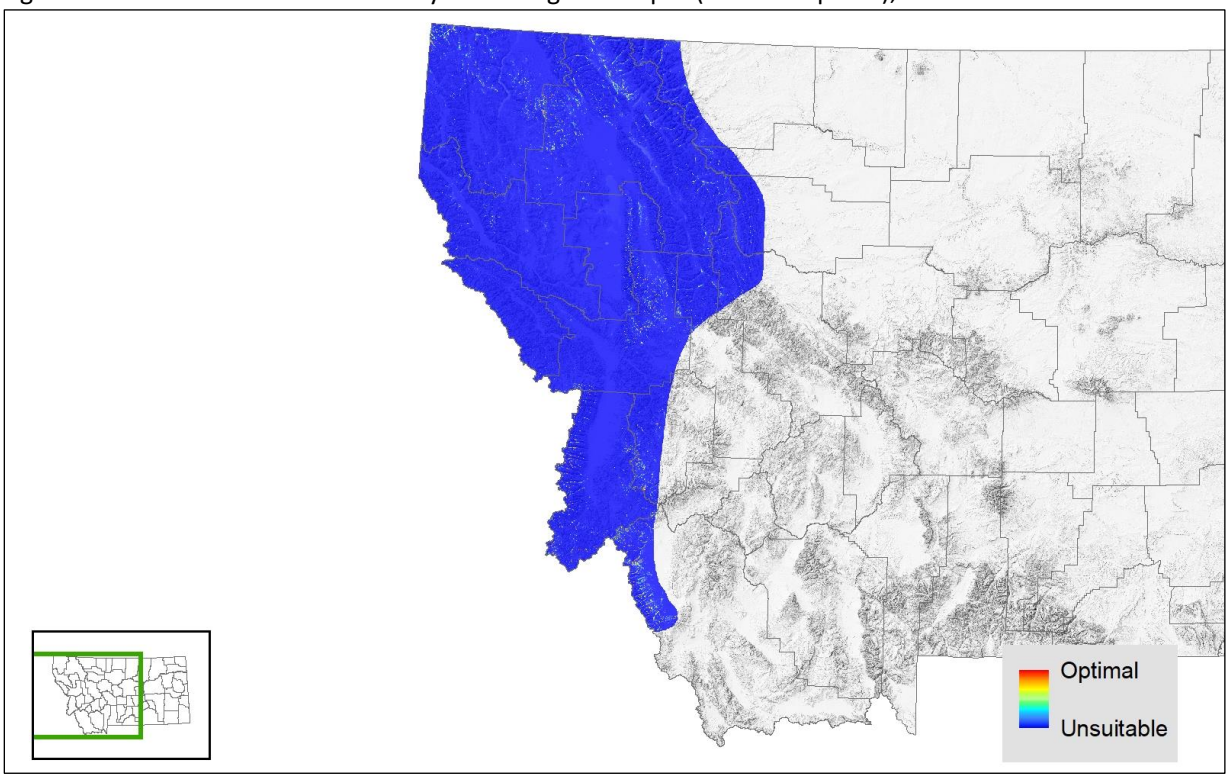


Figure 5. Continuous habitat suitability model output with relative deviance for each observation. Low deviance points fall within optimal or moderate habitat; high deviance points are in generally unsuitable habitat.

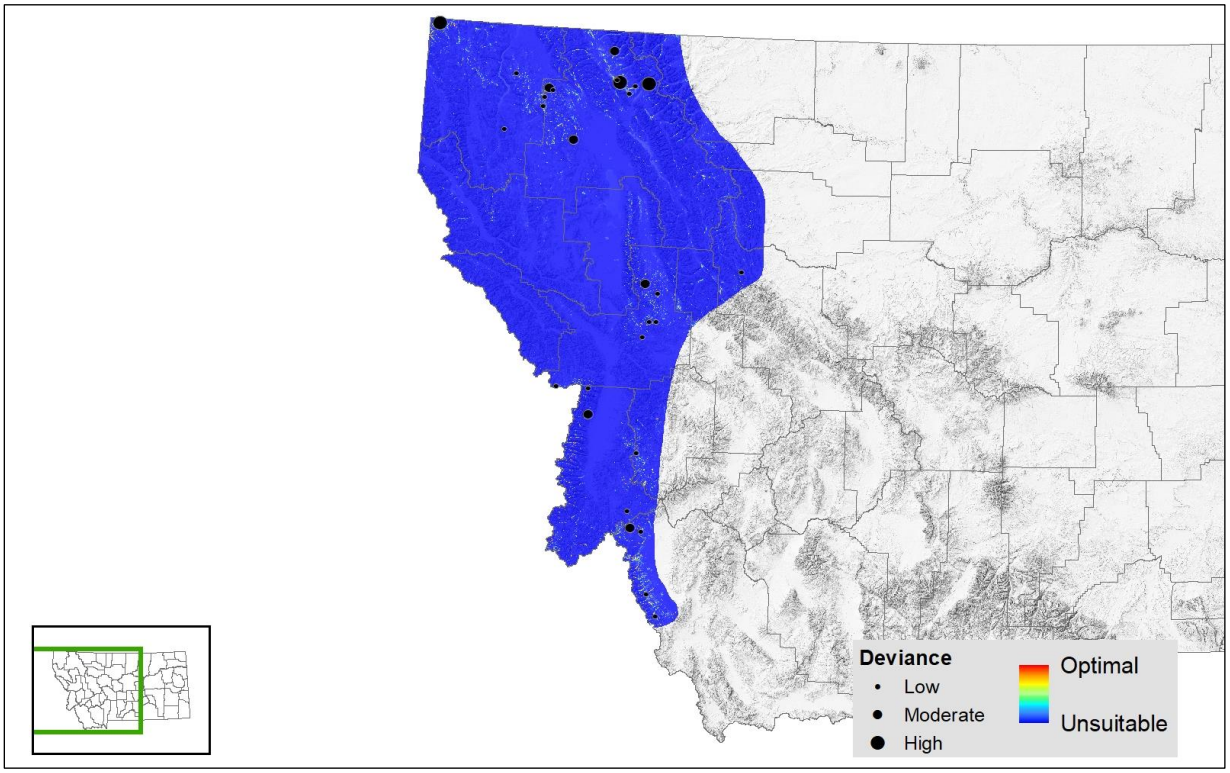


Figure 6. Standard deviation in the model output across the averaged models. Lower deviance (a solid blue map) indicates a better fitting model with lower variability between model iterations.

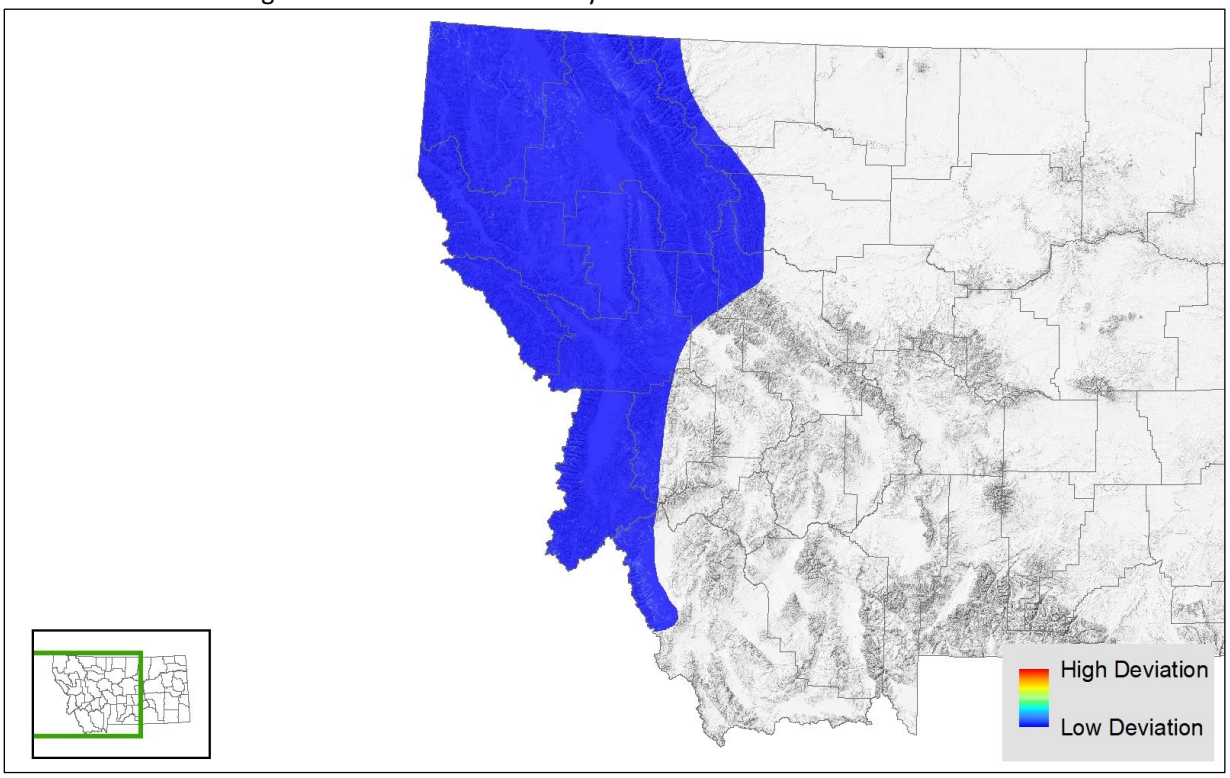


Figure 7. Model output for 90-meter pixels classified into habitat suitability classes.

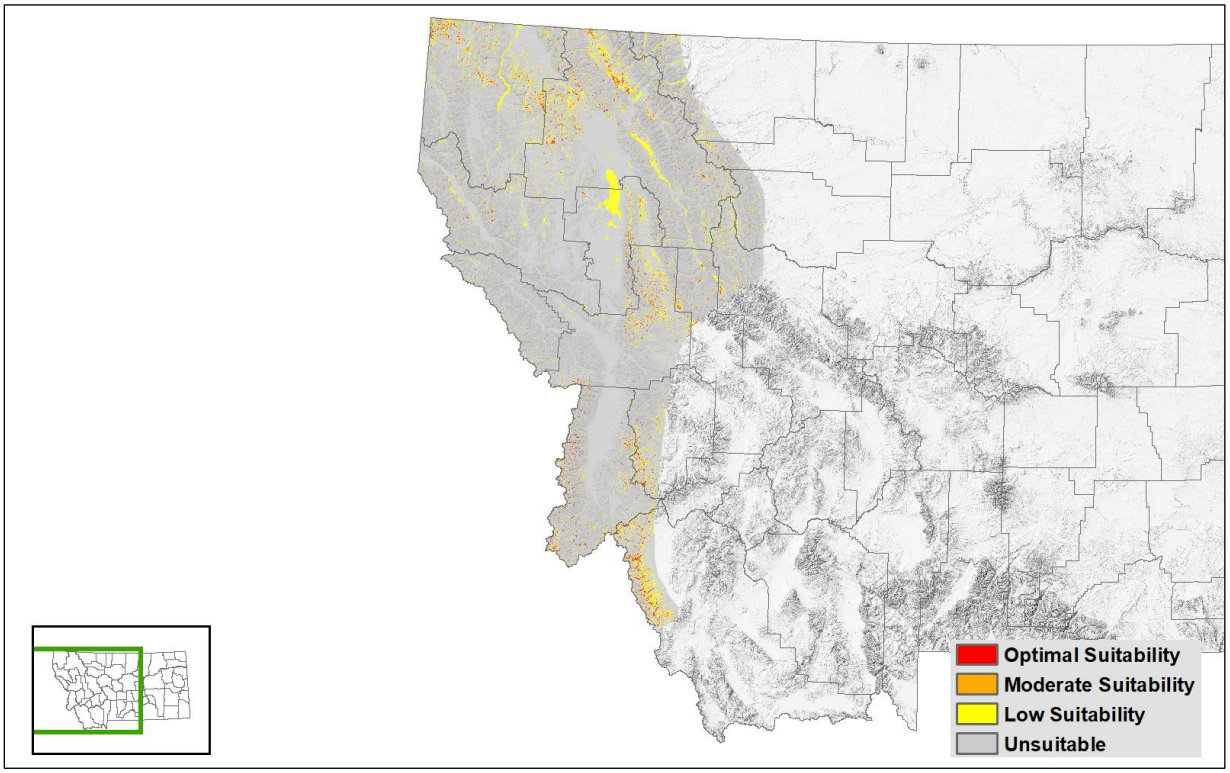


Figure 8. Model output classified into habitat suitability classes and aggregated into hexagons at a scale of 259 hectares per hexagon. This is the finest scale suggested for management decisions and survey planning.

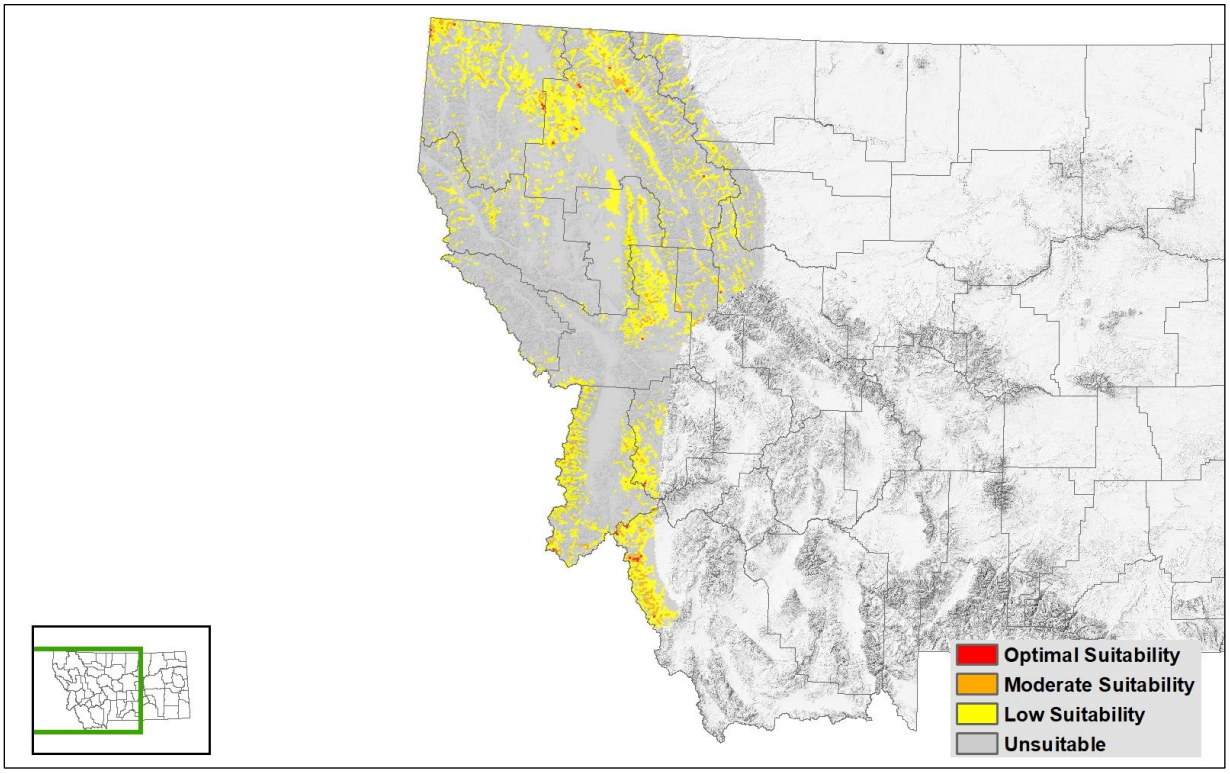
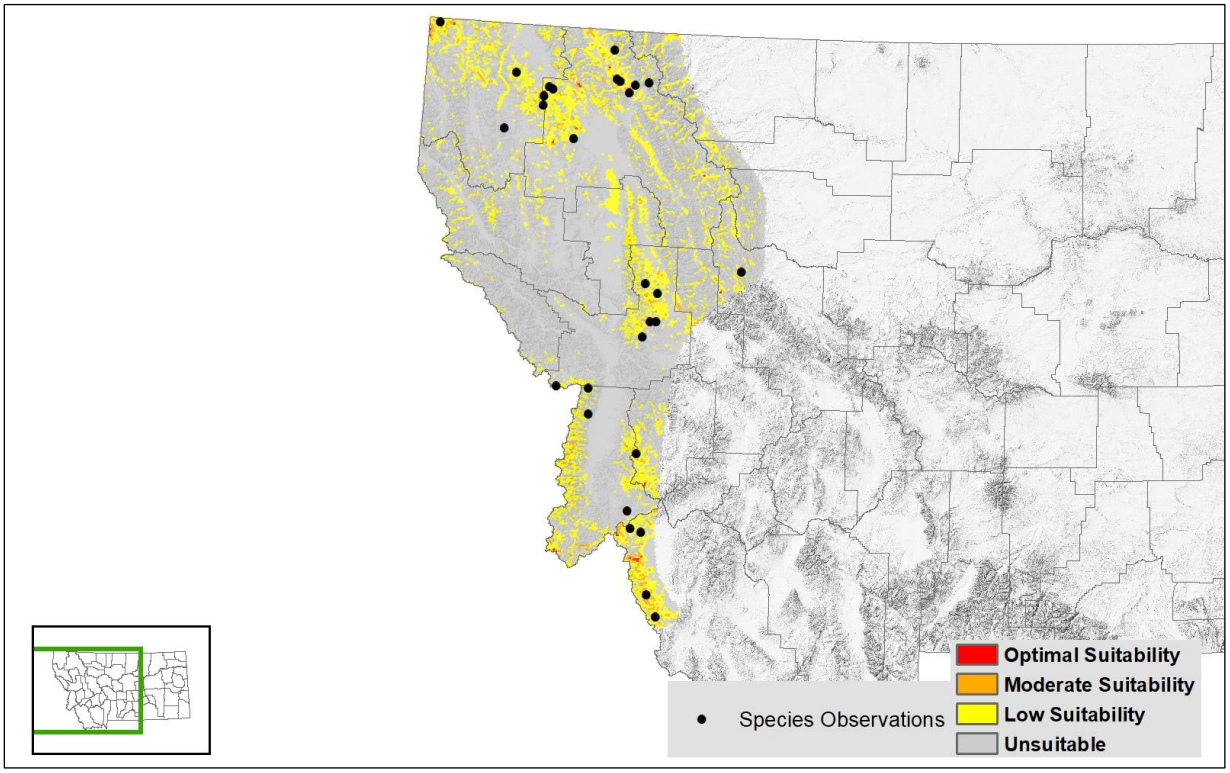


Figure 9. Model output classified into habitat suitability classes and aggregated into hexagons; observations used for modeling and potential survey locations (when available) are displayed for reference.



Deductive Modeling

Model Limitations and Suggested Uses

Species associations with ecological systems should be used to generate lists of potential species that may occupy broader landscapes for the purposes of landscape-level planning. Users of this information should be aware that the land cover data used to generate species associations was only intended to be used at broader landscape scales. Land cover mapping accuracy is particularly problematic when the systems occur as small patches or where the land cover types have been altered over the past decade. Thus, particular caution should be used when using the associations in assessments of smaller areas (e.g. less than one quarter of a public land survey system (PLSS) section, 64 hectares). Model outputs should not be used in place of on-the-ground surveys for species, and wildlife and land management agency biologists should be consulted about the value of using these associations to guide habitat management decisions for regional planning efforts or local projects. See Suggested Contacts for State and Federal Natural Resource Agencies attached to this document. Data used in model evaluation often have locational uncertainties that exceed the 30-meter pixel size of the land cover dataset, potentially intersecting incorrect ecological systems. Additionally, the habitat within a pixel may have been assigned to the wrong ecological system or the habitat may have been modified. As a result, evaluation metrics may be skewed low, especially for species occupying ecotones or patchy ecological systems. Finally, users should note that ecological systems associated with a species are only mapped within the range of that species, although portions of that ecological system may occur elsewhere.

Deductive Model Methods

Modeling Process

This model is based on the 2017 statewide land cover classifications at 30×30-meter raster pixels (Montana Land Use/Land Cover Dataset). Level 3 ecological systems (90) were used for this model and these data were originally mapped at a scale of 1:100,000. In general, species were associated as using an ecological system if structural characteristics of used habitat documented in the literature were present in the ecological system or large numbers of point observations were associated with the ecological system. However, species were not associated with an ecological system if there was no support in the literature for use of structural characteristics in an ecological system, even if point observations were associated with that system. Species were either commonly associated, occasionally associated, or not associated with each ecological system. This assignment was based on the degree to which the structural characteristics of an ecological system matched the preferred structural habitat characteristics for each species in the literature. The percentage of observations associated with each ecological system relative to the percent of Montana covered by each ecological system was also used to guide assignments of habitat quality. Associations are shown in Table 6.

Model Outputs and Evaluation

The model output is a spatial dataset of categorical habitat suitability based on ecological system associations (commonly or occasionally associated) within the species' presumed range (Figure 10) and resulting tabular estimates of the area of commonly and occasionally associated habitat (Table 7). We evaluated this model output based on known or potential distribution and habitat use in Montana and absolute validation indices (AVI) (Hirzel et al. 2006) using presence-only data (Table 8).

Deductive Model Results

Table 6: Ecological Systems Associated with Northern Bog Lemming

Ecological System	Code	Association	Count[a]
Alpine-Montane Wet Meadow	9217	Common	8
Northern Rocky Mountain Lower Montane Riparian Woodland and Shrubland	9155	Common	7
Rocky Mountain Lower Montane-Foothill Riparian Woodland and Shrubland	9156	Common	1
Rocky Mountain Subalpine-Montane Fen	9234	Common	1
Rocky Mountain Conifer Swamp	9111	Common	0
Rocky Mountain Wooded Vernal Pool	9162	Common	0
Rocky Mountain Subalpine-Montane Riparian Woodland	9171	Common	0
Rocky Mountain Subalpine-Montane Riparian Shrubland	9187	Common	0
Emergent Marsh	9222	Common	0
Rocky Mountain Mesic Montane Mixed Conifer Forest	4234	Occasional	2
Rocky Mountain Subalpine-Upper Montane Grassland	7113	Occasional	1
Rocky Mountain Subalpine-Montane Mesic Meadow	7118	Occasional	0

[a] A count of the observation records intersecting each ecological system, based on the 29 observation records used in the inductive model (see Table 1). This may be zero if the number of observations is low or if the ecological system is patchily distributed.

Table 7: Area of Range and Ecological System (ES) Classes

Measure	Value
Area of entire modeled range (percent of Montana)	60,682.2 km2 (15.9%)
Area of Commonly and Occasionally Associated ES	10,192.0 km^2
Area of Commonly Associated ES	1,761.0 km^2
Area of Occasionally Associated ES	8,431.0 km^2

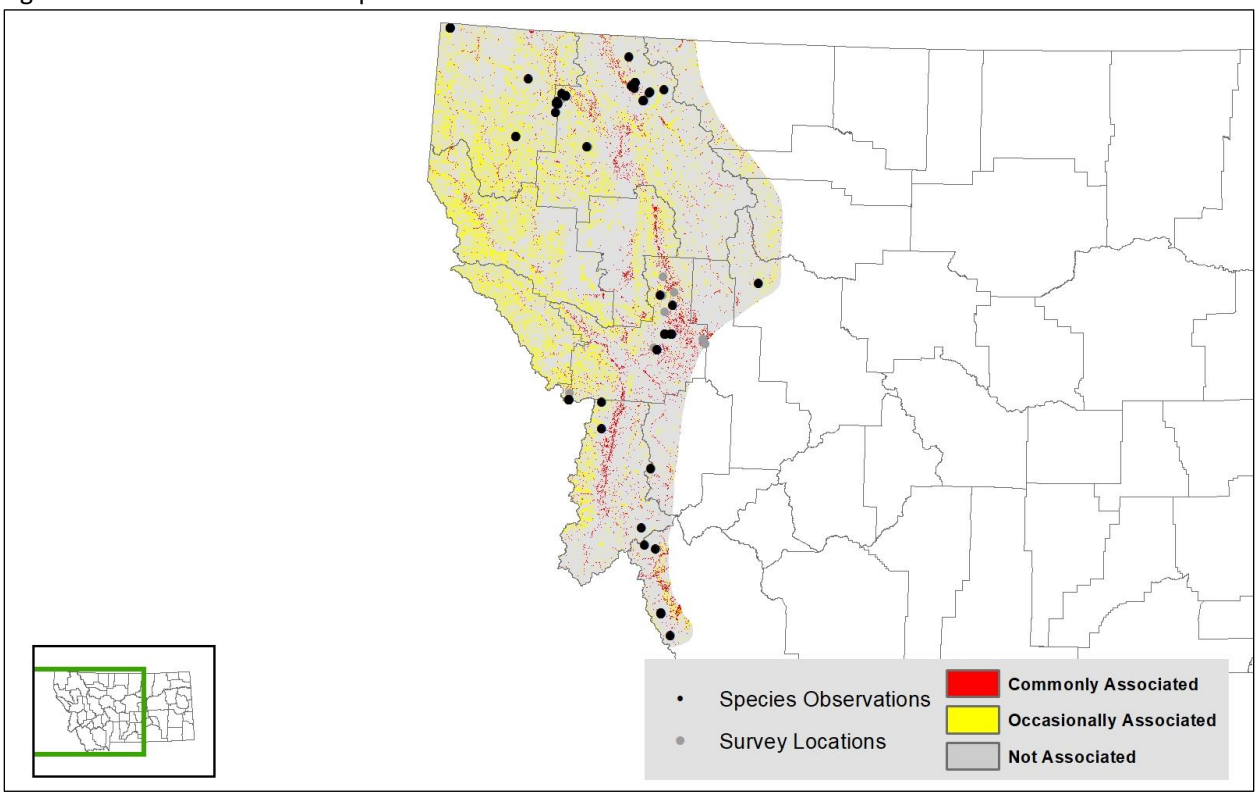
Table 8: Evaluation Metrics

Metric	Value
Commonly and Occasionally Associated ES AVI[a]	69.0%
Commonly Associated ES AVI[a]	58.6%
Occasionally Associated ES AVI[a]	10.3%

[a] Absolute Validation Index: The proportion of test locations that fall within the class(es).

Deductive Model Map Output

Figure 10. Deductive model output classified into habitat associations.



Literature Cited

Allouche, O., A. Tsoar, and R. Kadmon. 2006. Assessing the accuracy of species distribution models: prevalence, kappa and the true skill statistic (TSS). Journal of Applied Ecology 43: 1223-1232. https://doi.org/10.1111/j.1365-2664.2006.01214.x

De Marco, P. Jr. and C. C. Nóbrega. 2018. Evaluating collinearity effects on species distribution models: An approach based on virtual species simulation. PLoS ONE 13(9): e0202403. https://doi.org/10.1371/journal.pone.0202403

Elith, J., S. J. Phillips, T. Hastie, M. Dudík, Y. E. Chee, and C. J. Yates. 2011. A statistical explanation of MaxEnt for ecologists. Diversity and Distributions 17: 43-57. https://doi.org/10.1111/j.1472-4642.2010.00725.x

Feng, X., D. S. Park, Y. Liang, R. Pandey, M. Papeş. 2019. Collinearity in ecological niche modeling: Confusions and challenges. Ecology and Evolution 9: 10365-10376. https://doi.org/10.1002/ece3.5555

Hirzel, A. H., G. Le Lay, V. Helfer, C. Randin, and A. Guisana. 2006. Evaluating the ability of habitat suitability models to predict species presences. Ecological Modelling 199: 142-152. https://doi.org/10.1016/j.ecolmodel.2006.05.017

Lobo, J. M., A. Jiménez-Valverde, and R. Real. 2008. AUC: a misleading measure of the performance of predictive distribution models. Global Ecology and Biogeography 17: 145-151. https://doi.org/10.1111/j.1466-8238.2007.00358.x

Merow, C., M. J. Smith, and J. A. Silander Jr. 2013. A practical guide to MaxEnt for modeling species' distributions: what it does, and why inputs and settings matter. Ecography 36: 1058-1069. https://doi.org/10.1111/j.1600-0587.2013.07872.x

Phillips, S. J., R. P. Anderson, and R. E. Schapire. 2006. Maximum entropy modeling of species geographic distributions. Ecological Modeling 190: 231-259. https://doi.org/10.1016/j.ecolmodel.2005.03.026

Phillips, S. J., M. Dudík, R. E. Schapire. 2017. Maxent software for modeling species niches and distributions (Version 3.4.1). Available from: http://biodiversityinformatics.amnh.org/open_source/maxent

Phillips, S. J. and M. Dudík. 2008. Modeling of species distributions with MaxEnt: New extensions and a comprehensive evaluation. Ecography 31: 161-175. https://doi.org/10.1111/j.0906-7590.2008.5203.x

Pulliam, H. R. 2000. On the relationship between niche and distribution. Ecology Letters 3: 349–361. https://doi.org/10.1046/j.1461-0248.2000.00143.x

Radosavljevic, A., and R. P. Anderson. 2014. Making better Maxent models of species distributions: complexity, overfitting, and evaluation. Journal of Biogeography 41: 629–643. https://doi.org/10.1111/jbi.12227

Syfert, M. M., M. J. Smith, and D. A. Coomes. 2013. The effects of sampling bias and model complexity on the predictive performance of Maxent species distribution models. PLoS ONE 8(2): e55158. https://doi.org/10.1371/journal.pone.0055158

Wunderlich, R. F., Y. Lin, J. Anthony, and J. R. Petway. 2019. Two alternative evaluation metrics to replace the true skill statistic in the assessment of species distribution. Nature Conservation 35: 97-116. https://doi.org/10.3897/natureconservation.35.33918

Appendix

Table A. Detailed Descriptions of Environmental Layers

Layer Name	Class	Variable	Original Scale	Description
LC_AgDry_97	Landcover	Developed - Dry Agriculture	30m	Proportion (0-1) of cells classed as Agriculture without Irrigation within a 97-cell neighborhood (~150m radius).
LC_AgIrr_97	Landcover	Developed - Irrigated Lands	30m	Proportion (0-1) of cells classed as Agriculture with Irrigation within a 97-cell neighborhood (~150m radius).
LC_Alpine_97	Landcover	Alpine	30m	Proportion (0-1) of cells classed as Alpine cover types within a 97-cell neighborhood (~150m radius).
LC_Barren_97	Landcover	Sparse and Barren	30m	Proportion (0-1) of cells classed as Sparse or Barren within a 97-cell neighborhood (~150m radius).
LC_Developed_97	Landcover	Developed - All Other	30m	Proportion (0-1) of cells classed as Developed (e.g. towns, roads, mines) within a 97-cell neighborhood (~150m radius).
LC_ForestBurn_97	Landcover	Forest - Burned	30m	Proportion (0-1) of cells classed as Burned Forest within a 97-cell neighborhood (~150m radius).
LC_ForestConif_97	Landcover	Forest - Conifer	30m	Proportion (0-1) of cells classed as Conifer Forest within a 97-cell neighborhood (~150m radius).
LC_ForestDecid_97	Landcover	Forest - Deciduous	30m	Proportion (0-1) of cells classed as Deciduous Forest within a 97-cell neighborhood (~150m radius).
LC_ForestHarv_97	Landcover	Forest - Harvested	30m	Proportion (0-1) of cells classed as Harvest Forest within a 97-cell neighborhood (~150m radius).
LC_ForestInsct_97	Landcover	Forest - Insect Killed	30m	Proportion (0-1) of cells classed as Insect Killed Forest within a 97-cell neighborhood (~150m radius).
LC_Grassland_97	Landcover	Grasslands	30m	Proportion (0-1) of cells classed as Grassland cover types within a 97-cell neighborhood (~150m radius).
LC_IntroVeg_97	Landcover	Introduced Vegetation	30m	Proportion (0-1) of cells classed as Introduced Vegetation within a 97-cell neighborhood (~150m radius).
LC_ShrubBurn_97	Landcover	Shrublands - Burned	30m	Proportion (0-1) of cells classed as Burned Shrubland within a 97-cell neighborhood (~150m radius).
LC_Shrubland_97	Landcover	Shrublands	30m	Proportion (0-1) of cells classed as Shrubland cover types within a 97-cell neighborhood (~150m radius).
LC_WetRip_97	Landcover	Wetland Riparian	30m	Proportion (0-1) of cells classed as Wetland or Riparian within a 97-cell neighborhood (~150m radius).
LC_Dist2Forest	Landcover	Distance to Forest	30m	Distance in meters to any forest cover type, after consolidating to patches 900m^2.
MCO_DegreeDays	Climate	Degree Days	800m	Average annual total of degree days (°F) above 32°F for 1981-2010.
MCO_MaxSumTemp	Climate	Maximum Summer Temp	800m	Average maximum temperature (°C) in July for 1981-2010.
MCO_MinWinTemp	Climate	Minimum Winter Temp	800m	Average minimum temperature (°C) in January for 1981-2010.
MCO_NDVI	Climate	Normalized Difference Vegetation Index	925m	Normalized Difference Vegetation as a measure of yearly mean greenness from the MODIS Terra satellite, 2000-2014.
MTGeol_Dist2Alluv	Geology	Distance to Alluvium	vector	Distance in meters to alluvial, glacial, or other unconsolidated surface geology types.
MTGeol_Dist2C03	Geology	Distance to Carbonate Rock	vector	Distance in meters to geological units with major components of either limestone or dolostone.

Layer Name	Class	Variable	Original Scale	Description
NED_AspectEW	Landform	Aspect (East-West)	≈10m	Aspect of slopes, ranging from 1 (east) to -1 (west).
NED_AspectNS	Landform	Aspect (North-South)	≈10m	Aspect of slopes, ranging from 1 (north) to -1 (south).
NED_Elevation	Landform	Elevation	≈10m	Elevation in meters above mean sea level.
NED_Ruggedness	Landform	Ruggedness	≈10m	Vector ruggedness measure from 0 (flat) to 1 (rugged), based on 5-cell neighborhood.
NED_Slope	Landform	Slope	≈10m	Percent slope (x100) of landscape.
NED_SRISummer	Landform	Summer Solar Radiation	≈10m	Solar radiation (WH/m^2) for the day of the summer solstice.
NED_SRIWinter	Landform	Winter Solar Radiation	≈10m	Solar radiation (WH/m^2) for the day of the winter solstice.
NED_TPI	Landform	Topographic Position Index	≈10m	Relative topographic position, based on a 5- to 10-cell radius envelope; positive values represent ridges, negative values are valleys/drainages.
NHD_Dist2WaterEdge	Hydrography	Distance to Water Edge	vector	Distance in meters to edges of lakes, reservoirs, streams, or rivers, as mapped in high resolution NHD.
NHP_AnthroInfl	Human	Anthropogenic Influence	vector	An index of human impact on landscape, based on structure density and road use.
NRCS_FrostFreeDays	Climate	Frost Free Days	30m	Estimated number of days without frost: daily minimum temperature 0°C based on a 5 in 10 year probability.
NRCS_REAP	Climate	Relative Effective Annual Precipitation	10m	REAP, an adjusted annual precipitation estimate enhanced with DEM attributes (cm) over 30 years.
PRISM_Precipitation	Climate	Annual Precipitation	≈800m	Average annual precipitation (mm) for 1981-2010.
PRISM_WinPrecip	Climate	Percent Winter Precipitation	≈800m	Average percent (0 to 1) of the total annual precipitation that occurs during winter (Nov-Apr) for 1981-2010.
SoilGrid_BD	Soils	Bulk Density	100m	Bulk density (inversely related to pore space), g/cm^3 (0-5cm depth).
SoilGrid_Clay	Soils	Percent Clay	100m	Percent Clay in soil (0-5cm depth).
SoilGrid_EC	Soils	Electric Conductivity	100m	Electric conductivity (measure of salinity) of soil, dS/m (x100) (0-5cm depth).
SoilGrid_OrgC	Soils	Organic Carbon	100m	Soil organic carbon, % weight (x1000) (0-5cm depth).
SoilGrid_pH	Soils	Soil pH	100m	Soil pH (0-5cm depth).
SoilGrid_Sand	Soils	Percent Sand	100m	Percent Sand in soil (0-5cm depth).
SoilGrid_Silt	Soils	Percent Silt	100m	Percent Silt in soil (0-5cm depth); derived, based on Sand and Clay percentages.
SoilGrid_TotN	Soils	Total Nitrogen	100m	Total nitrogen in soil, % weight (x1000) (0-5cm depth).

Data Sources/Environmental Layer Name Prefix Key

LC - Montana Land Use/Land Cover Dataset (MSDI)

MCO - Montana Climate Office (MSDI)

MTGeol - Montana Bureau of Mines Geology (MSDI)

NED - National Elevation Dataset (MSDI)

NHD - National Hydrological Dataset (MSDI)

NHP - NHP Data (unpublished)

NRCS - Natural Resources Conservation Service (MSDI)

PRISM - PRISM Climate Group (OSU)

SoilGrid - US48 Soil Grids 100m (PSU)

Data Use Terms and Conditions

• Montana Natural Heritage Program (MTNHP) products and services are based on biological data and the objective interpretation of those data by professional scientists. MTNHP does not advocate any particular philosophy of natural resource protection, management, development, or public policy.

• MTNHP has no natural resource management or regulatory authority. Products, statements, and services from MTNHP are intended to inform parties as to the state of scientific knowledge about certain natural resources, and to further develop that knowledge. The information is not intended as natural resource management guidelines or prescriptions or a determination of environmental impacts. MTNHP recommends consultation with appropriate state, federal, and tribal resource management agencies and authorities in the area where your project is located.

• Information on the status and spatial distribution of biological resources produced by MTNHP are intended to inform parties of the state-wide status, known occurrence, or the likelihood of the presence of those resources. **These products are not intended to substitute for field-collected data, nor are they intended to be the sole basis for natural resource management decisions.**

• MTNHP does not portray its data as exhaustive or comprehensive inventories of rare species or biological communities. **Field verification of the absence or presence of sensitive species and biological communities will always be an important obligation of users of our data.**

• MTNHP responds equally to all requests for products and services, regardless of the purpose or identity of the requester.

• Because MTNHP constantly updates and revises its databases with new data and information, products will become outdated over time. Interested parties are encouraged to obtain the most current information possible from MTNHP, rather than using older products. We add, review, update, and delete records on a daily basis. Consequently, we strongly advise that you update your MTNHP data sets at a minimum of every three months for most applications of our information.

• MTNHP data require a certain degree of biological expertise for proper analysis, interpretation, and application. Our staff is available to advise you on questions regarding the interpretation or appropriate use of the data that we provide. Contact information for MTNHP staff is posted at: http://mtnhp.org/contact.asp

• The information provided to you by MTNHP may include sensitive data that if publicly released might jeopardize the welfare of threatened, endangered, or sensitive species or biological communities. This information is intended for distribution or use only within your department, agency, or business. Subcontractors may have access to the data during the course of any given project but should not be given a copy for their use on subsequent, unrelated work.

• MTNHP data are made freely available. **Duplication of hard-copy or digital MTNHP products with the intent to sell is prohibited without written consent by MTNHP.** Should you be asked by individuals outside your organization for the type of data that we provide, please refer them to MTNHP.

• MTNHP and appropriate staff members should be appropriately acknowledged as an information source in any third-party product involving MTNHP data, reports, papers, publications, or in maps that incorporate MTNHP graphic elements. The following is a suggested data citation format: *Montana Natural Heritage Program. {date type} for {species or species group} in {geographic filter, if applicable} Montana [Data set]. Retrieved January 1, 2020. Available from: http://mtnhp.org*

• Sources of our data include museum specimens, published and unpublished scientific literature, field surveys by state and federal agencies and private contractors, and reports from knowledgeable individuals. MTNHP actively solicits and encourages additions, corrections and updates, new observations or collections, and comments on any data we provide.

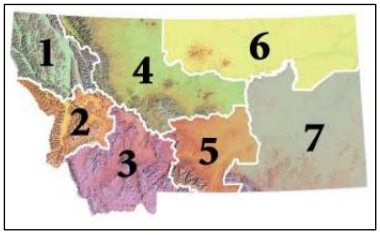
• MTNHP staff and contractors do not cross or survey privately-owned lands without express permission from the landowner. However, the program cannot guarantee that information provided to us by others was obtained under adherence to this policy.

Suggested Contacts for Natural Resource Management Agencies

As required by Montana statute (MCA 90-15), the Montana Natural Heritage Program works with state, federal, tribal, nongovernmental organizations, and private partners to ensure that the latest animal and plant distribution and status information is incorporated into our databases so that it can be used to inform a variety of permitting and planning processes and management decisions. We encourage you to contact state, federal, and tribal resource management agencies in the area where your project is located and review the permitting overviews by the Montana Department of Environmental Quality, the Montana Department of Natural Resources and Conservation and the Index of Environmental Permits for Montana for guidelines relevant to your efforts. In particular, we encourage you to contact the Montana Department of Fish, Wildlife, and Parks for the latest data and management information regarding hunted and high-profile management species and to use the U.S. Fish and Wildlife Service's Information Planning and Consultation (IPAC) website regarding U.S. Endangered Species Act listed Threatened, Endangered, or Candidate species.

For your convenience, we have compiled a list of relevant agency contacts and links below; check our website for updates.

Montana Fish, Wildlife, and Parks

Fish Species	Zachary Shattuck zshattuck@mt.gov (406) 444-1231 or Eric Roberts eroberts@mt.gov (406) 444-5334
American Bison Black-footed Ferret Black-tailed Prairie Dog Bald Eagle Golden Eagle Common Loon Least Tern Piping Plover Whooping Crane	Kristina Smucker ksmucker@mt.gov (406) 444-5209
Grizzly Bear Greater Sage Grouse Trumpeter Swan Big Game Upland Game Birds Furbearers	Brian Wakeling Brian.Wakeling@mt.gov (406) 444-3940
Managed Terrestrial Game and Nongame Animal Data	Smith Wells – MFWP Data Analyst smith.wells@mt.gov (406) 444-3759
Fisheries Data	Ryan Alger – MFWP Data Analyst ryan.alger@mt.gov (406) 444-5365
Wildlife and Fisheries Scientific Collector's Permits	https://fwp.mt.gov/buyandapply/commercialwildlifeandscientificpermits/scientific Kammi McClain for Wildlife Kammi.McClain@mt.gov (406) 444-2612 Kim Wedde for Fisheries kim.wedde@mt.gov (406) 444-5594
Fish and Wildlife Recommendations for Subdivision Development	Charlie Sperry CSperry@mt.gov (406) 444-3888 See also: https://fwp.mt.gov/conservation/living-with-wildlife/subdivision-recommendations
Regional Contacts  	Region 1 - Kalispell (406) 752-5501 fwprg12@mt.gov Region 2 - Missoula (406) 542-5500 fwprg22@mt.gov Region 3 - Bozeman (406) 577-7900 fwprg3@mt.gov Region 4 - Great Falls (406) 454-5840 fwprg42@mt.gov Region 5 - Billings (406) 247-2940 fwprg52@mt.gov Region 6 - Glasgow (406) 228-3700 fwprg62@mt.gov Region 7 - Miles City (406) 234-0900 fwprg72@mt.gov

Montana Department of Agriculture

General Contact Information: https://agr.mt.gov/About/Office-Locations/Office-Locations-and-Field-Offices
Noxious Weeds: https://agr.mt.gov/Noxious-Weeds

Montana Department of Environmental Quality

Permitting and Operator Assistance for all Environmental Permits: https://deq.mt.gov/Permitting

Montana Department of Natural Resources and Conservation

Overview of, and contacts for, licenses and permits for state lands, water, and forested lands: http://dnrc.mt.gov/licenses-and-permits

Stream Permitting (310 permits) and an overview of various water and stream related permits (e.g., Stream Protection Act 124, Federal Clean Water Act 404, Federal Rivers and Harbors Act Section 10, Short-term Water Quality Standard for Turbidity 318 Authorization, etc.). http://dnrc.mt.gov/divisions/cardd/conservation-districts/the-310-law

Flood and Fire Resources: http://dnrc.mt.gov/flood-and-fire

Bureau of Land Management

Montana Field Office Contacts:



Billings	(406) 896-5013
Butte	(406) 533-7600
Dillon	(406) 683-8000
Glasgow	(406) 228-3750
Havre	(406) 262-2820
Lewistown	(406) 538-1900
Malta	(406) 654-5100
Miles City	(406) 233-2800
Missoula	(406) 329-3914

United States Army Corps of Engineers

Montana Regulatory Office for federal permits related to construction in water and wetlands
(406) 441-1375 https://www.nwo.usace.army.mil/Missions/Regulatory-Program/Montana/

United States Environmental Protection Agency

Environmental information, notices, permitting, and contacts https://www.epa.gov/mt
Gateway to state resource locators https://www.envcap.org/srl/index.php

United States Fish and Wildlife Service

Information Planning and Conservation (IPAC) website: https://ecos.fws.gov/ipac/
Montana Ecological Services Field Office (406) 449-5225 https://www.fws.gov/montanafieldoffice/

United States Forest Service

Regional Office Contacts – Missoula			
Wildlife Program Leader	Tammy Fletcher	tammy.fletcher2@usda.gov	(406) 329-3086
Wildlife Ecologist	Cara Staab	cara.staab@usda.gov	(406) 329-3677
Fish Program Leader	Scott Spaulding	scott.spaulding@usda.gov	(406) 329-3287
Fish Ecologist	Cameron Thomas	cameron.thomas@usda.gov	(406) 329-3087
TES Program	Lydia Allen	lydia.allen@usda.gov	(406) 329-3558
Interagency Grizzly Bear Coordinator	Scott Jackson	scott.jackson@usda.gov	(406) 329-3664
Acting Regional Botanist	Amanda Hendrix	amanda.hendrix@usda.gov	(651) 447-3016
Regional Vegetation Ecologist	Mary Manning	marry.manning@usda.gov	(406) 329-3304
Invasive Species Program Manager	Michelle Cox	michelle.cox2@usda.gov	(406) 329-3669

Tribal Nations



Assiniboine Gros Ventre Tribes – Fort Belknap Reservation
Assiniboine Sioux Tribes – Fort Peck Reservation
Blackfeet Tribe - Blackfeet Reservation
Chippewa Creek Tribe - Rocky Boy's Reservation
Crow Tribe – Crow Reservation
Little Shell Chippewa Tribe
Northern Cheyenne Tribe – Northern Cheyenne Reservation
Salish Kootenai Tribes - Flathead Reservation

Natural Heritage Programs and Conservation Data Centres in Surrounding States and Provinces

Alberta Conservation Information Management System
British Columbia Conservation Data Centre
Idaho Natural Heritage Program
North Dakota Natural Heritage Program
Saskatchewan Conservation Data Centre
South Dakota Natural Heritage Program
Wyoming Natural Diversity Database

Invasive Species Management Contacts and Information

Aquatic Invasive Species

Montana Fish, Wildlife, and Parks Aquatic Invasive Species staff
Montana Department of Natural Resources and Conservation's Aquatic Invasive Species Grant Program
Montana Invasive Species Council (MISC)
Upper Columbia Conservation Commission (UC3)

Noxious Weeds

Montana Weed Control Association Contacts Webpage
Montana Biological Weed Control Coordination Project
Montana Department of Agriculture - Noxious Weeds
Montana Weed Control Association
Montana Fish, Wildlife, and Parks - Noxious Weeds
Montana State University Integrated Pest Management Extension
Integrated Noxious Weed Management after Wildfires
Fire Management and Invasive Plants