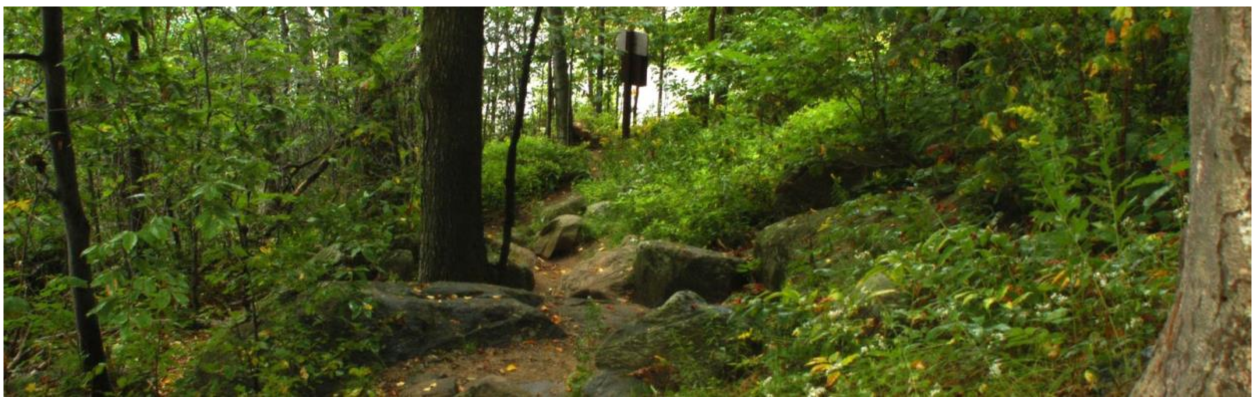
WILDLIFE & RECREATION

UNDERSTANDING AND MANAGING THE EFFECTS OF TRAIL USE ON WILDLIFE



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FOR

VERMONT FISH & WILDLIFE
VERMONT FORESTS, PARKS, AND RECREATION

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BACKGROUND

Trail-based recreation is an important part of Vermont's culture, industry, and landscape. Increased interest, participation, and investment in trail recreation has led to increased pressure on landowners to allow trail building on their property. The state of Vermont and Vermont's Agency of Natural Resources seeks to inform policy guidelines and land management decisions in order to balance natural resources protection and recreation opportunities.

To inform responsible management, Vermont Fish & Wildlife and Forests, Parks, and Recreation sought relevant, science-based information about the effect of trail-based recreation on natural resources. The effect of trail recreation on vegetation and soils is relatively well understood, but the relationship between trail recreation and wildlife is more complex. The research describing the relationship between wildlife and recreation has largely been conducted in landscapes dissimilar to the northeastern United States and includes many variables, making it difficult to find patterns in research results.

To help include relevant scientific information in recreation planning, Vermont Fish & Wildlife and Forests, Parks, and Recreation charged this report's author with the development of a review and recommendations document, specifying three goals:

- determine what is and is not known about the effect of recreation trails on wildlife, specifically related to the northeastern United States,
- develop a protocol and recommendations to apply the relevant ecological information in land management and recreation trail planning, and
- model the application of the scientifically informed management recommendations through example mapping and field study of Vermont landscapes.

Between September 2019 and October 2021, the current research about the effect of trail recreation on wildlife was assessed, and relevant scientific research was systematically reviewed, summarized, and analyzed for patterns. A three-phase management protocol for planning and managing recreation trails to minimize the impact to wildlife was created based on those findings. Example applications of the management protocol were created through GIS mapping and field verification of ecological features.

This report adds to the body of knowledge about the ecological impacts of recreation trails and how to responsibly manage land towards a balance of wildlife protection and recreation opportunities. This work will serve the Vermont Agency of Natural Resources Lands group in their process of informing policy guidelines and land management decisions around recreation trail building and management. This report should be considered in conjunction with other important work on the subject, such as New Hampshire Fish & Game's Trails for People and Wildlife.

This report should function as a useful starting place, but the work to establish understanding and responsible management of the wildlife-recreation relationship must continue. In order to successfully balance protection of an ecological functional landscape and providing recreation opportunities, it is imperative trail planners, builders, and users are thinking about the impacts of recreation on wildlife.

EXECUTIVE SUMMARY

Outdoor recreation can benefit conservation goals through inspiring connection to the landscape and a sense of stewardship. However, where recreation and wildlife habitat coexist, land managers have the challenging job of balancing access and protection. Effective management can accomplish protection of wildlife while providing the opportunities for recreation. This report provides management recommendations resulting from a review of relevant scientific research to provide guidance for decision-making about trail planning, management, and monitoring.

This literature review exhaustively analyzes peer-reviewed studies on the relationship between trail-based recreation and wildlife of the northeastern United States. The complexity of the wildlife-recreation relationship was reinforced through this research. Thousands of papers were reviewed to yield 50 highly relevant scientific research articles.

One primary goal of this research was to find trends in the wildlife-recreation relationship that can be used to develop management guidelines. Most of the trends reported here relate to specific landscapes, wildlife, and recreation activities. However, the following general trends emerged as prominent throughout the literature:

- Trail recreation has a negative effect on wildlife.
- Trail-free areas and avoidance of high-value wildlife resources minimize trail effects on wildlife.
- Trail disturbance can have the greatest effects during an animal's breeding season.
- Non-motorized recreation has a stronger effect on wildlife than motorized recreation.

The trends identified in the literature review informed management recommendations that are both scientifically based and applicable to the Vermont landscape. These recommendations are incorporated into a three-phase management protocol. These phases offer the following guidance to balance the dual mandate of protecting wildlife and providing opportunities for trail recreation:

- Phase 1 – designate permanent trail-free areas on the landscape
- Phase 2 – consolidate trails and avoid high value wildlife resources
- Phase 3 – monitor trailed areas for changes in wildlife, manage existing trails to minimize impact

The findings and recommendations of this report focus specifically on the wildlife and landscapes of the northeastern United States and southeastern Canada but are broadly relevant and can be used across many geographic regions. This information can also be used at varying scales of management, from multi-state regional planning to small, private trails.

This report is also a source for reference materials. The appendices offer extensive annotations and supporting references about the effects of trail recreation. They include findings specific to taxonomic group, guidance for monitoring the effects of trails on wildlife, and examples of the applied management recommendations on the Vermont landscape.

CHAPTER 1

LITERATURE REVIEW

EFFECTS OF TRAIL-BASED RECREATION ON WILDLIFE IN VERMONT

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EFFECTS OF TRAIL-BASED RECREATION ON WILDLIFE IN VERMONT

A SYSTEMATIC LITERATURE REVIEW

Prepared by Meredith Naughton, UVM Field Naturalist Program

INTRODUCTION

Recreation trails are an important part of the natural and cultural landscape in Vermont. Trails are popular for exercise and relaxation among residents and visitors alike, and the benefits that trails provide to people and communities are widely reported (Godbey, 2010; Rosenberger, 2009; Thomsen, 2018). Visitation of trails is increasing both locally and globally (Larson, 2016; Morse et al. 2020) and, understandably, there are more trails on the landscape than ever in recent history, along with increased pressure on land managers to build trails on protected land (Marion, 2016; Taylor, 2000). At the same time, trail recreation, once considered to have a negligible effect on the natural environment, is now widely recognized as ecologically impactful, with lasting negative impacts on our environment (Kerlinger et al., 2013; Kuss, 1986; Olive, 2009).

Protected natural areas serve multiple purposes, and most land managers have the dual mandate of managing natural areas to protect wildlife and provide outdoor recreation resources (Miller, 2020). With the simultaneous rise in trail use and recognition of trail impact, the job of effectively doing both is increasingly challenging. New guidance and tools are needed to meet these conservation objectives. Trails are a primary element of outdoor recreation infrastructure and present an opportunity for careful management that balances both conservation and recreation goals. To move forward with designing and implementing this management, land managers need a clear understanding of the multi-faceted relationship between wildlife and trail recreation.

Research examining that relationship, referred to as *recreation ecology*, has increased significantly in the last several decades. However, despite its increasing rate of publication, recreation ecology consists of a miniscule fraction of the research in ecology, wildlife, and conservation studies (Larson, 2016). Considering only that fraction of research, there is little focus on the wildlife and landscapes of northeastern North America. Several reviews of the literature examine wildlife-recreation relationships on a global or continental scale, but much of the research conducted in North America is focused on the western United States (Boyle & Samson, 1985; Cole & Knight, 1991; Larson, 2016; Leung & Marion, 2000; Marion et al., 2016; Oliff, 1999). There are no reviews of literature specifically relevant to the northeastern United

States, leaving a gap in understanding as land managers in the northeast look for guidance on developing effective management techniques.

LITERATURE REVIEW OBJECTIVES

To fill this gap in understanding and answer questions necessary to move forward with informed management actions in Vermont, I conducted an exhaustive, systematic literature review. This review clarifies wildlife-recreation relationships by compiling and analyzing the research addressing effects of non-consumptive, trail-based recreation on wildlife relevant to northeastern North America. The goals for this review are to:

- identify the known effects of trail-based recreation on Vermont wildlife,
- identify the primary factors contributing to the effects of trail-based recreation on Vermont wildlife,
- to synthesize what management strategies are recommended by articles included in this review.
- and to develop a profile of these studies to determine where more research is needed

The body of recreation ecology literature is a collection of works that "examines, assesses, and monitors visitor impacts, typically to protected natural areas, and their relationships to influential factors" (Leung & Marion, 2000). This review focuses on effects of trail-based recreation on wildlife; however, wildlife is certainly not the only element of the environment affected by recreation. Effects on soil, vegetation, and hydrology are also well-documented (Brown, 1977; Leung & Marion, 2000; Monz, 2013). This review examines the effect on wildlife because of its complexity and how little it has been studied relative to these other elements of the landscape (Monz, 2010). For these reasons the effect on wildlife requires the most clarification in order to design effective management protocols.

COMPLEXITY OF RECREATION EFFECT ON WILDLIFE

The effect of recreation on wildlife is an immensely complex topic. Responses of wildlife to any type of disturbance can vary widely depending on species and the individual animal (Kerlinger et al., 2013). Research examining these responses cannot capture the entirety of the response an animal has to a disturbance event, and typically focuses on one of several categories of response: physiological, behavioral, reproductive, abundance, or community-level. The diversity of responses measured leads to differing methodology and results across recreation-ecology research, adding to the complexity of finding common patterns with which to form the basis of management. Behavioral responses are the most studied type of wildlife response to recreation, most likely because behavioral responses can be the simplest to study. However, behavioral responses alone cannot reveal long-term impacts to whole animal populations or communities.

Each element of this relationship, both wildlife and recreation, can refer to many different activities or animals. In addition, there are almost innumerable additional variables that influence the type or severity of effect on wildlife. Tablado and Jenni (2017) add clarity and organization to this topic by breaking down the variables into level of response, mechanism of responding, and “modulating factors”. Mechanisms of response can include visual activation, physiological responses, or population changes. Modulating factors are extensively detailed and include intrinsic factors such as animal health, human factors such as number of visitors, and spatio-temporal factors such as season. Tablado and Jenni found that the difficulty in finding general patterns in recreation ecology is because of the many non-linear ways modulators accumulate and affect wildlife responses, however they were successful in demonstrating why trail use and research is so complex.

This complexity leads to a difficult time determining specific cause-and-effect relationships and associated management guidelines (Tablado & Jenni, 2017). For example, some ecologists hypothesize that there is an upper limit (often referred to as a *threshold*) of recreation beyond which there is a significant negative impact to wildlife. However, no generally applicable threshold has been determined because it depends on the specific location, species, habitat, and type of recreation, among many other factors.

PRIMARY VARIABLES

Tablado and Jenni (2017) specifically list and classify a catalog of the variables that influence the wildlife-recreation relationship and can significantly impact wildlife; however, they do not attempt to determine which modulating variables are most influential, nor do they offer which factors are most useful in managing land for minimal impact to wildlife. In this review, I chose prominent variables across the literature and tracked the most discussed variables that influence the effects of trails on wildlife. Because of the complexity of wildlife-recreation interactions, Chapter 1 groups the variables into themes to find patterns of discussion in the literature. These patterns are used to direct management recommendations in Chapter 2.

Of the many factors that influence wildlife response to trail recreation, the following variables were consistently represented as important across the literature.

- Consolidation of trails
- Zone of influence
- Breeding seasons
- Trail use volume
- Recreation activity type
- Taxonomic group

Focusing on these variables in the literature allowed me to develop generally applicable management strategies for the complex wildlife-recreation relationship. The physical placement of trails on the landscape, including consolidation of trails and the zone of influence, was the most discussed of the primary variables, and was echoed in the management recommendations made by authors.

Consolidating trails into a small portion of the landscape is frequently argued to have a less significant impact on wildlife overall than dispersing trails across the landscape. Consolidation of trails maximizes core habitat (undeveloped land where wildlife is not disturbed by regularly occurring recreation activities) and thus minimizes widespread impact to wildlife.

The zone of influence (ZOI) describes the area surrounding a trail where wildlife may be affected by recreation. This concept is often studied and discussed by describing how close wildlife must be to a recreator for the wildlife to show a behavioral response, often referred to as flight initiation distance or alert distance. This is a common theme in recreation ecology research and is frequently used as the primary or exclusive element for making management decisions about recreation trails. The ZOI and FID were discussed throughout the articles in this review and understanding it is an important element of minimizing the effect of trails on wildlife.

Several reviews have summarized the specific behavioral response distances of wildlife species, including a review from New Hampshire Fish & Game (Dertien, 2021; Miller, 2020; N.H. Fish & Game, 2017). This review classifies the zone of influence as one of several important modulating variables. I summarize the ZOI and FID discussed in the reviewed literature and also refer to previously published summary work for specific management recommendations (Appendix 1).

I categorized the management recommendations included in the articles as another means of determining important themes to guide my own management recommendations for Vermont. Management recommendations were categorized as physical regulation, seasonal regulation, volume regulation, visitor education, other, none. In Chapter 2 I use the outcomes of this review to describe the management strategies most effective for minimizing the impact of trail-based recreation on wildlife in Vermont.

METHODS

ARTICLE SEARCH

The article search process was designed to capture a wide range of scientific articles that encompass studies covering the many possible effects of any trail-based recreation activities on a broad range of wildlife. The goal was to be exhaustive in finding articles that meet the study criteria, and so a wide range of related articles were initially captured in order to meet this goal. Both EBSCOHost and Web of Science databases were searched. Within EBSCOHost the following databases were selected for searching: Academic Search Premier, Biological & Agricultural Index Plus, Environment Complete, GreenFILE, and Wildlife & Ecology Studies Worldwide. The following search phrases were used in combination (linked by “AND”) in a

Boolean/Phrase search through both EBSCOHost and Web of Science: <*trail or trails* or *recreat* or ski or skiing or hike or hiking or bike or biking or Off-Highway Vehicle or OHV or snowmobile*> AND <*wildlife or habitat*>. Next, articles cited in published, relevant literature reviews not already captured were added to the results from the initial search list.

SELECTION CRITERIA

This review was conducted to form a scientific foundation for planning and management of terrestrial recreation trails in Vermont. Consequently, articles were selected based on criteria that would allow for analysis of research specifically related to Vermont's wildlife and landscapes. For articles to be included in this review, they must have met the following criteria:

- Focus on terrestrial, non-consumptive, trail-based recreation AND
- Measure the responses of wildlife AND
- Be peer-reviewed, primary research* AND
- Have a northeastern North America study location OR
- Take place on a landscape represented in Vermont OR
- Include wildlife species present in Vermont

*Several exceptions were made for primary research published as a graduate thesis due to their repeated reference in the collected literature, though they did not go through the peer-review process of an academic journal,

Definitions for Criteria

Terrestrial: Recreation taking place on land. Aquatic recreation, such as swimming and boating, has also been shown to negatively affect both aquatic and terrestrial wildlife (Miller, 2020), but this review does not include aquatic activities as they do not make use of terrestrial trails.

Non-consumptive: Hunting and fishing are popular recreational uses of many natural areas but are outside the scope of this review. These activities already have extensive regulation from state and federal agencies, are not usually associated with trails, and introduce different variables influencing effect on wildlife.

Trails: Here, trails are defined as intentionally sited and built pathways through forested or otherwise natural (undeveloped) landscapes. The literature I reviewed examines landscapes with trails and/or activity mimicking trail-based recreation, such as experimentally applied walking on a consistent pathway through the forest without the existence of a built trail (Gutzwiller et al., 1994, 1998, Gutzwiller and Anderson, 1997, 1999). Details about trail construction design and substrate material were rarely described in the articles and are not considered in this review.

Recreation: Recreation includes many different activities that are constantly expanding and changing. Any activity deemed as recreation that made use of trails or mimicked possible trail use is included. Articles studying landscapes that include trails and allow recreation are also included (ex: Thompson, 2015). The search terms used to capture articles for this review included words indicating both specific types of common recreation (ex: *hike* or *hiking*), and general terms (ex: *recreat**, *trail* or *trails*) in order to capture any type of recreation.

Valuable information on the wildlife-recreation relationship can be found in review and synthesis papers, management reports, and other secondary or non-peer-reviewed sources. However, this review is based on peer-reviewed, primary literature to represent the results and frequency of concepts measured and discussed without bias from secondary reporting.

DATA COLLECTION

Data were collected from each article for the following categories: publication, geographic, taxonomic, recreation, study type, response, effect, primary variables, and management (Table 1). When multiple values were true for a variable, such as if more than one animal was studied in an article, each value was recorded and is represented in the data.

This review often focuses on the frequency of variables addressed in the reviewed articles. Although frequency of discussion does not indicate a measure of that variable's relative importance or effect on wildlife, evaluating these articles for common themes provides insight into the main factors researchers have deemed important in wildlife-recreation interactions. Assessing the proportion of articles that address each variable provides a sense of where our information on this topic is coming from and what gaps in research exist.

Table 1. Variables collected from articles included in the review.

Category	Variable	Values for the Variables	Data type
Publication	Author		text
	Title		text
	Journal		text
	Publication Year		date
Geographic	Continent		categorical
	Country		text
	In-Country Region		categorical
	State or Province		text

	Habitat Type	alpine, coniferous forest, deciduous forest, mixed forest, riparian, subalpine forest, taiga, urban, wetland, desert	categorical
Taxonomic	Group	small mammals, ungulates, carnivores, bats, ground and understory birds, midstory and overstory birds, waterfowl, birds of prey. amphibians and reptiles; invertebrates	categorical
Recreation	Type	foot travel, biking, skiing, OHV, non-specified	categorical
	Season	summer, winter, all seasons	categorical
Study Type		experimental, modeling, observational	categorical
Response	Type	behavioral, physiological, abundance, reproductive, community-level	categorical
Change	Type	immediate effect, sustained impact, dramatic impact, neutral or inconclusive	categorical
Primary variable		consolidation of trails, zone of influence, breeding, trail use volume, recreation type, taxonomic group	categorical
Management	Recommendations	location restriction, seasonal regulation, volume regulation, visitor education, other, none	categorical

Taxonomic classification

This review covers wildlife in several major taxonomic groups grouped as follows: mammals, birds, amphibians and reptiles, and invertebrates. Because most articles focus on mammals and birds, those were further divided into the following functional groups: small mammals, ungulates, carnivores, bats, ground and understory birds, midstory and overstory birds, waterfowl, and birds of prey. Although fish may also be affected by trail-based recreation, no studies examining recreation effect on fish met the selection criteria of this study.

Recreation Type

I identified the type of recreation studied in each article and used the following general values: foot travel, biking, skiing, OHV (off-highway vehicles such as ATVS or snowmobiles), and non-specified. Recreation type is also a primary variable (see below).

Study Type

Each article was categorized by its main means of evaluation, here named *study type*, to assess how recreation studies directly relevant to Vermont have been conducted. Study types are classified as experimental, observational, and modeling. For a study type to be classified as modeling, the study was conducted through simulation, with field-based data collection minimal or absent (ex: Grubb & King, 1991). Observational study types did not manipulate any element of recreation or the natural environment (ex: Davis, 2007), while experimental studies did (Ellison & Cleary, 1978).

Response Type

The type of wildlife response of interest for each study is captured in the response category: values range from individual-level responses (e.g., physiology, behavior) to population-level responses (e.g., abundance) or community-level responses (e.g., species richness). I have further subdivided these variables by type in Table 2, in which these values are reported by response type.

Table 2. Response types and values

Response Level	Response Type	Values
Individual	Behavioral	Alerting, fleeing/flushing, altered vocalization
	Physiological	Altered heart rate or stress hormone levels
Population	Abundance	Altered population numbers or home range
	Reproductive	Avian nest establishment, nest abandonment, success, or predation
Community		Diversity, species richness

Change

The field of recreation ecology has limited agreement on the language for defining some of its key elements. The words *effect* and *impact* are used interchangeably throughout the literature to describe change that occurs as a result of recreation. In this review, *change* is used as the general term to describe the change resulting from a recreation event. Once the type of change has been described by a research article, I use the words *effect* and *impact* to indicate levels of that change, as defined by Beale (2007). An *effect* describes a short-term response whose long term consequences are unknown, while an *impact* describes a change that is sustained beyond a single event. In this review, effects and impacts are distinguished in the results and discussion but are referred to generally as changes until that point.

Here, I categorize changes to provide some specificity to what change occurs with wildlife individuals, populations, or communities when exposed to trail-based recreation. Reporting the change to wildlife from recreation as “positive” or “negative” is inconsistent across the literature (Miller, 2020). Because of the highly complex nature of wildlife responses to disturbance (Beale, 2007), this review does not categorize a change in an individual, population, or community as “positive”. This is to avoid the misinterpretation of a “positive” change as a positive outcome, because a response deemed “positive” in one regard could have many cascading impacts on the ecological community.

Study results were categorized into four types of change: immediate negative effect, sustained negative impact, dramatic negative impact, and neutral/inconclusive (Table 3, below). Study results were recorded as having a negative change if the study authors classified it as such. As part of this review, I further categorized those results to distinguish different types of negative change. Negative changes were categorized as being an immediate effect, sustained impact, or dramatic impact, derived from effect and impact definitions in Beale, 2007 followed here (details in Table 3). The neutral or inconclusive effect value is for study results that did not find a significant response or were unable to determine a wildlife-recreation relationship.

Primary Variables

Primary variables are elements of the wildlife-recreation relationship that can alter the level or type of change to wildlife from recreation. Some examples of primary variables are the number of recreators, season, or location of trails. The categorization of “primary variable” is used here to determine the prevalence of these themes in the literature, and to determine the variables that most significantly influence the effect of recreation on wildlife. I used these prominent variables to guide generally applicable management recommendations for the complex wildlife-recreation relationship. An article was considered to have a particular primary variable if that theme is discussed somewhere in the article, thus this category represents the presence or absence of each primary variable value.

- *Consolidation of trails:* describes the spatial arrangement of trail across the landscape, and the geographic extent of trailed area. A certain linear distance of trails may be spread evenly across an area of land (dispersal), or the same trail distance may be concentrated into a small portion of that area of land (consolidation). *Topics included:* tightly consolidating or widely dispersing trails within an area, extent of the landscape with or without trails, density of trails within an area, trail or trail-free as an experimental variable.

- *Zone of influence:* describes a land management term referring to the effect of human disturbance, from development, trails, or other activity, projected over a space onto ecological processes (Ford, 2020). The zone of influence has driven many studies about changes imposed on wildlife by trail-based recreation. These studies often look at how far away from a trail wildlife is when responding to the presence of recreational disturbance, referred to as flight initiation distance (FID) or alert distance. While a physical trail takes up little space itself, wildlife disturbance involves broader surrounding areas in the natural landscape (Hennings, 2017). The concept may then be applied to developing management strategies that include avoiding certain landscape features providing a particularly valuable resource to wildlife, such as an area used for breeding or an important source of food. *Topics included:* distance from recreator where wildlife becomes alert (alert distance), distance from recreator where wildlife begins to move away (FID), proximity to trail as an experimental variable.

- *Breeding seasons:* describes the seasonal habits and needs that vary in northeastern United States and can affect wildlife's level of sensitivity to a recreation disturbance. During breeding season, from nest establishment to fledging, animals are engaging in activities such as seeking safety, preserving their energy, or using that energy specifically for their offspring. During this time a disruption to their daily habits may displace the animal or come at a higher energetic cost (Lesmerises, 2017). *Topics included:* establishment of nest or other reproductive location, mating, raising and feeding offspring, offspring success or fledging, nest or young predation, abandonment, wildlife activity pattern changes during this time.

- *Trail use volume:* describes the amount of use a trail receives by recreators. The change to wildlife from recreation may vary with the level of trail use. The broader body of recreation ecology incorporates the idea of a "threshold", or "carrying capacity", beyond which the changes resulting from recreation become significant for wildlife. *Topics included:* number of recreators or recreation groups, frequency of recreators or groups, threshold of maximum volume beyond which effect on wildlife occurs or becomes more significant.

- *Recreation activity type:* activities vary in season, speed, noise level, and more, and so may affect the change to wildlife from recreation. *Topics included:* any comparison between multiple recreation activities within one study.

- *Taxonomic group:* because wildlife species are each inherently different from one another, each may respond to recreation differently, thus affecting the change to wildlife. *Topics included:* any comparison between multiple species or taxonomic groups within one study.

Management Recommendations

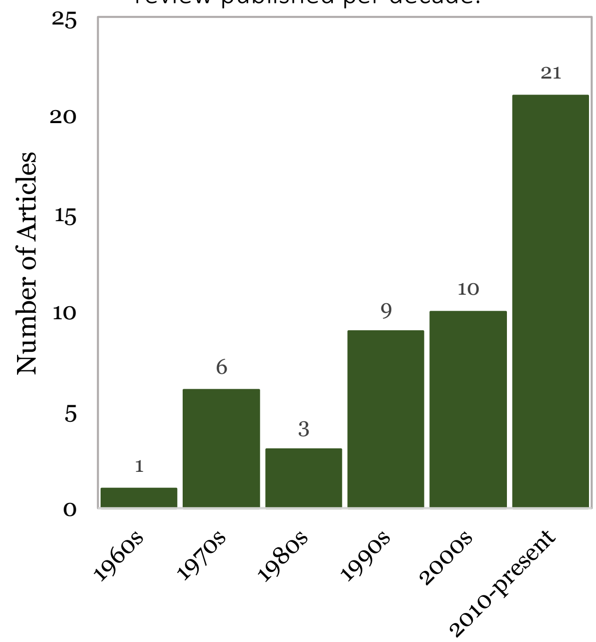
Management recommendations in this review were classified to organize and present strategies to minimize change to wildlife as suggested by the authors. I classified management recommendations into the following values: location restriction, seasonal regulation, volume regulation, visitor education, other, and none.

RESULTS & DISCUSSION

Through the article search process, I collected 2,142 articles and screened them for selection criteria. I removed 2,094 articles because they did not meet the review criteria, primarily because they were outside of the geographic focus area and did not include Vermont wildlife. The references cited in the remaining 48 articles were reviewed, yielding two more articles that met the review criteria for a total of 50 reviewed papers.

Studies were published over a period of 53 years (Figure 1) and were conducted in 21 states and 4 countries. However, only 28% of the articles were conducted in the focal region of northeastern United States and southeastern Canada. Over 30 species of wildlife were represented, and the effect of five categories of recreation were examined. Thirty-three studies were characterized as “observational”, 15 studies were characterized as “experimental”, and 2 were categorized as "modeling".

Figure 1. Number of articles in this review published per decade.



TYPE OF RECREATION

Types of recreation were not studied uniformly across the articles reviewed. Over half of the articles (56%) examined foot travel. Off-highway vehicle recreation was studied in 24% of articles, and skiing was studied in 14%. Articles examining skiing were split between alpine skiing (8% overall) and cross-country skiing (6% overall). Only 6% of articles (3 articles) examined biking as a type of recreation, each of which studied multi-purpose trails where biking was one of several forms of recreation permitted but was not the focal type. Some articles (16%) did not specify the forms of recreation permitted on the trails used for their studies. Prohibited recreation use is a topic of consideration in recreation ecology, however none of the articles in this review make distinctions about permitted or prohibited recreation occurring. Results distinguishing the difference in effect from different types of recreation are detailed below in *Primary Variables*.

STUDY TYPE

Studies in this review were primarily observational (66%). Studies using an experimental study design constituted 30% of studies, of which 93% measured behavioral responses (several of which also measured an additional response type). Only 4% (2 articles) principally used a modeling-based study design. In this review experimental treatments are most often seen as experimentally applied recreation, such as a hiker passing at specific distances or frequencies (e.g., Ellison & Cleary, 1978).

CHANGE

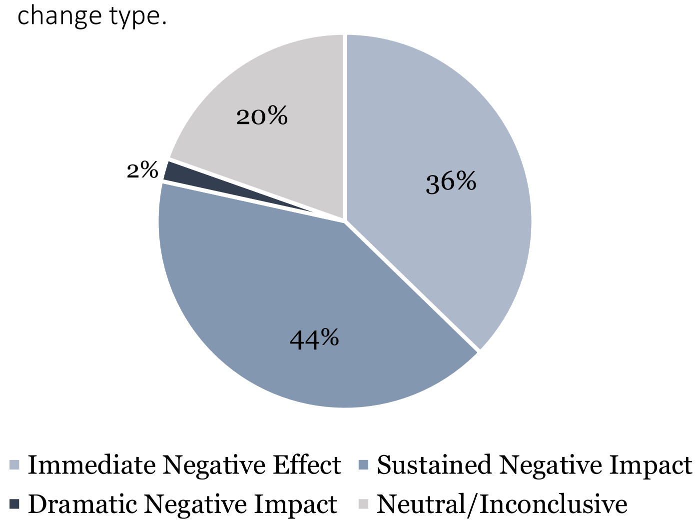
This review found a negative change to wildlife from trail recreation in 82% of articles (Figure 2). Of all reviewed articles, 36% showed an immediate effect, 44% showed a sustained impact, and 2% (1 article) showed a dramatic impact. A neutral or inconclusive result was found in 20% of articles. Articles with a neutral or inconclusive categorization were distributed across taxonomic groups (Figure 4b).

Table 3. Descriptions, examples, and conservation concerns of changes to wildlife from trail-based recreation. This table briefly describes each change type and gives an example(s) of each. These descriptions and examples are not intended to exhaustively characterize the changes found in this review, but rather to give context to this categorization. Examples are taken from articles within the scope of this review. Conservation concerns are cited from supporting information within the field of study.

Change Type	Description	Examples	Conservation Concern
Immediate Negative Effect	Primarily short term or behavioral; uses energy or alters necessary behavior	White-tailed deer *(Odocoileus virginianus)* heart rate increases in response to passing snowmobile, with or without associated behavior change (Moen, 1982)	May lead to chronic stress or disease (Romero & Butler, 2007)
		Breeding bald eagles *(Haliaeetus leucocephaus)* flushed from nest with approach of human (Fraser et al., 1985)	May lead to decreased recruitment, population decline, or avoidance of an area (Tarlow & Blumstein, 2007)
Sustained Negative Impact	Change that lasts beyond a recreation event, often at the population or community level	Moose *(Alces alces)* permanently displaced by presence of cross-country skiing (Ferguson & Keith 1982)	Avoidance of an area may lead to population decline (Stillman et al. 2000)
		Caterpillar *(Lepidoptera)* diversity and abundance significantly lower with higher spatial presence of trails (White et al., 2011)	Population decline may lead to threat or extirpation (Tablado & Jenni, 2017)

Dramatic Negative Impact	Extreme shifts in the health of a population or community	Extirpation of local population of wood turtles, *Clemmys insculpa* (Garber & Burger, 1995)	Decrease in overall biodiversity, ecosystem collapse (Wilcove, 1998; Hoekstra, 2005)
Neutral or Inconclusive	A change is not observed, is statistically insignificant, or is unknown	A nearly complete species turnover of Beetle *(Coleoptera)* species composition from ski trails to 5m into the forest, but similar levels of diversity and richness were maintained (Strong, 2002)	None, or studies not able to capture the complexity or scope of interactions

Figure 2. Percent of articles in this review with each change type.



Although much research is needed to provide specific details about causes and consequences of these changes, the community of recreators, ecologists, and land managers can accurately claim that trail-based recreation causes negative change to wildlife. Additionally, 44% of studies showed a negative change that continued and/or left a lasting impact on wildlife after recreation events. This is an important finding, because although some short-term wildlife responses to recreation, such as a behavioral response, can fall within the normal range of expected and energetically sustainable activity, lasting negative impacts to wildlife are a regular result of recreation.

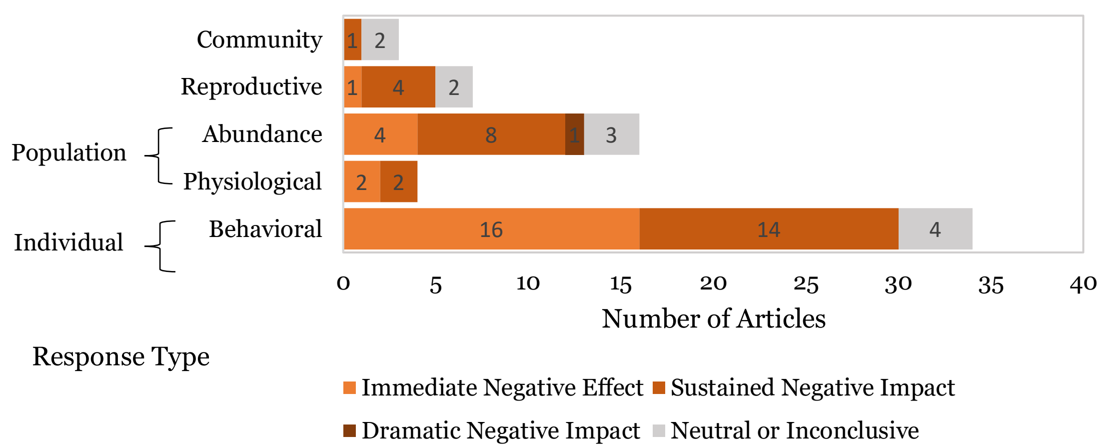
The single article demonstrating a dramatic negative impact to wildlife covered a period of over 20 years, whereas a vast majority of studies in this review were conducted in four years or less. Understanding the scope of change often requires timescales and methods unavailable to researchers. In one study of Bicknell's Thrush (*Catharus bicknelli*), a species of special concern globally and in Vermont, there was not a significant change related to distance from ski trails, however authors suggest ski trail development impacted their populations long before monitoring began (Hill, 2019). This may be the case with many species, where researchers are not able to conduct studies at the temporal or geographic scale required to understand lasting changes.

Reviews similar to this one have categorized some results as positive. For example, Larson et al. (2016) considered a change positive if the measured response type, such as species abundance or richness, increased through the study. I chose not to characterize results as positive because the goal of this review is to develop a clearer understanding of the overall change to wildlife from recreation trails. A species-specific positive result can be misleading because of an ecological cascade that has negative changes on one or many other species. For instance, Sirén et al., 2017 report that snow compaction along forest roads allowed greater mobility and decreased energy expenditure of certain canids (a "positive" effect), but also increased competition and threatened habitat for American martens (a "negative" change). Larson et al. (2016) does note that positive responses do not indicate a benefit to wildlife or biodiversity conservation.

RESPONSE TYPE

Changes to wildlife from recreation were primarily measured through responses of individual animals (72% of studies). Behavioral responses of animals were measured in 66% (34 articles) of studies, which makes up most individual responses. Few articles measured the physiological effects on wildlife (8%, 4 articles). Population-level responses are divided into changes in abundance (32%, 16 articles) and reproductive responses (14%, 7 articles). Relatively few articles (n=3 articles) measured effects at the community-level, comprising of only 6% of articles reviewed.

Figure 3. Categories of animal responses and associated wildlife change. This graph shows the number of articles that examine each specific response type: behavioral, physiological, abundance, reproductive, and community-level. Several articles examined multiple wildlife response types; all response types examined for each article are represented here. Each response type is further broken down by wildlife change category.

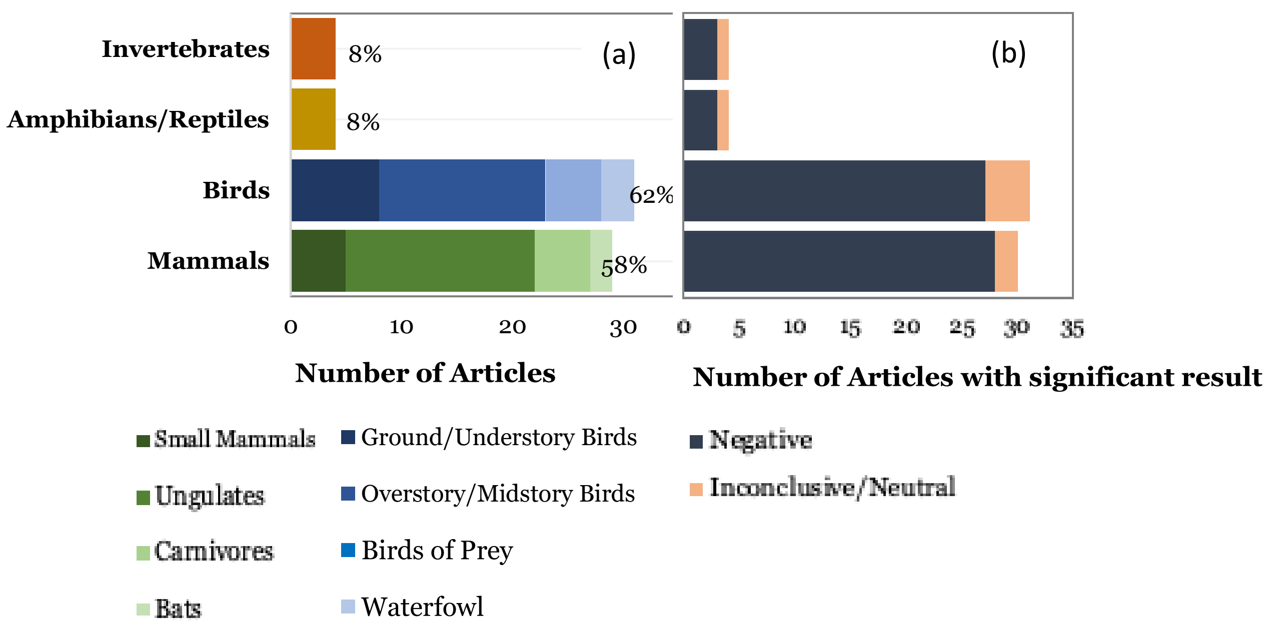


The extent to which recreation causes a lasting negative impact is still unknown because so many studies only measure short-term, behavioral responses. These behavioral responses primarily result in immediate effects (Figure 3), with long term consequences left unmeasured.

TAXONOMIC CLASSIFICATION

Research articles in this review disproportionately focused on birds (62% of studies) and mammals (58% of studies; Figure 4a). Amphibians and reptiles (8% of studies) and invertebrates (8% of studies) are represented, but there are considerably fewer articles addressing these groups (Figure 4a). Unlike the other taxonomic groups, invertebrates are not separated by species because invertebrate studies focused on communities rather than individual species. This review yielded no articles examining changes to fish from trail recreation. Within the mammal and bird groups, ungulates (17 studies) and overstory and midstory birds (15 studies) were the most researched functional groups. The ungulate group primarily consisted of moose, *Alces alces* (35% of ungulate studies), and white-tailed deer, *Odocoileus virginianus* (59% of ungulate studies).

Figure 4. Taxonomic groups represented by articles in this review. (a) number of articles in each taxonomic group. Percentages of articles in this review representing each taxonomic group are displayed at the end of each bar. Mammals and birds are divided into subcategories and displayed by color. Each species from articles studying multiple species is represented, resulting in >100%. Invertebrates are represented as the number of times studied as a group rather than individual species studied. (b) number of studies per taxonomic group with either a significant negative effect or an inconclusive or neutral result. Descriptions of negative effect and inconclusive or neutral results detailed below (Table 3).



The disproportionate representation of mammals (58%) and birds (62%) in the literature reviewed likely does not represent a disproportionate level of change to those taxonomic groups. In fact, reptiles and amphibians constitute only 8% of studies in this review but the only study categorized as having a dramatic negative impact examined a reptile (wood turtle, *Clemmys insculpta)* local extirpation as a result of introduced recreation trails (Garber & Burger, 1995). Invertebrates are an understudied group, especially relative to their diversity as they make up about 95% of animal species (Lewbart, 2006). Results distinguishing the difference in change experienced by different taxonomic groups are detailed below in "Primary Variables".

PRIMARY VARIABLES

Consolidation of trails

In this review, 36% of studies discussed the importance of this variable. Consolidation of trails considers trail placement at the landscape level with the goal of maintaining large, unfragmented areas of land and connectivity between habitat patches (Erb 2012; Thompson, 2015; White et al., 2011), both important in minimizing negative changes to wildlife from trails. According to a recent review, consolidation of trails on the landscape is an element of recreation planning receiving increasing consideration from ecologists and land managers (Miller, 2020). Of the articles here discussing the relative consolidation or dispersal of trails, 94% recommended restricting the physical location of trails on the landscape. This result demonstrates that the scientists considering this variable agree that the concept should be implemented in management. These management recommendations include limiting trails to protect forest corridors critical to sets of mammal species (Erb et al., 2012), and minimizing the spatial footprint and total area that trails span in order to reduce negative impacts to wildlife (Harris et al., 2014).

Within this body of literature, recreation trails are often considered a fragmenting feature that alters landscape patterns and functions (Wimpey & Marion, 2011). As an example, wildlife have been permanently displaced to areas with fewer or lower quality resources (Ferguson & Keith, 1982). If trails continue to become more widespread on the landscape, it follows that more wildlife may be displaced, and populations will suffer (Stillman, et al., 2000). Maximizing core area (without trails or other development) by consolidating trails prevents the increase of fragmentation and its effects throughout the forest, while still providing a recreational resource (Erb, 2012; Harris, 2014; Hennings, 2017; Miller, 2020; Thompson, 2015; Wimpey & Marion, 2011). The primary variable of consolidation of trails was often paired with discussions of local-level trail location and the zone of influence, discussed below. These two variables are combined in management recommendations as "Location of Trails" and "Location Restriction" (details in Figure 5).

Zone of Influence

This review found that 46% of the articles discussed the zone of influence of trails as an important variable in the change to wildlife from recreation. Data on zone of influence were primarily in the form of testing flight initiation and alert distances of wildlife. Zone of influence is found to vary greatly between species and habitat surroundings (Beale, 2007), but is still considered a useful factor for placing trails on the landscape (Hennings, 2017). Of the articles discussing the zone of influence, 67% recommended restricting the physical location of trails on the landscape. The zone of influence and flight initiation distances in this review were summarized and included with several other high-quality reviews covering the topic in Appendix 1 (Ford, 2020; Gaines, 2003; Hennings, 2017).

Breeding Season

Elements of breeding were discussed as variables influencing the change to wildlife from recreation in 36% percent of articles (18 articles) included in this review. Breeding activities and conditions such as nest establishment, pregnancy, lactation or other paternal care, and infancy are particularly sensitive times for wildlife—times when they need more and/or higher quality resources (Ellison & Cleary, 1978). The majority of these studies agree that animals are more prone to negative impact from recreation during breeding season and activities, and 66% of articles discussing the importance of breeding season found a significant negative impact associated with recreation during breeding season. Half the studies discussing the importance of breeding season (9 studies, 18% of all articles) suggested seasonal regulations in order to minimize the potential negative effects of recreation during this sensitive time (see "Management Recommendations" and Figure 5).

Trail Use Volume

This review captured seventeen studies (34% of overall, 14 articles) that addressed the effect of volume and frequency of recreation. Trail use volume thresholds are especially difficult to determine because of the complexity of interacting variables in the wildlife-recreation relationship (Marion, 2016), and the concept of volume threshold is a topic lacking data trends at a global level (Larson, 2016). Of the articles in this review examining trail use volume and frequency, half (7 articles) found a correlation between higher volume and greater change to wildlife, and half (7 articles) did not. Clearly, in some circumstances, increased recreation volume can increase the negative change to wildlife, but articles report either conflicting findings of specific thresholds (Garber & Burger, 1995) or a lack of a change altogether (Colescott & Gillingham, 1998). No pattern has emerged to support details about how much, when, or where increased recreation volume really matters.

One article in this review did attempt to quantify a volume threshold: 20 recreation permits (with unlimited annual visitation per permit) per 1,000 hectares was more recreation traffic than wood turtles (*Clemmys insculpta)* could survive (Garber & Burger, 1995). However, this threshold attempt doesn't clarify a sustainable level of recreation for wood turtles. Given the lack of clear evidence, trail use volume thresholds are important to study to develop our understanding of the effect of higher volumes of recreation traffic (Stankey & Lime, 1973).

Recreation Activity Type

In this review, the type of recreation activity was classified to help characterize the body of recreation ecology literature relating to the northeastern United States – the type of recreation may also affect the change to wildlife.

In this review, 10% of articles (5 articles) compared more than one type of recreation, all of which found that nonmotorized recreation had significantly more negative change to wildlife than motorized recreation. In four articles walking was specifically tested and showed a greater change to wildlife than OHVs (snowmobiles and all-terrain vehicles), horseback riders, boats, or vehicles (the type of non-motorized recreation was not specified in the fifth article). Although this review presents a small sample size, the trend of non-motorized recreation, including activities such as biking and skiing, having a greater negative effect than motorized recreation is seen on a global scale (Larson, 2016; Miller, 2020).

Several studies in this review suggest that motorized recreation has a less negative effect on wildlife due to a shorter duration of wildlife disturbance and predictable movement. One article tested the effect of speed of walking on wildlife (Fernández-Juric et al., 2007). The authors tested various speeds of walking and found a greater negative effect from slower movement. Another determined that the duration of disturbance to wildlife was the most important indicator of negative bald-eagle (*Haliaeetus leucocephalus*) response (Grubb & King, 1991). Another article compared walking with swinging arms to walking steadily without swinging arms and found that animals reacted more strongly to walkers swinging their arms (Oâ & Campbell, 2011).

Although some activities, such as biking and skiing, were not directly compared to motorized recreation by articles in this review. However, I estimate the effect of biking and skiing to be less negative than walking and more negative than OHVs because of their relative speed and predictable movement pattern. Studies outside of this review comparing the effects of trail recreation on vegetation and soil (Thurston & Reader, 2001) and on wildlife (Taylor & Knight, 2003) have found similar contrasting effects between foot travel and mountain biking, but they do note that mountain biking often covers more ground than foot travel and thus may accumulate a greater effect.

Taxonomic Group

Fourteen studies (28% of all articles) compared the recreation disturbance responses of multiple species. Of these articles, all but one reported a significant difference in response between different wildlife species. These studies primarily compared bird species, and a few compared mammal species. Only one trend arose from these articles, likely due to the variety of species studied and limited number of articles. Three compared ground-nesting and -feeding birds to other functional groups of birds, and all three found ground-nesting and feeding birds to incur a disproportionate impact as a result of recreational trails (Barton & Holmes, 2007;

Rodríguez-Prieto, 2014; Thompson, 2015). A recent report (Miller, 2020) also concluded that habitat specialists were more affected by trail-based recreation than habitat generalists (that variable was not examined in this review.)

In order to compare effects across taxa or recreation types, experiments must be comprehensive and controlled at a high level. Therefore, there are many gaps in our understanding about differential effect related to taxonomic and function groups. For example, there are no studies here comparing effect on amphibians or invertebrates with effect on mammals or birds. Additionally, the implications of the effect on invertebrates are poorly understood. Multiple studies found substantial differences in community composition between trail-side and inner-forest communities of invertebrates (Banschbach et al., 2012; Strong, 2002; White et al., 2011), but the implications for abundance and diversity of invertebrate species were not revealed.

Other findings about differential response of taxonomic and functional groups to recreation were supported by this literature but none with multiple sources of support.
A summary of findings for each taxonomic group is found in Appendix 2.

MANAGEMENT RECOMMENDATIONS

Most reviewed articles set a goal of conducting their study to better understand ways to manage land to minimize the negative effects of recreation on wildlife. I categorized the recommendations made by authors toward that goal into the following groups: trail location restriction, seasonal regulation, volume or frequency cap, visitor education, other, and none. Few articles gave recommendations outside of these categories and are noted as "other". Some articles gave no management recommendations.

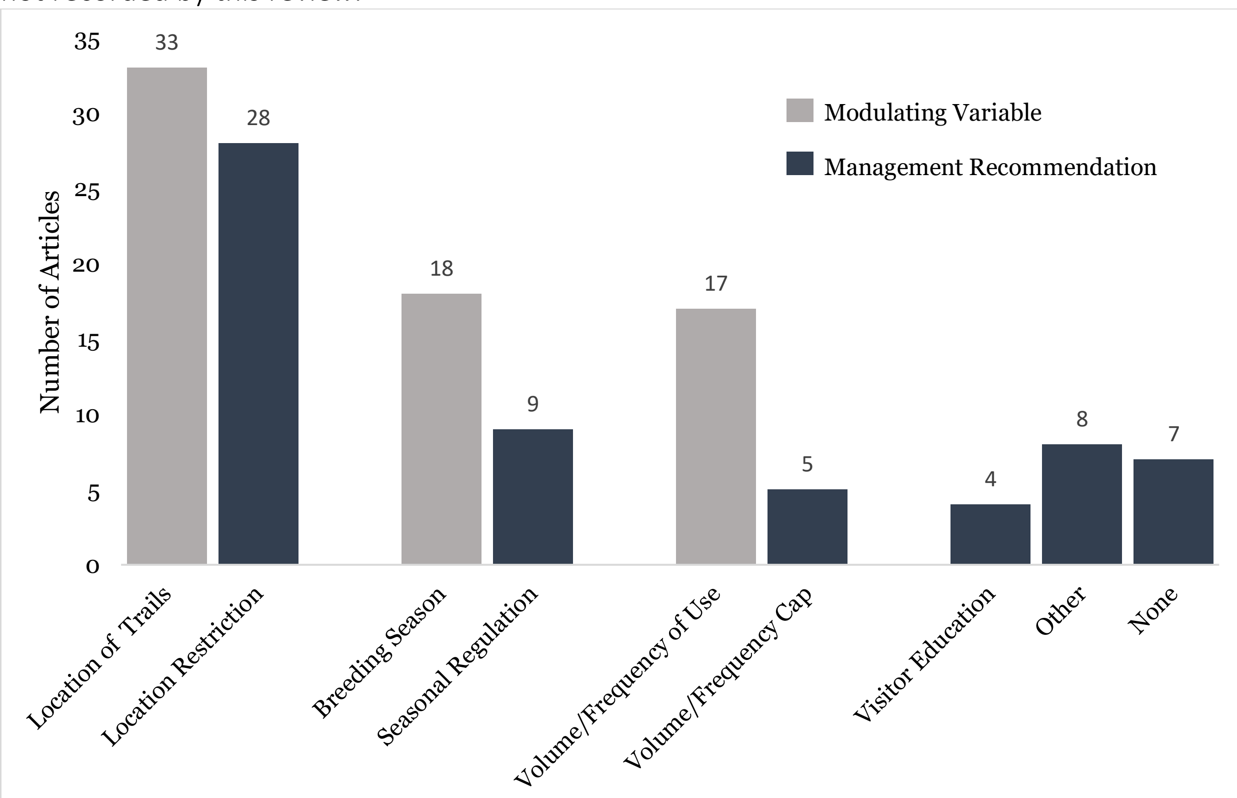
In this review, 66% of articles (33 articles) discussed location of trails as a primary variable affecting wildlife. This includes both small scale location, such as buffers around specific landscape features or wildlife resources, and landscape scale location to consolidate trails and leave large areas without recreation access or infrastructure. Of those, 70% (23 articles) specifically recommended trail location restrictions as a result of their research (Figure 5, below). Many articles agree that where consolidated trails exist, specific location of trails should also be considered.

Seasonal regulations to minimize negative effect on breeding wildlife were recommended in 18% (9 articles) of studies. Seasonal closures for breeding are already in place for some wildlife species such as falcons and bobcats, however this could be expanded to include more wildlife species. It is a management challenge to regulate breeding season recreation because breeding activities happen at different times for different animals. However, a coarse-filter approach to breeding season, capturing primary sensitive times for various taxonomic groups, could be used to implement a seasonal regulation and limit negative effects of recreation during that time.

Only 10% of articles recommended minimizing trail effect through a cap on volume or frequency of recreation, perhaps due to the lack of clear data about thresholds. Visitor education was only recommended in 8% of studies, and 14% of studies made no management recommendations. "Other" recommendations included temporal restrictions (Polich, 2016; Stalhaster & Kaiser, 1998; Zielinski et al., 2008), avoiding trail use on consecutive days (Dorrance et al., 1975), and trail effect offsets such as reforestation and land acquisition (Erb et al., 2012).

I use the collective information from this review to make specific management recommendations for trail recreation in Chapter 2.

Figure 5. Primary Variables and Associated Management Recommendations. The number of articles discussing the most common primary variables and the number of articles making associated management recommendations. The primary variables *consolidation of trails* and *zone of influence* were combined as *location of trails*. A primary variable for visitor education was not recorded by this review.



CONCLUSION

The primary finding that emerged from this review was the incredible complexity of this topic at every level. However, despite the complexity and current social relevance, recreation ecology makes up a relatively small percent of the published literature in ecology, recreation, and land management. The effect of trails on wildlife constitutes an even smaller percent of that literature (0.16% of publication volume, Larson, 2016). Animals respond to stimuli in complex and non-linear ways that differ depending on a multitude of variables (species, age, reproductive status, health, previous experience, time of day, season, climate, surrounding environment, type, volume, duration, speed, frequency of the stimulus—Tablado & Jenni, 2017). The way individuals respond can accumulate differently in populations, and population change can cause variable and cascading effects in wildlife communities (Stillman, et al., 2000; Tablado & Jenni, 2017). Overall, the findings of this review are consistent with global recreation ecology reviews (e.g., Larson et al., 2016; Miller, 2020a).

Despite this complexity, several trends became clear through this review and can be used to develop trail management strategies to minimize impact to wildlife and educate recreators. The overwhelming majority of the studies in this review saw a negative effect on wildlife due to recreation. Almost half of the studies saw a sustained negative impact on wildlife, despite many studies only measuring short term responses. Due to these results demonstrating such a negative effect, it is vital that consistent, science-based regulations be applied to landscapes for both proposed and existing recreation trails.

The location of recreation trails is clearly an important variable in the effect on wildlife. Locating new recreation trails away from unique landscape features and areas of high value to wildlife, in addition to consolidating trails on the landscape to leave large blocks of trail-free land, are agreed upon as effective ways to minimize the effect of trail recreation on wildlife. Vermont is unique in its landscapes, wildlife, and recreational practices. More research focused specifically on this geographic area will provide valuable information about the effects of local recreation on wildlife and how to manage trails to minimize their impact. Additionally, multiple topics of study still lack significant research, including differences in recreation type, the effect of higher volumes or frequencies of recreators, and effect on many underrepresented taxonomic groups of wildlife. These gaps in research leave a big opportunity for new exciting research, increased knowledge, and improved recreation management practices.

Reviewed sources are found in an annotated bibliography and organized by topic in Appendix 3. Additional references examining the effect of recreation and related topics that did not meet the criteria of this review are found in Appendix 4.

SUMMARIZED FINDINGS OF THE LITERATURE REVIEW

- Trail recreation has a negative effect on wildlife. Some examples of these effects include energetic loss, permanent displacement from habitat, and local extirpation.
- The incredible complexity of this topic relative to the limited scale of research makes it difficult to find many widely applicable trends. However, several broad trends arose from this body of literature.
- Wildlife is more sensitive to trail recreation during breeding season.

- Increased volume of trail use is not consistently or quantifiably linked to increased negative effects on wildlife.
- Non-motorized recreation tends to yield stronger negative effects on wildlife than motorized recreation, likely due to the slower, more erratic movement patters of non-motorized recreation.
- Designation of trail-free areas across the landscape and creating buffer zones around high value wildlife habitat are the most recommended methods to mitigate the effects of recreation.
- The research covered by this review primarily examines behavioral of ungulates and birds in response to foot travel.
- There is a lack of long-term research, population and community-level responses, and research on herpetofauna and invertebrates on this topic.

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CHAPTER 2

MANAGEMENT RECOMMENDATIONS

MINIMIZING THE EFFECTS OF TRAIL RECREATION ON WILDLIFE

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MANAGEMENT RECOMMENDATIONS

MINIMIZING THE EFFECTS OF TRAIL RECREATION ON WILDLIFE

Prepared by Meredith Naughton, UVM Field Naturalist Program

INTRODUCTION

The scientific literature clearly shows that trails have a negative effect on wildlife. However, it is possible to successfully balance recreational goals with maintaining an ecologically functional landscape. These recommendations focus on minimizing the effect of trail-based recreation on wildlife. By using this planning process and these minimization techniques, other ecological elements such as plants, soils, and waterways will also benefit.

Recreation trails may seem like a natural and unintrusive type of development; however, trails and their use leave a lasting negative impact. Once built, trails become a semi-permanent feature of the landscape. Their type and volume of use may change over time, but their recreational use will likely continue far into the future. This management protocol guides the careful, scientifically based consideration that must be given when deciding to build such a feature into the natural landscape. The primary suggestion developed in this report is managing visitor use and impact to wildlife through very thoughtful trail placement, because the greatest increase in impact occurs from no trails to initial trail use. Ecological and recreation assessments are necessary to place new trails wisely. Recommendations for ongoing management to minimize the effect on wildlife from existing trails are also important.

Management recommendations are divided into three chronological phases:

- Phase 1: landscape-level trail location planning
- Phase 2: site-level trail location planning
- Phase 3: monitoring and management of existing trails

The three phases of recommended management activities should be executed in successive order. For example, to build a new trail, Phase 1 must be completed before Phase 2 occurs. After Phases 1 and 2, Phase 3 guides continuing management. This report is organized by chronological phase.

PROCEDURE

The trail management process follows these sequential steps (Chart 1):

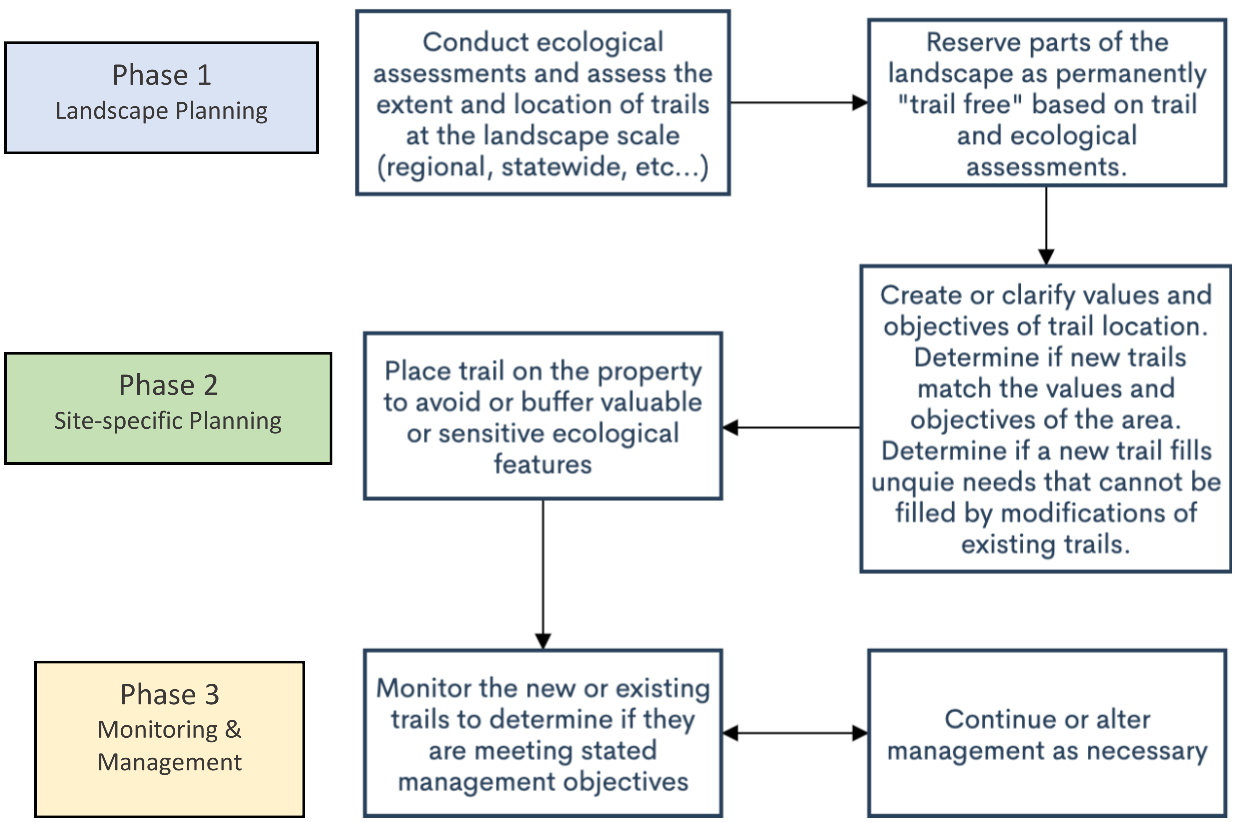
Phase 1 - Reserve parts of the landscape as permanently “trail-free”

1a. Determine the extent of the landscape-scale area, such as a management district, a state region, or statewide extent. Collect ecological and trail data on that area.
1b. Reserve high value landscape blocks and connectivity corridors as permanently "trail-free"

Phase 2 – Assess the need and determine specific placement of new trails
2a. Review goals and ecological and cultural features of the new trail location to determine if trails are valuable and appropriate there
2b. If building a trail, route the trail to avoid particularly valuable or sensitive ecological features. Do this in a way that consolidates and minimizes zone of influence.

Phase 3 - Manage existing trails to minimize impact to wildlife
3a. Clarify objectives of the property, determine effective indicators of impact to wildlife, implement a monitoring program to detect significant changes to wildlife from trail introduction and use
3b. Determine the appropriate scientifically supported trail management strategies and implement them to mitigate the impact of recreation trails on wildlife

Chart 1. Summarized process of managing trails to minimize impact on wildlife.



PHASE 1: LANDSCAPE-SCALE TRAIL PLANNING

Landscape-scale trail planning is the first, and possibly most significant, step in balancing opportunities for trail recreation and minimal wildlife impact. Before any management decisions can be made about a specific location or an individual trail, landscape-scale trail location planning must occur. The goal of Phase 1 is to designate permanent trail-free areas to ensure highly valuable habitat is not degraded by trail building and use.

First, the extent of landscape-scale decisions must be determined. The extent can vary from management district or region to statewide or beyond, referred to as the "management zone" from here forward. The management zone must include a broad area spanning many diverse major landscape features, such as mountains, valleys, and matrix forest, while also being detailed enough to include smaller features such as wildlife road crossings. This zone will contain many municipalities and will allow the opportunity to look beyond property boundaries to consider how forests, mountains, and watersheds interact and connect for large-scale ecological function. Using the appropriate scale for landscape-level decisions will protect and maintain a majority of wildlife species and their habitats. Landscape-level trail decisions are also able to take into consideration wildlife movement ecology, an important framework for planning and conservation (Fraser, 2018). These landscape-scale planning recommendations are informed by the literature review, which found many authors in strong agreement to retain trail-free areas and reserve large, connected blocks of the undeveloped landscape.

By following these recommendations and designating trail-free areas, the impact of recreation trails to wildlife will be minimized in addition to contributing to conservation goals such as maintaining biodiversity and preventing forest fragmentation. Landscape scale ecological functionality is not often considered in trail development decisions; however, this is an opportunity to look beyond parcel-level designations and consider the ecological region as an entire functioning unit.

PHASE 1 CHECKLIST

A. Conduct landscape-scale assessments

- Ecological Assessments
  - Locate and map high priority interior forest, connectivity corridors, and wildlife crossings
  - Determine the effective corridor width
- Trail & Recreation Assessments
  - How many miles of what kind of trails exist?
  - Where are these trails?
  - What is the extent of the zone of influence of these trails?

B. Plan Trail-Free Areas

- Overlay maps of high priority interior forest, connectivity corridors, and wildlife crossings
- Designate areas as permanently trail free where those ecological features overlap

A. LANDSCAPE-SCALE ASSESSMENTS

ECOLOGICAL ASSESSMENTS

In order to plan for future trail development, data must be collected about landscape scale ecological features within the management zone. These are features that, when conserved, maintain the ecological function of the natural landscape, including critical habitat for wildlife. This landscape-scale ecological approach is well-documented in Vermont Conservation Design, a conservation method designed to promote ecological function and mitigate threats such as habitat loss and fragmentation, non-native species, and climate change (Sorenson & Zaino, 2018).

Collecting this type of ecological data requires viewing the landscape with a coarse-scale lens. Identify and map the following features to provide the necessary coarse-scale ecological map to guide trail placement decisions: interior forest, connectivity corridors, and wildlife corridors. The following descriptions of these ecological features are adapted from Vermont Conservation Design (Sorenson & Zaino, 2018).

Interior Forest

The greatest impact to wildlife from recreation trails is the change from absence to presence of trails. A primary finding from the literature review is that large, unfragmented and trail-free blocks of natural landscape are needed to protect wildlife. Maintaining large areas of trail-free natural landscape protects a wide range of natural communities and associated wildlife, including wide-ranging, development sensitive, and climate-affected species.
Limited trail development at the edges of interior forest may not disrupt the function of these large landscape areas. However, limited development at the edges must not disrupt connectivity corridors or wildlife road crossings.

Connectivity Corridors

Connectivity corridors provide connected networks of natural landscapes for terrestrial wildlife with a large home range or specific resource needs to move through the region and find suitable habitat. Landscape connectivity is considered vital to mitigate adverse effects of human development on wildlife and biodiversity in general. Maintaining connectivity will be especially important as ranges of many species shift as a result of climate change. The ability to move throughout the landscape also allows for necessary ecological processes such as animal and native plant migration. Riparian corridors are also an important landscape element contributing to connectivity corridors. The proximity of large, forested areas and the type and scale of nearby development all contribute to the effectiveness of a connectivity corridor.

Effective Corridor Width

When identifying connectivity corridors, it is important to consider the “effective corridor width”. This is the width of the corridor that functions outside of the zone of influence and is without human influence. For example, if a trail runs alongside a proposed 300m wide corridor, the effective corridor width is 200m with a 100m primary zone of influence (see below for zone of influence description). This is not to say animals won’t be found outside of that 100m effective corridor, but human development and presence is likely exerting a negative impact within all but 100m of the area designed to protect wildlife (Ford, 2020; Hilty, 2019). Effective corridors are necessary for functional landscape connectivity.

Greater examination of spatial ecology relationships will help in determining these numbers and planning approaches. Additionally, if a corridor is designated for a very specific process, such as movement of deer from forage to winter yards, the width may be amended after investigation of species biology and ecological processes to be protected. However, it is important to use a scientifically based general approach to connectivity corridors until more specific information is available.

Wildlife Crossing Areas

Wildlife road crossings are a critical piece of landscape connectivity. Although they do not cover wide areas of the landscape themselves, crossing areas exist where there is suitable habitat on each side of the road, thus constituting vital elements in forest connectivity. For example, if a wildlife road crossing has undeveloped forest on each side of the road, those forests specifically provide shelter for animals moving across the landscape seeking food, habitat, breeding, or other necessary resources and so they become even more important to protect from recreation disturbance. Because recreation trails degrade wildlife habitat, leaving some wildlife to avoid the area or move their home range, recreation development at wildlife crossing areas will negatively impact the connectivity function of those forests. Documenting and mapping wildlife road crossings help us understand a valuable function of a piece of land that otherwise may not seem particularly valuable or sensitive.

TRAIL & RECREATION ASSESSMENTS

Trail & recreation data are important for landscape-scale planning in order to understand the extent to which trails already exist and in order to make informed decisions about trail additions or alterations. For example, if a trail network is proposed in relative proximity to an existing network, knowing the extent and location of the existing trails provides the opportunity to consider different solutions to fill the need met by the proposed trails. An additional access or improved parking at the existing network can increase usability while maintaining the current forest integrity at the proposed trail site.

The Phase 1 checklist guides the collection of landscape-scale trail data. A combination of written and mapped data best addresses the questions.

Determine the comprehensive zone of influence of current trails

The zone of influence (ZOI) is the effect of human disturbance from development, trails, or other activity, projected over a space onto ecological processes (Ford, 2020). The ZOI is determined in part by the generalized flight initiation distance (FID) and alert distance of a species. Determining and mapping the ZOI of recreation trails in a management zone will help in assessing the impact recreation can have over a broad space. The ZOI serves two roles in these management recommendations: first, to determine how much of an effect current trails have over the spatial environment; and second, to understand the spatial extent of impact new proposed trails can have.

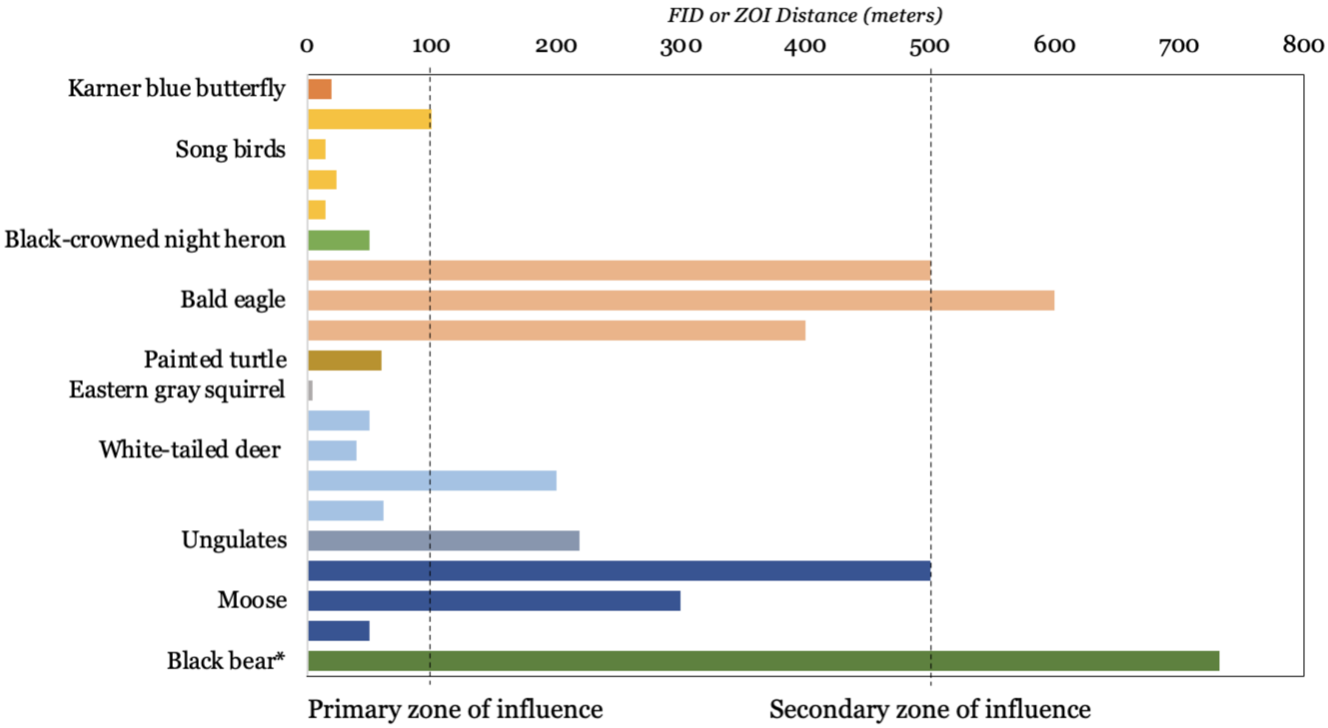
The ZOI and FID vary across species, context, disturbances, and landscapes. For example, an animal may forage within a few meters of a trail but avoid denning near a trail by hundreds of meters. Disturbance from trails originates from multiple different activities and affects many species across varied landscapes, making it most appropriate to use a generalized ZOI to interpret the landscape's varied wildlife uses and ecological function in the context of recreation trails. Here, the recommended zone of influence to use for management decisions and buffer distances is estimated at two scales: primary and secondary. These numbers incorporate reported ZOI distances and FID for wildlife of the northeastern United States to produce these general(Chart 2; Appendix 1; Ford, 2020).

- The primary zone of influence extends 100 meters from a recreation trail. This number represents the distance beyond which most species only experience minimal impact from trail recreation, as demonstrated by Chart 2, and concurs with the New Hampshire Fish & Game buffer distance. However, the primary zone of influence distance does not include distances within which unresearched or far-ranging species may be significantly impacted by trail recreation, such as moose, black bear, or bald eagles.
    - The primary zone of influence should be used to guide trail placement at least 100m away from sensitive or highly valuable natural communities or wildlife resources.
- The secondary zone of influence extends 500 meters from a recreation trail. This number includes distances at which most far-ranging species are no longer highly impacted by trail recreation. However, the secondary zone of influence still may not account for all far-ranging species, especially wildlife without researched responses to trail recreation.
    - The secondary zone of influence should be used to guide trail placement around certain habitat for highly sensitive or far-ranging species, such as a critical wildlife movement corridor, a bald eagle nest, or bear mast stand.

Recognizing that recreation ecology research is incredibly limited, it is also important to consider particularly sensitive wildlife or far-ranging wildlife in order to understand that these ZOI distances are likely a minimum for some animals. Some land managers may want to use a

200m primary buffer or 600m secondary buffer to offer more comprehensive wildlife protection.

Chart 2. Flight initiation (FID) and zone of influence (ZOI) distances found in the associated literature review. Chart details found in Appendix 1.



B. TRAIL-FREE AREAS

Trail-free designations are the most significant step in minimizing long term impact to ecological function and wildlife from the development of recreation trails. These trail free areas maintain an ecologically functional landscape and prevent the fragmenting effect of recreation trails. The identified and mapped landscape-scale elements detailed above should be used to guide designation of permanently trail-free areas (Chart 3).

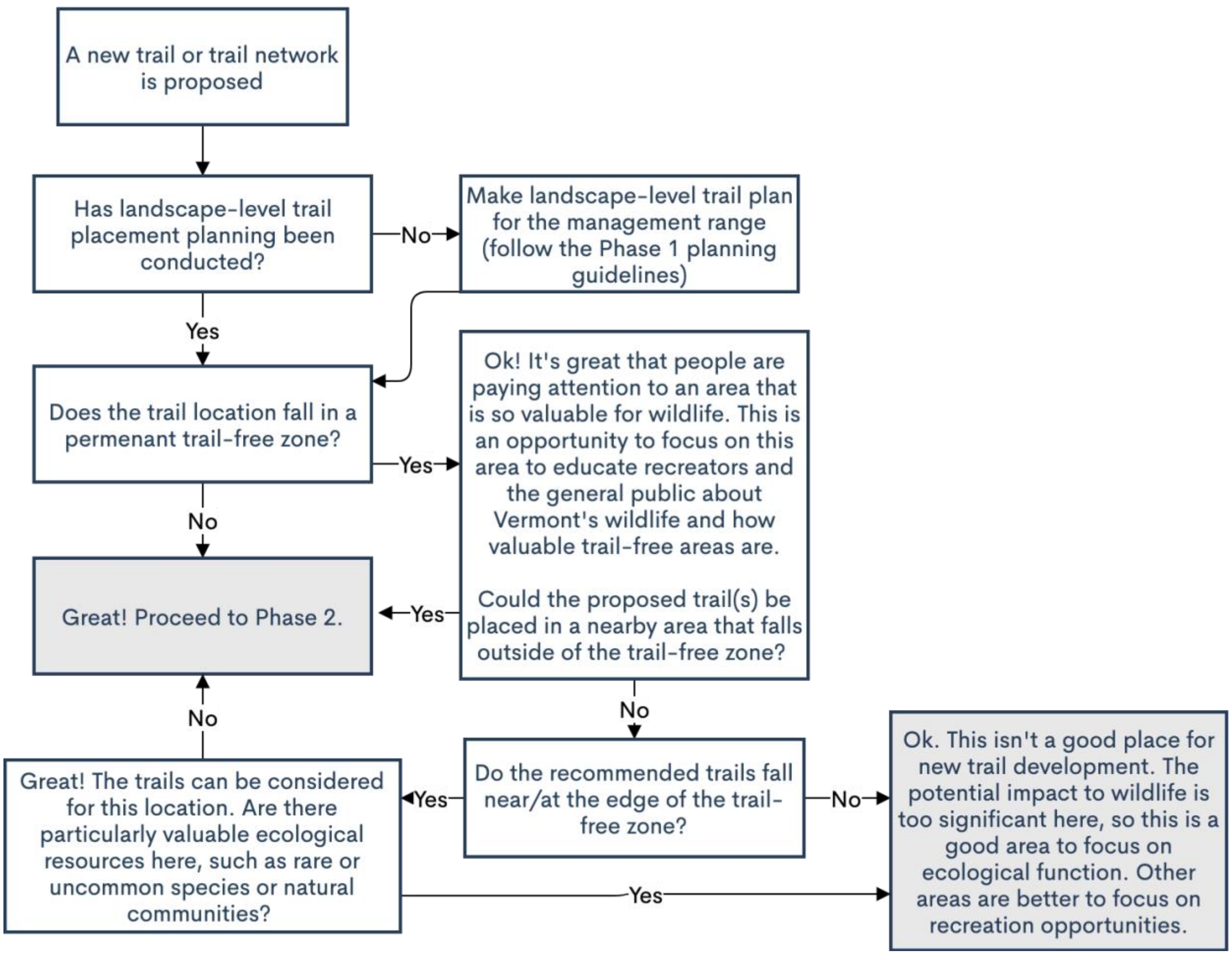
Where to designate trail-free areas?

Overlay the maps of interior forests, connectivity corridors, and wildlife crossing areas. The areas of overlap between interior forests, connectivity corridors, and/or wildlife crossing areas are the highest priority to be considered for the trail-free designations.

The total area of permanent trail-free land is not a fixed number. Here, as throughout the management process, recreation should be balanced with ecological priorities. For example, if the management range has significant trail development throughout, land managers must designate trail-free area to balance those recreation developments to ensure maintained ecological function despite potential pressure of new trail development.

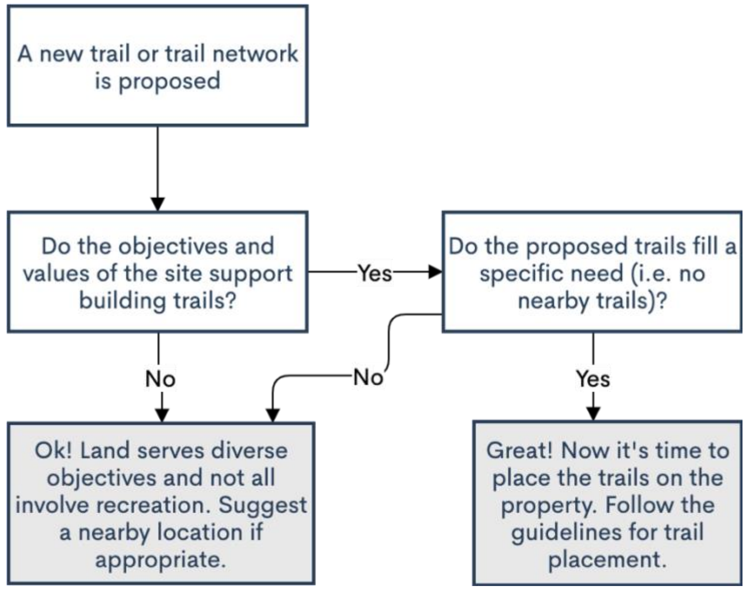
If development is proposed in a designated trail-free area, some locations within the trail-free area may be considered. Wildlife crossing areas should always be off limits for trail development, but edges of the designated trail-free areas may be cautiously considered for limited development. Edge development may have less impact than development in the interior of a trail-free block. However, this can lead to a precedent of edge development that can significantly encroach on the initial trail-free designation.

Chart 3. Phase 1 decision process for a new trail development



PHASE 2: SITE-SPECIFIC TRAIL PLACEMENT

Chart 4. Phase 2 for proposed new trail development



Once a trail plan has been developed in accordance with the location requirements of Phase 1, it can be assessed through Phase 2. If a trail or network is proposed for an area that has not undergone Phase 1 of wildlife-recreation planning, the proposal should be returned for revision.

If a trail is compatible with Phase 1 of wildlife-recreation planning, it still may or may not belong or be necessary. Phase 2 involves a decision-making process to determine if a new recreation trail is appropriate, followed by guidance on local-scale trail placement (Chart 4).

Throughout Phase 2, specific placement of a trail is referred to as a "location" or a "site". These terms refer to a specific area of land within the management zone. The site may refer to a specific property, piece of a property, or include multiple properties. Land often has objectives and values associated with it created by the landowner, land manager, local community, or other affiliates. These objectives and values will be used in Phase 2 to guide decisions about when and where to develop a new trail.

PHASE 2 CHECKLIST

A. Decision making process for new trails

- Does the addition of new trails align with the objectives and values of the location?

B. Site-specific trail location guidance

- Consolidate Trails
- Avoid sensitive and uncommon ecological features including:
    - Uncommon and rare natural communities
    - Lakes, ponds, and rivers
    - Riparian areas
    - Wetlands
    - Vernal pools
    - Grasslands
    - Rare, threatened, and endangered plants
- Mitigate impact where trails are near sensitive or uncommon ecological features

A. DECISION MAKING PROCESS FOR LOCATING NEW TRAILS

In Phase 2, review of local level requirements determines if a trail meets a locations goals and objectives. Consider the following questions to make that determination:

FOUNDATIONAL QUESTIONS

- What is the basic description of the site? Include location, ownership, and any other noteworthy description details.
- What are the current uses and values?
- Are there any restrictions or policies directly related to building this trail?
- Why is this trail or trail network being proposed? Does it fill a particular need?

ECOLOGICAL PROFILE

- What is the ecological profile of the site? Include size, topography, matrix forest, and aquatic features.
- Do any rare or uncommon natural communities exist?
  - Look specifically for unique ecological features particularly valuable for wildlife including vernal pools, wetlands, grasslands, caves, and mast stands.
- Are there any known rare or threatened plant species present on the land?

DIRECTION OF MANAGEMENT

- What is this site specifically managed for? What are the objectives and values of this site?
- Is it a goal of this site to provide trail-based recreation opportunities?
- Are there nearby existing recreation trails that meet recreation objectives?
  - If so, what adjustments can be made to the existing trails to fill the need that would be met by the proposed trails? For example, additional access points or parking.

The process of asking and answering these questions will provide a solid basis to determine if a trail is a suitable addition to the site. If an alternative solution that leads to fewer new trails becomes evident through this decision-making process, those alternative solutions should be used.

B. SITE-SPECIFIC TRAIL LOCATION GUIDANCE

If a proposed recreation trail is deemed a valuable and suitable addition to the landscape, Phase 2 also guides the specific placement of trails in the proposed area. These recommendations are written to minimize site-specific impacts to wildlife, such as breeding disruptions or degradation of valuable wildlife resources. Phase 2 targets sensitive environments likely to be physically impacted by human presence such as those with saturated soils or steep grades. Phase 2 also targets high value wildlife habitats with unique resources like specific types of shelter or vegetation. The landscape scale trailless designations protect some sensitive and high value areas, however not all habitat types are captured by this coarse-scale approach. Siting trails to avoid specific sensitive and high value areas, uncommon plant communities or physical features are protected, in addition to the wildlife that specifically relies on them.

The Phase 2 recommendations are informed by the findings of the associated literature review, conservation guidelines of Vermont Conservation Design Natural Community and Habitat Features (Sorenson & Zaino, 2018), and rare and uncommon species, communities, and physical landscape features. First, a vital spatial approach of consolidating trails is discussed, followed by categories of site-specific ecological features that should be avoided when building new recreation trails. If management is aimed at a specific species, strategies such as trail placement and buffer distances may be updated to reflect the ecology of that species. If circumstances lead to trails near sensitive, uncommon, or high-value areas, follow the guidance in Phase 3 to minimize the impact of these trails.

The following categories are not an exhaustive list of important wildlife habitat and resources that may exist in an area where a trail is proposed. These are intended to illustrate some common examples of ecological features to look for and associated planning guidance when placing new recreation trails. Examples of high value wildlife habitats not detailed below include beech and oak mast stands, rock outcrops, and old forests. The Phase 2, A. Ecological Profile questions will guide the specific ecological features to address during trail placement.

CONSOLIDATE TRAILS

Consolidating trails within a small area, rather than dispersing them across the landscape, minimizes recreation impact on wildlife (Thompson, 2015). Creating a concentrated area of trails follows the same rationale as the designation of trail-free areas. For example, the longer the trail and the more habitat types it intersects, the more the wildlife community is disturbed by recreators (Rodríguez-Prieto et al., 2014). The more spread-out trails are, the more impact they have to the landscape and wildlife. This is important in considering the effect across the landscape in order to protect core forest blocks, and to create effective wildlife crossings and corridors.

AVOID SENSITIVE & UNCOMMON ECOLOGICAL FEATURES

Uncommon and Rare Natural Communities

Natural communities are “interacting assemblages of plants and animals, their physical environments, and the natural processes that affect them” (Sorenson & Zaino, 2018). These environments vary widely, from a serpentine outcrop to a black spruce swamp to a red cedar woodland, and they differ from the matrix forests. Although landscape-scale trail-free areas may encompass some uncommon and rare natural communities, it is likely that not all natural communities are represented in these areas. The diversity of natural communities collectively

meet the needs of most of Vermont's wildlife. If uncommon or rare natural communities are disrupted by recreation trails, those ecological resources are diminished.
For example, the uncommon natural community dry-oak-hickory-hophornbeam forest provides natural features particularly valuable to wildlife. The dry-oak-hickory-hophornbeam forest has an abundance of shagbark hickory trees which are important for bat roosting among endangered species such as the Indiana bat and northern long-eared bat. This forest type also provides a valuable natural setting for several rare reptiles including the black rat snake, five-lined skink, and timber rattlesnake.

- New trails should not be built within uncommon or rare natural communities but can run at the edge of the communities where there is a reduced impact to the specific wildlife resource, such as an important foraging habitat (Bennett et al., 2009).

    - Many trails already exist in uncommon and rare natural communities, such as mountaintop trails through Alpine Meadow. These trails have a high recreation value and will continue to be used, however new trails in these areas should not be created. Although moving or closing these trails may not be a feasible management decision, consider other strategies to minimize impact to wildlife in these areas (detailed in Phase 3).

- The natural communities at the trail site should be examined within the regional context of wildlife function. There may also be common natural communities that provide a particular function in that location. For example, if a hemlock forest is used as a deer wintering area, that community should also be avoided to prevent deterioration of the wildlife resource.

Aquatic Features: Rivers, Streams, Lakes, and Ponds

Rivers, streams, lakes, and ponds are located throughout the landscape in the northeast and are found in both our cities and our most remote forests. These waters vary in size from the very small ephemeral streams to large rivers used for transport, and from small kettle ponds to Lake Champlain. Aquatic features provide special habitat for many aquatic, semi-aquatic, and terrestrial species, and often support concentrations of rare and uncommon wildlife. There is very limited research on the effect of trail recreation on aquatic species, such as fish, and while these recommendations do not focus on that effect, it is worth noting that trail recreation can affect nearby water bodies and aquatic species. Trail recreation can contribute to erosion, increased turbidity, altered composition of instream and streambank biota, and other processes that degrade the ecologically functional environment (Hennings, 2017).

- Minimize the number of times a trail crosses an aquatic feature. If a trail must cross a river or stream, it is acceptable to build a high-quality bridge over the water. The bridge must protect against erosion into the water and no additions of artificial barriers, such as dams, should be permitted.

- If a trail is proposed to run along the edge of an aquatic feature, the riparian area must remain intact and trail-free (see below).

Riparian Areas

The riparian areas alongside aquatic features protect them from sediment deposits and erosion and are unique habitats for plants and wildlife. Riparian areas are an important environment for animals that utilize both terrestrial and aquatic habitats, such as mink, otter, and wood turtle. Additionally, these riparian areas often serve as connectivity corridors for wildlife movement and gene flow.

- Include a minimum 50ft - 100ft buffer between aquatic features and trails to protect the aquatic features and promote a functioning riparian area (Vermont ANR, 2015).

- In a case where a riparian area is specifically planned as a wildlife connectivity corridor, the effective corridor width should be considered. As discussed above, the primary zone of influence of a trail is 100m, and the secondary zone of influence is 500m. The zone of influence defines the effective corridor width. Therefore a minimum buffer of 100m from the aquatic feature should be in place in cases when riparian areas are specially planned as a connectivity corridor.

- Recreation trails bisecting riparian areas degrade the quality of the movement corridor and forage habitat. However, if access to water through a riparian area is determined to be an important feature of the recreational landscape, access trails should be carefully placed and constructed. Few, high quality access points lead to less disruption. High quality access points are clearly built trails designed to minimize erosion or trail expansion.

Wetlands

Wetlands are “vegetated ecosystems characterized by abundant water” (Sorenson & Zaino, 2018). These ecosystems vary greatly in size, saturation, and nutrients leading to many different types of specific wetlands that support vast diversity of plants and animals. Functional wetlands provide numerous ecosystem services, including water filtration, flood mitigation, and protection from erosion. Additionally, they are critical wildlife habitat across taxonomic groups, including wetland specialists who cannot survive without nearby wetlands.
Trail recreation can greatly degrade the ecological function of a wetland. Placing trails in wetlands immediately degrades the environment as saturated wetland soils cannot support trails. Four studies in the associated literature review specifically examined the impact of trails in wetlands, all of which recommended not siting trails through wetlands and using a buffer distance to place trails away from the wetland. The suggested buffer distance varied based on focal species of the study, ranging from 15m for yellow-headed blackbirds to 300m for moose. Here, a compromise buffer distance of 100m is suggested. Standard wetland buffers are typically smaller, such as Vermont’s 50 ft - 100ft recommended buffer, but it is possible to specify these buffers to minimize the impact of trail recreation on wildlife. Wildlife can be

disrupted and negatively impacted from far distances, especially by slow activities, such as hiking.

- Do not site trails through any wetlands, and buffer trails away from wetlands by at least 100m.

- The Vermont Wetland Rules (Vermont Agency of Natural Resources, 2020) allows for recreation activities within wetlands and their buffers. However, this report recommends that additional trail recreation infrastructure may not be permitted in a wetland or within its buffer. Existing trails may continue use.

Vernal Pools

Vernal pools are wetlands that fill with water for part of the year and typically dry up during summer or early fall. This seasonal cycle and dry period allows amphibians like frogs, toads, and salamanders to reproduce and mature in vernal pools without the threat of fish and other predators who are unable to live in the temporary wetland. Reptiles, insects, crustaceans, birds, and mammals also use vernal pools throughout the time they are wet for food, water, and breeding. Spring ephemeral flowers often grow beside vernal pools and provide food for insects like bees and ants (Marchand, 2016). Amphibians use vernal pools as breeding areas from early spring through late summer, but they spend most of their year in the forest nearby. Many of the amphibians and other creatures using vernal pools return to the same pool year after year. If a pool is compromised or destroyed, it is likely that the population of amphibians using it as a breeding ground will also be lost (Clyde, 2016).

- Vernal pools require the 100m buffer of wetlands. An area with multiple, clustered vernal pools is a priority for applying the buffer because of the likelihood of higher activity than a single, isolated pool (Vermont Agency of Natural Resources, 2020).

Grasslands

Grasslands are maintained natural areas with a consistent management regime to remove thatch and allow the area to be dominated by non-invasive grasses. These areas are often used for grazing and haying. Grasslands are critical habitat for certain wildlife, most notably species of grassland birds that rely on these areas for breeding. Because grasslands are anthropogenic areas and maintained by disturbance, trails could presumably be a suitable addition to the landscape. However, it is vitally important that the grasslands are not disturbed during the breeding season, generally May to early August (Sorenson & Zaino, 2018). Because breeding season is a time wildlife is most sensitive to recreation disturbance, and May to August is a peak time for trail recreation, grasslands may not be an appropriate location for trails.

- Site trails outside of grasslands to minimize impact to wildlife from recreation. Placing trails at the edge of two habitats, such as a grassland, can have less of an impact.

- If trails are built through grasslands, they must be closed during the breeding season, roughly May through early August.

Rare, Threatened, and Endangered Plants

Endangered and threatened plants contribute to the ecological function of the landscape, and often support specialist relationships with certain wildlife. When endangered and threatened plants are known to occur at the site of a proposed trail, the specific ecology and disturbance regime of the plant should be considered to place the trail and/or manage the site of the plant. One of the biggest threats to endangered and threatened plants is the introduction of non-native species with the ability to outcompete them. Trails have been shown to facilitate the introduction of non-native plants via unintentional human-aided seed dispersal (Anderson et al., 2015).

- When possible, site recreation trails away from rare, threatened, and endangered plants. Depending on the ecology of the plant, various methods of management should be considered including buffering the trail a certain distance away from the plant.

MITIGATE IMPACT IN CASES OF TRAILS NEAR SENSITIVE AREAS

There may be cases where trails are sited in or near some of the sensitive areas detailed above. If that is the case, use management techniques to minimize impact to that area. These techniques include not putting gathering points in the sensitive areas, minimizing the zone of influence of trails in the sensitive areas, and restricting use during particularly sensitive times of the day or year.

PHASE 3: MONITORING & MANAGING RECREATION TRAILS

Phase 3 includes examples for monitoring trail impact and specific management recommendations for existing trails. Detailed guidelines for developing a monitoring program can be found in Appendix 5. Scientifically driven management techniques, such as carefully planning the location of trails or seasonal closures, are a great approach to start minimizing the impact of recreation trails on wildlife. However, without a way to assess the impact trails have on wildlife, it's difficult or impossible to tell if wildlife is still protected in a trailed area. Thus, it is vital to implement a way to check on the impact recreation trails are having on wildlife.

These recommendations are based primarily on the associated literature review, which examined scientific literature specifically related to the landscapes and wildlife of the northeastern United States. Despite this relevant relationship to the management region, applying widely varying studies to specific local decisions can introduce some uncertainty about whether our local wildlife respond in a similar way. Monitoring responses of wildlife to trail recreation gives us a way to focus our management approach to be most effective for the local area.

These recommendations can be used to generally decrease the impact of recreation trails on wildlife and can also be used to mitigate impact if monitoring reveals detrimental changes associated with recreation. Unlike Phases 1 and 2, these recommendations extend beyond the location of trails and include topics such as seasonal closures, dog restrictions, and volume restrictions.

PHASE 3 CHECKLIST

A. Monitoring & Assessment

- Examples of monitoring programs
- Appendix 5 – Guidelines for Developing a Recreation Ecology Monitoring Program.

B. Management Strategies

- Strategies
    - Education
    - Species-specific Management
    - Breeding Season
    - Winter Restrictions
    - Temporal Restrictions
    - Moving or Closing Trails
    - Gathering Points
    - Dogs
    - Use Local Ecology to Guide Management
    - Trail Building Practices
- Trail Management Question & Answer

A. MONITORING & ASSESSMENT

Trail recreation has a long history in Vermont, but recreation is changing and growing and with that so is our awareness of the effect it has on the landscape. The basic science is clear: trail recreation has a sustained negative impact on wildlife and the natural environment. However, the precise variables of impact, such as differences between recreation type or wildlife species, are not as clear. With those considerations – the growing trail use and development, clear negative impact, and unclear means of impact - responsible management *must* include monitoring ecological elements of systems that include recreation.

Land management typically includes planning with certain objectives in mind. Some objectives may be more specific, such as providing high quality resources for present amphibian species, and some may be less specific, such as maintaining an ecologically functional landscape. The objective of the property is useful for determining one or multiple indicators of change through monitoring. For example, if the objective of a property is to protect amphibians and their habitats, annual egg mass counts in vernal pools is a possible indicator of meeting those objectives.

A process of defining objectives, monitoring indicators, and adjusting management is necessary for responsible management of trail networks in ecologically functional landscapes. Monitoring is approached in many ways across disciplines. Many states, including Vermont and New Hampshire, have existing wildlife monitoring programs that can be adapted to monitor specific areas where recreation is present. Below are some examples of monitoring programs designed to detect change or impact due to recreation trails, assess management effectiveness, and inform future decisions. Specific guidance for developing a monitoring program can be found in Appendix 5.

CAMERA TRAPPING IN BRITISH COLOMBIA

In the South Chilcotin Mountains Provincial Park in British Colombia researchers used camera traps to collect data on wildlife and visitor activity. This monitoring protocol was designed to detect if there was a difference in wildlife presence related to recreational activity. They collected data on thirteen species, four types of trail recreation, and six environmental variables and used Bayesian modeling to find correlations. This monitoring protocol was used to demonstrate the difference in wildlife activity at one point in time, but this protocol could be conducted long-term in order to detect any change over time in response to different recreation or management activities. (Naidoo & Burton, 2020)

PROPOSED MONITORING & ADAPTIVE MANAGEMENT IN WASHINGTON STATE

This report offers guidance for developing a monitoring program and adaptive management techniques to respond to the impact of recreation on wildlife. In the report, they detail a hypothetical monitoring and adaptive management program. The goal of the program is to determine if a nature reserve will maintain its habitat effectiveness after a proposed new trail is built. (Gaines, et al., 2003)

- The focal species are breeding birds associated with late successional forest and the American marten.
- The objective is to determine if motorized and/or non-motorized trail recreation decreases habitat effectiveness for the focal species.
- The indicators monitored are 1) population indices for the focal species along the new trail, along previously existing trails, and in trailless areas, and 2) the zone of influence at which focal species may be affected by trails, compared to trailless areas.
- Monitoring would take place over two summer seasons following the building of the trail. Monitoring results would inform managers on the cumulative effect of trails and be used when making future trail building decisions.

B. MANAGEMENT STRATEGIES

EDUCATION

Regardless of any other management techniques carried out, visitor education about the impact of recreation trails should be a priority for land managers. It is a common misconception that recreation trails are ecologically neutral or only have a minimal effect. Now that the scientific community and land managers are starting to understand the extent to which recreation can impact wildlife, that impact must be communicated to recreators so they can be informed and involved in responsible recreation trail planning. Recreation education programs, such as mountain biking, skiing, and hiking clinics, should incorporate an ethic of care for the land that includes wildlife. Knowing that our presence in natural areas negatively impacts the ecological functionality of the landscape, and when and where those impacts are most pronounced, will allow all those advocating for more recreation opportunities to do so in an informed, responsible way.

SPECIES-SPECIFIC MANAGEMENT

Sensitivity to recreation disturbance varies among species, typically unrelated to their conservation status. Species-specific management can have far-reaching implications for the success of other species and therefore is recommended against when planning and managing recreation trails (Rodríguez-Prieto, et al., 2014). However, some properties lend themselves to specific management for one or a few species. Landowners may also prioritize managing for certain species. Refer to Appendix 2 for taxonomically specific information about the impact of recreation on wildlife.

BREEDING SEASON

Wildlife breeding season includes the process of mating, gestation or incubation, and parental care. Evidence is strong for an increased impact to wildlife from recreation during breeding season, and management suggestions in recreation ecology research reflect this. As an example, Grubb and King suggest a permanent buffer distance of 600m from known bald eagle nesting sites, and a doubled buffer distance during breeding season to 1200m (1991). This trend can be seen across taxonomic groups (including birds, mammals, and invertebrates) across recreation activities, as a result of snowmobiling or walking/hiking, and in geographically diverse areas.

Because breeding season and activities vary for each species, it is challenging to apply generalized breeding season restrictions. If breeding habitat features are known for the property, such as cliffs, vernal pools, or caves, consider closing trails in proximity to those features during breeding season of wildlife that may use them. This approach ties in closely with trail placement as described in Phase 2. If trails cannot be rerouted and are already in place in special habitats, such as grasslands, close those trails during a generalized season of wildlife breeding there.

Another way to minimize impact during breeding season is to select a suite of wildlife and develop a generalized breeding season and minimize trail use during that time. This season can coincide with mud season trail closures and may simply extend the closure to incorporate slightly earlier or later dates.

Trail building causes increased impacts to wildlife habitat and should be conducted when animals are least sensitive (Miller, 2020). Building new trails should be reserved for the fall, when breeding activities are generally at their lowest but the ground is still clear of snow.

WINTER RESTRICTIONS

Winter activities often mimic summer activities: snowshoeing may replace hiking, and Nordic skiing may replace mountain biking. In the northeast however, snowmobile trails are often an addition in winter to a landscape that receives little activity during the warmer seasons. Trails, including hiking, biking, and snowmobiling trails, that traverse deer wintering areas should be closed during the snow season. Because deer wintering areas (DWAs) provide refuge specifically in response to deep snow, disrupting those DWAs with recreation considerably degrades the function of those areas and can detrimentally affect deer during this sensitive season (Tomeo, 2000).

TEMPORAL RESTRICTIONS

Dawn and dusk are particularly active times for many wildlife species and restricting trail access to certain times of day can also minimize the impact of trail recreation. For example, bald eagles are more active particularly during early hours of the morning, leading to a greater negative effect of disturbance (Stahlmaster & Kaiser, 1998). Zielinski, et al. (2008) found little effect of off highway vehicle (OHV) activity on American marten and concluded this was likely because most OHV use occurred when marten were sheltered or inactive. Restricting trail activity during hours where wildlife of concern is most active, such as dawn and dusk, can minimize the overall impact of recreation trails.

MOVING OR CLOSING TRAILS

If trails are in highly sensitive or valuable areas, such as DWAs, riparian corridors, or avian breeding habitat, the most effective action for minimizing impact to wildlife is to move the trails away from the area (Barton & Holmes, 2007; Eckstein, et al., 1979). For example, the Vermont Agency of Natural Resources recommends relocating roads or other infrastructure, such as trails, outside of the riparian zone to restore riparian function if it is compromised (2015). Moving trails from the middle of sensitive and high value areas to run along the edge of them decreases the impact to the wildlife resource, such as valuable foraging habitat (Bennett et al., 2009).

An alternative to moving trails is closing them during the sensitive time of year or day. See *Breeding Season*, *Winter Restrictions*, and *Temporal Restrictions* sections above for more information.

GATHERING POINTS

Limit the number of gathering points along trails. Wildlife and vegetation are most disturbed at points of interest or viewpoints where visitors naturally gather. When possible, locate these gathering points in areas already disturbed, such as at the edge of a field. Additionally, human behavior is one of the primary factors that increases the impact of recreation on wildlife. Specific, limited, and carefully placed areas must be built to allow people to congregate and avoid widespread disturbance (Oâ & Campbell, 2011).

DOGS

Dogs significantly increase the impact of trail recreation to wildlife (Bennett, et al., 2009; Parsons, et al., 2016). Where possible, maintaining or implementing rules restricting dogs from trails prevent that increased impact from occurring. For trail networks that allow dogs, leash restrictions are shown to be somewhat effective in mitigating the impact dogs have on wildlife (Miller, et al., 2001; Parsons, et al., 2016). If dogs are already allowed on these trails, implement a leash requirement. Allowing dogs on trails without leashes yeilds the greatest impact to wildlife and is not recommended under any circumstance. For research directly related to the additional impact of dogs and recreation on wildlife, refer to Appendix 4.

TRAIL BUILDING PRACTICES

The process of building trails should also be required to have best practices that minimize impact to the natural environment. This review and these recommendations do not specifically address trail building, but the trail-building process is important to understand and include in making the decision to build a new trail. Trail building best practices are rarely, if ever, based on recommendations about the impact to wildlife. One important way to minimize trail building impact is to avoid breeding season of local sensitive wildlife species or focal species of management, for example, before May 15 for Bicknell's thrush (Rimmer, et al., 2004)

VOLUME OR FREQUENCY OF RECREATION

Once an area has recreation trails, the volume of traffic should not be the primary concern. Studies show that the primary impact of trails occurs with the change from no trails to trails, and increasing volume has a considerably smaller impact (Colescott & Gillingham, 1998; Ferguson & Keith, 1982).

Popular trails should be monitored for social trails, unpermitted new trails, and trail connectors, as these are often a result of high use areas. Although the overall ecological function of an area may not change much with the addition of one trail in a concentrated trail area, informal or unregulated trails are more likely to be poorly built, leading to erosion and vegetation impact more so than carefully constructed trails. In general, concentrating trail use into popular areas and leaving other parts of the landscape trail-free results in less ecological impact.

TYPE OF RECREATION

The strongest evidence to support different levels of impact from different types of trail recreation is related to motorized versus non-motorized recreation. Motorized recreation, such as snowmobiling and ATVing, is consistently shown to have less of an impact to wildlife than non-motorized recreation, such as hiking or skiing. Recreation trails are often designed specifically for motorized or non-motorized recreation, so the decision to change between those types is uncommon. There isn't strong evidence that non-motorized activities, including hiking, biking, and skiing, vary significantly in impact to wildlife. Therefore, limiting or changing the type of recreation permitted on trails is not recommended here to minimize impact of trails to wildlife.

CONCLUSION

These recommendations provide a scientifically based way to minimize the impact of trail recreation on wildlife. Much like other activities that take place in the forest, such as logging or building, recreation trails must have an associated review process and best management practices. These recommendations are an important step forward, but there is much work to be done towards understanding and balancing recreation and wildlife protection.

Next steps towards balancing recreation and wildlife protection include better describing the associations of natural communities with wildlife, especially rare or uncommon wildlife in the northeast. Additionally, the work of mapping designated trailless areas should be done for each region or state and made publicly available for all landowners and managers. These guidelines also should be developed into a more visual and easily understood guidebook that can be used by private landowners, consultants, land trusts, forestry companies, and more.

SUMMARIZED MANAGEMENT RECOMMENDATIONS

- Designate areas of the landscape as trail-free.
    - Prioritize large interior forest blocks, connectivity blocks, and high value wildlife crossing areas for the trail-free areas.
- When an area is determined as appropriate for trails, create primary (100m) and secondary (500m) buffer zones to avoid high value wildlife resources.
- Consolidate trails to limit dispersed negative effects.
- Monitor the trailed areas to inform effective, adaptive management.
- Promote a culture of responsible recreation by educating trail users about the negative effects on wildlife, and that wildlife and recreation can coexist through proper trail placement and considerate use.

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It is my hope that the results of this project help people work towards balancing the joy of being out on a trail and ensuring a future home for wildlife across the lands.

APPENDICES

VERMONT WILDLIFE & TRAIL RECREATION

BY
MEREDITH NAUGHTON
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APPENDIX 1
FLIGHT INITIATION & ZONE OF INFLUENCE DISTANCES

Prepared by Meredith Naughton, UVM Field Naturalist Program

Flight initiation distances (FID) and zone of influence (ZOI) distances from each article in the associated literature review are included in Table 1.

Tables 2 through 5 and Figure 1 are FID and ZOI numbers collected and reported by other literature reviews, included here for reference.

SUMMARY OF FLIGHT INITIATION AND ZONE OF INFLUENCE DISTANCES FROM THE ASSOCIATED REVIEW

Chart 1. Flight Initiation Distance, Zone of Influence, and Buffer Distances. Each row represents a scientific article in the associated literature review with a recorded FID or ZOI. Where a species or taxonomic group is studied in more than one article, a single color represents that group. Primary and secondary buffer distances determined by the management recommendations are displayed with dashed lines. *Black bear zone of influence is included for reference but was not in the associated literature review.

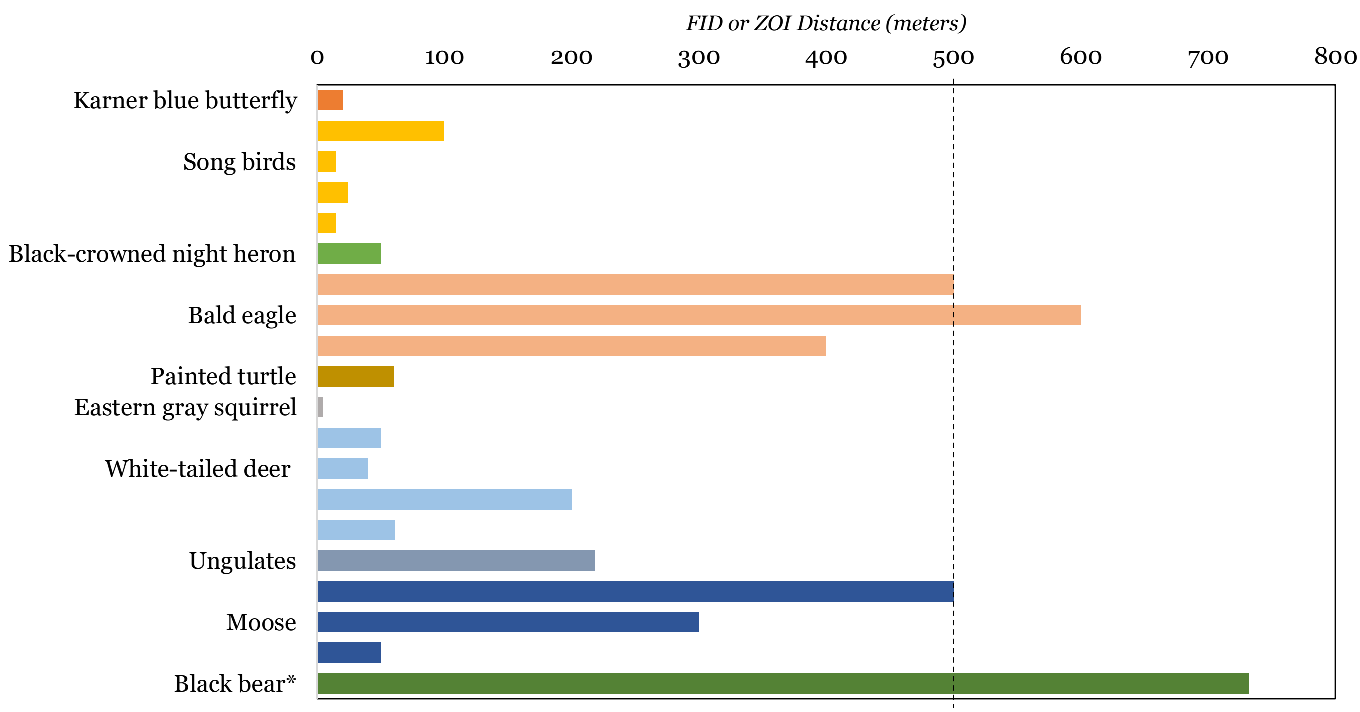


Table 1. Flight initiation distances in this report's systematically reviewed literature.

Reference	Animals	Activity	FID (m)	Notes
Barton & Holmes, 2007	Songbirds	Snowmobile	100	Within 100m is reduced-quality habitat shown to have higher rates of predation and abandonment
Bennett et al., 2009	Yellow-headed blackbirds	Walking/Hiking	15	Results of a simulation
Bennett et al., 2013	Karner blue butterfly	Walking/Hiking	20	Oviposition significantly higher when recreation is greater than 20m away; habitat is considered highly degraded within 10m of nest
Colescott & Gillingham, 1998	Moose	Snowmobile	300	Behavior is impacted at 300m distance, and more significantly impacted at 150 m distance and closer
Dorrance et al., 1975	White-tailed deer	Snowmobile	200	
Eckstein et al., 1979	White-tailed deer	Snowmobile	61	Authors suggest trails be confined to upland deciduous forests and routed away from coniferous forests
Engelhardt & Weladji, 2011	Eastern gray squirrel	Walking/Hiking	4.5	FID increased as human activity decreased
Ferguson & Keith, 1982	Moose	Nordic Skiing	500	
Fernandez-Juricic et al., 2007	Black-crowned night heron	Walking/Hiking	50	
Fraser et al., 1985	Bald eagle	Walking/Hiking	500	
Grooms & Urbanek, 2018	Bird diversity	Walking/Hiking		Authors suggest buffer zones but no specific distance
Grubb & King, 1991	Bald eagle	Walking/Hiking	600	Authors suggest permanent buffer of 600m, and a secondary buffer zone of 1200m during breeding season
Harris et al., 2014	Ungulates	Snowmobile, Skiing, Walking	218.5	This is the average FID for all papers reviewed in Harris, 2014
Miller et al., 2020	Deer and Coyote	Trail Building, Walking/Hiking	50	

Moen et al., 1982	White-tailed deer	Snowmobile	40	Greatest distance between deer and snowmobiles used in the experiment
Oa & Campbell, 2011	Passerine birds	Walking/Hiking	24	FID ranged from 24-18m
Polich, 2016	Painted turtle	Walking/Hiking	60	Average FID of turtles at a rural (less trafficked site)
Smith-Castro & Rodewald, 2010	Northern cardinal	Walking/Hiking	15	Authors did not explicitly publish their FIDs because they determined tendency to flush was a better predictor of sensitivity to human disturbance than FID. However, 15m was the highest FID recorded on a graph in the paper
Stalmaster & Kaiser, 1998	Bald eagle	Walking/Hiking	400	For the first 5 hours of daylight no activity within 400m

OUTSIDE SOURCES SUMMARIZING FLIGHT INITIATION AND ZONE OF INFLUENCE DISTANCES

Table 2. Zone of influence distance associated with the avoidance of residential areas and recreational trails, from Ford, 2020.

Disturbance	Species	Range (m)	Median (m)	Number of studies
Residential areas	Cougar	50–9990	3105	3
	Wolves	1000–6100	3546	3
	Grizzly bear	4000–8000	6000	4
	Black bear	5000	5000	1
Trails	Cougar	100	100	1
	Wolves	400	400	1
	Grizzly bear	21–8000	628	7
	Black bear	122–2000	732	2

Table 3. Effects of roads and trails on grizzly bears and gray wolves, from Gaines, 2003 (table 5).

Human activity	Focal species	Distance at which use is less than expected[a]	Road density at which use is less than expected[b]	References
		Meters	*Kilometers per square kilometer*	
Roads	Grizzly bear	500		Mattson et al. 1987
Roads	Grizzly bear	100		McLellan and Shackleton 1988
Roads	Grizzly bear	200 through spring 100 through summer 400 through autumn		Aune and Kasworm 1989
Roads	Grizzly bear	914		Kasworm and Manley 1990
Roads	Grizzly bear	500		Mace et al. 1996
Roads and trails	Grizzly bear	500		Hood and Parker 2001
Trails	Grizzly bear	813 through spring 878 through summer 1,129 through autumn		Mace and Waller 1996
Trails	Grizzly bear	122 through spring and fall		Kasworm and Manley 1990
Roads	Gray wolf		0.7	Harrison and Chapin 1998
Roads	Gray wolf		.4	Mladenoff et al. 1995
Roads	Gray wolf		.6	Mech et al. 1988
Roads	Gray wolf		.7	Thiel 1985
Roads	Gray wolf		.6	Jensen et al. 1986

[a] Distance from a linear recreation route in which use by an animal was statistically significantly less than expected.

[b] Density of roads at which use by an animal was statistically significantly less than expected.

Table 4. Displacement distances and mean distances from roads and trails reported for ungulate focal species, from Gaines, 2003 (table 8).

Human activity	Focal species	Distance displaced[a]	Mean distance[b]	References
		- - - - - - - - - - - - - - *Meters*	- - - - - - - - - - - - - -	
Hiking	Mule deer	191		Freddy et al. 1986
Snowmobiling	Mule deer	133		Freddy et al. 1986
Hiking	Mule deer	200		Ward et al. 1980
Hiking	Elk	86		Schultz and Bailey 1978
Skiing	Elk	650		Cassier et al. 1992
Skiing	Elk	Moved away from high-use (>8 persons per day) trail		Ferguson and Keith 1982
Hiking	Bighorn sheep	50		MacArthur et al. 1982
Hiking	Bighorn sheep	Did not affect sheep movements		Hicks and Elder 1979
Hiking	Bighorn sheep		200 at which sheep first responded	Papouchis et al. 2001
Roads and trails <500 visitors per year	Bighorn sheep	100		Smith et al. 1991
Roads and trails >500 visitors per year	Bighorn sheep	150		Smith et al. 1991
Road driving ≤1 vehicle per day	Bighorn sheep		354	Papouchis et al. 2001
Road driving 5 to 13 vehicles per day	Bighorn sheep		490	Papouchis et al. 2001
Road driving	Elk	400		Ward 1976
Road driving	Mule deer	800		Perry and Overly 1977
Road driving (closed to vehicles but open to all-terrain vehicles)			268 to 280	Johnson et al. 2000
Road driving (low traffic 0 to 1 vehicle per 12 hours)	Elk		869 to 890	Johnson et al. 2000
Road driving (medium traffic 2 to 4 vehicles per 12 hours)	Elk		909 to 1032	Johnson et al. 2000
Road driving (high traffic >4 vehicles per 12 hours)	Elk		1103 to 1560	Johnson et al. 2000

[a] Average distance at which animals reacted to human activities and were displaced from the area.
[b] Distance that radio-collared animals were located from roads.

Figure 1. Flight initation or alert distances for various wildlife species, from Hennings, 2017 (figure 9). Details in table 5 below.

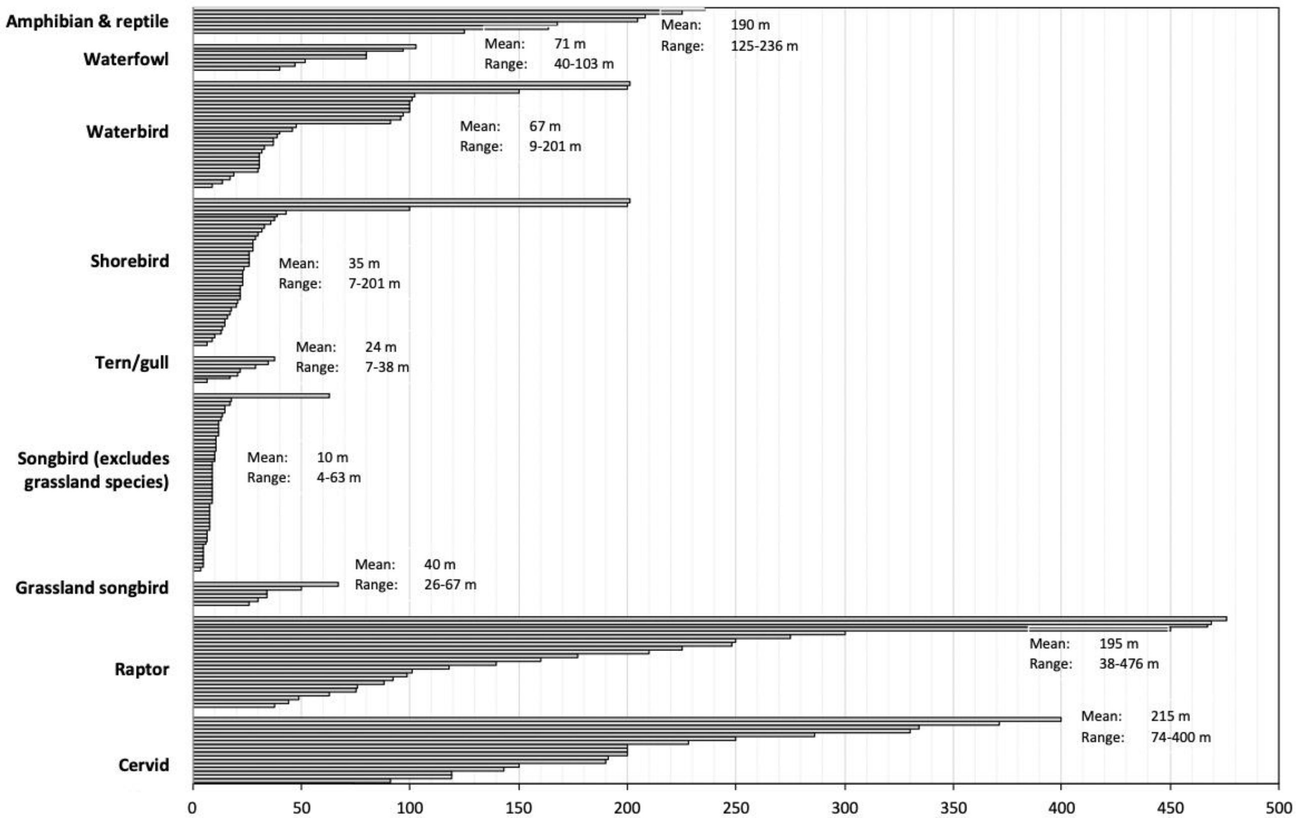


Table 5. Details for Figure 1: species groups Flight Initiation Distances or Alert Distances from scientific literature. Table from Hennings, 2017 (table 8)

Table 8. Summary statistics for species groups' Flight Initiation Distances or Alert Distances from the scientific literature. We excluded species groups with fewer than three data points from Figure 9 (**hummingbirds**, corvids, doves/pigeons, **woodpeckers** and bovids) although data for these species groups are in this table and Appendix 3. Flight Initiation Distance = FID; Alert Distance = AD. Amphibians and reptiles are based on life history requirements rather than FID or AD.

Species group	# of studies	Mean (meters)	Median (meters)	Range (meters)	Notes
Amphibians (amphibians & reptiles combined in Figure 9)	5	194	168	125-287	Rather than FID or AD, these distances documented several amphibian species' terrestrial migration distances from aquatic breeding sites to upland habitat. Trails routed through this general zone could cause issues for amphibians. Buffering wetlands by these distances can help identify potential migration areas. *Additional information:* Boardwalks or wildlife undercrossings can enhance connectivity for these species. Migration typically occurs during certain seasons (typically spring).
Reptiles	3	216	208	205-236	Species group includes studies on reptiles as a group, snakes and turtles, for which numbers were generally similar. *Additional information:* Reptiles such as snakes and lizards benefit from sunny forest openings on south-facing slopes. Pond turtles require uplands with specific soil characteristics for nesting.
Waterfowl	7	71	80	40-103	This average is for both migratory and resident ducks. Migratory ducks generally flush more readily than resident species. *Additional information:* Installing viewing blinds or vegetation screens between trails and wetlands may decrease effects.
Waterbirds	28	67	40	9-201	This group consists of herons, egrets and cormorants. *Additional information:* Several researchers suggested avoiding placing trails, or seasonally closing trails, within 100m of heron rookeries to avoid nest abandonment or failure.
Raptors	24	195	150	38-476	Raptors' FIDs are generally high; kestrels are on the lower end and eagles on the higher end. People on foot tend to be more disturbing than other uses such as boating, and ground-nesting species tend to have longer FIDs. *Additional information on Bald Eagles:* Known Bald Eagle nests and high-use feeding areas may need special consideration due to low abundance and sensitivity to disturbance. Vegetative screens can reduce FID for eagles.
Shorebirds	39	35	23	7-201	Some shorebirds can adapt somewhat to human presence while others, particularly migratory species, are more sensitive. Migrating/nesting species tend to be more disturbance-sensitive. Exclusionary fencing can be effective.
Terns/gulls	7	24	22	7-38	Information on this species group was limited.
Doves/pigeons	2	16	N/A	15-16	Information on this species group was limited.
Hummingbirds	1	6	N/A	6	Rufous hummingbird (single study).
Woodpeckers	2	18	N/A	17-19	We only found two woodpecker FIDs but they were very similar (17 and 19 m). Distances could be used to create a trail avoidance buffer around large snags or areas with multiple snags; larger areas may be needed for more sensitive species.
Corvids	2	50	N/A	24-76	Information on this species group was limited.
Songbirds (excludes grassland songbirds)	47	10	9	4-63	Most non-grassland songbirds had relatively short FIDs; however, it is difficult to detect birds in well vegetated areas, therefore forest-dwelling species may be under-represented in the literature. *Additional information:* Neotropical migratory birds are known to be especially disturbance-sensitive. Many migratory songbirds rely on fruiting shrubs during migration. In forest and shrub habitats, restoring vertical vegetation structure along trails to provide a visual screen and including fruiting shrubs for food and cover could help reduce effects of recreation on these species.
Grassland songbirds	6	40	34	26-67	Although grassland species are sometimes slow to flush, the median FID was substantially higher than other songbirds. If meadows and grasslands must be crossed, consider aligning trails on the outer edge of the habitat. Avoid placing trails through small meadows or grasslands to make such habitats available to nesting birds.
Deer/elk	18	215	200	74-400	Deer are sensitive to disturbance but their range of sensitivity is smaller than that of elk. Several variables mitigate the ability of elk to habituate to human disturbance. If elk are a priority at the site, consider these suggestions: • Add vegetation in a 50-100 m buffer between trails and known elk foraging areas (typically meadows and shrub habitat) to provide a visual screen. Ensure prompt closure of unauthorized trails in the buffer area. • Seasonal (spring) closures on trails within 200 m of high-use elk areas to protect pregnant elk or elk with young. • Seasonal closures of high-use elk areas during fall if any problematic encounters between people and rutting elk occur. These numbers may be on the low end but assume some habituation in recreational areas. See large carnivores for suggestions on protecting connectivity.
Bighorn sheep	3	104	165	46-200	Our area of interest excludes bighorn sheep, but we included this information in case land managers from other areas are interested in buffering trails from disturbing this species. Pregnant sheep/sheep with young/rutting males are most sensitive (spring and fall).
Large carnivores and general connectivity	Outside the scope of this report	N/A	N/A	N/A	The most important actions to conserve large carnivores are to: • Limit the total length of trails in a site. • When possible, leave large patches of habitat undisturbed. • Identify potential constrictions in connectivity and avoid trailheads in those areas. • Survey for and close unauthorized trails.

APPENDIX 2

RESPONSES TO RECREATION BY TAXONOMIC & FUNCTIONAL GROUP

Prepared by Meredith Naughton, UVM Field Naturalist Program

SMALL MAMMALS

- In Quebec, flight initiation distance (FID) of eastern grey squirrels (*Sciurus carolinensis)* increased with decreasing human exposure, and FID increased with increasing distance between the human and the squirrel when the approach by the human begins.
- The most important habitat factor in a broad-scale study of wildlife communities, including small mammals, in trailed areas was presence of large, intact forest.
- In North Carolina eastern gray squirrel (*Sciurus carolinensis*) showed altered timing of daily activity patterns and decreased use of the trail area after new trails were built.
- Eastern grey squirrel showed temporal avoidance of humans in protected areas with recreation, both with and without dogs, though this avoidance was greatest for people accompanied by a dog.

CITATIONS:

Engelhardt & Weladji, 2011	Kays et al., 2017	Parsons et al. 2016
Erb et al., 2012	Miller, 2020	

UNGULATES

- Moose (*Alces alces*) behavior was altered by snowmobile traffic within 300m of a trail, and more significantly within 150m of a trail. Moose were permanently displaced to less favorable habitats. The frequency of snowmobiles did not affect observed moose numbers in the study area.
- In a Minnesota forest with frequent public snowmobile traffic, snowmobiles resulted in displacement of white-tailed deer (*Odocoileus virginianus*) in areas within 200m of a trail but did not significantly impact their home ranges.
- In a Minnesota forest with only experimentally applied snowmobile traffic, snowmobiles significantly increased home range size and displacement of white-tailed deer from areas adjacent to trails. Some white-tailed deer were more sensitive and changed their home ranges entirely as a result of snowmobile traffic.

- Fewer moose were consistently observed within 500m of cross-country ski trails than there was more than 500m away from trails. Moose occupy an area near cross-country ski trails less frequently than surrounding habitat. Utilization of heavily trafficked cross-country ski areas was 60% of utilization of areas that were lightly used. However, daily changes in number of skiers did not cause any further displacement effects.
- Winter recreation is most detrimental to ungulates when it is: 1) unpredictable, 2) spanning large areas, 3) long in duration, 4) large spatial footprint, 5) nonmotorized, and 6) when animals are displaced to poor quality habitats.
- About 75% of all white-tailed deer allowed a vehicle or horse rider to approach to 100m, but only 50% allowed a walking person to approach to 100m.
- The presence of humans on hiking trails triggered a response from all observed caribou in a Quebec study. Lactating females with a calf and lone females avoided trails that had many hikers during the daytime. However, females without a calf spent more of their time near trails in vigilance, while lactating females were more prone to trade vigilance for foraging behavior.
- White-tailed deer showed altered timing of daily activity patterns after new trails were built.
- A white-tailed deer's heart rate increased each time a snowmobile run was taken from any distance (40m, 20m or 2m), even when it displayed no behavioral changes. Heart rates increased an average of 2.5 times pre-stimulus rates from snowmobile activity within 40m (no difference 2m - 40m), for an average of 2 minutes, without signs of habituation.
- On days they were disturbed by cross-country skiers, moose moved about 33 times faster than they did at the same time on days not disturbed. They showed increased movement rates up to 3 hours following disturbance, leading to increased energy expenditures and eventually a negative effect on population growth.
- White-tailed deer showed temporal avoidance of humans in protected areas with recreation, both with and without dogs, though this avoidance was greatest for people accompanied by a dog.
- In Maine, a significantly greater number of deer responded with flight (instead of no flight) to a walker than to a snowmobile in all snow, weather, habitat, and temporal conditions recorded. Number of deer displaying no flight increased progressively throughout the winter each sampling year, possibly due to decreased energy or habituation.
- Moose response behavior (stopping feeding, fleeing) increased when recreators were loud or very active.
- Moose in urban areas had the highest glucocorticoid (stress hormone) levels, followed by moose in an area with high snowmobile use. In the areas with infrequent human presence, noise from and view of humans did correlate with a higher glucocorticoid level.

CITATIONS:

Colescott & Gillingham, 1998	Kays et al., 2017	Neumann et al., 2010
Dorrance et al., 1975	Kucera, 1976	Parsons et al. 2016
Erb et al., 2012	Lesmerises et al., 2017	Richens, 1978
Ferguson & Keith, 1982	Miller, 2020	Silverberg et al., 2003
Harris et al., 2017	Moen, 1976; 1982	Tomeo, 2000

CARNIVORES

- American black bears (*Ursus americanas*) showed a significant avoidance of high-use trail areas. Forest loss in areas adjacent to trails negatively affected the occurrence of black bears and bobcats (*Lynx rufus*).
- Coyotes (*Canis latrans*), and racoons (*Procyon lotor*) changed their activity timing and during near a trail area while a new trail was built.
- Occupancy and circadian activity of American marten (*Martes americana*) did not differ significantly between off highway vehicle (OHV) use and non-use areas, likely because most OHV use occurred at a time when martens were sheltered or inactive.
- Based on camera trapping data, coyotes and black bears used trails for travel quite often, however no coyote and very few black bears used a trail within an hour after a passing hiker.

CITATIONS:

Erb et al., 2012
Kays et al., 2017
Lesmerises et al., 2017
Miller, 2020
Zielinski, et al., 2008

BATS

- Barbastelle bats (Barbastella barbastellus) (a European species) abandoned their roosts at certain levels of frequency and density of recreationists in a hardwood forest. The bats were most disturbed during peak disturbance (weekend recreation) and least disturbed during midweek, midday recreation. However, no threshold for disturbance was determined. The greatest disturbance came from unrestricted recreationist movement and recreationists with dogs.

CITATIONS:

Bennett et al., 2009
Krusic et al., 1996

WATERFOWL

- Colonies of Double-crested cormorants (*Nannopterum auritum*) in Quebec where human disturbance was applied experienced increased gull predation and nest failure, and control colonies had a higher number of late season nests than experimental colonies. Nest abandonment is most likely to happen during early season breeding and disturbance should minimized or eliminated during that time.
- The proportion of time nestlings Black-crowned night heron (*Nycticorax nycticorax*) spent scanning, a vigilance response, significantly increased in the presence of

pedestrians. Little evidence supported increased disturbance response with varying frequency of pedestrians, although responses varied with distance from the disturbance. Additionally, quicker pedestrian travel yielded lower proportion of time in disturbance response behavior as compared to the longer the pedestrians were in proximity to the nests (such as with slower walkers or birdwatchers).
- Low richness and diversity of species were found occurring with high rates of trail use in four state parks in Arkansas.

CITATIONS:

Ellison & Cleary, 1978 | Fernández-Juricic et al., 2007 | Grooms & Urbanek, 2018

BIRDS: UNDERSTORY & GROUND

- Ground- and shrub-nesting songbirds increased nest desertion and abandonment, and decreased predation with proximity to OHV trail. Predation and abandonment was higher for ground-nesting than shrub-nesting birds.
- Proximity to hiking trails did not significantly influenced abundance, detection probabilities, or seasonal movements of montane forest birds in New Hampshire.
- Low richness and diversity of several bird species were found occurring with high rates of trail use in state parks in Arkansas. Environmental factors including increased abundance and height variation of trailside woody vegetation, along with habitat heterogeneity led to higher richness and diversity in avian communities.
- Ovenbirds in central Indiana were disturbed significantly more often than eight other species of bird. Authors found a consistent pattern of less disturbance when trail use was "low", and considerably higher rates of disturbance when trail use was "high".
- Authors found that the longer the trail and the more habitat types the trail intersects, the more frequently birds are disturbed by recreationists.
- The area of trail-free habitat had a significant positive influence on the density of forest birds, particularly ground-foraging and -nesting species.
- Relative abundance of three forest-interior species and two interior-edge species were negatively related to trail width. Red-eyed Vireo (*Vireo olivaceus*) nests were more likely to be parasitized closer to wide trails. Interior bird abundance is affected to at least 50m on either side of forest roads and double-track trails, which amounts to 10ha of unsuitable forest habitat for every 1km of track.

CITATIONS:

Barton & Holmes, 2007	Kays et al., 2017	Walters, 2010
Deluca & King, 2014	Rodríguez-Prieto et al., 2014	
Grooms & Urbanek, 2018	Thompson, 2015	

- In Illinois, nesting yellow-headed blackbirds were disturbed by nearby trails, particularly within 10-15 meters, but nest success was not affected.
- Low richness and diversity of several bird species were found occurring with high rates of trail use in state parks in Arkansas. Environmental factors including increased abundance and height variation of trailside woody vegetation, along with habitat heterogeneity led to higher richness and diversity in avian communities.
- In a comparison between control sites without human activity and experimental sites with a hiker, mean singing date was 11 days earlier for control sites than for intruded sites for the Ruby-crowned Kinglet, which the authors state is "considerable"; song occurrence and singing consistency were higher on control sites than intruded sites.
- Mean abundances of American Robin was 57% lower and Hermit Thrush were 48% lower in hiking sites than in control sites.
- There was a positive relationship found between detectability period (the time a bird remains near its initial flush point) and number of conspecifics, indicating birds are less tolerant of intrusion when they are solitary or in smaller groups.
- Brighter and more conspicuous birds responded to human intrusion from longer distances and flushed sooner.
- Adult and nesting densities of Bicknell’s thrush (*Catharus bicknelli*) are greatest adjacent to disturbances, both anthropogenic (such as ski trails) and natural. However, fitness benefits have not been found for Bicknell's thrush breeding near disturbances. Findings from radio telemetry of adult Bicknell’s thrushes showed that ski trails wider than 35-40m appear to restrict thrush movements, and that small or narrow forest patches were rarely used.
- Bird size and human behavior were significant indicators of alert distance in Ontario, with larger birds and walkers with swinging arms (vs no swinging arms) having longer alert distances. Alert distance averages ranged from ~28m (Crow) to ~15m (House Sparrow and Black Capped Chickadee), and flight distance averages ranged from ~24m (Crow) to ~13m (House Sparrow and Eastern Phoebe). Alert and flight distance with varying human behavior ranged from 24m and 22m (respectively) with 90-degree arm swings, to 13m and 11m with sideways approach and no arm swing.
- Authors found in central Indiana that the longer the trail and the more habitat types the trail intersects, the more frequently the bird community is disturbed by recreationists.
- Northern cardinals (*Cardinalis cardinalis)* were 6 times more likely to flush when nests were approached directly, and females on higher nests were less likely to flush.
- An area of trail-free habitat, compared to a trailed area, had a significant positive influence on the density of forest birds in Ontario.
- Relative abundance of three forest-interior species and two interior-edge species were negatively related to trail width, while they were positively related for four edge species.
- In Ontario, Red-eyed vireo (*Vireo olivaceus*) nests were more likely to be parasitized closer to wide trails. Rose-breasted grosbeak (*Pheucticus ludovicianus*) nest success was

lowest close to forest roads and wide trails, with increasing success with increasing distance from them.

- Interior bird abundance is affected to at least 50m on either side of forest roads and double-track trails, which amounts to 10ha of unsuitable forest habitat for every 1km of track.

CITATIONS:

Bennett et al., 2009
Grooms & Urbanek, 2018
Gutzwiller & Anderson, 1997; 1999
Gutzwiller et al., 1994; 1998
Hill, 2019
Oâ & Campbell, 2011
Rimmer et al., 2001
Rodríguez-Prieto et al., 2014
Smith-Castro & Rodewald, 2010; 2010
Thompson, 2015
Walters, 2010

BIRDS OF PREY

- Bald eagles (*Haliaeetus leucocephalus*) flushed from a broad variety of distances in response to approaches on foot (57m - 991m), leading the authors to believe the eagles do not readily adapt to new stimuli and suggesting the difficulties of implementing a single buffer zone over a broad geographic area.
- Low richness and diversity of several bird species were found occurring with high rates of trail use in state parks in Arkansas. Environmental factors including increased abundance and height variation of trailside woody vegetation, along with habitat heterogeneity led to higher richness and diversity in avian communities.
- Pedestrians caused the highest rate of disturbance response to bald eagles (*Haliaeetus leucocephalus*) of various recreation activities. Distance was found to be the most important recreation variable determining disturbance, with duration second. The authors determined 630m as the threshold for response to recreationist, as 75% of responsive behaviors occurred within that distance.
- There was no significant difference in nest success of 115 “somewhat grown and less vulnerable” bald eagles in northern Minnesota across areas with different “wilderness factors”.
- Feeding activity of bald eagles declined exponentially, and the number of eagles in the study area was negatively correlated with daily number of recreation events. Foot traffic was most disturbing to eagles. Eagles required nearly 4 hours to resume feeding after disturbance by foot, compared to 36 minutes after boat traffic. Eagles resumed feeding relatively soon after initial disturbances of the day, but after 20 events they were slower to resume feeding and after 40 events feeding was uncommon.

CITATIONS:

Fraser et al., 1985
Grooms & Urbanek, 2018
Grubb & King, 1991
Mathisen, 1968
Stalmaster & Kaiser, 1998

AMPHIBIANS & REPTILES

- Significantly more salamanders were found trail-side than away from trails in Georgia forests due to significantly more logs in trail-side habitat, affecting terrestrial salamanders by altering their distribution through creating habitat as a result of trail creation and maintenance. The average number of salamanders per log did not differ trail-side versus away from trails.
- Wood turtle (*Clemmys insculpa*) populations declined rapidly, to the point of extirpation, during a monitoring study after recreation was allowed in the forests in Connecticut.
- Northern dusky (*Desmognathus fuscus fuscus*) and Spring salamander (Gyrinophilus porphyriticus) populations were significantly lower in ski areas streams. Northern dusky salamander in control streams also had significantly longer mean body length.
- Average FID of painted turtles (*Chrysemys picta*) at a rural site (~60m) was significantly greater than an urban site (~41 m), supporting the hypothesis that FID would be higher where there is less human disturbance. Findings at both rural and urban sites indicated that FID was greater in the morning when temperatures were cooler, presumably because turtles are more able to move quickly once their bodies have warmed and thus tolerate a shorter FID.

CITATIONS:

Davis, 2007	Hagen, 1999	Polich, 2016
Garber & Burger, 1995		

INVERTEBRATES

- Ant communities in Vermont were found to have significantly greater total numbers of ants and ant nests in the edge sites compared to the interior sites although there was no significant difference in species richness.
- Endangered Karner blue butterflies, *Lycaeides melissa samuelis,* flushed as a result of recreational disturbance, and recreation degraded the quality of habitat in proximity to the trail, less than 10m. Oviposition rates were significantly higher where recreation occurred greater than 20m from nests. A simulation model revealed that regularly occurring disturbance such as this could reduce egg laying potential and significantly restrict host plant choice, impacting populations.
- Beetle communities on Mt. Mansfield in Vermont had a nearly complete species turnover from the ski trail to 5m into the forest, although species diversity and richness remained similar in each of the three locations. Absence of forest species in the ski trail suggests that these trails act as barriers to dispersal for many ground beetles.

- Trail impact was a significant negative predictor of caterpillar diversity and abundance, and host plant availability was a near-significant positive predictor for caterpillar diversity and abundance.

CITATIONS:

Banschbach et al., 2012
Bennett et al., 2013
Strong, 2002
White et al., 2011

APPENDIX 3
REVIEW SOURCES ANNOTATED BIBLIOGRAPHY & ORGANIZED BY TOPIC

Prepared by Meredith Naughton, UVM Field Naturalist Program

ANNOTATED BIBLIOGRAPHY

Banschbach, V. S., Yeamans, R., Brunelle, A., Gulka, A., & Holmes, M. (2012). Edge Effects on Community and Social Structure of Northern Temperate Deciduous Forest Ants. Psyche: A Journal of Entomology, 2012, 1–7. https://doi.org/10.1155/2012/548260

- Ant communities were studied at edge and interior sites at Mills Riverside Park in Jericho, VT to assess the effect of recreation-based fragmentation.
- Significantly greater total numbers of ants and ant nests were found in the edge sites compared to the interior sites, although there was no significant difference in species richness. The authors hypothesize that edge habitat created by trail could influence reproduction of the most common ant species, *Aphaenogaster rudis.*
- Habitat features were not characterized at each site type. However, resource availability, such as presence of downed woody debris, is a potential explanation for greater ant abundance at edge sites.

Barton, D. C., & Holmes, A. L. (2007). Off-Highway Vehicle Trail Impacts on Breeding Songbirds in Northeastern California. Journal of Wildlife Management, 71(5), 1617–1620. https://doi.org/10.2193/2006-026

- Ground and shrub-nesting songbirds, including the Blue-gray gnatcatcher (*Polioptila caerulea*), Brown-headed cowbird (*Molothrus ater*), Chipping sparrow (*Spizella passerine*), and Mourning dove (*Senaida macroura*), were observed in northeastern California at varying distances from Off-Highway Vehicle (OHV) trails to estimate rates of nest predation, abandonment, desertion, and success.
- Study results suggested that proximity to OHV trail increased nest desertion and abandonment, and decreased predation.
- Predation and abandonment were higher for ground-nesting than shrub-nesting birds.
- Management implications: areas within 100m of OHV trails provide reduced-quality habitat to nesting songbirds, particularly for species that already experience low fecundity due to nest abandonment or desertion of breeding attempts.
- Recommendation: avoid or limit breeding habitat when placing OHV trails, particularly for rare and endangered birds.

Bennett, V. J., Beard, M., Zollner, P. A., Fernández-Juricic, E., Westphal, L., & LeBlanc, C. L. (2009). Understanding wildlife responses to human disturbance through simulation modelling: A management tool. Ecological Complexity, 6(2), 113–134. https://doi.org/10.1016/j.ecocom.2008.08.002

- Study tests a Simulation of Disturbance Activities (SODA) model in two case studies.
- In Illinois, nesting yellow-headed blackbirds (*Xanthocephalus xanthocephalus*) were used to model disturbance as a result of trail location in a wetland preserve. The birds were visibly disturbed by nearby trails, particularly within 10-15 meters, but nest success was not affected.
- In England, the model was used to examine whether barbastelle bats (*Barbastella barbastellus)* abandoned their roosts at certain levels of frequency and density of recreationists in a hardwood forest. The simulation showed the bats were most disturbed during peak disturbance (weekend recreation) and least disturbed during midweek, midday recreation. However, no threshold for disturbance was determined.
- The greatest disturbance came from unrestricted recreationist movement (not confined to trails) and recreationists with dogs.

Bennett, V. J., Quinn, V. S., & Zollner, P. A. (2013). Exploring the implications of recreational disturbance on an endangered butterfly using a novel modelling approach. Biodiversity and Conservation, 22(8), 1783–1798. https://doi.org/10.1007/s10531-013-0512-6

- The authors observed responses of the federally endangered Karner blue butterflies (*Lycaeides melissa samuelis)* to recreation on a hiking trail through a lowland marsh and black oak barren in Indiana Dunes National Park.
- Field surveys showed that the butterflies flushed as a result of recreational disturbance, and that recreation degraded the quality of habitat in proximity to the trail (~10m). A simulation model revealed that regularly occurring disturbance such as this could reduce egg laying potential and significantly restrict host plant choice, impacting populations.
- Recommendation: authors suggest moving trails and other public access away from breeding habitat. They developed a model (SODA) to simulate the potentially alleviated butterfly response to recreators.

Colescott, J., & Gillingham, M. (1998). Reaction of moose (Alces alces) to snowmobile traffic in the Greysriver Valley, Wyoming. Alces, 34(2), 120–125.

- Moose (*Alces alces*) were observed at varying distances from a snowmobile trail in western Wyoming. The trail divided lowland willow-dominated riparian area and upland mixed forest. Moose were observed in the riparian area.
- Moose behavior was altered by snowmobile traffic within 300m of the trail, and more significantly within 150m of the trail, and displaced moose to less favorable habitats.
- The frequency of snowmobiles did not affect observed moose numbers in the study area.

Davis, A. K. (2007). Walking Trails in a Nature Preserve Alter Terrestrial Salamander Distributions. Natural Areas Journal, 27(4), 385–389. https://doi.org/10.3375/0885-8608(2007)27[385:WTIANP]2.0.CO;2

- This study examined numbers of terrestrial salamanders found under logs and stones trail-side versus 25m away from walking trails in a nature preserve including mixed forests and wetlands in Georgia.
- Significantly more salamanders were found trail-side than away from trails due to significantly more logs in trail-side habitat. The average number of salamanders per log did not differ trail-side versus away from trails.
- The author concludes that trails do affect terrestrial salamanders by altering their distribution through creating habitat as a result of trail creation and maintenance. However, it is inconclusive whether this alteration has a positive, negative, or neutral effect on salamander populations or broader distribution.

Deluca, W. V., & King, D. I. (2014). Influence of hiking trails on montane birds. Journal of Wildlife Management, 78(3), 494–502. https://doi.org/10.1002/jwmg.675

- This study looked at abundance of 5 species of montane birds in the White Mountains, NH for differences in abundance trail-side, 200m from a trail, and 400m from a trail. The authors also examined the potential effect of hiking on the reproductive success of one of the birds, the blackpoll warbler (*Setophaga striata*).
- Little evidence was found to suggest hiking trails influenced abundance, detection probabilities, or seasonal movements of these montane forest birds. Also, daily nest survival of the blackpoll warbler did not vary with distance from trail.
- This study did not compare montane bird abundance in similar habitats without trail present, where a difference in abundance may have been detected as trails have been shown to affect a wide corridor around a trail.

Dorrance, M. J., Savage, P. J., & Huff, D. E. (1975). Effects of Snowmobiles on White-Tailed Deer. The Journal of Wildlife Management, 39(3), 563–569. JSTOR. https://doi.org/10.2307/3800399

- The authors tracked radio locations of white-tailed deer (*Odocoileus virginianus*) in two pine-oak forests in Minnesota, one with frequent public snowmobile traffic, and one with only the experimentally applied snowmobile traffic.
- The effects were subtle in the forest with frequent public snowmobile traffic. Snowmobiles resulted in displacement of deer in areas within 200m of a trail but did not significantly impact their home ranges. However, the authors hypothesize that during severe winters on small or poor home ranges, the displacement of deer from even small segments of their home range can be detrimental.
- In the forest with only experimentally applied snowmobile traffic, snowmobiles had a more pronounced affect including significantly increased home range size and displacement from areas adjacent to trails Some deer were more sensitive and changed their home ranges entirely as a result of snowmobile traffic.
- This study suggests presence (vs. absence) of trails has a more significant impact on wildlife than trail traffic at varying levels. Recommendations: to reduce disturbance of white-tailed deer by snowmobile traffic route trails away from areas where deer concentrate in winter and avoid use of a particular trail on consecutive days.

Eckstein, R. G., O'Brien, T. F., Rongstad, O. J., & Bollinger, J. G. (1979). Snowmobile Effects on Movements of White-tailed Deer: A Case-study. Environmental Conservation, 6(1), 45–51. https://doi.org/10.1017/S0376892900002216

- Snowmobile traffic was experimentally applied on certain days of the week to look at the effect on winter home ranges, movements, and activity patterns of white-tailed deer (*Odocoileus virginianus*) in northern Wisconsin.
- Some deer were significantly farther from trails on days when snowmobiles were present and "intensive" snowmobiling cause a significant increase in deer activity during a normally inactive period between 7pm and 10pm. However, this study did not find any strong trends of disturbance.
- Other studies note that results in Eckstein, 1979 were seriously impacted by adjacent logging operations during the entirety of the study which supposedly only investigated snowmobile disturbance (Moen, 1982).

Ellison, L. N., & Cleary, L. (1978). Effects of Human Disturbance on Breeding of Double-Crested Cormorants. The Auk, 95(3), 510–517. JSTOR.

- Double-crested cormorants (*Phalacrocoras auritus*) were studied during the breeding season (June and July) on two islands uninhabited by humans in the St. Lawrence River in Quebec.
- Human disturbance was applied experimentally during to test if there is an effect on reproductive success, including nest abandonment, gull predation, nest failure, and decreased late season nesting. The human disturbance treatment was applied by experimenters visiting the nest colonies 1-2 times per week.
- The colonies where human disturbance was applied experienced increased gull predation and nest failure, and control colonies had a higher number of late season nests than experimental colonies.
- Recommendation: the authors conclude nest abandonment is most likely to happen during early season breeding and disturbance should be minimized or eliminated during that time.

Engelhardt, S. C., & Weladji, R. B. (2011). Effects of levels of human exposure on flight initiation distance and distance to refuge in foraging eastern gray squirrels (Sciurus carolinensis). Canadian Journal of Zoology, 89(9), 823–830. https://doi.org/10.1139/z11-054

- Flight initiation distance (FID) and distance to refuge of eastern grey squirrels (*Sciurus carolinensis)* was studied in Quebec in seven sites corresponding to three different levels of human exposure.
- The authors found that FID increased with decreasing human exposure, and FID increased with increasing starting distance.
- They concluded that risk posed to gray squirrels is reduced or minimized in areas frequently visited by humans and may be attributed to habituation in increased nonlethal stimuli in the form of exposure to humans.

Erb, P. L., McShea, W. J., & Guralnick, R. P. (2012). Anthropogenic Influences on Macro-Level Mammal Occupancy in the Appalachian Trail Corridor. PLoS ONE, 7(8), e42574. https://doi.org/10.1371/journal.pone.0042574

- Presence/absence of eight different mammal species were sampled using camera traps along a 1024 km section of the Appalachian Trail from Pennsylvania to North Carolina to determine occupancy and distribution of these animals in a high-activity recreation corridor.
- There were several significant findings: black bears (*Ursus americanas)* showed a significant avoidance of high-use trail areas; the amount of oak forest was the most significant predictor of occupancy for all eight mammals except opossum (*Didelphis virginiana)* and coyote (*Canis latrans)*; forest loss in adjacent areas negatively affected the occurrence of black bears and bobcats (*Lynx rufus)*, while positively affecting occurrence of red and gray fox (*Vulpes vulpes* and *Urocyon cinereoargenteus)* and raccoon (*Procyon lotor*). Additionally, all focal species responded to changes in forest cover at a larger scale (5km-10km) than a smaller scale (500m-3km).
- Recommendation: protecting current forest habitat, encouraging continued reforestation and land acquisition. Forest corridors on a large and small scale are critical for a number of mammal species, and it is necessary to incorporate local and landscape scale wildlife activity into management.

Ferguson', M. A. D., & Keith, L. B. (1982). Influence of Nordic Skiing on Distribution of Moose and Elk in Elk Island National Park, Alberta. 96, 11.

- Moose (*Alces alces)* and elk (*Cervus canadensis)* distributions were assessed by aerial counts, pellet counts, and track counts during the winter in mixed forests in Alberta, Canada to determine the effects of cross-country skiing on their distribution.
- The primary finding was that moose occupy an area near cross-country ski trails less frequently than surrounding habitat; utilization of heavily used cross-country ski areas was 60% of utilization of areas that were lightly used.
- The authors provided no management recommendations.

Fernández-Juricic, E., Zollner, P. A., LeBlanc, C., & Westphal, L. M. (2007). Responses of Nestling Black-Crowned Night Herons (Nycticorax nycticorax) to Aquatic and Terrestrial Recreational Activities: A Manipulative Study. Waterbirds: The International Journal of Waterbird Biology, 30(4), 554–565. JSTOR.

- Researchers observed black-crowned night heron (*Nycticorax nycticorax*) nestlings in a wetland in northeastern Illinois for disturbance responses in the presence of pedestrians and canoeists.
- The proportion of time nestlings spent scanning, a vigilance response, significantly increased in the presence of pedestrians. Little evidence supported increased disturbance responses with varying frequency of pedestrians, although disturbance responses varied with distance from the disturbance. Additionally, quicker pedestrian travel yielded lower proportion of time in disturbance response behavior as compared to the longer the pedestrians were in proximity to the nests (such as with slower walkers or birdwatchers).

- Recommendation: an increased distance between pathways and nests with a minimum 50m buffer zone.

Fraser, J. D., Frenzel, L. D., & Mathisen, J. E. (1985). The Impact of Human Activities on Breeding Bald Eagles in North-Central Minnesota. The Journal of Wildlife Management, 49(3), 585–592. JSTOR. https://doi.org/10.2307/3801676

- The authors examined the impact of humans approaching on foot, of nearby houses, and of aircraft on bald eagles *(Haliaeetus leucocephalus)* by looking at flushing behavior and nest success.
- The bald eagles flushed from a broad variety of distancing (57m - 991m), leading the authors to believe the eagles do not readily adapt to new stimuli and suggesting the difficulties of implementing a single buffer zone over a broad geographic area.
- Recommendation: continued efforts towards enforcement and education to minimize impact on bald eagles, but do not specify what type of enforcement or education.

Garber, S. D., & Burger, J. (1995). A 20-Yr Study Documenting the Relationship Between Turtle Decline and Human Recreation. Ecological Applications, 5(4), 1151–1162. JSTOR. https://doi.org/10.2307/2269362

- Wood turtle (*Clemmys insculpa*) populations were monitored from 1974 - 1993. Recreation access to hikers was previously denied, but during the second half of the study it was allowed on a permit-basis. Population data was analyzed to determine if recreation affected wood turtle abundance.
- The wood turtle populations declined rapidly during the time when recreation was allowed in the forests. The authors examined increased predation, global pollution, and weather-related anomalies as possible causes of the decline but determined none but human disturbance were primary causes.
- Recommendation: authors determined 20 permits (allowing each permit holder to bring guests) per 1000 hect per year creates more human traffic than a wood turtle population can survive. The authors suggest limiting the number of people in an area to few or none in order to limit detrimental effects, particularly to long-lived species with delayed maturity.

Grooms, B. P., & Urbanek, R. E. (2018). Exploring the effects of non-consumptive recreation, trail use, and environmental factors on state park avian biodiversity. Journal of Environmental Management, 227, 55–61. https://doi.org/10.1016/j.jenvman.2018.08.080

- Authors examine bird species diversity and richness in four state parks in Arkansas. They conduct point counts and investigate trail use numbers, trail design, weather patterns, and surrounding vegetation.
- Several findings and associated recommendations came from this study. Low richness and diversity of species were found occurring with high rates of trail use, leading the authors to suggest limiting the rate of trail use.
- Environmental factors, including increased abundance and height variation of trailside woody vegetation, along with habitat heterogeneity lead to higher richness and diversity in avian communities. Restricting mowing or vegetation clearing alongside trails is suggested.

- Recommendation: designing trails to reduce or eliminate recreationists from straying from the trails also have a positive impact on avian communities. Intentionally wide and deep trails, as opposed to wide, deep trails as a result of unsustainably built trails, are considered a better design by the authors.

Grubb, T. G., & King, R. M. (1991). Assessing Human Disturbance of Breeding Bald Eagles with Classification Tree Models. The Journal of Wildlife Management, 55(3), 500–511. JSTOR. https://doi.org/10.2307/3808982

- Bald eagles (*Haliaeetus leucocephalus*) were observed at 13 sites in central Arizona during the breeding season to determine disturbance affect across distance and disturbance (recreation) type. A classification tree model was used to evaluate response severity and form disturbance-specific management criteria.
- Pedestrians caused the highest rate of disturbance response to bald eagles of all activities.
- Distance was found to be the most important recreation variable determining disturbance, with duration second.
- Recommendation: authors determined 630m as the initiation distance for response to recreationist, as 75% of responsive behaviors occurred within that distance. They suggest a minimum primary protection zone of 600m from breeding bald eagles, within which no human activity is permitted at any time. They suggest secondary protection zone of 1,200m, within which limited, non-permanent activity may be allowed during the non-breeding season.

Gutzwiller, K. J., & Anderson, S. H. (1997). Does Human Intrusion Alter the Seasonal Timing of Avian Song during Breeding Periods? The Auk, 114(1), 55–65. https://doi.org/10.2307/4089065

- Human intrusion during the breeding season was experimentally applied to determine if it influenced seasonal timing of primary song for Ruby-crowned Kinglet (*Reulus calendula*), Yellow-rumped Warbler (*Dendroica coronata*), and Dark-eyed Junco (*Junco hyemalis*), thus potentially altering breeding success. The intrusion treatment consisted of one person walking in a study area for 1-5 hrs per week.
- Most differences in singing times were not statistically significant. However, mean singing date was 11 days earlier for control sites than for intruded sites for the Ruby-crowned Kinglet, which the authors state is "considerable".
- The authors consider their results "conservative" and support the conclusion that human intrusion did not, as a generalization, induce moderate or large changes in the seasonal timing of primary song, but may have induced small changes that their analysis did not detect.

Gutzwiller, K. J., & Anderson, S. H. (1999). Spatial Extent of Human-Intrusion Effects on Subalpine Bird Distributions. The Condor, 101(2), 378–389. https://doi.org/10.2307/1370001

- Human intrusion during the breeding season was experimentally applied to determine if it influenced distributions of nine different song birds, including American Robin (*Turdus migratorius*), Hermit Thrush (*Catharus guttatus*), Ruby-crowned Kinglet (*Reulus calendula*), Yellow-rumped Warbler (*Dendroica coronata*), and Dark-eyed Junco (*Junco*

hyemalis). The intrusion treatment consisted of one person walking in a study area for 1-5 hrs per week.

- Intrusions did not displace birds during most years, however mean abundances of American Robin were 57% lower and Hermit Thrush were 48% lower in intruded sites than in control sites.
- Authors conclude that human intrusion affects birds on a species- and context-specific level and suggest land managers should limit human intrusion in places and at times that offer the most (or specific) avian resources.

Gutzwiller, K. J., Marcum, H. A., Harvey, H. B., Roth, J. D., & Anderson, S. H. (1998). Bird Tolerance to Human Intrusion in Wyoming Montane Forests. The Condor, 100(3), 519–527. https://doi.org/10.2307/1369718

- Human intrusion during the breeding season was experimentally applied to examine detectability period (the time a bird remains near its initial flush point), and approach distance (how close an individual can get before a bird flushes). The intrusion treatment consisted of one person walking in a study area for 1-5 hrs per week.
- There was a positive relationship found between detectability period and number of conspecifics, indicating birds are less tolerant of intrusion when they are solitary or in smaller groups.
- The authors also found that brighter and more conspicuous birds responded to human intrusion from longer distances and flushed sooner.
- Authors emphasize the potential difference between species and even individuals in response to human intrusion and suggest more research on the factors that influence tolerance of human intrusion.

Gutzwiller, K. J., Wiedenmann, R. T., Clements, K. L., & Anderson, S. H. (1994). Effects of Human Intrusion on Song Occurrence and Singing Consistency in Subalpine Birds. The Auk, 111(1), 28–37. JSTOR. https://doi.org/10.2307/4088502

- This study examined whether human intrusion influenced occurrence and consistency of primary song in breeding subalpine birds during a 10-week period on 30 1.0-ha sites. Intrusion consisted of one person walking through a site for 1-2 hours.
- Song occurrence and singing consistency were higher on control sites than intruded sites, and the disturbance influence was present on intruded sites for several days when singing activity was recorded. However, within species responses varied.
- The authors suggest more research.

Hagen, K. (1999). The Effects of Ski Area Development on Populations of Stream Salamanders in Central Vermont. Antioch University.

- Populations of three species of aquatic salamanders from seven Vermont ski area streams were compared with populations from seven control streams located in areas with little human activity.
- Northern dusky (Desmognathus fuscus fuscus) and Spring salamander (Gyrinophilus porphyriticus) populations were significantly lower in ski areas streams. Northern dusky salamander in control streams also had significantly longer mean body length.

- Two-lined salamanders (Eurycea bislineata) did not differ significantly between the two stream types.
- The author concludes that downhill skiing and its associated development may negatively impact populations of Vermont stream salamanders.

Harris, G., Nielson, R. M., Rinaldi, T., & Lohuis, T. (2014). Effects of winter recreation on northern ungulates with focus on moose (Alces alces) and snowmobiles. European Journal of Wildlife Research, 60(1), 45–58. https://doi.org/10.1007/s10344-013-0749-0

- Two-part study involving 1) a literature review of winter recreation effects on northern ungulates, and 2) quantifying behavioral responses of moose (*Alces alces)* to snowmobiles to add to gaps in the review.
- The literature review concluded that various forms of winter recreation elicit diverse and inconsistent behavioral responses from ungulates. However, the study provided 6 strong guidelines for when recreation affects ungulates.
- Winter recreation is most detrimental to ungulates when: 1) unpredictable, 2) spanning large areas, 3) long in duration, 4) large spatial footprint, 5) nonmotorized, and 6) when animals are displaced to poor quality habitats.

Hill, J. (2019). Continued Exploration of the Relationship between Downhill Ski Area Edges and Bicknell's Thrush in the Northeastern U.S. Using Mountain Birdwatch Data (2016-2019). Vermont Center for Ecostudies.

- Data was used from 4 years of citizen science point counts to analyze patterns of abundance in Bicknell's Thrush (*Catharus bicknelli*) as they relate to alpine ski trail disturbances.
- Adult and nesting densities are greatest adjacent to disturbances, both anthropogenic (such as ski trails) and natural. However, fitness benefits have not been found for Bicknell's Thrush breeding near disturbances.
- Bicknell's Thrush are likely displaced by initial creation of ski runs and other activities that fragment forests, because local patch size is positively related to occupancy probability in this species. The authors suggest more research to determine if ski area development displaces individuals of the species or if they resettle locally in the landscape.

Kays, R., Parsons, A. W., Baker, M. C., Kalies, E. L., Forrester, T., Costello, R., Rota, C. T., Millspaugh, J. J., & McShea, W. J. (2017). Does hunting or hiking affect wildlife communities in protected areas? Journal of Applied Ecology, 54(1). https://doi.org/10.1111/1365-2664.12700

- This was a broad-scale observational survey of wildlife communities in 32 protected areas across 6 states in the eastern US, comparing areas with hunting to areas with recreation trails (primarily used for hiking and biking). Data was collected at 1,972 locations by camera trap.
- Recreation level was compared using camera distance from trail (0 - 250m) and number of people recorded at each site. Comparing these factors, the occupancy models showed that recreation had a relatively minor effect on the distribution and habitat preferences of wildlife. The most important habitat factor was presence of large, intact

forest. The minor effect of trail-based recreation may be a result of all sites allowing trail-based recreation and not including a comparison of area with no recreation.
- The authors considered the trail networks of this region to be "relatively sparse", and the study was able to demonstrate that recreation trails were not widely avoided by most species of wildlife.

Krusic, R. A., Yamasaki, M., Neefus, C. D., & Pekins, P. J. (1996). Bat Habitat Use in White Mountain National Forest. The Journal of Wildlife Management, 60(3), 625–631. JSTOR. https://doi.org/10.2307/3802081
- Bat flight and feeding activity was surveyed using live capture and ultrasonic detection in relation to forest stand type and age and was compared across different habitat features such as trails and water bodies.
- Bats were recorded in both flight and feeding activity along trails, however they were used disproportionately as travel corridors.
- Recommendation: No negative effect was associated with trail presence. Because of bat use of trails, dead and dying trees proximal to trails should not be removed for trail maintenance as they may be used for roosts.

Kucera, E. (1976). Deer flushing distance as related to observer's mode of travel. Wildl. Soc. Bull., 4, 128–129.
- This study examines flushing behavior of white-tailed deer (*Odocoileus virginianus)* in response to walking, horseback riding, and vehicle driving at distances from <25m to >100m.
- About 75% of all deer allowed a vehicle or rider to approach to 100m, but only 50% allowed a walking person to approach to 100m. However, response of deer varied greatly at all distances.
- The author concludes that approaching deer in a vehicle or on horseback is less disturbing than walking. No management recommendation is offered as the study is aimed at best practice for conducting wildlife observation.

Lesmerises, F., Johnson, C. J., & St-Laurent, M.-H. (2017). Refuge or predation risk? Alternate ways to perceive hiker disturbance based on maternal state of female caribou. Ecology and Evolution, 7(3), 845–854. https://doi.org/10.1002/ece3.2672
- The authors measured the behavioral responses of female caribou (*Rangifer tarandus*) proximal to hiking trails in Gaspesie National Park, Quebec to test if caribou responded negatively to human activity or if human activity decreased their magnitude of perceived risk (thus serving as a refuge). They specifically observed lactating females as individuals that may be more tolerant of risk to increase foraging time.
- The presence of humans on hiking trails triggered a response from all observed caribou.
- Lactating females with a calf and lone females avoided trails during the daytime that had many hikers. However, females without a calf spent more of their time near trails in vigilance, while lactating females were more prone to trade vigilance for foraging behavior.

- Incidental finding: Based on camera trapping data, coyotes and black bears used trails for travel quite often, however no coyote and very few black bear used a trail within an hour after a passing hiker.

Mathisen, J. E. (1968). Effects of Human Disturbance on Nesting of Bald Eagles. The Journal of Wildlife Management, 32(1), 1–6. https://doi.org/10.2307/3798229

- The author observed nesting success of 115 bald eagles in a recreational area in northern Minnesota. The nests were each categorized into one of three different "wildnerness factors" indicating level of exposure to human activities.
- There was no statistically significant difference in nesting success between "low" and "high" wilderness factor nests.
- The recreation in this largely begins in mid-June, after the eaglets hatch are somewhat grown. If the recreation activity occurred during the more vulnerable stages of egg laying or incubation the results may show that human activity has an effect on nest success. The author voices concern over large nesting birds as human recreation grows and recommends more research.

Miller, A. (2020). Wildlife response to recreational trail building: An experimental method and Appalacian case study. Journal for Nature Conservation, 56, 125815.

- Animals were monitored by trail camera before, during, and after new trail construction in a state park in North Carolina primarily covered by oak forest.
- The most recorded species were analyzed for change in activity. A control zone was used to control for seasonal effects on wildlife activity.
- White-tailed deer (*Odocoileus virginianus*) and eastern gray squirrel (*Sciurus carolinensis*) showed altered timing of daily activity patterns after completion of trail construction, and squirrels showed decreased use of the trail area after the completion. White-tailed deer, coyotes (*Canis latrans*), and racoons (*Procyon lotor*) changed their activity near the trail area during construction, but their activity returned to pre-construction patterns soon after completion.
- Recommendation: trail building and trail use alters habitat quality for some species, and suggest trail building be restricted to a short time period during a season when species of concern are least sensitive, such as avoiding breeding season.

Moen, A. (1982). Effects of disturbance by snowmobiles on heart rate of captive White-tailed deer. N. Y. Fish and Game J, 29, 176–183.

- A six-month old male deer (*Odocoileus virginianus*) (one of about 15 captive deer) in an observation yard was equipped with cardiac monitors and observed while a snowmobile passed at 40m, 20m, and 2m from the deer pen.
- The deer's heart rate increased each time a snowmobile run was taken, even when it displayed no behavioral changes.
- Heart rates increased an average of 2.5 times pre-stimulus rates from snowmobile activity within 40m (no difference 2m - 40m), for an average of 2 minutes, without signs of habituation.

Moen, A. N. (1976). Energy Conservation by White-Tailed Deer in the Winter. Ecology, 57(1), 192–198. JSTOR. https://doi.org/10.2307/1936411

- This study of white-tailed deer (*Odocoileus virginianus*) relates deer activity to changes in winter weather conditions to determine if deer are more likely to increase or decrease their energy expenditure as a winter survival strategy.
- The authors found that as temperatures decrease and snow depths increase (specifically from January - March), the most beneficial way for deer to conserve energy is to decrease activity through slower walking, staying on level terrain, and avoiding deep snow.
- Unnecessary energy loss and deer fatality may be prevented by disturbing deer as little as possible, specifically limiting disturbance by dogs and snowmobiles. The authors observed little to no disturbance from walking through the area on snowshoes.

Neumann, W., Ericsson, G., & Dettki, H. (2010). Does off-trail backcountry skiing disturb moose? European Journal of Wildlife Research, 56(4), 513–518. https://doi.org/10.1007/s10344-009-0340-x

- Nine free-ranging female moose (*Alces alces)* were repeatedly exposed to skiing in Northern Sweden.
- Moose were systematically disturbed by 1-2 cross country skiers directly approaching and until moose were displaced. Moose were then tracked and observed for an additional 30 minutes. This was repeated a total of three times over 7 days.
- Moose moved about 33 times faster than they did at the same time on days not disturbed. They showed increased movement rates up to 3 hours following disturbance, leading to increased energy expenditures and eventually a negative effect on population growth.

Oâ, M., & Campbell, N. (2011). Passerine reactions to human behaviour and vegetation structure in Peterborough, Canada. 5.

- The authors studied alert and flight distance of 12 bird species in urban parks in Ontario, Canada.
- Bird size and human behavior were significant indicators of alert distance, with larger birds and walkers with swinging arms (vs no swinging arms) having longer alert distances.
- Alert distance averages ranged from ~28m (Crow) to ~15m (House Sparrow and Black Capped Chickadee), and flight distance averages ranged from ~24m (Crow) to ~13m (House Sparrow and Eastern Phoebe).
- Alert and flight distance with varying human behavior ranged from 24m and 22m (respectively) with 90-degree arm swings, to 13m and 11m with sideways approach and no arm swing.
- Recommendation: study suggests building specific areas for people to congregate in and concentrated trail areas to avoid widespread disturbance.

Parsons, A. W., Bland, C., Forrester, T., Baker-Whatton, M. C., Schuttler, S. G., McShea, W. J., Costello, R., & Kays, R. (2016). The ecological impact of humans and dogs on wildlife in protected areas in eastern North America. Biological Conservation, 203, 75–88. https://doi.org/10.1016/j.biocon.2016.09.001

- Game cameras (1,951) were set up across 33 protected areas in the southeastern United States and collected by citizen scientists. Prey species of white-tailed deer *(Odocoileus virginianus*), eastern grey squirrel *(Sciurus* carolinensis), and northern raccoon (*Procyon lotor*) were observed for behavioral responses to humans, dogs, and coyotes.
- All species showed temporal avoidance of humans, both with and without dogs, though this avoidance was greatest for people accompanied by a dog.
- Results indicate that humans are perceived as a greater risk than coyotes, which increases when dogs accompany their owners.

Polich, R. (2016). Flight initiation distance in a freshwater turtle, Chrysemys picta. Chelonian Conservation and Biology, 15(2), 214–218.

- Authors test the difference in flight initiation distance (*Chrysemys picta)* (FID) in painted turtles at two locations along the Mississippi River in Illinois. One location (referred to as "urban") is a popular camping, fishing, and hiking area while the other has been off-limits to the public for almost 100 years (referred to as "rural").
- Authors supported their hypothesis that FID would be higher where there is less human disturbance. Average FID of turtles at the rural site (~60m) was significantly greater than at the urban site (~41 m).
- Another finding at both sites indicated that FID was greater in the morning when temperatures were cooler, presumably because turtles are more able to move quickly once their bodies have warmed and thus tolerate a shorter FID.
- Authors warn that consistent flushing from basking could decrease fitness and survival of turtles and other ectothermic vertebrates. They suggest more research.

Richens, V. (1978). Response of White-Tailed Deer to Snowmobiles and Snowmobile Trails in Maine. Canadian Field-Naturalist, 94(4), 334–344.

- Behavioral responses of white-tailed deer (*Odocoileus virginianus)* to snowmobiles were studied from 1972-1975 in remote central Maine.
- Deer response to a snowmobile and a walker was categorized as flight or no flight. A significantly greater number of deer responded with flight to a walker than to a snowmobile in all snow, weather, habitat, and temporal conditions recorded.
- Number of deer displaying no flight increased progressively throughout the winter each sampling year, possibly due to decreased energy or habituation.
- Authors considered that the packed trail of a snowmobile could be advantageous for deer and suggest more studies to determine if snowmobile trails connecting deer winter areas and forage areas could be beneficial.

Rimmer, C. C., McFarland, K. P., Lambert, J. D., & Renfrew, R. B. (2004). Evaluating the Use of Vermont Ski Areas by Bicknell's Thrush: Applications for Whiteface Mountain, New York. 51.

- Data was analyzed from a long-term population study of Bicknell's Thrush (*Catharus bicknelli*) on Mt. Mansfield and Stratton Mountain in Vermont to determine ski area use by the species. This data was used to project possible impacts of a proposed ski development project in northern New York.
- Findings from radio telemetry of adult thrushes showed that ski trails wider than 35-40m appear to restrict thrush movements, and that small or narrow habitat patches were rarely used. Overall, few significant differences existed for population and reproduction parameters of the Bicknell's Thrush between developed ski areas and natural forests.
- Authors include a detailed series of recommendations to minimize trail building project impacts, post-construction habitat maintenance, and project mitigation. These include strategies such as trail construction before May 15th, when many thrushes return to breeding habitat, and a broadly-based conservation perspective that extends beyond the site of local impacts.

Rodríguez-Prieto, I., Bennett, V. J., Zollner, P. A., Mycroft, M., List, M., & Fernández-Juricic, E. (2014). Simulating the responses of forest bird species to multi-use recreational trails. Landscape and Urban Planning, 127, 164–172.
https://doi.org/10.1016/j.landurbplan.2014.03.008

- Study examines the effect of trail design across different species using simulation modeling in central Indiana.
- Ovenbirds (*Seiurus aurocapilla)* were disturbed significantly more often than any other of the 8 species of bird. Authors found a consistent pattern of less disturbance when trail use was "low", and considerably higher rates of disturbance when trail use was "high".
- Authors found that the longer the trail and the more habitat types the trail intersects, the more frequently the bird community is disturbed by recreationists.
- Authors conclude that trail design best suited for one species is not necessarily appropriate for another, and caution that land management should not be based on a single species of concern because it could have far-reaching negative ecological implications.

Silverberg, J. K., Pekins, P. J., & Robertson, R. A. (2003). Moose Responses to Wildlife Viewing and Traffic Stimuli. Alces Vol., 39, 8.

- Moose behavior at a salt lick was observed in response to human presence and traffic stimuli. The salt lick was proximal to a road and a viewing blind.
- There was minimal change in behavior to quiet viewers in the blind, although response behavior (stopping feeding, fleeing) increased when viewers were loud or very active. Moose responses to trucks passing and cars stopping were measurable and pronounced, as moose fled at >3 times the rate of response to a quiet viewer in a blind.

Smith-Castro, J. R., & Rodewald, A. D. (2010a). Effects of Recreational Trails on Northern Cardinals (Cardinalis cardinalis) in Forested Urban Parks. Natural Areas Journal, 30(3), 328–337. JSTOR.

- This study examines Northern Cardinals (*Cardinalis cardinalis*) in Ohio riparian forest parks to see if trails have a negative effect on avian reproduction by either reducing nest attendance due to direct human disturbance (nests within 100m of a trail) or modifying vegetation characteristics around nests. Each of the 125 nests was observed for 1 hour to determine the ratio of time spent incubating versus away from the nest.
- Nest attendance rate was not significantly related to distance to trail, nest height, or trail use. Trail use was estimated to be 1.02 "events" per hour. The authors found little evidence that recreational trails negatively affected Northern Cardinals.
- Authors note that their 1-hour observation period during egg incubation may have been insufficient to detect attendance patterns, since trail use was approximately 1 event per hour, and suggest more research.

Smith-Castro, J. R., & Rodewald, A. D. (2010b). Behavioral responses of nesting birds to human disturbance along recreational trails: Nesting Birds and Human Disturbance. Journal of Field Ornithology, 81(2), 130–138. https://doi.org/10.1111/j.1557-9263.2010.00270.x

- Flight initiation distance of Northern Cardinals *(Cardinalis* cardinalis) at their nests was recorded in 18 riparian forests in Ohio to compare direct approach and walking on adjacent trails.
- Cardinals were 6 times more likely to flush when nests were approached directly, and females on higher nests were less likely to flush.
- No association between nest survival and tendency of bird flushing was found, and the nest height had the best correlation to nest survival.

Stalmaster, M. V., & Kaiser, J. L. (1998). Effects of Recreational Activity on Wintering Bald Eagles. Wildlife Monographs, 137, 3–46. JSTOR.

- This observational study examined eagles in their wintering habitat along the Skagit River in Washington in a predominantly fir forest with alder and cottonwood along the river.
- Feeding activity declined exponentially and the number of eagles in the study area was negatively correlated with daily number of recreation events.
- Foot traffic was most disturbing to eagles (more than fishing boats and wildlife viewing boats). Eagles required nearly 4 hours to resume feeding after disturbance by foot, compared to 36 minutes after boat traffic
- Eagles resumed feeding relatively soon after initial disturbances of the day, but after 20 events they were slower to resume feeding and after 40 events feeding was uncommon.
- Recommendation: prohibit recreational activity for the first 5 hours of daylight within 400m of eagles.

Strong, A. M. (2002). Ski trail effects on a beetle (Coleoptera: Carabidae, Elateridae) community in Vermont. Journal of Insect Conservation, 6(3), 149–159. https://doi.org/10.1023/A:1023223532149

- Beetle diversity and species composition were examined on in the Stowe alpine ski area in Mt. Mansfield State Forest in Vermont. Beetles were collected from the maintained ski trails, at the forest edge, and 5m into the forest.
- There was a nearly complete species turnover from the ski trail to the forest, although species diversity and richness remained at similar levels in each of the three locations. Absence of forest species in the ski trail suggests that these trails act as barriers to dispersal for many ground beetles.
- The concern is for beetle species in the "islands" of forest between ski trails within the boundaries of the ski area. These beetles are at higher risk for extirpation due to stochastic or climatic events, and their inability to gap-cross the ski trails.
- The root cause of species differences here is not the recreational activity itself, because alpine skiing is done when the vegetation is covered with snow and the insects are not active, but rather it is due to the landscape manipulation that allows for the activity (including mowing).

Thompson, B. (2015). Recreational Trails Reduce the Density of Ground-Dwelling Birds in Protected Areas. Environmental Management, 55(5), 1181–1190. https://doi.org/10.1007/s00267-015-0458-4

- This study looks at the impacts of recreation trails on forest birds in Ontario, Canada using point count surveys to assess the density of the birds in 24 mapped patches of protected areas.
- The area of trail-free habitat had a significant influence on the density of forest birds, particularly ground-foraging and -nesting species.
- Recommendation: trail density and forest community type had no significant influence on density or functional guild richness. Limiting the density of trails is not as important as managing the extent to which they fragment habitat.

Tomeo, M. A. (2000). Fecal measurement of stress responses to snowmobiles in moose (Alces alces). 48.

- The physiological impact of snowmobiles on moose (*Alces alces*) was measured by comparing glucocorticoid levels in moose fecal samples collected in wilderness areas with and without snowmobiling, and in urban areas.
- Urban moose had the highest glucocorticoid levels, followed by moose in an area with high snowmobile use. Additional research questions addressed the effect of audibility and visibility of human presence on glucocorticoid levels and found that in the areas with low human audibility and visibility, noise from and view of humans did correlate with a higher glucocorticoid level.
- Recommendation: the presence of snowmobile activity may be sufficiently stressful enough to amplify challenges to survival posed by the natural winter environment, and suggests managers regulate snowmobile use in areas of winter wildlife habitat and restrict it accordingly.

Walters, B. J. (2010). The influence of recreational trails on breeding birds in two large southern Ontario forests. Library and Archives Canada = Bibliothèque et Archives Canada.

- Forest breeding songbird communities were observed with point count surveys and nest monitoring to determine if trail presence and width affected bird abundance and breeding in two southern Ontario forests. Trail sizes were grouped in single track (20-70cm), double track (120-210cm), and "wide" or forest roads (22-1000cm).
- Relative abundance of three forest-interior species and two interior-edge species were negatively related to trail width, while they were positively related for four edge species.
- Red-eyed Vireo (*Vireo olivaceus*) nests were more likely to be parasitized closer to wide trails. Rose-breasted Grosbeak (*Pheucticus ludovicianus*) nest success was lowest close to forest roads and wide trails, with increasing success with increasing distance from them.
- Recommendation: interior bird abundance is affected to at least 50m on either side of forest roads, and to a lesser extent double-track trails. The author concludes that this amounts to 10ha of unsuitable forest habitat for every 1km of track.

White, P. J. T., McGill, B. J., & Lechowicz, M. J. (2011). Human-disturbance and caterpillars in managed forest fragments. Biodiversity and Conservation, 20(8), 1745–1762. https://doi.org/10.1007/s10531-011-0059-3

- Authors hypothesize that trailside habitat may have a similar effect on caterpillars as edge habitat, which has shown to positively affect caterpillar growth and survival.
- They created a trail index to quantify trail impact at each study site and collected caterpillars at 18 quadrants in each of 4 deciduous forests in urban and rural southern Quebec.
- Across all quadrants at all sites, trail index was a significant negative predictor of caterpillar diversity and abundance, and host plant availability was a near-significant positive predictor for caterpillar diversity and abundance. This result does not support their hypothesis.
- Recommendation: limit the proliferation of recreation trails because limiting intra-forest disturbance is very important for forest communities.

Zielinski, W. J., Slauson, K. M., & Bowles, A. E. (2008). Effects of Off-Highway Vehicle Use on the American Marten. The Journal of Wildlife Management, 72(7), 1558–1571. https://doi.org/10.2193/2007-397

- Effects of off-highway vehicles in Lake Tahoe and High Sierra regions in California were evaluated by comparing American marten (*Martes americana*) occupancy rates and circadian activity in areas with OHV use and wilderness areas without it.
- Occupancy and circadian activity did not differ significantly between use and non-use areas. The authors conclude that the level of OHV use at the study locations did not produce substantial effects on marten population.
- The authors state that the lack of effects may be due to OHV use not being perceived as a threat to martens, or habituation to OHV presence. Additionally, most OHV use occurred at a time when martens were sheltered or inactive. They suggest more research.

SOURCES ORGANIZED BY TOPIC

TAXA

Mammals	Birds	Herpetofauna	Invertebrates
Bennett et al., 2009	Barton & Holmes, 2007	Davis, 2007	Banschbach et al., 2012
Colescott & Gillingham, 1998	Bennett et al., 2009	Garber & Burger, 1995	Bennett et al., 2013
Dorrance et al., 1975	Deluca & King, 2014	Hagen, 1999	Strong, 2002
Engelhardt & Weladji, 2011	Ellison & Cleary, 1978	Polich, 2016	White et al., 2011
Erb et al., 2012	Fernández-Juricic et al., 2007		
Ferguson & Keith, 1982	Fraser et al., 1985		
Harris et al., 2017	Grooms & Urbanek, 2018		
Kays et al., 2017	Grubb & King, 1991		
Kucera, 1976	Gutzwiller & Anderson, 1997; 1999		
Krusic et al., 1996	Gutzwiller et al., 1994; 1998		
Lesmerises et al., 2017	Hill, 2019		
Miller, 2020	Kays, et al., 2017		
Moen, 1976; 1982	Mathisen, 1968		
Neumann et al., 2010	Oâ & Campbell, 2011		
Parsons et al. 2016	Rimmer et al., 2001		
Richens, 1978	Rodríguez-Prieto et al., 2014		
Silverberg et al., 2003	Smith-Castro & Rodewald, 2010; 2010		
Tomeo, 2000	Stalmaster & Kaiser, 1998		
Zielinski, et al., 2008	Thompson, 2015		
	Walters, 2010		

ACTIVITY

Foot Travel	Biking	Off-Highway Vehicle (ATV, Snowmobile)	Skiing	Not Specified
Bennett et al., 2009; 2013 Davis, 2007 Deluca & King, 2014 Engelhardt & Weladji, 2011 Erb et al., 2012 Fernández-Juricic et al., 2007 Fraser et al., 1985 Garber & Burger, 1995 Grooms & Urbanek, 2018 Grubb & King, 1991 Gutzwiller & Anderson, 1997; 1999 Gutzwiller et al., 1994; 1998 Kays et al., 2017 Kucera, 1976 Lesmerises et al., 2017 Miller, 2020 Oâ & Campbell, 2011 Parsons et al., 2016 Polich, 2016 Rodríguez-Prieto et al., 2014 Silverberg et al., 2003 Smith-Castro & Rodewald, 2010 Stalmaster & Kaiser, 1998 Walters, 2010	Bennett, 2009 Kays et al., 2017 Walters, 2010	Barton & Holmes, 2007 Colescott & Gillingham, 1998 Dorrance et al., 1975 Eckstein et al., 1979 Harris et al., 2014 Moen, 1976; 1982 Richens, 1978 Tomeo, 2000 Walters, 2008 Zielinski et al., 2008	Ferguson & Keith, 1982 Hagen, 1999 Harris, et al., 2014 Hill, 2019 Neumann et al., 2010 Rimmer et al., 2004 Strong, 2002	Banschbach et al., 2012 Ellison & Cleary, 1978 Krusic et al., 1996 Mathisen, 1968 Miller, 2020 Smith Castro & Rodewald, 2010 Thompson, 2015 White et al., 2011

PRIMARY VARIABLE

Consolidation of Trails	Zone of Influence	Breeding	Trail Use Volume	Recreation Type	Taxon Group
Bennett, et al., 2009; 2013 Colescott & Gillingham, 1998 Erb, et al., 2012 Ferguson & Keith, 1982 Grooms & Urbanek, 2018 Harris, et al., 2014 Kays, et al., 2017 Miller, 2020 Oa & Campbell, 2011 Polich, 2016 Rimmer, et al., 2004 Rodriguez-Prieto, et al., 2014 Strong, 2002 Thompson, 2015 Walters, 2010 White, et al., 2011	Barton & Holmes, 2007 Bennet, et al., 2009; 2013 Colescott & Gillingham, 1998 Eckstein, et al., 1979 Enhelhardt & Weladji, 2011 Erb, et al., 2012 Fernandez-Juricic, et al., 2007 Fraser, et al., 1985 Grooms & Urbanek, 2018 Grubb & King, 1991 Gutzwiller & Anderson, 1999 Gutzwiller, et al., 1998 Kucera, 1976 Lesmerises, et al., 2017 Mathisen, 1968 Miller, 2020 Moen, 1982 Neumann, et al., 2010	Barton & Holmes, 2007 Bennett et al., 2009; 2013 Deluca & King, 2014 Ellison & Cleary, 1978 Fernández-Juricic et al., 2007 Fraser et al., 1985 Grubb & King, 1991 Gutzwiller et al., 1994; 1998 Gutzwiller & Anderson, 1997; 1999 Lesmerises et al., 2017 Mathisen, 1968 Smith-Castro & Rodewald, 2010 Walters, 2010	Bennett et al., 2009 Colescott & Gillingham, 1998 Engelhardt & Weladji, 2011 Erb et al., 2012 Ferguson’ & Keith, 1982 Garber & Burger, 1995 Harris et al., 2014 Lesmerises et al., 2017 Miller, 2020 Moen, 1982 Neumann et al., 2010 Rodríguez-Prieto et al., 2014 Stalmaster & Kaiser, 1998 Zielinski et al., 2008	Eckstein, 1979 Grubb & King, 1991 Harris, et al., 2014 Richens, 1978 Walters, 2010	Barton & Holmes, 2007 Deluca & King, 2014 Erb et al., 2012 Gutzwiller et al., 1994; 1998 Gutzwiller & Anderson, 1997; 1999 Kays et al., 2017 Miller, 2020 Oâ & Campbell, 2011 Parsons et al., 2016 Rodríguez-Prieto et al., 2014 Thompson, 2015 Walters, 2010

Zielinski, et al., 2008	Oa & Campbell, 2011 Polich, 2016 Smith-Castro & Rodewald, 2010 Stalmaster & Kaiser, 1998 Strong, 2002 Zielinski, et al., 2008				

APPENDIX 4

RELATED RECREATION ECOLOGY REFERENCES

Prepared by Meredith Naughton, UVM Field Naturalist Program

The following 332 studies examine the impact of outdoor recreation but did not meet literature review criteria. These are not exhaustive lists for their topic or geographic region, but rather were collected during the exhaustive review of northeastern North American recreation ecology and categorized as relevant for future reference. References are listed alphabetically by author, and categorized into the following lists:

Topic

- My Top 10
- Previous Literature Reviews
- Background Science: Impact to Vegetation & Disturbance Ecology
- Dogs and Recreation Impact
- Aquatic and Recreation Impact

Geographic Location

- North America
- Temperate Zone Outside of North America
- Outside of Temperate Zone

My Top 10 serves as a starting place for recreation ecology literature and lists ten references I found particularly informative during this research. Lists generally do not overlap. For example, a reference on the *Background Science* list is a research article about a disturbance ecology experiment conducted in Arizona but it is not also listed on the *North America* list.

MY TOP 10

Author	Year	Title
Bötsch, Y., et al.	2018	Effect of recreational trails on forest birds: Human presence matters
Coppes, J., et al.	2018	Habitat suitability modulates the response of wildlife to human recreation
Ford, A. T., et al.	2020	Effective corridor width: linking the spatial ecology of wildlife with land use policy
Hammitt, W. E., et al.	2015	Wildland Recreation: ecology and management
Larson, C., et al.	2016	Effects of recreation on animals revealed as widespread through a global systematic review
Miller, A., et al.	2020	Sustaining wildlife with recreation on public lands: a synthesis of research findings, management practices, and research needs
Monz, C. A., et al.	2010	Sustaining visitor use in protected areas: Future opportunities in recreation ecology research based on the USA experience
Patten, M. A. & Burger, J. C.	2018	Reserves as double-edged sword: Avoidance behavior in an urban-adjacent wildland
Reed, S. E. & Merenlender, A.	2008	Quiet, Nonconsumptive Recreation Reduces Protected Area Effectiveness
Tablado, Z. & Jenni, L.	2017	Determinants of uncertainty in wildlife responses to human disturbance

OTHER REVIEWS: EFFECT OF RECREATION IMPACT

Author	Year	Title
Baker, M. R., et al.	2013	Review of factors influencing stress hormones in fish and wildlife
Ballantyne, M. & Pickering, C. M.	2015	The impacts of trail infrastructure on vegetation and soils: Current literature and future directions
Beale, C. M.	2007	The Behavioral Ecology of Disturbance Responses
Bateman, P. W. & Fleming, P. A.	2017	Are negative effects of tourist activities on wildlife over-reported? A review of assessment methods and empirical results
Boyle, S. A. & Samson, F. B.	1985	Effects of Nonconsumptive Recreation on Wildlife: A Review
Burgin, S. & Hardiman, N.	2012	Is the evolving sport of mountain biking compatible with fauna conservation in national parks?
Chase, L., et al.	2011	Literature Review for the Vermont Trail Collaborative: Summary of Findings and Annotated Bibliography
Cole, D. N. & Knight, R. L.	1991	Wildlife preservation and recreational use: Conflicting goals of wildland management
Cole, D. N.	1989	Leave No Trace - How recreational activities affect wildlife
Daigle, P.	2010	A summary of the environmental impacts of roads, management responses, and research gaps: A literature review
Ford, A. T., et al.	2020	Effective corridor width: linking the spatial ecology of wildlife with land use policy
Gaines, W. L., et al.	2003	Assessing the cumulative effects of linear recreation routes on wildlife habitats on the Okanogan and Wenatchee National Forests.
Garland, L.	1993	Annotated Bibliography of Wildlife Responses to Selected Human Land Use and Recreational Activities
Hennings, L.	2016	Impacts of dogs on wildlife and water quality: A literature review
Hennings, L.	2017	Hiking, mountain biking and equestrian use in natural areas: A recreation ecology literature review
Huddart, D. & Stott, T.	2019	Outdoor Recreation: Environmental Impacts and Management (Book)

International Mountain Biking Association	2015	A Comparison of Environmental Impacts from Mountain Bicycles, Class 1 Electric Mountain Bicycles, and Motorcycles
Jordan, M.	2000	Ecological impacts of recreation use of trails: a literature review
Knight, R. & Gutzwiller, K.	2013	Wildlife and Recreationists; Coexistence through Management and Research (Book)
Larson, C. L., et al.	2016	Effects of recreation on animals revealed as widespread through a global systematic review
Larson, C. L., et al.	2019	A meta-analysis of recreation effects on vertebrate species richness and abundance
Leung, Y. & Marion, J. L.	2000	Recreation Impacts and Management in Wilderness: A State-of-Knowledge Review
Marion, J. & Wimpey, J.	2007	Environmental Impacts of Mountain Biking: Science Review and Best Practices
Marion, J. L.	2016	A Review and Synthesis of Recreation Ecology Research Supporting Carrying Capacity and Visitor Use Management Decision-making
Marion, J. L.	2019	Impacts to Wildlife: Managing Visitors and Resources to Protect Wildlife
Martínez-Abraín, A., et al.	2010	A systematic review of the effects of recreational activities on nesting birds of prey
Miller, A., et al.	2020	Sustaining wildlife with recreation on public lands: a synthesis of research findings, management practices, and research needs
Monz, C. A.	2013	Recent advances in recreation ecology and the implications of different relationships between recreation use and ecological impacts
Monz, C. A., et al.	2010	Assessment and Monitoring of Recreation Impacts and Resource Conditions on Mountain Summits: Examples From the Northern Forest, USA
Mullet, T. C.	2010	Cumulative ecological effects of snowmobiles
NH Fish and Game Department	2017	Planning Trails for People and Wildlife - Literature Review
Olliff, T.	1999	Effects of Winter Recreation on Wildlife of the Greater Yellowstone Area: A Literature Review and Assessment

Pomerantz, G. A., et al.	1988	Assessing Impact of Recreation on Wildlife: A Classification Scheme
Quinn, M & Chernoff, G.	2010	Mountain Biking: A Review of the Ecological Effects
Sato, C., et al.	2013	The Effects of Winter Recreation on Alpine and Subalpine Fauna: A Systematic Review and Meta-Analysis
Stankey, G. & Lime, D.	1973	Recreational Carrying Capacity: An Annotated Bibliography
Stankowich, T.	2008	Ungulate flight responses to human disturbance: A review and meta-analysis
Steven, R., et al.	2011	A review of the impacts of nature based recreation on birds
Tablado, J. & Jenni, L.	2017	Determinants of uncertainty in wildlife responses to human disturbance
Tempel, D., et al.	2008	Linking wilderness research and management volume 5: Understanding and managing backcountry recreation impacts on terrestrial wildlife: an annotated reading list
U.S. Dept. of the Interior	1985	A Literature Review of The President's Commission on American Outdoors

BACKGROUND SCIENCE: RECREATION IMPACT TO VEGETATION & DISTURBANCE ECOLOGY

Author	Year	Title
Barros, A. & Pickering, M.	2017	How Networks of Informal Trails Cause Landscape Level Damage to Vegetation
Beeman, L. E.	1975	Population Characteristics, Movement, and Activities of the Black Bear (Ursus americaus)
Bélanger, L & Bédard, J.	1990	Energetic Cost of Man-Induced Disturbance to Staging Snow Geese
Bélanger, L & Bédard, J.	1989	Responses of Staging Greater Snow Geese to Human Disturbance
Bennett, V. J., et al.	2013	Modeling the indirect effects of road networks on the foraging activities of bats
Blumstein, D. T.	2016	Habituation and sensitization: new thoughts about old ideas
Blumstein, D. T., et al	2003	Testing a key assumption of wildlife buffer zones: is flight initiation distance a species-specific trait?
Brown, C. L., et al.	2018	Resource selection and movement of male moose in response to varying levels of off-road vehicle access
Brown, J. H, et al.	1977	Effects of recreational use on forested sites
Clare, J. D., et al.	2015	Predicting bobcat abundance at a landscape scale and evaluating occupancy as a density index in central Wisconsin
Cole, D. N.	1978	Estimating the Susceptibility of Wildland Vegetation to Trailside Alteration
Crooks, K. R.	2002	Relative Sensitivities of Mammalian Carnivores to Habitat Fragmentation
Cyr, N. E. & Romero, L. M.	2009	Identifying hormonal habituation in field studies of stress
Drasher, C. E.	2017	Effects of Roads on Black Bear Distribution in Southern Vermont
Dwyer, T.	1988	Demographic Characteristics of a Maine Woodcock Population and Effects of Habitat Management
Dyer, S.	2001	Avoidance of Industrial Development by Woodland Caribou

Espenshade, J. L., et al.	2018	Public acceptability of development in the Northern Forest of Vermont, USA—The influence of wildlife information, recreation involvement, and demographic characteristics
Fahrig, L.	2003	The effects of habitat fragmentation on biodiversity
Ferguson, P., et al.	2017	Assessing conservation lands for forest birds in an exurban landscape
Ferrarini, A., et al.	2008	Planning low-impact tourist paths within a Site of Community Importance through the optimisation of biological and logistic criteria
Frid, A. & Dill, L.	2002	Human-Caused Disturbance Stimuli as a Form of Predation Risk
Gaynor, K. M., et al.	2018	The influence of human disturbance on wildlife nocturnality
Geffroy, B.	2015	How Nature-Based Tourism Might Increase Prey Vulnerability to Predators
Geffroy, B., et al.	2017	Physiological and Behavioral Consequences of Human Visitation
Gower, S. T.	2008	Are horses responsible for introducing non-native plants along forest trails in the eastern United States?
Grigolato, S., et al.	2018	Assessment of noise level and noise propagation generated by light-lift helicopters in mountain natural environments
Hall, C. N. & Kuss, F. R.	1989	Vegetation alteration along trails in Shenandoah National Park, Virginia
Harshaw, H., et al.	2006	How well are outdoor recreationists represented in forest land-use planning?
Havlick, D. G., et al.	2016	Informal trail creation: hiking, trail running, and mountain bicycling in shortgrass prairie
Hawes, M., et al.	2006	A method for surveying the condition of extensive walking track systems
Hill, W. & Pickering, C. M.	2006	Vegetation associated with different walking track types in the Kosciuszko alpine area, Australia
Honda, T., et al.	2019	Sensitization to human decreases human-wildlife conflict: empirical and simulation study
Huang, X., et al.	2015	Impacts of trails on plants, soil and their interactions in the subalpine meadows of Mount Jade Dragon, Northwestern Yunnan of China

Hughes, J., et al.	2013	A review of the interactions between free-roaming domestic dogs and wildlife
Johnson, C. J. & St-Laurent, M. H.	2011	Unifying Framework for Understanding Impacts of Human Developments on Wildlife
Jokimäki, J., et al.	2011	Merging wildlife community ecology with animal behavioral ecology for a better urban landscape planning
Jones, C., et al.	2016	Understanding the conflicting values associated with motorized recreation in protected areas
Jordan, M.	2000	Ecological impacts of recreational use of trails: a literature review
Kim, M. & Daigle, J. J.	2012	Monitoring of Vegetation Impact Due to Trampling on Cadillac Mountain Summit Using High Spatial Resolution Remote Sensing Data Sets
Kim, M., et al.	2014	Vegetation Cover Change Detection by Satellite Imagery on Cadillac Mountain, Acadia National Park, Maine, USA: Does it Have Potential for Hiking Trail Management?
Knight, J.	2009	Making Wildlife Viewable: Habituation and Attraction
Kostrakiewicz-Gieralt, K.	2020	The Effect of Visitors on the Properties of Vegetation of Calcareous Grasslands in the Context of Width and Distances from Tourist Trails
LaPaix, R., et al.	2012	Patterns of exotic plants in relation to anthropogenic edges within urban forest remnants
Le Corre, N., et al.	2013	Wintering waterbirds and recreationists in natural areas: A sociological approach to the awareness of bird disturbance
Lucas-Borja, M. E., et al.	2011	The effects of human trampling on the microbiological properties of soil and vegetation in mediterranean mountain areas
Manning, R. E., et al.	2010	Recreational Carrying Capacity of Lake Umbagog National Wildlife Refuge
Marchand, M. N. & Litvaitis, J. A.	2004	Effects of Habitat Features and Landscape Composition on the Population Structure of a Common Aquatic Turtle in a Region Undergoing Rapid Development
Marion, J. L. & Leung, Y.	2001	Trail resource impacts and an examination of alternative assessment techniques
Marsh, D. M. & Beckman, N. G.	2004	Effects of Forest roads on the abundance and activity of terrestrial salamanders

Marsh, D. M., et al.	2005	Forest Roads as Partial Barriers to Terrestrial Salamander Movement
Marzano, M. & Dandy, N.	2012	Recreationist behaviour in forests and the disturbance of wildlife
Mason, S., et al.	2015	Recreational trampling negatively impacts vegetation structure of an Australian biodiversity hotspot
Massachusetts Department of Conservation & Recreation	2014	Trail Guidelines and Best Management Practices Manual
Monz, C. A., et al.	2010	Sustaining visitor use in protected areas: Future opportunities in recreation ecology research based on the USA experience
Ngugi, M.R., et al.	2014	Non-native plant species richness adjacent to a horse trail network in seven National Parks in southeast Queensland, Australia
Nickel, B.	2020	Human presence and human footprint have non-equivalent effects on wildlife spatiotemporal habitat use
Patel, A. & Rapport, D. J.	2000	Assessing the Impacts of Deer Browsing, Prescribed Burns, Visitor Use, and Trails on an Oak-Pine Forest: Pinery Provincial Park, Ontario, Canada
Pickering, C. M. & Barros, A.	2015	Using functional traits to assess the resistance of subalpine grassland to trampling by mountain biking and hiking
Pickering, C. M., et al.	2010	Comparing hiking, mountain biking and horse-riding impacts on vegetation and soils in Australia and the United States of America
Pickering, C. M., et al.	2011	Assessing the impacts of mountain biking and hiking on subalpine grassland in Australia using an experimental protocol
Pirotta, E., et al.	2018	Understanding the population consequences of disturbance
Pollack, E. M.	1951	Food Habits of the Bobcat in the New England States
Potito, A. P. & Beatty, S. W.	2005	Impacts of Recreation Trails on Exotic and Ruderal Species Distribution in Grassland Areas Along the Colorado Front Range
Puttker, T.	2020	Indirect effects of habitat loss via habitat fragmentation: A cross-taxa analysis of forest-dependent species
Queiroz, R. E., et al.	2014	Plant diversity in hiking trails crossing Natura 2000 areas in the Azores: implications for tourism and nature conservation

Reed, G. C.	2013	Bobcats in New Hampshire: understanding the relationships between habitat suitability, connectivity, and abundance in a changing landscape
Rew, L. J., et al.	2018	Hitching a ride: Seed accrual rates on different types of vehicles
Robinson, C., et al.	2010	A conceptual framework for understanding, assessing, and mitigating ecological effects of forest roads
Romero, M. L.	2004	Physiological stress in ecology: Lessons from biomedical research
Rosenberg, K.	2004	Effects of recreational development on forest-breeding birds in U.S. National Forests
Rowe, H. I., et al.	2018	Comparison of trailside degradation across a gradient of trail use in the Sonoran Desert
Scarl, J.	2012	Assessing and Reducing Threats to Mountain Birds on the Appalachian Trail through Monitoring, Modeling, and GIS Analysis
Seebacher, F.	2012	Determining environmental causes of biological effects: the need for a mechanistic physiological dimension in conservation biology
Siren, et al.	2017	Potential influence of high-elevation wind farms on carnivore mobility
Stankowich, T. & Blumstein, D. T.	2005	Fear in animals: A meta-analysis and review of risk assessment
Steidl, R. J. & Powell, B. F.	2006	Assessing the Effects of Human Activities on Wildlife
Steven, R., et al.	2011	A review of the impacts of nature based recreation on birds
Stokowski, P. A.	2000	Environmental and Social Effects of ATVs and ORVs:
Strong, A. M., et al.	2001	Effects of mountain resorts on wildlife
Svajda, J., et al.	2016	Trail impact monitoring in Rocky Mountain National Park, USA
Tablado, Z. & Jenni, L.	2017	Determinants of uncertainty in wildlife responses to human disturbance
Tarlow, E. M. & Blumstein, D. T.	2007	Evaluating methods to quantify anthropogenic stressors on wild animals
Taylor, A. & Knight, R.	2003	Behavioral Responses of Wildlife to Human Activity: Terminology and Methods

Thurston, E. & Reader, R. J.	2001	Impacts of Experimentally Applied Mountain Biking and Hiking on Vegetation and Soil of a Deciduous Forest
Tomczyk, A. M.	2011	A GIS assessment and modelling of environmental sensitivity of recreational trails: The case of Gorce National Park, Poland
Tomczyk, A. M. & Ewertowski, M.	2013	Quantifying short-term surface changes on recreational trails: The use of topographic surveys and 'digital elevation models of differences' (DODs)
Tomczyk, A. M. & Ewertowski, M. W.	2016	Recreational trails in the Poprad Landscape Park, Poland: the spatial pattern of trail impacts and use-related, environmental, and managerial factors
Törn, A., et al.	2009	Comparing the impacts of hiking, skiing and horse riding on trail and vegetation in different types of forest
Tyler, N., et al.	2014	Ultraviolet vision and avoidance of power lines in birds and mammals
U.S. Dept. of the Interior	1985	A Literature Review of The President's Commission on American Outdoors
Vangansbeke, P., et al.	2017	Spatially combining wood production and recreation with biodiversity conservation
van der Zande, A.N., et al.	1980	The impact of roads on the densities of four bird species in an open field habitat—evidence of a long-distance effect
Vistnes, I. & Nellemann, C.	2001	Avoidance of Cabins, Roads, and Power Lines by Reindeer during Calving
Wells, F. H., et al.	2012	Recreational Trails as Corridors for Alien Plants in the Rocky Mountains, USA
White, D.	1997	Assessing Risks to Biodiversity from Future Landscape Change
Whittaker, D. & Knight, R. L.	1998	Understanding Wildlife Responses to Humans
Wiberg, K., et al.	1980	The 1992 Vermont Recreation Survey and Environmental Index. Vermonter's Perceptions of Recreation and Environmental Issues in Vermont
Wilkerson, E. & Whitman, A.	2009	Recreation trails in Maine and New Hampshire: a comparison of motorized, non-motorized, and non-mechanized trails
Wimpey, J. & Marion, J. L.	2011	A spatial exploration of informal trail networks within Great Falls Park, VA

Wright, A.	2007	Anthropogenic Noise as a Stressor in Animals: A Multidisciplinary Perspective
Wrigley, K. T.	2015	An Ecological Assessment of Backcountry Ski Trails at Bolton Backcountry in Bolton, VT
Zuckerberg, B. & Pauli, J. N.	2018	Conserving and managing the subnivium: Subnivium Refugium

DOGS, WILDLIFE, & RECREATION

Author	Year	Title
Banks, P. B. & Bryant, J. V	2007	Four-legged friend or foe? Dog walking displaces native birds from natural areas
Forrest, A., et al.	2006	Effects of dog leash laws and habitat type on avian and small mammal communities in urban parks
Henngings, L.	2016	Impacts of dogs on wildlife and water quality: A literature review
Jorgensen, J. G. & Brown, M. B.	2014	Piping plovers Charadrius melodus and dogs: compliance with and attitudes toward a leash law on public beaches at Lake McConaughy, Nebraska, USA.
Kellner, A. S.	2017	Outdoor recreation at the wildland-urban interface: examining human activity patterns and compliance with dog management policies
Langston	2007	What effects do walkers and dogs have on the distribution and productivity of breeding European nightjar
Lenth, B. E., et al.	2008	The Effects of Dogs on Wildlife Communities
Miller, S. G., et al.	2001	Wildlife Responses to Pedestrians and Dogs
Parsons, A., et al.	2016	The ecological impact of humans and dogs on wildlife in protected areas in eastern North America
Reed, S. & Merelender, A.	2011	Effects of Management of Domestic Dogs and Recreation on Carnivores in Protected Areas in Northern California
Silva-Rodríguez, E. A. & Sieving, K. E.	2012	Domestic dogs shape the landscape-scale distribution of a threatened forest ungulate
The Nature Conservancy - Vermont	2018	Current Dog Research: Annotated Bibliography
Weston, M. A., et al.	2014	Bark in the park: a review of domestic dogs in parks
Williams, K. J. H., et al.	2009	Birds and beaches, dogs and leashes: dog owners’ sense of obligation to leash dogs on beaches in Victoria, Australia
Young, J. K., et al.	2011	Is wildlife going to the dogs? Impacts of feral and free-roaming dogs on wildlife populations

AQUATIC IMPACT

Author	Year	Title
Arp, C. D. & Simmons, T.	2012	Analyzing the Impacts of Off-Road Vehicle (ORV) Trails on Watershed Processes in Wrangell-St. Elias National Park and Preserve, Alaska
Aukerman, R. & Springer, W. T.	1976	Effects of Recreation on Water Quality in Wildlands
Barnett, M., et al.	2016	Water-based Recreation and Water Quality Perception and Concern Among Utahns
Cooke, M. T. & Xia L.	2020	Impacts of Land-Based Recreation on Water Quality
Crase, L. & Gillespie, R.	2008	The impact of water quality and water level on the recreation values of Lake Hume
Gregg, D. & Greiner, R.	2008	The direct impact of recreation on the water quality in the Great Barrier Reef Marine Park
Hunt, L. M., et al.	2019	Predicting spatial patterns of recreational boating to understand potential impacts to fisheries and aquatic ecosystems
Jaakson, R.	1998	River Recreation Boating Impacts
Liddle, M. J. & Scorgie H. R. A.	1980	The effects of recreation on freshwater plants and animals: A review
Myer, N., et al.	2021	A day on the shore: Ecological impacts of non-motorised recreational activities in and around inland water bodies
O'Leary, J. T. & Behrens-Tepper, J. C.	1985	Impact Of Recreation Activity Specialization On Management And Program Support For Water Resources
Olive, N. D. & Marion, J. L	2009	The influence of use-related, environmental, and managerial factors on soil loss from recreational trails
Piotr, D., et al.	2019	The Impact of Recreational Activities on Aquatic Vegetation in Alpine Lakes
President's Commision on Americans Outdoors	1986	A Literature Review
Phillip, D. A. T., et al.	2009	Impact of recreation on recreational water quality of a small tropical stream

Tuite, C. H., et al.	1984	Some Ecological Factors Affecting Winter Wildfowl Distribution on Inland Waters in England and Wales, and the Influence of Water-Based Recreation
Venohr, M., et al.	2018	The underestimated dynamics and impacts of water-based recreational activities on freshwater ecosystems
Znamenskaya, T., et al.	2018	Factors of the Development of Water Erosion in the Zone of Recreation Activity in the Ol'khon Region

NORTH AMERICA

Author	Year	Title
Bhardwaj, M., et al.	2015	Aggressive behavior by Western Bluebirds varies with anthropogenic disturbance to breeding habitat
Bleicher, S. S. & Rosenzweig, M. L.	2018	Too much of a good thing? A landscape-of-fear analysis for collared peccaries Pecari tajacu reveals hikers act as a greater deterrent than thorny or bitter food
Bunnell, K. D, et al.	2006	Potential Impacts of Coyotes and Snowmobiles on Lynx Conservation in the Intermountain West
Borkowski, J. J., et al	2006	Behavioral responses of bison and elk in Yellowstone to snowmobiles and snow coaches
Brown, C.	2010	The effects of anthropogenic noise and human activities on ungulate behavior
Cassirer, E. F.	1992	Elk responses to disturbance by cross-country skiers in Yellowstone National Park
Chalfoun, A. D.	2011	Effects of pathways within Grand Teton National Park on avian diversity, abundance, distribution, nesting productivity, and breeding behaviors
Cole, J. S., et al.	2019	Effects of off-highway vehicles on avian abundance and diversity in a designated vehicular recreation area
Creel, S., et a.	2002	Snowmobile Activity and Glucocorticoid Stress Responses in Wolves and Elk
D'Acunto, L. E., et al.	2018	Simulating the success of trail closure strategies on reducing human disturbance to nesting Golden Eagles
Erwin, R. M.	1980	Breeding habitat use by colonially nesting waterbirds in two mid-atlantic US regions under different regimes of human disturbance
Fortin, D., & Andruskiw, M.	2003	Behavioral Response of Free-Ranging Bison to Human Disturbance
Freddy, D. J., et al.	1986	Responses of Mule Deer to Disturbance by Persons Afoot and Snowmobiles
Gaines, W. L., et al.	2003	Assessing the cumulative effects of linear recreation routes on wildlife habitats on the Okanogan and Wenatchee National Forests.
George, S. L. & Crooks, K. R.	2006	Recreation and large mammal activity in an urban nature reserve

Gese, E. M., et al.	2013	The Influence of Snowmobile Trails on Coyote Movements during Winter in High-Elevation Landscapes
Girard, T. L., et al.	2013	Landscape-Scale Factors Affecting Feral Horse Habitat Use During Summer Within The Rocky Mountain Foothills
Goldstein, M. I., et al.	2010	Brown Bear Den Habitat and Winter Recreation in South-Central Alaska
Guntenspergen, G. R.	2014	Application of Threshold Concepts to Ecological Managment Problems: Occupancy of Golden Eages in Denali National Park, Alaska
Heinemeyer, K., et al.	2019	Wolverines in winter: indirect habitat loss and functional responses to backcountry recreation
Hicks, L. L. &Elder, J. M.	1979	Human Disturbance of Sierra Nevada Bighorn Sheep
Holmes & Geupel	2005	Effects of Trail Width on the Densities of Four Species of Breeding Birds in Chaparral
Kit, M., et al.	2009	Wildlife Species and Habitat Assessment of Proposed Trails in Mount Spokane State Park
Klein, M. L.	1993	Waterbird Behavioral Responses to Human Disturbances
Kolbe, J. A., et al.	2007	The Effect of Snowmobile Trails on Coyote Movements Within Lynx Home Ranges
Ladle, A., et al.	2019	Grizzly bear response to spatio-temporal variability in human recreational activity
Ladle, A., et al.	2018	The role of human outdoor recreation in shaping patterns of grizzly bear-black bear co-occurrence
Ladle, A., et al.	2017	Predictive modelling of ecological patterns along linear-feature networks
Lomas, E., et al.	2015	Persistence of Northern Pacific Rattlesnakes masks the impact of human disturbance on weight and body condition
Lomas, E., et al.	2019	Movement Ecology of Northern Pacific Rattlesnakes (Crotalus o. oreganus) in Response to Disturbance
Longshore, K., et al.	2013	Detecting short-term responses to weekend recreation activity: Desert bighorn sheep avoidance of hiking trails: Short-Term Response of Bighorn Sheep
MacArthur, R.	1982	Cardiac and Behavioral Responses of Mountain Sheep to Human Disturbance

Markovchick-Nicholls, L., et al.	2008	Relationships between Human Disturbance and Wildlife Land Use in Urban Habitat Fragments: Human Disturbance in Habitat Fragments
McClure, C.	2009	Report on Wildlife Responses to Motorized Winter Recreation in Yellowstone
McLellan, B. N. & Shackleton, D. M.	1989	Immediate Reactions of Grizzly Bears to Human Activities
Miller, J.	2000	Recreational trails, human activity, and nest predation in lowland riparian areas
Miller, S. G., et al.	2001	Wildlife Responses to Pedestrians and Dogs
Miller, S. G., et al.	1998	Influence of Recreational Trails on Breeding Bird Communities
Morrison, J. R., et al.	1995	The Effects of Ski Area Expansion on Elk
Morrison, C. D., et al.	2014	Habitat selection of a re-colonized cougar population in response to seasonal fluctuations of human activity
Musiani, M., et al.	2010	How humans shape wolf behavior in Banff and Kootenay National Parks, Canada
Naylor, L. M., et al.	2009	Behavioral Responses of North American Elk to Recreational Activity
Nyhof, P. E. & Trulio, L.	2015	Basking Western Pond Turtle Response to Recreational Trail Use in Urban California
Olson, L. E., et al.	2018	Sharing the same slope: Behavioral responses of a threatened mesocarnivore to motorized and nonmotorized winter recreation
Papouchis, C. M., et al.	2001	Responses of Desert Bighorn Sheep to Increased Human Recreation
Patten, M. A. & Burger, J. C.	2018	Reserves as double-edged sword: Avoidance behavior in an urban-adjacent wildland
Pauli, B. P., et al.	2017	Forecasting disturbance effects on wildlife: tolerance does not mitigate effects of increased recreation on wildlands
Reed, S. E.		A pilot study of potential effects of human recreation
Reed, S. E. & Merenlender, A. M.	2011	Effects of Management of Domestic Dogs and Recreation on Carnivores in Protected Areas in Northern California
Reed, S. E. & Merenlender, A. M.	2008	Quiet, Nonconsumptive Recreation Reduces Protected Area Effectiveness

Reilly, M. L., et al.	2017	Spatial and temporal response of wildlife to recreational activities in the San Francisco Bay ecoregion
Riffell, S. K., et al.	1996	Does Repeated Human Intrusion Cause Cumulative Declines in Avian Richness and Abundance?
Rodgers, J. A. & Smith, H. T.	1997	Buffer zone distances to protect foraging and loafing water birds from disturbance in Florida
Rogala, J. K., et al.	2011	Human Activity Differentially Redistributes Large Mammals in the Canadian Rockies National Parks
Sarmento, W. M. & Berger, J.	2017	Human visitation limits the utility of protected areas as ecological baselines
Schultz, R. D. & Bailey, J. A.	1978	Responses of National Park Elk to Human Activity
Seip, D. R., et al.	2007	Displacement of Mountain Caribou From Winter Habitat by Snowmobiles
Shivley, D	2008	Blowing Smoke in Yellowstone: Air Quality Impacts of Oversnow Motorized Recreation in the Park
Snetsinger, S. D. & White, K.	2009	Recreation and trail impacts on wildlife species of interest in Mount Spokane State Park
Sojda, R.	1978	Effects of snowmobile activity on wintering pheasants and wetland vegetation in northern Iowa marshes
Spaul, R. J. & Heath, J. A.	2016	Nonmotorized recreation and motorized recreation in shrub-steppe habitats affects behavior and reproduction of golden eagles (Aquila chrysaetos)
Spaul, R. J. & Heath, J. A.	2017	Flushing Responses of Golden Eagles (Aquila chrysaetos) In Response To Recreation
Squires, J. R., et al.	2006	Effects of Winter Recreation on Coyotes and Lynx
Squires, J. R., et al.	2019	Winter recreation and Canada lynx: reducing conflict through niche partitioning
Stafl, N. & O'Connor, M. I.	2015	American Pikas' (Ochotona princeps) Foraging Response to Hikers and Sensitivity to Heat in an Alpine Environment
Suraci, J. P., et al.	2019	Fear of humans as apex predators has landscape-scale impacts from mountain lions to mice
Sweanor, L. L., et al.	2008	Puma and Human Spatial and Temporal Use of a Popular California State Park

Taylor, A. R. & Knight, R. L.	2003	Wildlife responses to recreation and associated visitor perceptions
Trulio, L. A. & Sokale, J.	2008	Foraging Shorebird Response to Trail Use Around San Francisco Bay
Trulio, L. A. & White, H. R.	2017	Wintering Waterfowl Avoidance and Tolerance of Recreational Trail Use
U.S. Forest Service	2014	Final Environmental Impact Statement: Ochoco Summit Trail System Project, Environmental Consequences - Wildlife (Chapter 3)
White, P. J., et al.	2006	Behavioral Responses of Wildlife to Snowmobiles and Coaches in Yellowstone
Whiteman, J.P.	2013	Footload influences wildlife use of compacted trails in the snow
Whittington, J., et al.	2005	Spatial Responses of Wolves to Roads and Trails in Mountain Valleys
Wiedmann, B. P. & Bleich, V. C.	2014	Demographic responses of bighorn sheep to recreational activities: A trial of a trail: Bighorn Sheep Responses to Recreation
Wisdom, M. J., et al.	2004	Effects of Off-road Recreation on Mule Deer and Elk
Wisdom, M. J., et al.	2018	Elk responses to trail-based recreation on public forests
Zollner, P.	2010	Simulating the implications of recreational disturbance on Karner blue butterflies (Lycaeides melissa samuelis) at the Indiana Dunes National Lakeshore.

TEMPERATE ZONE, OUTSIDE OF NORTH AMERICA

Author	Year	Title
Arlettaz, R., et al.	2015	Disturbance of wildlife by outdoor winter recreation: Allostatic stress response and altered activity-energy budgets
Arlettaz, R., et al.	2007	Spreading free-riding snow sports represent a novel serious threat for wildlife
Barja, I., et al.	2007	Stress physiological responses to tourist pressure in a wild population of European pine marten
Beale, C. M. & Monaghan, P.	2005	Modeling the Effects of Limiting the Number of Visitors on Failure Rates of Seabird Nests
Beale, C. M. & Monaghan, P.	2004	Human disturbance: people as predation-free predators?
Boer, H. D., et al.	2004	Flight distance in roe deer Capreolus capreolus and fallow deer Dama dama as related to hunting and other factors | Request PDF
Borkowski, J.	2001	Flight behaviour and observability in human-disturbed sika deer
Bötsch, Y., et al.	2017	Experimental evidence of human recreational disturbance effects on bird-territory establishment
Bötsch, Y., et al.	2018	Effect of recreational trails on forest birds: Human presence matters
Braunisch, V., et al.	2011	Spatially explicit modeling of conflict zones between wildlife and snow sports: prioritizing areas for winter refuges
Caprio, E., et al.	2009	Assessing habitat/landscape predictors of bird diversity in managed deciduous forests: a seasonal and guild-based approach
Ciach, M., et al.	2017	Watch your step: insect mortality on hiking trails
Ciach, M., & Pęksa, Ł.	2019	Human-induced environmental changes influence habitat use by an ungulate over the long term
Colman, J. E., et al.	2012	Responses of wild reindeer (Rangifer tarandus tarandus) when provoked by a snow-kiter or skier: A model approach
Coppes, J., et al.	2017	Human recreation affects spatio-temporal habitat use patterns in red deer (Cervus elaphus)

Coppes, J., et al.	2017	Outdoor recreation causes effective habitat reduction in capercaillie Tetrao urogallus: a major threat for geographically restricted populations
Coppes, J., et al.	2018	Habitat suitability modulates the response of wildlife to human recreation
Densmore, P., & French, K.	2005	Effects of recreation areas on avian communities in coastal New South Wales’ parks
Dynowski, P., et al.	2019	The Impact of Recreational Activities on Aquatic Vegetation in Alpine Lakes
Eggermann, J., et al.	2013	Stress-Hormone Levels of Wolves in Relation to Breeding Season, Pack Size, Human Activity, and Prey Density
Ellenberg, U., et al.	2013	Heart rate responses provide an objective evaluation of human disturbance stimuli in breeding birds
Fernández-Juricic, E., et al.	2003	Testing the risk-disturbance hypothesis in a fragmented landscape: nonlinear responses of house sparrows to humans
Finney, S.K., et al.	2005	The effect of recreational disturbance on an upland breeding bird, the golden plover Pluvialis apricaria
Formenti, N., et al.	2018	Increased hormonal stress response of Apennine chamois induced by interspecific interactions and anthropogenic disturbance
Gander, H., & Ingold, P.	1997	Reactions of male alpine chamois Rupicapra r. rupicapra to hikers, joggers and mountainbikers
Haigh, A., et al.	2017	Managed parks as a refuge for the threatened red squirrel (Sciurus vulgaris) in light of human disturbance
Holm, L.	2009	Experimental disturbance by walkers affects behaviour and territory density of nesting Black-tailed Godwit Limosa limosa
Honda, T., et al.	2019	Sensitization to human decreases human-wildlife conflict: empirical and simulation study
Huhta, E. & Sulkava, P.	2014	The impact of nature-based tourism on bird communities: A case study in Pallas-Yllästunturi National Park
Illich, I. P. & Haslett, J. R.	1994	Responses of Assemblages of Orthoptera to Management and Use of Ski Slopes on Upper Sub-Alpine Meadows in the Austrian Alps

Immitzer, M., et al.	2014	Effects of habitat quality and hiking trails on the occurrence of Black Grouse (Tetrao tetrix) at the northern fringe of alpine distribution in Austria
Janssen, J.	2014	Ungulates vs. Recreationist: Temporal and spatial responses of wildlife to nature-based tourism
Kangas, K., et al.	2010	Recreation-induced changes in boreal bird communities in protected areas
Kycko, M., et al.	2017	Assessment of Hyperspectral Remote Sensing for Analyzing the Impact of Human Trampling on Alpine Swards
Li, W., et al.	2005	Hiking Trails and Tourism Impact Assessment In Protected Area: Jiuzhaigou Biosphere Reserve, China
Liley, D., & Sutherland, W. J.	2007	Predicting the population consequences of human disturbance for Ringed Plovers Charadrius hiaticula: a game theory approach
Lowney, A.	2011	Impact of mountain bike trails on red squirrel population (Sciurus vulgaris) in Whinlatter Forest, Cumbria
Mainini, B., et al.	1993	Behaviour of marmots marmota marmota under the influence of different hiking activities
Mallord, J. W., et al	2007	Linking recreational disturbance to population size in a ground-nesting passerine
Nellemann, C., et al.	2010	Effects of Recreational Cabins, Trails and Their Removal for Restoration of Reindeer Winter Ranges
Oberosler, V., et al.	2017	The influence of human disturbance on occupancy and activity patterns of mammals in the Italian Alps from systematic camera trapping
Pauli, B. P., et al.	2017	Forecasting disturbance effects on wildlife: tolerance does not mitigate effects of increased recreation on wildlands
Pęksa, Ł., & Ciach, M.	2015	Negative effects of mass tourism on high mountain fauna: the case of the Tatra chamois Rupicapra rupicapra tatrica
Reimers, E., et al.	2010	Habituation responses in wild reindeer exposed to recreational activities
Remacha, C., & Delgado, J. A.	2009	Spatial nest-box selection of cavity-nesting bird species in response to proximity to recreational infrastructures
Rixen, C.	2013	Impacts of outdoor winter recreation on alpine wildlife and mitigation approaches: a case study of the black grouse

Scholten, J., et al.	2018	Red deer (Cervus elaphus) avoid mountain biking trails
Thiel, D., et al.	2008	Ski tourism affects habitat use and evokes a physiological stress response in capercaillie Tetrao urogallus: a new methodological approach
Thiel, D., et al.	2007	Effects of Recreation and Hunting on Flushing Distance of Capercaillie
Tyler, N.J.C.	1991	Short-term behavioural responses of Svalbard reindeer Rangifer tarandus platyrhynchus to direct provocation by a snowmobile
van der Zande, A.N., et al.	1984	Impact of outdoor recreation on the density of a number of breeding bird species in woods adjacent to urban residential areas
van der Zande, A.N. & Vos, P.	1984	Impact of a Semi-experimental increase in recreation intensity on the densities of birds in groves and hedges on a lake shore in The Netherlands
Vistnes, I. I., et al.	2008	Summer distribution of wild reindeer in relation to human activity and insect stress
Westekemper, K., et al.	2018	Stay on trails – effects of human recreation on the spatiotemporal behavior of red deer Cervus elaphus in a German national park

OUTSIDE OF TEMPERATE ZONE

Author	Year	Title
Aastrup, P.	2000	Responses of West Greenland caribou to the approach of humans on foot
Almeida Cunha, A.	2010	Negative effects of tourism in a Brazilian Atlantic forest National Park
Alwis, N.S., et al.	2016	Response of tropical avifauna to visitor recreational disturbances: a case study from the Sinharaja World Heritage Forest, Sri Lanka
Anderson, D. W.	1988	In My Experience: Dose-Response Relationship between Human Disturbance and Brown Pelican Breeding Success
Anttonen, M., et al.	2011	Range Selection by Semi-Domesticated Reindeer (Rangifer tarandus tarandus) in Relation to Infrastructure and Human Activity in the Boreal Forest Environment, Northern Finland
Baker, A. D. & Leberg, P. L.	2018	Impacts of human recreation on carnivores in protected areas
Ballantyne, M., et al.	2014	Recreational trails are an important cause of fragmentation in endangered urban forests: A case-study from Australia
Ballantyne, M & Pickering, C. M.	2015	Differences in the impacts of formal and informal recreational trails on urban forest loss and tree structure
Baltensperger, A. P., et al.	2017	Expansion of American marten (Martes americana) distribution in response to climate and landscape change on the Kenai Peninsula, Alaska
Blake, J. G., et al.	2017	Effects of human traffic on use of trails by mammals in lowland forest of eastern Ecuador
Davis, C.A., et al.	2010	Mountain Biking Trail Use Affects Reproductive Success of Nesting Golden-Cheeked Warblers
Dewidar, K., et al.	2016	Detecting the environmental impact of off-road vehicles on Rawdat Al Shams in central Saudi Arabia by remote sensing
Ewacha, M. V. A., et al.	2017	Disturbance and chronic levels of cortisol in boreal woodland caribou
Fernández-Juricic, E., et al.	2005	Sensitivity of wildlife to spatial patterns of recreationist behavior: A critical assessment of minimum approaching distances and buffer areas for grassland birds

Greenberg, J. R. & Holekamp, K. E.	2017	Human disturbance affects personality development in a wild carnivore
Heil, L., et al.	2007	Avian responses to tourism in the biogeographically isolated high Córdoba Mountains, Argentina
Jiang, T. Y., et al.	2013	Behavioral responses of blue sheep (Pseudois nayaur) to nonlethal human recreational disturbance
Kevan, P. G., et al.	1995	Vehicle Tracks on High Arctic Tundra: Their Effects on the Soil, Vegetation, and Soil Arthropods
Mahoney, S. P., et al.	2001	Caribou reactions to provocation by snow machine
Malo, J. E., et al.	2011	Measuring ungulate tolerance to human with flight distance: A reliable visitor management tool?
McDougall, P.	2012	Is passive observation of habituated animals truly passive?
Ota, A., et al.	2019	Effects of nonlethal tourist activity on the diel activity patterns of mammals in a National Park in Peninsular Malaysia
Rode, K.D., et al.	2018	Survey-based assessment of the frequency and potential impacts of recreation on polar bears
Schmidt, F. A., et al.	2017	Ant assemblage and morphological traits differ in response to soil compaction
Silva-Rodríguez, E. A. & Sieving, K. E.	2012	Domestic dogs shape the landscape-scale distribution of a threatened forest ungulate
van Vierssen Trip, N., & Wiersma, Y.F.	2015	A Comparison of All-Terrain Vehicle (ATV) Trail Impacts on Boreal Habitats Across Scales
Wolf, I. D. & Croft, D. B.	2010	Minimizing disturbance to wildlife by tourists approaching on foot or in a car: A study of kangaroos in the Australian rangelands
Wolf, I.D., et al.	2013	Vegetation moderates impacts of tourism usage on bird communities along roads and hiking trails
Zhang, M., et al.	2013	Flight responses of blue sheep in Ningxia Helan Mountain National Nature Reserve

APPENDIX 5
GUIDELINES FOR DEVELOPING A RECREATION ECOLOGY MONITORING PROTOCOL

Prepared by Meredith Naughton, UVM Field Naturalist Program

INTRODUCTION

Monitoring is approached in many ways across disciplines. Here, monitoring is gathering information about certain ecological variables to assess an ecosystem's condition and gauge changes over time. Monitoring elements of an ecosystem, including wildlife variables such as population density, can help assess management effectiveness and inform future decisions. Because of the careful consideration with which recreation trails are built and managed, it is vital for accountable and effective management that the ecological function of the trailed area be monitored.

However, monitoring may produce incomplete or useless information without specific objectives (Yoccoz, 2001). Substantial thought should be put into the basic questions of "*why*" an area is being monitored, "*what*" is being monitored, and "*how*" to monitor it. Here, I offer some guidance to these questions. The specific elements of what and how to monitor is left up to the land managers and ecologists to determine based on the location and objectives of each property.

Below is some guidance on monitoring for land with a dual purpose of protecting natural resources and supporting public uses. The following monitoring guidelines apply to protecting natural resources, specifically monitoring for impact to wildlife from trail recreation. Monitoring the public satisfaction and use of the recreation trail may also inform management and meet the goals of a property, but those are not detailed here.

WHY MONITOR?

It's necessary to know why monitoring is important and what the objectives are, of both monitoring and the property itself. As stated above, ecological monitoring can be a useful element of informed land management as it strives to balance both recreational use and ecological protection. The monitoring described here is used to determine if ecological protection is maintained, and specifically if wildlife protection is effective. The more specific the objectives of the property are, the more accurate monitoring can be in determining whether those objectives are being met.

The following are essential questions and suggestions to help guide monitoring a recreation area:

Why is this area being monitored?

- What are the objectives of the monitored area?
- Why is this area ecologically unique?

What are the objectives of the monitored area?

- The more specific a property's objectives are, the better a monitoring program can be designed to detect if management actions are meeting those objectives.

Why is this area ecologically unique?

- If the objectives are nonspecific, such as "protect natural resources" or "protect wildlife", can they be detailed and reflective of the property?
    - What natural resources or wildlife are characteristic of this area? What makes this area ecologically unique?
        - For example, a property with number vernal pools could strive to "protect natural resources and wildlife, and specifically maintain functional amphibian breeding habitats".
    - If taxonomically specific objectives don't make sense for a property, generally informative indicators can be used (detailed below)

WHAT TO MONITOR

Determining what to monitor to detect a significant change in the ecological system is a critical piece of designing an effective monitoring program (Yoccoz, 2001). The key guiding questions regarding what to monitor are:

- What do you want to detect through this monitoring?
- What ecological elements are you collecting data on?
- What specific data are you collecting?

What do you want to detect through this monitoring?

- When monitoring programs are designed to inform management, they provide two levels of information:
    - the current state of what's monitored
    - changes in what's monitored as a response to management actions
- I suggest monitoring be designed to detect significant change in the indicators chosen to detect impact to wildlife.
    - Detecting larger changes is often more financial and temporal efficient than detecting incremental change. Additionally, as discussed in the literature review,

wildlife responses are highly variable and complex, and significant changes are often needed to signal a trend.

What ecological elements are you collecting data on?

Ideally, monitoring the ecological response to management actions could detect any associated ecological change. However, a monitoring program must also be practical to be valuable. Ongoing, comprehensive ecological assessments are too time intensive and cost prohibitive to be practical. Therefore, one or more indicators should be chosen to most accurately and easily signal change in the system. Below is a list of general elements of a good indicator of change in ecological monitoring for impact to wildlife (adapted from Hammit, 2015). A good indicator should be:

- Measurable - quantitative and subject to measurement;
- Reliable - capable of being measured precisely by different people;
- Cost-effective - capable of being measured using inexpensive equipment and techniques;
- Significant - related to impacts that, should they occur, would be considered serious problems. These problems should be defined in the objectives of management;
- Efficient - capable of reflecting the condition of more than itself, reducing the number of indicators that must be assessed. The indicator should be present when the area is in good ecological condition;
- Responsive - related to attributes that are subject to management control.

What specific data are you collecting?

Once you've determined your indicator(s), you must be clear and consistent about what data you collect to monitor them. Follow the same guidelines above to determine what data is most appropriate to collect on your indicators.

HOW TO MONITOR

Some of the final decisions when creating a monitoring program are how to collect the data that will later inform management. Below are a few important guiding questions to answer as you create your management program.

- What are you using to collect data?
- How often should you monitor?
- Who should monitor?

What are you using to collect data?

The equipment used to collect data should be decided on through a similar list of qualities as a good indicator. Specifically, the equipment used to collect data should be reliable, cost-effective, and responsive. Technological data collection, such as game cameras or acoustic recorders, can provide a way to collect a significant amount of data without anyone in the field. However, the equipment may be cost-prohibitive, as may be the time it takes to sort through photos and recordings. Alternatively, field observations done by volunteers may be quite cost-effective, but if the volunteers need to be highly skilled, the data collection may be better carried out by a hired and trained field technician.

How often should you monitor?

The frequency and timing of monitoring will largely be guided by the indicators chosen. Additionally, the frequency should be dictated by what will produce a significant and responsive result. When possible, annual monitoring to compliment the phenological cycles of the indicators are ideal. Annual monitoring of breeding activities is often an appropriate way to assess wildlife population consistency. Vernal pool egg mass counts and acoustic monitoring for interior forest birds during spring can produce significant and responsive data. Monitoring can occur on a more infrequent basis after establishing a consistent state of the area. However, when new trails are established or significant changes are observed, monitoring should return to its ideal frequency in order to detect changes as necessary (Rowland & Vojta, 2013).

Who should monitor?

The level of skill, training, consistency, and frequency of monitoring required will determine who can conduct the monitoring. If each of those qualities are required at a low level, volunteers or citizen-science initiatives could manage the data collection. However, it is likely that a trained professional may be needed for monitoring when it involves population assessments, habitat assessments, or other more complex data collection.

Regardless of who collects data, an ecologist is needed for each management range to analyze the data collected and make management adjustments as needed. Ideally this person is trained in habitat assessment, wildlife biology, and recreation ecology, and will advise the landowners and trail builders throughout the building and management process. This person would play an integral role in the planning and management of new and existing recreation trails, in addition to monitoring wildlife and ecological function as trails continue to see changes in volume and usage into the future.

ADDITIONAL RESOURCES

Many states, including Vermont and New Hampshire, have existing wildlife monitoring programs. These programs can be adapted to specifically examine changes in wildlife as a result of recreation. Below are several sources that also provide detailed information about developing a wildlife monitoring protocol to detect change as a result of recreation:

Baumgardt, J. A., Morrison, M. L., Brennan, L. A., Pierce, B. L., & Campbell, T. A. (2019). Development of multispecies, long-term monitoring programs for resource management. *Rangeland Ecology & Management*, *72*(1), 168-181.

Cole, D. N. (2004). Monitoring and management of recreation in protected areas: the contributions and limitations of science. In *Policies, methods and tools for visitor management: proceedings of the Second International Conference on Monitoring and Management of Visitor Flows in Recreational and Protected Areas: June 16-20, 2004, Rovaniemi, Finland. Working Papers of the Finnish Forest Research Institute 2. Helsinki: Finnish Forest Research Institute: 10-17*.

Interagency Visitor Use Management Council (US). (2016). *Visitor use management framework: A guide to providing sustainable outdoor recreation*. US Department of the Interior, National Park Service.

Wisdom, M. J., Rowland, M. M., Vojta, C. D., & Goldstein, M. I. (2013). Monitoring human disturbances for management of wildlife species and their habitats. *In: Rowland, MM; Vojta, CD; tech. eds. 2013. A technical guide for monitoring wildlife habitat. Gen. Tech. Rep. WO-89. Washington, DC: US Department of Agriculture, Forest Service: 46 p.*, 7-1.

REFERENCES

Hammitt, W. E., Cole, D. N., & Monz, C. A. (2015). *Wildland recreation: ecology and management*. John Wiley & Sons.

Rowland, M. M., & Vojta, C. D. (2013). A technical guide for monitoring wildlife habitat. *Gen. Tech. Rep. WO-89. Washington, DC: US Department of Agriculture, Forest Service: 400 p.*, *89*.

Yoccoz, N. G., Nichols, J. D., & Boulinier, T. (2001). Monitoring of biological diversity in space and time. *Trends in ecology & evolution*, *16*(8), 446-453.

APPENDIX 6

APPLIED MANAGEMENT RECOMMENDATIONS

Prepared by Meredith Naughton, UVM Field Naturalist Program

INTRODUCTION

The following maps and descriptions represent examples of the applied management recommendations from Chapter 2.

All map data was obtained from the Vermont Geodata Portal, or created as a product of this project.

PHASE 1 APPLIED RECOMMENDATIONS

The state of Vermont is divided into 5 land management districts. For Phase 1 landscape scale trail planning, District 4 central Vermont serves as the extent of the management zone. Trail free areas were designated (Map 3) as a result of landscape scale ecological (Map 1) and trail (Map 2) assessments.

MAP 1: LANDSCAPE-SCALE ECOLOGICAL ASSESSMENTS

Ecological assessments identified high priority interior forest, connectivity blocks, high value wildlife crossings, and where these features overlap.

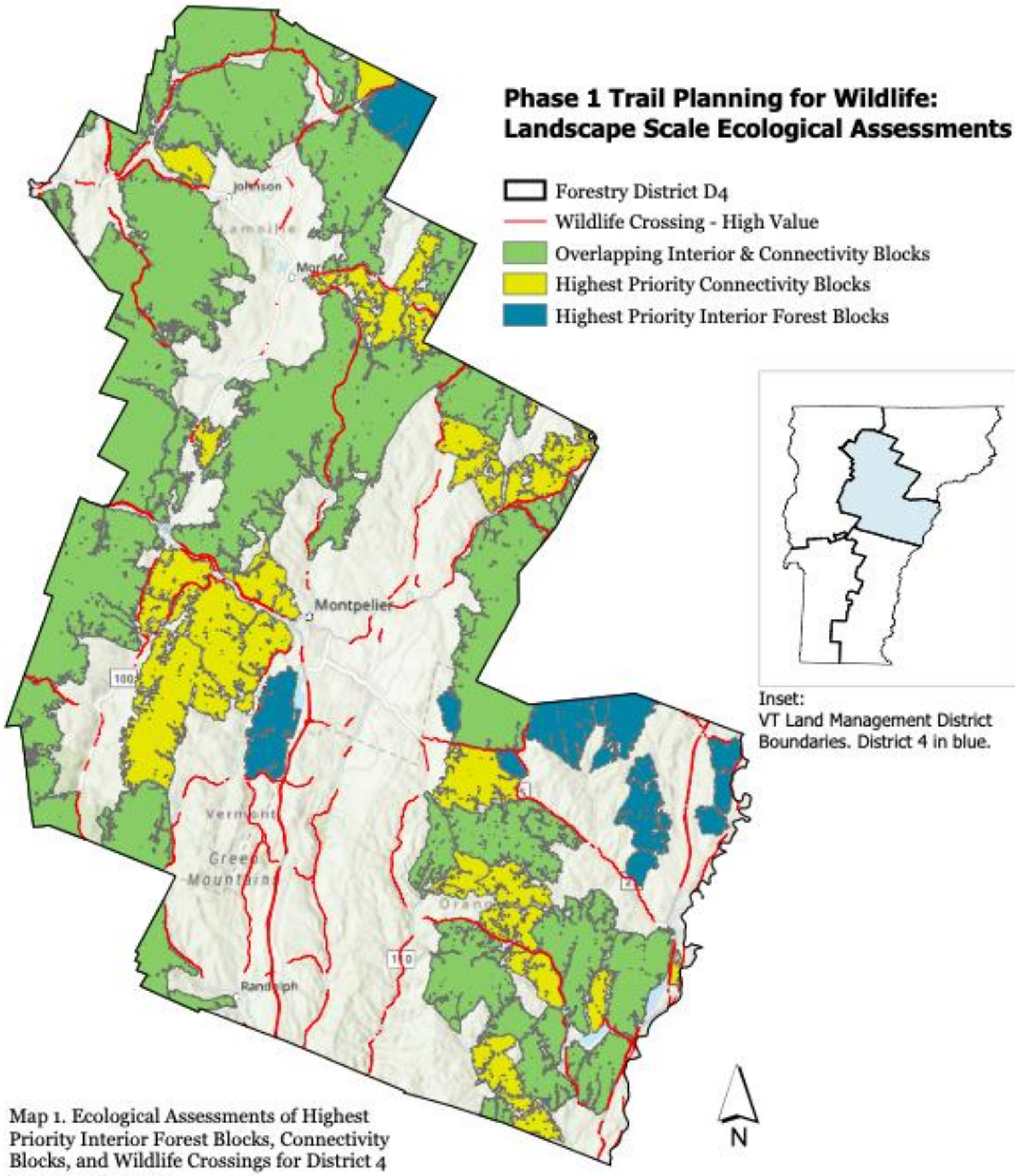
MAP 1: LANDSCAPE-SCALE TRAIL ASSESSMENTS

For the purpose of this applied recommendation, trail location data found in Vermont Geodata Portal was used to calculate the zone of influence. Other trails likely exist within the management zone and an extensive search of existing trail data should be conducted during Phase 1 planning in order to reserve highly ecologically functional areas as trail-free.

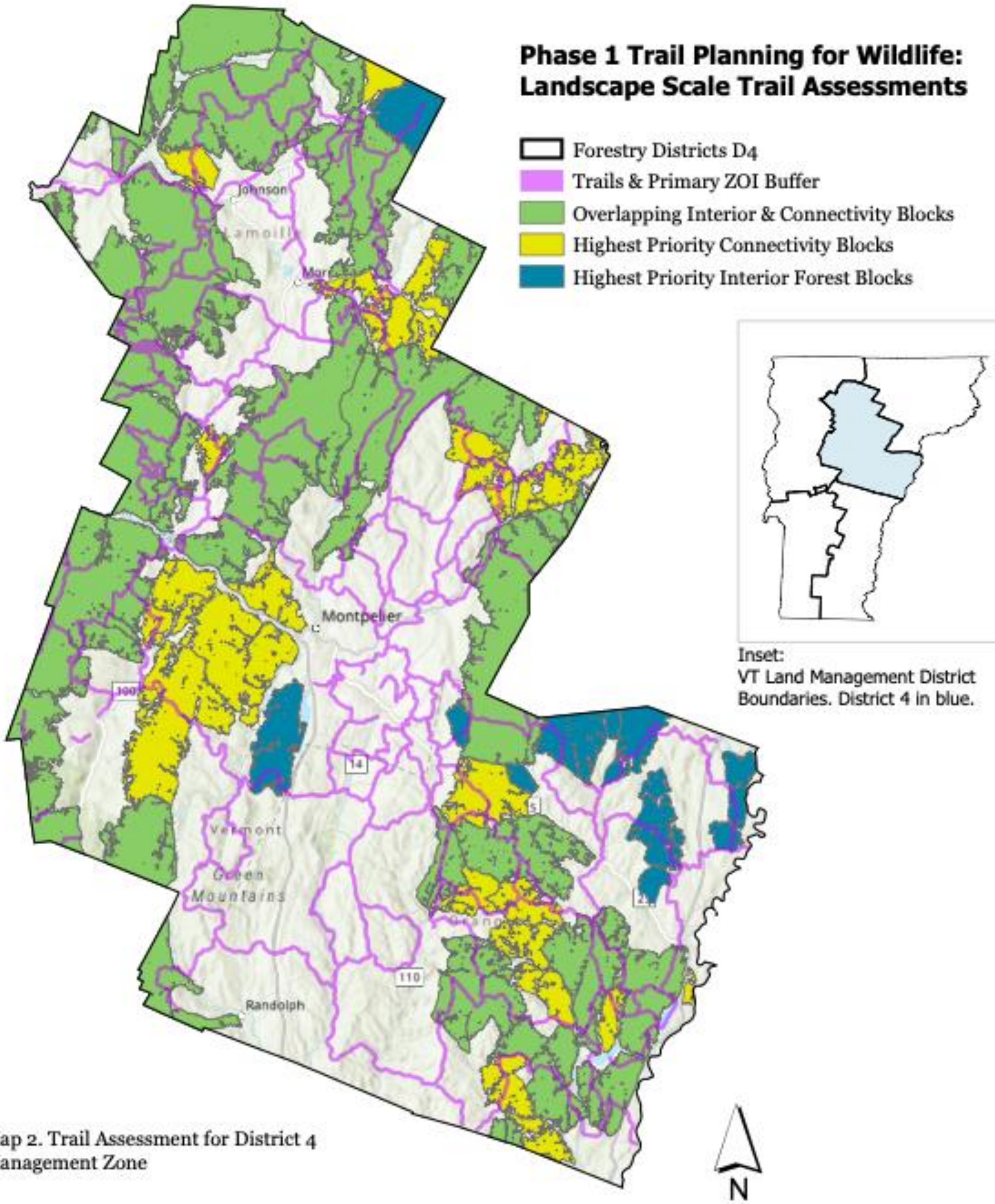
The primary zone of influence was used as Based on the trail data used here, trails within the management zone have a total estimated zone of influence of 129,685.89 acres.

MAP 3: TRAIL-FREE DESIGNATIONS

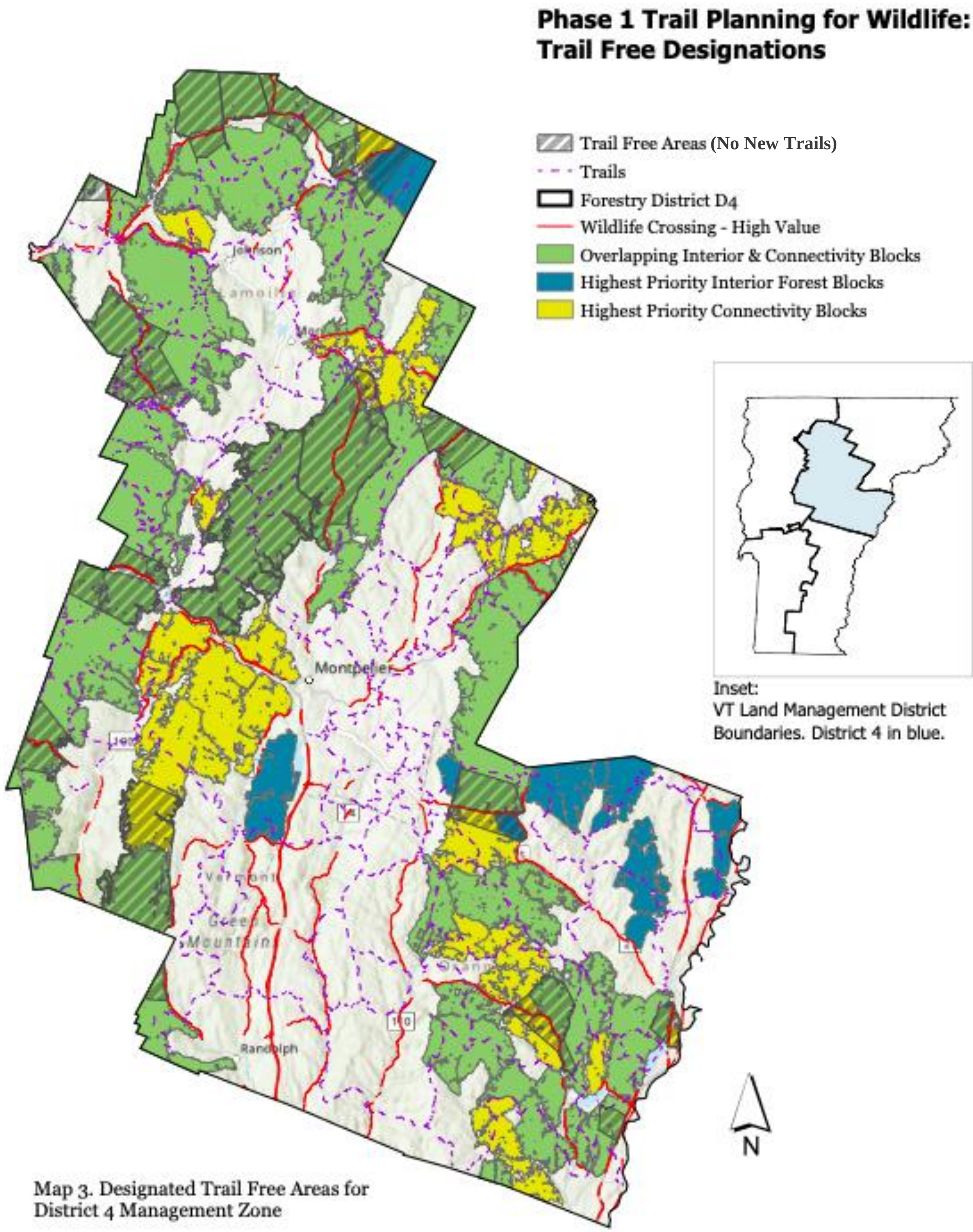
Trail free areas were designated based on the location of co-occurring highest priority interior forest, highest priority connectivity blocks, and highest value wildlife crossings (WCV value of 8 or higher). Areas with fewer existing trails were prioritized to reserve as trail-free areas.



Map 1. Ecological Assessments of Highest Priority Interior Forest Blocks, Connectivity Blocks, and Wildlife Crossings for District 4 Management Zone



Map 2. Trail Assessment for District 4 Management Zone



Map 3. Designated Trail Free Areas for District 4 Management Zone

PHASE 2 APPLIED RECOMMENDATIONS

For Phase 2 site-specific trail planning, I chose a location within District 4 management zone focus on. I use Perry Hill trails in Waterbury, Vermont to describe the ways a current trail system does and does not fit the management recommendations in Chapter 2 of this report (Map 4). Then, I describe considerations for adding trails on the landscape (Map 5).

EXISTING TRAILS

Map 4 shows current trails, natural communities, and other ecological features at Perry Hill in Waterbury, Vermont. Trail free area here represents an overlap of highest priority interior forest and highest priority connectivity blocks.

These trails are popular for mountain biking, hiking, and cross-country skiing. They were built without the ecologically based regulations included in this report. These trails successfully follow some guidelines of Chapter 2's management recommendations, and there are some potential areas of concern.

Guidelines followed by Perry Hill

- Trails are generally consolidated on the landscape
- Trails exist at the edge of the trail-free area

Potential areas of concern at Perry Hill

- Trails exist in deer wintering area (DWA)
- Trails exist at a high value wildlife road crossing
- Trails exist immediately adjacent to high value ecological features, including vernal pools, seeps, and a rare natural community

ADDITION OF TRAILS

Map 5 shows the natural communities of Perry Hill in finer detail. The following is an example of the procedure if additional trails were deemed beneficial to the recreation resource here.

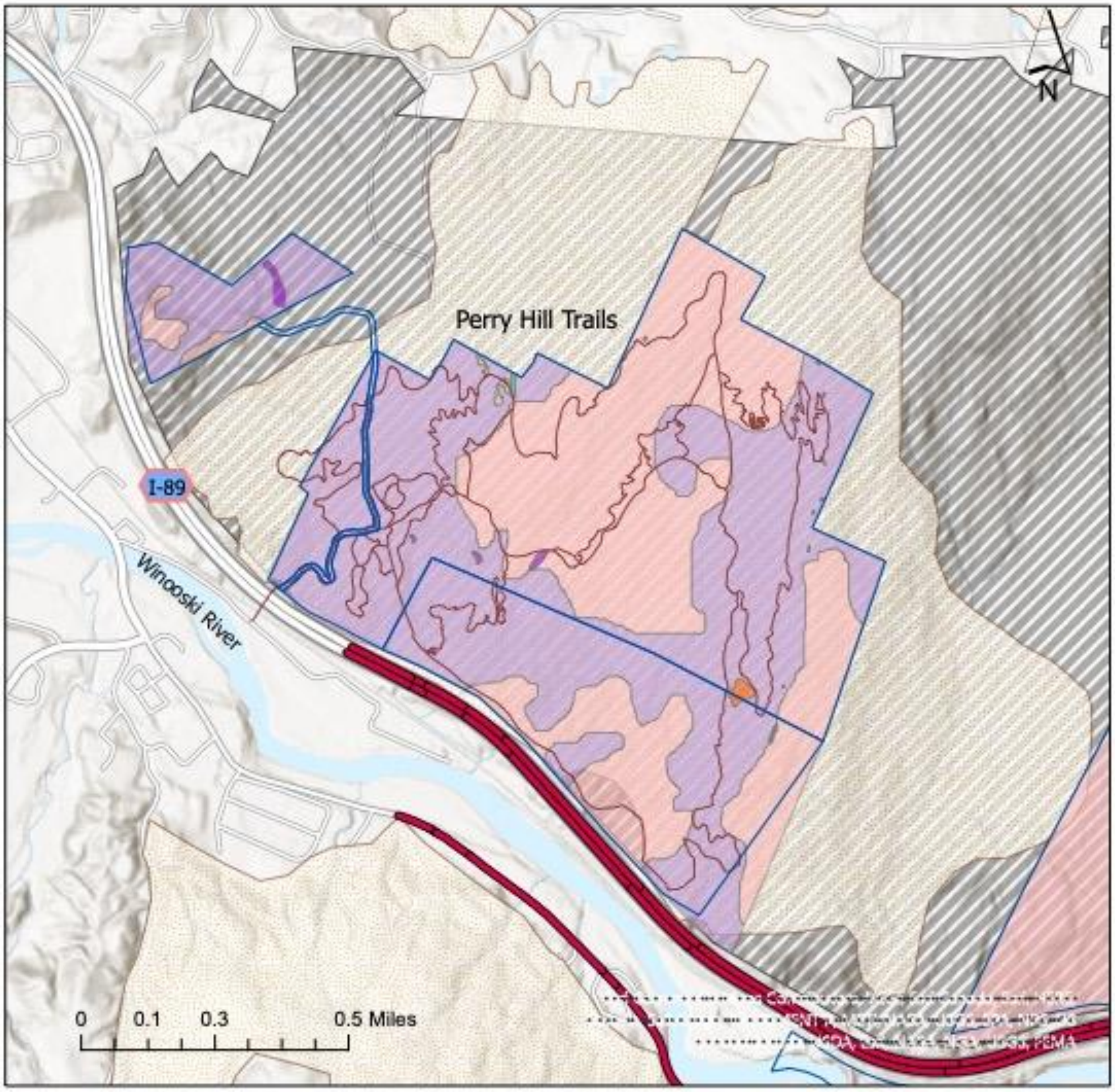
Phase 1 Landscape Scale considerations

Trails fall within then designated Trail Free Area. However, if additional trails are going to be built, consolidate them near existing trails and build them at the edge of the Trail Free Area

Phase 2 Site-specific considerations

Sensitive natural communities, including vernal pools, seeps, and red pine forest should be avoided and buffered. The mapped DWA covers the entire site. Any area with a proposed new trail should be field checked for use as a DWA.

Phase 2 Trail Planning for Wildlife:
Site-specific Planning for Perry Hill Trails, Waterbury, VT

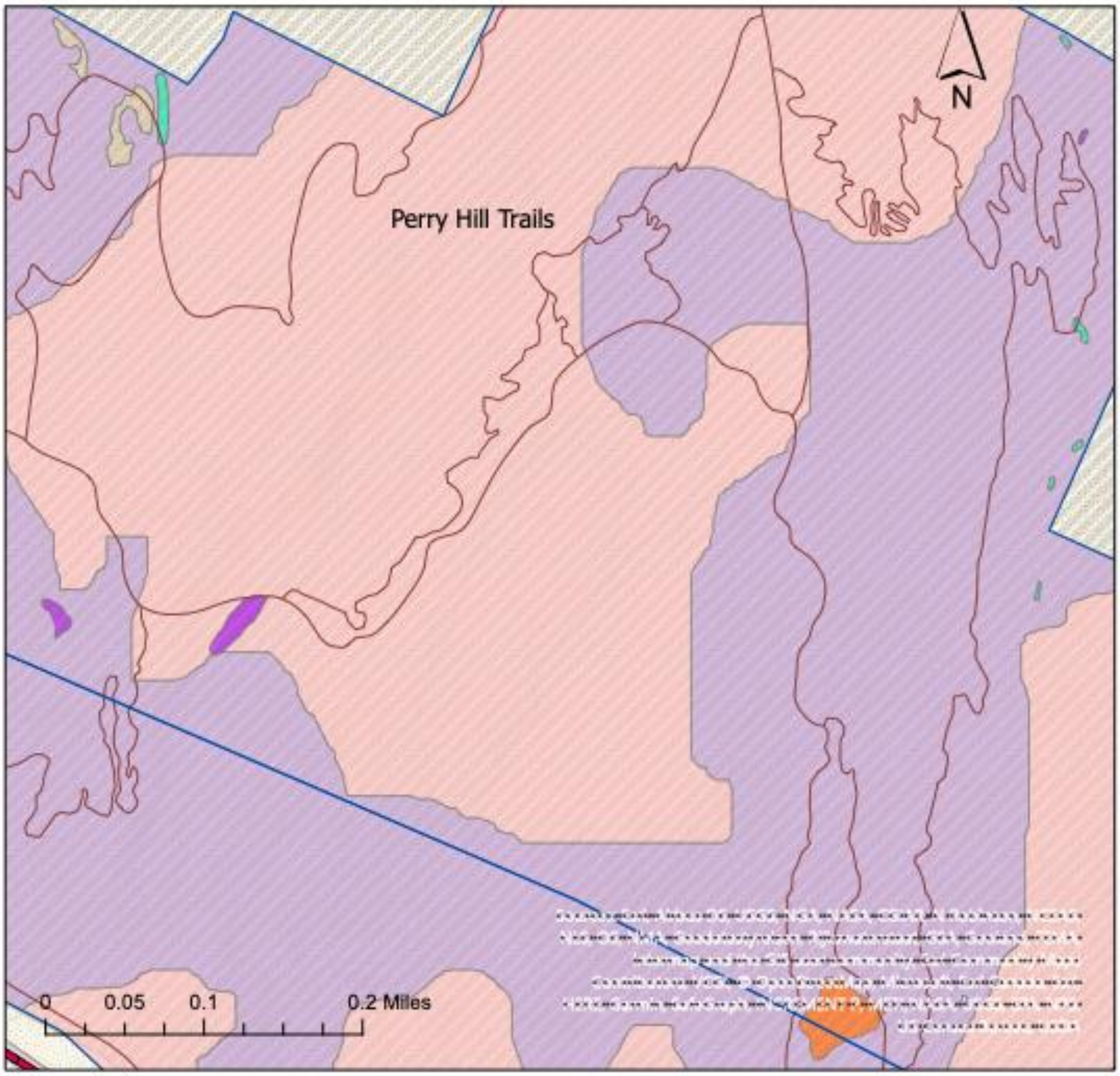


Map 4. Map of existing trails, natural communities, and other ecological designations at Perry Hill in Waterbury, VT.

ANR Lands
Trails
High Value Wildlife Crossing
Mesic Red Oak Northern Hardwood Forest
Hemlock Northern Hardwood Forest
Open Land
Seep
Temperate Acidic Outcrop
Red Pine Forest
Deer Wintering Areas
Trail Free Area **(No New Trails)**
Vernal Pool

Inset:
VT Land Management District Boundaries. District 4 in blue. Map 4 location at red star.

Phase 2 Trail Planning for Wildlife: Site-specific Planning for Perry Hill Trails, Waterbury, VT



Map 5. Map of existing trails, natural communities, and other ecological designations at Perry Hill in Waterbury, VT.

- ANR Lands
- Trails
- High Value Wildlife Crossing
- Vernal Pool
- Seep
- Temperate Acidic Outcrop
- Open Land
- Mesic Red Oak Northern Hardwood Forest
- Hemlock Northern Hardwood Forest
- Red Pine Forest
- Deer Wintering Areas
- Trail Free Area **(No New Trails)**

Inset: VT Land Management District Boundaries. District 4 in blue. Map 4 location at red star.