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Memo



Metro

600 NE Grand Ave.
Portland, OR 97232-2736

Date: September 26, 2017

From: Dan Moeller, Parks and Nature Conservation Program Director

Lisa Goorjian, Parks Planning and Operations Program Director

Subject: Recreation Ecology Literature Review

Thank you for your interest in Metro's review of the scientific literature on the effects of recreation on natural areas. This body of research will play an important role in helping Metro deliver on its parks and nature mission: to protect water quality, fish and wildlife habitat, and create opportunities to enjoy nature close to home through a connected system of parks, trails and natural areas.

Funding for the acquisition of most of Metro's 17,000-acre portfolio came from bond measures approved by voters across greater Portland in 1995 and 2006. Funding for operations comes from Metro's general fund, grants and two levies approved by voters in 2013 and 2016. Producing this document helps Metro keep the commitment we made to our region's residents in our System Plan in 2016 to use the best available science to guide the management of our parks and nature system.

The nature of a literature review is to summarize what has been studied, what has been learned and what the experts have concluded, thus providing a common ground for discussion. The attached document addresses the effects of three user groups — hikers, mountain bikers and equestrians — on trails, habitat, wildlife and water quality. It summarizes the findings of over 500 articles written and reviewed by the scientific community.

There is inherent tension within our mission. Providing people with access to nature has well-documented benefits including physical, psychological and spiritual health. People who have contact with nature learn to care about the environment, which can translate to personal conservation practices, volunteerism, voter support and funding to protect and restore nature. At the same time, recreational use of natural areas — whether by people on foot, bikes or horses, and with or without pets — has impacts on the plants, fish and wildlife living in these areas. Unmanaged, these impacts can undo many of the benefits these areas provide.

When planning public access, Metro works with the community to determine the types and levels of recreation that are desired and appropriate at a site, and how to design trail systems that avoid, minimize and mitigate impacts to wildlife and natural resources. These decisions can be complex.

Each natural area is unique. Differences influence a site's vulnerability to, or resilience against, negative effects from public use. Visitor access, ecological, and management goals differ among sites based on variables such as proximity to population centers, public interest, funding, concerns from neighbors or special interest groups, and politics. No single set of solutions works in every case.

The information provided here is intended to enhance collaboration in planning, designing and managing visitor access at sites where water quality, habitat and wildlife are important assets. Informed by this knowledge, we will be better able to make sound decisions about offering public access that accommodates people while also protecting the nature of a site.



Hiking, mountain biking and equestrian use in natural areas: A recreation ecology literature review

September 2017

Lori Hennings

Senior Natural Resource Scientist, Metro Parks and Nature

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TABLE OF CONTENTS

1. Introduction.....	1
1.1 Purpose of Literature Review	1
1.2 Trends in Recreational Activities.....	3
1.3 Key Findings	3
2. Effects of Recreation on Vegetation, Soil and Trail Condition.....	5
2.1 Initial Trail Construction	5
2.2 Vegetation Damage Adjacent to Trails.....	6
2.3 Soil Erosion and Compaction	10
2.4 Trail Widening and Incision.....	11
2.5 Amount of Use	13
2.6 Trail Effects by User Group.....	13
3. Effects of Unauthorized Trails	17
4. User Conflicts and Perceived Effects on Wildlife.....	21
5. Effects on Ecological Processes and Habitat.....	26
5.1 Riparian Habitat and Water Quality	27
5.2 Habitat Loss, Fragmentation, and Edge Effects	29
5.3 Invasive Species.....	34
6. Overview of Effects on Wildlife.....	39
6.1 Disturbance and the Antipredator Response	39
6.2 Habituation, Sensitization and Tolerance	42
6.3 Size Matters: Individuals and Herds	45
6.4 Speed and Directness of Approach.....	46
6.5 Habitat Structure and Nest or Perch Height.....	46
6.6 Season, Reproductive Status and Time of Day.....	47

6.7 Noise and Light Pollution	48
7. Effects on Wildlife by Species Group	53
7.1 Species Group: Invertebrates	53
7.2 Species Group: Reptiles and Amphibians	54
7.3 Species Group: Birds	56
7.4 Species Group: Mammals.....	65
8. Tools to Help Manage Negative Effects.....	74
8.1 Trail Design and Construction Resources	74
8.2 Recreational Carrying Capacity and Visitor Use Frameworks	78
8.3 Monitoring Approaches	79
8.4 Addressing Unauthorized Trails	82
8.5 Protecting Riparian Habitat and Water Quality	83
8.6 Minimizing Fragmentation and Edge Effects.....	85
8.7 Minimizing Effects of Recreational Use on Wildlife	88
Gathering local wildlife information.....	88
Wildlife flight initiation and alert distances	90
8.8 Reducing Conflicts between User Groups	95
8.9 Notes about Signage and Educational Messaging	97
Literature Cited.....	99

TABLES

Table 1. Summary of understory plant life forms' resistance, resilience, and presumed tolerance

Table 2. Variables associated with increased erosion

Table 3. Summary of methods used to measure trail-induced fragmentation or related effects on formal (FT) or unauthorized trails (UT)

Table 4. Definitions of terms used in wildlife studies to measure antipredator response, including tolerance to human disturbance

Table 5. Classification of recreational-use impact on wildlife derived from interviews with refuge managers in the northeastern U.S.

Table 6. A sampling of available trail design and construction guidance documents

Table 7. Examples of indicators, thresholds and triggers to assess and address visitor impacts

Table 8. Summary statistics for species groups' Flight Initiation Distances or Alert Distances from the scientific literature

FIGURES

Figure 1. Some key factors influencing environmental outcomes when recreational access is introduced to a natural area

Figure 2. Comparison of Region 2 and Oregon statewide residents' recreational investment priorities

Figure 3. Illustration of the effect of trail slope on severity of erosion

Figure 4. Unauthorized trail at a Metro natural area

Figure 5. Unauthorized trail in a Metro natural area leading from a residence

Figure 6. Statistically significant trends for Oregon breeding birds by group, 1966-2013

Figure 7. The Lakeside pedestrian and wildlife undercrossing in Portland, Oregon

Figure 8. Typical habitat size requirements for selected wildlife species

Figure 9. Flight Initiation or alert distances for various wildlife species groups

Figure 10. Example of a simple way to use the data presented in Table 8 to consider potential effects of human disturbance on waterfowl from a planned wildlife viewing blind adjacent to a large wetland

APPENDICES

Appendix 1. Impacts of dogs literature review (previously completed)

Appendix 2. Scientific names for species discussed in text

Appendix 3. Flight Initiation Distance (FID), Alert Distance and related variables for various wildlife species that occur in the U.S.

1. INTRODUCTION

1.1 PURPOSE OF LITERATURE REVIEW

Metro is the regional government in the Portland, Oregon area. Thanks to the region's voters, the agency has acquired approximately 17,000 acres of natural areas to protect water quality, wildlife habitat and connect people with nature. The goal of this document is to better understand the trade-offs between different types and levels of recreational access in the context of our work to protect habitat and water quality, and provide access to nature in a growing urban area. Only by thoroughly understanding the effects of recreational activities on wildlife and water quality are we able to avoid, minimize and mitigate potential harm to the resources we are committed to protecting.

Recreation ecology is the scientific study of environmental impacts resulting from recreational activity in protected natural areas. The nature of a literature review is to summarize what has been studied, what has been learned, and what the experts have concluded. This document reviews the literature on overall and relative effects of three user groups – hikers, mountain bikers and equestrians – on trails, habitat, and wildlife to help inform ecologically appropriate placement and construction of trails in natural areas. Studies are reviewed from the U.S. and elsewhere, with a focus on soft-surface trails in natural areas. We included limited information about other non-motorized trail user groups such as trail runners and beach walkers. Motorized off-road vehicles were omitted from this review because they are generally not allowed on natural area trails within the urban and near-urban region. A previous literature review on the effects of dogs on wildlife and water quality is included as Appendix 1.

Studies vary in terminology for our recreational groups of interest. In this report “hiker” generally means a person walking along a trail for various reasons such as exercise, wildlife watching or moving between places. “Mountain biker” refers to a non-motorized bicycle rider on a soft or natural surface trail; alternative terms in the literature include off-road bicyclists or off-road cyclists. “Equestrian” refers to a person riding a horse on a trail. Throughout the text we refer to these as “user groups.”

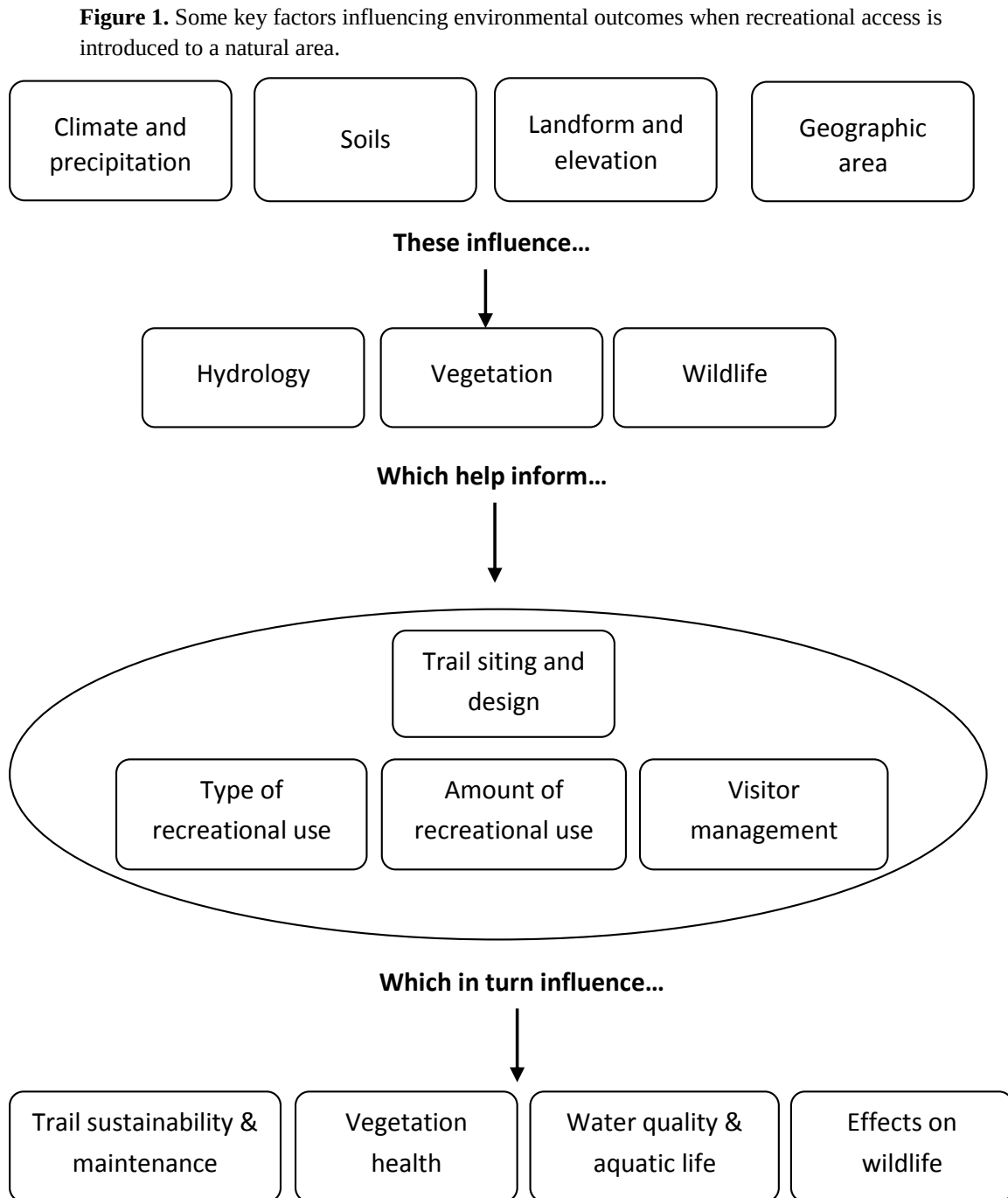
Trails provide people with important opportunities to improve health and well-being, and providing access to nature is especially important in urban areas.[\[2-5\]](#) However, as indicated in various literature reviews, trails and trail use can damage natural areas including negatively affecting soils, vegetation, water quality, plants, and animals.[\[6-27\]](#) Damage to trails or habitats and negative effects on wildlife are more likely when trails are inappropriately located, designed, constructed, maintained or used, or when unauthorized trails are allowed to proliferate. These issues can also increase trail maintenance costs[\[28-30\]](#) and negatively affect visitors' experience.[\[31-33\]](#)

This document reviews the types of recreational effects in Chapters 2-7, including information about user group-specific effects. Each chapter includes a summary of key points. Chapter 8 offers information on how to minimize, monitor and manage effects. Throughout the review we provide representative study examples with additional citations.

We paid close attention to the effects of recreation on wildlife (Chapters 6 and 7) because they are less well documented than physical effects such as erosion or vegetation damage. Scientific names for species mentioned in the text are in Appendix 2. For wildlife, human disturbance increases animals' stress and can cause them to hide, change behavior or flee. Some species, such as those that do well in urban areas, are generalists and can tolerate

human disturbance. Other species such as pregnant animals, long-distance migrants, and habitat specialists tend to be more stressed and displaced by trail users. Some species may permanently leave a natural area.

Figure 1 illustrates the relationships between environmental, trail design, recreational use and their effects on trail damage, water quality, vegetation damage and wildlife.

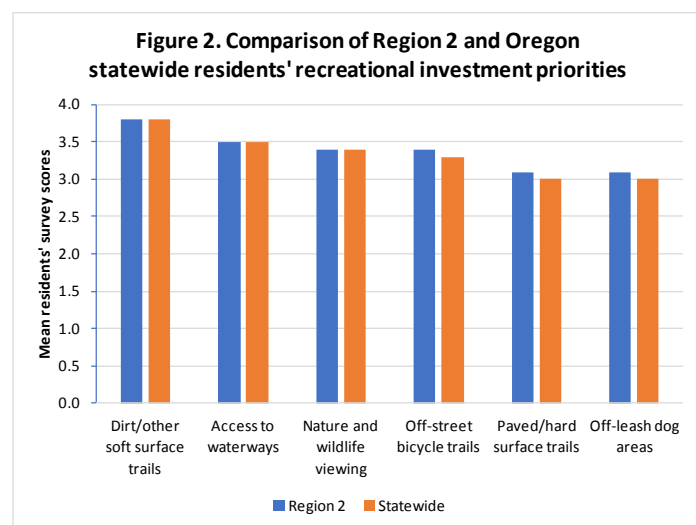


1.2 TRENDS IN RECREATIONAL ACTIVITIES

Natural areas are subject to competing demands by different user groups, and demand increases with population.[34] Nationwide and in Oregon, walking/hiking is typically the most common form of recreational use at parks and natural areas. Oregon's *Statewide Comprehensive Outdoor Recreation Plan* (SCORP)[34] identifies the most rapidly increasing U.S. adult recreational activities as walking for pleasure, viewing/photographing birds, and day hiking. Interest in mountain biking is rising in the U.S., with 8.3 million U.S. residents riding mountain bikes in 2015, a 22 percent increase since 2006.[35] The number of hikers increased even more during the same time period – up 24 percent, to 37.2 million participants. In Oregon, equestrian use demand is expected to increase, but hiking and mountain biking demand will still comprise the majority of terrestrial trail use.

In a recent survey, Oregonians identified their top priorities for future recreational access investments.¹ The report's data are compiled statewide, plus divided by county-based planning regions.[34] Region 2, the most populous, includes the greater Portland metropolitan region and areas around the cities of Newberg, Salem and Hood River (Washington, Multnomah, Clackamas, Yamhill, Columbia, Hood River, Polk and Marion Counties).

Figure 2 compares residents' recreational investment priorities at the Region 2 and statewide levels.[34] The top three priorities are identical for state and Region 2. However, Region 2 residents place slightly more value on investments in off-street bicycle trails (which include but are not limited to mountain bikes), paved/hard surface trails, and off-leash dog areas compared to residents throughout the state. Locally, some area residents have recently requested that Metro increase the amount of mountain biking and equestrian trails and allow dogs in its natural areas, triggering the need for this review as well as a recent review of the effects of dogs on wildlife and water quality (Appendix 1).



1.3 KEY FINDINGS

Our literature review identified four key themes differentiating recreational user effects on trails from users' effects on wildlife:

1. **Affected area:** The physical impacts from formal (planned) trail construction and use are typically limited to a relatively narrow corridor. In contrast, when people use trails the disturbance effects on wildlife may extend hundreds of meters from the trail into natural areas.

¹ Equestrian use was not offered as an option in this survey. Data related to picnic sites, playgrounds, sports fields, motorized vehicles and community gardens were excluded because this review's focus is on trails and natural areas.

2. **Predictability of effects:** Effects of user groups on trails are fairly predictable based on variables such as topography, soils and climate, but those same user groups' effects on wildlife are more complex because they vary by season, habitat, species, and individual animals' temperament.
3. **Effects of increased use:** For trails, the most significant damage usually occurs when a trail is first built, although higher levels of recreational cause additional damage. For wildlife, negative effects tend to grow stronger with increased trail use.
4. **How different user groups affect wildlife and trails:** While all trail user groups can cause trail damage or disturb wildlife, the results of this review suggest the following generalizations when comparing hiking, mountain biking and equestrian user groups:
 - a. Trails – Equestrians cause the greatest amount of soil loss and trail damage compared to the other two user groups. The magnitude of trail effects from hikers and mountain bikers appear to be similar to one another.
 - b. Wildlife – Equestrians appear to cause the least wildlife disturbance. Hikers disturb wildlife, with increased effects when talking or stopping to view or photograph wildlife. Fast-moving trail users such as mountain bikers and trail runners are particularly disturbing to wildlife due to the element of surprise.

Although this literature review focuses on potentially harmful effects of recreational trail use on wildlife and the environment, we recognize that providing access to nature fulfills an innate human need and creates opportunities for people to appreciate, benefit from and value the natural world. Such experiences and values are essential to the continued protection and long-term care of our natural environment. This report identifies specific effects and provides information for natural area planners and land managers to help evaluate and reduce these effects.

2. EFFECTS OF RECREATION ON VEGETATION, SOIL AND TRAIL CONDITION

Many recreational trail studies focus on user groups' effects on soils, vegetation, trail incision, trail widening, and trail proliferation. In general, the effects of recreational use on trails happen quickly but recovery is slow.[\[24\]](#) Several studies suggest that regardless of type of recreational use, the most significant physical effects occur during trail construction.[\[14, 15, 19, 24, 36\]](#) Once a trail is built, the magnitude of additional effects depends on the amount and type of visitor use, trail density, spatial distribution and environmental variables.[\[37-40\]](#) Slope, soil type, precipitation and vegetation type strongly influence the degree of trail damage from recreational use.

The following sections review effects of trail construction and use on vegetation, soil, and trail conditions, followed by a section on the effects of specific user groups. Understanding how habitat, wildlife and trail condition are affected by various types and degree of recreation use will enable more informed decision making about trail location, design and management, and to better understand or predict the tradeoffs of providing access to nature.

2.1 INITIAL TRAIL CONSTRUCTION

Trail construction causes temporary and permanent disturbance to a site. Vegetation is removed and soils are compacted within the width of the trail itself. Vegetation is cleared to maintain a specified clearance area to make trails safe and passable. In addition, trail construction often requires temporary disturbance to allow for construction activities such as grading. However, vegetation damage from initial trail construction is typically limited to a fairly narrow corridor.[\[41\]](#)

Damage from trail construction can include the following (note that the trail construction industry has standard best management practices for construction that are designed to minimize these impacts - see Chapter 8):

- vegetation loss [\[41\]](#)
- loss of leaf litter and organic material[\[42-44\]](#)
- changes in microclimate due to reduced shade[\[45\]](#)
- introduction of invasive weed seeds carried in on boots and equipment, with germination facilitated by ground disturbance[\[46\]](#)
- tree damage or root exposure[\[47\]](#)
- wildlife disturbance, habitat damage and potential loss of connectivity, depending on trail width and wildlife species (Chapters 5-7)[\[48, 49\]](#)

For poorly designed and sited trails, immediate and lasting environmental effects from trail construction may be more significant than those caused by trail use.[\[14, 15, 19, 36, 50\]](#) However, soft surface trails can sometimes be built without disturbing trees, and lasting habitat effects such as altered microclimate can be minimized if the trail is properly sited, designed and constructed and vegetation disturbance is minimized. For example, Metro constructs many of its trails without removing trees.

Trail clearing width and height influence the extent of vegetation damage from trail construction. The trail clearing width is the space to each side of the trail tread that is cleared for trail users; this is the widest area of direct physical effects resulting from trail construction.[\[51, 52\]](#) The clearing width is designed to protect trail users from obstructions that would physically extend into the trail corridor or impede travel progress. Clearing width and height needed vary by trail user group. For example, when appropriately designed, vertical clearance is higher for

an equestrian trail compared to a hiking trail; wheelchair accessible or multi-use trail designs tend to be wider than other trail types.[53] Widths will also vary based on setting and numbers of visitors expected.[54, 55]

2.2 VEGETATION DAMAGE ADJACENT TO TRAILS

This section summarizes research related to vegetation trampling adjacent to trails. Trailside trampling can occur when trail users step aside to let other users pass, move off of the formal trail to avoid muddy conditions, walk or ride side-by-side, cut corners, or when the formal trail is indistinct.[16, 56-58]

Protecting trailside vegetation is important because plants intercept rainwater and their roots help soils absorb water, thereby slowing surface water flow, protecting water quality, and reducing trail-damaging runoff and erosion. Vegetation removal can alter local (“micro-”) climate, resulting in more sun and wind exposure and causing dryer, warmer conditions (Section 5.2). Such circumstances can stress native and favor invasive plant species.[30, 59-61] Protecting trailside vegetation limits the total amount of habitat affected by the trail system. In addition, trees and shrubs can reduce stress on wildlife by providing a visual buffer between trail users and wildlife (Chapter 6).[62]

How damage occurs. Trail users cause two types of stress to plants: physical damage to the plant resulting in impaired food production, water loss and repair/regeneration energy demands; and altered soil habitats that impair root processes such as nutrient uptake and ability of the plant to spread.[12] These stressors can vary in severity depending on soils, drainage, elevation and aspect, habitat type (e.g., grassland or forest), and plant characteristics.[12]

Measuring plant tolerance to trampling. Many vegetation studies are trampling experiments – various user types taking a controlled number of passes to mimic varying intensity of use. Trampling studies are typically conducted where no trails currently exist.

Because most trampling studies are short term and use a limited number of passes (e.g., ranging from 25 to 1,500), they may underestimate effects that would emerge over long-term and higher intensity uses. They are however, quite useful for measuring effects of initial trail creation, informing trail layouts in areas with sensitive habitats, and prioritizing activities such as de-activating unauthorized trails.

Trampling studies also hold the advantage of controlling for user group, habitat type and the number of users (trampling intensity).

Trampling studies focus on the resistance, resilience and sometimes, the tolerance of plants to trampling.[63] *Resistance* measures the amount of damage to plants caused by direct trampling via hiking, mountain biking or equestrian use. At higher uses, even resistant plant species’ ability to withstand effects declines. *Resilience* measures plant recovery over time after trampling is halted. This is an important distinction because resistant plants are not necessarily resilient. *Tolerance* is a better measure but is less frequently used; tolerance combines resistance and resilience. Plants with high tolerance are less prone to long-term damage by trail users. Table 1 summarizes some of the information available on plant forms, resistance, resilience and tolerance.

Resistance is the amount of damage caused by trampling

Resilience is how well plants recover after trampling

Tolerance combines resistance and resilience

Plant form characteristics and their susceptibility to trampling. Plant form – including characteristics such as woody versus herbaceous, rooting/propagation form, stature and erectness, and whether plants are grasses, forbs

or shrubs – strongly influences how well plants can tolerate trampling, probably more than other factors such as soils.[12, 21, 63-65]

Some vegetation types, such as plants with tubers or bulbs, or many sun-loving plants, are more tolerant of trampling than others (Table 1). On the other hand, non-woody shade tolerant plants are susceptible to trampling damage because they tend to have large leaf surfaces supported by rigid, easily crushed stems.[66] Woody shrubs are also susceptible because when stems are broken or crushed, all of the buds are destroyed.

For example, in western Montana, trampling effects differed between vegetation community types.[67] Grassland habitat proved much more resistant than forested habitat types, with no noticeable grassland cover loss until 1,600 trampling passes. Other studies also found grasslands and meadows, which tend to occur in flatter areas, to be more resistant to trampling than shrub or forest communities. However, trail users in flat areas tend to spread out, causing wider and sometimes multiple parallel trails.[12, 58, 64, 68, 69]

In Australia, upright plants such as bracken ferns were least resistant to trampling; a tall grass understory was moderately resistant, and a short grass understory was most resistant.[64] Species richness decreased most rapidly in the least resistant plant community.

Cole and Trull conducted an experiment in the Okanagan National Forest within four vegetation types at varying trampling intensities.[70] They differentiated between resistance (direct damage) and resilience (recovery after one year). Both vegetation type and trampling intensity had significant effects. Sedge meadow was much more resistant than forbs, but recovery after a year was better in forbs. The lowest recovery was in the two woody vegetation types, which were susceptible even to low levels of trampling. High resistance was primarily determined by stature, arrangement, and toughness/flexibility of above-ground plant tissues. Resilience, on the other hand, was higher in plants with tough perennial vegetation and high growth rates. The most resistant and resilient (tolerant) plants were low growing and had either tufted growth form or leaves in basal whorls that grow flat against the ground (graminoids: grasses, sedges and rushes). Non-resistant plants that also had low resilience included certain tree seedlings and broad-leafed herbs; the latter were eliminated after as few as 25 passes.

Non-resistant plants are common in forested settings, where just a few user passes can affect forest plant communities.

In a subsequent study Cole found that plant morphological characteristics explained more of the variation in response to trampling than the site characteristics that were assessed (altitude, tree canopy cover or total ground layer vegetation cover, although they did not measure soil moisture or fertility).[63] In this study, plant species' tolerance was more correlated with resilience than resistance – in fact, resilience and resistance were sometimes negatively correlated with one another. The most resilient plants were hemicryptophytes (buds at or near the soil surface, such as dandelions) and geophytes (resting buds lying beneath the surface of the ground as a rhizome, bulb or corm; see Table 1). Pescott's review of the literature on vegetation recovery after trampling had similar findings; plant form was the key variable and was more important than the amount of trampling.[21] Thus, placing trails in the most resilient – which appears to correlate more closely with tolerance – rather than resistant plant communities may result in less damage over time, particularly when trails are wider, in moister settings or where there is a high likelihood of unauthorized trails. Tolerant plant communities are better yet, but such plant communities may be uncommon in a given region.

Regardless of habitat type or the number of trampling passes, these studies suggest that predicting the effects of trail users on vegetation depends largely on plant form, although other factors such as proper trail siting and construction, trail slope, soil type, user group and amount of use also play roles. When plants next to trails are non-tolerant, trail users that step aside or go around other users can cause substantial vegetation damage and subsequent erosion and trail widening compared to areas with more tolerant species.

In summary, more trampling-sensitive plants have these characteristics: soft delicate leaves, a single exposed perennating² bud, growth activity throughout the traffic season, adaptation to moist habitats, and shade-tolerant species. [\[71\]](#) Plants that adapt well to trampling include weed-like characteristics: tough but flexible stems, annual reproduction with high numbers of small seeds, ability to penetrate compacted soils, and the ability to withstand quicker drying, high solar intensity, and higher maximum temperatures of unsheltered locations. A locally-specific list of native species with some or all of these characteristics could aid in selecting native planting palettes for revegetation or to withstand trampling, such as alongside trails.

² Perennation is the ability of plants to survive from one germinating season to another, especially through storage organs such as tubers or rhizomes. Typically these would have relatively high tolerance; however, an exposed perennating bulb is vulnerable to damage from trampling.

Table 1. Summary of understory plant life forms' resistance, resilience, and presumed tolerance to trampling. Derived primarily from data presented in Yorks et al.'s meta-analysis of vegetation tolerance to foot traffic.[71]

Plant life form	Root form	Life span	Other characteristics	Assumed tolerance based on resistance & resilience
Shrubs <i>Small to medium sized woody plants; tend to be vulnerable to trampling</i>	Root forms: fibrous or tap Resistance: Fibrous and tap roots are similar Resilience: Tap roots are more resilient than fibrous	Perennial	Resistance: deciduous and evergreen are similar Resilience: deciduous > evergreen	Most tolerant: shrubs with tap roots; deciduous shrubs.
Tree seedlings	Typically fibrous	Perennial	Resistance: evergreen > deciduous Resilience: deciduous > evergreen	Most tolerant: probably deciduous, because resilience correlates more strongly with tolerance than does resistance
Forbs <i>Herbaceous flowering plants that are not graminoids</i>	Root forms: fibrous, tap, fleshy Resistance: fairly similar; most resistant in this order: fibrous, tap, fleshy Resilience: tap roots are more resilient than fibrous or fleshy	Perennial – less resistant, less resilient Annual – more resistant, more resilient	<u>Reproductive pathway</u> ³ Resistance: Stolon > seed > rhizome Resilience: Stolon > seed > rhizome	Most tolerant: annual forbs with tap roots; stolon reproductive pathway
Graminoids <i>Grasses, sedges and rushes</i>	Root form: fibrous	Perennial – less resistant, less resilient Annual – more resistant, more resilient	<u>Reproductive pathway</u> Resistance: Tiller > seed and rhizome > stolon Resilience: Tiller > rhizome > stolon > seed	Most tolerant: annuals
Cryptophytes (specifically, geophytes subdivision) <i>Plants with reproductive structures underground, including corms or bulbs, such as onions and lilies</i>	Root form: fleshy	Perennial		Tend to be more tolerant than many other life forms
Hemicryptophytes <i>Buds at or near the soil surface, such as dandelions and daisies; many have rosette basal leaves</i>	Root form: typically tap or fibrous	Annual or perennial		Tend to be more tolerant than many other life forms

³ Stolons are horizontal, above-ground stems. Rhizomes are specialized horizontal stems below the soil surface that eventually turn upward ("runners"). Tillers stems are produced by grass plants, and refer to all shoots that grow after the initial parent shoot grows from a seed.

2.3 SOIL EROSION AND COMPACTION

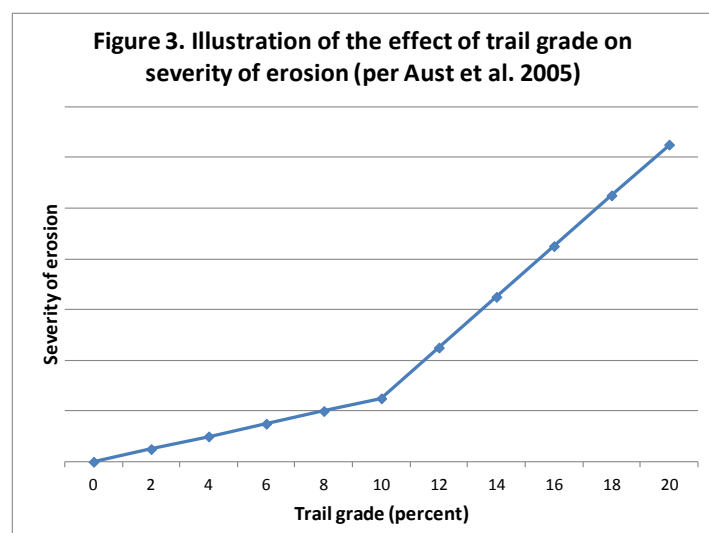
Soil loss through erosion can be a significant and long-term effect of recreational trail use.[19, 39, 72] Soil erosion has potential to harm at-risk aquatic wildlife and threaten downstream water quality (Section 5.1). Erosion occurs when water runs off the trail surface, carrying soil particles with it. Typical signs of erosion include exposed roots, bare rock, visible micro-channels on the trail surface and trail ruts.[54] Limiting soil erosion on trails is important because left unchecked it is likely to become increasingly severe, have negative environmental consequences, may impede trail use, and can contribute to trail widening over time due to users seeking to circumvent muddy areas.[16, 56]

Soil characteristics and susceptibility to erosion. Geomorphic processes – the natural mechanisms of weathering, erosion and deposition, including landform – are the most important drivers of trail erosion, and may be more important than the type of recreational use.[16, 73] Factors that correlate with the severity of erosion include soil texture, steepness of terrain, elevation, proximity to water resources, trail design and other variables (Table 2), vegetation characteristics (Section 2.2) and the weight and force of different types of trail user groups. Trail slope and erosion effects in general are magnified in wet areas and during wet seasons.[14, 29, 31, 54, 58, 68, 72-79]

How damage occurs. Trampling loosens the top layer of soils while simultaneously compacting soils below, both which increase the potential for erosion.[80, 81] Soil compaction is influenced by soil bulk density, defined as the weight of dry soil per unit volume. Although it may seem counter-intuitive, sandy soils tend to have high bulk density, while clay soils have low bulk density; it has to do with the size and shape of soil particles, their arrangement, and the voids between the particles.[82] Bulk density increases with soil compaction. Soils with lower bulk density such as clay are more prone to compaction, whereas denser soils are more prone to yielding sediment for erosion.[29, 79, 83, 84] More compacted soils have fewer pockets of air space (pores), and the fewer pores are available the longer it will take for water to infiltrate – generating more runoff, the agent for soil erosion.[85] Trails with deeper soils are also more prone to incision and erosion.[29]

Appropriate trail design can minimize risk of erosion. Trail grade (slope) and slope alignment angle (also called trail angle or cross slope) are two erosion-related factors to consider in trail design.[56] Trail grade refers to the steepness of the trail itself. Trail sections with grades above approximately 10-12 percent tend to be more erosion-prone (Figure 3),[29] and longer sections of trails with relatively steep trail grades can be problematic because runoff has a chance to accelerate down the slope, generating more force to dislodge soil particles and carry them further.[58, 84, 86] Frequent grade reversal, cross slope, and erosion control features on sloped trails can substantially reduce soil erosion and trail damage (Chapter 8).

Trail slope alignment angle is the orientation of the trail (0-90 degrees) to the prevailing grade of the landform.[77] A low slope alignment angle trail section is oriented up- and down-slope; a high slope alignment angle trail section



is oriented along the contour. Trails with low slope alignment angles take a steep, direct path up and down a hill and have poor drainage and higher erosion risk.[\[16, 52\]](#)

Guidance from the International Mountain Bicycling Association (IMBA), the Professional Trailbuilder’s Association (PTBA) and others recommend following the “10 percent rule:” the average or overall trail grade should not exceed 10 percent.[\[28, 87-89\]](#) The IMBA, PTBA and other guidance documents also recommend following the “half rule” guidance, in which trail grades should not be greater than half the grade of the slope across which the trail is built,[\[28, 87-89\]](#) although Marion and Wimpey did not find any direct research backing this guidance.[\[90\]](#) Marion and Olive offer literature-derived guidance for maximum slopes depending on user type and setting.[\[77\]](#)

Olive and Marion reviewed the literature and identified key factors that make trails more susceptible to erosion (Table 2, with additional literature citations added).[\[72\]](#)

Table 2. Variables associated with increased erosion. (Adapted from Olive and Marion, 2009[\[72\]](#))

Variable associated with increased erosion	Characteristics
Soil texture	Homogenous texture, fine- or course-grained textures. Clayey soils are most at risk because they have low bulk density and can be heavily compacted when dry, but also have high ability to retain water, swelling when inundated. [73]
Vegetation	Some types of plants are more vulnerable than others (Section 2.2). Trails in more vulnerable plant communities may expose soil and increase erosion risk.
Steep terrain	Steep terrain elevates the risk of erosion. [77]
Higher elevation	The greater rainfall typically found at higher elevations can increase erosion rates. [29, 54]
Proximity to water resources	Moist soils in riparian areas are especially vulnerable to erosion. Riparian vegetation is easily damaged, which can expose bare soil. [31, 73, 76, 77, 79]
Vegetation	Lack of tree cover increases erosion risk. Tree cover can protect trail treads by reducing the amount of water reaching the ground and reducing “splash erosion.” [91]
Trail design	Trails with low slope alignment angles and those exceeding the “half rule” are more at risk of erosion. [72, 90]
Maintenance	No or ineffective tread drainage features. Erosion reduction features such as tread outslope, grade reversals or rolling grade dips reduce trail erosion. Traditional water bars are no longer considered a best practice because they can exacerbate trail erosion when they fail. [29]
Visitor management	Failure to regulate amount or type of use; lack of education to reduce effects. [92]
User-related	High use in sensitive vegetation/soil types, improper use for environmental and design factors, failure to stay on formal paths, high use during wet conditions.

2.4 TRAIL WIDENING AND INCISION

Leung and Marion state that the most critical problems associated with trails are soil compaction, trail widening, trail incision and resultant soil loss.[\[16\]](#) The variations in vegetation, soils, landform and moisture discussed above influence the degree of unintended trail widening and incision (deepening).[\[39\]](#) Wider trails tend to occur in flat areas where users seek to avoid wet areas associated with standing water and mud, whereas more incised trails tend to occur on sections with steeper trail slope alignments (Section 2.4).[\[29, 58, 75, 76\]](#)

Trail widening. Trail widening and multiple treads often occur in open, flat areas where people can walk or ride side by side and easily pass other trail users, or when trail users are trying to avoid muddy, puddled, or other

problematic trail sections.[16, 24, 93] Heavily used trails tend to become wider because hikers, mountain bikers and equestrians move off trail to pass stopped or slower-moving groups of people.[93] Horses tend to create rougher trails, leading to wider trails when other visitors step around the trail to find a smoother trail surface.[79, 94] However, Dale and Weaver found little difference between hiking-only trails in meadows versus those used by both hikers and horses.[95]

Several studies have compared trail widths for formal and unauthorized trails. In their expansive study of mountain biking effects in the American southwest, Foti et al. compared the mean width and depth of formal versus unauthorized mountain biker trails and found that unauthorized trails were wider, but formal trails were deeper[58]. A study in woodland habitat in Tennessee and Kentucky also documented wider unauthorized trails compared to formal trails.[77] In Foti et al.'s mountain biking study, maximum trail depth increased significantly from shallow (<5 percent) to steeper trail grades; slopes greater than 12 percent were strongly correlated with high soil and vegetation degradation. Mountain bikers often "cut the corners" at 90-degree trail intersections, substantially widening trails there. Signs were placed at the trail intersections, and the researchers postulated that signage placed before fast-moving bikes enter the intersection may help reduce this effect.

Trail widening often occurs in flat, open habitats or when trails are muddy.

Compaction and erosion of the trail tread lead to trail incision.

Trail incision. Trail incision is a result of compaction and erosion of the trail tread.[77] Trails constructed on soils with fine, homogenous textures or on steeper slopes are prone to incision.[77] On the large-scale Appalachian Trail in Great Smoky Mountains National Park, trail incision was associated with trail grade, soil type, vegetation type, elevation, precipitation, and visitor use whereas trail width was related only to soil and vegetation types.[39]

On a smaller scale, Godwin investigated how the processes of soil erosion and compaction influence trail incision along the New World Gulch Trail in Montana.[76] Trail grade, amount of water runoff and estimated soil bulk density were significant factors. Steeper trail grades led to more erosion, and both trail grade and erosion were associated with trail incision. Trail use led to soil compaction, which tends to exacerbate erosion.[29, 79, 83, 84] These studies emphasize the importance of accounting for trail grade, soil characteristics and vegetation in order to minimize incision when planning trails.

Trail surface can help reduce the effect of slope on trail incision, with thicker gravel being associated with lower erosion and incision. Aust et al. studied the effects of horses on trails in Virginia hardwood forests.[29] Trail incision was deepest on trails with bare soil; at medium and high (but not at low) levels of use, application of gravel mitigated but did not prevent incision. On un-graveled or lightly gravelled trails, soil erosion increased dramatically after approximately 12 percent trail grade; maximum incision peaked in the 12-17 percent trail grade range, but declined along steeper trails. The thickest, 3.5-inch gravel depth led to less incision even on higher trail grades, although the authors noted that management actions such as grading may have mitigated effects at higher slopes.

The types of use can also influence the degree of trail incision. For example, in the northern Rocky Mountains, multi-use trails (horses and hikers) became more incised over time compared to hikers alone.[95] There were not enough horse-only trails to include in the data analysis.

2.5 AMOUNT OF USE

The topic of recreational carrying capacity or the acceptable amount of use, for individual trails or at a site, arises repeatedly in the literature.[\[17, 93, 96-98\]](#) In this case, by carrying capacity we mean the amount, and sometimes type, of recreation that can occur without causing excessive trail or environmental damage (related wildlife issues are described in Chapters 6 and 7). Carrying capacity can also refer to the amount of use beyond which user conflict or negative user experience may occur. Carrying capacity is a critical trail management issue, and can be increased by avoiding placing trails in sensitive plant communities and wildlife areas. Visitor use frameworks can be used to help identify the upper limits of recreational users or negative effects for any given site (Section 8.2).

Once a trail is established, vegetation and trail damage tend to increase incrementally with the number of users up to a certain point, although vegetation damage tends to stay within a few meters of trails.[\[58, 77, 95, 99\]](#) For example, Dale and Weaver studied subalpine forest trails in the Rocky Mountains.[\[95\]](#) Trail widths increased slowly with increasing traffic. Trails used by both hikers and horses were deeper, but not wider, than hiking trails. Most vegetation damage was within 1-2 meters of the trail. When the amount of use is held uniform or substantial use has already occurred, factors such as soil properties, moisture, vegetation type and landform, and different types of recreational use tend to drive additional on and near-trail damage.[\[12, 21, 100\]](#)

Trampling studies (Section 2.2) often attempt to test trail use thresholds, beyond which substantial vegetation damage may occur. This type of threshold study can provide a quantifiable indicator of the environmental damage caused by trail users and can provide habitat-specific information about a site's potential carrying capacity. The literature provides numerous examples of thresholds of use, beyond which unacceptable damage on or near trails may occur.[\[58, 67, 69, 70, 99, 101-106\]](#)

2.6 TRAIL EFFECTS BY USER GROUP

Many studies have examined the effects on trails by individual user groups. Most focus on hiking, but several also investigated mountain biking or equestrian use, including several literature reviews. [\[7, 15, 18, 20, 22, 27, 31, 41, 66, 72, 73, 80, 99, 107-109\]](#) Several comparative studies document damage at lower levels of use for some user groups compared to others.[\[78, 79, 99, 102, 105, 109\]](#)

Studies document that within our three user groups, horses tend to be most damaging to trails even at low levels of use, due to the concentrated weight of the horse and rider on a relatively small area (hooves).[\[7, 14, 20, 72, 77, 79, 84, 103, 109-111\]](#) Several researchers recommended a reduced number or length of dedicated equestrian trails in natural areas.[\[14, 72, 110\]](#) Horses tend to kick up topsoil and compact the soils below; with the topsoil gone, the finer soils that remain are more easily eroded, and trails are also more prone to becoming muddy.[\[72, 112\]](#)

On formal trails, the effects from hikers and mountain bikers appear to be similar in type and severity.[\[68, 78, 105, 113\]](#) Some mountain bikers prefer trails with steeper slopes, downhill features and sharp curves[\[75, 113\]](#), which can cause significant impacts on poorly designed and maintained trails or on unauthorized trails. Mountain bikers can cover more ground than hikers[\[113\]](#) and can cause incision and excess soil and vegetation damage from skidding, jumps, bridges and other technical features.[\[9, 86, 105, 114\]](#) However, there are usually more hikers than mountain bikers on mixed use trails, and hikers may create more unauthorized trails than mountain bikers because it is easy to walk off trails. Without more specific studies, we are unable to determine on a one-to-one basis whether one user group (hikers versus mountain bikers) causes more trail damage than the other.

In Tennessee and Kentucky oak woodlands, the type of use was more important to trail condition than the number of users.[77] Equestrian trails were substantially more degraded than hiking and mountain biking trails; hiking trails were slightly more degraded than mountain biking trails. For example:

- Soil loss from erosion was lowest for mountain biking trails, somewhat higher for hiking trails, and nearly an order of magnitude higher for equestrian trails.
- Percentage of trails with severe erosion (>12.7 cm deep) was 9 percent for equestrian trails, 1.4 percent for hiking trails and 0.6 percent for bike trails.
- Equestrian trails were widest, followed by hiking and biking trails. However, the researchers did not state whether this was use-related or due to original trail design.

Researchers in Montana and Wyoming forests found that increased traffic of any kind led to wider trails, and that equestrian trails were deeper but not wider than hiking trails.[95] Other studies also document deeper trails from horses than other uses.[77, 109, 111] Whitaker found that horse trails in the Great Smoky Mountains National Park were wider and deeper than hiking trails. Studies also suggest that soils may be especially important when considering equestrian use; trails with deeper soils are more prone to incision and erosion,[29] and equestrian trails may be ill-advised in such circumstances.

In Montana researchers conducted a trampling study comparing hiker, equestrian and motorcycle effects in meadow and forested habitats.[68] Although our literature review does not address motorcycles as a user group, the results help tease out relative effects of different user groups. Hikers were less damaging than the other two user groups. Hikers and equestrians were most damaging when going downhill, with the reverse pattern seen in motorcycles. Damage was generally worse on steeper slopes and curves, and damage occurred less quickly in grassy compared to woody vegetation types.

In contrast, Pickering's trampling study in subalpine Australian habitats found that mountain bikers caused more damage on up- or downhill slopes compared to hikers, which finding was only apparent at the higher 500-pass use.[99] Because some trampling studies test only 100-250 passes, such user-specific differences may not always be revealed.

In Finland, researchers compared the effects of hiking, skiing and equestrian use on trails.[109] Effects were related to recreational activity, research site and forest type. Equestrian trails were as deep as hiking trails but hiking trails had 150 times more users. Hiking trail plots had little to no vegetation cover; equestrian plots had lower vegetation cover than controls. Equestrian trails had more forbs and grasses, many of them non-native (Section 5.3).

Four trampling studies from Montana also reveal that horses create more erosion and rougher trails than other user groups. In the first study, one third of total sediment mobilization was due to user groups, with the remainder due to soil texture and slope.[73] Horses and hikers made more sediment available than mountain bikers, particularly on wet trails. These effects

Horses tend to damage trails more than hikers or mountain bikers.

occurred on newly created trails at only 100 passes. The second, third and fourth Montana studies compared the relative effects of hikers, horses and llamas on trail erosion. DeLuca et al. found that all user groups made sediment available for erosion.[79] Hiker and llama effects were similar; horses caused greater soil compaction, yielded more sediment and caused rougher trails. More passes resulted in more damage. Cole and Spildie assessed

user group trampling effects at the time of the study and one year later.[\[103\]](#) Horse traffic caused the strongest effects, which were still visible after one year. Hiker and llama effects were lowest, less permanent and similar. The degree of effects differed by vegetation. In the fourth study, Patterson simulated rainfall to assess erosion potential.[\[84\]](#) User groups did not compact soils on wet trails, but did on dry trails. Horses caused the most erosion in wet and dry plots and at both low and high intensity, causing rougher trails than other user groups.

Horses cause specific effects including manure on or near trails, which introduces excess nutrients, invasive species seeds and can trigger conflict with other user groups (Section 5.3).[\[29, 112, 115, 116\]](#) In addition, grazing can affect vegetation, especially in riparian areas.[\[105, 117, 118\]](#)

Landsberg et al. reviewed the scientific literature to guide management for appropriate equestrian use on trails.[\[14\]](#) Effects were generally strongest on sections of established trails that were wet, boggy or steep. The authors recommended limiting trails in such areas, prohibiting dogs on equestrian trails because of the potential for accident, injury and disturbance, and other best practices.

The research is clear that equestrians are more damaging to formal trails than hikers or mountain bikers on a per-user basis. It is unclear whether hikers or mountain bikers differ substantially in this respect. In contrast, visitor effects on wildlife are often least for equestrians, followed by hikers and mountain bikers (Chapter 7). It is crucial to understand the potential effects of different user groups on both trails and wildlife to develop appropriate trail placement, design and construction methods, and management practices.

CHAPTER 2 SUMMARY – User impacts on trail condition and vegetation

Initial trail construction

- Trail construction causes loss of vegetation, leaf litter and organic material.
- Reduced tree and shrub cover can cause locally warmer, dryer conditions (microclimate effects).
- Weed seeds may be carried in on boots and equipment, with germination facilitated by ground disturbance.
- For poorly designed and sited trails, immediate and lasting environmental effects from trail construction may be more significant than those caused by trail use.

Vegetation impacts

- Trampling causes direct physical vegetation damage. It also alters soil habitats that support plants.
- The ability of plants to resist and recover from trampling influence erosion and trail width over time.
- Plant life form is a major factor determining the ability to resist and recover from trampling.
- Herbaceous perennial plants with primary growth points at or near the soil line (e.g. grasses, clover and dandelions) and plants with bulbs, corms, rhizomes and tubers withstand more trampling over time.
- Woody and shade-tolerant plants are generally not as tolerant to trampling as other types of plants.
- Vegetation damage and loss lead to soil erosion.

Soil impacts

- Water runoff is the energy that moves soil particles. Runoff is related to landform, climate and seasonality.
- Vegetation damage, loosening of soil surface, soil compaction and steep slopes set the stage for erosion.
- Lighter soils are more prone to compaction, whereas heavier soils are more prone to erosion.
- Clayey soils are at high erosion risk because they are easily compacted when dry, but swell when inundated.
- Trails in naturally moist places such as springs, wetlands, floodplains and streamside areas, or higher elevations with more rainfall, are particularly prone to soil erosion and associated trail damage.
- Erosion potential increases linearly with trail grade up to approximately 10% grade; the effect is magnified above 10-12%. Trails with low slope alignment angles and those exceeding the “half rule” are more at risk of erosion.
- Effective trail tread drainage features are important to reducing soil erosion.

Trail widening and incision

- Wider trails tend to occur in more flat areas.
- Steeper trail grades can lead to lead to trail incision. Soil amendments including thick layers of gravel and water diversion features on unpaved trails may reduce this impact.
- Heavily used or muddy/puddled areas lead people to step or travel off-trail, causing wider, braided trails.
- Easily eroded soils are more prone to incision.

Amount of use

- Once a trail is established, damage tends to increase incrementally with higher use.
- In some cases, there may be a threshold effect beyond which little further damage is evident.
- Trampling studies fail to account for high use and impacts from long-term ongoing use.

Trail effects by user group

- Hikers and mountain bikers appear to have fairly similar types and severity of trail impacts on formal trails.
- Horses typically cause more trail damage compared to hikers and mountain bikers.

3. EFFECTS OF UNAUTHORIZED TRAILS

Trails can be roughly divided into three categories: surfaced formal trails (paved, gravel, stonework, etc.), unsurfaced or natural surface formal trails, and unauthorized trails created by trail users outside of the formal trail system. Unauthorized trails are also known as user-created, informal, social, or demand trails.[56, 119] All user groups tend to create unauthorized trails.[14, 19, 47]

Unauthorized trails are created when visitors want to see or do something that cannot be accessed on formal trails, such as scenic views or stream and river corridors; for “bathroom breaks;” or to avoid poor trail conditions or other trail users.[94, 120, 121] User-created trail effects can be formidable because the trails are new,[14, 19] unplanned, unmaintained, are often in steep terrain[122] or in sensitive or muddy habitats, and can spread weeds and damage riparian areas.[14, 16] Unauthorized trails create the same sort of effects as described in previous sections. Unauthorized trails can also create edge effects and may increase habitat fragmentation, as discussed in Section 5.2. They also cause significant wildlife disturbance; people walking, cycling or riding horses off-trail are more disturbing to wildlife because they are less predictable than on formal trails with regular use (Chapters 6 and 7).[123, 124]

Why do visitors go off-trail? Although unauthorized trails can often be found throughout a site, they tend to be clustered around formal access areas, neighborhoods and roads.[32, 121, 125, 126] Van Winkle mapped 23 km of unauthorized trails branching off from formal trails in Portland’s Forest Park.[121] Twenty-eight percent of unauthorized trails were linked to “hidden” behaviors including bathroom stops, party spots, waste dumping and illegal encampments. Another 29 percent of unauthorized trails provided access from private properties into the park. Unauthorized trails were common near trailheads, intersections and to gain access to water, and tended to be clustered in higher use areas.

Hockett et al. surveyed trail users about their off-trail experiences in Maryland and tested methods to reduce unauthorized trails.[92] In controls with no treatment, 70 percent of survey respondents reported hiking off-trail intentionally for an average of 2.8 different reasons or motivations. The most common self-reported motivations were to get to a scenic vista or take a photo (51 percent), to avoid or pass others (45 percent), or because of poor or challenging trail conditions (43 percent). In treatment areas that included educational and “stay on trail” types of signs, unobtrusive observers recording actual visitor behavior found that off-trail rates declined to 6.5 percent compared to 29.7 percent in the control. Observed numbers were lower than self-reported rates because treatment areas provided only a small representation of the total area. Signage clearly reduced off-trail effects (Section 8.9).

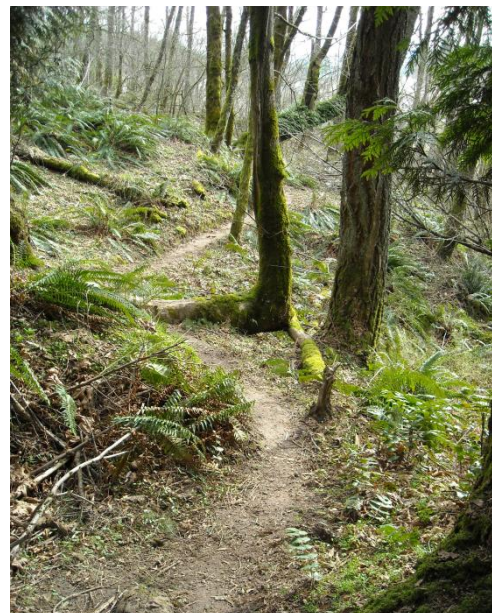


Figure 4. Unauthorized trail at a Metro natural area. *Photo credit: Chris Hagel.*

In Virginia, Wimpey and Marion identified the following motivations and behaviors for off-trail traffic and the creation of unauthorized trails:[94]

- Access – users leave the formal trail network to access park areas not reached by formal trails. (*Author's addition: users desire access to nature close to home, creating trails from backyards or nearby roads.*)
- Avoidance – visitors leave formal trails due to undesirable conditions on the trail (e.g., mud, erosion, crowding, conflicts or difficult terrain).
- Exploration – visitors are drawn away from formal trails to investigate unknown areas.
- Accidental – visitors follow an unauthorized trail due to poor formal trail marking or inattentiveness.
- Shortcuts – visitors leave a formal trail to reduce hiking time.
- Attraction – visitors leave a formal trail to see, study, or photograph interesting wildlife, plants, vistas, or to investigate interesting sounds or an inviting unauthorized trail's destination.
- Activities – visitors leave unauthorized trails to engage in off-trail recreational activities such as orienteering and geocaching.

In addition, illegal encampments can cause significant environmental damage including creation of unauthorized trails, destruction of vegetation, litter, debris from shelter structures and human waste that can enter waterways. [127, 128] Illegal encampments are likely to be located near pedestrian access points such as trails or near transportation facilities such as light rail stations, and are often found in natural areas.[128] This can be difficult to handle without suddenly displacing homeless people who are not connected to available social services and resources, or for whom such resources are unavailable.

People sometimes leave trails to appreciate nature, damaging the very resource they want to see. In an observational study in an Australian biodiversity hotspot, 41 of 213 visitors (19 percent) left trails to observe wildflowers and trampled vegetation in the process.[69] Visitors followed the least path of resistance, moving through areas with bare ground and stepping around shrubs and trees. Vegetation height and cover declined in response to tourist use.

Recreational activities such as geocaching, letterboxing and more recently, “Pokemon Go” can also lead to unauthorized trails in sensitive habitat areas.[19, 56, 94, 129-131] Some land management organizations have implemented policies that prohibit off-trail geocaching and associated damage to natural resources.[130]

Effects of unauthorized trails on habitat.

Unauthorized trails often substantially increase the total length of trails in a natural area (see also Chapter 5).[14, 32, 105, 121, 122, 132, 133] For example, in San Diego County 45 percent of mapped trails were user-created with contributions from bikers, hikers and equestrians.[132] An Australian urban forest study found that nearly 60 percent of all trails were user-created; unauthorized biking and hiking trails were



Figure 5. Unauthorized trail leading from a residence in a Metro natural area. *Photo credit: Chris Hagel.*

common and overall, approximately 6 percent of all habitat was lost or damaged due to unauthorized trails and adjacent edge effects.[\[32\]](#)

From this review it is difficult to state unequivocally whether one user group creates more, or more damaging unauthorized trails than another on a per-user basis; damage may relate most strongly to the number of users and user behavior. Hikers are often the largest user group and can easily move off-trail, creating their own trails for a variety of reasons including viewpoints, visiting riparian areas and short-cutting switchbacks.[\[14, 28, 92\]](#) Equestrians are especially damaging to the ground surface therefore any off-trail activity by this user group is likely to be destructive,[\[20, 103\]](#) but equestrian use is and will likely remain less common in parks and natural areas than hiking and mountain biking in Oregon.[\[34\]](#) Several studies described unauthorized trail effects from mountain bikes, and this appears to be an emerging or increasing issue in some natural areas.[\[134-136\]](#)

Mountain bikers sometimes create their own trails to increase technical features. These features can cause environmental and safety issues, posing a challenge for park planners and managers that can be difficult to address.[\[17, 133, 137, 138\]](#) For example, a mountain bike study in a 29-ha Australian forest remnant identified 116 unauthorized features, mostly jumps, ditches and mounds, collectively resulting in 1,601 m² of bare soil and 4,010 m² of undergrowth cleared, about 2 percent of the total natural area.[\[137\]](#) A large scale mountain biking study conducted for Shimano Corporation found numerous unauthorized trails in the southwestern U.S., likely from both hikers and mountain bikers.[\[58\]](#) Unauthorized bike trails tended to be wider, steeper, and often with braided trails compared to hiking trails. Mountain bikes caused additional damage at curves and junctions and multiple trailing was common in riparian areas. While these studies document that certain effects were more serious from mountain bikers than from hikers, they do not determine whether one user group is more damaging than the other at the site level.

A local example illustrates the difficulties of managing unauthorized trails. In 2010, The City of Portland's Parks & Recreation staff discovered significant effects on habitat along an unauthorized mile-long trail in the 5,172-acre natural area, which is an important wildlife corridor where deer and elk are active.[\[134\]](#) The unauthorized trail had been used previously by hikers and illegal campers, but new damage was caused by mountain bikers who greatly modified the trail tread to create technical features and water drainage crossings. They cut down trees, built a bridge, dammed a stream, and carefully camouflaged the trail entry with shrubs. The park includes 28 miles of authorized mountain bike trails on park roads and fire lanes,[\[139\]](#) but these types of trails are not necessarily attractive for some mountain bikers.[\[140\]](#) City ecologists estimated that the trail would take up to 15 years of ongoing restoration for the habitat to fully recover. The mountain biking advocacy community condemned the trail, asked mountain bikers to avoid its use, and assisted Park staff in closing and reclaiming the trail.

The potential for added trail length and damage from unauthorized trails is one of the most compelling reasons to monitor and maintain recreational sites, enforce regulations, and provide signage and educational information for trail users.[\[14, 58, 92\]](#) Table 7 in Section 8.4 offers some methods for surveying and monitoring unauthorized trails, and Chapter 8 includes approaches to reduce creation of unauthorized trails, including recommendations for signage.[\[56, 141, 142\]](#) One way to limit unauthorized trails is to install rocks, logs or other features to limit users to the intended tread.[\[143\]](#)

CHAPTER 3 SUMMARY – Unauthorized trails

- All user groups create unauthorized trails.
- Unauthorized trails may comprise more than half of the trails in a natural area.
- Unauthorized trails tend to have steeper trail grades compared to formal trails leading to more erosion and trail incision than formal trails.
- Edge effects are substantially increased by unauthorized trails.
- Unauthorized trails tend to be clustered around formal access areas, neighborhoods and roads.
- Users frequently create unauthorized trails to access special features such as views, streams and wetlands, or for secret activities such as bathroom break hideouts.
- Illegal encampments can cause substantial environmental damage. Encampments may be located near trails or transportation facilities such as light rail stations. Encampments are associated with unauthorized trails, destruction of vegetation, litter and human waste.
- Hikers are typically the most common recreationists and can readily move off of formal trails to create their own unauthorized trails.
- User-created technical mountain biking features such as steep slopes, jumps, and mounds can significantly damage natural resources.
- Horses can do substantial damage when creating unauthorized trails due to the amount of weight concentrated on a small area (hooves).

4. USER CONFLICTS AND PERCEIVED EFFECTS ON WILDLIFE

Previous sections discussed the effects of recreation on and near trails. This chapter bridges on- and near-trail effects, human behavior and the effects of recreation on wildlife. Chapters 5-7 address how recreational use influences habitat and wildlife.

User group conflicts. Hikers are the most ubiquitous trail users in most public natural areas.[\[35\]](#) Mountain biking is a relatively new sport that began in the 1970's, but is gaining in popularity.[\[144\]](#) Although many trails are dedicated solely to hiking, there are relatively few devoted only to mountain biking or equestrian use.

Conflicts between user groups on multi-use trails may arise from a variety of situations, such as:

- a feeling of being crowded[\[96\]](#)
- perceptions of safety hazards (e.g., mountain bikers move quickly and quietly)[\[145\]](#)
- a sense of propriety from regular visitors[\[146\]](#)
- discomfort with non-traditional uses (e.g., hikers question whether bikes should be allowed)[\[144\]](#)
- negative attitudes towards perceived environmental damage from other user groups[\[96, 145\]](#)
- belief from hikers that mountain biking is inappropriate in a natural setting[\[145\]](#)
- interference with the reason for the visit (e.g., other visitors scaring wildlife away from birdwatchers)[\[116, 144, 147\]](#)
- lack of courtesy from or irresponsibility by other users[\[144\]](#)
- poor trail design, such as blind corners[\[144\]](#)
- mountain bikers, hikers or equestrians on trails not designated for that use[\[148\]](#)
- encountering trail users with dogs, especially off-leash[\[78, 116, 149, 150\]](#)

While hikers and mountain bikers may have fairly similar physical effects on formal trails, the social aspects may differ. Trail users that visit a natural area more than once tend to internalize a set of rules of conduct, attitudes or opinions that influence the way they perceive other visitors.[\[96\]](#) Specific user groups tend to share these “social norms” which reflect their experiential expectations in a natural area.[\[144, 151\]](#) For example, hikers may expect a quiet, private walk in nature where they may see wildlife. Mountain bikers may desire exercise and challenge in a beautiful setting, and equestrians may seek a more social nature experience with friends.

If one group perceives that another user group does not share the same social norms, conflicts may arise. Some of the conflicts reflect more theoretical concerns rather than actual negative encounters between, for example, hikers and mountain bikers.[\[116, 144, 145, 152\]](#) Hikers often perceive mountain bikers and equestrians as sources of conflict, but the other user groups don't feel the same, or feel as strongly, about hikers – a sort of one-way conflict.[\[78, 86, 144, 145, 150-155\]](#)

One researcher suggested that equestrian use differs slightly from hikers and mountain bikers, in that equestrians are more physically separated from the environment; these differences can cause perceived social conflict.[\[96\]](#) It is also possible that the sheer size and bulk of a rider and horse is physically intimidating to other trail users. Researchers studied conflicts between hikers and pack “stock” animals (primarily horses and mules), in several California wilderness areas.[\[115\]](#) Over half of hikers surveyed found it undesirable or very undesirable to meet stock users, but only ten percent of stock users felt the same about hikers. Conflicts appeared to relate more to user groups' attitudes toward one another than actual on-the-trail conflicts. In addition, hikers disliked

encountering horse dung on trails. The authors stated, “While persuasive and educational messages may reduce conflict between hikers and horse users, if managers fail to reduce the number of encounters that create conflict or effects of horse use that hikers label as inappropriate, they may find some restrictions on horse use to be necessary.”

Conflicts among user groups can arise without any actual contact occurring. In fact, perceived conflict is sometimes greater for people who haven’t encountered other user groups on the trail.[\[115, 116, 145\]](#) For instance, visitor surveys in New Zealand revealed that overall, 21 percent of hikers anticipated or encountered negative interactions with mountain bikers.[\[145\]](#) Of those, more negative perceptions came from hikers that had not encountered a biker; a higher percentage of older trail users (58 percent) fell in this category than younger ones. If visitors expected to share trails with mountain bikers they perceived fewer conflicts. Most hikers (74 percent) felt that any conflicts with mountain bikers arose from just a few irresponsible riders. Nearly 60 percent of respondents disagreed that biking and hiking have similar effects on the environment, whereas studies suggest that they actually have fairly similar effects, provided they stay on formal trails.[\[68, 78, 105, 113\]](#) Tire tracks are more visible than boot tracks, which may partially explain this opinion. The researchers suggested that the following actions may decrease user conflicts: (a) increasing awareness that bike encounters are likely, and that those encounters are likely to be amicable and non-threatening; (b) ensuring that biking advocates promote a code of conduct reinforcing positive encounters; and (c) land managers wishing to reduce perceived conflicts may want to devote extra attention to older hikers, particularly when considering an aging population.

Setting expectations is crucial to managing user conflicts. Hikers that expect to see mountain bikers and equestrians perceive fewer conflicts.

Equestrians can elicit similar concerns among other user groups.[\[14\]](#) Beeton found that survey respondents with negative views about equestrians had not encountered any on trails, noting the need for better education of both land managers and visitors to improve compatibility between user groups on trails. [\[14, 146\]](#) However, some research suggests that fewer numbers of equestrians are acceptable to other user groups compared to mountain bikers or hikers.[\[115\]](#) In addition, although equestrian use is often restricted to certain trails in natural areas, most equestrian trails also allow other user groups, leading to a different problem: Horses may be frightened by hikers, mountain bikers and dogs.[\[14\]](#) It is also more difficult to align equestrian trails near roads because traffic noise can frighten the animals.

Direct user group conflict does occur. Researchers in Montana assessed the extent of and reasons for conflict between hikers and mountain bikers.[\[152\]](#) Only six percent of hikers said they had never encountered a mountain biker there. They found that mountain bikers tended to perceive mountain bikers and hikers as more similar than did hikers. Nearly two-thirds of hikers disliked sharing trails with mountain bikers but most had trouble saying why, although discourteous and too-fast bikers were mentioned. Real differences between the two groups such as environmental attitudes did not match hikers’ perceptions. The researchers suggested that to reduce feelings of conflict between the two groups, managers should educate mountain bikers about behaviors that others consider unacceptable, and educate hikers about the similarities in values between hikers and mountain bikers. They also believed that more direct management approaches such as regulations and enforcement must also be considered, especially to target non-compliant users. Chiu and Kriwoken found that hikers’ primary conflicts with mountain bikers were due to excessive speed and failure of bikers to give adequate warning of their approach.[\[78\]](#) However,

conflicts between the two user groups were uncommon and the two groups were fairly amenable to mixed use trails.

Although hikers, mountain bikers and equestrians tend to have similar environmental values,[144, 147, 152] these values sometimes vary by group. In Australia researchers surveying various user groups found that environmental values differed by users' age, level of education and gender.[147] People over age 45, those that received a university education, and females had the strongest environmental values. However, the general orientation towards environmental values did not significantly differ between hikers, joggers and mountain bikers. Other studies also suggest that older and more educated visitors tend to have more robust environmental knowledge.[151, 156, 157]

Trail runners' reasons for being in a natural area differ from other on-foot user groups, and that may be reflected in their values and knowledge. Australian researchers found that trail joggers/runners were less concerned about weeds than other user groups, especially compared to older visitors and hikers.[157] In another study runners and cyclists were least likely (1 percent) to stop and read signs such as "share the trail, manage your dog, private property;" walkers were most likely (6.1 percent).[92] However, research on this topic is sparse and these studies may not pertain to other places and settings.

There may be perceptual and actual use differences among recreational users in suburban versus rural settings. Scientists in Switzerland interviewed hikers and mountain bikers about their perceptions of forest health, recreational effects on the environment and conflicts between user groups.[151] Interviewees' habitat knowledge increased with age and education. Over half of the suburban forest survey respondents reported experiencing conflicts with other forest visitors, especially mountain bikers. Only approximately one-fourth of mountain bikers reported experiencing conflict with hikers. Twenty-five percent of hikers and 29 percent of the bikers at the suburban site felt that recreation was causing a decrease in biodiversity; in contrast, at the rural site, 31 percent of hikers but only 9 percent of mountain bikers felt that their user group negatively affected biodiversity. If this holds true for other areas, education about visitors' effects on wildlife may be especially important in rural areas.

Perceived value differences - real or not - can lead to conflict between different user groups.

Our review suggests that these factors may influence user group conflicts on trails:

- User group – hikers tend to anticipate and perceive more conflicts with other groups than vice versa.
- Experience – hikers that encounter mountain bikers or equestrians are less likely to perceive conflicts than hikers that haven't encountered mountain bikers or equestrians.
- Age and education – older, more educated trail users tend to have more concern for the environment, and perceived or actual differences in these values can cause conflict.
- Social values – one user group may perceive (sometimes incorrectly) that another group's values are different, such as environmental values or codes of conduct.
- Expectations – If two or more user groups are authorized to use trails from the outset, the two groups perceive and experience less conflict with one another.

These studies suggest that differences between user groups' expectations and social values, rather than interpersonal conflict, are key sources of perceived conflict.[144] However, the literature suggests that users'

experiential expectations may be modified through several means, such that user groups experiencing conflict in one setting may co-exist in relative harmony elsewhere.

Several researchers found that trails that are multi-use from the beginning have fewer perceived or actual user group conflicts.[\[116, 145, 158, 159\]](#) This is an important consideration when contemplating multi-use trails in a natural area.

Self-perception about effects on wildlife. Several studies demonstrate that natural area visitors often don't believe or acknowledge that they are having much of an effect on wildlife, or assign blame to different user groups rather than accepting responsibility themselves.[\[19, 113, 160-162\]](#) Some natural area visitors assume that when they see wildlife it means that they are not disturbing the animals or conversely, that because they didn't see any wildlife they didn't disturb any.[\[161, 163\]](#) Neither of these is likely to be true.

For example, in Utah about half of recreational visitors surveyed did not believe that recreation was having a negative effect on wildlife; of those that did, each user group blamed other groups for the strongest effects.[\[113\]](#) In Austria, 56 percent of people surveyed at a national park agreed that wildlife is in general disturbed by human activity.[\[161\]](#)

However, half of the recreationists felt that their own recreational uses were not having a negative effect on wildlife and only 12 percent believed that they had disturbed wildlife in their visit that day. Dog-walkers ranked their activities as less disturbing than other user groups' activities, but an ample body of research demonstrates that people with dogs actually cause a stronger wildlife response than people without dogs (Appendix 1).

Visitors often don't understand that they are disturbing wildlife, or assume other user groups are most disturbing to wildlife.

A European study exploring user groups' views about their effects on amphibians found that nearly half of respondents felt that their effects were low or zero, but if there were effects they often blamed other user groups.[\[156\]](#) However, mountain bikers thought their activities damaged amphibian habitat, but felt that walkers and dog-walkers did not. Dog walkers felt that dogs on leash did not disturb amphibians at all, and that off-leash dogs had little effect. People who visited the forest most frequently thought they had the least impact on amphibians. Actual effects of these user groups on amphibians were not studied therefore the real answer is unclear.

CHAPTER 4 SUMMARY - User conflicts and perceived effects on wildlife

- Conflicts on multi-use trails may arise from a variety of situations – for example feelings of being crowded, a sense of propriety from regular visitors, safety concerns or discourteous trail users.
- Many factors can influence user group conflicts on trails including user group, experience, age, education, social values and visitor expectations.
- Perceived or actual differences in environmental values can cause conflicts.
- Older and more educated visitors, but not necessarily different user groups, tend to have stronger environmental values than younger or less educated visitors.
- Other user groups generally do not consider hikers a major source of conflict, whereas hikers often perceive mountain bikers and equestrians as sources of conflict.
- Mountain bikers tend to be amenable to sharing trails with hikers.
- Hikers' negative perceptions about mountain bikers are higher if they have not actually encountered them.
- Trails that start out multi-use have fewer perceived or actual user group conflicts.
- Most people understand in theory that human use impacts wildlife.
- Many trail users do not recognize that their visit that day impacted wildlife.

5. EFFECTS ON ECOLOGICAL PROCESSES AND HABITAT

Ecological processes are actions that result from the interacting physical, chemical and biological attributes of ecosystems. [\[164\]](#) Examples of ecological processes include photosynthesis, nutrient and hydrologic cycles, dynamic aspects of food webs, succession, evolution, migration, and the movement of disturbances across a landscape. Research demonstrates that recreational disturbance alters habitat, wildlife communities and food webs (Chapters 6 and 7). Some effects are unavoidable, but the severity of effects can be reduced by implementing good practices during and after trail construction (Chapter 8).

Trails and trail users can alter ecological processes in several ways, such as:

1. Vegetation damage or removal, altered species composition and changes in the amount of light around trails can affect photosynthesis. [\[12, 45, 63, 69, 70, 80, 165\]](#)
2. Soil compaction, erosion and vegetation loss change stormwater run-off patterns, thereby altering the hydrologic cycle. [\[14, 29, 54, 58, 68, 72-78, 80, 81, 166\]](#)
3. Human disturbance can differentially influence wildlife species' behavior and distribution, thereby altering food webs. [\[26, 167\]](#) For example, large carnivores tend to avoid areas with busy trails, leading to increased deer and elk herbivory on shrubs, resulting in fewer seed-dispersing songbirds. [\[168-173\]](#)
4. Recreational disturbance can alter densities and reduce reproductive success for some species with potential for population-level effects. [\[174-181\]](#)
5. Invasive species delivered by feet, wheels and hooves can alter plant communities, thereby introducing disturbance and changing the amount and type of food and cover available to wildlife. [\[14, 22, 23, 105, 157, 182-189\]](#)
6. Physical or behavioral habitat fragmentation and edge effects may favor generalist wildlife species, leading to changes in functional groups and communities and potentially deterring migration. [\[32, 56, 59, 94, 122, 133, 167\]](#)

As an example of the effects of recreation on ecological processes, Ballantyne and Pickering found that trail users substantially reduced a keystone⁴ shrub species on and near the trail. [\[190\]](#) The shrub species was a "nurse shrub," which facilitated the establishment of multiple rare dwarf herbaceous and graminoid species that grew beneath its canopy. The reduction of the keystone shrub species led to reduced abundance of the associated rare species and facilitated growth of taller, leafier plants; this altered habitat structure and species composition. These changes along ridgelines altered wind profiles and further reduced the keystone shrub species' ability to reproduce, thrive and serve as a nurse shrub for the rare dwarf species.

Naaem et al. state that the loss of biodiversity in an ecosystem often causes the following impacts on ecosystem functioning: [\[191\]](#)

- Plant production may decline as regional and local diversity declines.
- Ecosystem resistance to environmental perturbations, such as drought, may be lessened as biodiversity is reduced.
- Ecosystem processes such as soil nitrogen levels, water use, plant productivity, and pest and disease cycles may become more variable as diversity declines.

⁴ Keystone species are those that have a disproportionately large effect on other species; examples include beaver and large carnivores.

Trails can cause population-level effects for some wildlife species, although this is seldom documented due to the amount of space and time required for such studies.[\[192\]](#) In southern English heathlands, recreational trail use reduced the probability of woodlarks colonizing suitable habitat to less than 50 percent at only eight walkers per hour.[\[193\]](#) Even though birds breeding in disturbed patches responded by producing more chicks per pair of birds, per season, it was not enough to make up for the loss of productivity because hundreds of disturbed patches of otherwise suitable habitat were not colonized. The researchers estimated an overall 17 percent reduction in productivity in the disturbed versus undisturbed sites.

In another example of potential population-level effects from recreation, scientists conducted a 5-year study comparing the productivity of elk in undisturbed settings to animals that were repeatedly approached by humans on foot.[\[194\]](#) The treatment group had fewer calves than undisturbed elk. Although elk resumed normal reproductive output over the next two study years, it did not make up for the loss of productivity from the treatment year. Although this short-term study was not designed to monitor long-term population effects, the example suggests that if elk are unable to habituate to direct human disturbance, recreational foot traffic could cause population declines over time.

5.1 RIPARIAN HABITAT AND WATER QUALITY

Changes in riparian habitat and water quality influence the types of species that can utilize such habitats, resulting in changes in ecological processes. If not built and managed appropriately (Section 8.2), trails can damage riparian habitat and impair water quality to varying degrees through trampling, altering drainage patterns and introducing excess runoff and sediments to streams.[\[18, 56\]](#)

People like to visit streams, wetlands and rivers and will often create their own trails there.[\[77, 121\]](#) For example, some heavily used riparian trails can experience excessive damage anywhere the stream is not protected by fence or steep slopes.[\[121\]](#)

In her literature review, Pickering summarized the potential direct and indirect effects of equestrian use on riparian areas and water quality, which with one noted exception apply to other user groups as well:[\[22\]](#)

- defoliation of riparian vegetation
- introduction of invasive aquatic and terrestrial species
- soil loss and compaction (which can also prevent re-establishment of native plants)
- increased turbidity associated with soil erosion and eroded streambanks
- degraded water quality
- altered composition of instream and streambank biota
- increased input of sediments
- increased input of nutrients [associated with horse manure and urine] with potential for excessive algal growth
- impaired aquatic ecosystem health

Defoliation and soil compaction from any source will decrease water infiltration, creating more runoff into streams.[\[14, 72\]](#) When these issues occur in riparian areas increased stream bank erosion may occur, leading to channel widening and further sedimentation.

Trails can alter patterns of water distribution, as discussed in Section 2.3. In their 2007 review of the environmental impacts of mountain biking, Marion and Wimpey commented, “Poorly designed trails can also alter hydrologic functions – for instance, trails can intercept and divert water from seeps or springs, which serve important ecological functions. In those situations, water can sometimes flow along the tread, leading to muddiness or erosion and in the case of cupped and eroded treads, the water may flow some distance before it is diverted off the trail, changing the ecology of small wetland or riparian areas.”^[18] Due to their linear nature, mountain bike treads can re-direct trail runoff water into undesirable areas or cause new small channels to form.^[195]

Stream crossings. Bridges and culverts tend to cause fewer water quality issues than at-grade crossings such as fords, although all types of crossings may degrade water quality.^[29, 196] In Virginia, researchers studied the effects of 11 multi-use (hikers, mountain bikers and equestrians) stream crossings on water quality.^[196] Crossing types included fords and culverts. The researchers documented impaired water quality below versus above stream crossings, as indicated by degraded macroinvertebrate communities. Their models estimated that soil erosion rates for non-motorized trail users would be 13 times higher along stream crossing approaches compared to undisturbed nearby forest, and 2.4 times higher than a nearby 2-year old clear-cut.

An instream hiking study in Utah found that as more hikers crossed stream fords, they kicked up increasing amounts of streambed invertebrates and organic matter, reaching a threshold at approximately 120 hikers per hour. The researchers suggested that streambed invertebrates were washed away after this amount of disturbance.^[197] Hikers also displaced stream bed sediments, increasing stream turbidity. These effects were spatially limited and suggest a relatively minimal effect on water quality in Utah, an area that is prone to flash-flooding and where invertebrates are adapted to disturbance.

In contrast, researchers at California’s Yosemite National Park found longer term effects in a two-year study of stream fords used by mules, horses and hikers.^[198] They compared benthic (stream bottom) invertebrates, which are excellent water quality indicators, above and below two crossings during spring and fall. Differences were clear immediately below fords with finer substrate, a thick periphyton⁵ layer, and higher pollution-tolerant but lower pollution-intolerant taxa, indicating impaired water quality. Seasonal differences corresponding with higher visitor use were evident: the difference in upstream versus downstream water quality was greater in fall than in spring, suggesting cumulative effects from recreationists crossing the fords throughout the summer tourist season. Horses likely defecated in the stream, as suggested by bits of hay found in downstream pools. The researchers postulated that urine and feces inputs could be reduced by halting horses for a short time prior to entering the stream. Horses also tend to urinate and defecate near trailheads.^[51] Several other studies suggested that horse dung and urine may increase nutrients in streams,^[22, 51, 105, 112, 117] although none of them actually measured this potential effect.

Stream crossings, especially fords, can cause water quality issues and harm aquatic wildlife.

We found no studies testing whether stream crossings affect vertebrate species. However, members of the salmon family require cold, clear water and lay their eggs in gravels along stream bottoms.^[199] Sediments introduced or

⁵ Periphyton refers to freshwater organisms attached to or clinging to plants and other objects projecting above the bottom sediments.

kicked up by people near or crossing streams may clog fish gills and reduce reproductive success for some species, and may also carry excess nutrients that can de-oxygenate water and cause algal blooms.[\[18\]](#)

It is possible to mitigate some of these water quality effects. McClaran recommended focusing monitoring and management for pack stock on soil erosion and defoliation near streambanks.[\[117\]](#) Marion and Wimpey offered a set of best practices to reduce trail effects on streams and riparian areas (Chapter 8).[\[18\]](#)

5.2 HABITAT LOSS, FRAGMENTATION, AND EDGE EFFECTS

Habitat fragmentation is the process of dividing large areas of habitat into multiple smaller, increasingly disconnected patches.[\[200, 201\]](#) Habitat fragmentation changes ecological processes by diminishing the landscape's capacity to sustain viable native wildlife populations. The primary drivers of this effect include habitat loss, reduced habitat patch size, increased edge habitat, loss of connectivity between habitat patches and modification of disturbance regimes. Effects can increase over time as species are extirpated for various reasons and there is no means of recolonizing isolated habitat patches.[\[202, 203\]](#)

As habitats are divided, the edges of each patch are subject to changes in light, wind, moisture, invasive seed sources, and human disturbance that reduce habitat quality for some plant and animal species.[\[59, 119, 167, 169, 204-207\]](#) While fragmentation and habitat edges sometimes benefit edge dwelling and generalist species, they are detrimental to more sensitive wildlife such as large carnivores,[\[169, 170, 208-210\]](#) species needing large home ranges and many Neotropical migratory songbirds.[\[132, 201, 205, 211-214\]](#)

Trails can cause habitat loss[\[32, 45, 121, 215\]](#) and are associated with invasive species (Section 5.3), but do they literally fragment wildlife habitat? In terms of the traditional physical reductions of habitat patch size and isolation associated with fragmentation, perhaps not to a large degree. Trail disturbance is typically limited to a fairly narrow corridor, and trails do not usually create new barriers within a habitat patch that would physically prevent most wildlife movement, although there may be exceptions such as raised trails blocking amphibian or turtle movement. However, trails do alter habitat and create edge effects. Various studies document trail-associated changes in vegetation structure, composition, and increased non-native species similar in nature to edge effects around the outside of a forest.[\[7, 125, 165, 216\]](#) Disturbance from trail use also triggers wildlife avoidance behavior in many species, which may be as impactful as physical habitat fragmentation (Chapters 7 and 8).

Edge effects. Trails and trail use create edge effects when habitat along the trail corridor is altered. Invasive species introductions are associated with edge effects (Section 5.3), as are structural changes in forests adjacent to formal and unauthorized trails including loss of tree and shrub cover.[\[32, 56, 122, 125, 204, 217\]](#) Such changes alter the quality and amount of habitat available to wildlife. Because even narrow trails may cause edge effects, unauthorized trails can substantially increase the total amount of edge habitat at a site.

There is evidence that edge effects in forests are both vertical and horizontal. We found two studies that examined the three-dimensional nature of edge effects. In the first, to test for edge effects in fragmented New Zealand temperate forests, researchers placed 25 data loggers at five heights from tree canopy to ground level, at five distances of up to 16 m from forest edges.[\[165\]](#) The scientists measured microclimate variables including air temperature, vapor pressure deficit and incident light. Compared to forest interior habitat, the loggers showed a breakdown of vertical stratification at forest edges for all microclimate variables measured.

In the second study, Yan et al. studied edge effects from trails in Chinese fir forests based on epiphytic bryophytes⁶ on trees and microclimate variables.[45] Altered microclimates were apparent at trail edges which had more light, warmer air temperatures, fewer leaves and lower humidity compared to controls. It is worth noting that these types of microclimate changes would favor invasive plant species over natives in many settings. Bryophyte species richness and percent cover were significantly lower at trail edges. The authors concluded that the presence of a hiking trail – even as narrow as 1.5 meters – indirectly influenced epiphytic bryophyte communities by altering microclimate. They recommended minimizing disturbance by reducing the number of trees cut during trail construction so as to reduce the size of the canopy opening.

These studies documented vertical and horizontal effects that altered both microclimate conditions and living organisms, thereby altering habitat. Because wildlife keys in on habitat types and characteristics, it follows that such changes may also alter wildlife communities.

Measuring edge effects and fragmentation caused by formal and unauthorized trails. Trail planners may wish to estimate edge effects or related variables to assess existing conditions or compare potential effects between different proposed trail alignments. We found several studies in which researchers developed or used tools to estimate the amount of habitat loss, edge effects and loosely defined “fragmentation” caused by formal and unauthorized trails.[32, 56, 94, 121, 122, 125, 217] Appropriate methodologies depend on the research need (e.g., planned versus existing trail networks) and availability of funds and technically skilled staff or contractors. Each method employs GIS, and most studies with existing trail networks will require some fieldwork for the most reliable results.

Trails – both formal and unauthorized – cause edge effects and damage habitat.

However, these techniques can provide quantifiable, biologically meaningful measures of fragmentation to inform trail design and management without conducting more resource-intensive wildlife or habitat studies. The studies below and in Table 3 provide examples of such approaches.

Researchers in Australia developed a detailed GIS- and field-based approach to assess the extent and characteristics of trail-induced fragmentation in an existing forested natural area. To calculate habitat loss they buffered trail centerlines based on field-measured averages for each trail type then added actual habitat loss adjacent to trails.[32] Formal and unauthorized trails did not differ in the loss of structural components of the forest, although soil loss was greater on unauthorized trails. Trails caused an estimated edge effect plus habitat loss area of more than 47 ha (6 percent of the total study area). Over half of this loss was due to unauthorized trails (Chapter 3). Fragmentation was most correlated with the number of access points per remnant and the total length of trails. Newsome and Davies built on some of these methodologies to assess mountain biking effects at a national park in western Australia; their methods included mounting a GPS unit set to “tracking” on a bike, recording the unauthorized trail routes and noting unauthorized technical and erosion features.[133]

Scientists in Virginia used GIS- and field-based methods to explore the geographic and physical/topographic characteristics of unauthorized and formal trails in four study areas.[94] One research question was whether landscape fragmentation metrics can be used to summarize the relative effects of formal and unauthorized trail networks on a protected natural area. Unauthorized trails were on average twice as steep as formal trails, but narrower (0.9 m mean unauthorized trail width, 2.5 m formal). Unauthorized trails created a smaller total

⁶Epiphytic refers to something that grows harmlessly on another living organism, in this case bryophytes – the group including mosses, liverworts and hornworts.

disturbance area than formal trails, even when the total length of unauthorized trails was greater. However, fragmentation metrics suggested strong additive effects when including unauthorized trails. For example, the number of habitat “patches” created by all trails compared to formal trails alone doubled in high use recreation areas and was as much as 1,900 percent higher than in low use recreation areas. Similarly, Marion and Leung found a high density of unauthorized trails, especially near the river, and when those were included in fragmentation metrics the number of discrete patches increased from 70 to 443; 48 percent of unauthorized trails fell in the “highly impacted” category.[\[56\]](#)

Ballantyne and Pickering compared trail surface condition, loss of forest strata and changes in tree structure between formal and unauthorized trails in 17 urban forest remnants in Australia.[\[125\]](#) Loss of forest cover and maximum widths were similar between formal and unauthorized trails. Wider trails had the most canopy loss, but unauthorized trails led to the greatest cumulative forest loss. Unauthorized mountain bike trails accounted for 65 percent of the lost canopy. Other studies indicate that formal multi-use trails tend to be wider than single-use trails because there tends to be more users, and hikers are generally expected to step off of trails to allow equestrians to pass by.[\[115, 204\]](#)

These studies indicate that unauthorized trails contribute significantly to edge effects, effects may vary from one site to another, and measuring such effects can help inform recreational access planning and site management. Table 3 summarizes some methods used to measure or estimate edge effects from formal and informal trails.

A note about wildlife habitat fragmentation and edge effects due to trail use. Although a few wildlife species are attracted to trails, many more species avoid trails or change their behavior to varying degrees (Chapter 7). The result is a zone of influence around trails that alters the distribution and abundance of wildlife, similar to trail-induced changes in plant communities. In addition, heavily used trails or recreational areas may cause the most disturbance-sensitive wildlife to avoid an area altogether, thereby effectively fragmenting their habitat. These effects on wildlife are conceptually similar to the traditional definitions of edge effects and physical habitat fragmentation.

Table 3. Summary of methods used to measure trail-induced fragmentation or related effects on formal (FT) or unauthorized trails (UT).

Reference and location	Study purpose	Habitat type(s)	Methods	Results
Ballantyne, Pickering et al., 2014 [125] and related studies [32, 122, 217] ⁷ Coastal Queensland in eastern Australia	Compare relative effects of FT/UT mountain bike trails in 17 remnants endangered forest type, urban areas	Forest remnants near urban area; tall open Blackbutt (<i>Eucalyptus pilularis</i> dominated) forest	Mapped all trails, FT & UT. Measured maximum width, depth and slope of the trail and distance from trail edges to the litter layer, understory, midstory and trees – 40 FT, 40 UT. Measured Weighted Mean Patch Index (WMPI) and Largest 5 Patches Index (L5PI) and then compared remnants using ANOVA.	• Most trails were UT (bare earth, 32.1km, 74%); the rest were hardened formal trails. • Maximum widths were similar; UTs had greater slopes, more soil loss. • 17.1 ha lost to trails and adjacent habitat; 65% of this was due to UT, which had greater length. • UTs tended to be in denser urban areas; there were numerous UT points of entry. • Formal trails caused more canopy loss than UT. • Fragmentation as measured by WMPI was greater in forest remnants dominated by UTs, but no differences in fragmentation per the L5PI index.
Marion and Leung, 2011[56] Great Falls Park in Virginia, and Boston Harbor Islands National Recreation Area in Massachusetts	Test cases for different monitoring protocols for visitor impacts. Procedures were developed, field tested, refined, and applied to a selection of four park trails. Field-located all trails. Also tested trail condition methods at Zion National Park.	Great Falls Park: Several rare ecosystems with >200 local, national or global rare, threatened and endangered species. Boston Harbor: 34 islands and peninsulas within Boston Harbor; variety of habitat types including river gorge, rocky islands and forested floodplains and bluffs	• <u>Great Falls Park</u>: used park boundary polygon as base • Buffered trails by ½ trail width each side, FT and UT • Intersected buffered trail segments, removed from base layer to create 2 shapefiles: 1 FT only and 1 FT + UT • Used shapefiles to calculate landscape fragmentation metrics including Mean Patch Size (MPS) and # patches • <u>Boston Harbor</u>: buffered trails for threats to rare T&E species using 50-m buffer	• <u>Great Falls</u>: High UT densities leading to river or adjacent cliffs (views) were of great concern. • Nearly half of UTs were in the lowest condition classes, in which erosion was initiated or prevalent. • UT lengths nearly equaled FT lengths. • Number of discrete patches increased from 70 using FT to 440 when UT trails were added. • Mean patch size was reduced from 40,239 m² using only FTs to 6,273m² for all trails. • UTs = high concern for invasive species. • <u>Boston Harbor</u>: 141 m of UT found within 50 m of known T&E species.

⁷ These papers are related and conducted partially on the same study sites. Some different information was in each study but the results were generally similar.

Reference and location	Study purpose	Habitat type(s)	Methods	Results
Wimpey and Marion, 2011 [94] Great Falls Park, VA	Compared FTs and UTs: physical, topographic, fragmentation, and biodiversity hotspots	Several rare ecosystems with >200 local, nationally or globally rare, threatened and endangered species.	• Collected linear trail features using GPS • Measured condition class per Marion et al. [77] and average tread width by trail segment • Fragmentation: similar to [56]; removed infrastructure first • Hotspot analysis: used ArcMAP 9.3's spatial analyst line density tool • Used four landscape fragmentation indices: # patches, MPS, largest patch index, mean perimeter:area ratio	• UTs had higher grades, were in steeper terrains, aligned more closely to fall-line, and were narrower than FTs. • Hotspot findings similar to [56]. • Developed typologies of visitor motives, behaviors leading to UT creation: access to other areas of park; avoiding poor trail conditions or other trail users; exploring unknown areas; accidental – poor trail signage; shortcuts; attraction – visitors want to see or photograph wildlife, plants, etc. vistas; activities such as orienteering or geocaching.
Van Winkle, 2014 [121] Forest Park, Portland, OR	Characterize the effects of UTs on understory plant communities	Predominantly deciduous and coniferous forest	• Mapped, quantitatively evaluated 382 UTs. • Used line density spatial analysis tools. • Established 30 transects along UTs to characterize understory communities, plus 30 paired controls.	• 28% of UTs were linked to “hidden” behaviors including bathroom stops, party spots, waste dumping and camps. • 29% of total unauthorized trail length provided park access from private properties, which tended to be longer than other UTs. • UT hotspots were associated with trailheads, intersections and to gain access to water; tended to be clustered in higher use areas. • UTs showed plant community and structural changes, and led to exotic species invasions; effects similar to FT but in narrower band (approx. 2m FT, 1 m UT for the most intense effects).

5.3 INVASIVE SPECIES

According to the U.S. Fish and Wildlife Service, invasive species are a leading cause of wildlife population declines and extinctions.[218] Invasive species are also expensive, causing at least \$34 billion in damage and control costs each year in the U.S.[219]. Trails are key vectors for invasive species introductions into natural areas, creating an edge effect on each side of a trail.

All trail user groups introduce weeds and pathogens to natural areas including hikers,[23, 157, 182-185] mountain bikers[105, 185, 186] and equestrians.[14, 22, 23, 187-189]. Formal and unauthorized trails in a natural area can lead to substantial increases in invasive species over large areas.[32, 217, 220] A review paper found that hikers, mountain bikers and equestrians dispersed at least 225 species of non-native seeds; most were of European origin.[23] Scientists in South Africa used brushes to scrape seeds off of the shoes of hikers, dog walkers and cyclists, and also surveyed non-native plant species near the three different types of trails.[185] The highest incidence of seeds was on dog walkers' shoes, although they concluded that any type of tourist can be a vector for alien seed dispersal. All three types of trails had invasive species, while non-trail controls had few invasive species.

In her 2000 literature review on recreation ecology, Jordan commented that "it is not possible to tell from reports of weeds along trail sides if the weedy species were out-competing native species, or if they were just 'filling in' ecological space opened up by reduction of native species due to unfavorable environmental change (due to trampling, microclimate change, etc.). Some of both probably may occur, depending on circumstances." [7]

Many invasive species thrive in disturbed areas or with more available light, and trails can provide conditions that facilitate those species.[30, 59-61] Invasive plants also tend to have resilient life forms mentioned in Chapter 2 and can out-complete less resistant native species.[23, 221]

Spatial extent. Most unwanted species appear to stay relatively close to trails, but some shade-thriving species such as garlic mustard (*Alliaria petiolata*) encroach well into undisturbed habitat, with habitat-altering consequences.[60, 216, 222] Invasive species are associated with reductions of and changes in native plant cover and species across many geographies and habitats.[105] Various studies found that most weed species extended in the range of 2-20 m from trails,[95, 121, 189, 216, 222, 223] although many studies fail to account for a potential time lag from dispersal to germination and spread of seeds.[224] At the higher end, 20 meters on each side of the trail would create a 40-meter trail corridor zone of influence, plus the width of the trail itself.

However, smaller areas of influence are more common. For example, a local study documented that the strongest invasive species impacts occurred within the first meter on each side of unauthorized, and within two meters on each side of formal trails in the City of Portland's Forest Park.[121] The researcher mapped approximately 9.4 km of unauthorized trails branching from formal trails; the park has 129 km of formal trails. Assuming 4-m total widths for formal (2 m on each side of trail centerline) and 2-m widths for unauthorized trails to represent trailside invasive species encroachment, formal and unauthorized trails plus adjacent areas of invasive species cover at least 53.5 ha, or about 2.6 percent of the Forest Park's total area.

Despite studies documenting that most invasive species' effects fall within a few meters of trails, it only takes one destructive species such as garlic mustard, ivy (*Hedera* species), old man's beard (*Clematis vitalba*) or reed canarygrass (*Phalaris arundinacea*) to significantly degrade habitat. It is not unusual for non-native plant species to

exist in low numbers for a decade or more before becoming invasive,[224] therefore short-term studies of one to three years are unlikely to document the full effects of invasive species due to trails.

Hikers. Hikers carry seeds on their clothes, shoes and shoelaces, and may carry seeds far into and between natural areas.[23] Mount and Pickering’s review documented that at least 139 plant species can attach to clothing, of which 134 occur in major weed databases.[225] Another study found that although most seeds on hikers’ shoes fell off within 5 m, seeds still remained after 5 km; modeling suggested that shoes were more effective at dispersing seeds over long distances than wind.[226]

As mentioned above, dog-walkers and their dogs may be particularly effective at spreading invasive weed seeds. A South African study found the greatest amount of invasive species along dog walking trails compared to hiking and cycling trails.[185] Of the three groups, all carried invasive seeds but dog walkers’ shoes carried the highest seed load.

An experimental study found that walking in trousers distributed 17 percent fewer seeds than walking in shorts because shorts allowed uncovered socks and bootlaces to collect more seeds.[225] The average number of seeds collected per 100-m roadside walk included:

- Per boot: 66 seeds
- Per uncovered sock (shorts): 157 seeds vs. 10 per covered sock (trousers)
- Per uncovered bootlace: 66 seeds vs. 30 per covered bootlace
- Per trouser leg: 156 seeds

The study demonstrated that the type of clothing worn by a hiker can influence seed attachment and subsequent distribution. In further detail, normal socks collected more seeds and from a greater range of species, both native and non-native, than hiking socks.[225] Longer hikes resulted in more accumulated, and presumably more distributed, weed seeds.

Trail users can also spread pathogens that harm or kill trees. Researchers studying California hiking trails found strong associations between human recreational trail use and the spread of the pathogen causing Sudden Oak Death (*Phytophthora ramorum*), a fungus-like water mold.[183] While the pathogen does not appear to affect Oregon white oak (*Quercus garryana*) and has not yet reached northwestern Oregon’s natural areas, it does have the potential to affect other species including Douglas fir (*Pseudotsuga menziesii*) and Pacific madrone (*Arbutus menziesii*).[227] In California the costs to treat, remove and replace trees damaged from Sudden Oak Death are expected to be \$7.5 million from 2010 to 2020, with a \$135 million loss in residential property values.[218] Several researchers developed a prototype bike tire scrubber to reduce the spread of Sudden Oak Death that could be used as a best practice to reduce threats from these and other invasive species.[228] Trail use in protected areas have also been documented to spread the root-rotting fungus *Phytophthora cinnamomi*. [23]

Mountain bikers. Although the potential for mountain bikers to disperse weed seeds is commonly mentioned in the literature, we found few experimental studies examining this potential threat. With the emerging importance of mountain bikers as a user group, this is a relatively new topic of study. Hikers and equestrians have been regular trail users for much longer, thus there are more studies on these two user groups.

In Australia, Pickering et al. compared weed seed attachment in dry conditions on horses versus mountain bikes.[229] The researchers established 20 transects through which a horse or a mountain biker was led for 100 m. Seeds were meticulously collected after each transect crossing. Horses carried more weed species' seeds and the species composition differed between the two, but horses and bikes carried similar numbers of seeds. The authors recommended best practices similar to those for hikers – that is, seed and dirt removal devices near trailheads – and suggested enhanced efforts in areas of high ecological importance.

In an urban forest in Germany, Weiss et al. experimentally exposed mountain bikes to five species of seeds and subsequently rode them at a series of distances ranging from 1 to 500 m, in both damp and wet conditions.[46] The seed species were selected to represent different traits; depending on the species, up to 40 percent of seeds attached to bike tires. Although seed dispersal was relatively low in dry conditions, seeds stayed attached for up to 500 m in damp, and up to 100 m in wet conditions. Over half of all seeds detached within the first five meters. In contrast, seeds attached to the bike frame showed no significant decline at these distances. Seed traits were an important factor in persistence of attachment.

In contrast, a South Africa study examined mountain bike tires and associated riders' shoes for seeds found no seeds on tires, although seeds were present on two of the cyclists' shoes.[185] However, the brevity of the study (three days, of which two were dry) and small sample size (10 mountain bikers) may underestimate potential effects. In addition, the seeds were collected when riders first entered the natural area, without controlling for factors such as initial versus post-seed exposure on bikes and bikers.

Horses. We found numerous studies and literature reviews documenting weed issues due to horses.[7, 14, 20, 22, 112, 187-189, 222, 223, 230-233] Horses may be especially impactful because their pastures and hay tend to include seeds from weedy species.[14] In addition, nutrient enrichment from horse dung and urine may enhance growing conditions for weedy species, and horses churn soil which can facilitate germination.[20, 61, 79, 105, 187, 234]

Horses can carry these seeds long distances on their hooves, coats and in manure, and have long digestive periods capable of retaining seeds over significant distances.[23, 182, 188, 223] Adult horses can produce 17-26 kg of dung per day;[105] globally at least 244 weed species' seeds have been found in horse manure.[187] The highest risk for seeds sprouting from manure is in disturbed, damp sites and when riders go off-trail,[14] which suggests that placing horse trails or indeed, any type of trails in floodplains and near streams and wetlands increases the risk of invasive species introductions.

Any recreational use can introduce invasive species seeds. Multi-use trails tend to harbor more invasives than single use trails.

The seed species that germinate along equestrian trails tend to be resilient to trampling. Ansong et al. reviewed 15 studies on seed germination from horse dung.[182] Nearly two-thirds of problem species were forbs, a third were graminoids, most were perennials, and nearly half were invasive. Another review found weedy perennial graminoids and herbs particularly prevalent along equestrian trails compared to other types of trails.[23] Manure along a trail in western Colorado yielded 20 species and 564 seedlings: 12 species were graminoids, six were forbs, and one each shrub and tree.[232] These findings concur with the resilient species' life forms discussed in Section 2.2 (vegetation effects); the most abundant and successful non-native species along equestrian trails tend to be those that can survive in diminished conditions and withstand ongoing trampling.

Several studies found that while many seeds were present in horse dung or germinated from dung in the lab, relatively few germinated from manure experimentally placed along equestrian trails.[\[222, 223, 230\]](#) However, these short-term studies do not account for multiple horses defecating over time, providing ongoing opportunities for weed establishment; they also fail to account for potential lag times between when seeds are first introduced to a natural area and when they spread to the point of becoming invasive.[\[224\]](#) In addition, some seeds require specific conditions such as a low temperature cycle to germinate, which may not occur every year while seeds lie dormant in the seed bank.[\[233\]](#) For instance, Australian researchers identified weeds being dispersed in trailside horse manure, and also which weed species were already established along equestrian trails.[\[189\]](#) Substantial percentages (from 20-55 percent) of horse manure weeds also grew along equestrian trails in their three study sites, although some vehicles also used these fairly wide, hardened trails.

Horses can also carry seeds in their coats and hooves.[\[19, 22, 223\]](#) A review of tourist seed dispersal found that 42 weed species transferred from horse coats between nature reserves. In Belgium, scientists collected and germinated seeds from the coats of large herbivores (cattle, donkey and horses).[\[233\]](#) Seeds from 75 plant species germinated in the lab and there was evidence of seed transfer within and between sites. The authors considered herbivore seed dispersal to be a potentially important restoration mechanism; this may be the case in undisturbed settings but in recreational settings, any restoration benefits may be offset by weed invasions.

Numerous studies found more non-native species and cover along equestrian trails compared to controls, or compared to other trail types.[\[110, 188, 230, 231\]](#) For example in Illinois, 23 exotic species germinated from dung in the lab but only one of those species was found in the field; however, more exotic species were found along horse than non-horse trails.[\[230\]](#) In Missouri, more species and a higher proportion of non-native species were documented along equestrian trails compared to old roads and intact communities.[\[231\]](#) In Queensland, Australia researchers examining diversity and distribution patterns of non-native plant species adjacent to equestrian trails found 39 non-native plant species within 20 m of trail, 30 of which were within 0-5 m of trails.[\[222\]](#)

One U.S. study found little evidence that horses are significant distributors of non-native seeds.[\[223\]](#) The researcher collected horse hay, manure, and hoof debris samples at five endurance rides in five states. He sowed sub-samples in pots and placed them on trails, and conducted plant surveys along 50-m transects perpendicular to equestrian and hiker-only trails at three sites. Some seeds germinated in pots, but few seeds germinated along trails; they concluded that hay and manure contain non-native plant seeds but that they rarely become established on equestrian trails due to harsh environmental conditions. However, this was a one-year study and the author acknowledged that several years' study would be necessary to better quantify the likelihood of the non-native invasive species to become established and out-compete native species. The preponderance of evidence in other studies suggests that horses do disperse non-native seeds along trails over space and time and overall, and that horses may be a stronger non-native seed vector per user than hikers and mountain bikers.

Multi-use trails and amount of use. Multi-use trails may have more invasive species cover than single-use trails; this is logical given that the findings above indicate that each type of user can distribute weed seeds in different ways. A study in California's Santa Monica Mountains compared single- versus multi-use trails in two sites with different shrubby habitat types.[\[204\]](#) Multi-use trails had higher proportions of exotic species and cover. The magnitude of these effects differed between the two different habitat types. These findings led the researcher to suggest that multi-use trails should be concentrated in (a) small areas, and (b) in the site less prone to exotic species invasion. Higher trail use is also correlated with increased non-native species and cover.[\[23, 189\]](#)

CHAPTER 5 SUMMARY – Effects on ecological processes and habitats

Ecological processes

- Trails and trail use change ecological processes through altered vegetation communities, soil impacts, distorted food webs and altered wildlife communities.

Riparian habitat and water quality

- Improperly sited or designed trails can alter the patterns of surface water drainage, creating excessive runoff that can alter hydrology and carry excess sediments to streams.
- Defoliation and trampling near stream crossings can compact soils, damage riparian vegetation and streambanks, and increase sediment inputs.
- Trails near and across streams without appropriate crossing structures can impair water quality through sedimentation and increased turbidity, potentially harming sensitive aquatic wildlife.
- Instream macroinvertebrate communities, which are indicators of water quality, have been found to be degraded immediately below stream culverts and fords. Similar studies were not found for stream crossings that use bridges.

Habitat loss, fragmentation and edge effects

- Trails do not typically fragment habitats in the traditional sense – that is, by physically separating habitat patches – but they do cause edge effects including invasive species and altered vegetative structure.
- Trails cause edge effects by introducing invasive species, altering habitat structure and composition, and changing microclimates. Physical edge effects are typically fairly limited in extent.
- Several studies offer methods of calculating physical edge effects due to trails.
- Trails – informal or formal – can collectively cause significant habitat loss.
- Disturbance from a trail is typically limited to a fairly narrow corridor, and trails do not usually create new barriers within a habitat patch that would physically prevent most wildlife movement.
- However, trail use can act as a fragmenting agent for wildlife by creating “zones of avoidance” that may extend much further than physical edge effects.
- Certain wildlife species such as large carnivores and area-sensitive birds may be reduced in or absent from sites that are fragmented by trails and recreational activity.

Invasive species

- Unaware trail users can carry non-native species far into and between natural areas.
- For hikers, the type of clothing worn can influence seed attachment.
- Horse dung, fur and hooves can carry many invasive species’ seeds and between into natural areas. Hikers and even more so, dog walkers can also be significant vectors. Less is known about mountain bikes and their riders although they are capable of collecting and distributing weed seeds.
- Grasses, herbs and perennial weed species are the most common invaders but trail users can also spread pathogens such as Sudden Oak Death and root-rotting fungus.
- Multi-use trails tend to have more invasive species than single-use trails.

6. OVERVIEW OF EFFECTS ON WILDLIFE

Trails may degrade or fragment wildlife habitat and can also alter the activities of nearby animals, causing avoidance behavior in some and food-related attraction behavior in others. Although habitat effects from trails tend to be limited to a relatively narrow corridor, wildlife disturbance can extend considerably further into natural landscapes (Appendix 3). Species-specific responses to the same sources of disturbance can vary considerably and are discussed in Chapter 7.

The reality is that most of the time land managers lack site-specific formal wildlife surveys to inform their work before (baseline data), or after a site is opened for recreational access. Most wildlife studies are conducted after a site is opened for recreation, when disturbance may already have altered wildlife communities. This does not mean studies at disturbed sites are meaningless, because there will still be a range of sensitivity across wildlife species at the site to inform land management. However, care should be taken in interpreting results at disturbed sites without pre-disturbance data or undisturbed controls, because wildlife communities will already be altered from natural conditions. Another drawback to determining the true costs of recreation on wildlife is the need for statistical significance to validate results: animals that are already rare will be excluded from the findings due to small sample sizes.^[235] These issues suggest a conservative approach to estimating effects of recreation on wildlife.

When research is conducted in areas that are already disturbed, the most sensitive wildlife species at the site – those that do not readily habituate to human disturbance (Section 6.2) – may experience reduced fitness, impaired reproductive success (potential reproductive “habitat sink”), or have already disappeared. If animals have already vacated a disturbed site when a study is initiated, the results are certain to underestimate disturbance effects on wildlife.

6.1 DISTURBANCE AND THE ANTIPREDATOR RESPONSE

Studies have documented that animals exhibit physiological responses – the so-called stress response – before anything is visible to researchers.^[236, 237] Stress response is the functional response of an animal to an external stressor, such as seasonal changes in temperature and food availability or sudden disturbance.^[238] Specific stress hormones are released to enable the animal to physically respond to the stressor, and the heart rate increases.^[237-242] Acute stress response, when an animal reacts to an immediate situation, can benefit the animal by triggering it to respond appropriately to a threat. However, chronic stress such as repeated disturbances over time may reduce wildlife health, reproduction and growth, impair animals’ immune system and increase vulnerability to parasites and diseases.^[239, 243, 244] Long-term wildlife stress studies are scarce because they can be expensive, complex and may negatively impact the animals under study.

Wildlife subjected to human disturbance exhibit stress reactions termed the “antipredator response” in an attempt to avoid or minimize perceived threats.^[19, 245, 246] Behavioral responses may include increased alertness to potential threats (vigilance), fleeing, habitat selection or avoidance, and altered feeding or breeding behavior.^[246-248] Variability in behavioral responses essentially derives from a cost-benefit analysis: Does it cost more energetically or in terms of risk to hide, flee from or ignore the perceived threat?^[249] Animals may be alert and experience stress response long before they initiate antipredator responses. By the time an animal flees, it has already spent energy being vigilant at the expense of normal activities.

In their seminal paper discussing the tradeoffs (“economics”) of fleeing from predators, Ydenberg and Dill[249] asserted that the decision for an animal to flee may be deferred through economic costs. Under the economics model, FID should increase with increasing risk of predation and decrease with increasing cost of flight. For example, an animal may allow a person to approach more closely (shorter FID) in an area of abundant food, because the energy gained through extra feeding time compensates for the increased predation risk.[251] Similarly, if good cover is nearby a deer may wait longer to flee due to decreased risk of capture, or a bird with young in the nest may let a person approach more closely because biologically, it costs more to flee and abandon significant parental investment. In isolated habitats or where there is no suitable alternative for foraging nearby, wildlife may not flee at all because there is nowhere else to go.[246, 252]

Typical wildlife disturbance studies measure antipredator response through variables including stress hormone levels (e.g., measuring hormones in wildlife scat near trails versus controls, or through blood samples), indicators of reproductive output such as nest success, alert distance, FID, displacement distance, travel time, or time to resume normal behavior. There is a confusing array of potential disturbance behavior terms in the literature, and we found some variability in how these terms were used. Table 4 defines some of these terms to aid the discussion that follows.

Table 4. Definitions of terms used in wildlife studies to measure antipredator response, including tolerance to human disturbance.

Term	Alternative terms in the literature	Definition
Alert distance (AD)[250]	Vigilance distance Detectability period	The distance between an animal and an approaching human at which point the animal begins to exhibit alert behaviors to the human.[250]
Flight initiation distance (FID)[123, 253-257]	Flight distance Flight zone Escape flight distance Approach distance Flush distance Response distance	The distance from a person at which an animal first flees from perceived danger. The higher the FID, the lower the animals’ tolerance to disturbance.
Displacement distance[258, 259]	Travel distance Distance moved Flush distance	The distance an animal moves away from the perceived threat, once flight has been initiated.
Travel time[260]		The amount of time a displaced animal spends moving away from a perceived threat (sometimes used when displacement distance cannot be easily measured).
Time to resume normal behavior[261]		The amount of time post-disturbance it takes an animal to discontinue antipredator response(s).
Detectability period[262]		The amount of time that a bird or other animal remains near its initial flush point. Shorter detectability period indicates lower tolerance to human intrusion.
Buffer distance[254, 263, 264]	Set-back distance Buffer zone Minimum approach distance	Typically used to establish guidelines to reduce wildlife disturbance.

The U.S. Forest Service researchers reviewed 238 articles on human disturbance effects on wildlife, including information on 395 wildlife species.[259] Of all types of interactions on non-motorized trails, their results indicated that displacement or avoidance affected the highest percentage of species, followed by disturbance such as alert

distance. While the results may simply reflect the most popular or simple study topics – and underestimate the potential physiological effects of vigilance – the body of research does document the broad interest in and effects of human disturbance on wildlife.

In 2000 Jordan reviewed the literature pertaining to trails and wildlife, in which studies indicated several key points:[7]

- direct approaches cause greater wildlife disturbance than tangential approaches (Section 6.4)
- rapid movement by trail runners is more disturbing than slower hikers (Section 6.4)
- children and photographers⁸ are especially disturbing to birds
- passing or stopping vehicles are less disturbing than people on foot

Disturbance can have a multitude of significant effects on wildlife. For example, studies document that disturbance reduces reproductive success for some wildlife species.[25, 194, 265, 266] Numerous scientists have found that female deer and elk, and deer and elk groups with young offspring, show greater alert and flight responses to human disturbances than other wildlife groups.[25] Stress hormones may cause male songbirds to reduce their territorial defense, females to reduce feeding of their young, nestlings to have reduced weight and poor immune systems, and adult birds to abandon nests.[244, 265-267]

Antipredator response can directly and indirectly affect individuals, communities and populations.[246, 268, 269] We found few studies documenting population-level effects from trails and disturbance, as summarized in the wildlife sections below. To be relevant, such studies need to be fairly large scale and conducted over several years – a complex and expensive approach.

Knight and Cole identified several key factors that influence wildlife response to disturbance:[270]

- type of disturbance (e.g., hikers, mountain bikers or equestrians)
- timing (e.g., during breeding season disturbance may affect productivity; during other seasons it may affect foraging/survival)
- location (e.g., animals avoiding areas where they can easily be seen)
- frequency (e.g., more visitors can reduce avian nest productivity; we would also include duration here)
- predictability (e.g., on-trail visitors are less disturbing than off-trail visitors)
- characteristics of wildlife (e.g., habituation or sensitization)

Pomerantz et al. developed a classification scheme to assess the effects of recreation on wildlife.[271] Their six categories are in Table 5 below. These types of effects are reviewed in Chapter 7.

Bennett et al. developed a spatially explicit model to explore spatiotemporal patterns of anthropogenic disturbances on wildlife for Yellow-headed Blackbirds, which could be adapted to other species if single-species management or more complex approaches to multi-species buffers were needed.[272] Using a simpler approach, FID and alert distances can provide some general guidance for minimizing disturbance to wildlife (Chapter 8). Weston et al. reviewed FID studies for Australian birds and called for standardized, widely available data to allow for greater application of these data to the management of disturbance.[273]

⁸ The Audubon Society offers a guide to ethical wildlife photography: <http://www.audubon.org/get-outside/audubons-guide-ethical-bird-photography>

Table 5. Classification of recreational use effects on wildlife derived from interviews with refuge managers in the northeastern U.S. (From: [\[271\]](#))

Category of Effect	Description of Effect
Direct mortality	Immediate, on-site death of an animal.
Indirect mortality	Eventual, untimely death of an animal caused by an event or agent that predisposed an animal to death.
Lowered productivity	Reduced fecundity rate, nesting success, or reduced survival rate of young before dispersal from nest or birth site.
Reduced use of refuge	Wildlife not using refuge as frequently, or not using it in the manner they normally would in the absence of visitor activity.
Reduced use of preferred habitat on refuge	Wildlife use is relegated to less suitable habitat on the refuge due to visitor activity.
Aberrant behavior or stress	Wildlife demonstrating unusual behavior or signs of stress that are likely to result in reduced reproductive or survival rates.

Amount of use. In many cases, higher numbers of visitors cause more effects on wildlife including invertebrates, beetles, shorebirds, waterfowl, songbirds, herons, deer and elk, carnivores, and other species.[\[8, 19, 176, 178, 253, 274-283\]](#) As with trail and vegetation damage, in some cases there may be visitor number thresholds beyond which fewer animals or species use an area.

Some wildlife species can habituate to fairly high numbers of visitors without apparent harm, while others become increasingly sensitized to human disturbance (Section 6.2). For example, guanacos in Argentina appeared to have a threshold of approximately 250 visitors per day, beyond which the number of animals observed declined.[\[284\]](#) Other studies suggest visitor threshold effects for Sanderlings in Georgia (20 visitors per day)[\[285\]](#) and songbirds in the Netherlands, where eight out of 13 species showed thresholds ranging from 8-37 visitors per hectare.[\[235\]](#) Mexican Spotted Owls on the Colorado Plateau appeared to have a threshold around 50 hikers per day.[\[286\]](#) Regardless of any threshold effects, the majority of the research indicates that more visitors will cause more wildlife effects in general. The types of disturbance matter too, as discussed in the wildlife sections below.

Different wildlife species respond differentially to visual, auditory, olfactory and tactile stimuli. This variability is both difficult to study and critical to understanding the true effects of trail users on wildlife. The sections below describe and attempt to make sense of this variability to help inform our work.

A note about dogs. The research we reviewed strongly suggests that dogs are more alarming to wildlife than any non-motorized recreational user group without dogs. We previously reviewed the literature pertaining to the effects of dogs on wildlife (Appendix 1).[\[287\]](#) The evidence that dogs negatively affect wildlife is found repeatedly throughout the literature. People with dogs – on leash and even more so for off-leash dogs – appear to be more detrimental to wildlife than people without dogs. Land managers should consider prohibiting dogs at sites where conserving wildlife is a top priority.

6.2 HABITUATION, SENSITIZATION AND TOLERANCE

Evidence suggests that some wildlife species can become accustomed (habituate) to certain predictable, non-threatening disturbances such as people regularly walking on a trail in a natural area. Habituated animals (or those that appear to be habituated) still respond behaviorally and/or physiologically, but the amount of habitat affected via avoidance behavior or the magnitude of the disturbance response may diminish over time.[\[25, 173, 288, 289\]](#) Habituation is a gradient rather than a binary yes or no. Wildlife responses occur at different magnitudes in

different contexts, and responses may vary by species and even by individual.[\[248, 282, 290, 291\]](#) There is evidence to support that the capacity to habituate is species-specific.[\[292-294\]](#)

The term “habituation” is often used inappropriately in the literature, and this can lead to misinterpreting or underestimating the effects of human disturbance on wildlife. Bejder et al. differentiate the following terms:[\[248\]](#)

Habituation: the relative persistent waning of a response due to repeated stimulation, which is not followed by any kind of reinforcement - a process involving a reduction in response over time as individuals learn that there are neither adverse nor beneficial consequences of the occurrence of the stimulus.

Sensitization: the opposite of habituation - increased behavioral responsiveness over time when animals learn that a repeated or ongoing stimulus has significant consequences for the animal.

Tolerance: the type or intensity of disturbance that an individual tolerates without responding in a defined way; rather than a process, it is a state (for example, a threshold above which antipredator response occurs.)

Habituation and sensitization are appropriately studied by taking sequential measures of the same individuals over time, whereas tolerance is measured through instantaneous measures of many individuals at one time – for example, groups of elk being subjected to different types and levels of disturbance. Researchers often assume that tolerance equals habituation, when this may not in fact be the case. Bejder et al. suggest there are at least four potential explanatory mechanisms for habituation-like responses:[\[248\]](#)

1. Learning – some individuals become more tolerant (habituated) or less tolerant (sensitized) to disturbance through process of behavioral adaptation. This is the only mechanism that leads to true habituation or sensitization.
2. Displacement – individuals move out of an area. Displacement can be mistaken for habituation when most individuals move out of an area but the most bold or tolerant individuals remain behind. This could skew results towards tolerant individuals, which may not be advantageous to people or wildlife (for example, when a bolder cougar remains at a site whereas more human-averse cougar move away).
3. Physiology – for example, repeated or prolonged exposure to a stimulus such as loud noise impairs function such as hearing.
4. Ecology – there is some other variable in the habitat that prevents the individual from responding to the stimulus but physiological stress responses continue. For example, there may be no suitable adjacent habitat therefore an animal remains at the site, or wintering animals may prioritize obtaining food over moving away from human disturbance.

Habituation does not mean animals are unaffected by disturbance. What might appear to be habituation may actually be a choice of “lesser evils,” such as an animal’s decision to forage rather than taking flight during winter because the energetic cost of fleeing could mean starvation, or animals using disturbed habitats to avoid predators (next section). Many studies suggested some degree of habituation in various species depending on the circumstances,[\[67, 124, 248, 256, 270, 285, 295-298\]](#) although Bejder et al. posit that some studies may be documenting tolerance rather than true habituation, and that conclusions about habituation or sensitization derived from behavioral responses can only be inferred, not proven.[\[248\]](#)

Less fit animals may be less likely to flee from human disturbance than healthy individuals. An English bird study demonstrates how easy it would be to mistake habituation for what is in fact an ecological response to changing conditions. Researchers conducted a 3-year winter disturbance study on oystercatchers foraging over mussel beds to assess whether the birds' response to human disturbance changed as food resources became more scarce.[\[299\]](#) Undisturbed controls were included in the study. As winter progressed, oystercatchers required more energy to endure harsh conditions while food became increasingly scarce. They had to spend more time feeding to survive, and their behavioral response to human disturbance steadily decreased in order to meet the most immediate need. The risk of starvation became more significant than the risk of predation.

The control group's behavioral response to human disturbance remained constant. Without controls in this study, the scientists could have assumed they were observing habituation, but in fact it was a strategy to survive. In the authors' words,

"These results have implications for studies which assume that a larger behavioural response means that a species is more vulnerable to disturbance. The opposite may be true. To more fully understand the effect of disturbance, studies should measure both behavioural responses and the ease with which animals are meeting their requirements. Conservation effort should be directed towards species which need to spend a high proportion of their time feeding, but still have a large response to disturbance."

Scottish investigators also found that an animal's fitness can mediate antipredator response.[\[251\]](#) The researchers explored the link between a shorebird species' behavioral responses and individual fitness without directly measuring physiological attributes such as stress hormones. Using experimental and control treatments, birds at one site were fed mealworms every day for three days. On the fourth day the researchers recorded FID, flight length and alert distance for control and treatment birds. Birds whose condition was enhanced (fed mealworms) showed stronger anti-predator responses than unfed birds. Rather than habituating, the most vulnerable birds were more at risk of predation because their top priority was feeding rather than avoiding predation. The authors stated, "These findings suggest that our current management of the impact of human disturbance may be based on inaccurate assessments of vulnerability."

The predator shelter effect. In addition to differences in individual fitness, another phenomenon resembles but is not true habituation. The so-called "predator shelter effect" occurs when prey species spatially redistribute themselves to avoid predators.[\[172, 288, 300-305\]](#) For example, animals may seasonally avoid areas open to hunting by moving into areas with higher human disturbance but lower risk of predation, such as protected natural areas or suburban neighborhoods. This effect is especially well documented for elk (Section 7.4). The predator shelter effect does not represent true habituation; rather, it is a response to avoid the greater threat of being killed by hunters. In fact, elk in such circumstances tend to shift their activities more towards night-time, probably to reduce interactions with humans (Section 6.6).[\[173, 303\]](#)

The studies cited in this chapter suggest that there are species-specific responses to disturbance, including whether animals may become habituated or sensitized. True habituation is not easily measured, and what appears to be habituation is often not the case. Animals can experience significant stress without fleeing; when this is misconstrued as habituation, disturbance effects on wildlife are underestimated. Animals that do not appear to avoid recreational disturbance may still be experiencing stress or are unable to leave a site for some reason. Apparent habituation is not a true measure of whether people are disturbing wildlife.

6.3 SIZE MATTERS: INDIVIDUALS AND HERDS

Animal size. Larger sized animals tend to be more sensitive to human disturbance, although there is species-specific variability[[247](#), [256](#)]. We found one exception in a study of bison, mule deer and pronghorn,[[113](#)] but these are all large mammals therefore species-specific traits may have been more important than size. Numerous studies document larger alert and flight initiation distances (FIDs), and sometimes avoidance behavior in animals with higher body mass including birds[[123](#), [247](#), [306](#), [307](#)] and carnivores[[168](#), [169](#)] One likely reason is visibility, which correlates with detection distance: larger animals can see predators from further away than smaller animals[[308](#)], and animals that are more visible (such as larger animals or those in open habitats) are more nervous around potential threats because they perceive more risk.[[306](#), [308](#), [309](#)]

Stankowich and Blumstein’s literature review and meta-analysis on the topic of animal size revealed that larger animals typically have longer FIDs, indicating increased sensitivity to potential predators.[[247](#)] The review also found that animals in good condition had longer FIDs than those in poor condition, which is logical given that the decision to take flight is a cost/benefit decision and fleeing is energetically expensive. Blumstein et al. reviewed studies on bird detection distance as a key factor explaining variability between species’ response to human disturbance.[[308](#)] Larger birds tended to detect the presence of humans at a longer distance compared to smaller birds. Other bird studies on multiple continents support these results.[[123](#), [250](#), [254](#), [256](#), [262](#), [306](#), [309](#), [310](#)]

Larger animals and larger groups of animals tend to be more disturbance-sensitive.

Flock or herd size. In addition to body size, studies on numerous wildlife species indicate that larger groups of terrestrial animals tend to be more sensitive to human disturbance.[[113](#), [247](#), [254](#), [262](#), [270](#), [311-313](#)] A major review and study of fear and risk assessment in animals found that in general, all taxa except fish tend to respond more quickly (larger FID) in groups than as one or a few individuals, although there were a few exceptions.[[247](#)]

Animals may also perceive a reduced risk of predation in a larger group (“safety in numbers”).[[249](#), [298](#), [313](#)] Individual animals in a group do not need to be as vigilant because one or a few animals can serve as lookouts, leaving the remainder free to forage.[[163](#), [268](#)] However, if the lookout shows alarm it can cause the entire flock or herd to move away from the disturbance. This larger group sensitivity may also have to do with visibility, as other studies have shown that more visible animals tend to be more wary.[[254](#), [306](#), [308](#), [309](#)]

The tendency towards longer FIDs in larger groups may depend in part on group composition, particularly due to reproductive status. In a 5-year Yellowstone study examining elk vigilance due to natural predators, researchers found that adult males were less vigilant and fed more than females in any herd size. Female elk without young were more vigilant in small compared to large sized herds. However, females with young were more vigilant than other elk in any sized herd.[[314](#)] Herds with many mother elk were more vigilant than herds with few or no mothers. Section 6.6 includes additional information about this topic.

6.4 SPEED AND DIRECTNESS OF APPROACH

Whether an animal can see an approaching predator and has sufficient time to flee influence an animal's response to an approaching threat.[315] Consequently both predator and prey size, speed, and directness of approach modify antipredator responses.[247, 249] Humans are large compared to most other potential predators therefore a strong antipredator response can be expected based simply on size.

Faster approaches generally elicit a stronger antipredator response and cause longer flight distances compared to slower approaches.[6, 247, 249, 254, 316-318] In particular, joggers and mountain bikers can approach wildlife quickly and quietly and are sometimes more disturbing to wildlife than hikers,[297, 316, 317] although we did find one exception in the case of Bald Eagles in Idaho.[319] For example, slow-moving walkers such as photographers and wildlife watchers tend to actively seek out and approach wildlife, search for rare or unusual species, and stay in the vicinity for longer than typical hikers, therefore these activities may be particularly threatening to wildlife.[6, 97, 320]

Stankowich and Blumstein conducted a meta-analysis of 61 research papers that analyzed antipredator response in various wildlife species.[247] Results indicated that reptiles, even more than other animals, respond strongly to the speed of a potential predator's approach. Non-mammalian species showed a 60 percent increase in perceived risk when predators approached more quickly. The researchers did not have sufficient mammalian data for significant findings, although a later study by the same primary author found that deer in northern California showed longer FIDs when approached more quickly by a human.[318]

Animals tend to flee more readily when approached quickly or directly.

Multiple studies indicate that prey species show more fear (longer alert distance and FID) when a predator directly approaches them compared to a trajectory that appears to pass them by.[247, 275, 318, 321] However, researchers evaluating potential buffer distances in Argentina grasslands studied five bird species' alert distance and FID responses to direct versus tangential approaches.[315] Four out of five species showed greater alert distance and FID with tangential rather than direct approaches. We suggest the possibility that grassland birds react differently to predators compared to forest-dwelling birds due to their visibility upon flushing in open structure habitats; in some cases it may be safer to hide than to flush. Miller et al.'s study in Colorado grasslands supports this theory; dogs consistently elicited the strongest anti-predator response (Appendix 1),[287] yet grassland birds had shorter FIDs when approached by a human with a dog or a dog alone, compared to a human without a dog.[322] The next section addresses relationships between vegetation cover and antipredator response in more detail.

6.5 HABITAT STRUCTURE AND NEST OR PERCH HEIGHT

Vegetation cover is known to be important to many wildlife species' reactions to human disturbance. Animals tend to be less responsive to disturbance in tall or complex habitat or in other situations where predators are less likely to see them.[25, 176, 268, 323] Mourning Dove nest success in Iowa depended in part on vegetation cover and nest concealment.[324] In Madrid, Spain birds that spent time foraging on the ground showed a higher disturbance tolerance when good cover was nearby.[250] In Utah, ground- and shrub-nesting and ground-foraging birds were more likely to be found in undisturbed areas than in campgrounds, attributed to differences in shrub and sapling density, litter depth, and amount of dead woody vegetation occurring between the two habitats.[323] In Finland, researchers found a strong decline in ground nesting bird abundance near trails compared to

undisturbed areas, but no commensurate reductions in cavity or tree canopy nesters.[325] The best predictive variables for ground-dwelling birds related to number of recreationists, area of tourism infrastructure, and habitat characteristics. In Sri Lanka, bird species that used the understory were more susceptible to disturbance from hikers on a nature trail than away from trails.[178] These studies indicate that good vegetative cover can reduce birds' antipredator response in many situations. Perch height also affects bird antipredator response; birds perched higher up in trees tend to wait longer to flush.[123, 321, 326, 327]

Cervids show similar responses to enhanced cover. Deer and elk tend to wait longer to react to disturbance when forest or shrub habitat is nearby, presumably because they can quickly move to the safety of cover.[25, 268] In Scotland, red deer (elk are called red deer in Europe) during recreational seasons were more vigilant in meadows and shrublands compared to woodlands; most of the vigilant animals in disturbed heather and woodland habitats and in less disturbed habitats were standing, but in disturbed grasslands the main posture was lying down.[302] The researchers suggested that vigilant animals in grasslands lay down to be less conspicuous, while maintaining the ability to scan their surroundings. A review and meta-analysis indicated that elk that are further from cover have longer FIDs.[247] A study in central China found that ungulates' habitat use near trails depended on good vegetative cover.[176] These findings make sense, because vigilance and antipredator response are closely linked to perceived risk, and risk of predation is lower when animals can hide.

6.6 SEASON, REPRODUCTIVE STATUS AND TIME OF DAY

Reproductive status and season. Across multiple mammal species, research shows that pregnant females or those with young are especially sensitive to human disturbance.[124, 314, 328-330] For example, studies document stronger antipredator responses in pregnant elk or herds with young elk.[25, 331] Ciuti et al. studied mouflon, a type of wild sheep in Sardinia; groups with lambs fled at greater distances than male groups, and female groups without lambs.[329] In Canada, bison and herds with young were displaced further by human disturbance than herds without young.[328]

Birds may also be especially vulnerable to human disturbance during nesting season (see also Section 7.3). Endangered Belding's Savannah Sparrow became alert earlier and moved farther during the non-breeding season, possibly because they were non-territorial and in larger flocks in the non-breeding season.[332] Nestlings are unable to flee therefore for songbirds, protecting parental investment may outweigh the flight response up to a point. Female Ferruginous Hawks, a ground-nesting species, defended nests substantially more vigorously than male birds even though both parents participate in nesting.[333]

Some studies show seasonal differences in wildlife response to human disturbance, likely also pertaining to reproduction status. A study on desert bighorn sheep found that females fled further from human disturbance during spring lambing season, and males fled further during fall rut.[124] In the northeastern U.S., heron rookeries with a 50-meter buffer zone to prevent daily tourist visits showed no short-term reproductive losses.[8] However, people entering rookeries led to nest mortality rates of 15-28 percent depending on the heron species. This study and one on European pine marten suggest that in some cases, the increased number of recreationists with the coming of spring may be a confounding variable with actual reproductive status.[274] Nonetheless, there is ample evidence that pregnant animals or those with young – especially mammals – are particularly sensitive to human disturbance.

Pregnant animals and those with young are especially nervous around human disturbance.

Time of day. Some animals alter the timing of movement and foraging to reduce conflicts with recreationists; this is particularly well documented in mammals.[\[173, 209, 334\]](#) In the San Francisco Bay area, certain mammal species altered the timing of their activities in areas where non-motorized recreation was allowed.[\[209, 335\]](#) Coyotes became more active at night and less active during the day; gray foxes were more active just before dawn and less active after dusk; and mule deer shifted peak activities towards earlier pre-dawn and later post-dusk periods, when recreationists were generally absent. Researchers in Colorado found that bull elk used residential areas more at night, when human encounters were at a minimum (Section 6.1).[\[173\]](#) Long-term data for eight species using wildlife over- and underpasses at Banff National Park, Canada indicated that four mammal species – black bear, deer, elk and wolves – shifted the time of day they used shared pedestrian/wildlife crossings in response to increased human activities.[\[336\]](#) In another study wolves in British Columbia shifted their activities to night in response to higher levels of recreational disturbance[\[172\]](#), and a study in southern France found similar results for wild sheep.[\[303\]](#)

Some wildlife species shift to night-time activities to avoid human disturbance.

Changes in the timing of habitat use in response to disturbance is less well documented in birds, likely because they would be difficult to see at night and are less nocturnal than mammals. Mammals are generally larger and can be affixed with a GPS unit with relative ease compared to birds. However, we did find several relevant studies for shorebirds and waterbirds. Shorebirds in Florida fed more at night in response to human disturbance,[\[275\]](#) and waterfowl are known to forage more at night when under heavy hunting pressure.[\[337, 338\]](#) In India, storks that normally foraged during the day altered their behavior to night-time foraging due to the presence of fisherman.[\[339\]](#) Another Indian study showed similar results for pelicans.[\[340\]](#)

Human disturbance can alter foraging and other behavior for many species. Shifting to night-time foraging helps these species avoid risk of predation and can help make up for foraging time lost due to disturbance. It is unknown whether this type of compensatory behavior affects the fitness of these wildlife species. Night time can serve as a refuge for wildlife and may be the only time animals can avoid human activity, but human disturbance is not always limited to daylight hours. For example, mountain bikers sometimes ride at night in Portland’s Forest Park.[\[341\]](#)

6.7 NOISE AND LIGHT POLLUTION

Noise pollution. Human-created noise can alter wildlife behavior including habitat selection, foraging patterns, and overall energy budgets.[\[331, 342-345\]](#) We found numerous studies documenting the effects of road noise on wildlife, including research showing that some animals change the pitch of their songs near loud roadways.[\[268, 342, 343, 346-354\]](#) Shannon et al.’s subject review documented reduced wildlife abundance in noisy habitats, increased vigilance, altered foraging patterns, impacts on individual fitness, and changes in the structure of wildlife communities.[\[345\]](#) Francis et al. reviewed the literature relating to how human-altered “soundscapes” influence both wildlife and people.[\[355\]](#) The review found that anthropogenic noise can alter behavior, physiology, reproductive success and distributions of wildlife. As a side note, the authors also found that natural soundscapes provide important, positive psychological benefits to people – for example, birdsong can facilitate more rapid stress recovery rates, and natural sounds can improve cognitive function.

We found several studies investigating noise effects directly due to non-motorized recreational users. The studies summarized below found that recreationists engaged in conversation elicit a stronger antipredator response compared to silent recreationists, and higher volume conversations tend to cause stronger wildlife responses.

Swaddle et al. proposed a research framework for investigating evolutionary responses to noise and light pollution.[356]

Researchers tested the response of a rain forest bird community to noise by playing a recorded conversation while conducting bird surveys.[357] Conversation noise of 50 decibels (approximately library speaking volume) caused 35 percent fewer bird detections and reduced detected species richness by 33 percent. They found similar but slightly stronger results at 60 decibel conversation noise, approximately the volume of an excited child. Bird vocalizations important to territory defense, breeding behavior and predator detection showed a 37 percent decline. Birds showed similar strong reactions both near an ecotourist lodge and in an intact reserve, suggesting a lack of habituation. Insectivorous birds were most sensitive. A New Zealand study also found that bird species with animal-based diets were more sensitive to noise than birds with plant-based diets.[358]

Noise has the potential to impair antipredator responses, potentially leading to increased wildlife mortality. A study conducted in California and Wyoming found that anthropogenic noise reduced the distance at which ground-foraging birds and one flycatcher (but not species within the tree canopy) flushed, suggesting that such noise either distracts these species from detecting potential threats as easily, noise masked the approach of the observer, or both.[359]

Other studies document the effects of anthropogenic noise on wildlife. Variation in feeding behavior for five species of waterbirds at a Florida refuge was largely explained by whether people were present, the number of people present, and the amount of noise made by the people.[278] In the Amazon, researchers approached Hoatzins (an at-risk bird species) by canoe playing recorded human conversations at different volumes.[360] The distance at which Hoatzins became agitated, as well as their FID correlated positively with noise volume. The birds apparently began to habituate to silent approaches by the end of the 10-week study period, but recorded conversations continued to cause the same antipredator responses over the full study period. The authors suggested that remaining silent would provide the most wildlife viewing opportunities. Another Hoatzin study found high stress responses and reduced chick survival in response to ecotourism.[236] These studies illustrate the species-specific nature of responses to different types of disturbance. Although reptile research is sparse, lizards have a particularly keen sense of hearing,[361] and may be easily disturbed by noise from recreationists.

Even low levels of conversational noise can disturb wildlife.

We found two studies documenting negative effects of conversational noise on mammals. An Australian study testing wildlife response to various human disturbances found that people talking significantly lengthened FID of two kangaroo species compared to human approaches without conversation.[330] In an Arizona cave, bats in a *Myotis* maternity colony engaged in more takeoffs, landings and showed increased activity levels in response to tour groups engaged in conversation compared to silent tourists.[362]

A few studies show neutral or positive effects for certain species near busy roads.[350, 363] For example, elk in Grand Teton National Park did not react strongly to road noise, but they did react to pedestrians.[331] In a New Mexico study, researchers compared artificial nest depredation in natural gas fields with high levels of compressor noise with controls (gas fields with no compressors).[344] Nest depredation decreased with increasing noise; Western Scrub Jays depredated nests in controls, but not in noisy gas fields. However, there was insufficient information to determine whether jays were avoiding noisy areas, or whether some other factor was involved.

Although it can be difficult to tease out differential effects from noise and human presence, the studies summarized here suggest that simple conversational noise in natural areas can reduce habitat quality and affect productivity for some wildlife species, and can also reduce visitors' wildlife viewing opportunities. We surmise that the magnitude of the effect depends on the number of users; for example, on busy nature trails the daytime conversational noise might be fairly constant and the effect nearly continuous. This could cause more noise-sensitive species to avoid near-trail habitat completely – a displacement effect. In addition, additional road traffic or new roads associated with recreational access may adversely affect some wildlife species.

Artificial light pollution. Some trails have artificial lighting for night-time visibility or safety. Studies demonstrate that artificial light can affect wildlife behavior.[364] Nocturnal animals accustomed to navigating in darkness can become disoriented by artificial light; night lighting can temporarily blind and disorient certain species such as some frogs, nocturnal insects and migrating birds, making them vulnerable to predation or in the case of birds, window strikes.[364-366] Artificial night light can induce diurnal birds such as the American Robin to sing territorially at night or earlier in the morning, wasting valuable energy.[365, 367] Artificial lights on turbines, communication towers, power lines and buildings near trails can interfere with songbird migration and cause substantial wildlife mortality.[365, 368-370]

Nocturnal animals are most likely to show effects from ecological light pollution, and studies have shown effects on bat behavior including foraging, commuting, emergence, roosting and hibernation.[365, 371-374] For example, a researcher studied bats along a gradient of light intensity along an Ohio bicycle trail.[373] Three bat species occurred in lit areas and tended to be positively associated with the amount of light, but there appeared to be a light threshold beyond which bats did not use the trail area. A European study of house-dwelling bats found that juveniles were smaller in night-lit houses than in those that were not lit, suggesting that artificial light reduced these animals' fitness.[372] In Ontario, Canada researchers tested the effects of artificial light on two bat species using 11 lit buildings, with two unlit buildings – one for each species – as controls.[374] Compared to the initial population levels, bat populations in the experimental colonies decreased by 41 to 96 percent, whereas populations in the control buildings increased by 57 and 97 percent. These studies indicate that artificial lighting can harm bats.

Nocturnal wildlife species such as bats are especially vulnerable to effects from artificial light.

Artificial light attracts some species and repels others, with implications for habitat connectivity. In a study conducted in Wilsonville, Oregon researchers installed artificial lights to explore animal usage of a bridge under-road crossing structure.[375] Different levels of light and an unlit control were established. Sand tracks recorded 23 wildlife species using the structures, of which 9 had sufficient data for analysis. Columbian black-tailed deer, deer mice, and Virginia opossums used the unlit bridge section less often when adjacent sections were lit. The authors concluded that artificial light may be interrupting connectivity for these species. Some large carnivores have also been shown to avoid artificial light.[210, 376]

Artificial light can alter feeding habitats for some species. Insects and other arthropods may be attracted or repelled by light, which can attract bats.[377, 378] Certain diurnal bird and reptile species will also forage under artificial light, potentially benefiting those species but not their prey.[11, 379] In a study of six wading bird species in Portugal, researchers found that the majority of species shifted more to night-time foraging in areas with artificial street lights.[379] A Florida study found that mice used fewer habitat patches and harvested fewer seeds near artificial light.[380] In New York, researchers discovered numerous migratory songbird species foraging around artificial stadium lights at night.[381] The consequences of such behavioral shifts are unknown.

If artificial lighting along trails is deemed necessary, wildlife effects can be partially mitigated, for example by following best practices that meet the Illuminating Engineering Society of North America's standards.^[382] The Audubon Society of Portland produced a useful guide for bird-friendly building design.^[383] Directing light downward or away from habitat, reducing glare and using lower wattage flat lens fixtures along trails reduces light pollution. Some urban areas are making strides toward reducing night lighting, such as the "Lights Out Portland [Oregon]" campaign.^[384] This approach has the added benefit of reducing cost and energy use. To reduce wildlife effects from recreation, ideas could include limiting trail access from dusk to dawn or employing lighting standards or restrictions.

CHAPTER 6 SUMMARY – Overview of effects on wildlife

Disturbance and the antipredator response

- Wildlife species respond to human disturbance physiologically and by freezing, hiding or moving away.
- Higher disturbance levels generally cause stronger effects (although note habituation, below).
- Wildlife response to disturbance may vary substantially between species.
- Studies do not always reveal the strongest impacts because the most disturbance-sensitive species are naturally rare in number or are already gone from disturbed sites.

Habituation, sensitization and tolerance

- Some, but not all, species may become less reactive to human disturbance over time (habituation). On the other hand, some species react to continuing disturbance by becoming more sensitized.
- Some habituation-like responses are actually predator avoidance or occur because the need for resources such as food during winter outweighs the antipredator response.
- Animals have personalities; gregarious and adventurous individuals may habituate more readily, which is not always to their advantage.
- Wildlife does not appear to habituate to the presence of dogs; impacts linger after dogs are gone because the scent of dogs repels wildlife (see Appendix 1).

Size matters: Individuals and herds

- Larger animals and larger flocks/herds tend to flee more readily, possibly because they are more visible.

Speed and directness of approach

- Whether an animal is visible, can see an approaching predator and has sufficient time to flee influence wildlife response to an approaching threat.
- Faster and more direct approaches generally elicit stronger antipredator responses.
- Prey species show more fear when directly approached by predators or people.
- Animals know when a visitor is looking directly at them and will show increased antipredator response.

Habitat structure and perch height

- Animals in open areas or without nearby cover are more reactive to disturbance. If they can't see you or they think you can't see them, they tend to hide rather than flee.
- Grassland songbirds may be an exception and tend to wait until the last second to flush.
- Birds that nest or perch higher in trees react less to disturbance than those closer to the ground.

Season, reproductive status and time of day

- Animals may be displaced by space or time (e.g., switching to night-time foraging).
- Animals that are pregnant or have young, and groups with same, tend to flee more readily and are particularly vulnerable to disturbance.

Noise and ecological light pollution

- Conversational noise along trails can be very disturbing to wildlife.
- Artificial light can repel (or attract) wildlife, disrupt bat colonies and interfere with animals' navigation.

7. EFFECTS ON WILDLIFE BY SPECIES GROUP

7.1 SPECIES GROUP: INVERTEBRATES

We located few articles relating to the effects of recreation on invertebrate communities, although several issues related to trail use likely affect invertebrates (e.g., soil compaction, erosion, trampling and vegetation loss, artificial light). This group has not been widely studied in recreation ecology, and none of the studies we found differentiated recreational user group effects. In addition to invertebrates being intrinsically important as unique species, they are foundational food web components in many ecosystems.

Trails may influence invertebrates by reducing the amount of available habitat, particularly shrub cover. [\[103, 125\]](#) Hagar studied the relationship between bird abundance, availability of arthropod prey, and composition of understory vegetation in western Oregon forests. [\[385\]](#) Tall deciduous shrubs supported high abundances of arthropods – especially butterflies and moths – and aerial arthropods were positively related to deciduous shrub cover. Shrub cover also best explained the abundance and foraging patterns of several insectivorous Neotropical migratory songbirds. Most Neotropical migratory songbirds are insectivorous, and a reduction in shrub habitat near trails would reduce invertebrates and therefore negatively affect some bird species.

We found two studies investigating effects of stream crossings on in-stream invertebrate communities. In Zion National Park in Utah, densities of drifting aquatic invertebrates and organic matter in the water column increased with higher numbers of hikers crossing streams, with an apparent threshold effect around 500 hikers per day after which invertebrates and organic matter available to drift may have been depleted. Invertebrates appeared to readily recolonize affected reaches with no apparent long-term harm [\[197\]](#).

In contrast, a stream study in Yosemite National Park, California examined benthic macroinvertebrates (living in the stream bed and visible with the bare eye) above and immediately below two trail stream fords in spring and fall. [\[198\]](#) Benthic macroinvertebrates are known water quality indicators, unlike invertebrates found in the water column such as those collected in the Yosemite study. Downstream differences were evident below fords, with finer substrate, a thick periphyton layer, and higher pollution-tolerant but lower pollution-sensitive macroinvertebrate taxa. Differences in both spring, before hiking started, and fall suggested long-term effects. Trails were used by hikers and equestrians, thus it was not possible to disentangle user group-specific effects. Such studies suggest that while an occasional stream crossing may not cause widespread and lasting impacts, higher densities of crossings may cause impacts on aquatic invertebrates and water quality.

One study documented potential impacts to invertebrate on beaches. In Australia, trampling caused 5 percent to 55 percent reductions in invertebrate abundance and richness along the lower part of a beach where most of the tourists walked, compared to non-frequented areas. [\[386\]](#) On heavily used beaches this could have important implications for shorebirds, which rely on invertebrates for food, as well as on the invertebrate communities themselves. Although no studies were found, it is feasible that soil compaction associated with trail use would alter below-ground invertebrate communities; this would be an interesting topic of future studies in recreational ecology.

Researchers in California found that use of a natural area preserve by hikers and trail runners led to reduced butterfly diversity and local loss of some native species. [\[387\]](#) In an urban area in Russia, recreational effects

changed the species composition, set of dominant species, degree of dominance and ratio between classes of carabid beetles. The heavier the recreation, the more significant was the decrease in beetle species diversity.[277]

A study in Poland compared spider communities on two lake islands, one which was isolated and the other frequently disturbed by tourists.[177] Tourism compacted soils, altered soil fertility and reduced organic matter; these changes led to more homogenous habitat on tourist islands. Species that were segregated on the undisturbed island were intermingled on the tourist island, with unknown consequences. The authors suggested that this “community disassembly” might be an early sign that tourism was having a negative effect on ecosystem functioning.

7.2 SPECIES GROUP: REPTILES AND AMPHIBIANS

We located several reptile and amphibian studies relating to recreation ecology. Although the research is sparse, it appears that reptiles are vulnerable to disturbance, while some trail effects on amphibians may relate more to habitat elements such as logs. Frogs, which are more mobile than salamanders, may be especially sensitive to recreational disturbance as described below.

For salamanders, the effects of trails may have more to do with habitat than disturbance. Researchers in Georgia studied terrestrial salamander distribution in paired plots near and away from trails.[388] Logs cut to create or maintain trails were often laid down alongside the trails, resulting in more logs near compared to away from trails. Salamander abundance increased with log abundance, thus there were more salamanders along trails. An Ohio study showed similar results.[389] However, salamander abundance in North Carolina was significantly lower on old, narrow abandoned logging roads in forests compared with adjacent upslope sites.[390] Salamander abundance was not correlated with invertebrate abundance or richness therefore it was not likely a food issue, but related to habitat alterations including structural simplification similar to the edge effects found adjacent to trails.

These studies illustrate an important point. For some species, maintaining vegetative structural diversity and retaining or adding specific habitat features such as dead wood may substantially reduce negative trail effects for some wildlife species, and could even improve habitat compared to conditions prior to recreational access. The alterations in microclimate associated with edge effects – especially dryer conditions – may pose a problem in some cases, but we located no such studies. One study documented that the internal condition of dead wood (e.g., moisture) is resistant to microclimate changes,[391] thus it is possible that installing sufficient dead wood would help offset this issue.

The studies mentioned above tested salamander abundance alongside versus away from trails, but their methods were not designed to test whether salamanders moved across trails. Trails may create barriers for some reptile and amphibian species. A study in Virginia examined salamander movement adjacent to unpaved hiking trails versus controls located away from trails.[392] The researcher used a fluorescent pigment powder applied to each individual that showed the animal’s travel pathway. Salamander use near trails did not differ between gravel and dirt surface trails, but of 49 individuals located along hiking trails, only one salamander crossed a trail.

In a central Spain experimental study, researchers simulated human disturbance (walkers) on frogs using stream banks.[261] The more a given frog was disturbed, the longer it took to recover to pre-disturbance activities. This suggests sensitization, the opposite of habituation. Flight initiation distance did not differ between low and high disturbance levels, although FID was shorter where there was higher vegetative cover, possibly either because (a)

the perceived risk of predation was less because they could hide, or (b) the frogs couldn't see the approaching person until he/she was close. Frog abundance was lower in areas closer to recreational areas, suggesting population-level disturbance effects.

Researchers in northern Italy collected data about human disturbance, environmental features such as leaf litter disturbance and tree size, and reptile, amphibian, and bird distribution within 44 wood patches in a large urban park.[44] They found strong species-specific and some wildlife group-specific differences in the response to the same source of disturbance. Reptiles were strongly, negatively associated with the amount of human use and somewhat so with reductions in leaf litter caused by trampling. Amphibian density was unaffected by human disturbance levels, but declined with declining leaf litter. Birds and mammals varied. This study demonstrates the substantial variability in wildlife responses to human disturbance and human-induced habitat changes.

Invasive species may be an issue for some amphibian species. A study in Gresham, Oregon examined amphibian community composition and occurrence patterns in relationship to various local and landscape attributes. Three out of five native amphibian species were negatively correlated with invasive species.[393] Trails are vectors for invasive species, and such introductions could reduce breeding habitat quality for some pond-breeding amphibian species.

We found no studies examining amphibian mortality due to recreational trails although amphibian deaths from road crossings are well documented, as is the success of amphibian undercrossings in reducing mortality.[394-396] This author has observed local seasonal mortalities of Northern red-legged frogs, rough-skinned newts, and garter snakes (*Thamnophis* species) on paved multi-use trails. Wildlife mortality on recreational trails would be a valuable topic for future studies, particularly studies comparing effects of different user groups, amount of use and type of trail.

Two Spanish lizard studies illustrate the importance of research methods in studying the effects of recreation. In the first study, researchers found evidence of habituation-like responses in tourist sites compared to controls, as indicated by shorter FIDs and flight distances.[397] In the second study, researchers found that lizards used the same antipredator escape strategies with tourists compared to other types of disturbance, with similar FIDs.[398] However, lizards in areas with high tourism levels had reduced fitness (more ticks, poorer body condition and dampened immune systems) compared to lizards in areas with fewer tourists. The authors stated that lizard body condition and health should be included in disturbance studies in order to accurately assess the real effects of tourism on lizard populations. Stankowich and Blumstein's review and meta-analysis found that reptiles are especially vulnerable to faster approaches.[247]

Turtles are vulnerable to recreational disturbance. Connecticut researchers monitored 133 wood turtles in two separated populations for 20 years, before and after human recreation (hiking and fishing) was introduced to the watershed.[399] After a 9-year pre-disturbance study period indicating population stability, once the sites were opened to recreation, both populations declined in tandem with the number of recreational permits issued. Mean turtle age increased while juveniles and females decreased; these are indicators of a population in decline. The last turtles were re-captured 1991, and none during the last two years of the study; the two turtle populations were stable prior to disturbance, but disappeared completely within 10 years of opening to recreational use.

A conservation assessment of western pond turtles in Oregon cited recreational disturbance as a key threat to this declining species, especially when basking or during nesting.[400] Although no specific studies were cited the

document provided local examples of trails and recreational uses adjacent to aquatic habitats occupied by pond turtles including examples in Eugene and in Fern Ridge, Lookout, and Fall Creek reservoirs. A subsequent guidance document included a goal to “Manage recreation near turtle-use areas to reduce disturbance,” including best practices to reduce effects when designing and constructing new recreational trails.[49]

A western pond turtle study in northern California found that recreational disturbance overall reduced basking time along a newly opened trail.[401] Runners, walkers, bicyclists and vehicles (mostly pickup trucks) all caused some basking turtles to flush underwater, but motorized vehicles exerted the strongest influence (2, 5, 6 and 45 percent of turtles flushed, respectively). However, observers were positioned within 20-30 meters of basking turtles, which may have been a compounding variable because non-motorized disturbance was already introduced by the observers. Nevertheless, turtles showed statistically significant differences between each of the four types of recreation use.

Amphibians and reptiles such as turtles are less mobile than other wildlife species. Specific habitat features such as dead wood and rock piles often provide both key habitat (cover, temperature refugia) and connectivity within and between habitat patches – for example, across clear-cuts. Strategically installing such features and ensuring appropriate vegetative cover will probably not prevent, but may help ameliorate the effects of recreation on this sensitive group of animals. Clearings on sunny south-facing slopes provide valuable reptile habitat. Special consideration should be given to avoid trail-induced mortality, such as considering crossing structures when placing trails between wetlands. It is also important to avoid disconnecting pond turtles with their upland nesting habitat. The Partners for Amphibian and Reptile Conservation (PARC) offers guidance to enhance habitat in the Pacific Northwest[402] and other geographic regions in the U.S. and parts of Canada.⁹

Laying logs beside a trail can help reduce the impacts of recreation on salamanders.

7.3 SPECIES GROUP: BIRDS

Birds are the second-most studied terrestrial wildlife group in the recreation ecology literature, behind mammals.[192] Birds are relatively easy to locate by sight and sound, and the multitude of species provides ample comparative study opportunities. The literature reveals several patterns linked to migratory status and species guilds. We found evidence of differential effects based on both recreational user group and intensity of use.

All bird species will flush if approached too closely, but certain characteristics influence the distance at which birds flush from humans. Blumstein et al. conducted a literature review and meta-analysis involving 150 bird species, examining inter-specific variation in bird responses to human disturbance.[308] Larger birds flushed more readily than smaller birds because they could see people from greater distances (Section 6.3). Fitness¹⁰ related responses such as the amount of food consumed are also important; for example, birds in winter may wait longer to flush because the need for food dampens the antipredator response (Chapter 6).[251]

Detection distance only explains part of birds’ FID. In another Blumstein study, FID in birds depended in part on intruder starting distance for 64 of 68 Australian species; the further away a person began to approach a bird (“starting distance”), the earlier the bird flushed.[292] This relationship held true whether it was in open or

⁹ <http://separc.org/products/#/habitat-guidelines/>

¹⁰ Fitness refers to reproductive success and reflects how well an organism is adapted to its environment.

wooded habitats. The author suggested this could be explained by at least two factors: first, that animals detecting an approaching predator from further away may reduce the cost of flight by flying earlier, which could for example avoid the need to escape at maximum velocity. An alternative could be that it would energetically cost more for birds to remain if they needed to be vigilant for a long period. Several other studies also found positive correlations between starting distance and FID or alert distance.[\[254, 255, 403, 404\]](#)

Starting distance may explain some of the variability in FID between studies for the same species (Appendix 3). It could also have implications for wildlife near trails, because trail users may be detectable at least audibly for long distances, creating a longer disturbance period per visitor and therefore a shorter undisturbed period between trail users passing by. It also suggests that some birds may flush before a surveyor arrives to count birds, with less sensitive species or individuals remaining. If this is the case, it is likely that many studies underestimate the effects of recreation on birds and other wildlife.

Fernandez-Juricic et al. conducted a series of urban and disturbance related bird studies in habitat remnants in Spain and the Americas.[\[123, 250, 279, 280, 315, 405\]](#). In addition to the classic habitat patch size and structural diversity correlations, they found:

- Higher pedestrian traffic reduced breeding bird species richness and abundance in urban parks.
- The amount of pedestrian traffic was the only factor significantly associated with inter-annual changes in species composition.
- Locally, human disturbance constrained the time and space of foraging and breeding opportunities, thus reducing fragment suitability.
- Regionally, high levels of disturbance increased extirpation and decreased colonization probabilities.
- Habitat structure influenced the flush distance of some ground-feeding bird species.
- Larger birds flushed more readily than smaller birds and landed further away from the disturbance.
- Alert distance provided a better, more conservative measure of bird disturbance than FID and may be useful to determining minimum approaching distances (buffers) to conserve birds in urban parks.

These findings are in keeping with many other studies we reviewed here.

Photographers, people with small children, bird watchers and those engaging in loud conversations may be especially detrimental to bird communities because they are unpredictable and generally alarming (Chapter 6).[\[6, 180, 320, 406, 407\]](#) Photographers and wildlife watchers tend to stop, look directly at wildlife and even follow them around, triggering stronger antipredator responses than when people are simply passing by; they also tend to seek out rare species and look for nests. Curious, excited children tend to run around and shout in an unpredictable fashion. These types of issues can be partially mitigated by providing wildlife viewing blinds, education and signage such as “Quiet please – sensitive nesting birds,” or if necessary, seasonal trail closures in areas hosting particularly sensitive species such as nesting Bald Eagles or heron rookeries. As many national wildlife refuge visitors have learned to accept, the U.S. Fish and Wildlife Service routinely, seasonally closes portions of trails to protect breeding waterfowl and waterbird populations. The American Birding Association has a “Code of Birding Ethics” that includes best practices such as limiting the use of bird song recordings to attract birds, keeping well back from nests and colonies, and staying on trails.[\[408\]](#)

Although we found many bird studies measuring potential effects for single user groups or hikers versus motor vehicles, boats or aircraft, studies directly comparing the effects of our three user groups are less common.[\[26,](#)

[406](#)] Such studies are difficult because (a) bird communities are complex and contain many species and guilds, (b) sites with more than one type of dedicated single-use trails are rare, and (c) bird surveyors cause disturbance which can confound results. In addition, it is more difficult to affix a GPS unit to birds than to large mammals, bird vocalizations can only be heard within a relatively short radius around the observer, and birds are smaller and less visible than many mammal species. However, birds comprise by far the largest group of terrestrial vertebrate wildlife species and are crucial to maintaining a site's biological diversity.

Generalists versus specialists. Some birds specialize on specific habitats or food resources, whereas others can succeed in a variety of circumstances. Studies show that habitat specialists are reduced, and generalists – which include most species that tend to tolerate or be associated with human use – increased near trails and in fragmented habitats. [\[193, 205, 357, 409-413\]](#)

In France, researchers used long-term Breeding Bird Survey data and associated landscape fragmentation metrics to assess whether habitat specialist bird species were more vulnerable to habitat fragmentation than generalist species. [\[412\]](#) Results fell on a gradient in which specialist bird species, but not generalists, declined with increasing fragmentation. European researchers found similar results for birds along a rural to urban gradient. [\[413\]](#) These large-scale studies support that habitat specialists are especially vulnerable to human disturbance.

This pattern of generalist/specialist species holds true for recreational disturbance as well. In Boulder, Colorado researchers compared near-trail bird communities and controls away from trails in grassland and woodland ecosystems. [\[410\]](#) In both ecosystem types, wildlife species composition differed between trail and control sites, with generalist species more abundant near trails and relatively fewer habitat specialists. This study identified a trail “zone of influence” of about 75 meters from the trail for most species.

Migratory birds and those that require a specific habitat type may be more vulnerable to recreational disturbance.

Various studies have documented that some species are negatively associated with trails. In Colorado, Miller et al. found that the following species were negatively associated with trails: Vesper Sparrow, Western Meadowlark, Grasshopper Sparrow, Western Wood-pewee, Chipping Sparrow, Pygmy Nuthatch, Mountain Chickadee, Townsend's Solitaire and Solitary Vireo. [\[410\]](#) In Canada, the density of forest birds – especially those that forage or nest on the ground – were significantly reduced near trails. [\[175\]](#) Northern Parulas were more abundant in areas with fewer trails and edges, while other bird species' habitat use was not correlated with trails. [\[411\]](#)

Together these studies suggest that Neotropical migratory birds and habitat specialists such as grassland and oak-associated species tend to avoid trails and are adversely affected by habitat fragmentation. Because these types of species are declining more quickly than generalist species, they warrant special attention when considering trail alignment alternatives.

Altered breeding behavior and reproductive success. Trail use and human disturbance can lead to increased avian nest predation and reduced reproductive success [\[7, 181, 193, 410, 411, 414-416\]](#) In Hocken et al.'s literature review, 36 of 40 papers revealed that human disturbance reduced breeding success. [\[417\]](#) Several shorebird studies observed reduced or absent nesting on disturbed beaches. [\[8, 181\]](#) Numerous songbird studies found reduced nest success or reduced nesting frequency near trails and edges. [\[211, 212, 325, 410, 416, 418-420\]](#)

For example, researchers in Colorado studied the influence of trails on breeding birds in grasslands and forested habitats. Grassland, but not forest, birds nested more frequently near trails. Nest predation was greater near trails

in both habitats.[410] A literature review and meta-analysis found that the nest success of many species of ground-nesting birds was reduced by disturbance of people on foot.[416] In Finland, Kangas et al. conducted bird surveys along forested hiking trails and undisturbed controls.[325] Although there was no change in species richness, the relative abundance and community composition did change. Open cup ground nesters were strongly negatively associated with trails, unlike shrub, tree or cavity nesters. Their results demonstrate that relatively low visitor pressure can have negative effects on specific bird guilds.

A study in Europe found differences in behavior and breeding success for a chickadee relative, the Blue Tit.[420] The researchers compared spring birds living in natural woodlands with those living in urban parks, considering whether thermal conditions affected breeding behavior. Nest success was positively associated with warmer temperatures in woodlands, but not in urban parks. In urban parks, lower temperatures and rainy days led to increased nest survival and productivity, apparently because there were fewer park visitors on days with poor weather.

Nest parasitism occurs when bird species such as Brown-headed Cowbirds and certain members of the cuckoo family lay their eggs in another “host” bird’s nest, leaving any further parental investment to the host bird. Brown-headed Cowbirds do not even build nests. Cowbird chicks hatch quickly and have a flat spot on their rear ends that assists in pushing host species’ eggs and young out of the nest. In addition, cowbird chicks are often much larger than host species’ young and require more food. These factors significantly reduce reproductive output for host birds.

Cowbirds frequent habitat edges searching for open-cup nests in which to lay their eggs.[411, 420, 421] Trails create edges, and birds nesting near trails may be especially vulnerable to nest parasitism by Brown-headed Cowbirds. For example, cowbirds were more abundant near roads and trails in a large natural area in Colorado[418] and more abundant close to trails than away from trails in Illinois.[422] However, not all studies link cowbird parasitism with trails or trails use.[410]

Common nest predators such as corvids, raccoons and squirrels are attracted to recreational areas, trails and edge habitats, where they can more easily find nests and consume eggs or nestlings.[174, 245, 414, 422-425] Some nest predators may be attracted to both trails and humans.[425] A local study found that American Crows are more abundant near trails and revealed positive or negative associations with edge habitat for several avian species.[426] Marzluff et al. found that crows in North America tend to be most abundant and are increasing rapidly in urban areas,[427] thus birds nesting in urban and suburban natural areas may be increased at risk of nest depredation.

Common nest predators tend to be more abundant near trails.

Researchers in North Carolina found that mammalian nest predators were most common in edge-dominated forested corridor widths of 200 m or less, and were positively correlated with the number and width of trails.[174] Raccoons in Illinois tended to follow linear landscape features such as fencerows, forest edges and mowed trails during nocturnal foraging.[424] In Colorado, bird but not mammalian predators attacked more artificial nests near trails than away from trails.[414] However, artificial nest studies must be interpreted with caution, because they do not necessarily reflect reality.[428, 429]

The importance of good vegetative cover is elevated for birds nesting near trails. For example, Northern Cardinals tend to do well near humans, but have been shown to alter nest placement near trails. Cardinals in urban forested

parks in Ohio did not experience reduced nest success in relation to trails, but nest sites closer to trails were surrounded by more small stems, placed at greater heights and were better concealed compared to nests away from trails.[321] Birds with higher nests were less likely to flush from trail users. Other studies showed similar results for different avian species in disturbed habitats; Burhans and Thompson found that higher-nesting birds' nests were more successful,[411] and in Finland open-cup nesters breeding higher in trees showed reduced disturbance responses compared to ground-nesters.[325]

Human disturbance can influence breeding bird behavior in more subtle ways, such as altering spring birds' singing patterns or aggression towards other bird species.[253, 286, 430] For example, pairs of Mexican Spotted Owls in the Colorado Plateau greatly increased vocalizations with nearby trail users.[286] In another study breeding male Western Bluebirds were more aggressive towards House Wrens and American Goldfinches when humans were present; females were more aggressive only towards House Wrens, which compete for nest cavities.[253] When people were near nest boxes, birds flushed and stayed away from the boxes for up to half an hour.

Habituation. Birds – primarily resident species – exhibit habituation or habituation-like responses.[241, 245, 255, 256, 281, 405] A researcher in England tested flush distance for birds on or low to the ground in suburban versus rural areas.[256] Urban birds allowed surveyors to approach more closely before flushing, and smaller birds allowed closer approach than larger birds. However, some migratory and specialist bird species found in significant numbers in rural areas did not occur in suburban areas, and may not tolerate disturbance well. Møller had similar findings in Europe.[431] Other studies have found an apparent lack of habituation or sensitization for some bird species, particularly in areas of high disturbance.[254, 285, 357] Storch's global review of grouse studies found modest habituation-type responses for some species, but the majority of studies documented negative associations with recreational use and other human disturbance, with some evidence of sensitization.[432]

Some studies simultaneously tested wildlife species' behavioral and physiological responses to disturbance. For example, two corvid species in Europe had fewer parasites but flushed more readily in tourist sites compared to non-tourist sites; it appeared that the physiological tradeoffs favored staying close to disturbance.[245] Although they flushed more readily in tourist areas, they did not fly as far compared to controls. Birds in tourist sites had lower stress hormones; the combination of dampened behavioral and physiological responses suggests true habituation.

Amount of Use. Despite evidence of habituation-like responses for some species, the body of literature we reviewed indicates that many bird species exhibit stronger antipredator responses with increased numbers of trail users or other types of human disturbance in a variety of circumstances.[181, 235, 261, 275, 278-280, 283, 285, 286, 297, 306, 333, 357, 409, 433, 434] This trend has been shown for shorebirds and waterbirds,[181, 275, 276, 283, 285] songbirds,[235, 279, 435] and raptors[286, 333, 409, 433]. In natural areas already open to the public, increasing recreational demand is likely to reduce biological diversity.

For example, in the San Francisco Bay Area the number of shorebirds decreased with increasing trail use.[283] Researchers in Spain found that 16 of 17 forest-dwelling bird species were negatively affected by increasing pedestrian rates in urban parks after accounting for the effects of fragment size and isolation.[279] In Colorado lowland riparian areas scientists studied habitat use by birds along an urban-to-rural gradient.[435] At sites with recreational trails (paved, multi-use), trail use intensity explained 60 percent of the variation in the occurrence of low-foraging species and nearly 90 percent of the variation in habitat use by ground-foraging species. In the Netherlands, eight of 13 bird species near urban areas showed significant negative correlations with increasing

recreation intensities.[235] In Sri Lanka, the abundance of birds near trails declined significantly with increasing levels of trail users.[178]

The evidence is strong that increased numbers of trail users alter bird communities, particularly for species moving about on or near the ground. It is important to account for this effect when planning the placement and extent of trails: effects will be stronger in more heavily used sites.

LONG-DISTANCE MIGRATORY BIRDS

Many studies suggest that migratory birds are especially susceptible to habitat fragmentation and disturbance effects.[211, 212, 306, 419, 435-443] Specifically in the U.S., Neotropical migratory songbirds (NMBs) are well documented in this respect.[211, 212, 419, 435, 437, 438, 440, 443-445] Many NMB species need large habitat areas to maintain populations, wider travel corridors and high quality stopover habitat compared to residents or short-distance migrants[212, 439, 443-449] A local study[450] and studies done elsewhere indicate that NMBs are negatively associated with urbanization.[435, 447, 451, 452]

Why are Neotropical migrants more susceptible to human disturbance than many other bird species? Several factors may account for this trend. Most Neotropical migrants are insectivores, migrating north to take advantage of spring arthropod emergence.[212, 453] Many are area-sensitive; large habitats and wider corridors tend to have better three-dimensional habitat structure and more native shrubs than smaller patches and these characteristics are associated with increased insect abundance.[385, 438, 445, 454] Neotropical migrants require high quality habitat in their wintering grounds, migratory stopover habitat and breeding habitat; disruptions to any of those habitats may negatively affect these birds.[455-457] Because they are migratory, NMBs are probably not accustomed to the type of disturbances that may occur routinely within the home ranges of resident bird species.

Migratory birds in other countries, and non-songbird Neotropical migrants, show similar negative trends with disturbance and fragmentation. In India, migratory birds were less tolerant of the presence of people than were resident birds; migrants flushed sooner than residents and were more sensitive to the number of people approaching than residents.[306] Klein et al. found that most resident water bird species (e.g., herons and ducks) at a Florida refuge were less sensitive to disturbance than were migrants, especially early in the season when migrating ducks first arrived.[458]

Migratory birds throughout the world tend to be more disturbance-sensitive than resident species.

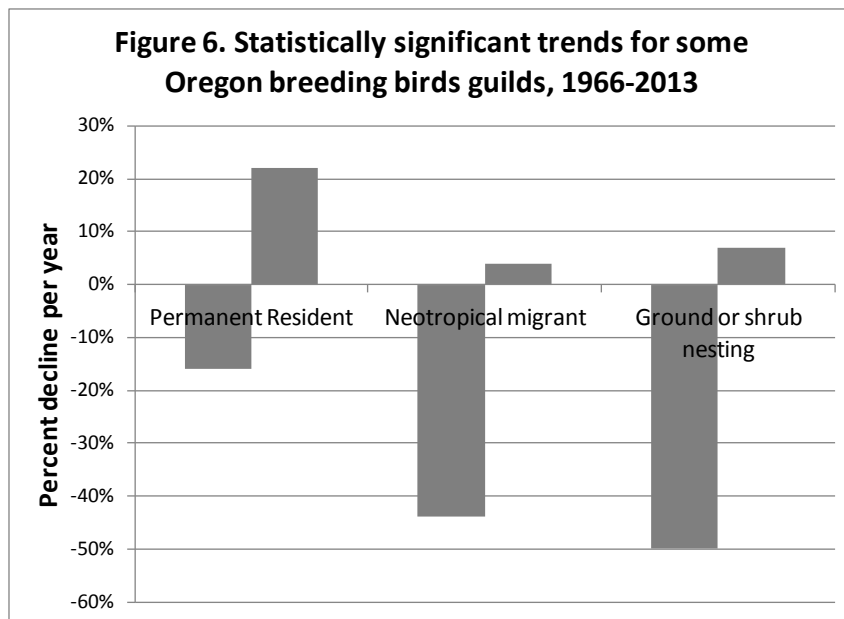
Migration is energy intensive, and human disturbance may reduce time available for feeding, making birds less fit to migrate. A Tennessee researcher found that long-distance migrants, but not resident species, required areas of low disturbance to sufficiently acquire fat stores; she suggested that conservation measures for quality NMB stopover habitat should focus on reducing pedestrian activity.[457]

Several studies documented reduced nest success for Neotropical migrants in fragmented landscapes. Donovan et al. studied four Neotropical migratory songbirds in two Midwestern regions.[211] Nest failure was significantly higher in fragmented forests than in contiguous forests for all four species. Researchers in Colorado found reduced nest success for migratory birds nesting in the urban-rural interface compared to those nesting in more intact forests.[418] In a large-scale study covering nine Midwestern states, biologists found that NMB nest predation and cowbird parasitism increased with increasing forest fragmentation.[459]

Recreational disturbance may cause some birds to increase the size of their breeding territories, effectively reducing the amount of available habitat to conspecifics. Male territories for an endangered songbird in Austin, Texas were five times as large along mountain biking trails compared to controls.[\[415\]](#) Nest success was 35 percent for biking sites versus 70 percent at controls, and nests at biking sites were abandoned three times more frequently than controls. The study did not consider other types of recreational use.

Long-term breeding bird survey data are available through the USGS' North American Breeding Bird Survey (BBS) website.[\[460\]](#) Figure 6 illustrates long-term trends for birds by specific guilds. Over the past 47 years permanent resident species increased nationwide, whereas Neotropical migrants and ground- or shrub-

nesting birds decreased substantially. Doubtless a variety of factors led to these declines, but these trends suggest that particular attention should be paid to these groups when considering the effects of trails in natural areas because both guilds seem to be more sensitive to human disturbance than other species.



SHOREBIRDS, WADING BIRDS AND WATERBIRDS

Considerable research has been conducted on this group of birds, possibly because they tend to be more visible than, for example, forest-dwelling songbirds. Many shorebird, wading bird and waterbird species are known to be sensitive to human disturbance.[\[8, 181, 254, 275, 276, 281, 283, 297, 320, 338, 403, 458, 461-465\]](#) These birds often avoid heavily disturbed areas and may spend more time feeding at night to avoid people or to make up for disturbance-induced nutritional deficits.[\[275, 338\]](#) Rather than habituating, some species may become sensitized to human disturbance.[\[285, 461, 463\]](#)

Carney and Sydeman reviewed the effects of human disturbance on nesting colonial waterbirds.[\[8\]](#) Most studies found significant negative effects from human disturbance including physiological parameters, behavior, reproductive success, changes in spatial distribution of nests, and reductions in breeding populations. The authors offered specific advice to limit effects on nesting herons including delaying visiting nests until one week before hatching, and limiting visitation to once every three days. Researchers in Florida studied disturbance effects on 16 species of waterbirds and suggested that a buffer of about 100 m should minimize disturbance to most species.[\[264\]](#) Such practices could help reduce recreational effects on wildlife.

Several studies suggest that some shorebird species are unable to habituate to human disturbance. At a migratory shorebird staging area in Massachusetts, four out of seven shorebird species' reaction to disturbance was stronger in more disturbed areas, suggesting sensitization to human disturbance.[\[461\]](#) In California, Snowy Plovers were

less abundant near trail heads and at least over the short term, did not appear to habituate to human disturbance.[463] However, some species may habituate to human disturbance.[281]

Numerous studies show that higher levels of recreation reduce the abundance of shorebirds and waterbirds.[8, 275, 276, 283, 297, 461] For example, in Florida the number of people within 100 m altered Sanderling feeding timing (more at night) and birds moved to less crowded areas of the beach.[275] Sanderlings spent more time running/flying rather than foraging when more people were present. In the San Francisco Bay area, researchers studied shorebird metrics related to trail use at three study sites.[283] On lower (weekday) versus higher use (weekend) days, the number of shorebirds decreased with increasing trail use; higher trail-use days averaged 25 percent fewer birds. Argentinian water bird species' richness and abundance at heavily disturbed sites were higher on weekdays compared to weekends, when more visitors were present.[276]

Season may play an important role in how water-associated birds react to human disturbance.[8] For example, wintering snowy plovers on beaches near Santa Barbara, California reacted to human disturbance at half the distance (40 m) in winter compared to breeding season distances reported in the literature (80m), suggesting that the need for food partially over-rode human disturbance effects.[463] Timing within a single season can matter too; researchers in England found that Oystercatchers showed decreasing reactions to human disturbance as the winter progressed.[299] Disturbance events were at least two weeks apart, therefore the response was likely related to resource scarcity rather than habituation. Heron rookeries in Florida experienced a 15-28% nest mortality rate when humans entered the rookeries;[458] Appendix 3 includes references with recommended buffer distances to protect nesting colonies.

Human encroachment into heron rookeries can cause nest failure.

Other studies link changes in shorebird and waterbird feeding patterns with human disturbance.[281, 285, 320, 463] Sanderlings on a high-disturbance beach in Georgia had lower foraging success than those on a low-disturbance beach, with no evidence of habituation on high-disturbance sites.[285] Burger and Gochfeld's study showed similar results, plus a shift towards more night-time feeding in highly disturbed sites.[275] Feeding rates of Snowy Plovers were shown to decrease with increased human activities in California.[463] In a Florida wildlife refuge herons, egrets, pelicans, cormorants, grebes and Anhingas foraging or perching within 50 m of people walking by fled.[320] Sixty to 80 percent of herons either slowly moved away or fled from observers on foot, except for Green Herons, which waited until the observer got close. Green Herons rely on cryptic coloration to avoid predation and such species may wait longer before flushing. Photographers in this study were more disturbing than nature observers.

Waterfowl can also be sensitive to human disturbance.[320, 458, 466-471] Anglers, bird watchers and hikers along shorelines can displace waterfowl from feeding grounds, reduce breeding pairs and breeding success, and lower individual fitness.[469] A researcher in Germany found that a single angler can prevent ducks from establishing territories in areas of open water of less than 1 ha.[472] Mottled Ducks in Florida were sensitive to approach by humans on foot and moved away or fled in 95 percent of the trials.[320] In the same study, Pied-billed Grebes consistently moved or flew away from people approaching on foot and were more sensitive than most other waterbirds. A study of fish-eating waterbirds using Wisconsin lakes found that three species – Osprey, Common Merganser and Common Loon – did not occur in lakes with high levels of human disturbance.[470] This study illustrates why controls are important in disturbance studies; without undisturbed sites, the local extirpations of these species would have gone undetected.

In California's Sacramento Valley, the heart rates of wintering Greater White-fronted Geese increased as experimental observers approached, nearly tripling immediately before and after flushing. [467] In addition to interrupting normal feeding and resting behavior, this causes birds to burn extra calories that may be needed to survive the winter. There is also evidence that migratory waterfowl are more disturbance-sensitive than non-migratory species, as has been found for other taxa. [458]

To conserve the most disturbance sensitive water-associated bird, protecting specific areas at a site may be an effective solution for some species. In California, researchers erected barriers to protect roosting Snowy Plovers from disturbance; the barriers reduced the disturbance rates by more than 50 percent and abundance in the protected area increased throughout the season. [181] Once the barriers were in place, the shorebirds contracted their area of use to behind the barriers when humans were present. They began breeding behind the barriers when no nests were previously recorded at the beach, and bred in increasing numbers each year with high success. In another California study, wetland birds including several shorebird species were studied on both sides of a fence erected to eliminate human disturbance on one side. [403] On the protected side, birds reacted similarly to control sites. Heron rookeries in the northeastern U.S. showed no short-term reproductive losses when the rookery was buffered from disturbance by 50 m. [462]

We found numerous studies documenting alert distances and FIDs in recreational areas. Table 8 in Chapter 8 summarizes alert distances and FIDs from a variety of shorebird, wading and waterbird studies.

BIRDS OF PREY

Research concerning the effects of recreation on birds of prey is somewhat sparse. Bald Eagles may be the most studied raptor species in North America and it is clear that human disturbance is an issue for this species. [327, 433, 473-477]

Researchers in Washington conducted a 3-year study of wintering Bald Eagle-human interactions in the Skagit River Bald Eagle Natural Area. [433] Eagle abundance was negatively correlated with recreation intensity, which peaked on the weekends, and feeding was disrupted by an estimated 35 percent. Hikers were most disturbing, but motorboats disturbed a larger area and therefore more eagles. There appeared to be a threshold of about 20 daily recreational events after which eagles were slow to resume feeding and after 40 events, feeding was uncommon. Eagles did not resume eating for four hours after foot traffic disturbance, compared to 36 minutes following boat traffic. Sub-adults were less disturbance tolerant than adult eagles. The researchers recommended prohibiting recreation until after 11:00 a.m. and within 400 m of eagles. Public education was deemed important to reduce effects.

Anthony et al. reviewed the literature on Bald Eagles and found that recreation can exert both short- and long-term effects on behavior. [473] Long-term effects can include reductions in survival, particularly during winter and especially for juveniles. In an Arizona study, Bald Eagles flushed more often from perches than nests in spring; pedestrians, especially hikers, caused the most disturbance (compared to aquatic users, vehicles, noise from gunshots/sonic booms and aircraft), ranking highest in response frequency and duration. [474] Pedestrians within 275 meters caused a 79 percent eagle response rate. The researchers suggested a minimum disturbance buffer of 600 meters around breeding eagles, beyond which response frequency dropped below 30 percent.

Bald Eagles and other large raptors are sensitive to recreational disturbance.

Guinn proposed a hypothesis under which a “generational habituation” occurs. Under this theory, eaglets hatched in nests near human disturbance imprint on such areas and select human-associated areas for their own nests as adults.[478] However, this theory remains to be proven, and other studies show the potential for long term impacts. Bald Eagles nesting in suburban and rural landscapes in Florida showed no difference in the number of chicks fledged or survival rates, but suburban fledglings initiated northward migration later and had only 65-72 percent longer term survival compared to 89 percent of rural fledglings.[479]

Research exploring links between other species of raptors and human disturbance are less common. In New Mexico, adult Ferruginous Hawks increased nest-defense intensity with repeated human visits to the nest; the authors recommended a 650-m buffer to prevent nest-attending hawks from flushing.[333] In Argentinian mountains, carnivorous bird densities were lower near recreational trails.[409] The frequency of visitation negatively affected two raptor species, a buteo and a falcon. Hikers near forested Mexican Spotted Owl nests caused altered feeding and grooming behavior for females and significantly increased vocalization for both males and females.[286] In a winter grassland raptor study American Kestrels, Merlin, Rough-legged Hawks, Ferruginous Hawks, and Golden Eagles were more likely to flush when approached by a walker than a vehicle.[257] Overall, 97 percent of raptors approached by walkers flushed with a mean flush distance of 118 m, whereas only 38 percent of raptors approached by car flushed with a mean flush distance of 75m.

The raptor studies we located suggest that:

1. Large raptor species tend to be disturbance-sensitive, as indicated by longer alert distances and FIDs.
2. People on foot tend to be more disturbing than boats, vehicles and aircraft.
3. There is scant evidence of habituation to hikers, and such research is generally lacking for mountain bikers and equestrians.
4. Both breeding and wintering birds are sensitive to disturbance, although FIDs and similar measures may differ.

7.4 SPECIES GROUP: MAMMALS

Mammals, especially members of the deer family, are the most studied group in the field of recreation ecology.[192] Studies have been conducted on deer, elk, pronghorn, wild sheep and a few smaller mammal species. We also found numerous studies on large carnivores. Mammalian disturbance studies may compare effects between recreational user groups, mammal species, or some combination of both.

UNGULATES (HOOVED MAMMALS)

Cervids are ungulates in the deer family including deer, elk and moose; other non-cervid ungulates include sheep and pronghorn. Large carnivores such as cougar prey on ungulates, and altering the balance of prey species and their predators can have significant consequences to food webs.[168, 171, 172, 313, 480, 481] However, human influences on vegetation, as measured by land use change, exert an even more powerful effect than predator-prey relationships;[482] habitat loss leaves less room for animals and is closely linked with fragmentation.[483]

Numerous studies measured alert or flight distances for ungulates in a variety of human disturbance scenarios. In the studies we reviewed, deer and elk had especially long antipredator responses, with distances ranging from 74-400 meters depending on setting and user intensity. Table 8, Figure 9 and Appendix 3 summarize this information.

Topics discussed in previous sections also apply to cervids. For example, the predator shelter effect is well documented for elk (Section 6.2),[\[25, 172, 268, 288, 301, 302, 305\]](#) and several cervid studies document that antipredator responses increase in tandem with the number of visitors.[\[124, 282, 284, 484, 485\]](#) Larger deer and elk herds are typically more sensitive to disturbance.[\[113, 247, 268, 311, 331\]](#)

Deer and elk may avoid human recreation by switching to more nocturnal activities or periods of reduced disturbance.[\[173, 303, 335, 336\]](#) For example, the probability of detecting deer during the day in a California urban nature reserve was lower with increasing levels of human recreation.[\[282\]](#) In northeastern Oregon, radio-collared elk reduced their movements late in the day, after experimental disturbances were ceased.[\[486\]](#)

Some cervid studies attempt to tease out relationships between recreational users and impacts from busy roadways.[\[268, 331, 487\]](#) Brown et al. investigated the potential effects of human disturbance on elk and pronghorn along a transportation corridor in Grand Teton National Park, with a focus on road noise.[\[331\]](#) The ungulates demonstrated reduced antipredator responses with increasing levels of vehicular traffic. In contrast, they showed significant antipredator responses to the presence of pedestrians and to passing motorcycles, the latter which are noisier than most other motor vehicles. The authors surmised that the wildlife either did not necessarily associate noise with risk of predation, or that it cost too much energy to continuously respond to the most frequent and predictable human disturbances. However, a study in a Canadian provincial park documented reduced ungulate use of habitat areas within sight of roads with heavier traffic, but groups of three cervid species were three times more abundant on weekdays compared to weekends, when more recreationists used the site.[\[487\]](#) Thus, although cervid species' responses to traffic may vary, their general avoidance of recreationists appears to be consistent.

Pregnant elk or groups with young do not appear to habituate to recreational disturbance. Recreation can directly, negatively affect elk reproductive success, with potential population-scale effects. A 5-year disturbance study on elk reproductive success in Colorado found that undisturbed control sites' calf/cow proportions were similar throughout the study period.[\[194\]](#) In treatment sites (1 pre-disturbance year, 2 disturbance, 2 post-disturbance), productivity rebounded following release from disturbance and recovered by the second post-disturbance year, but there was no increase in productivity to make up for losses. This study demonstrates the potential for significant population effects over time in recreational areas and makes a strong argument for leaving some areas undisturbed. Studies showing stronger ungulate responses for females during spring or females with young support this finding.[\[8, 25, 124, 314, 328-332\]](#) A study in Yellowstone National Park compared individual and group vigilance for adult elk females with and without calves, in small and large herds.[\[314\]](#) Females without calves increased scanning and decreased foraging in high natural predator risk situations in small but not large herds. Females with calves behaved similarly, except they did not decrease vigilance regardless of herd size; group vigilance depended in part on herd size and composition.

Recreational disturbance may cause population-level impacts for elk.

Recreation can also influence cervid diet. For example, researchers in Scotland found that reducing disturbance near open grasslands, which are important food sources but lack adequate cover, would provide nutritional benefits to deer.[\[302\]](#) In another Scottish study examining elk pellets in disturbed versus undisturbed sites, elk shifted spring and winter diets in disturbed compared to undisturbed sites.[\[488\]](#)

A study in Utah examined pronghorn response to disturbance before (1 year) and after (2 years) the study area was opened to recreation.[\[312\]](#) In the two years after opening, groups of pronghorn stayed significantly farther

from trails. Smaller groups stayed further from trails than larger groups, in contrast with studies on deer and elk.[308, 314] There was no evidence of habituation during the study period. Although not statistically significant, groups with fawns appeared to be more sensitive to disturbance. Unlike deer and elk, pronghorn prefer large open habitats and their visibility may alter antipredator responses.

Researchers in Argentina found that guanacos, a member of the camel family native to South America, developed a tolerance to vehicles and pedestrians in tourist areas that extended approximately 500 m around recreational areas.[284] However, field surveyors saw substantially fewer guanacos on days with higher numbers of visitors, with an apparent threshold effect of 247 visitors per day. Different methodologies yielded different results: flight distance analysis showed no response, but sighting frequency analysis revealed a fairly strong effect.

Two recreational disturbance studies on mouflon, a species of wild sheep native to old-world regions, demonstrated antipredator behavior in response to recreational pressures. In southern France, researchers contrasted days with high or low hunting or tourism pressures to assess responses of 66 GPS-collared Mediterranean mouflon.[303] In areas with intense tourism animals shifted to more nocturnal activity, compensating for foraging time lost due to tourist disturbance during the day. In another study, researchers in Sardinia found that female groups with lambs had longer FIDs compared to male groups or female groups without lambs.[329]

These studies reveal that ungulates as a group are vulnerable to recreational disturbance; herd size and composition influence antipredator response; some ungulates shift to nocturnal activities to avoid human disturbance; and recreational pressure can reduce or alter the types and amounts of food available to wildlife.

LARGE CARNIVORES

Apex predators are those at the top of the food web, upon which virtually no other wildlife species prey.[169] Large carnivores such as cougar and wolves are apex predators in the U.S. Humans have a long history of removing large carnivores from the landscape, partly because of safety fears but also due to competition for prey species such as deer and elk. Most large carnivores have already been lost from more than 95–99 percent of the contiguous United States and Mexico.[489] The range reductions and disappearance of large carnivores across many landscapes have important implications for food webs;[168-171] habitat fragmentation and human disturbance have played key roles in carnivore reductions.[169]

Mesopredator release. The disappearance of large predators in an ecosystem causes a “mesopredator release” in which medium- and smaller sized predators such as foxes, skunks, raccoons and domestic cats become much more prevalent in the absence of larger carnivores,[168, 170] a common issue in urban areas.[423] Oregon State University researchers studying North American range shifts over the past 200 years showed that 60 percent of mesopredators’ ranges have expanded, but all large predator ranges have contracted.[168] Reductions in large carnivores and the resultant release of mesopredators such as domestic cats, raccoons and opossums near urban and disturbed areas lead to increased predation on prey species such as small mammals, reptiles, birds and bird nests.[174, 321]

Coyotes fall on the low end of the large carnivore group. Crooks and Soulé studied interactions between coyotes, other mesopredators and scrub-breeding birds in 28 urban habitat fragments in California.[170] There were twice as many mesopredators in patches with no coyotes. Patches with higher mesopredator abundance had fewer

species and fewer birds, even after accounting for area effects and time since isolation [longer isolation leads to fewer species[[202](#), [490-493](#)]]. The researchers postulated that “the interactions between coyotes, cats and birds probably have the strongest effect on the decline and extinction of scrub-breeding birds.” Coyotes were documented to predate cats in the study, thereby reducing cat predation on birds.

“Reverse” predator shelter. The previous large mammal discussion documented deer and elk using more disturbed areas as predator shelters, and the reverse effect can be seen for large carnivores, in which they avoid recreational and hunting areas. In Alberta, Canada researchers set up cameras along trails and roads to examine spatial relationships between people, prey (elk, moose and deer) and large predator species including wolves, bear, cougar and coyotes.[[305](#)] Human activity of more than 18 humans/day on trails and roads displaced predators but not prey species; cervids were three times more abundant on roads and trails with more than 32 humans/day, a good example of the predator shelter effect. Another example of this phenomenon was documented in the Yellowstone ecosystem, where pregnant moose shifted towards roads to give birth; brown bears, which commonly predate moose, avoided roads.[[300](#)] Another study in three Canadian national parks used GPS units to observe spatial distributions of elk and wolves in recreational areas.[[172](#)] Both wolves and elk avoided trails and roads within the first 50 m. However, wolves avoided areas 50-400 m from roads and trails, whereas elk appeared to use these areas as a predator shelter.

Habitat fragmentation and human disturbance. Our review indicates that large carnivores are sensitive to both habitat fragmentation and human disturbance,[[169](#), [170](#), [209](#), [282](#), [293](#), [300](#), [494-497](#)] and several studies specifically document large carnivore avoidance of trails and recreational areas.[[170](#), [172](#), [209](#), [282](#), [305](#), [494](#), [498](#)]

For example, a researcher in southern California conducted track surveys for nine native and two exotic carnivore species in 29 suburban habitat fragments and 10 control sites.[[169](#)] Cougar and other large carnivores were more sensitive to habitat fragmentation and occurred less frequently in suburban areas, but not control sites, compared to medium and small sized carnivores. Also in southern California, cougar were negatively associated with bicycle, but not equestrian use.[[295](#)] In Canada’s Banff National Park, researchers studied large carnivore use of wildlife undercrossings that were also used by recreationists.[[495](#)] Cougar and black bear preferentially used underpasses with less recreational activity and that were further from town.

The boldness of individual carnivores appears to influence habitat use in recreational areas. Researchers radio-collared 10 cougar at a state park in California to examine whether recreationists influences the animals use of space and time.[[496](#)] Some cougars tended to avoid areas with human activities, but other individuals did not. There were no cougar-human conflicts despite increasing numbers of recreationists in the park. Other studies suggest that individual animal’s temperaments can influence habituation-like responses.[[124](#), [291](#)]

Scientists in northern California surveyed mammalian carnivore scat in 28 protected areas including paired sites with and without recreation.[[494](#)] Scat was collected to enable DNA verification of species. The researchers found that dispersed, non-motorized recreation led to a five-fold decline in native carnivore density, and recreational sites revealed a substantial shift in carnivore composition towards non-native species; the authors stated that there is a “pressing need for new approaches to the designation and management of protected areas.”

Several U.S. studies indicate that bobcats and coyotes are negatively associated with disturbance and recreational use,[[170](#), [209](#), [282](#), [494](#), [497](#)] although coyotes do not necessarily avoid urban areas. Coyotes in southern California were positively associated with certain levels of urbanization, but the researchers did not test effects of

recreation; the study also found negative associations with urbanization for bobcats, gray foxes and mountain lions.[293] Gehrt et al. found that while coyotes in Chicago readily used urban areas, they used urban land cover within their territories less than expected.[499]

A southern California study found that deer, bobcats and coyotes became less active during the day in recreational areas, and effects were stronger in areas with heavy recreation.[282] Another southern California study found that adult female bobcats avoided human use areas more than adult male and young female bobcats.[294] The latter two had larger territories in human-dominated areas, suggesting reduced habitat suitability. Both bobcats and coyotes shifted more to night-time foraging activities near urban areas. Ordenata et al. found that bobcats, gray foxes and mountain lions were found less frequently near southern Californian urban areas compared to non-urban areas.[293]

The literature revealed differences between some carnivores' use of recreational trails. For example, red fox seem somewhat amenable to using recreational trails and disturbed areas,[13, 293, 497, 498, 500, 501] whereas gray fox seem to avoid them or switch their activities to night-time.[209, 498] In a study along the Appalachian Trail, red fox (but not gray fox, which were also present) were associated with, and black bears tended to avoid high use trail segments.[498]

Very large national parks in Canada are of course different from the Portland-Vancouver urban region, but the relationship between disturbance and large carnivores does not change: trails and recreational areas tend to repel large carnivores resulting in mesopredator release, with real potential to disrupt entire ecosystems and ecosystem processes by altering food webs, habitat and wildlife community dynamics. Recreational disturbance also substantially reduces the amount of habitat available to large carnivores.

Larger carnivores are sensitive to habitat fragmentation and tend to avoid recreational areas.

Smaller carnivores may also be vulnerable to human disturbance and fragmentation. For example, researchers in Spain studied how fecal hormones in native wildcats (*Felix sylvestris*, ancestor of domestic cats) change seasonally and with different levels of disturbance.[502] Stress hormones were higher in park areas with more visitors, and were more elevated during spring and fall (reproductive seasons). The researchers recommended maintaining some areas of the park free of visitors, and controlling the number of users during wildcat gestation in recreational areas. In Portland, Oregon shorttail weasel were only found in remnant habitat patches larger than 10ha, likely due to home range requirements, sensitivity to disturbance or both.[503] A California study found evidence of area sensitivity for long-tailed weasels.[169]

Domestic dogs. The presence of dogs – a domesticated subspecies of wolves – appears to repel many wildlife species. A Colorado study showed reduced deer activity within 50 meters of trails where dogs were prohibited, but the distance doubled to at least 100 m for trails that allowed dogs, with similar effects on a variety of small mammals including squirrels, rabbits, chipmunks, mice, and prairie dog burrow locations.[497] The study was done using pellet surveys and other methods, and did not differentiate between day and night. Our previous review on the effects of dogs on wildlife revealed a pattern in which humans with dogs were more disturbing to wildlife than humans without dogs (Appendix 1).[287]

SMALLER MAMMALS

We found only a few trail-related studies on smaller non-carnivorous mammals. In Wyoming, the abundance of red squirrels subjected to low levels of disturbance (1-5 human disturbance events per week) did not differ from controls, although higher disturbance levels may have revealed effects.[\[504\]](#) However, small mammals endemic to California chaparral habitat were less diverse and abundant in disturbed sites, with the opposite patterns for disturbance-associated species; this related to changes in vegetation associated with trails and roads rather than directly linked to specific disturbance or level of use, the latter which were not studied.[\[126\]](#) In Colorado, prairie dogs were more wary of humans with dogs than humans alone, although they showed antipredator responses in both situations.[\[149\]](#)

Eastern chipmunks in Quebec, Canada were distributed non-randomly according to their temperament across a gradient of human disturbance.[\[291\]](#) More docile and more explorative individuals tended to have territories in more disturbed areas, although it is unclear whether this related to habituation. Stress hormones (cortisol) measured in the animals' hair was related to temperament rather than level of disturbance, therefore it was not possible to disentangle disturbance from temperament variables. Nonetheless, stress levels were higher in summer during tourist season.

Three marmot studies in Washington's Olympic Mountains[\[505\]](#) and the Swiss Alps[\[506, 507\]](#) suggest some habituation to hiker disturbance but increased wariness. However, habituation did not seem to be the case when dogs were present.[\[505\]](#) Marmots at high-use sites in the Olympics showed reduced responses to hikers compared to low use sites, but they were warier and looked up more when foraging. Despite these behavioral changes, marmots at high versus low use sites showed no difference in reproductive and survival rates, and they were in similar body condition. It appears that marmots' strategies in high-use sites effectively avoided the strongest disturbance effects. In the Swiss Alps, marmots were less disturbed by on-trail than by off-trail hikers, suggesting some degree of habituation.[\[507\]](#) The second Swiss Alps study showed similar habituation-like results, with a late summer increase in magnitude of antipredator response in both recreational areas and remote areas, but to a much larger extent in remote areas.

Except for issues with artificial light (Section 6.7) and the potential for cave visitors' conversational noise to be disturbing to bats,[\[362\]](#) we found little information directly examining effects of recreation and trails on bats. One study used mist nets to examine differences between an urban park and rural riparian bat communities.[\[508\]](#) Species diversity and evenness were lower in cities, and the most common bat – big brown bat, *Eptesicus fuscus*, were even more common in city parks. Several other bat species showed the opposite pattern. However, the study did not directly address recreationists or habitat variables.

USER GROUP COMPARISONS

In the studies we reviewed some found hikers more disturbing, but more studies found mountain bikers more disturbing to wildlife. People with dogs are clearly more disturbing than other visitors (Appendix 1). Equestrians appear to be least disturbing to wildlife.[\[209, 260, 268, 282, 290, 296, 486\]](#)

Animals are more alarmed when visitors behave in unpredictable ways, therefore faster approaches generally elicit a stronger antipredator response and cause longer flight distances compared to slower approaches.[\[19, 247, 254, 316-318\]](#) For example, several studies found that mountain bikers[\[260, 296, 316, 486\]](#) and joggers or trail

runners[297, 316, 317] caused a greater antipredator response than hikers or equestrians. Shorebirds, herons and ducks on the Atlantic Coast[317] and on New England beaches [297] flushed more readily from joggers than from people walking. European scientists showed that male alpine chamois fled further from joggers and mountain bikers than from hikers.[316]

We found two exceptions to the “speed of approach” rule. In one study, a smaller proportion of joggers on the beach disturbed wintering Snowy Plovers than did walkers.[463] Another study showed that Bald Eagles flushed more readily from walkers than from bicyclists; however, the birds moved further away from bicyclists.[319]

Several elk studies compared the effects of different forms of recreation on wildlife. A researcher in northeastern Oregon radio-collared elk to explore responses of four types of recreational disturbances: ATVs, mountain biking, hiking and equestrian use (two publications on the same study).[296, 486] All four activities elicited antipredator responses. Time spent traveling increased in response to, and was significantly different between types of disturbances. Response to ATVs was most severe followed by mountain bikers, hikers, and equestrians in that order. Morning disturbance response was strongest. In this two-year study, some habituation appeared to occur but disturbance was still evident. Comparing results between visual observation and radio-collars, collars showed stronger effects, suggesting that studies based on visual estimates alone may underestimate recreational effects on wildlife. A companion study of 13 radio-collared female elk found similar results: mountain biking and hiking were less impactful than ATVs, but mountain bikers caused a stronger response than hikers.[260]

In studies where hikers were most disturbing to wildlife, hikers often went off-trail thereby reducing the predictability of their behavior.[113, 124, 268] Hikers in Utah caused the strongest responses in desert bighorn sheep (animals fled in 61 percent of encounters), followed by vehicles (17 percent fled) and mountain bikers (6 percent fled); hikers were more likely to go off trail and often directly approached sheep.[124] Ciuti et al.’s study in Canada found that ATVs were more disturbing to elk than hikers, mountain bikers or equestrians.[268] Bikers and equestrians mostly stayed on roads and showed little effect on elk, but hikers frequently went off-trail. In Utah, Taylor and Knight studied bison, mule deer and pronghorn responses to hikers and mountain bikers.[113] There was a 70 percent probability of individuals from any species flushing within 100m of visitors on trails. When people went off-trail, mule deer showed a 96 percent probability of flushing within 100 m of the visitors; their probability of flushing did not drop to 70 percent until visitors were 390 meters away. These studies make it clear that people venturing off of established trails are especially disturbing to wildlife.

People with dogs appear to be most disturbing, and equestrians least disturbing to wildlife. Hikers and mountain bikers fall somewhere in between.

An Austrian researcher studied physiological and behavioral reactions of elk born and kept in large pens, using direct observation and implanted heart rate transmitters.[290] As with several other studies,[296, 486] elk were most reactive to disturbance during the morning hours, and antipredator responses varied by season. Elk were disturbed for at least 10 minutes after gunshots or walkers passed by, but less so for equestrians. The researcher did not test responses to bicyclists.

Scientists compared the effects of non-motorized recreation types on mammals in a large-scale northern California study to ascertain whether recreationists reduced wildlife use and whether there was a safe distance from trails that could inform appropriate trail placement within vegetated corridors.[209] Mountain lions and mule deer were negatively associated with the amount of hiking; raccoons were negatively associated with the amount of

mountain biking; striped skunks were less abundant in the presence of hikers with dogs. The researcher also found that gray fox and coyote became more active at night in response to any level of human recreation. Mule deer were sensitive to any level of human recreation. The study illustrates the difficulties in making generalizations about wildlife responses to recreationists.

Taken together, these studies suggest that:

- People with dogs may be more disturbing to wildlife than any other non-motorized recreational use.
- When visitors stay on trails, mountain bikers and joggers/trail runners tend to be more alarming to wildlife than hikers because they move faster and wildlife encounters can be sudden and unpredictable.
- Off-trail hikers and perhaps any off-trail users (we did not find off-trail research for other user groups) are most alarming to wildlife, because animals do not expect to encounter people there and these users' movements are therefore unpredictable.
- Among non-motorized recreational uses, equestrians appear to have the least effect on wildlife.

CHAPTER 7 SUMMARY – Effects on wildlife by species group

Invertebrates

- Trails in forests can reduce shrub and canopy cover, which provide key invertebrate habitat. Invertebrates are important food resources for songbirds, especially during the breeding season. However trail construction does not always require tree or shrub removal.
- Stream crossings, especially fords, can impair instream macroinvertebrate communities.
- Trail users may compact soils and damage below-ground invertebrate habitat.
- Recreational use has been shown to alter beetle, butterfly and spider communities.

Reptiles and amphibians

- Less mobile animals such as salamanders and turtles on land cannot escape quickly.
- For salamanders, habitat variables such as logs and leaf litter near trails may be more important than trail use.
- Trail use may create movement barriers for some amphibian species, especially when trails intersect mass breeding migrations.
- Frogs can be easily disturbed and may become sensitized to recreationists near streams.
- Lizards may be especially vulnerable to recreational disturbance. Less is known about other reptiles.

Birds

- Generalist species tend to do well near trails, whereas migratory species of songbirds and waterfowl do not.
- Some year-round resident species show evidence of habituation-like responses.
- Larger bird species tend to flush more readily than smaller species.
- Species that nest and perch higher up in trees are less vulnerable to recreational disturbance.
- Higher recreational traffic leads to fewer bird species and altered nest success.
- Common nest predators such as jays, crows, Brown-headed Cowbirds and squirrels are attracted to edge habitats, recreational areas and trails.
- Shorebirds, waterbirds and wading birds are vulnerable to disturbance, especially at high levels of use.
- Bald Eagles and other (especially ground-nesting) raptors are very sensitive to people on foot, and to a lesser degree for other disturbance types such as boats, vehicles and aircraft.

Mammals

- Any visible or audible human presence can negatively affect ungulates, carnivores and probably small mammals.
- Human disturbance can reduce elk reproductive success.
- The predator shelter effect, in which animals move to non-hunted areas during hunting season, is well documented for elk. In such cases elk tend to shift towards night-time activities to avoid humans.
- Higher levels of recreational use cause higher levels of disturbance for ungulates.
- Large carnivores are fragmentation-sensitive, are even more sensitive to human disturbance than ungulates, and tend to avoid recreational areas rather than habituating (except red fox).
- Reduction in large carnivores can lead to increases in medium-sized carnivores (the so-called “mesopredator release” effect), thereby altering food webs and disproportionately affecting birds and small mammals.

User group comparisons

- People who go off-trail or stop to view or photograph wildlife elicit higher stress response than users passing by on trails or roads.
- Horses appear to be least disturbing of our three user groups. Fast-moving recreationists such as mountain bikes and trail runners tend to be more disturbing than hikers.
- People with dogs are more disturbing to wildlife than people without dogs.

8. TOOLS TO HELP MANAGE NEGATIVE EFFECTS

Conflicting goals can arise when a natural area is managed to preserve or enhance habitat while also providing recreational access. When the decision is made to provide recreational access to a site there are many available tools, frameworks and approaches designed to mitigate a variety of potential environmental effects from trail construction and use.

This chapter summarizes some of the more commonly used trail design and construction guidance documents currently available. Resources to reduce negative effects on wildlife are less common, therefore in this chapter we also consolidate information from a substantial body of literature to help consider how to reduce such effects. The information provided here is not meant to be prescriptive; rather, it holds promise to spur collaborative approaches to develop standards or best practices.

8.1 TRAIL DESIGN AND CONSTRUCTION RESOURCES

With proper site selection and trail alignment planning, impacts to natural resources can be reduced. As a simple example, consider siting new trails on sites or portions of sites that already have a history of public use rather than undisturbed sites. Vegetation removed or damaged during trail construction can be replanted to enhance recovery and provide a screen for wildlife.

When planning a park or trail it is important to consult land managers, conservation scientists and local experts to identify the most sensitive areas. Seeking win-win situations can further conservation goals while introducing or formalizing recreational access. Examples include thinning trees in order to diversify forests while also opening up view opportunities for people, or replacing culverts with bridges to facilitate both trail crossings and fish and wildlife movement.^[509] Such dual purpose approaches may also expand project funding opportunities.

Several guidebooks offer best practices for trail design and construction (Table 6). Some guidebooks focus on single user groups – hikers, mountain bikers or equestrians – while others are non-specific or cover several user groups. For mountain biking, several agencies have adopted the International Mountain Bicycling Association’s basic guidelines^[510] for trail design and construction for sustainable non-motorized trails.^[87, 341, 510]

IMBA’s 2007 guidance document offers 11 essential elements of sustainable trails:

1. Trail location: Sidehill trails are best. Water tends to collect in flatter trail settings, causing trail widening over time.
2. Sustainable trail alignment: Avoid the fall line by gently traversing the slope, rather than traveling directly up or down it.
3. Half rule: A trail’s grade should never exceed half the grade of the sidehill upon which it is located. Trail grade is calculated by dividing total elevation gain by total length of the uphill section times 100 to obtain percent.
4. Sustainable trail grade: Follow the ten percent average guideline.
5. Maximum sustainable trail grade: Typically the maximum sustainable trail grade is approximately 15 percent for a short distance, but is site-specific and may be substantially lower or occasionally higher.

6. Grade reversals: Frequent drainage features, including grade reversals and outslopes, are essential. A grade reversal is a spot at which a trail briefly changes elevation, dropping subtly before rising again. This forces water to drain at the lowest point before it can gain volume and momentum.
7. Outslope: The downhill side of trails crossing hillsides should tilt slightly down and away from the high side to ensure proper drainage.
8. Adapt trail design to soil texture [here we would add plant communities and life form].
9. Minimize user-caused soil displacement: Abrupt turns and sharp hills are locations most susceptible to user-caused soil movement.
10. Prevent user-created trails: The document provides a section on avoiding and managing unauthorized trails.
11. Maintenance: The fundamental goal is to get water off of the trail and keep users on it. IMBA's *Trail Solutions* guidebook includes details on this topic.[\[87\]](#)

Table 6 summarizes some of the trail design and construction guidance documents currently available. The list is not comprehensive and is not meant to be an endorsement of any particular guidance document. Note that only three of the documents include any significant guidance for minimizing the effects of trails and recreation on wildlife; these are noted in the table. Sections 8.7 and 8.8 provide more information that may be useful in developing wildlife-related best practices.

Table 6. A sampling of available trail design and construction guidance documents.

Guidance document	Primary user group focus	Comments
A human dimensions review of human-wildlife disturbance: A literature review of impacts, frameworks, and management solutions [97]	Various user groups	USGS research review and best practices report focused on identifying and reducing the negative effects of trails and recreation on wildlife. Includes information on social carrying capacity and other human dimensions. This reference has the most valuable and complete set of potential management solutions for wildlife of all the references we reviewed. <i>Extensive wildlife guidance information.</i>
Complete guide to trail building and maintenance, fourth edition [511]	Various	Book published by the Appalachian Mountain Club. Includes chapters on trails on private land, cost estimates. <i>Lacks wildlife guidance.</i>
Environmentally sustainable trail management [40]	Various	Book chapter that includes key elements of a potential trail plan, trail placement, construction and maintenance guidance, techniques for wet soils, tread hardening and more. <i>Lacks wildlife guidance.</i>
Equestrian design guidebook for trails, trailheads, and campgrounds [51]	Horses	Designed more for backcountry and campgrounds, but includes extensive guidance that can be useful for equestrian trails in many settings. Chapter 13 provides information on reducing environmental and health concerns. <i>Lacks wildlife guidance except for "dangerous creatures."</i>
Green trails: Best practices for environmentally friendly trails [43]	Hiking	Guidance for planning and building environmentally friendly "green" trails. Includes recommendations to complement existing standards and guidelines adopted by local parks and watershed groups in the Portland, Oregon area. <i>Substantial wildlife guidance information.</i>
Guidelines and best practices for the design, construction and maintenance of sustainable trails for all Ontarians [36]	Various	Trail construction and maintenance best practices. <i>Limited wildlife guidance.</i>

Guidance document	Primary user group focus	Comments
Guidelines for managing and restoring natural plant communities along trails and waterways[512]	Various	Detailed information on native plant restoration and management, including good information on riparian environments and controlling exotic species. <i>Lacks wildlife guidance.</i>
IMBA's Trailbuilding basics[513]	Mountain bikes	Designed to train land managers, mountain bike club leaders and other trail users on trail construction and maintenance techniques. <i>Lacks wildlife guidance.</i>
Informal trails and the spread of invasive species in urban natural areas: Spatial analysis of informal trails and their effects on understory plant communities in Forest Park, Portland, Oregon[121]	Various	Thesis of local research regarding unauthorized trails. Includes a "Management implications" section that outlines ways to minimize negative effects of unauthorized trails. <i>Lacks wildlife guidance.</i>
Leave no trace in the outdoors[514]	Various	Well known guidance document and website (LNT.org) to reduce the human footprint on the recreational landscape. Discusses concepts such as dispersed vs. concentrated use. <i>Lacks wildlife guidance.</i>
Lightly on the land: The SCA trail building and maintenance manual[515]	Various	Guidance on designing and building trails with environmental health in mind. <i>Limited wildlife guidance.</i>
Managing mountain biking - IMBA's guide to providing great riding[510]	Mountain biking	<i>Managing Mountain Biking</i> is a companion to IMBA's trail building how-to book <i>Trail Solutions: IMBA's Guide to Building Sweet Singletrack</i> . [87] Includes guidance on overcoming user conflicts, minimizing environmental impacts, managing risk, and providing technically challenging riding. While <i>Trail Solutions</i> covers trail construction, <i>Managing Mountain Biking</i> focuses on solving mountain biking issues through innovative trail design, effective partnerships, and visitor management strategies. <i>Lacks wildlife guidance.</i>
Managing visitor impacts in parks: A multi-method study of the effectiveness of alternative management practices[93]	Various	Research and exploration of best practices to keep visitors on trails. <i>Lacks wildlife guidance.</i>
Natural surface trails by design: Physical and human essentials of sustainable, enjoyable trails[516]	Various	Includes 11 concepts to explain, relate, and predict what actually happens on all natural surface trails in terms of their basic forces and relationships, both physical and human. Focuses on the reasons for issues and potential solutions. <i>Lacks wildlife guidance.</i>
Planning & managing environmentally friendly mountain bike trails: Ecological impacts, managing for future generations, resources[58]	Mountain biking	Extensive research based in the southwestern U.S. Describes ecological impacts, compares with other user groups and provides best practices for sustainable trails. Provides specific recommendations for resource managers. <i>Limited wildlife guidance.</i>
Planning trails with wildlife in mind. A handbook for trails planners[37]	Various	Colorado State Parks' guidance document to minimize negative effects on wildlife. Includes numerous case studies and best practices. Key wildlife guidance document.

Guidance document	Primary user group focus	Comments
Research for the development of Best Management Practices to minimize horse trail impacts on the Hoosier National Forest [29]	Horses	Research investigates horse trail impacts to identify relationships between various levels of horse use, management alternatives, and factors that are most easily manipulated by managers to avoid/minimize horse trail impacts – e.g., gravel thickness of >3.5 inches combined with periodic grading can effectively minimize soil erosion on horse trails. Provides best management practices based on the research. <i>Limited wildlife guidance.</i>
Ten factors that affect the severity of environmental impacts of visitors in protected areas [100]	Various	Guidance for managing environmental impacts in terms of a site's conservation value, resistance and resilience of ecosystem and vegetation types, susceptibility to erosion, severity of direct and indirect impacts, likely amount of use, social and ecological aspects of timing of use, and total area likely to be affected. <i>Lacks wildlife guidance.</i>
The influence of use, environmental and managerial factors on the width of recreational trails [41]	Hiking trails	Research to evaluate the relative influences of use, managerial and environmental factors on trail width from a survey of all formal trails in Acadia National Park, Maine, USA. Study found differences in trail width based on trail surface type (class), and the presence or absence of trail borders. Potential guidance for trail design and implementation. <i>Lacks wildlife guidance.</i>
Trail construction and maintenance notebook [28]	Various	General Technical Report developed by the U.S. Forest service and transportation agencies. Includes information on trail design and building basics. Slightly out of date (for example, includes water bar recommendations). Substantial information on building trails in wet areas and crossing streams and rivers. <i>Lacks wildlife guidance.</i>
Trail design guidelines for Portland's park system [53]	Various	Includes specifications for a variety of trail types. <i>Limited wildlife guidance.</i>
Trail fundamentals and trail management objectives [517]	Various user groups	U.S. Forest Service's training reference package for trail design and construction. Standard soft surface trails, snow and water trails. <i>Excludes significant wildlife guidance.</i>
Trail planning, design, and development guidelines [518]	Various	Minnesota Department of Natural Resources guidance document. Fairly comprehensive how-to and best practices guidebook for developing all types of recreational trails. Some information is out of date (e.g., water bars). <i>Excludes significant wildlife guidance.</i>
Trail solutions: IMBA's guide to building sweet singletrack [87]	Mountain biking, but generally applicable to many user groups	Information-rich trail construction guidance document with sections on planning and designing trails, environmental considerations including water resources, managing user conflicts, partnerships, mountain bike patrols, signage, and more. <i>Incomplete wildlife review and limited guidance.</i>
Trails guidelines and best practices manual [89]	Various	Thorough guidance document including trail system planning, development, management, maintenance and monitory information. <i>Limited wildlife guidance.</i>

8.2 RECREATIONAL CARRYING CAPACITY AND VISITOR USE FRAMEWORKS

As human population and recreational demand increased during the 1960s through the 1980s, issues with overcrowding and environmental damage arose. Land managers began applying the concept of population carrying capacity – a line of inquiry more typical to wildlife studies – to humans in recreational settings.[\[519\]](#)

Recreational carrying capacity refers to the amount of recreational use a trail or site can support beyond which excessive environmental/biological damage, social and managerial issues, or decreased visitor experience may occur.[\[520\]](#) The idea is to identify social (recreationist) or ecological thresholds based on a predetermined set of standards which when exceeded, trigger specific management actions to reduce impacts.[\[17, 97, 98, 521\]](#)

“Parks are to be used for outdoor recreation, but the impacts of use must not degrade park resources or experiences to the point that they cannot be enjoyed by future generations. The sustainability of parks for outdoor recreation must recognize these inherent limits (carrying capacities), and these limits are explicitly addressed in management-by-objectives frameworks in the form of standards for park resources and the visitor experience.” (Manning et al. 2011)[\[1\]](#)

Watson et al. outlined the more technical components of a good sampling strategy for estimating visitor use.[\[522\]](#) D’Antonio et al.’s research paper presented techniques for estimating recreation use levels and outlined a socio-ecological approach that can be used by managers of smaller, local natural areas to balance dual missions of natural resource protection and managing for recreation use.[\[120\]](#)

However, the application of carrying capacity metrics used in either social or ecological approaches can be complex for several reasons.[\[520, 523\]](#) Sometimes the true carrying capacity limit is not recognized until it is been reached or exceeded.[\[96\]](#) Identifying the upper limits of carrying capacity can also be subjective because it depends on the goals of the land managers and their opinions on acceptable levels of impacts. In addition, there are many variables that can influence the environment (such as sensitivity of habitat, bad weather and landslides) or make recreational users feel crowded or infringed upon (such as adding a new user group when a site has traditionally only allowed hikers, or when a few disrespectful users create perceived conflicts at a site).

Due to these and other drawbacks, federal land managers identified the need for new frameworks that could address visitor use issues in more practical ways.[\[97\]](#) Recreational visitor use frameworks provide a common approach to planning for and managing visitor use at a recreational site. Rather than identifying specific numbers of allowable trail users, these frameworks generally place the primary emphasis on desired conditions at the site. For example, crowding and congestion along trails can lead to trail widening and vegetation loss when people step off trail to avoid other users; when these effects exceed a pre-defined standard, management actions may be triggered. The downside to such frameworks is that they usually fail to factor in wildlife disturbance issues (Table 6), thereby substantially underestimating visitor impacts.

We found numerous references describing, reviewing or evaluating carrying capacity or visitor use framework approaches.[\[1, 33, 47, 66, 93, 96, 115, 118, 519-521, 524-532\]](#) In 2007, Cline et al. reviewed management frameworks that address recreational carrying capacity.[\[97\]](#) All have the same primary components including a definition of recreation, associated indicators and standards of quality, monitoring indicator variables, and specific management actions to address issues identified through monitoring. Each framework also maintains environmental, social and managerial dimensions, although they generally do not provide specific guidance on wildlife. Examples of some of these frameworks include:

- Protected Area Visitor Impact Management Framework (VIM or PAVIM)[[520](#), [528](#)]
- Limits of Acceptable Change (LAC) developed by the U.S. Forest Service[[33](#), [530](#)]
- Visitor Experience and Resource Protection (VERP) developed by the U.S. Park Service [[527](#), [529](#)]
- Quality Upgrading and Learning (QUAL)[[531](#)]
- The new interagency Visitor Use Management Framework (see below)[[528](#)]

Table 3 in Cline’s review summarizes the steps involved in three of the most commonly used methods - the VIM, LAC and VERP frameworks.[[97](#)] Farrell and Marion suggest that the PAVIM approach may be preferable to Limits of Acceptable Change and similar frameworks if managers lack sufficient funds and staff to collect and analyze data and the more intensive monitoring recommended under other frameworks.[[520](#)]

In 2016 a new *Visitor Use Management Framework*, co-published by six U.S. federal agencies, provides a detailed methodology that incorporates a “sliding scale” of effort to ensure that investment of time, funds and other resources aligns with project complexity and consequences of management decisions.¹¹[[528](#)] Under this approach, identifying carrying capacities is not always necessary. The document lays out specific steps to address four key elements: (1) building the foundation for the framework; (2) defining visitor use management direction; (3) identifying management strategies; and (4) implementing, monitoring, evaluating and adjusting management actions. Two companion guidance documents - the *Visitor Capacity Guidebook* and an *Indicators, Thresholds and Monitoring Guidebook* – were scheduled for release in 2016 but were not yet available at the time of this writing.

Any of these frameworks, possibly in simplified form for smaller sites or when low visitor use is anticipated, could be valuable to assist in managing recreational access, provided the framework contains site-specific management objectives, associated indicators, and specific thresholds (standards) that trigger specific management actions.[[97](#)] The common element is that indicators are measured and compared to established standards; if conditions do not meet the standards, management actions may be triggered in order to meet management objectives.

8.3 MONITORING APPROACHES

A strong monitoring and management framework can essentially increase a trail’s or a site’s carrying capacity by identifying and managing effects before they degrade the resource or jeopardize the visitor experience. On the other hand, such a framework may result in recommendations to reduce use, such as seasonal closures on specific trails or limiting trails and specific trail user groups to areas with less steep slopes. This section provides information on monitoring approaches that can be used to help guide site management.

Monitoring is the systematic collection of information to inform whether goals are being met. Monitoring goals, indicators and specific “not to exceed” thresholds (also known as targets or standards) are necessary to determine whether management actions are needed to stay below acceptable damage thresholds. An effective monitoring program can help identify issues before they become difficult or expensive to correct.

Visitor use frameworks include monitoring strategies (Section 8.2). Monitoring guidance is available for various user groups including hiking/general use,[[42](#), [52](#), [56](#), [94](#)] mountain biking[[58](#), [86](#)] and equestrian trails.[[29](#), [94](#), [148](#)] Houston reviewed monitoring approaches for Oregon State Parks and Recreation in 2012 and with an advisory group, developed a Rapid Trail Condition Assessment[[533](#)].

¹¹ See <https://visitorusemanagement.nps.gov/VUM/Framework>

When developing projects, monitoring frameworks typically recommend building in funds and staff time for monitoring and maintenance.[\[98, 527, 528, 534\]](#) One way to reduce the cost of monitoring is to engage partner organizations for studies and monitoring, as well as vegetation management.[\[534\]](#) Engaging residents as site stewards and “community [citizen] scientists” can be an excellent way to leverage limited resources and engage the public.[\[535\]](#)

Marion and others identified three general types of trail surveys to assist in managing trail systems:[\[56\]](#)

- Trail attribute inventory – use GPS units to map accurate GIS-based trail system characteristics. Can be used to map unauthorized and formal trails or other attributes such as views, use, etc. Assists mapping, planning, analytical and decision-making functions.
- Trail condition assessment – documents trail conditions and impact levels. Data can be compared against quantitative Limits of Acceptable Change/VERP type standards of quality or to determine where and how much trail conditions are changing over time. Typically uses point sampling and transect survey methods.
- Trail prescriptive management assessment – used to evaluate and document maintenance needs, sustainability attributes, use-type capabilities, and relocation options. Prescriptive maintenance work logs document the condition of or work needed on existing trail features, or the need for new features, including gates/barriers, bridges, signs, and tread drainage features such as grade dips and grade reversals.

Indicators and thresholds. Indicators are measurable, manageable variables that are proxies for management objectives. Common trail condition indicators include tread width, tread muddiness, erosion and incision. Thresholds, also known as standards or targets, define the minimum acceptable condition of indicators.[\[1\]](#) Thresholds are predetermined levels of the indicators which if exceeded, may trigger management actions. Thresholds should be set at or below acceptable, predetermined levels of visitor use effects, and should be responsive to trends in changing conditions as identified by monitoring.[\[528\]](#)

Selecting indicators and specific thresholds need not be overly complicated; it is most efficient to use as few indicators as possible to sufficiently inform management actions. The National Park Service (NPS) described eight characteristics of good indicators,[\[527\]](#) stating that they should:

- be specific – for example, instead of using “water quality,” use “bacteria per volume of water”
- be objective rather than subjective
- be reliable and repeatable
- relate to visitor use – for example, levels of use, types of use, or behavior of visitor
- be sensitive to visitor use over a relatively short time period
- be responsive to, and help determine the effectiveness of, management action
- directly inform specific conditions related to management objectives
- not result in destructive resource impacts that would significantly detract from the quality of the visitor experience
- address prominent issues and management concerns, such as visitor impacts that could affect a natural area’s purpose or significance

The National Park Service also suggests selecting indicators that are easy to measure, easy to train for monitoring, cost-effective, have minimal natural variability, show a gradient of conditions, have a large sampling time window,

and can be compared to any past monitoring efforts' data.[527] Table 2 in Wimpey and Marion's monitoring protocols also provides a good summary of criteria for selecting indicators of resource condition.[98]

Table 7 provides some examples to aid in the thought process behind establishing indicators and thresholds. Thresholds and triggers should reflect site-specific "actionable items" in terms of trail management.

Table 7. Examples of indicators and thresholds to assess and address visitor effects.

Type of effect	Indicator example	Threshold example	Reference
Area of trail disturbance	The mean trail width times the trail length	Area of disturbance should not exceed (predetermined value) per unit of trail section	[536]
Cold-water fish	Population sampling of salmonids in stream during and following project implementation. (Comparing up- and downstream spawning conditions is also an option.)	No downward trend for more than 3 consecutive years.	[528]
Compaction and erosion	Percent of exposed soil	Percentage of exposed trail per predefined trail length should not exceed (predetermined value) %	[536]
Erosion	Hazard rating for soil erosion into stream at marked sections along the entire trail.	Soil erosion hazard rating will not exceed "low" in 80% of the water influence zone.	[528]
Excessive muddiness	Sections of trail with wet, muddy soils	Trail sections ≥ 10 feet that show imbedded foot or hoof prints ≥ 0.5 inches deep	[537]
Informal trails	Length per unit area, % of formal trail length, # per unit length on formal trails	Informal trails should not exceed (predetermined value)% percent of all trail lengths	[536]
Landscape fragmentation	Largest patch index; GIS-measured trail and site attributes.	Largest Patches Index Five (LPI5) of no more than 92.8%. Decreasing percentages will indicate an increased degree of fragmentation.	[94, 524]
Landscape fragmentation	Mean patch size; GIS-measured trail and site attributes.	Mean patch size should not fall below [select appropriate threshold for a given site] ¹²	[94]
Landscape fragmentation	Mean perimeter-area ratio; GIS-measured trail and site attributes.	Mean ratio should not fall below [select appropriate threshold for a given site] ⁷	[94]
Noise	"Soundscapes" as measured by the change in sound levels from natural ambient in areas more than 100 feet from roads or trails, and (2) the amount of time above speech interference thresholds in areas more than 100 feet from roads. ¹³	Hourly change in sound levels not to exceed 3 dB.	[524]
Riparian effects	River bank erosion. Combination of vegetative cover condition and substrate erosion condition characteristics.	1. Channel morphology: <10% increase in cross-sectional area due to bank scour in 80% of sites. 2. Vegetation condition: <10% cover of bare ground in 80% of sites [or trail reaches].	[524]
Trail widening	Cross sectional area; maximum value, value/unit length, running average/unit length	Hiking trails at site should not exceed (predetermined value) feet in width	[536]

¹² Could be used for planning purposes to determine potential fragmenting effects from different trail alignments.

¹³ The researchers proposed this method for impacts of road noise on ability for trail users to converse/hear each other, but this could also be used to gauge potential noise impacts from trail users on wildlife.

Type of effect	Indicator example	Threshold example	Reference
Water quality	Instream water quality based on official water quality standards	Water quality will not come within 5% of the listed State Department of Public Health and Environment and forest plan water quality standards. ¹⁴	[528]
Water quality	Benthic invertebrates – sensitive taxa or Index of Biotic Integrity (IBI) above and below stream crossings, bridges or culverts. ¹⁵	Reduction in below-crossing IBI values of a pre-determined percent, or in # sensitive taxa, or sensitive/non-sensitive taxa ratio.	[196]
Water-related effects	Unauthorized trail stream crossings.	Of the existing unauthorized trails, none leads to stream crossings in the lower third of the drainage/creek where salmon spawn.	[528]

8.4 ADDRESSING UNAUTHORIZED TRAILS

Monitoring and managing unauthorized trails is important because effects at a given site can be severe and widespread (Chapter 3). The literature we reviewed suggests several approaches to avoid or reduce possible negative environmental effects due to the creation and use of unauthorized trails. These include determining why the trails were created, monitoring the site for unauthorized trails, prioritizing their removal, and avoiding future creation (or re-creation) of such trails.

Understanding the circumstances for unauthorized trail creation can help guide effective management actions and reduce the likelihood of such trails in the future.[133] Unauthorized trails are created for a variety of purposes (Chapter 3), including valid reasons such as safety or to avoid overly challenging or muddy areas.[29, 57, 66, 77] In other cases unauthorized trails are created to access special features such as views, streams and wetlands. Indistinct trails can lead to accidental trail proliferation, particularly in rocky areas.[57] Good trail design can help alleviate some of these more predictable issues. However, some effects such as bathroom stops and trails from peoples’ back yards are less predictable.

Trail designs can avoid some of these issues through trail placement or by providing limited formal access to sensitive areas where people tend to want to go anyway. For example, designing trails along side slopes rather than in the floodplain, or installing sufficient depths and types of gravel, can reduce the need for people to step off trails to avoid mud.[29, 57] Strategically including short spur trails to access sensitive habitat areas or view points in the initial trail design can reduce or eliminate the need for damaging unauthorized trails in these areas[37, 93, 533] Signage for views such as “photo point” can draw users to these formal spur trails.[93, 538]

When prioritizing which unauthorized trails to address first, consider focusing on the most sensitive habitat or wildlife areas first.[133] Once located, there are two options for addressing an unauthorized trail. The first is to close it using physical barriers (e.g., brush piles or logs) and restoration, with signage and education as needed.[133] The second option is to recognize that in some situations, an unauthorized trail is in an appropriate area or is likely to be re-created. In such cases land managers can incorporate the unauthorized trail into the formal trail system and take measures to ensure the trail design and surface are sustainable.

¹⁴ Continuous or ongoing (e.g., weekly) monitoring will provide more accurate measures of change than grab samples.

¹⁵ IBIs based on “reference conditions” in pristine areas may not be sensitive enough to detect site-level changes in disturbed areas; in some cases measures such as sensitive/non-sensitive taxa ratios may better reflect local condition changes.

Collaborative management approaches. One way to reduce unauthorized trails is to partner with user groups in collaborative-based recreation management to monitor and “self-police” inappropriate trail creation or use.^[133, 534] Volunteer site stewards can also help identify emerging problems with unauthorized trails.^[524] For example, in Oregon’s Black Rock Forest the Oregon Department of Forestry partnered with the Black Rock Mountain Biking Association to address ongoing issues at the site.^[534] The approach improved communication; it also provided opportunities to pool resources to protect sensitive areas and create improved recreational opportunities at reduced costs to the land manager. The collaborative group identified the following key processes and practices that influence the ability to improve environmental outcomes:

- Leave fundamental value differences out of the decision-making process.
- Strive to create an inclusive atmosphere.
- Write specific agreements and plan for ongoing communication while maintaining open communication.
- Hold formal annual meetings.
- Provide quality leadership.
- Meet onsite to review past and present projects.

Under this collaborative management approach, the Black Rock Mountain Biking Association’s daily visits to the site have virtually eliminated the construction of unauthorized trails.

Monitoring for unauthorized trails. Without a monitoring approach in place, unauthorized trails can proliferate unbeknownst to land managers. Assessments of unauthorized trails can provide managers with spatial data to assist in identifying, prioritizing and managing these unwanted features. The City of Boulder report^[57] and other references ^[52, 56, 98, 137, 539] include information on locating and correcting unauthorized trails, and Table 7 includes some examples of indicators and thresholds related to unauthorized trails and habitat fragmentation. Methodologies typically include GIS-assisted field work to map trails, field work to assess the condition of these trails such as where soil erosion is beginning or prevalent, and prioritizing removal based on habitat sensitivity, condition class or fragmentation metrics. Table 4 in Marion and Leung’s *Indicators and protocols for monitoring impacts of formal and informal trails in protected areas* used the following metrics for both formal and unauthorized trails, both in the same table for comparison: aggregate length of trail, disturbance area, disturbance density, number of patches and mean patch size. The latter two are fragmentation metrics.

Practices to deter future creation (or re-creation) of unauthorized trails. The literature we reviewed included several approaches to avoid unauthorized trail creation at a site. For example, trail users are less likely to go off trail in heavily vegetated areas,^[540] therefore planting shrubs and trees in problematic areas may be an effective deterrent, and would also improve wildlife habitat. Park et al. suggested using an integrated suite of direct (e.g., closing trails; uniformed rangers for enforcement) and indirect (e.g., educational) management practices to control unauthorized trail creation and use.^[93] Employing signage and educational information specifically at natural area points of entry and at the head of unauthorized trails can help reduce impacts (Section 8.9). In very problematic areas such as key sensitive species locations, it may be effective to install cameras and post “under video surveillance” type signs to make clear that users are being monitored.^[541]

8.5 PROTECTING RIPARIAN HABITAT AND WATER QUALITY

Trails in riparian areas or that cross streams can damage habitat and impair water quality. Practices to reduce effects on these sensitive resources are available in the literature.^[28, 29, 40, 53, 90, 509, 542, 543] Some of the

practices in Metro's *Green Trails* guidebook[43] include the following general suggestions (additional references are included for more detailed information):

- Rather than placing a trail along a stream, consider routing the trail outside of the riparian area and creating a spur trail(s) to the stream.[37]
- Minimize the number of stream crossings.[37] The U.S. Forest Service trail construction guidance document includes best practices for stream and river crossings.[28]
- Use fish-[509, 542] and wildlife-friendly[543] culvert designs.
- A raised trail in a wet area, such as a boardwalk, will keep people on the trail.[18, 88, 97]

The literature revealed other potentially useful recommendations to protect streams and riparian areas. For example, Colorado State Parks recommends avoiding crossings at or near stream confluences,[37] which are particularly ecologically sensitive. Marion and Wimpey suggest scouting streams carefully for the most resistant location such as rocky banks, and designing water crossings so the trail descends into and climbs out of the stream crossing, preventing stream water from flowing down the trail.[18] The City of Portland's trail design guidelines recommends installing dense shrub plantings, brush piles, or carefully designed fencing where trails intersect waterways to deter trail users from denuding streambanks and eroding soil, and states that bridges are preferable to culverts for stream crossings.[53, 88] Aust and others suggest designing water drainage from trails in riparian areas in a thin sheet flow that, prior to reaching water resources, travels through >15 horizontal feet of organic litter and vegetation to settle out or filter soil particles.[29]

When stream crossing structures are required, the City of Portland's *Trail Design Guidelines* offers guidance including design schematics for boardwalks, bridges and culverts as well as methods to avoid soil loss in riparian areas.[53] Blinn et al. provide forestry-based ideas for temporary stream and wetland crossings using some innovative approaches,[544] and Neese et al.'s publication includes guidance on floating trail bridges and docks.[545] We aren't necessarily endorsing these approaches; each site is different. The primary considerations for any stream or wetland crossing design should be to protect riparian vegetation, streambanks and shorelines, maintain or improve water quality, and provide appropriate wildlife passage. The Forest Services' TRACS assessment provides guidance on monitoring the conditions of various stream crossing structures over time.[52]

Sometimes trail construction can help improve wildlife passage. For example, the Lakeside underpass in Portland, Oregon was designed to accommodate a future trail.[543] Collaboration between scientists, transportation and trails planners resulted in relatively inexpensive modifications to improve wildlife passage including natural substrate, rock shelves to provide passage during high water flow, and elevated sidewalks. Metro's *Wildlife crossings: Providing safe passage for urban wildlife*[543] and wildlife corridors literature review[445] provide additional information on wildlife crossing structures and connectivity.

Climate change is expected to alter hydrology in some areas, including more intense rain storms in the Pacific Northwest.[546] Sizing culverts, bridges and crossings with this in mind can help preserve valuable infrastructure. More intense storms can also lead to additional trail damage; taking extra measures to avoid future erosion, such as adding deeper gravel in some areas than suggested in design specifications, may reduce future trail maintenance needs. The potential for larger floods – where standing water is likely to remain for some time due to sheer water volume – also argues for keeping trails out of floodplains, because trails are likely to be underwater more frequently as our climate changes.

8.6 MINIMIZING FRAGMENTATION AND EDGE EFFECTS

As described in Section 5.2, trails and trail use can cause habitat fragmentation and edge effects. Building any trail is likely to cause some environmental effects[58] therefore if recreation is to be introduced to a site, the most direct way to reduce these types of environmental effects is to keep the total lengths of trails in a natural area to the minimum needed to meet recreational demand and provide a quality visitor experience. This would have the added value of reducing unauthorized trails, which are frequently associated with formal trails (Chapter 3).

The majority of the guidance documents in Table 6 lack substantive recommendations on how to protect sensitive habitat areas, wildlife, and ways to reduce habitat fragmentation and edge effects. Such guidance

documents are written from the perspective of trail planners and recreational site managers and naturally focus on trail construction, maintenance and the visitor experience. Similarly, wildlife biologists and natural resource staff would be expected to focus on protecting natural resources. The keys to achieving the goals of both groups are communication and informed compromise.

In 2004 Metro published *Green trails: Guidelines for environmentally friendly trails*. [43] Along with other natural resource related guidance the document includes the following general principles to use, as much as is feasible, for planning trails to preserve sensitive natural resources and minimize habitat fragmentation:

- Keep trails to a minimum
- Use existing disturbance corridors¹⁶
- Locate trails at habitat edges rather than through the middle of a habitat patch
- Keep trails out of core¹⁷ habitat areas
- Maintain habitat connectivity and avoid placing trails in small patches of high-quality connector habitat
- Avoid habitat for threatened, endangered and sensitive species

How much habitat is enough? When routing trails through a natural area, leaving some larger undisturbed core habitat areas can benefit a variety of area-sensitive wildlife species. Figure 8 provides examples of typical area requirements for some wildlife species, derived from Metro's 2010 *Wildlife corridors and permeability* literature review.[445] Although not reflected in Figure 8, large carnivores are generally disturbance-sensitive and require large habitat patches, as discussed in Section 7.4.

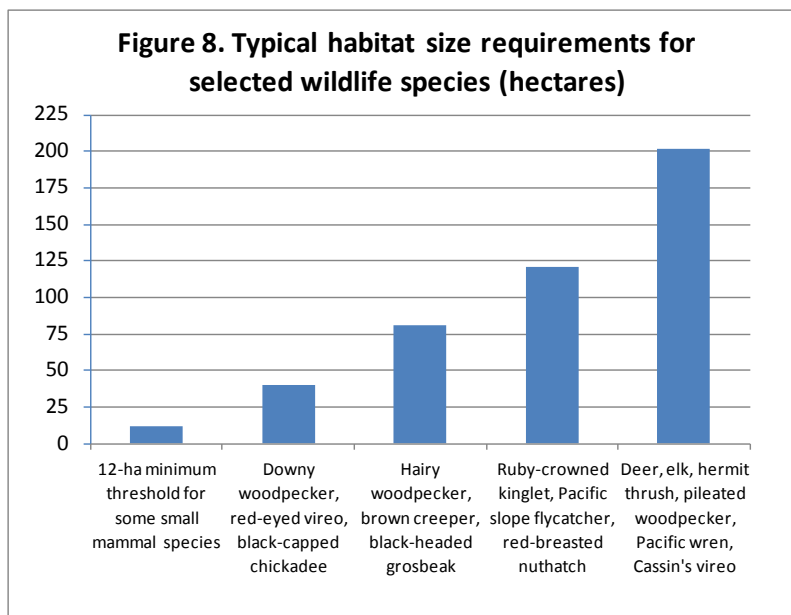


Figure 7. The Lakeside pedestrian and wildlife undercrossing in Portland, Oregon.

¹⁶ Disturbance corridors include existing or abandoned rail lines, powerline corridors, old farm or forest roads, unauthorized trails when appropriate, right of way corridors, swaths adjacent to roadways, construction routes over buried utilities, utility maintenance access routes, and routes to quarries.

¹⁷ Examples of core habitats include areas containing state- or federally-listed sensitive, threatened or endangered plant or animal species, exemplary natural communities, or exceptional native diversity. Large habitat patches are often considered core habitat because they can support more species and tend to have better habitat conditions compared to small patches.

Minimizing invasive species. Issues with invasive species associated with trail building and trail use are discussed in Section 5.3. Preventing the introduction of invasive species is critical because once introduced, it can be expensive to treat them [18] and they cannot always be fully eradicated, thereby raising the risk of distributing seeds to other sites via visitors, wildlife, wind or water. There is often a time lag between when seeds are first transported to a natural area and serious invasive species infestations,[224] thus regular monitoring and treatment for problem species and areas can help lower the severity of the problem.



Best practices to decrease invasive species seed loads include ensuring that natural area management staff and contractors follow best practices including cleaning boots, equipment and machinery;[30, 216] practicing Early Detection-Rapid Response (EDRR) before, during and after building trails, which can significantly reduce weed management costs;[30] minimizing soil disturbance;[30] using an Integrated Pest Management Plan (IPM), which can also reduce the need for pesticides;[30] and retaining tree and shrub cover to shade out invasives.[98] Another way to prevent establishment of invasive species is to educate visitors to be aware of their ability to carry non-native plant seeds on their bikes or clothing, and encourage them to remove seeds by washing mud from bikes, tires, shoes, and clothing.[30, 157] The latter may include installing trailhead educational signage (Section 8.9) and “clean your boots” and “clean your tires” stations.[30, 74, 228]

Cal-IPC’s invasive species prevention manual provides a wealth of invasive species management information.[30] This guidebook states the following overall principles for preventing invasions:

- **Take time to plan.** Proper planning can reduce future maintenance costs by reducing the potential for invasive plant introduction and spread. A good first step is to conduct a pre-activity assessment of the work area to determine which activities could spread weeds and which best practices are applicable.
- **Stop movement of invasive plant materials and seeds.** The movement of workers, materials and equipment can carry weeds within and between sites. The CAL_IPC manual identifies potential vectors of spread and how to eliminate them or reduce their effects.
- **Reduce soil and vegetation disturbance.** Disturbance can allow invasive plants to colonize a new area. When disturbance is unavoidable, managers should conduct follow-up monitoring to ensure early detection of any invasive plants that may have been introduced.
- **Maintain desired plant communities.** A healthy plant community with native and desirable species provides resistance to invasive plant establishment.

- **Practice early detection and rapid response (EDRR).** Early detection and eradication of small populations helps prevent the spread of invasive plants and significantly reduces potential for future management time and expenses

Cal-IPC's list of best practices is described in detail in the text, and includes best practices for planning, project materials, travel, tool, equipment and vehicle cleaning, clothing, boots and gear cleaning, and waste disposal.

The Minnesota Department of Natural Resources' *Guidelines for managing and restoring natural plant communities along trails and waterways* manual includes a chapter on controlling invasive species.[512] The document states that invasive species control can be achieved by understanding the origin and biological behavior of invasive species [Davis and Sheley offer a framework for this issue[547]]; identifying and ranking the extent of exotic plant invasion; focusing control efforts on those plant communities that still have high ecological diversity to encourage natural regeneration of native plants; and monitoring treated sites regularly and thoroughly to keep invasive species under control.

Prioritizing treatment of invasive species. Cal-IPC suggests prioritizing treatment of invasive species as follows:[30]

- Species known or suspected to be invasive but still in small numbers (e.g., EDRR species)
- Species that can alter ecosystem processes
- Species with the potential to alter fire regimes
- Species that occur in areas of high conservation value
- Species with the potential to require high management costs
- Species that are likely to be controlled successfully
- Species determined to be of concern as identified through regional partnerships

Finding information about invasive species. Several resources are available to help identify and treat invasive species. Local Soil and Water Conservation Districts typically have weed identification and control programs. Some invasive species control guidance documents are habitat-specific; for example, Stanley et al. produced a report on controlling invasive species in Pacific Northwest native prairie habitats.[548].

Several resources are specific to the greater Portland area or the state of Oregon. The greater Portland-Vancouver region has a 4-county Cooperative Weed Management Area (<https://4countycwma.org/>). Soil and Water Conservation Districts (SWCDs) have weed identification and control programs and often have dedicated invasive species staff. Local jurisdictions and agencies (e.g., the City of Portland Bureau of Environmental Services invasive species program; Clean Water Services in the Tualatin watershed) are good resources. iMapInvasives (<https://sites.google.com/site/orimapresources/>) is an excellent resource to map or find weed locations.

Methods to estimate edge effects. Several methods to estimate edge effects from planned or existing trails are provided in Table 3. These methods can be particularly useful for comparing relative effects from different potential trail alignments or estimating effects from unauthorized trails, the latter which can provide guidance on where to prioritize removing such trails.

8.7 MINIMIZING EFFECTS OF RECREATIONAL USE ON WILDLIFE

Several references offer potentially valuable ideas and suggestions to help reduce negative recreational effects on wildlife.[\[37, 43, 97, 263\]](#) For example, Colorado State Parks' *Planning trails with wildlife in mind* handbook offers the following “rules of thumb” when considering effects of trails on wildlife:[\[37\]](#)

1. Lack of wildlife knowledge: Because there isn't much detailed knowledge about the effects of human disturbance on wildlife, be cautious in planning a trail, carefully weighing the alternatives.
2. Make do: Use the best wildlife information available, even if it is scarce. Solicit the advice of a biologist.
3. Considerable differences: Not only do different species respond differently to trails, different populations of the same species may respond differently, based on previous encounters with people.
4. Concentrated use: Generally, it is better to concentrate recreational use rather than disperse it. If social trails have developed in an area, it is probably better to consolidate them into one or a few trails.
5. Type of trail use: Some animals are more alarmed by hikers than by people who stay in their vehicles, especially if the vehicles don't stop.
6. Dog controls: If dogs are to be allowed on a trail where there are sensitive wildlife species, the dogs should be leashed or excluded seasonally to reduce conflicts. [When wildlife is one of a site's highest priorities, prohibiting dogs is preferable – see Appendix 1.]
7. Screening: The natural visual screening of a trail in a wooded area frequently makes most wildlife tolerate greater human disturbance than they would in open terrain. In some areas, it may be possible to plant a vegetative screen or build a screening fence to accomplish similar effects. [Our literature review indicates that vegetative cover may be as important as the number of visitors.[\[62\]](#)]
8. Impacts vs. benefits: Some wildlife effects cannot be resolved through management. Clear assessment of effects may lead to trail realignment.
9. Breeding areas or other special locations: Either avoid key wildlife breeding areas or close trails through them at the times such wildlife are most sensitive to human disturbance.
10. Enforcing closures: If there won't be sufficient resources to enforce a trail closure during wildlife-sensitive seasons, consider rerouting the trail through another area.

Chapter 6.7 reviewed the effects of noise and light pollution. Potential solutions could include limiting the extent of trails to minimize wildlife effects and providing education or signage to reduce conversation or conversation volume. Physical sound barriers could be useful where especially noisy roads negatively affect important wildlife areas. Minimizing trail lighting and ensuring that light does not encroach into habitat can help reduce lighting effects.

Formally incorporating wildlife considerations into the trail planning process right at the beginning is essential to reducing negative effects from recreational use. If trail planning is already well underway, it may be too late to gather sufficient wildlife information to inform trail alignments. However, collecting new wildlife information can help inform future management of existing trail systems.

GATHERING LOCAL WILDLIFE INFORMATION

Sometimes land managers do not have the expertise or the means to conduct formal or informal wildlife surveys. Timing can also be an issue; some wildlife species vary seasonally in their habitat use, such as Neotropical

migratory songbirds or deer and elk moving between winter and summer grounds. There are several ways to help overcome such obstacles. Consulting a biologist early in the process can help guide the process of wildlife data collection.

Habitat maps and species-habitat associations. Maps delineating general habitat types such as mixed forest, oak savanna, riparian forest and wetlands are a first step to understanding what wildlife may be using a site. A logical next step is to ascertain what species live in the area and what habitats they use. Sometimes this information is readily available. For example, Johnson and O’Neil’s *Wildlife-Habitat Relationships in Oregon and Washington* provides a wealth of species-specific information including range maps, habitat associations and special habitat elements required by some species (e.g., snags for birds or rock piles for lizards).

Collecting local wildlife information from other sources. Some sources of wildlife information can be collected in the office. Examples include information from local biologists at state and federal fish and wildlife agencies; governmental agencies with nearby natural land holdings; parks departments; online resources such as NatureServe (www.natureserve.org), i-Naturalist (www.inaturalist.org), E-bird (www.ebird.org) and Breeding Bird Survey (www.pwrc.usgs.gov/bbs/) data; and nature-oriented nonprofits such as The Audubon Society, The Nature Conservancy and the Wildlife Conservation Society.

Residents adjacent to a site are often familiar with the wildlife on their lands, such as locations of amphibian breeding ponds, native turtles, eagle nests and whether cougar, bear or elk move through. They may also be willing to collect information in certain instances. For example, a Portland area resident adjacent to the region’s largest natural area organized her neighbors to map elk sightings, which aided conservation planning. Open houses during the trail planning process can provide an opportunity for numerous residents to document wildlife they see in the neighborhood, as well as engage them more intimately with the project. Field staff members conducting restoration, maintenance or other activities often detect wildlife or wildlife sign, and such observations (including spatially explicit information) can be compiled into a wildlife list for the site.

Collecting wildlife information in the field. Several options are available for collecting field data, depending on the amount of time and resources available. Volunteers such as wildlife trackers or skilled amateur birdwatchers can be asked to survey a site. Community science projects and “bioblitzes” can yield relatively rich, site-specific wildlife information.^[535] Wildlife cameras set in strategic locations, for example along wildlife trails or near water sources, can produce accurate, although incomplete, wildlife information. This approach is especially useful because some wildlife species are naturally nocturnal or switch to night-time activities in order to avoid human disturbance (Section 6.6), and daytime surveys may not detect such species.

Professional wildlife biologists can be hired to collect preliminary or longer term wildlife data in a natural area. Different types of animals require different survey methods. Some examples include:

- Amphibians: egg mass surveys and local area searches; track plates for some species; fluorescent dye; other methods ^[549-551]
- Reptiles: area searches, sometimes including placing boards or other hiding places at a site to check later; capture-mark-recapture studies to assess movement patterns; pit traps (regularly checked to avoid mortality); other methods^[549-551]

- Birds: point counts, area searches, transects, mist-netting or nest surveys; multi-season studies are useful to ascertain how sites are used during migration or in the winter; area searches may be more effective in winter[551-553]
- Mammals: non-lethal trap arrays or pit traps (regularly checked to avoid mortality) for small mammals; for larger mammals, visual observations, tracking surveys, wildlife cameras or radio-collar studies to assess presence or movement patterns[551, 554]
- Habitat: Comprehensive guidance in *Inventory and monitoring of wildlife habitat*[551]

Several publications describe a variety of wildlife monitoring techniques.[551, 555-557] The U.S. Forest Services' habitat monitoring book includes a chapter on monitoring human disturbances for management of wildlife species and their habitats.[558] When considering wildlife monitoring techniques at the site level, methods to estimate wildlife populations may not be necessary; the most important things to know for trail planning are what species are using the site, where, and when. Steidl and Powell provide information on wildlife monitoring methods and how to choose an appropriate wildlife response measure for assessing the effects of human activity on wildlife.[559]

WILDLIFE FLIGHT INITIATION AND ALERT DISTANCES

Even with high quality wildlife data, estimating the potential effects of trails and recreation on wildlife can be difficult. The sheer number of wildlife species adds a great deal of complexity. Wildlife use of a site can change with variables such as location, restoration efforts, nearby land use changes, vegetation density, topography, wildlife species, season, reproductive status, habituation-type responses and chance. In addition, different species can react differently to the types and amount of trail use at a site. Due to these complexities, specific guidance on estimating or measuring potential wildlife effects is sparse.

However, a substantial body of literature documents wildlife responses to human disturbance. During the course of this literature review we compiled flight initiation distance (FID) and when available, alert distance information for various species that occur in the U.S. species (Appendix 3). Species were clustered into groups in Table 8 and Figure 9; the mean, median and range of disturbance response distances for species groups are provided.

Bird FIDs are typically 30 percent shorter on average than the alert distance.[163] Because most studies only consider FID, the median distances in Table 8 underestimate the distance at which wildlife become disturbed by humans. On the other hand, it is unknown the extent to where, when and which species habituate, therefore some studies in wildlands may overestimate the distances needed by species that can habituate to regularly disturbed landscapes such as suburban and urban areas. Also, FIDs and particularly alert distances for small animals and shy songbirds such as Neotropical migrants are difficult to measure because they are hard to see or tend to avoid disturbance altogether.

In the absence of higher quality wildlife information, land managers who want to roughly estimate wildlife response distances at a given site could select studies from Table 8 that are relevant to their geographic area or site, or use species groups' median, to consider potential effects from existing recreational uses or compare potential effects between different proposed trail alignments. Due to considerable uncertainties in how closely these data mirror local wildlife community responses, such an approach should not be viewed as prescriptive.

Figure 9 illustrates the flight initiation or alert distances from Table 8 and the more detailed study-specific information in Appendix 3. Figure 10 shows an example of how such data could be used to consider the potential impacts of recreation on wildlife.

Figure 9. Flight Initiation or alert distances for various wildlife species.
See Appendix Table 3 for underlying data.

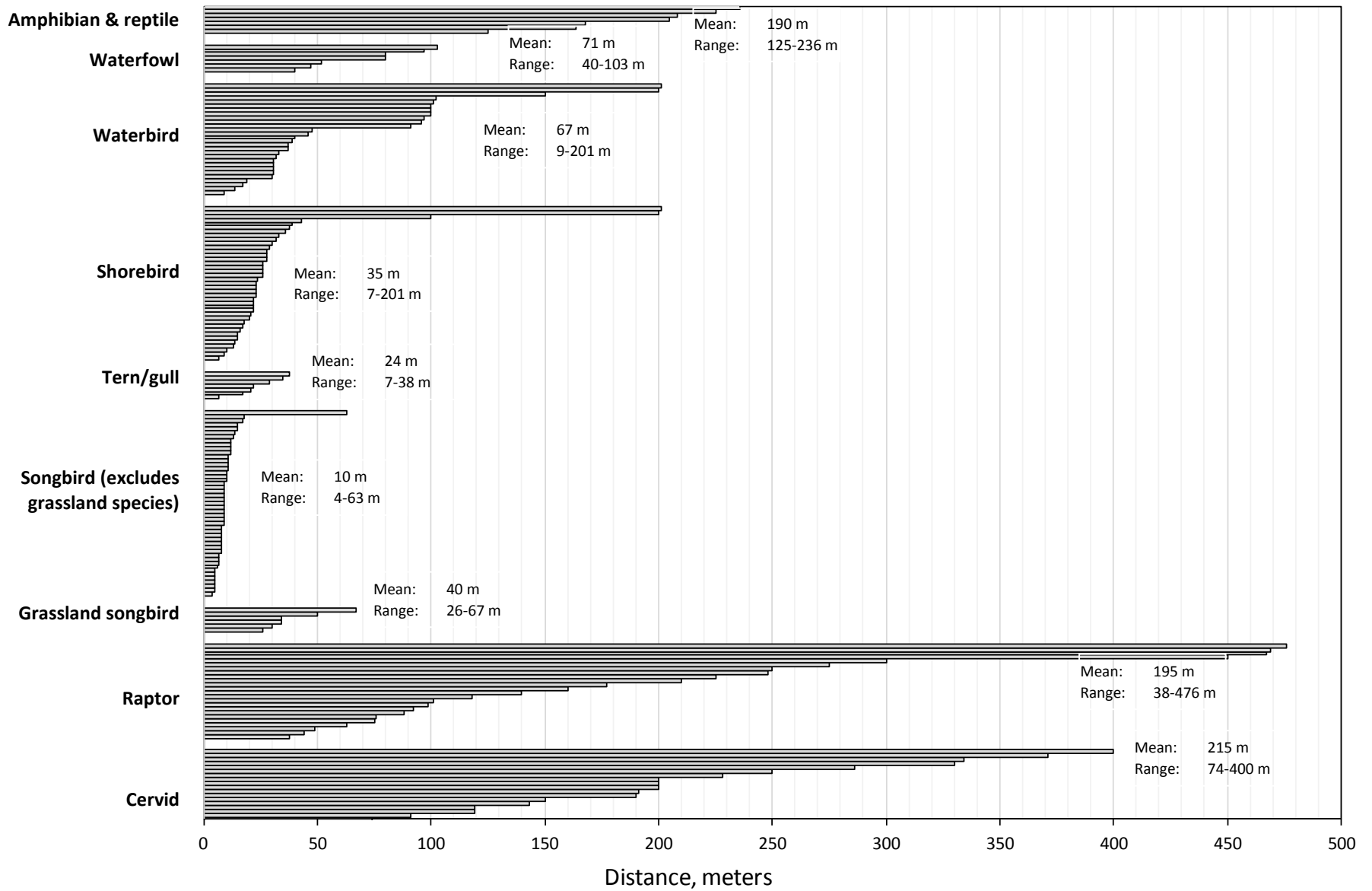


Table 8. Summary statistics for species groups' Flight Initiation Distances or Alert Distances from the scientific literature. We excluded species groups with fewer than three data points from Figure 9 (**hummingbirds**, corvids, doves/pigeons, **woodpeckers** and bovids) although data for these species 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. <i>Additional information:</i> 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. <i>Additional information:</i> 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. <i>Additional information:</i> 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. <i>Additional information:</i> 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. <i>Additional information on Bald Eagles:</i> 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.

Species group	# of studies	Mean (meters)	Median (meters)	Range (meters)	Notes
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. <i>Additional information:</i> 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.



Figure 10. Example of a simple way to use the data presented in Table 8 to consider potential effects of human disturbance on waterfowl from a planned wildlife viewing blind adjacent to a large wetland. The median FID value for waterfowl (80 m) is drawn in orange. If migratory waterfowl are of particular concern, the higher end of the FID range (103 m) could be used.

8.8 REDUCING CONFLICTS BETWEEN USER GROUPS

The literature was rich with information on the types, reasons, and potential solutions for conflicts between user groups (Chapter 4). Several references emphasized that user groups that start out using trails together experience less perceived conflict; expectations are set at the beginning and no users are displaced. Some of the practices to reduce or avoid such recreational user group conflicts are described below.

Moore's review and synthesis of conflicts on multiple-use trails provides a clear, concise set of recommendations to reduce user conflicts on a variety of trail surfaces:[116]

1. Recognize conflict as the perception of a visitor interfering with another visitor's reasons for visiting the natural area.
2. Identify potential user groups and involve them as early as possible.
3. Actively and vigorously promote trail etiquette; target the audience, get the information into users' hands as quickly as possible, and present in simple, interesting, understandable and sometimes lighthearted/humorous ways.
4. Understand the needs of present and likely future users of each trail. This is critical for anticipating and managing conflicts and requires patience, effort, and sincere active listening.
5. Identify actual sources of conflicts – get beyond emotions and stereotypes as quickly as possible and get to the root of any problems that exist.
6. Minimize the number of conflicts in problem areas – for example, in congested areas and at trailheads. Disperse use and provide separate trails when necessary and after careful consideration of environmental effects.
7. Work with affected users (all parties involved) to reach mutually agreeable solutions. Users who are not involved as part of the solution are likely to be part of the problem now and in the future.
8. Encourage positive interaction among trail users; their values are likely more similar than different. Positive interactions both on and off the trail can break down barriers and stereotypes and build understanding, good will and cooperation. One example is to bring the different types of visitors together for joint trail building or maintenance projects.
9. Use the most "light-handed" management approaches possible that will still achieve the objectives. This is essential to providing the freedom of choice and natural environments that are so important to trail-based recreation.
10. Plan and act locally – whenever possible, address issues regarding multiple use trails at the local level. This allows greater sensitivity to local needs and provides better flexibility for addressing difficult issues on a case-by-case basis. This also facilitates involvement of the people most affected by any decisions, and most able to assist in their successful implementation.
11. Monitor the ongoing effectiveness of the decisions made and programs implemented. It is essential to evaluate the effectiveness of the actions designed to minimize conflicts; provide for safe, high-quality trail experiences; and protect natural resources. Conscious, deliberate monitoring is the only way to determine if conflicts are indeed being reduced and what changes in programs might be needed. This is only possible within the context of clearly understood and agreed-upon objectives for each trail area.

The literature indicates that hikers view mountain bikers and equestrians more negatively than the reverse (Chapter 4). Employing a two-pronged approach in which (1) hikers receive educational information about shared values with other groups, and (2) mountain bikers and equestrians are particularly encouraged to follow appropriate codes of conduct may be effective in reducing conflicts.

Preventing and reducing user conflicts does not necessarily follow the messaging outlined in Section 8.9. In the case of conflict, more positive messages may be more effective. Educational signage such as "share the trail" types of messages, including indicating which users have right-of-way priority, can reduce conflicts. Messages that emphasize shared values that user groups hold in common such as "we all care" can be effective.[88] However,

signage may also be viewed as a visual impact on the landscape therefore a strategic approach such as placing signs at trail entries and problem areas may improve the user experience.

Engaging trail user groups can be an effective approach to enforcing codes of conduct through peer pressure. Creating a trail ambassador program with all user groups to provide etiquette guidance and monitoring is one way to reduce management and enforcement needed at a site. For more information about this type of approach see “collaborative management approaches” in Section 8.4.

We found several examples of codes of conduct, including for hikers,[[560](#), [561](#)] mountain bikers[[58](#), [562](#)] and equestrians.[[14](#), [20](#), [146](#), [563](#)] Note that most codes of conduct address user conflicts rather than environmental issues; incorporating environmental values into these rules and responsibilities could help decrease negative effects from trail users. Canada’s Trent University has a website with links to many codes of conduct.¹⁸ Numerous other references provide codes of conduct or additional guidance for minimizing user group conflicts.[[96](#), [116](#), [144-146](#), [150](#), [564](#)]

8.9 NOTES ABOUT SIGNAGE AND EDUCATIONAL MESSAGING

Messages conveyed in a variety of ways can be effective at changing some peoples’ undesirable behaviors.[[564](#)] The body of research we reviewed suggests several approaches for effective visitor education through signage.

Several studies or reviews investigated the effectiveness of different approaches to visitor education. In a study conducted in Maine, Turner found that signage is least effective on people engaged in illegal, malicious, and unavoidable activities, and is most effective on uninformed and unskilled actions.[[538](#)] Marion and Reed reviewed the literature on education programs to address user-related damage to natural resources, social conditions and neighboring communities; they concluded that “...there is adequate evidence that most of the visitor education methods evaluated did affect visitor knowledge, attitudes, behaviour, and/or resource conditions in the intended direction.”[[564](#)] Most of the papers they reviewed identified the content and delivery of messages, audience characteristics, and theoretical underpinnings as important to the effectiveness of such messaging.

Technical language information. Messages may present the “ought” (injunctive) or the “is” (descriptive) of behavior and may be stated positively (prescriptive) or negatively (proscriptive).[[141](#), [564](#)] Winter’s experiments in Sequoia National Park directly tested the effectiveness of different types of messages used in signage.[[141](#)]

Evidence suggests that injunctive-proscriptive messages are often the most effective route in gaining desired behavior, and that negative messaging (“do not”) appear to work best. For example:

- Most effective: To protect sensitive habitat, please do not go off the trail. (injunctive-proscriptive; these types of messages may be the most memorable)
- Less effective: Many visitors in the past have stayed on trails, helping to protect vegetation. (descriptive-prescriptive; states the desired behavior as the norm, encourages desirable behavior)
- Less effective: Please stay on paths to protect natural vegetation.(injunctive-prescriptive, basically saying “stay on the trail”)
- NO: Many visitors in the past have left the established trail, changing the natural vegetation in this park. (descriptive-proscriptive; presents the undesirable behavior as the norm)

¹⁸ <http://www.trentu.ca/academic/trailstudies/moreethics.html>

There is some evidence that people behave better when they think other visitors might see them doing something wrong. In the Petrified Wood National Park, researchers used a 2 x 2 factorial design (type of normative information – injunctive versus descriptive; and normative focus – strong negatively worded versus weak positively worded) to test whether positively or negatively phrased normative messages were most effective at deterring theft of petrified wood.^[565] The investigators experimentally placed marked pieces of petrified wood along trails, then counted theft of marked wood along trails with different types of signage. The signs read:

1. “Please leave petrified wood in the park” accompanied by a picture of a visitor admiring and photographing a piece of wood.
2. “Many past visitors have removed the petrified wood from the park, changing the state of the Petrified Forest” accompanied by pictures of three visitors taking wood.
3. “The vast majority of past visitors have left the petrified wood in the park, preserving the natural state of the Petrified Forest,” accompanied by pictures of three visitors admiring and photographing a piece of wood.
4. “Please don’t remove the petrified wood from the park” accompanied by a picture of a visitor stealing a piece of wood, with a red circle-and-bar symbol superimposed on the hand.

All four messages essentially said the same thing, but the last message, which strongly focused recipients on injunctive normative information, was much more effective. In fact, the second message actually increased theft whereas the fourth message reduced it. The theory is that observers focus more on the negative message, which increases the sign’s effectiveness. In addition, clearly pointing out the undesirable behavior as forbidden may deter undesirable behavior because visitors might worry about what other people would think.

The “Leave No Trace” environmental education approach is widely regarded as an effective tool to reducing user effects.^[514] In sites or areas with significant impact issues, one approach is to strategically place staff or volunteers to provide personal educational contact with visitors; this type of personal contact can be quite effective.^[564] Messages delivered via multiple methods (e.g., personal contacts, posters and brochures at trailheads, signs along trails) are most effective.^[92] Multi-lingual signs that reflect the diversity of surrounding communities and expected visitors can help ensure that everyone gets the message.^[141] Current best practices include using minimal text and relying on clear graphics that are universally comprehensible. Graphics also work for the segment of the population that use different languages or cannot read. Several articles provide more in-depth information about signage and messaging at a site.^[141, 564-566]

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Appendix 1: Literature review on the impacts of dogs on wildlife and water quality

The impacts of dogs on wildlife and water quality: A literature review

Compiled by Lori Hennings, Metro Parks and Nature, April 2016

SUMMARY

Metro periodically reviews the science literature behind its natural resource policies to ensure policies are based on the most current science. Recently staff reviewed the scientific literature regarding the impacts of dogs on wildlife to inform Metro Regulatory Code Title 10.01, which excludes pets from most Metro properties. The only exceptions are service dogs, leashed dogs on some regional trails, Broughton Beach, boat ramps and properties managed by others through intergovernmental agreements that are integrated into larger parks where leashed dogs are allowed (e.g., Forest Park).

Any human related activity can disturb wildlife. In order to meet Metro's dual goals of protecting natural resources and providing access to nature, Metro has tried to strategically locate trails in less sensitive habitat and to ensure that human activity is as non-disruptive as possible. Part of that strategy has been to allow public access, while limiting certain activities such as bringing dogs into natural areas.

The evidence that dogs negatively impact wildlife is overwhelming. It is clear that people with dogs – on leash or off – are much more detrimental to wildlife than people without dogs. Dogs (*Canis lupus familiaris*) are considered to be a subspecies of wolves (*Canis lupus*), and wildlife perceive dogs as predators.⁽³⁰⁾ Impacts include:

1. **Physical and temporal displacement** – The presence of dogs causes wildlife to move away, temporarily or permanently reducing the amount of available habitat in which to feed, breed and rest. Animals become less active during the day to avoid dog interactions. Furthermore, the scent of dogs repels wildlife and the effects remain after the dogs are gone.
2. **Disturbance and stress response** – Animals are alarmed and cease their routine activities. This increases the amount of energy they use, while simultaneously reducing their opportunities to feed. Repeated stress causes long-term impacts on wildlife including reduced reproduction and growth, suppressed immune system and increased vulnerability to disease and parasites.
3. **Indirect and direct mortality** – Dogs transmit diseases (such as canine distemper and rabies) to and from wildlife. Loose dogs kill wildlife.
4. **Human disease and water quality impacts** - Dog waste pollutes water and transmits harmful parasites and diseases to people.

INTRODUCTION

Metro owns 17,000 acres of parks and natural areas and does not allow dogs or other pets on the vast majority of these lands. Exceptions include service animals, leashed dogs on some regional trails, Broughton Beach, boat ramps and certain properties managed by others through intergovernmental

agreements that are integrated into larger parks where leashed dogs are allowed (e.g., Forest Park). The policy that prohibits visitors from bringing pets to most of Metro's managed parks and natural areas was initiated by Multnomah County in the 1980s and continued in practice after Metro assumed management of those parks in the early 1990s. After a review of the scientific literature and meaningful public discourse, Metro formally adopted the pets policy into its code in 1997 (Metro Council Regulatory code Title 10.01 adopted in Ordinance 96-659A).

To ensure this decision reflects the most up-to-date information, Metro staff examined 54 peer-reviewed scientific journal articles and several research reports relating to the impacts of dogs in natural areas, including numerous literature reviews on the impacts of various types of recreation on wildlife and habitat.^(10, 28, 42,54,61,63, 65,68,71,73,77) The results of our literature review are summarized below.

PHYSICAL AND TEMPORAL DISPLACEMENT

Displacement may be the most significant impact due to the amount of habitat affected. The presence of dogs causes most wildlife to move away from an area, which temporarily or permanently reduces the amount of functionally available habitat to wildlife. The research is clear that people with dogs disturb wildlife more than humans alone.^(5,10,33,38,39,41,44,61,68,69) These effects reduce a natural area's carrying capacity for wildlife, and also reduces wildlife viewing experiences for visitors.

Studies on a variety of wildlife in many countries and settings demonstrate that dogs along trails and in natural areas significantly alter wildlife behavior.^(9,33,39,41,49,53,58) A 2011 literature review found negative dog effects in all 11 papers that examined such effects.⁽⁶⁵⁾ Studies demonstrate dog-specific impacts on reptiles,^(29,31,48) shorebirds and waterfowl,^(24,32,51,69) songbirds,^(5,9,10) small mammals,^(33,39,56) deer, elk and bighorn sheep,^(4,36,38,44,49,59,63) and carnivores.^(22,33,52,58)

A study in France found that two hikers disturbed an area of 3.7 hectares walking near wild sheep, whereas two hikers with dogs disturbed 7.5 hectares around the sheep.⁽⁴¹⁾ In Chicago, migratory songbirds were less abundant in yards with dogs.⁽⁹⁾ Dog walking in Australian woodlands led to a 35% reduction in bird diversity and a 41% reduction in the overall number of birds.⁽⁵⁾ The same study showed some disturbance of birds by humans, but typically less than half that induced by dogs.

Studies in California and Colorado showed that bobcats avoided areas where dogs were present, including spatial displacement^(22,33,52) and temporal displacement in which bobcats switched to night time for most activities.⁽²²⁾ The Colorado study also demonstrated significantly lower deer activity near trails specifically in areas that allowed dogs, and this effect extended at least 100 meters off-trail.⁽³³⁾ This negative effect was also true for small mammals including squirrels, rabbits, chipmunks and mice, with the impact extending at least 50 meters off-trail.

Evidence suggests that some wildlife species can habituate to certain predictable, non-threatening disturbances such as people walking on a trail in a natural area; this effectively lowers the stress response. Part of this adaptation may be due to wildlife learning what is and isn't a threat, and also

avoidance of hunters.^(19,55,63,70) Habituated animals still react, but amount of habitat affected is not as large.^(55,56,63,70) However, dogs – especially off-leash dogs – may prevent wildlife habituation because wildlife consistently see them as predators. Dog-specific disturbance has been studied for birds, with no evidence of habituation even with leashed dogs, even where dog-walking was frequent; this effect was much weaker for people without dogs.⁽⁵⁾

Even the scent of dog urine or feces can trigger wildlife to avoid an area. Therefore, the impacts of dog presence can linger long after the dog is gone, even days later. One literature review found that predator odors caused escape, avoidance, freezing, and altered behavior in a large suite of wildlife species including scores of amphibian, reptile, bird, and mammal species from other studies.⁽³⁰⁾ The scent of domestic dogs has been shown to repel American beaver (*Castor Canadensis*), mountain beaver (*Aplodontia rufa*), deer (*Odocoileus* species), elk (*Cervus elaphus*), and a wide variety of wildlife native to other countries.^(20,30) Mountain beaver cause economic damage to young tree stands in the Pacific Northwest, and foresters are considering using dog urine as a repellent.⁽²⁰⁾ An experimental study demonstrated that dog feces are an effective repellent for sheep, with no habituation observed over seven successive days.⁽¹⁾

One Colorado study showed mixed effects of dogs on wildlife.⁽⁴⁴⁾ The study compared effects of pedestrians alone, pedestrians with leashed dogs and unleashed dogs alone on grassland birds. Vesper Sparrows (*Pooecetes gramineus*) and Western Meadowlarks (*Sturnella neglecta*) waited until dogs were closest to flush – that is, they fly or run away. This could be an attempt to remain undetected against the greatest threat, but could also mean that these bird species perceive humans as a greater threat than dogs. However, the same study found strong dog-specific impacts on mule deer in woodlands. A literature review found that ungulates (deer, elk and sheep) had stronger flight responses in open habitats compared to forested habitats.⁽⁶³⁾ Unlike small ground-nesting songbirds, larger animals would have no cover and could easily be seen in open habitats.

The disturbance effects of off-leash dogs are stronger than on-leash and substantially expand the amount of wildlife habitat affected,^(32,59,63,69) and the unpredictability of off-leash dogs may prevent wildlife habituation in large areas of habitat.^(5,10,32,61,69) The negative effects are increased even further when dogs and people venture off-trail, probably because their behavior is less predictable.^(44,67) Off-leash dogs are likely to reduce the number and types of wildlife in large areas of habitat.

A Colorado study found off-leash dogs ventured up to 85 meters from the trail, although this result was from 1 square meter plots covering a very small percentage of the area.⁽³³⁾ Remote cameras in another study documented the same dog 1.5 miles apart in the same day.⁽⁶¹⁾ In Utah, mule deer showed a 96% probability of flushing within 100 meters of recreationists located off trails; their probability of flushing did not drop to 70% until the deer were 390 meters from the recreationists.⁽⁶⁷⁾ A California shorebird study found that off-leash dogs were a disproportionate source of disturbance, and that plovers did not habituate to disturbance; birds were disturbed once every 27 minutes on weekends.⁽³²⁾

To illustrate the potential of dogs to displace wildlife we explored two well-known local park examples that allow dogs on leash. Forest Park is one of the largest urban parks in the U.S. and was always intended to connect urban dwellers with nature; people have been walking their dogs there since before the park's 1948 dedication. Forest Park covers 5,172 acres of forest, including approximately 80 miles of trails and service. Using a very conservative 25-meter buffer around mapped trails to represent the "human + dog on leash" area of disturbance and assuming 100% compliance with leash rules, the area affected would be 1,406 acres – that's 28% of the entire park. In 651-acre Tryon Creek Natural Area, 207 acres of land (32%) is within 25 meters of a trail.

DISTURBANCE AND STRESS RESPONSE

Stress response is the functional response of an animal to an external stressor, such as seasonal changes in temperature and food availability or sudden disturbance.⁽³⁾ Specific stress hormones are released to enable the animal to physically respond to the stressor. Acute stress response, when an animal reacts to an immediate situation, can benefit an animal by triggering it to respond appropriately to a threat. However, chronic stress such as repeated disturbances over time may reduce wildlife health, reproduction, growth, impair the immune system and increase vulnerability to parasites and diseases.^(16,27,75)

Dogs cause wildlife to be more alert, which reduces feeding, sleeping, grooming and breeding activities and wastes vital energy stores that may mean life or death when resources are low, such as during winter or reproduction.^(8,32,40,41,69) Animals release stress hormones and their heart rates elevate in response.^(3,27,37,38) When stress becomes too high, animals may flush, freeze, or hide.^(26,30)

Several studies document that disturbance reduces reproductive success for some wildlife species.^(11,35,40,50,63) Numerous studies found that female deer and elk, and deer and elk groups with young offspring, show greater flight responses to human disturbances than other groups.⁽⁶³⁾ Stress hormones may cause male songbirds to reduce their territorial defense, females to reduce feeding of their young, nestlings to have reduced weight and poor immune systems, and adult birds to abandon nests.^(11,34,35,76) A Colorado study showed that elk repeatedly approached by humans had fewer young.⁽⁵⁰⁾ Although research is lacking on whether dogs specifically reduce the reproductive success of wildlife, the fact that humans with dogs create much stronger disturbance effects than without dogs^(5,33,38,41,44,61,68,69) implies that these stress effects would be magnified if people had dogs with them.

INDIRECT AND DIRECT MORTALITY

Dogs chase and kill many wildlife species including reptiles, small mammals, deer and foxes.^(12,13,29,31,48,58,62) A Canadian study found that domestic dogs were one of the top three predators that killed white-tailed deer fawns.⁽⁴⁾ In northern Idaho winter deer grounds, an Idaho Fish and Game conservation officer witnessed or received reports of 39 incidents of dogs chasing deer, directly resulting in the deaths of at least 12 animals.⁽³⁶⁾ A study in southern Chile revealed that domestic dogs preyed on

most of the mammal species present in the study area.⁽⁶⁰⁾ A 2014 literature review of dogs in parks identified 19 studies that investigated the effects of dogs preying on wildlife.⁽⁷³⁾ Of these, 13 reported observing or finding strong evidence of dog predation on wildlife. The Audubon Society of Portland's Wildlife Care Center took in 1,681 known "dog-caught" injured animals from 1987 through March 2016.⁽²⁾

Dogs transmit diseases to wildlife and vice versa including rabies, Giardia, distemper and parvovirus.^(18,23,66,74) A Mexico City study concluded that feral dogs continually transmitted parvovirus, toxoplasmosis and rabies to wildlife including opossums, ringtails, skunks, weasels and squirrels.⁽⁶⁶⁾ Large carnivores such as cougars are especially vulnerable to domestic dog diseases including canine distemper.⁽⁷⁴⁾

HUMAN DISEASE AND WATER QUALITY IMPACTS

Under the Oregon Department of Environmental Quality (DEQ), Metro is a Designated Management Agency to protect water quality in compliance with the federal Clean Water Act. Limiting dog access at most natural areas is one of Metro's commitments to DEQ, because dog feces pollute water. Feces are often delivered to waterways through stormwater.⁽⁵⁷⁾ The average dog produces ½ to ¾ pound of fecal matter each day – a hundred dogs can produce more than 500 pounds of waste per week.⁽⁴⁵⁾ The DEQ identifies pet waste as a significant contributor to one of the region's most ubiquitous and serious pollutants, *E. coli* bacteria. Contact with *E. coli*-polluted water can make people sick. Because dog waste can be a relatively simple source to reduce or eliminate exposure to *E. coli*, DEQ considers reducing or eliminating dog waste an important action item in jurisdictions' clean water implementation plans for the Willamette Basin watershed.⁽⁴⁷⁾

Humans can catch parasites and diseases such as hookworms (causes rash), roundworms (may cause vision loss in small children, rash, fever, or cough) and salmonella (causes gastrointestinal illness) from dog waste.^(7,57) Aside from potential illnesses, dog waste can negatively affect visitors' experience in a natural area. Dog waste left on the ground is a leading complaint in Portland parks, and violators may be fined up to \$150 per incident.⁽¹⁴⁾

Several examples illustrate local dog impacts. A Clean Water Services DNA study found that dog waste alone accounts for an average of 13% of fecal bacteria in stream study sites in the Tualatin River Basin.⁽¹⁷⁾ Off-leash dog walking is documented to cause erosion in Portland's Marshall Park, creating sediment problems in stream water.⁽¹⁵⁾ In 2014 Portland school administrators expressed concern because playgrounds had become "a minefield for animal waste" from people using school grounds as after hours, off-leash dog parks, threatening the health of school children.⁽²¹⁾ The City of Gresham found extremely high levels of *E. coli* bacteria in water quality samples of a very specific stretch of a stream, where dog feces were found along stream banks behind several yards with dogs.¹ The city sent letters to

¹ Personal communication with Katie Holzer, Watershed Scientist at the City of Gresham, Oregon, 4/11/2016.

residents in the neighborhood about the incident and how to properly dispose of dog feces; the levels have not been elevated in follow-up sampling.

BELIEF, BEHAVIOR AND REALITY

People do not always take responsibility for their impacts on wildlife. Several studies demonstrate that natural area visitors, including dog owners, often don't believe they are having much of an effect on wildlife, or assign blame to different user groups rather than accepting responsibility themselves.^(6,64,67,68) Some natural area visitors assume that when they see wildlife, it means that they are not disturbing the animals – or worse, that because they didn't see any wildlife, they didn't disturb any.⁽⁶⁴⁾

For example, in Utah, about half of recreational visitors surveyed did not believe that recreation was having a negative impact on wildlife; of those that did, each user group blamed other groups for the strongest impacts.⁽⁶⁷⁾ In Austria, 56% of people surveyed at a national park agreed that wildlife is in general disturbed by human activity.⁽⁶⁴⁾ However, only 12% believed that they had disturbed wildlife in their visit that day, and dog-walkers ranked their activities as less disturbing than other user groups' activities. When asking different user groups to rate the impacts of overall human disturbance on wildlife, dog-walkers rated the impacts the lowest, at 2.6 out of 5 possible impact points.

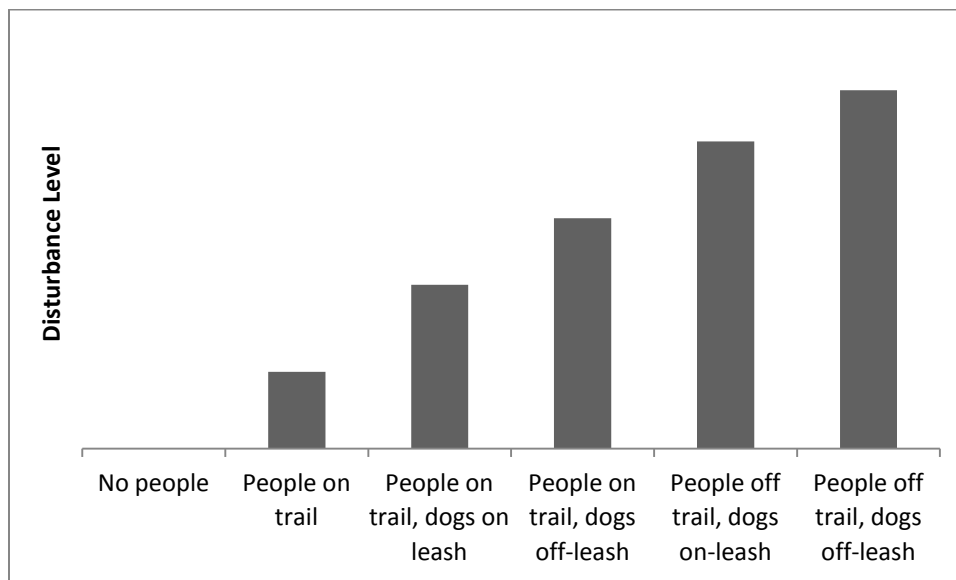
Surveys indicate that many dog owners desire fewer restrictions, while non-dog owners often feel the opposite.^(72,73) However dog owners don't always follow the rules, and some dog owners allow their dogs to run free in leash-only natural areas.^(32,52,73) In a Santa Barbara study, only 21% of dogs were leashed despite posted leash requirements.⁽³²⁾ And despite regulations and claims to the contrary, dog owners often don't pick up their dog's waste.^(6,32) An English study revealed that although 95% of visitors claimed to pick up their dog's waste only 19-46% actually did so, depending on location within the park.⁽⁶⁾

DISCUSSION

In summary, people and their dogs disturb wildlife, and people are not always aware of or willing to acknowledge the significance of their own impacts. Wildlife perceive dogs as predators. Dogs subject wildlife to physical and temporal displacement from habitat, and dog scent repels wildlife with lingering impacts. Dogs disturb wildlife which can induce long-term stress, impact animals' immune system and reduce reproduction. Dogs spread disease to and outright kill wildlife. People with dogs are much more detrimental to wildlife than people alone; off-leash dogs are worse; and off-trail impacts are the highest (Figure 1).

Urban wildlife is subjected to many human-induced stressors including habitat loss, degraded and fragmented habitat, impacts from a variety of user groups, roads, trails, infrastructure, noise and light pollution.⁽²⁶⁾ These stressors will increase with population; from July 2014 to 2015 the Portland-Vancouver metropolitan region added 40,621 new residents.⁽⁴³⁾ Current population in the region stands at 2.4 million, with another 400,000 residents expected over the next 20 years.

Figure 1. Conceptual illustration of the relative impacts on wildlife due to people without and with dogs.



Among medium to high density cities, Portland currently ranks second in the total area covered by parks at nearly 18%, and also second in the number of park acres per resident.⁽²⁵⁾ Of 34 park providers in the Portland region, all but four allow dogs in most or all of their natural areas, typically on-leash; more than two-thirds also offer dog parks or off-leash dog areas (Table 1 at end of document).

Wildlife conservation is not the only valid reason to preserve natural areas. Park providers must weigh the trade-offs between wildlife, habitat, water quality and recreational values. But when considering different types of public access in a natural area, it is important to understand that the research is clear: people with dogs substantially increase the amount of wildlife habitat affected and are more detrimental to wildlife than people without dogs.

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Table 1. Park providers' dog policies in the greater Portland, Oregon metropolitan area.

Parks provider	No dogs allowed	Some parks allow dogs	Dogs allowed	On-leash	Free to roam	Off-leash areas or dog park
Audubon Society of Portland	X					
City of Beaverton		X ²		X		X
City of Cornelius			X	X ³		
City of Durham			X	X		X
City of Fairview		X ⁴		X		
City of Forest Grove			X	X		X
City of Gladstone			X	X		X
City of Gresham			X	X		X
City of Happy Valley			X	X ⁵		X
City of Hillsboro			X	X		X
City of Lake Oswego			X	X		X
City of Milwaukie ⁶			X	X		X
City of Oregon City			X	X		X ⁷
City of Portland		X		X ⁸		X ⁹
City of Sherwood			X	X		X
City of Tigard			X	X		X
City of Troutdale		X ¹⁰		X		X ¹¹
City of Tualatin			X	X		X
City of West Linn			X	X		X ¹²
City of Wilsonville			X	X		X
City of Wood Village			X	X		
Clackamas County			X	X		X
Clean Water Services (Fernhill Wetlands)	X					

² All parks except fountain provided by Tualatin Hills Parks & Recreation District.

³ Considering off-leash dog area at Water Park.

⁴ Dogs on leash allowed at all parks except Salish Ponds (no dogs).

⁵ Dogs on leash except prohibited in playgrounds.

⁶ All city parks are operated by North Clackamas Parks and Recreation Department.

⁷ The City of Oregon City is currently testing off-leash areas in three parks.

⁸ Dogs on-leash except prohibited at Foster Floodplain Natural Area, Tanner Springs Park, Whitaker Ponds Nature Park, Riverview Natural Area, and the amphitheater at Mt Tabor Park.

⁹ 33 off-leash dog areas.⁴⁶

¹⁰ Most parks: dogs not allowed. Exception: Sunrise Park and large Beaver Creek Greenway, leash only. Considering two more on-leash dogs allowed parks.

¹¹ Plans for an off-leash area at Sunrise Park.

¹² One off-leash dog area: field near parking lot at Mary S. Young Park. Off-leash dogs were identified as an issue by parks board.

Parks provider	No dogs allowed	Some parks allow dogs	Dogs allowed	On-leash	Free to roam	Off-leash areas or dog park
Federal / State (Sandy River Natural Area)			X ¹³	X	X	X
Metro		X ¹⁴				
N. Clackamas Parks & Recreation			X			X
OR Department of Fish and Wildlife			X	X ¹⁵	X	X
OR Parks & Recreation Department			X	X		X
Port of Portland		X ¹⁶		X		
The Nature Conservancy	X					
The Wetlands Conservancy			X ¹⁷	X	X	
Tualatin Hills Park and Rec. District		X ¹⁸		X		X
U.S. Fish & Wildlife Service	X					
U.S. Forest Service ¹⁹			X	X	X	X

¹³ Leashes required only on/near Confluence Trail and in parking area. Leash-off everywhere else. Region's largest off-leash area, and heavily used.

¹⁴ Metro does not allow dogs except for service dogs, leashed dogs on regional trails, Broughton Beach, boat ramps and properties managed by others through intergovernmental agreements that are integrated into larger parks where leashed dogs are allowed (e.g., Forest Park).

¹⁵ All dogs must be on leash, except while hunting during seasons authorized on Sauvie Island Wildlife Area, or pursuant to a valid "Competitive Hunting Dog Trial Permit" or "Sauvie Island Wildlife Area Individual Dog Training Permit."

¹⁶ Includes Vanport Wetlands and mitigation sites. No dogs allowed except Government Island State Recreation Area (leased to Oregon Parks Department).

¹⁷ No formal policy.

¹⁸ Dogs allowed on-leash except Tualatin Hills Nature Park and Cooper Mountain Nature Park.

¹⁹ Refers specifically to the Sandy River Delta, owned and administered by the National Forest Service, Columbia River Gorge National Scenic Area.

Appendix 2. Scientific names for wildlife species mentioned in the text. Common names for birds are formally set by the American Ornithologists' Union, therefore they are capitalized.

Common name	Scientific name
Acorn Woodpecker	<i>Melanerpes formicivorus</i>
American bison	<i>Bison bison</i>
American Bushtit	<i>Psaltirparus minimus</i>
American Crow	<i>Corvus brachyrhynchos</i>
American Goldfinch	<i>Spinus tristis</i>
American Kestrel	<i>Falco sparverius</i>
American pika	<i>Ochotona princeps</i>
American Robin	<i>Turdus migratorius</i>
American Yellow Warbler	<i>Dendroica aestiva</i>
Anhinga	<i>Anhinga anhinga</i>
Ash-throated Flycatcher	<i>Myiarchus cinerascens</i>
Bald Eagle	<i>Haliaeetus leucocephalus</i>
Barn Swallow	<i>Hirunda rustica</i>
Belding's Savannah Sparrow	<i>Passerculus sandwichensis beldingi</i>
Bewick's Wren	<i>Thryomanes bewickii</i>
Bighorn Sheep	<i>Ovis canadensis</i>
Black bear	<i>Ursus americanus</i>
Black Phoebe	<i>Sayornis nigricans</i>
Black-crowned Night Heron	<i>Nycticorax nycticorax</i>
Black-necked Stilt	<i>Himantopus mexicanus</i>
Black-tail deer	<i>Odocoileus hemionus</i> (subspecies of mule deer)
Blue Tit	<i>Cyanistes caeruleus</i>
Bobcat	<i>Lynx rufus</i>
Brown-headed Cowbird	<i>Molothrus ater</i>
Burrowing Owl	<i>Athene cunicularia</i>
Cactus Wren	<i>Campylorhynchus brunneicapillus</i>
California (Western) Scrub Jay	<i>Aphelocoma californica</i>
California Quail	<i>Callipepla californica</i>
California Towhee	<i>Melospiza crissalis</i>
Canvasback	<i>Aythya valisineria</i>
Caspian Tern	<i>Hydroprogne caspia</i>
Chamois	<i>Rubicapra rubicapra</i>
Chipping Sparrow	<i>Spizella passerina</i>
Columbian black-tailed deer	<i>Odocoileus hemionus columbianus</i>
Common Loon	<i>Gavia immer</i>
Common Merganser	<i>Mergus merganser</i>
Common Raven	<i>Corvus corax</i>
Common Redpoll	<i>Acanthis flammea</i>
Common Snipe	<i>Gallinago gallinago</i>
Common Tern	<i>Sterna hirundo</i>
Common Yellowthroat	<i>Geothlypis trichas</i>
Cougar (a.k.a. mountain lion, puma, catamount)	<i>Puma concolor</i>
Coyote	<i>Canis latrans</i>
Dark-eyed Junco	<i>Junco hyemalis</i>
Deer mouse	<i>Peromyscus maniculatus</i>
Desert bighorn sheep	<i>Ovis Canadensis nelsoni</i>
Double-crested Cormorant	<i>Phalacrocorax auritus</i>
Eastern chipmunk	<i>Tamias striatus</i>

Common name	Scientific name
Eider ducks	<i>Somateria species</i>
Elk	<i>Cervus canadensis</i> or <i>C. elaphus</i> ¹⁹
European pine marten	<i>Martes martes</i>
Ferruginous Hawk	<i>Buteo regalis</i>
Golden Eagle	<i>Aquila chrysaetos</i>
Grasshopper Sparrow	<i>Ammodramus savannarum</i>
Gray fox	<i>Urocyon cinereoargenteus</i>
Gray Jay	<i>Perisoreus canadensis</i>
Gray wolf	<i>Canis lupus</i>
Great Blue Heron	<i>Ardea herodias</i>
Great Egret	<i>Ardea alba</i>
Greater White-fronted Goose	<i>Anser albifrons</i>
Greater Yellowlegs	<i>Tringa melanoleuca</i>
Green Heron	<i>Butorides virescens</i>
Grey (Black-bellied) Plover	<i>Pluvialis squatarola</i>
Guanaco	<i>Lama guanicoe</i>
Hoatzin	<i>Ophisthocomus hoazin</i>
House Finch	<i>Haemorhous mexicanus</i>
House Wren	<i>Troglodytes aedon</i>
Least Sandpiper	<i>Calidris minutilla</i>
Long-billed Curlew	<i>Numenius americanus</i>
Marbled Godwit	<i>Limosa fedoa</i>
Marmot	<i>Marmota species</i>
Merlin	<i>Falco columbarius</i>
Mexican Spotted Owl	<i>Strix occidentalis lucida</i>
Moose	<i>Alces alces</i>
Mottled Duck	<i>Anas fulvigula</i>
Mouflon	<i>Ovis orientalis</i>
Mountain Chickadee	<i>Poecile gambeli</i>
Mourning Dove	<i>Zenaida macroura</i>
Mule Deer	<i>Odocoileus hemionus</i>
Northern Cardinal	<i>Cardinalis cardinalis</i>
Northern Flicker	<i>Colaptes auratus</i>
Northern Mockingbird	<i>Mimus polyglottos</i>
Northern Parula	<i>Setophaga americana</i>
Northern Red-legged Frog	<i>Rana aurora</i>
Osprey	<i>Pandion haliaetus</i>
Oystercatcher	<i>Haematopus ostralegus</i>
Pacific Golden Plover	<i>Pluvialis fulva</i>
Painted stork	<i>Mycteria leucocephala</i>
Pectoral Sandpiper	<i>Calidris melanotos</i>
Phainopepla	<i>Phainopepla nitens</i>
Pied-billed Grebe	<i>Podilymbus podiceps</i>
Prairie dog	<i>Cynomys species</i>
Prairie Falcon	<i>Falco mexicanus</i>
Pronghorn	<i>Antilocapra americana</i>
Pygmy Nuthatch	<i>Sitta pygmaea</i>
Raccoon	<i>Procyon lotor</i>
Red fox	<i>Vulpes vulpes</i>

¹⁹ Until recently, European red deer and elk were considered to be one species, *Cervus elaphus*. More recently, elk in the U.S. are classified as *C. canadensis* (with 6 sub-species, including the former U.S. *C. elaphus*) and European red deer as *C. elaphus*.

Common name	Scientific name
Red squirrel	<i>Sciurus vulgaris</i>
Ring-billed Gull	<i>Larus delawarensis</i>
Rough-legged Buzzard (=Hawk)	<i>Buteo lagopus</i>
Rough-skinned Newt	<i>Taricha granulosa</i>
Ruby-crowned Kinglet	<i>Regulus calendula</i>
Ruddy Duck	<i>Oxyura jamaicensis</i>
Ruddy Turnstone	<i>Arenaria interpres</i>
Rufous Hummingbird	<i>Selasphorus rufus</i>
Sanderling	<i>Calidris alba</i>
Scaup species	<i>Aythya species</i>
Sharp-tailed Sandpiper	<i>Calidris acuminata</i>
Short-billed Dowitcher	<i>Limnodromus griseus</i>
Snowy Egret	<i>Egretta thula</i>
Snowy Plover	<i>Charadrius nivosus</i> (Western ssp. = <i>Charadrius nivosus nivosus</i>)
Solitary Vireo	<i>Vireo species</i> (Solitary Vireo was split into several species)
Song Sparrow	<i>Melospiza melodia</i>
Spotted Towhee	<i>Pipilo maculatus</i>
Striped skunk	<i>Mephitis mephitis</i>
Townsend's Solitaire	<i>Myadestes townsendi</i>
Vesper Sparrow	<i>Pooecetes gramineus</i>
Virginia Opossum	<i>Didelphis virginiana</i>
Western Bluebird	<i>Sialia mexicana</i>
Western Gull	<i>Larus occidentalis</i>
Western Meadowlark	<i>Sturnella neglecta</i>
Western pond turtle	<i>Actinemys marmorata</i>
Western Sandpiper	<i>Calidris mauri</i>
Western Wood-peewee	<i>Contopus sordidulus</i>
Whimbrel	<i>Numenius phaeopus</i>
White-crowned Sparrow	<i>Zonotrichia leucophrys</i>
Willet	<i>Tringa semipalmata</i>
Wood turtle	<i>Clemmys insculpta</i>
Woodlark	<i>Lullula arborea</i>
Wrentit	<i>Chamaea fasciata</i>
Yellow-headed Blackbird	<i>Xanthocephalus xanthocephalus</i>
Yellow-rumped Warbler	<i>Setophaga coronata</i> or <i>auduboni</i> ²⁰

²⁰ Yellow-rumped Warbler has been split into these two species since this study was conducted.

Appendix 3. Flight Initiation Distance (FID), Alert Distance and related variables for various wildlife species that occur in the U.S. Distances are rounded to the nearest meter. When only a range of distances was provided, we used the mid-point and so noted.

Group	Species	Study area	Disturbance factor	Variable measured	Notes	Source	Distance
Amphibian & reptile	Amphibians	Various	Human intrusion and trail impacts	Mean distance of adults from water		[567]	125
Amphibian & reptile	<i>Ambystoma</i> salamanders	Various	Human intrusion and trail impacts	Migration distances from aquatic breeding sites to uplands	Recommended distance to provide 95% of pond-breeding salamanders' population with adequate adjacent terrestrial habitat.	[568]	164
Amphibian & reptile	Salamanders	Various	Human intrusion and trail impacts	Terrestrial migration distance	Range: 117-218 m	[567]	168
Amphibian & reptile	Turtles	Various	Human intrusion and trail impacts	Zone of disturbance	Mean minimum and maximum core terrestrial habitat for species group. Range: 123-287 m. Used mid-point.	[567]	205
Amphibian & reptile	Reptiles	Various	Human intrusion and trail impacts	Core terrestrial habitat for species group	Range: 127-289 m. Used mid-point.	[567]	208
Amphibian & reptile	Amphibians	Various	Human intrusion and trail impacts	Migration distances from aquatic breeding sites to uplands	Mean minimum and maximum core terrestrial habitat for species group. Range: 159-290 m. Used mid-point.	[567]	225
Amphibian & reptile	Snakes	Various	Human intrusion and trail impacts	Core terrestrial habitat for species group	Range of core terrestrial habitat: 168-304 m. Used mid-point.	[567]	236
Amphibian & reptile	Frogs	Various	Human intrusion and trail impacts	Terrestrial migration distance	Range of recommended corridor widths. Range: 205-368 m	[567]	287
Bovid	Bighorn Sheep	Alberta, Canada wildlife sanctuary, various habitats	Person on foot	Distance displaced by person walking over ridge without dog	Winter range. Heart rate monitors and visual observations. Some evidence of sensitization.	[237]	46
Bovid	Bighorn Sheep	Alberta, Canada wildlife sanctuary, various habitats	Person on foot	Distance displaced by person walking over ridge with dog	Winter range. Heart rate monitors and visual observations. Some evidence of sensitization.	[237]	65
Bovid	Bighorn Sheep	UT national park; dry canyon habitat	Person on foot	Displacement distance	Response to person on foot stronger than vehicles or mountain bikers.	[124]	200
Cervid	Black-tailed deer	Marin County, CA, mixed habitats	Walker	FID	Depended in part on observer starting distance, speed, directness	[318]	74
Cervid	Black-tailed deer	Marin County, CA, mixed habitats	Jogger	FID	Depended in part on observer starting distance, speed, directness	[318]	91
Cervid	Elk	Meadows in Colorado parklands	Person on foot	FID	Fall/winter range of distances: 29-208 m	[173]	119

Group	Species	Study area	Disturbance factor	Variable measured	Notes	Source	Distance
Cervid	Mule deer	Antelope Island State Park in Utah, various habitats	Mountain bikes	FID	On or off trail	[113]	119
Cervid	Elk	Various	Person on foot	FID	Range: 85-201 m	[263]	143
Cervid	Mule deer	Antelope Island State Park in Utah, various habitats	Person on foot	FID	On or off trail	[113]	150
Cervid	Mule deer	Antelope Island State Park in Utah, various habitats	Person on foot and mountain bikes	Alert distance	On trail. These were similar for hikers and mountain bikers, thus we used the combined mean.	[113]	190
Cervid	Mule deer	Colorado state wildlife area, sagebrush dominant	Person on foot	FID	Winter range. Signs of sensitization but low number of trials.	[258]	191
Cervid	Elk	Various	Person on foot	FID	Winter	[37]	200
Cervid	Mule deer	Various	Person on foot	FID	Range: 149-250 m	[263]	200
Cervid	Mule deer	Various	Person on foot	FID	Winter	[37]	200
Cervid	Mule deer	Antelope Island State Park in Utah, various habitats	Person on foot and mountain bikers	Alert distances	Off trail. These were similar for hikers and mountain bikers; we used the combined mean.	[113]	228
Cervid	Mule deer	Various	Person on foot	FID	Medium disturbance areas	[37]	250
Cervid	Elk (red deer)	Scottish highlands	Person on foot	Distance displaced from trail	GPS collared. Lower trail use days avg. 49 walkers per day (weekday).	[484]	286
Cervid	Mule deer	Various	Person on foot	FID	Low disturbance areas	[37]	330
Cervid	Mule deer	Colorado state wildlife area, sagebrush dominant	Person on foot	Alert distance	Winter range. Signs of sensitization but low number of trials.	[258]	334
Cervid	Elk (red deer)	Scottish highlands	Person on foot	Distance displaced from trail	GPS collared. Higher trail use days avg. 204 walkers per day (weekend).	[484]	371
Cervid	Elk	Canadian Rocky Mountains	Hikers, mountain bikes, equestrians	Distance displaced from trail	GPS collared study; multi-season, multi-year study. Trail use was >2 people/hour.	[172]	400
Corvid	American Crow	N America, Australia and Europe; variety of habitats	Person on foot	FID (back-transformed from $\log^{FID}$)	Large-scale study	[310]	24
Corvid	Common Raven	N America, Australia and Europe; variety of habitats	Person on foot	FID (back-transformed from $\log^{FID}$)	Large-scale study	[310]	76

Group	Species	Study area	Disturbance factor	Variable measured	Notes	Source	Distance
Dove/pigeon	Mourning Dove	N America, Australia and Europe; variety of habitats	Person on foot	FID	Large-scale study	[309]	15
Dove/pigeon	Mourning Dove	N America, Australia and Europe; variety of habitats	Person on foot	FID (back-transformed from $\log^{FID}$)	Large-scale study	[310]	16
Grassland songbird	Vesper Sparrow	Colorado grasslands	Person on foot	FID	On trail.	[322]	26
Grassland songbird	Meadowlark species	Various	Person on foot	FID		[263]	30
Grassland songbird	Vesper Sparrow	Colorado grasslands	Person on foot	FID	Off trail.	[322]	34
Grassland songbird	Western Meadowlark	N America, Australia and Europe; variety of habitats	Person on foot	FID (back-transformed from $\log^{FID}$)	Large-scale study	[310]	34
Grassland songbird	Western Meadowlark	Colorado grasslands	Person on foot	FID	On trail.	[322]	50
Grassland songbird	Western Meadowlark	Colorado grasslands	Person on foot	FID	Off trail.	[322]	67
Hummingbird	Rufous Hummingbird	N America, Australia and Europe; variety of habitats	Person on foot	FID (back-transformed from $\log^{FID}$)	Large-scale study	[310]	6
Raptor	Burrowing Owl	Argentina grasslands	Person on foot	FID	Nesting season; male	[569]	38
Raptor	American Kestrel	Colorado grasslands	Person on foot	FID	Winter	[257]	44
Raptor	Burrowing Owl	Argentina grasslands	Person on foot	FID	Nesting season; female	[569]	49
Raptor	Ferruginous Hawk	Colorado grasslands	Person on foot	FID	Winter	[257]	63
Raptor	American Kestrel	Various	Person on foot	FID	Winter	[37]	75
Raptor	Merlin	Colorado grasslands	Person on foot	FID	Winter	[257]	76
Raptor	Bald Eagle	Columbia River Estuary, OR & WA	Land-based recreationists	Zone of disturbance	Recommended buffer around wintering eagles when there is a vegetation screen between bird & person. Used midpoint of range.	[433]	88
Raptor	Prairie Falcon	Colorado grasslands	Person on foot	FID	Winter	[257]	92
Raptor	Merlin	Various	Person on foot	FID	Range: 17-180 m	[263]	99
Raptor	Bald Eagle	Various	Person on foot, bicycle or horse	FID	Distance between disturbance and nest site; USFWS national guidelines.	[570]	101
Raptor	Prairie Falcon	Various	Person on foot	FID	Range 24-185 m	[263]	118

Group	Species	Study area	Disturbance factor	Variable measured	Notes	Source	Distance
Raptor	Ferruginous Hawk	Various	Person on foot	FID	Winter	[37]	140
Raptor	Prairie Falcon	Various	Person on foot	FID	Winter	[37]	160
Raptor	Rough-legged Buzzard (=Hawk)	Colorado grasslands	Person on foot	FID	Winter	[257]	177
Raptor	Rough-legged Buzzard (=Hawk)	Various	Person on foot	FID	Winter	[37]	210
Raptor	Golden Eagle	Colorado grasslands	Person on foot	FID	Winter	[257]	225
Raptor	Golden Eagle	Various	Person on foot	FID	Range: 105-390 m	[263]	248
Raptor	Bald Eagle	Various	Person on foot	FID	Land activities near roost on shoreline	[37]	250
Raptor	Bald Eagle	Columbia River Estuary, OR & WA	Land-based recreationists	Zone of disturbance	Recommended buffer around wintering eagles when there is no vegetation screen between bird & person. Used midpoint of range.	[433]	275
Raptor	Golden Eagle	Various	Person on foot	FID	Winter	[37]	300
Raptor	Bald Eagle	Pacific Northwest aquatic-shoreline habitats	Recreationists	Zone of disturbance	Recommended buffer zone around winter foraging habitat	[473]	450
Raptor	Bald Eagle	Various	Person on foot	FID	Range: 53-884 m	[263]	467
Raptor	Rough-legged Buzzard (=Hawk)	Various	Person on foot	FID	Range 54-884 m	[263]	469
Raptor	Bald Eagle	Minnesota national forest on lake shoreline	Person on foot	FID	Breeding birds. Range: 57-991 m	[571]	476
Raptor	Ferruginous Hawk	New Mexico grasslands	Person on foot	FID	Distance needed to prevent 95% of nest-attending hawks from flushing	[333]	650
Shorebird	Least Sandpiper	Southern CA wildlife refuge, fenced	Person on foot	FID	High human use; ~42 visitors/hour; July-December surveys (from graphically presented data)	[403]	7
Shorebird	Least Sandpiper	N America, Australia and Europe; variety of habitats	Person on foot	FID	Large-scale study	[309]	9
Shorebird	Western Sandpiper	Southern CA wildlife refuge, fenced	Person on foot	FID	High human use; ~42 visitors/hour; July-December surveys (from graphically presented data)	[403]	10
Shorebird	Short-billed Dowitcher	N America, Australia and Europe; variety of habitats	Person on foot	FID	Large-scale study	[309]	13

Group	Species	Study area	Disturbance factor	Variable measured	Notes	Source	Distance
Shorebird	Ruddy Turnstone	N America, Australia and Europe; variety of habitats	Person on foot	FID	Large-scale study	[309]	14
Shorebird	Black-necked Stilt	Southern CA wildlife refuge, fenced	Person on foot	FID	High human use; ~42 visitors/hour; July-December surveys (from graphically presented data)	[403]	15
Shorebird	Sharp-tailed Sandpiper	N America, Australia and Europe; variety of habitats	Person on foot	FID	Large-scale study	[309]	15
Shorebird	Western Sandpiper	N America, Australia and Europe; variety of habitats	Person on foot	FID	Large-scale study	[309]	16
Shorebird	Willet	Southern CA wildlife refuge, fenced	Person on foot	FID	High human use; ~42 visitors/hour; July-December surveys (from graphically presented data)	[403]	17
Shorebird	Marbled Godwit	N America, Australia and Europe; variety of habitats	Person on foot	FID	Large-scale study	[309]	18
Shorebird	Willet	N America, Australia and Europe; variety of habitats	Person on foot	FID (back-transformed from $\log^{FID}$)	Large-scale study	[310]	20
Shorebird	Willet	N America, Australia and Europe; variety of habitats	Person on foot	FID	Large-scale study	[309]	21
Shorebird	Black-necked Stilt	N America, Australia and Europe; variety of habitats	Person on foot	FID	Large-scale study	[309]	22
Shorebird	Black-necked Stilt	N America, Australia and Europe; variety of habitats	Person on foot	FID (back-transformed from $\log^{FID}$)	Large-scale study	[310]	22
Shorebird	Pacific Golden Plover	N America, Australia and Europe; variety of habitats	Person on foot	FID	Large-scale study	[309]	22
Shorebird	Pacific Golden Plover	N America, Australia and Europe; variety of habitats	Person on foot	FID (back-transformed from $\log^{FID}$)	Large-scale study	[310]	22

Group	Species	Study area	Disturbance factor	Variable measured	Notes	Source	Distance
Shorebird	Greater Yellowlegs	Southern CA wildlife refuge, fenced	Person on foot	FID	High human use; ~42 visitors/hour; July-December surveys (from graphically presented data)	[403]	23
Shorebird	Grey (=Black-bellied) Plover	N America, Australia and Europe; variety of habitats	Person on foot	FID (back-transformed from $\log^{FID}$)	Large-scale study	[310]	23
Shorebird	Pectoral Sandpiper	Australia shorelines	Person on foot	FID	October through March surveys	[254]	23
Shorebird	Western Sandpiper	Southern CA wildlife refuge, unfenced	Person on foot	FID	Low human use <5 visitors/hour; July-December surveys (from graphically presented data)	[403]	23
Shorebird	Least Sandpiper	Southern CA wildlife refuge, unfenced	Person on foot	FID	Low human use <5 visitors/hour; July-December surveys (from graphically presented data)	[403]	24
Shorebird	Common Snipe	N America, Australia and Europe; variety of habitats	Person on foot	FID (back-transformed from $\log^{FID}$)	Large-scale study	[310]	26
Shorebird	Long-billed Curlew	N America, Australia and Europe; variety of habitats	Person on foot	FID	Large-scale study	[309]	26
Shorebird	Long-billed Curlew	N America, Australia and Europe; variety of habitats	Person on foot	FID (back-transformed from $\log^{FID}$)	Large-scale study	[310]	26
Shorebird	Ruddy Turnstone	Rocky beaches in Scotland	Person on foot	FID	Augmented nutrition experiment. Less fit (unfed) birds did not flush as readily	[251]	26
Shorebird	Black-necked Stilt	Southern CA wildlife refuge, unfenced	Person on foot	FID	Low human use <5 visitors/hour; July-December surveys (from graphically presented data)	[403]	28
Shorebird	Greater Yellowlegs	Southern CA wildlife refuge, unfenced	Person on foot	FID	Low human use <5 visitors/hour; July-December surveys (from graphically presented data)	[403]	28
Shorebird	Willet	Southern CA wildlife refuge, unfenced	Person on foot	FID	Low human use <5 visitors/hour; July-December surveys (from graphically presented data)	[403]	28

Group	Species	Study area	Disturbance factor	Variable measured	Notes	Source	Distance
Shorebird	Grey (=Black-bellied) Plover	Southern CA wildlife refuge, fenced	Person on foot	FID	High human use; ~42 visitors/hour; July-December surveys (from graphically presented data)	[403]	29
Shorebird	Ruddy Turnstone	Australia shorelines	Person on foot	FID	October through March surveys	[254]	30
Shorebird	Sanderling	N America, Australia and Europe; variety of habitats	Person on foot	FID (back-transformed from $\log^{FID}$)	Large-scale study	[310]	32
Shorebird	Sharp-tailed Sandpiper	Australia, southern coast	Person on foot	FID	Relatively undisturbed beach	[572]	33
Shorebird	Grey (=Black-bellied) Plover	N America, Australia and Europe; variety of habitats	Person on foot	FID	Large-scale study	[309]	36
Shorebird	Whimbrel	N America, Australia and Europe; variety of habitats	Person on foot	FID	Large-scale study	[309]	38
Shorebird	Sharp-tailed Sandpiper	Australia, southern coast	Person on foot with dog		Relatively undisturbed beach	[572]	39
Shorebird	Grey (=Black-bellied) Plover	Southern CA wildlife refuge, high use	Person on foot	FID	Low human use <5 visitors/hour; July-December surveys (from graphically presented data)	[403]	43
Shorebird	Sanderling	Florida coastline	Person on foot	Distance within which people disrupted feeding		[275]	100
Shorebird	Golden Plover	Various	Person on foot	FID	People on trail	[37]	200
Shorebird	Golden Plover	Various	Person on foot	FID		[263]	201
Small mammal	American pika	2 national parks in British Columbia, montane habitats	People on foot	Alert distance	No difference between direct and tangential approaches	[573]	31
Songbird	Mountain Chickadee	Wyoming montane forests	Person on foot	FID	Spring surveys. FID range: 1-13 m	[262]	4
Songbird	Ruby-crowned Kinglet	N America, Australia and Europe; variety of habitats	Person on foot	FID	Large-scale study	[309]	5
Songbird	Ruby-crowned Kinglet	N America, Australia and Europe; variety of habitats	Person on foot	FID (back-transformed from $\log^{FID}$)	Large-scale study	[310]	5
Songbird	Song Sparrow	NC and PA habitats	Person on foot	FID	Urban; spring	[574]	5

Group	Species	Study area	Disturbance factor	Variable measured	Notes	Source	Distance
Songbird	Song Sparrow	SW Virginia habitats	Person on foot	FID	Urban; spring	[326]	5
Songbird	Wrentit	N America, Australia and Europe; variety of habitats	Person on foot	FID	Large-scale study	[309]	5
Songbird	Wrentit	N America, Australia and Europe; variety of habitats	Person on foot	FID (back-transformed from $\log^{FID}$)	Large-scale study	[310]	5
Songbird	House Wren	N America, Australia and Europe; variety of habitats	Person on foot	FID (back-transformed from $\log^{FID}$)	Large-scale study	[310]	6
Songbird	American Bushtit	N America, Australia and Europe; variety of habitats	Person on foot	FID	Large-scale study	[309]	7
Songbird	American Bushtit	N America, Australia and Europe; variety of habitats	Person on foot	FID (back-transformed from $\log^{FID}$)	Large-scale study	[310]	7
Songbird	Common Redpoll	N America, Australia and Europe; variety of habitats	Person on foot	FID (back-transformed from $\log^{FID}$)	Large-scale study	[310]	7
Songbird	Bewick's Wren	N America, Australia and Europe; variety of habitats	Person on foot	FID (back-transformed from $\log^{FID}$)	Large-scale study	[310]	8
Songbird	Brown-headed Cowbird	N America, Australia and Europe; variety of habitats	Person on foot	FID (back-transformed from $\log^{FID}$)	Large-scale study	[310]	8
Songbird	Dark-eyed Junco	Wyoming montane forests	Person on foot	FID	Spring surveys. FID range: 1-20 m	[262]	8
Songbird	Song Sparrow	N America, Australia and Europe; variety of habitats	Person on foot	FID	Large-scale study	[309]	8
Songbird	Song Sparrow	N America, Australia and Europe; variety of habitats	Person on foot	FID (back-transformed from $\log^{FID}$)	Large-scale study	[310]	8
Songbird	White-crowned Sparrow	N America, Australia and Europe; variety of habitats	Person on foot	FID (back-transformed from $\log^{FID}$)	Large-scale study	[310]	8

Group	Species	Study area	Disturbance factor	Variable measured	Notes	Source	Distance
Songbird	Yellow Warbler	N America, Australia and Europe; variety of habitats	Person on foot	FID (back-transformed from $\log^{FID}$)	Large-scale study	[310]	8
Songbird	American Robin	Various	Person on foot	FID		[263]	9
Songbird	Common Yellowthroat	N America, Australia and Europe; variety of habitats	Person on foot	FID (back-transformed from $\log^{FID}$)	Large-scale study	[310]	9
Songbird	Dark-eyed Junco	N America, Australia and Europe; variety of habitats	Person on foot	FID	Large-scale study	[309]	9
Songbird	Dark-eyed Junco	N America, Australia and Europe; variety of habitats	Person on foot	FID (back-transformed from $\log^{FID}$)	Large-scale study	[310]	9
Songbird	Gray Jay	Wyoming montane forests	Person on foot	FID	Spring surveys. FID range: 1-30 m	[262]	9
Songbird	Northern Cardinal	SW Virginia habitats	Person on foot	FID	Urban; spring	[326]	9
Songbird	Song Sparrow	SW Virginia habitats	Person on foot	FID	Rural; spring	[326]	9
Songbird	White-crowned Sparrow	N America, Australia and Europe; variety of habitats	Person on foot	FID	Large-scale study	[309]	9
Songbird	Yellow-rumped warbler	N America, Australia and Europe; variety of habitats	Person on foot	FID	Large-scale study	[309]	9
Songbird	Yellow-rumped Warbler	N America, Australia and Europe; variety of habitats	Person on foot	FID (back-transformed from $\log^{FID}$)	Large-scale study	[310]	9
Songbird	Yellow-rumped Warbler	Wyoming montane forests	Person on foot	FID	Spring surveys. FID range: 2-27 m	[262]	9
Songbird	American Goldfinch	N America, Australia and Europe; variety of habitats	Person on foot	FID (back-transformed from $\log^{FID}$)	Large-scale study	[310]	10
Songbird	House Finch	N America, Australia and Europe; variety of habitats	Person on foot	FID (back-transformed from $\log^{FID}$)	Large-scale study	[310]	10
Songbird	Spotted Towhee	N America, Australia and Europe; variety of habitats	Person on foot	FID	Large-scale study	[309]	10

Group	Species	Study area	Disturbance factor	Variable measured	Notes	Source	Distance
Songbird	American Robin	N America, Australia and Europe; variety of habitats	Person on foot	FID	Large-scale study	[309]	11
Songbird	American Robin	N America, Australia and Europe; variety of habitats	Person on foot	FID (back-transformed from $\log^{FID}$)	Large-scale study	[310]	11
Songbird	Barn Swallow	N America, Australia and Europe; variety of habitats	Person on foot	FID (back-transformed from $\log^{FID}$)	Large-scale study	[310]	11
Songbird	Cactus Wren	N America, Australia and Europe; variety of habitats	Person on foot	FID (back-transformed from $\log^{FID}$)	Large-scale study	[310]	11
Songbird	American Robin	Wyoming montane forests	Person on foot	FID	Spring surveys. FID range: 2-37 m	[262]	12
Songbird	Barn Swallow	Denmark, agricultural lands	Person on foot	FID	Nesting study	[575]	12
Songbird	California Towhee	N America, Australia and Europe; variety of habitats	Person on foot	FID	Large-scale study	[309]	12
Songbird	Northern Mockingbird	N America, Australia and Europe; variety of habitats	Person on foot	FID (back-transformed from $\log^{FID}$)	Large-scale study	[310]	12
Songbird	Northern Cardinal	SW Virginia habitats	Person on foot	FID	Rural; spring	[326]	13
Songbird	Phainopepla	N America, Australia and Europe; variety of habitats	Person on foot	FID (back-transformed from $\log^{FID}$)	Large-scale study	[310]	14
Songbird	California (Western) Scrub Jay	N America, Australia and Europe; variety of habitats	Person on foot	FID	Large-scale study	[309]	15
Songbird	Song Sparrow	NC and PA habitats	Person on foot	FID	Rural; spring	[574]	15
Songbird	Ash-throated Flycatcher	N America, Australia and Europe; variety of habitats	Person on foot	FID (back-transformed from $\log^{FID}$)	Large-scale study	[310]	17
Songbird	Black Phoebe	N America, Australia and Europe; variety of habitats	Person on foot	FID (back-transformed from $\log^{FID}$)	Large-scale study	[310]	18

Group	Species	Study area	Disturbance factor	Variable measured	Notes	Source	Distance
Songbird	Belding's Savannah Sparrow	California salt marshes	Person on foot	Vigilance and FID	FID was longer in higher recreational areas	[332]	63
Tern/gull	Ring-billed gull	Southern CA wildlife refuge, fenced	Person on foot	FID	High human use; ~42 visitors/hour; July-December surveys (from graphically presented data)	[403]	7
Tern/gull	Western Gull	N America, Australia and Europe; variety of habitats	Person on foot	FID	Large-scale study	[309]	17
Tern/gull	Common Tern	N America, Australia and Europe; variety of habitats	Person on foot	FID (back-transformed from $\log^{FID}$)	Large-scale study	[310]	21
Tern/gull	Ring-billed Gull	N America, Australia and Europe; variety of habitats	Person on foot	FID	Large-scale study	[309]	22
Tern/gull	Ring-billed gull	Southern CA wildlife refuge, unfenced	Person on foot	FID	Low human use <5 visitors/hour; July-December surveys (from graphically presented data)	[403]	29
Tern/gull	Caspian Tern	N America, Australia and Europe; variety of habitats	Person on foot	FID	Large-scale study	[309]	35
Tern/gull	Caspian Tern	N America, Australia and Europe; variety of habitats	Person on foot	FID (back-transformed from $\log^{FID}$)	Large-scale study	[310]	38
Waterbird	Snowy Egret	Southern CA wildlife refuge, fenced	Person on foot	FID	High human use; ~42 visitors/hour; July-December surveys (from graphically presented data)	[403]	9
Waterbird	Great Blue Heron	Southern CA wildlife refuge, fenced	Person on foot	FID	High human use; ~42 visitors/hour; July-December surveys (from graphically presented data)	[403]	14
Waterbird	Great Egret	Southern CA wildlife refuge, fenced	Person on foot	FID	High human use; ~42 visitors/hour; July-December surveys (from graphically presented data)	[403]	17
Waterbird	Snowy Egret	N America, Australia and Europe; variety of habitats	Person on foot	FID	Large-scale study	[309]	19
Waterbird	Double-crested Cormorant	Several swampy private sites, central Florida	Person on foot	FID	Distance at which colonial waterbirds flushed from nests	[576]	30

Group	Species	Study area	Disturbance factor	Variable measured	Notes	Source	Distance
Waterbird	Black-crowned Night Heron nest colony	Several swampy private sites, central Florida	Person on foot	FID	Distance at which colonial waterbirds flushed from nests	[576]	31
Waterbird	Double-crested Cormorant	Florida riparian/aquatic habitats	Person on foot	FID	Foraging or loafing birds	[264]	31
Waterbird	Great Blue heron	Florida riparian/aquatic habitats	Person on foot	FID	Foraging or loafing birds	[264]	31
Waterbird	Great Egret	Several swampy private sites, central Florida	Person on foot	FID	Distance at which colonial waterbirds flushed from nests	[576]	31
Waterbird	Great Blue Heron	Several swampy private sites, central Florida	Person on foot	FID	Distance at which colonial waterbirds flushed from nests	[576]	32
Waterbird	Snowy Egret	Southern CA wildlife refuge, unfenced	Person on foot	FID	Low human use <5 visitors/hour; July-December surveys (from graphically presented data)	[403]	33
Waterbird	Great Blue Heron	N America, Australia and Europe; variety of habitats	Person on foot	FID	Large-scale study	[309]	37
Waterbird	Great Blue Heron	N America, Australia and Europe; variety of habitats	Person on foot	FID (back-transformed from $\log^{FID}$)	Large-scale study	[310]	37
Waterbird	Great Egret	N America, Australia and Europe; variety of habitats	Person on foot	FID (back-transformed from $\log^{FID}$)	Large-scale study	[310]	39
Waterbird	Great Egret	N America, Australia and Europe; variety of habitats	Person on foot	FID	Large-scale study	[309]	40
Waterbird	Great Blue Heron	Southern CA wildlife refuge, unfenced	Person on foot	FID	Low human use <5 visitors/hour; July-December surveys (from graphically presented data)	[403]	46
Waterbird	Great Egret	Southern CA wildlife refuge, unfenced	Person on foot	FID	Low human use <5 visitors/hour; July-December surveys (from graphically presented data)	[403]	48
Waterbird	Great Egret	Several swampy private sites, central Florida	Person on foot	Zone of disturbance	Recommended set-back distances between breeding colonial waterbirds and walkers	[576]	91

Group	Species	Study area	Disturbance factor	Variable measured	Notes	Source	Distance
Waterbird	Double-crested Cormorant	Several swampy private sites, central Florida	Person on foot	Zone of disturbance	Recommended set-back distances between breeding colonial waterbirds and walkers	[576]	96
Waterbird	Black-crowned Night Heron nest colony	Several swampy private sites, central Florida	Person on foot	Zone of disturbance	Recommended set-back distances between breeding colonial waterbirds and walkers	[576]	97
Waterbird	Great Blue heron	Florida riparian/aquatic habitats	Person on foot	Zone of disturbance	Recommended distances between breeding foraging or loafing waterbirds and walkers	[264]	100
Waterbird	Great Blue Heron	Several swampy private sites, central Florida	Person on foot	Zone of disturbance	Recommended distances between breeding colonial waterbirds and walkers	[576]	100
Waterbird	Waterbirds	Florida riparian/aquatic habitats	Various tourist activities	FID	To minimize disturbance to most species of waterbirds studied in FL	[264]	100
Waterbird	Great Egret	Various	Person on foot	FID		[263]	101
Waterbird	Double-crested Cormorant	Florida riparian/aquatic habitats	Person on foot	Zone of disturbance	Recommended set-back distances between breeding foraging or loafing waterbirds and walkers	[264]	102
Waterbird	Heron rookeries	Ding Darling NWR, Florida; riparian/aquatic habitats	Person on foot	Distance at which disturbance reduced reproductive success	Buffer zone at which no short-term reproductive losses (entering rookery = 15-28% nest mortality). Recommended range: 50-250 m	[458]	150
Waterbird	Great Blue Heron	Various	Person on foot	FID	Land-based activities	[37]	200
Waterbird	Great Blue Heron	Various	Person on foot	FID		[263]	201
Waterfowl	Ruddy Duck	California salt ponds in winter	Person on foot	Change in # birds based on distance bands	Used high end of the band after which # birds declined	[577]	40
Waterfowl	Greater White-fronted Goose	Sacramento Valley, CA agricultural lands in winter	Person on foot	FID	Used radio-transmitters. Winter, range 25-100 m	[467]	47
Waterfowl	Eider ducks	Various	Person on foot	FID	Without dog	[37]	52
Waterfowl	Canvasback	California salt ponds in winter	Person on foot	FID	Change in # birds based on distance bands; used high end of the band after which #birds declined	[577]	80
Waterfowl	Scaup species	California salt ponds in winter	Person on foot	Change in # birds based on distance bands	Used high end of the band after which # birds declined	[577]	80

Group	Species	Study area	Disturbance factor	Variable measured	Notes	Source	Distance
Waterfowl	Ducks	Kansas wetlands, migratory waterfowl in winter	Person on foot	FID	Point of interest: Nearly half of flushing groups of birds cause a secondary flush	[466]	97
Waterfowl	Eider ducks	Various	Person on foot	FID	With dog	[37]	103
Woodpecker	Acorn Woodpecker	N America, Australia and Europe; variety of habitats	Person on foot	FID (back-transformed from $\log^{FID}$)	Large-scale study	[310]	17
Woodpecker	Northern Flicker	N America, Australia and Europe; variety of habitats	Person on foot	FID (back-transformed from $\log^{FID}$)	Large-scale study	[310]	19