Chapter 7. Monitoring Human Disturbances for Management of Wildlife Species and Their Habitats

Michael J. Wisdom
Mary M. Rowland
Christina D. Vojta
Michael I. Goldstein

7.1 Objectives

Human disturbances dominate national forests and grasslands and affect habitats and species in multifaceted ways. In the past, planning and management efforts focused mainly on the management activities of silviculture, prescribed fire, and livestock grazing. Those disturbances remain as common agents to monitor and evaluate. A variety of additional human disturbances, however, are now prevalent and deserve attention, including roads and traffic, recreation, energy extraction, urban expansion, and nonnative or invasive species. Monitoring and evaluating the most prevalent human disturbances that occur in a given local management unit or ecoregion is needed to meet planning requirements and to assess the diverse effects of such disturbances on wildlife habitats and species.

The goal of this chapter is to provide guidance and methods to select and monitor the primary **human disturbance agents** operating in a given area as part of habitat monitoring for terrestrial habitats of emphasis species. We assigned the following objectives for this chapter.

- Describe the most common human disturbance agents that may affect habitats or species on national forests or other large spatial extents used for Forest Service planning and management.
- Summarize some of the general effects of example disturbance agents on habitats and species with supporting literature.
- Provide criteria and rationale for selecting human disturbance agents to monitor and evaluate.
- Describe methods for monitoring the selected human disturbance agents and for estimating or modeling the assumed effects on habitats and habitat use.
- Provide examples of the monitoring process for human disturbances common to most national forests and grasslands, but that have received less emphasis in traditional monitoring programs.

7.2 Key Concepts

7.2.1 Human Disturbance Agents and Regimes

We define a human disturbance, or human disturbance agent, as any human-associated factor that affects emphasis species or their habitats. This definition builds on the classical definition from disturbance ecology provided by Pickett and White (1985:11), which states, "A disturbance is any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment." Our definition of a human disturbance, which is a subset of this broader definition, focuses on resulting changes in conditions for habitats and populations of emphasis species.

Importantly, our definition includes all human-caused changes in conditions, positive and negative. Moreover, whether human-caused changes are deemed positive or negative entirely depends on management objectives and societal values. An effect from a particular disturbance event that meets management objectives or societal values is predictably viewed as positive, and those that do not are typically considered negative. This point is particularly important, considering that any human disturbance typically increases habitat abundance or habitat use for some species, while simultaneously reducing abundance or use for other species. Which effects are important to management depend on objectives for the emphasis species (the species of interest) and their habitats, and this point is emphasized throughout this chapter. Without explicit management objectives, it will be difficult to select which types of human disturbances to monitor and what types of effects from the disturbances are considered acceptable or are of interest.

That as context, we refer to all human activities and land uses as disturbance agents because they affect species and habitats through the same pathways as other disturbances that operate in the absence of human influence, in the same manner defined by Pickett and White (1985) for all disturbances (table 7.1). Disturbance agents take many forms, with effects that manifest in myriad ways (table 7.1). Roads, for example, affect wildlife and habitats directly through habitat loss and fragmentation (figure 7.1), the spread of invasive plants, and increased mortality (section 7.5.1). Road effects typify the many pathways through which most human disturbances affect vertebrate species and change the probability of population persistence (figure 7.1). Human disturbances have thus received increasing attention as part of Forest Service planning and management in response to the increasing presence and influence of such disturbances, as required by the National Environmental Policy Act.

A concept closely related to disturbance agents is that of human disturbance regime, which is the extent, frequency, duration, and magnitude of how a human disturbance agent functions; that is, how a disturbance agent operates in time and space. Human disturbance regimes have these same characteristics as natural disturbance regimes (Van

Table 7.1.—*Human disturbance agents and potential negative effects on habitats and populations of emphasis species, with example references. See text for additional discussion about positive effects of human disturbance.*

Human disturbance agents	Associated effects	Examples	Example references[a]
Agricultural conversions	Habitat—habitat loss	Habitat loss from conversion of native plant communities to agricultural uses.	Dobler 1994, Fischer et al. 1997, Warner 1994
	Habitat—habitat fragmentation	Conversion of grassland and shrubland habitats to agriculture may lead to fragmentation of remaining native habitats, resulting in interference with animal movements, dispersal, or population fragmentation.	Connelly et al. 2004; Knick and Rotenberry 1995, 1997, 2002; Knick et al. 2003
	Population—direct mortality	Nest and egg destruction, or directly mortality of animals, from mechanical or other methods used to remove habitat or to cultivate lands adjacent to sagebrush.	Best 1986, Bryan and Best 1994, Patterson 1952
Climate change	Habitat—habitat loss and degradation	Gradually increasing temperatures have contributed to drought and more severe and frequent wildfires, escalating the spread of nonnative invasive plants; forest insect pests are able to survive in more northern climates and eliminate forest habitats.	Bachelet et al. 2001, Neilson et al. 2005, Root et al. 2002, Smith et al. 2000
	Population—major geographic shifts in animal communities	Major geographic shifts in habitats and associated animal distributions may lead to population fragmentation and isolation and increased species extinctions.	Parmesan 2006, Root et al. 2002, Root and Schneider 2006
Communication towers	Population—mortality	Collisions of birds and bats with cell and radio towers can lead to mortality or injury.	Mabey and Paul 2007, Manville 2005
Disease transmission	Population—direct mortality	Disturbance from oil and gas development may lead to concentrations of native ungulates on winter ranges, exacerbating disease transmission during the stressful winter season. Man-made water sources may increase transmission of mosquito-borne diseases, such as West Nile virus, in birds.	Naugle et al. 2004, 2005; Rowland 2004; USDI USFWS 2005; Walker et al. 2004, 2007
Nonnative and invasive plants	Habitat—habitat loss, degradation	Establishment of nonnative and/or invasive plants can displace native species and alter ecological processes.	Bergquist et al. 2007, D'Antonio and Vitousek 1992, Knick 1999, Menakis et al. 2003, Moser et al. 2009, West 1999
Fences	Habitat—habitat fragmentation	Construction of fences (e.g., along roadways or for allotment pastures) can fragment habitats and interfere with animal movement.	Boone and Hobbs 2004, O'Gara and Yoakum 2004
	Population—direct mortality	Animals can collide with fences or become entangled, leading to injury or death.	Boone and Hobbs 2004, Call and Maser 1985, Todd 2001
Herbicides	Habitat—habitat loss and fragmentation	Herbicides used extensively before the 1980s for conversion and removal of sagebrush and other shrubland communities, especially if native understory vegetation was in relatively good condition.	Best 1972; Braun 1998; Braun and Beck 1977; Connelly et al. 2000, 2004; Miller and Eddleman 2000
Livestock grazing	Habitat—habitat degradation	High grazing pressure by livestock can reduce native perennial grasses and forbs in the understory (changes in composition and structure) as well as increase presence of invasive species in some situations, with resulting declines in forage and other habitat conditions for emphasis species.	Bock et al. 1993, Fleischner 1994, Guthrey 1996, Thines et al. 2004
	Population—direct mortality	Livestock may trample eggs in nests or burrows of some species.	Beck and Mitchell 2000, Fleischner 1994, Holmes et al. 2003
Military training	Habitat—habitat fragmentation	Training exercises degrade and fragment habitat and facilitate invasion by nonnative plants.	Holmes and Humple 2000, Knick and Rotenberry 1997

Table 7.1.—*Human disturbance agents and potential negative effects on habitats and populations of emphasis species, with example references. See text for additional discussion about positive effects of human disturbance (continued).*

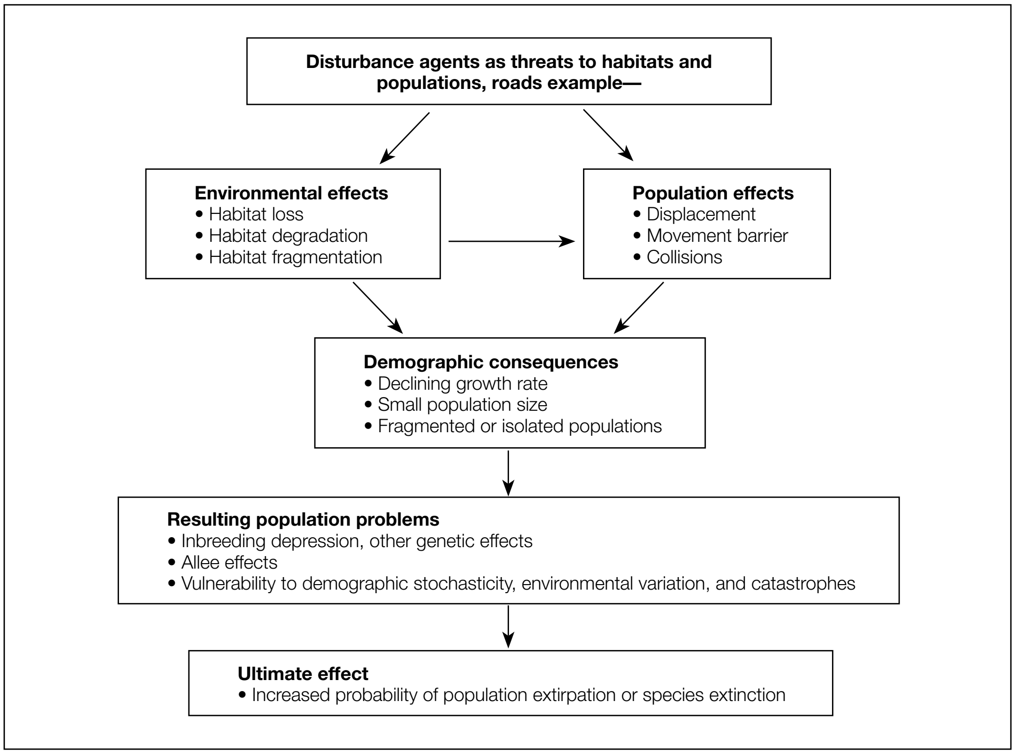
Human disturbance agents	Associated effects	Examples	Example references[a]
Mining	Habitat—habitat loss and fragmentation	Fragmentation and outright loss of habitat to surface mines and associated mine tailings and roads, especially coal mines.	Braun 1998, Neely et al. 2001, Ricketts et al. 1999,
	Habitat—habitat degradation	Native species diversity may decline when invasive species may become established in sites disturbed by mining activities.	Gonella and Neel 1996, Ripley et al. 1996
	Population—disturbance	Disturbance and potential abandonment of habitat because of traffic, noise, and related human activity at mine site; example affected species—bats and greater sage-grouse.	Bednarz 1984, Kuck et al. 1985
Oil and natural gas field development	Habitat—habitat loss, fragmentation	Pipelines, roads, well pads, and associated collection facilities fragment habitats; outright loss of habitat also occurs from roads and well pads and other facilities constructed for field development.	Thomson et al. 2005, Weller et al. 2002
	Habitat—habitat degradation	Disturbed sites (e.g., roadsides and well pads) may become infested with invasive species; disposal of water produced during coal bed methane extraction can lead to salinization of surrounding soils.	Doherty et al. 2008, Gelbard and Belnap 2003, McBeth et al. 2003, Parendes and Jones 2000, Sawyer et al. 2005, Thomson et al. 2005, Walker et al. 2007, Zink et al. 1995
Pesticides	Habitat—habitat degradation	Decrease in forage base by killing insects used as prey.	Holmes et al. 2003, Johnson 1987
	Population—mortality	Direct mortality of birds and other vertebrates, and nontarget invertebrates, exposed to pesticides, and indirect mortality through consumption of contaminated insects.	Blus 1996, Blus et al. 1989, Patterson 1952
Power lines	Habitat—habitat degradation	Disturbance of vegetation and soils in corridors can lead to increased invasion of nonnative species in these areas.	Braun 1998, Zink et al. 1995
	Population—increased rates of predation	Poles and towers for transmission lines may serve as additional perches or nest sites for corvids and raptors, increasing the potential for predation on emphasis species.	Knight and Kawashima 1993, Steenhof et al. 1993
	Population—direct mortality	Birds may collide with power lines, resulting in injury or death; electrocution of perching raptors and other birds also occurs.	Harmata et al. 2001, O'Neil 1988
Railroads	Habitat—habitat loss, degradation	Same effects as highways.	Jaeger et al. 2007, Van der Grift 1999
	Population—displacement, mortality	Same effects as highways.	Andersen et al. 1991, Seiler and Helldin 2006
Recreation (also table 7.2)	Habitat—habitat degradation	Off-road vehicle use can degrade habitats (e.g., by increasing presence of nonnative annual grasses).	Berry 1980, Havlick 2002, Munger et al. 2003
	Population—human disturbance	Recreational activities such as off-road vehicle use affect species in many ways (e.g., through increased physiological stress, displacement, or direct mortality).	Havlick 2002, Goldstein et al. 2010, Knight and Gutzwiller 1995, Munger et al. 2003
Reservoirs, dams, and other water developments	Habitat—habitat loss and degradation	Habitat loss from establishment of reservoirs; degradation of habitat near livestock water structures from overgrazing and man-made changes in hydrologic regimes.	Braun 1998, Nachlinger et al. 2001, Nilsson and Berggren 2008, Schroeder et al. 1999
	Habitat—habitat degradation	Altered stream flows and hydrological regimes may degrade or change habitat for aquatic and riparian species.	Pierson et al. 2001, 2002, 2003

Table 7.1.—*Human disturbance agents and potential negative effects on habitats and populations of emphasis species, with example references. See text for additional discussion about positive effects of human disturbance (continued).*

Human disturbance agents	Associated effects	Examples	Example references[a]
Roads, highways, and motorized trails	Habitat—habitat loss	Creation of roads and highways and their associated rights-of-way result in direct loss of habitat.	Forman 2000; Forman et al. 1997, 2003; Trombulak and Frissell 2000
	Habitat—habitat fragmentation, degradation	Creation of roads and highways fragments habitat; road construction and use facilitate the spread of invasive plants; dust from vehicle traffic can affect respiration in amphibians and alter rates of photosynthesis.	Forman 2000; Forman et al. 1997, 2003; Trombulak and Frissell 2000
	Population—barrier to migration or road avoidance	Roads may act as movement or migration barriers to less mobile species; animals may avoid areas affected by traffic or other activities associated with roads.	Coffin 2007, Goldstein et al. 2010, Reynolds-Hogland and Mitchell 2007, Spellerberg 2002
	Population—direct and indirect mortality	Death or injury from collisions with vehicles, and increased mortality from poaching because of improved access.	Blumton 1989, Dodd et al. 2004, Todd 2001, Woods et al. 2004
Silviculture	Habitat—loss or gain; change in habitat fragmentation	Timber harvest increases early seral habitat and reduces late-seral habitat; harvest, forest thinning, prescribed burns, and salvage logging often reduce large snag and large log habitat; small-area versus large-areas silvicultural prescriptions increase versus decrease habitat fragmentation.	Hanley et al. 2005, Hutto 2002, McIver and Starr 2001, Saab et al. 2007b, Wisdom et al. 2000, Wisdom and Bate 2008
Urbanization, human population growth	Habitat—habitat loss, degradation, fragmentation	Urban development results in habitat loss, degradation, and fragmentation of adjacent or nearby wildlands because of altered fire regimes, introduction of invasive plants, increased recreation activities, and other stressors.	Gavier-Pizarro et al. 2010a, 2010b; Gimmi et al. 2001; Gude et al. 2008; Hammer et al. 2007; Hansen et al. 2005; Hawbaker et al. 2005; Pilliod et al. 2006; Radeloff et al. 2005, 2010; Syphard et al. 2009; Theobald et al. 1997
	Population—human disturbance	Abandonment of habitats by native wildlife in response to increased human activities in urban and exurban areas. Predation by dogs and cats on native vertebrates in urban areas, and by corvids in which food associated with garbage is available. Human population density is highly correlated with threats to biodiversity.	Arrowood et al. 2001, Glennon and Porter 2005, Lenth et al. 2008, Maestas et al. 2003, Knick et al. 2003, Millsap and Bear 2000, Sawyer et al. 2005, Theobald et al. 1997
Wind energy development	Habitat—habitat degradation	Increase of noxious weeds in areas around turbines or along roads needed to access turbines; loss of habitat from road construction and turbine installation.	Arnett et al. 2008; Forman et al. 1997, 2003; Gelbard and Belnap 2003; Johnson et al. 2004; Leddy et al. 1999; USDI Bureau of Land Management 2005
	Population—displacement, mortality	Noise and other disturbances associated with wind farms may displace animals—deaths and injuries of birds and bats from collisions with wind turbines. Species avoidance of areas near turbines because of the association of such structures with nests or perches of avian predators such as corvids.	Erickson et al. 2001, Larsen and Madsen 2000, Leddy et al. 1999

[a] *Modified from Wisdom et al. (2005) and Rowland and Leu (2011).*

Figure 7.1.—*Example pathways of human disturbance effects on habitats and populations of emphasis species, using roads as the example disturbance agent (modified from Wisdom et al. 2005).*



der Maarel 1993). Some disturbance regimes are episodic, occurring infrequently at specific periods of short duration but at high magnitude, often playing out over large spatial extents (outbreak period), with longer periods of inactivity or dormancy. Examples include stand-replacement wildfires or hunting seasons of short duration but a high density of hunters. Other disturbance regimes are chronic, which manifest more evenly over time, often with magnitudes less obvious and frequently underestimated. Examples include networks of electric transmission lines and consistent but low-frequency vehicle traffic (Wisdom et al. 2000). Some chronic disturbance regimes can be deceptive, with substantial effects camouflaged as part of background conditions. An example is long-term herbivory by wild or domestic ungulates (Wisdom et al. 2006).

Not all human disturbance regimes are distinctly episodic or distinctly chronic, but may reflect characteristics of both. What is important, however, is that the regime associated with a disturbance agent is understood well enough to design and implement a meaningful monitoring approach compatible with the period over which the regime's characteristics can be measured (addressed in the following section and in chapters 1 and 3). Often, episodic disturbances are not measured over periods sufficiently long to fully capture outbreak and dormant periods. By contrast, chronic regimes may not be measured in sufficient isolation from other background conditions to detect their presence and accurately estimate their effects.

An example of these challenges is the potential effects on habitats and species from climate change. One potential effect of climate change is an increased frequency of a catastrophic event (e.g., increased frequency of tornados or hurricanes), which changes the episodic disturbance regime. Other effects of climate change may result in longer periods of drought each year, sustained over many years, which change the chronic regime.

Complicating the situation further is the interaction of multiple human disturbances, simultaneously and synergistically operating on a given landscape. For example, if climate change is projected to reduce the area dominated by wet forest vegetation types and increase areas dominated by dry forest and dry grassland types, this shift may increase the frequency and intensity of human-caused wildfires and associated habitat loss in areas of high human uses, such as in areas of high recreation use or near large **exurban** developments. Thus, a change in the chronic disturbance regime subsequently causes a change in the episodic disturbance regime. In such cases, monitoring the changes in all types of disturbance regimes associated with all the interacting human disturbances is essential for effective monitoring of the affected emphasis species and habitats of interest.

7.2.2 Human Disturbance Monitoring

Human disturbance monitoring is the detection of change in a disturbance agent's regime over time and space. In this chapter, we focus on human disturbance monitoring in relation to management of habitats and populations of emphasis species. Many other types of human disturbance monitoring are possible in relation to ecosystem and community properties and processes, but these topics are outside the scope and objectives of this chapter. Instead, our focus is on practical approaches for design and implementation of monitoring of the more common human disturbance agents and associated disturbance regimes, specifically in relation to the needs of terrestrial vertebrates selected for special management emphasis. Human disturbance monitoring requires appropriate and consistent methods, data sources, and data collection over multiple time points, as conducted at spatial and temporal scales compatible with the disturbance regime and associated management objectives.

The Forest Service (Holthausen et al. 2005) identifies three types of monitoring: (1) targeted, (2) context, and (3) cause-and-effect (chapter 1, section 1.3.2). The monitoring approaches described in this chapter are useful for targeted or context monitoring. Cause-and-effect monitoring typically requires manipulative, controlled experiments conducted as formal research, or carefully designed observational research, neither of which is addressed here. These types of formal research are not addressed here because we focus on management-based monitoring of human disturbances, rather than gaining new knowledge about effects from results of monitoring. The latter is a topic for research, in contrast to management-based monitoring.

Monitoring human disturbances can be conducted at different intensities. Low-intensity monitoring typically uses existing, coarse-grained data that require less effort for acquisition and analysis. An example is corporate databases for road systems and recreation trails (chapter 4, table 4.11). High-intensity monitoring typically requires collecting new data at higher resolution, frequently addressing fine-grained temporal dynamics of human activities that may occur daily, weekly, or seasonally. An example is monitoring the daily frequency of motorized and nonmotorized trail uses. Chapter 3 (3.3.1) addresses the different levels of sampling intensity and scale.

7.2.3 Why Monitor Human Disturbances as Part of Habitat Monitoring?

Monitoring human disturbances as part of habitat monitoring for emphasis species is important for three reasons: (1) human disturbances can alter the distribution and abundance of habitats, and thus the suitability of habitats for species use; (2) human disturbances can change species use of habitats even when habitats themselves are not affected; and (3) compliance with, and effectiveness of, land management objectives can be addressed with this information. Consequently, human disturbance monitoring enables Forest Service managers to further evaluate changes in habitats or species use of habitats.

All human disturbances, however, have multifaceted effects on habitats and species (e.g., figure 7.1). Consequently, in sections in which we address evaluation of effects from human disturbance monitoring, as well as in tables 7.1 and 7.2, we do not restrict our treatment to habitats, but also address effects on populations, such as changes in habitat use, shifts in distribution, and identification of source versus sink environments (Wisdom et al. 2000). Source environments result in stable or increasing populations, whereas sink environments do not have sufficient resources or conditions to maintain a population (Pulliam and Danielson 1991). Human disturbances can have strong influences on the amount and distribution of source versus sink areas (see summary by Wisdom et al. 2000).

Monitoring human disturbances is by definition focused on the disturbance agent and regime (e.g., change in density of motorized routes or rate of motorized use on the routes). Estimating effects of a particular disturbance agent and event on habitats and species is a process that follows that of human disturbance monitoring. Effects on species will dramatically vary by species and spatial and temporal scales. Consequently, resultant effects on habitats and species are not part of the formal process of human disturbance monitoring included in this technical guide. We assume that specific effects on habitats and species will be evaluated or estimated based on existing, empirical knowledge or models developed from existing research rather than directly measuring these effects as part of monitoring human disturbances. We provide examples of different types of effects of human disturbances on habitats and species as part of each example, however, and summarize many types of effects in table 7.1. These example effects and summary effects are provided for context and rationale for why certain human disturbances might be selected for monitoring in relation to their potential effects on habitats and species of interest.

Low-intensity human disturbance monitoring often relies on existing spatial data or updates to these data from a variety of public sources. Additional data may be required for monitoring some disturbance agents at a high intensity, such as monitoring the frequency of all-terrain vehicle (ATV) use on motorized trails on a daily or weekly basis. The types of disturbances to be monitored and the intensity of that monitoring depend on management objectives and the types of potential effects of interest on emphasis species, as detailed in the next section.

Importantly, we focus on human disturbances common to most national forests and grasslands, but that commonly have received less emphasis in more traditional monitoring programs. Examples of human disturbances common to local management units, but not emphasized in traditional monitoring programs, include roads and associated human uses, recreation, and housing developments near NFS lands. By contrast, many other human disturbances common to national forests and grasslands have been emphasized in monitoring programs, such as silviculture, livestock grazing, mining, prescribed fire, and wildfire. Monitoring approaches for these latter disturbances are summarized in the following section but are not repeated in detail in this chapter because of past development and emphasis in traditional programs of Forest Service monitoring.

7.2.4 Additional Human Disturbances To Consider

We describe the following additional human disturbances that should be considered for monitoring because of their potential effects on habitats and species. Specific monitoring approaches for each of these disturbances are beyond the scope of this chapter. Many of these disturbances, however, such as livestock grazing, silvicultural activities, fire, and energy development and mining, have well-established monitoring programs. Data from these established monitoring programs often can be used to address monitoring objectives for emphasis species.

Invasive plants and animals—Nonnative invasive species (NNIS) of plants and animals pose major threats to habitats and species across many national forests and grasslands (Moser et al. 2009). Monitoring changes in habitat related to NNIS is an obvious, major issue for all national forests and grasslands. Displacement of native plant and animal species by NNIS is a common effect and one that is difficult or often impossible to anticipate. Challenges in managing these species are many and include (1) identifying which newly arrived NNIS have highest potential to spread and cause substantial problems; (2) accurately predicting the extent and degree of potential effects for those species identified as problems; (3) intervening at early stages to prevent or substantially reduce the spread of such species; (4) reacting effectively, following a major outbreak of such species, to mitigate or reduce the undesired effects; and (5) finding ways to adapt to the presence of, and changes brought about by, NNIS that have established themselves as major components of ecosystems. These five challenges are associated with five potential phases of invasion and spread of NNIS: (1) local arrival, (2) local establishment, (3) extensive spread, (4) extensive establishment, and (5) extensive dominance and associated effects.

Because of the complexity of management challenges associated with NNIS and the different phases of invasion that require different management responses, no single method or set of methods for monitoring invasion and evaluating potential effects is relevant to all times and locations. Instead, the monitoring approach must be adapted to the particular phase of invasion, must address relevant aspects of the species' life history and competitive relations with native species, and must consider the environmental context and dynamics of the particular ecosystem. In addition, the dynamics of establishing invasive species can be facilitated substantially through many other types of human disturbance. Thus, holistic management of all human disturbances often is needed to effectively manage these species. Consequently, the methods required for effective monitoring of NNIS are beyond the scope of this chapter. See Mooney and Hobbs (2000), Zavaleta et al. (2001), and D'Antonio and Meyerson (2002) for recommended approaches to monitoring and managing NNIS. Data on existing locations of invasive species on National Forest System (NFS) lands are stored in a Natural Resource Manager (NRM) application and can aid in developing monitoring programs in which invasive species are an important consideration for the emphasis species (chapter 9, section 9.3.1). The Forest Service is currently developing protocols for inventory and monitoring of invasive species (FSH 2909.11).

Livestock grazing and supporting infrastructure—Grazing by domestic ungulates has a variety of effects on species and habitats (table 7.1). Most negative effects are geographically and context specific and thus do not apply to all times and environments. In general, effects of livestock grazing are increasingly negative in more arid environments or in areas that lack an evolutionary history of grazing by wild ungulates, especially by bulk grazers. In areas in which plants have coevolved with bulk grazing by wild ungulates, grazing by livestock may have positive effects, depending on the timing, extent, and utilization (Holechek et al. 2001).

Monitoring livestock grazing and estimating effects typically has focused on monitoring the grazing utilization of dominant grass species that often compose much of the livestock diet. Appropriate levels of utilization have been defined for all major biomes in North America (Holechek et al. 2001). Appropriate utilization levels have been established only in terms of sustaining major grass species for livestock forage, however, and do not necessarily relate to effects on habitats and species. Moreover, such monitoring often is generalized over large range allotments, and habitat-specific effects on riparian areas, meadows, flat terrain, and near developed water sources can be substantially different. Consequently, monitoring of livestock grazing and estimating effects require more fine-scale spatial analysis within grazing allotments beyond the conventional monitoring of forage utilization at a coarse scale of each allotment. Holechek et al. (2001) provided examples of how distributions of livestock vary with common landscape conditions, such as variation in terrain and distance from water. We address this type of monitoring in the section on motorized routes regarding use of **distance bands**.

Fences are predictably associated with livestock grazing, and the type and degree of effects often are unrecognized or ignored. Fences act as barriers to movement of some large mammals, and they may disrupt movements and increase mortality of many large mammals (table 7.1). Fences also provide perches and hunting posts for raptors, which may impact some sensitive species that are prey for corvids, jays, hawks, eagles, and falcons. Evaluation of fence effects generally involves (1) mapping fence locations in relation to seasonal migration routes and daily movement patterns of large mammals and (2) monitoring changes in potential effects over time with mitigation activities or with planned additional fencing. Evaluation of predation effects can use distance bands away from fence lines and the change in those distance categories with changes in fence lines over time, similar to our examples for monitoring linear routes.

In addition, water developments are a common infrastructure in support of livestock grazing. Developed water sources for livestock have a variety of effects on habitats and species (table 7.1). A common misconception is that water sources developed for livestock also are needed by wildlife. In most areas, however, adequate water sources for wildlife exist, and the effects on wildlife from increased water development for livestock often are negative (table 7.1). Livestock use is highly concentrated near water, often resulting in habitat degradation and loss. Consequently, evaluating spatial effects using the distance from water developments and monitoring how those effects change with a reduction or increase in water developments are important components of habitat monitoring in relation to livestock grazing. Evaluation can be done by using concentric distance bands away from water sources and by monitoring changes in these spatial effects with changes in the location and number of water sources over time.

Monitoring livestock grazing and associated infrastructure and estimating potential effects typically involve the use of spatial data that accurately predict the distribution of livestock. For example, grazing use is highest on flat terrain and close to water, and it is reduced with increasing slope and distance from water (Holechek et al. 2001). Spatial layers of topography and water sources, therefore, can easily be used as part of the monitoring process and combined with maps of fence lines to estimate potential effects on species and habitats with use of distance estimates. Distance bands closest to water, to fence lines, and on flatter terrain will have the most negative effects on species and habitats, with least impact to areas farthest from water and fences and those on steep terrain. Monitoring involves mapping changes in water sources and fence lines over time or proposed by management, because water improvement projects for livestock are common and fence lines often are increased over time.

Distribution of livestock can be monitored in combination with knowledge of the grazing system and stocking rate (density). Stocking rate, in particular, affects the structure and composition of vegetation more than any other variable (Wisdom and Thomas 1996). Changes in stocking rate thus are useful to monitor, along with the grazing system and season of use (Holechek et al. 2001), to estimate effects on habitats and species. Many of the effects of different types of livestock grazing on wildlife habitats and species are summarized in Krausman (1996).

Silviculture—Vegetation management for producing and harvesting wood for commercial products remains a major disturbance agent in most national forests. Consequently, silvicultural treatments have some of the most extensive effects of any management activity on vegetation structure and composition, patch size and configuration, and landscape composition. Accordingly, chapters 3, 4, and 6 provide guidance for monitoring vegetation change, including effects from silvicultural activities. In addition, a plethora of research syntheses have addressed this topic (e.g., see Hunter 1990, Oliver and Larson 1990, Lindenmayer et al. 2008, Swanson et al. 2011). Monitoring in relation to silviculture thus is not addressed in this chapter, with the exception of the road infrastructure that accompanies and supports most silvicultural treatments. Monitoring effects of such roads and their management is addressed as part of monitoring linear routes, as described in example 1.

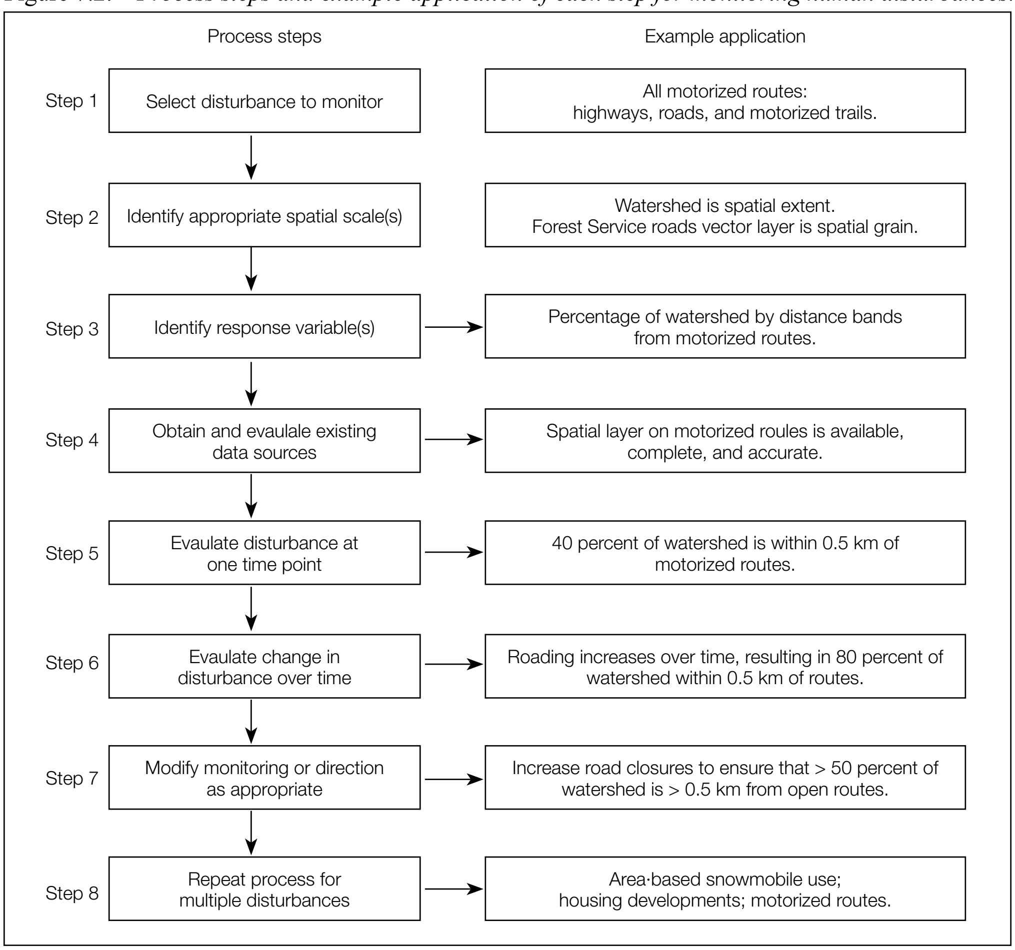
Energy development and mining—Energy development and mining are common activities on many NFS and other public lands, and these land uses are growing rapidly. Examples include development of oil and gas fields and supporting infrastructure (e.g., pipelines, power lines, and roads that serve the field), wind farms, and strip or shaft mines for mineral extraction. Effects include habitat loss associated with the extraction area (i.e., the oil or gas well pad or the strip mine or shaft) and habitat loss and degradation associated with the supporting infrastructure (table 7.1). Often, the most deleterious and pervasive effects are associated with the multitude of roads, pipelines, and power lines that serve the extraction area. Monitoring energy development and estimating the resulting changes in habitats require spatial analysis in relation to varying distances from the energy development or mining site and from the supporting infrastructure and how those distances change over time with changes in development or mining, such as with use of the methods illustrated by Wisdom et al. (2005). Monitoring all associated infrastructure that supports energy development and mining sites, including roads, pipelines, transmission lines, and dump sites, is an essential part of this process (Wisdom et al. 2005).

Power lines—Electric transmission lines often are overlooked as a major disturbance agent, despite their many negative effects on habitats and species and despite their widespread presence within and near national forests and grasslands. Transmission lines convert habitat to nonhabitat, increase fragmentation of remaining habitats, enhance predation of sensitive species, facilitate invasions of NNIS, establish movement barriers or avoidance zones for wildlife, and contribute to many other undesired effects related to motorized access and use along the transmission right-of-way (Wisdom et al. 2005) (table 7.1). Many of these negative effects diminish with increasing distance from the transmission lines. Accordingly, the same type of distance band analysis used for other linear features such as highways, roads, and motorized trails can be used for monitoring the presence and change in line locations and estimating effects, as illustrated in Wisdom et al. (2005). Electric transmission lines are easily monitored with spatial data layers available from power companies and Federal agencies that regulate power use. Some information is restricted, however, and formal permission must be granted from power companies before spatial data on all lines can be obtained.

7.3 Process Steps for Monitoring Human Disturbances

The generalized steps for monitoring human disturbances (figure 7.2) are similar to those outlined for habitat monitoring in previous chapters, but are customized here for specific use in human disturbance monitoring. Decisions at each step are largely dictated by the management direction and policy on which the monitoring process is based (chapter 1) or by the associated conditions of management interest. Without clear management and policy direction, particularly quantifiable direction, the monitoring process will

Figure 7.2.—*Process steps and example application of each step for monitoring human disturbances.*



km = kilometer.

become more challenging and less effective, given the additional assumptions that must be made about how the monitoring process can be related back to the direction, policy, or associated conditions. Although these steps are logical and straightforward, actual design and implementation of an effective approach for monitoring human disturbances on emphasis species is a complex analytical endeavor, and it can be improved substantially from collaboration with a statistician or biometrician.

Step 1. Select Disturbance Agents To Monitor

The topics, controversies, effects, decisions, and management direction associated with land use planning provide essential context for selecting the disturbance agents that warrant monitoring. It is logistically impossible to monitor all human disturbances and estimate effects on all habitats and species. Consequently, a key starting point is to establish clear rationale and criteria for identifying and prioritizing which disturbance agents will be the focus of monitoring. The criteria in the following section were customized for consideration in human disturbance monitoring but support the more general criteria for habitat monitoring outlined in chapter 2. To identify which human disturbance agents to monitor, use the following criteria.

- ***Spatial extent or pervasiveness of the agent—***Disturbance agents that affect large areas of the planning unit are likely to affect many habitats and species and, thus, are likely targets for monitoring.
- ***Prior evidence of the agent having the potential for significant effects on habitats and species—***Some disturbance agents have obvious and significant effects that have been documented from the scientific literature and from their obvious presence on NFS lands (e.g., motorized routes), whereas other agents may have little history of operating on, or affecting, habitats on NFS lands (e.g., pesticides).
- ***Agreement among resource specialists and managers about the relative importance of the agent in the area and the rationale for the agent's importance, including consideration of expert views on the issue—***The expertise of resource specialists and managers, who have direct knowledge and experience with resource issues in the analysis area, provides a strong basis for selecting disturbance agents that warrant monitoring.
- ***Public opinion about the agent—***Views expressed by the public and vested land users provide context in helping select disturbance agents for monitoring. These views indicate the degree to which potential disturbance effects are of interest to society.
- ***Available resources to address the agent—***Funding or staffing shortages often limit the degree to which particular disturbances can be monitored. Nonetheless, resource shortages for monitoring important disturbance agents need to be clearly identified so that the shortages can be acknowledged and considered.
- ***Timeframe required to monitor a disturbance or resultant treatments designed to mitigate undesirable effects—***The time intervals appropriate to monitor a given

human disturbance can influence the feasibility of such monitoring, such as episodic disturbances that may be unpredictable in timing of occurrence versus chronic and often more cryptic disturbances that operate more evenly over time.

- ***Costs versus benefits of addressing the agent*****—**Some disturbance agents may have already caused obvious negative effects on wildlife habitats or populations, or research may have documented the overwhelming nature of a given human disturbance, with negative effects that may be difficult or impossible to mitigate or reverse, thus reducing the benefits of monitoring the agent or the feasibility of mitigating effects in management. An example is an invasive plant species that is so well established that it defies obliteration and instead has become naturalized in many environments. A variety of NNIS fit this description (Richardson et al. 2000). These situations must be well documented from past research to justify the reduced focus on human disturbance monitoring.
- ***Management opportunities provided by contiguous land ownership, such as expansive areas of Federal lands*****—**It might be challenging or impossible to effectively monitor disturbance agents on fragmented land ownerships if the goal is to monitor the agents as they relate solely to national forest and grassland management. Alternatively, monitoring human disturbances and estimating their effects on NFS lands adjacent to or near other land ownerships, particularly urban developments, may be of highest management priority, given the many negative effects on habitats and species in such areas.
- ***Technologies capable of monitoring the targeted resources and effects*****—**Most disturbance agents require remote sensing technologies for effective and efficient monitoring; however, some fine-grained, dispersed disturbances, such as livestock grazing, may be difficult to monitor in contrast with remote monitoring of more easily quantified activities, such as oil and gas development. The correct match of methods and technologies with the disturbance agents is key to successful monitoring.
- ***Potential effects of the agent on nontarget habitats or species and other resource goals not directly related to the resources of interest*****—**The monitoring approaches outlined here are designed to support management objectives for habitats and species. Potential effects on other resources, however, also justify the need for monitoring.

Documenting the rationale for selection of disturbance agents provides the foundation for an effective monitoring plan. Such documentation provides an essential framework for monitoring and for helping secure needed funds and staffing to conduct the work.

Step 2. Choose Targeted or Context Monitoring

A targeted monitoring approach is designed to address specific management direction or influences of management or conditions of interest. For example, management restrictions placed on the location and frequency of helicopter skiing, owing to concerns about disturbance effects on an emphasis species like wolverine, would justify targeted monitoring of this recreation activity.

In other situations, monitoring may not be explicitly designed to address existing management direction or specific habitats for particular species. Instead, monitoring might be designed to gain insight about a disturbance regime's characteristics (extent, frequency, duration, and magnitude), such that potential effects of emerging or previously unrecognized issues might be better understood, which is context monitoring. For example, a set of caves may not have specific management direction that protects these sites from spelunking, but understanding the context of human use and potential effects may be warranted to understand whether management protection may be beneficial for associated species such as bats (e.g., roosting in the caves). In these cases, context monitoring is appropriate, with results available for potential consideration in future management processes, but not explicitly tied to existing direction.

Step 3. Identify Appropriate Spatial Scales

After selecting a particular disturbance agent and type of monitoring, choose appropriate spatial scales for evaluating the associated objectives and actions. Chapter 2 (section 2.2.6) addresses spatial scale, which is composed of spatial extent and spatial grain, each of which requires consideration in matching the goals of human disturbance monitoring with the appropriate type of spatial data needed to meet goals (Gutzwiller and Cole 2005, Peterson and Parker 1998, Turner et al. 2001). Ultimately, the spatial accuracy of data used for human disturbance monitoring must be sufficient to meet goals. Spatial accuracy is the combination of bias and precision of spatial estimates. Low bias and high precision result in high accuracy of spatial estimates.

Deciding on the appropriate spatial scales is not trivial—monitoring results will vary with scale, and some results may be extremely scale sensitive (chapter 4, section 4.2.4). Consequently, all three characteristics of spatial scale (extent, grain, and accuracy) warrant careful consideration as part of monitoring. In addition, management planning and activities are scale specific, and monitoring needs to be compatible in scale.

Step 4. Identify Metrics for the Selected Disturbance Agents

Metrics are characteristics of the disturbance agent and associated regime that are measurable and relevant to monitor. For example, issues of road management might require monitoring the density of roads, the percentage of area by distance categories from roads, or the frequency of traffic on each road system (section 7.4). Similarly, energy extraction activities could be monitored by estimating the change in density of gas and oil wells; the associated number, type, and length of roads, pipelines, and transmission lines that serve the extraction sites; and the area impacted, summarized by distance categories from the extraction sites (section 7.2.4).

Three main types of metrics are commonly used for monitoring and evaluating human disturbances: (1) distance, (2) density, and (3) rate. Use of these metrics for human disturbance monitoring is illustrated in our examples in subsequent sections.

Select appropriate metrics based on prior management direction or specified conditions of interest. For example, if direction for managing motorized access is established in terms of density of roads open to motorized use, then density estimates are obviously of monitoring interest. Similarly, if management direction limits the rate of trail use (e.g., restrictions on the number of persons hiking or horseback riding per day on a trail system during particular seasons), then rate estimates are of interest. Unfortunately, in some cases, it may not be possible to make a straightforward connection to management direction. In such cases, the use of context monitoring, without explicit connection to management direction, may be appropriate.

Step 5. Obtain and Evaluate Existing Data Sources for Selected Metrics

Most data used to monitor human disturbances are spatially explicit. Moreover, many spatial layers currently exist for monitoring the more common human disturbances of interest, such as motorized routes or housing developments near NFS lands (chapter 4, table 4.11). Unfortunately, such data sources often are not centralized, and several disparate data sources may need to be assimilated for monitoring. In other cases, centralized data sources are available but have unknown accuracy. In still other cases, documented accuracy of the data is provided through metadata, but such data may still contain errors of omission, such as road systems that are not mapped. These problems require that data layers be evaluated before their use—for completeness, accuracy, and relevance to management objectives.

Step 6. Identify the Appropriate Period for Monitoring

Specify the desired, appropriate temporal scale for monitoring the disturbance agents. That is, select the proper temporal extent in relation to the disturbance regime associated with the particular human disturbance, and ensure that potential biases associated with different methods of estimating change over different periods (differences in **temporal grain** and resulting temporal accuracy) are reconciled (Noon and Dale 2002).

Notably, use of different methods or data sources to monitor disturbances for each period will affect the spatial grain and accuracy, in turn affecting estimates of change over time. As with spatial scale, the objectives of an analysis determine requirements for temporal extent and accuracy. Evaluations conducted over short periods may reveal little change in habitat conditions, incorrectly suggesting that change has been minimal. Or, evaluations over short periods may capture effects of an infrequent but large episodic event, falsely suggesting that change has been substantial. By contrast, changes measured over multiple time points, spanning longer periods, are more likely to reveal past dynamics of habitat change that are easier to interpret. Consequently, matching the appropriate period with the dynamics of the disturbance to be monitored, within the desired management timeframe, is essential for effective monitoring.

An additional complicating factor is that different methods often are used to estimate conditions at different times. In general, estimates become increasingly coarse in resolution as one goes farther back in time, when less powerful or sophisticated software or analysis tools were available. By contrast, estimates made closer to the present often rely on the same or similar methods of estimating conditions. Differences in methods used at different times must be accounted for in the analyses and subsequent inferences.

Step 7. Monitor the Metrics Over the Designated Period

After identifying an appropriate period for monitoring, estimate changes in metric values in relation to habitat of the emphasis species and management direction. Monitoring methods will differ substantially with the specific metrics and the designated spatial and temporal scales. For example, monitoring compliance with management direction that closes a set of roads to motorized traffic during hunting seasons may require use of automated vehicle counters or motion sensors installed at the start of a closed road system to detect motorized use on the closed roads during the hunting period. By contrast, monitoring compliance with management direction to obliterate specific roads and trails to eliminate motorized uses may simply involve field visits to the targeted road systems to monitor whether obliterations or other impediments to traffic have been implemented and continue to be maintained according to management direction.

The key to successful monitoring of these metrics is to follow a well-designed plan that is developed before actual monitoring begins. Such plans need to explicitly follow directions provided in previous steps (steps 1 through 6), detail all objectives and methods in written form, undergo formal peer review from experts on the specific topics, and receive management approval to ensure their utility for management and increase the probability of needed funding and staffing.

Step 8. Ensure That Monitoring Outcomes Are Reported in the Context of Management

Results from monitoring must be formally documented and reported so they can be used in planning and management (chapter 3, section 3.3.5). If results are part of targeted monitoring, several factors must be considered and interpreted correctly, including (1) whether the monitoring design was adequate to evaluate management direction or associated conditions, (2) whether the management direction or conditions were quantified clearly beforehand to allow for monitoring results to be used for effective evaluation of the direction or conditions, and (3) whether prior assumptions were clearly established to address problems arising from the previously listed factors. Many challenges associated with interpreting monitoring results for management can be reduced or mitigated by clearly documenting how changes in the habitat attributes will be interpreted and used in planning and management. This documentation needs to occur as part of the monitoring plan.

If results are part of context monitoring, findings may suggest the need to modify management direction or to allay any potential concerns about the issue or its potential effects on habitats and species. If the approach is targeted monitoring, any of four actions may be appropriate after estimating effects and comparing monitoring results with management direction: (1) the monitoring approach may need to be modified to improve its use in estimating effects and evaluating management direction or associated conditions, (2) management direction may need modification in response to noncompliance or undesired effects, (3) both monitoring and management direction may need modification to improve the relationship, and (4) none of these actions may be necessary because the monitoring process worked effectively and results indicated no need for changes in management.

Step 9. Repeat Process Steps for Multiple Disturbances

A combination of human disturbances typically operates simultaneously on a given landscape, with combined effects that can affect emphasis species and their habitats in ways that may exceed or differ from effects of the individual disturbance agents (Paine et al. 1998). As a consequence, an additional and often highly effective step in the monitoring process is to evaluate the combined effects of the individual disturbances that are monitored. Evaluating the combined effects from results of monitoring a set of human disturbances is important because the results can be used to further inform management direction or prompt changes in direction, owing to unexpected outcomes that are not apparent from estimating effects from individual disturbances. Three generalized types of potential effects are likely when considering multiple human disturbances operating together: (1) cumulative effects; (2) interactive effects; and (3) special types of interactions, such as threshold effects or limiting factor effects. The following paragraphs present a brief overview of these concepts.

Cumulative effects are those in which the combined effects of human disturbances are additive. That is, the effect of one disturbance combines with one or more other disturbances such that the total or cumulative effect equals the sum of effects from all individual disturbances (Gutzwiller and Cole 2005). An example is human footprint analysis in which the spatial effects of two or more conditions or disturbances are overlaid on one another (Leu et al. 2008, Sanderson et al. 2002). The resulting maps depict areas in which potential effects of multiple disturbances may be quite negative, versus areas in which multiple disturbance effects are relatively benign in nature. When classical statistical analyses are employed, additive effects are typically modeled and analyzed with multiple linear regressions. Kutner et al. (2005) provide helpful guidance on regression approaches.

Interactive effects are those in which one or more human disturbances affect other disturbances, such that overall effects are not additive but instead manifest in less predictable ways. Typically, a synergy of effects is brought about by the combination of individual disturbances, resulting in more severe or more benign effects than expected by simply adding individual disturbances. Multiplicative effects and geometric effects, for example, can increase by orders of magnitude that can far exceed additive processes. One example is the coupling of roadside invasion by nonnative annual grasses with increased susceptibility of adjacent habitats to human-caused wildfires (Wisdom et al. 2005). In this case, disturbances from road maintenance activities and motorized uses facilitate the invasion and establishment of nonnative annual grasses along roadsides, resulting in habitat degradation. In turn, the nonnative grasses serve as an ideal flash fuel, sufficient to initiate wildfires, which often start from human activities along roads (e.g., burning cigarettes thrown from a car window). These fires then spread into nearby native vegetation, thereby eliminating important habitat for wildlife near roads. The resulting soil disturbance from the wildfire then provides an ideal medium for further spread and establishment of non-native annual grasses, in turn increasing the probability of subjecting adjacent native vegetation to additional fires. This cycle can continue at increasing distances from the road, with effects that are substantially greater than either the single or the additive effects of the combination of disturbances.

When classical statistical methods are used, interactive effects often are modeled using multivariate linear regression; values of the predictor variables often are multiplied together, or used in quadratic or cubic form, to create new predictor values. The number of possibilities becomes quite large, but the combinations provide flexibility in fitting the shape of a response to the interactive effects of human disturbances (predictor) variables.

Other types of interactions include threshold effects and limiting factor effects. Threshold effects can be interactive when two or more disturbances combine to cause habitat or population declines that are precipitous, after a particular condition is reached. Identifying such thresholds requires a detailed understanding of the synergy of two or more interacting disturbances across the spectrum of conditions above and below such thresholds. Similarly, limiting factor effects result when a particular effect from one disturbance overwhelms the effects of others (chapter 2, section 2.3.2). In these cases, equal attention to each disturbance agent is neither efficient nor effective. Gaining knowledge about which disturbance agents, if any, may be operating as limiting factors, however, may not be possible without monitoring all disturbances and estimating effects in relation to associated habitats and species of interest. Fitting of threshold and limiting factors may require complex, interactive multiple regression models, nonlinear regression models, or even neural networks and other data mining or curve fitting procedures (Kutner et al. 2005). In detecting and modeling these more complex relationships, include a statistician or biometrician as part of the habitat monitoring team.

Integrated monitoring of multiple disturbance agents may not be possible because of time, funding, or logistical constraints, thus limiting detection of some of the effects described previously. As the complexity of a model increases, the number of terms in the regression analysis increases and the old rule of thumb applies, namely the sample size (e.g., number of field plots) needs to be about 10 times the number of predictor terms in a model. Nonetheless, evaluating effects from multiple disturbances can take advantage of whatever results are available from monitoring individual disturbances, so that patterns about potential types of effects like those described previously might be documented. Documenting and accounting for such patterns can complement the focus on individual disturbance agents in the monitoring process.

7.4 Key Metrics for Quantitative Monitoring of Human Disturbances

Three general metrics or types of estimates often are used to monitor human disturbances: (1) distance, (2) density, and (3) rate. We define and describe these disturbances here because they are most relevant among many possible metrics for monitoring the types of human disturbances most common to NFS lands (section 7.5).

Distance Estimates

Distance is a measure of the proximity of one object on a landscape to another. For human disturbance analyses, distance estimates often are used to partition the landscape into distance zones or categories in relation to a source of disturbance, such as a road, campground, or housing development. These distance zones or categories often are referred to as **distance bands** (Rowland et al. 2000, 2005; Theobald and Hobbs 2002). For example, a watershed might be partitioned into distance bands away from roads, each 0.1-mile (mi) wide, or away from transmission lines or campgrounds. Use of distance bands or zones provides a flexible and accurate means of identifying portions of the landscape close to, versus far from, linear routes. The percentage of a landscape within each distance band can then be mapped and monitored over time, and results can be compared with management goals and direction.

Density Estimates

Density is the number per unit area of a measurable feature of interest. Density is a common measure of many landscape features, such as roads, trails, campgrounds, livestock water sources, oil and gas wells, and any other human use areas that are readily mapped. Density is often used as a landscape metric because it is easy to estimate, presumably easy to interpret, and has a long history of use in establishing management direction. Perhaps the most notable density estimate is road density, which has been used as a generic indicator of human activities and their effects on a variety of large mammals such as elk (*Cervus elaphus*; Lyon 1983), brown bear (*Usrus arctos*) (Mattson et al. 1996), gray wolf (*Canis lupus*; Mech et al. 1988), and wolverine (*Gulo gulo*; Rowland et al. 2003).

Although density may be easy to calculate, exactly how the calculations are made and used to estimate effects on habitats and populations of emphasis species can strongly influence results. In most cases, density is actually a surrogate for distance because habitats and species are typically affected based on the distance from a human disturbance, often measured with distance bands (Rowland et al. 2000, Theobald and Hobbs 2002).

By contrast, density does not measure distance, instead measuring how concentrated a disturbance is at a given spatial extent. Such estimates can be misleading if a large analysis area has a high density of some feature in one area but a low density in the remaining sections and if the results are averaged across the entire area. In such cases, the mean road density calculated over the entire analysis area provides a result intermediate to these extremes and does not depict the full range of conditions. Use of distance bands in this same analysis area provides the area in each distance category in relation to a disturbance, which more accurately reflects spatial variation in the disturbance across the landscape (Rowland et al. 2000, 2005).

Rate Estimates

Rate is the frequency of an event per unit time, such as the number of vehicles passing along a road every 24 hours, or the number of hikers using a trail system per month. Many types of rates may be relevant when monitoring human disturbances because rates are a direct measure of a given disturbance regime in time and often are spatially explicit. For example, the daily rate of a certain recreation use can largely determine the types and magnitude of effects on a species' use of the affected habitat, such as the rate of motorized traffic on forest roads (e.g., Wisdom et al. 2004b) or motorized trails (Wisdom et al. 2004a), rate of snowmobile use on winter trails (Davenport et al. 2003), or rate of hiker use of a forest trail system (Gaines et al. 2003). Rates are an important complement to distance and density estimates because distance and density are estimated at fixed times, whereas rates measure temporal dynamics of a given disturbance on a more continuous or finer time scale. Often, the rate at which a human disturbance occurs more accurately depicts potential effects on habitats and species than a simple depiction of a human use area (e.g., road, campground, housing development) that reports distance or density estimates but does not estimate actual use (Wisdom et al. 2004b).

7.5 Common Disturbance Agents on National Forests and Grasslands

We focus on methods for monitoring and estimating effects of three of the most common human disturbances on national forests and grasslands: (1) motorized routes, defined as linear routes used for motorized travel, typically composed of highways, roads, and motorized trails (railroads can also be included); (2) recreation activities common to local management units; and (3) housing developments near national forests and grasslands, such as rural housing, suburban, or urban (exurban) developments with easy access to NFS lands. Many other human disturbances warrant monitoring on NFS lands, such as silvicultural activities, livestock grazing, fire, invasive species, energy extraction, electric transmission lines, mining, and climate change (table 7.1).

Some of these additional disturbances, however, typically are monitored as part of existing management programs (e.g., livestock grazing, silviculture, fire) and thus have prior monitoring protocols in use. Others are addressed indirectly in other chapters of this guide, as measured through protocols for monitoring vegetation-based habitat attributes (chapter 4). In other cases, these disturbances affect a substantial area of particular local management units but are less common or more localized on many national forests and grasslands (e.g., energy extraction, mining, transmission lines). Finally, in at least one case—climate change—the disturbance is not only appropriate to monitor at smaller spatial extents such as watersheds within an individual management unit, but also warrants monitoring at spatial extents vastly larger than that of individual or multiple management units, requiring approaches that span all land ownerships and administrative units at regional and continental scales (chapter 2, section 2.2.7). For the three examples highlighted in this chapter, we address how potential effects of climate change might interact with effects of the human disturbance that is featured in the example.

Regardless of the type of human disturbance, most types can be addressed by using methods highlighted in this chapter. Consequently, we briefly describe the general effects of each of the additional disturbances on habitats and species in section 7.2.4 and suggest how monitoring approaches described in this chapter could be adapted, if appropriate, for these disturbances. For other disturbance agents, we describe why these agents require monitoring approaches beyond the scope of this chapter.

Our three examples use the same spatial extent and landscape, which is a hypothetical, 20,000-acre watershed of mixed landownership (figure 7.3). Other spatial extents of larger size and type also are appropriate for monitoring the types of human disturbances in our examples. Our use of a watershed as an analysis unit is of no special significance; it simply is the spatial extent at which management objectives were established for the examples and, thus, the extent at which monitoring would be conducted. In addition, the mix of NFS and private lands within and adjacent to the watershed is typical of many landscapes. Consequently, this approach is helpful in illustrating the need to monitor human disturbances holistically among ownerships to fully understand and document changes over time and to estimate the effects accurately in relation to monitoring and management goals on NFS lands. Moreover, the watershed scale also is appropriate for a variety of landscape analyses for species of conservation concern on public lands (Wisdom et al. 2000).

Each example is composed of three sections: (1) introductory text that provides a brief overview, justification, and context for monitoring the disturbance; (2) the process steps and metrics as used for monitoring and a summary of the monitoring results; and (3) the potential effects on example habitats or species based on the monitoring results. It is important to note that monitoring a given human disturbance focuses on measuring change in the disturbance over time. Estimating effects from results of the monitoring approach is an important but additional process beyond the formal monitoring process.

Figure 7.3.—*The watershed spatial extent used for three examples of human disturbance monitoring and the pattern of public and private lands within it. This landownership pattern of a watershed dominated by National Forest System lands (areas of white), interspersed with small, disjunct blocks of private inholdings, is typical of many watersheds in national forests and grasslands, especially in the Eastern United States.*

Effects analysis can differ widely in approach and methods, as dictated by the specific emphasis species and habitats targeted for management or of conservation concern. Although we describe some general ways to estimate effects from our monitoring examples, comprehensive treatment of this topic is beyond the scope of this chapter.

For each example, we also address how projected effects of climate change might be considered as an additional, interactive disturbance factor with that of the human disturbance being monitored. We introduce and highlight climate change in this manner because it potentially interacts with all other human disturbances and effects, or it can override other disturbances and effects. Thus, consideration of potential effects of climate change provides important context for all other types of human disturbance monitoring in relation to emphasis species and habitats and associated management objectives.

7.5.1 Example 1—Motorized Routes: Highways, Roads, and Motorized Trails

Linear routes used for motorized travel are associated with a myriad of negative effects on habitats and species (table 7.1, figure 7.1). Effects include habitat loss, habitat fragmentation, and spread of invasive plants (Formann 2000, Spellerberg 2002, Trombulak and Frissell 2000). The composite effects of road-associated habitat loss and fragmentation favor vertebrate species adapted to patchy, disturbed habitats (Frid and Dill 2002). Motorized travel also directly impacts animals, through collisions, poaching, overharvest, displacement, movement barriers, and increased energy costs from exposure to human activities (Wisdom et al. 2000; table 7.1, figure 7.1). The scope and magnitude of these effects differ dramatically with the type of route, its infrastructure, and the frequency and types of motorized uses (Frid and Dill 2002, Havlick 2002).

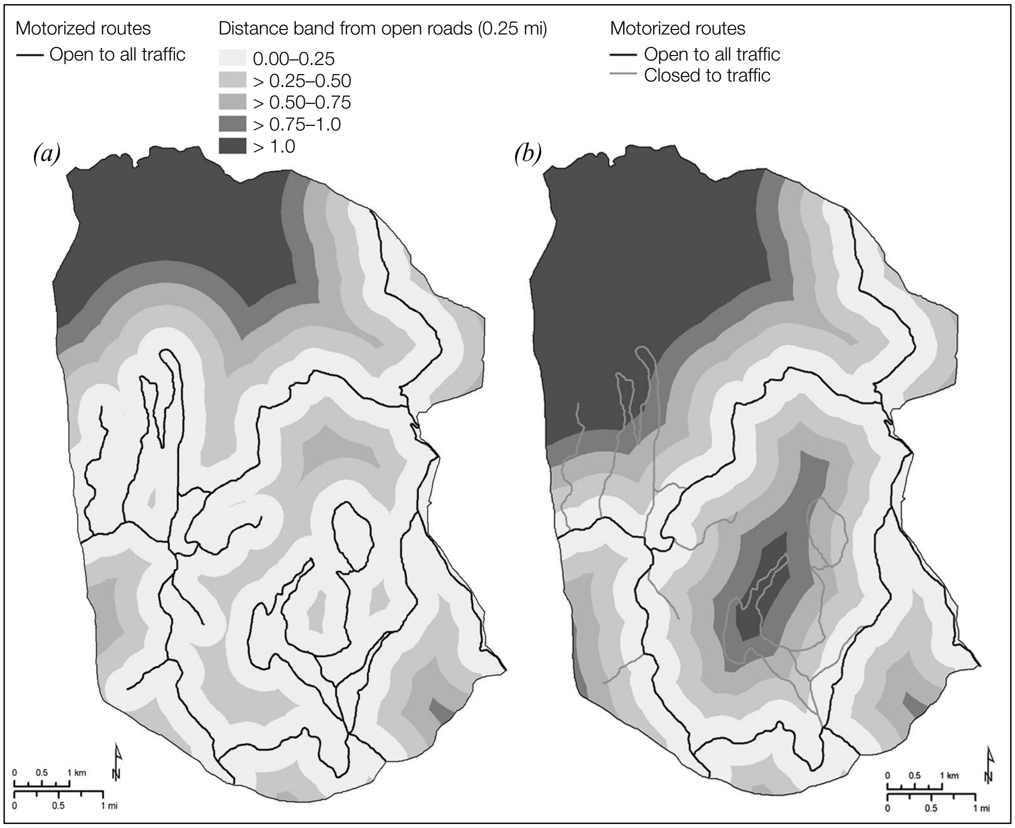
Highways, for example, eliminate the most habitats because of their extensive infrastructure and wide rights-of-way. Narrow trails used by ATVs and dirt bikes, by contrast, have a smaller area of direct habitat loss adjacent to these linear routes. High-speed, high-frequency traffic on highways and highly used railroads also are substantial causes of animal mortality via collisions (Clevenger et al. 2001, Dodd et al. 2004, Van der Grift 1999), whereas secondary or primitive Forest Service roads may cause less direct mortality. Despite these generalizations, the large network of motorized roads and trails on NFS lands may have cumulative effects on species and habitats—such as strong avoidance of habitats near such routes or the pervasive spread of invasive plants—that can exceed those from highways or railroads because of the extensive network of these roads and trails on most national forests and grasslands (Forman 2000). The specific effects depend on the type and spatial extent of the road and motorized trail systems. Another example effect is motorized trails and primitive roads facilitating overharvest of game animals and poaching (Cole et al. 1997); these sources of animal mortality may be substantially less along highways and substantially higher on NFS roads and trails.

Consequently, many effects from motorized routes are not obvious, and generalizations about more deleterious effects being associated with well-developed and higher frequency traffic routes may be unwarranted. Accordingly, the type of linear route used for motorized travel needs to be monitored in relation to, and characterized by, the potential effects associated with that route, considering the plethora of potential effects (table 7.1).

Monitoring

In this first example, the human disturbance selected for monitoring (step 1) is the linear routes open to motorized travel (motorized routes, figure 7.4). Rationale for selecting this disturbance follows that described previously for process step 1 (section 7.3). Importantly, all linear routes open to motorized use are included as part of monitoring, including highways, forest roads, and trails open to ATVs and dirt bikes. A targeted monitoring approach is taken (step 2), owing to the need to explicitly relate the results

Figure 7.4.—*Example watershed characterized by distance bands buffered from linear routes open to motorized travel, mapped for two time points 5 years apart. The specific road management direction for this watershed is that more than 40 percent of the area needs to be more than 0.5 mi from motorized routes. At time point 1 (a), 25 percent of the watershed is more than 0.5 mi from motorized routes. At time point 2 (b), 46 percent of the watershed is more than 0.5 mi from motorized routes.*



mi = mile.

to management direction. In this case, management direction specifies the percentage of watershed area to be maintained by distance from linear routes open to motorized use. Specifically, the watershed is to be managed so that more than 40 percent of the watershed area is more than 0.5 mi from the nearest route open to motorized use.

The appropriate spatial extent for management is the watershed (step 3) because, in this case, management direction was specified for this extent. The watershed extent is nested within administrative extents of ranger district, national forests and grasslands, and region, allowing for monitoring results across many watersheds to be summarized at larger spatial extents of interest to management. Complicating the monitoring process within all these extents is the mixed ownership of public and private lands (figure 7.3).

Spatial grain in this example is the resolution of the road vector layers available from the national forest or grassland in which the watershed is located. These vector layers, typically included in standardized geospatial formats (e.g., geodatabases, coverages, or shapefiles), are available for Forest Service regions or for individual national forests and grasslands (chapter 4, table 4.11). Road locations for this example vector layer are assumed to be accurate to within 1 to 2 meters (m) of their true location, based on the accuracy of Global Positioning System (GPS) technologies that were used to inventory all motorized routes in the district.

The selected metric (step 4) is the percentage of watershed area within distance categories (distance bands) from the routes open to motorized travel (table 7.2). This metric was selected because management direction established for the watershed was specified in terms of setting limits on the percentage of area within certain distance bands from routes open to motorized use. A complete roads and trails layer containing all routes open to motorized use in the district is obtained and used as the basis for evaluation (step 5).

The period over which monitoring occurs is 5 years (step 6), which is the length of time in which road management direction is to be achieved under a revised forest plan. The specific road management direction for this watershed is that more than 40 percent of the area needs to be more than 0.5 mi from motorized routes. Evaluation of change in the disturbance over time (step 6) shows that miles of open roads have changed substantially: only 25 percent of the watershed was more than 0.5 mi from motorized routes 5 years ago (figure 7.4a), but currently 46 percent of watershed area is more than 0.5 mi from routes (figure 7.4b, table 7.2). Negative effects on emphasis species that avoid roads or experience increased mortality near roads thus have been reduced over time (step 7, see next section for effects). Consequently, no additional management actions (e.g., additional road closures and obliterations) are deemed appropriate (step 8). Effects on habitats for emphasis species from these monitoring results can then be considered with results from monitoring other human disturbances, such as area-based snowmobile use (figure 7.5) and housing developments on nearby ownerships (figure 7.6). Cumulative effects from monitoring these multiple land uses can be estimated and considered as part of more holistic management of the watershed (step 9, section 7.5.4). Also note that off-road motorized uses that do not follow linear routes are not addressed in this example but are addressed in example 2 on monitoring recreation as a human disturbance.

Table 7.2.—*Percentage of watershed area within distance bands from nearest linear route open to motorized travel and from nearest housing development to National Forest System lands, estimated and mapped for two time points 5 years apart. See examples 1 and 3 in text for details.*

	Distance band (miles)									
	Time point 1					**Time point 2**				
Human disturbance	0.00 to 0.25	> 0.25 to 0.50	> 0.50 to 0.75	> 0.75 to 1.00	> 1.00	0.00 to 0.25	> 0.25 to 0.50	> 0.50 to 0.75	> 0.75 to 1.00	> 1.00
Linear routes	53	22	8	5	12	32	22	14	9	23
Housing	1	3	5	7	84	2	9	16	21	52

Figure 7.5.—*Example landscape used by snowmobiles under area-based use, assuming all areas of less than 30 percent slope can be traversed under current management regulations. Approximately 75 percent of the landscape can be traversed efficiently by snowmobiles in this example.*

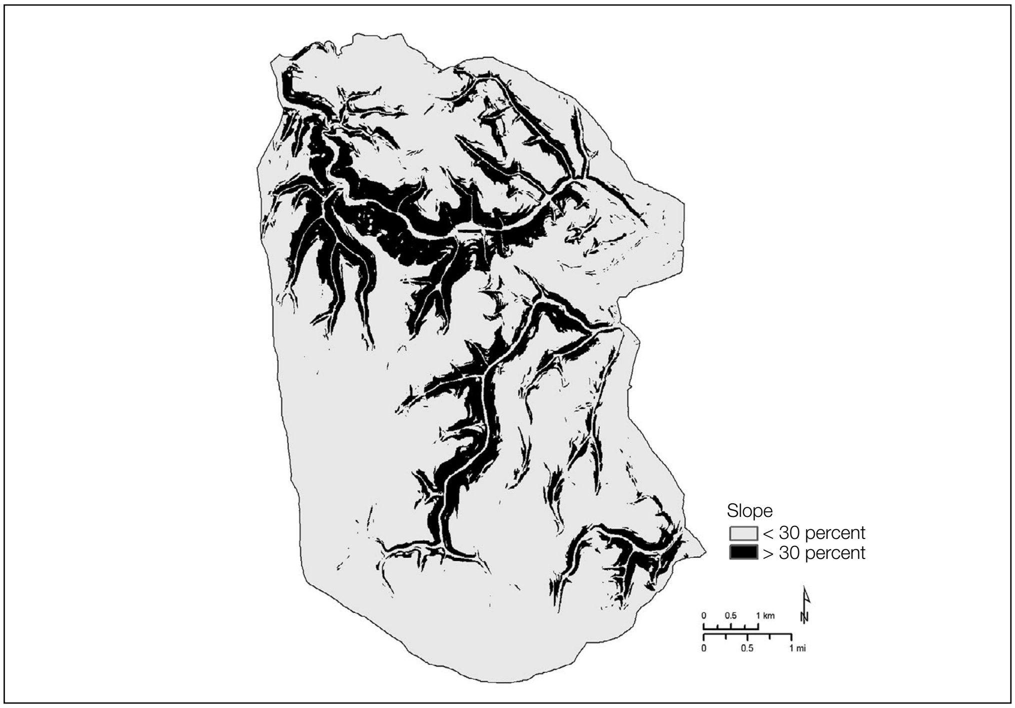
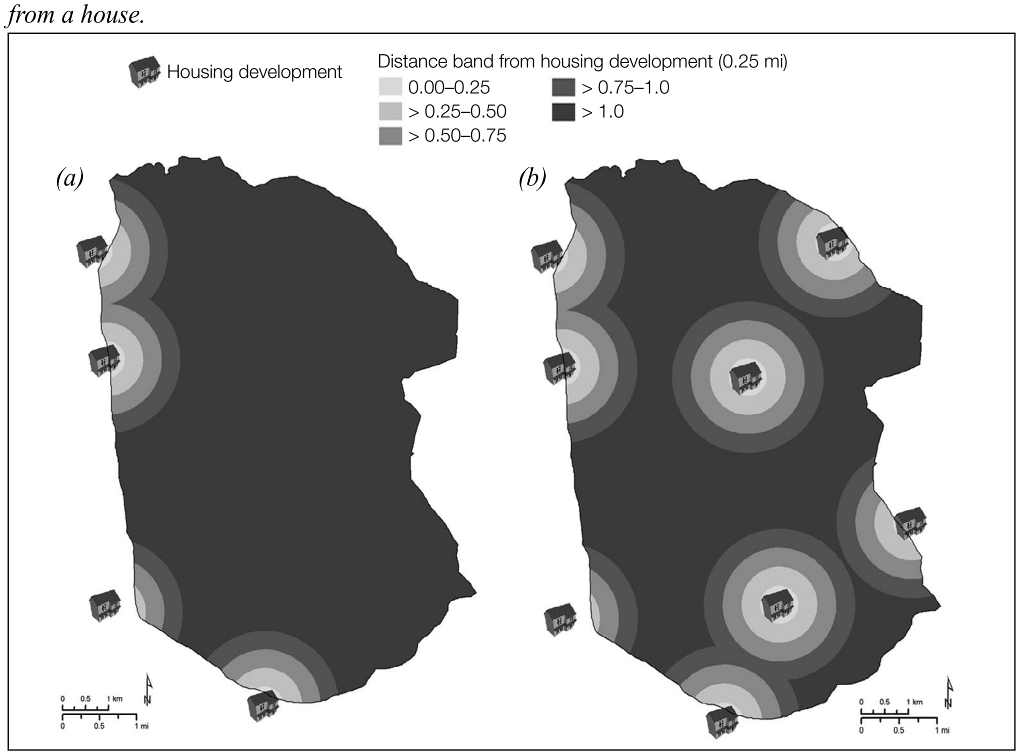


Figure 7.6.—*Example watershed characterized by distance bands buffered from houses, mapped for two time points 5 years apart. At time point 1 (a), 84 percent of the watershed area is more than 1.0 mi from housing. At time point 2 (b), only 52 percent of the watershed area is more than 1.0 mi from a house.*



mi = mile.

Estimating Effects

Linear routes used for motorized travel can be monitored and their effects estimated with use of distance, density, and rate estimates (table 7.3, figure 7.4). In the example in figure 7.4, most (75 percent) of the landscape at monitoring time point 1 (5 years ago) was within 0.5 mi of roads and trails open to motorized use (table 7.3), but this percentage was about 50 percent at time point 2 (current time). Changes in these percentages can easily be monitored in relation to management objectives or proposed management for the period of interest, as demonstrated in this example. In turn, distance bands from nearest linear route can be used as effect zones for species and habitats that are sensitive to human activities associated with routes. For example, invasive plant establishment often occurs within 100 yards (yd) of roads or trails, and this distance band can be considered an area of habitat loss or of severe degradation for native vegetation (Gelbard and Belnap 2003). In the example in figure 7.4a at time point 1, 53 percent of the area is within 0.25 mi of a linear route (all routes, regardless of motorized use regulations), and this zone could contain large areas in which native habitats are eliminated or substantially degraded by invasive plant establishment. A variety of additional edge effects occur at varying distances from roads, with effects that vary widely among species and ecological properties and processes of interest (Forman et al. 2003).

Similarly, elk avoid areas close to roads and trails open to motorized use and select areas at longer distances from such routes (Rowland et al. 2000, 2005; Wisdom et al. 2004b). These patterns can be summarized by distance band and then related to changes in road management (table 7.2). For example, the large area of the watershed within 0.25 mi of a linear route open to motorized vehicles would be expected to receive less than 20 percent of potential use compared with areas more than 1.0 mi from open routes. This large area of low predicted elk use was substantially reduced in area at time point 2 (figure 7.4b) with additional road closures and obliterations.

Although our example uses distance bands away from roads, density estimates also can be used to monitor linear routes and evaluate their effects. For the landscape in figure 7.4, mean density of linear routes open to motorized use was 3.66/mi^2 at time 1 and 1.94/mi^2 at time point 2. Road density is a commonly used metric for setting management direction and monitoring compliance with that direction (Rowland et al. 2005). Many wildlife species are sensitive to effects of roads as measured using road density (table 7.1) (Trombulak and Frissell 2000, Wisdom et al. 2000), and thus the results of monitoring density can be directly related to potential effects on road-sensitive species like brown bear (Graves et al. 2007; Suring et al. 2004, 2006), gray wolf (Mech et al. 1988), wolverine (Rowland et al. 2003), and elk (Lyon 1983).

Although not used in our example, rates also can be used to monitor motorized use on a given linear route, which often is an important indicator of the relative effects on native species sensitive to such use. For example, the rate of motorized traffic on roads and ATV use on trails affects distributions of ungulate species like elk, because one pass of a motorized vehicle or ATV per day causes increased movement rates and flight responses (Wisdom et al. 2004a, 2004b). Thus, monitoring the rate of motorized use on roads and trails (including ATV use) to assess how many days they are used at least once by vehicles is an effective monitoring approach for predicting effects on elk, a species that increases its avoidance area from roads and trails with increasing rates of motorized uses (Wisdom et al. 2004b).

The potential interactions of climate change with effects of linear routes can be strongly positive or negative. If, for example, climate change is projected to increase the area of wet forest types from dry forest or dry grassland types, then the increased cover associated with the wet forest type may partially mitigate the effects of the linear routes. By contrast, if climate change is projected to decrease the area in wet forest types and increase the area in dry forest and dry grassland types, then the more open conditions will magnify the effects of the linear routes.

7.5.2 Example 2—Recreation

Recreational uses of national forests are increasing rapidly and represent one of the largest, most spatially pervasive sources of human disturbance on public lands (Gutzwiller and Cole 2005, Knight and Gutzwiller 1995, Reed and Merenlender 2008). Recreation consists of two basic forms: (1) linear-based recreation and (2) area-based recreation (table 7.3). **Linear-based recreation** is any form of recreation that follows a linear path, such as roads, trails, rivers, riparian zones, ridgetops, or other linear features that are conducive to human travel. **Area-based recreation** is any form of recreation that is not restricted to a linear route, but is constrained only by varying combinations of technologies, environmental conditions, and management regulations. Area-based recreation typically originates from a specific access point (e.g., a parking lot or drop-off location) and radiates outward from the point over an area conducive for the activity.

Management restrictions often dictate whether a certain type of recreation is linear or area based (table 7.3). For example, snowmobiles might be limited to specific routes, or permitted on all terrain, depending on regulations (figures 7.4 and 7.5). Similarly, backcountry skiing or snowshoeing could follow a particular trail or linear feature, but it often radiates outward from a particular access point to a larger area beyond a narrow line if terrain and travel regulations allow. By contrast, some types of recreation are always linear based or always area based. River rafting is always linear based. Helicopter skiing is always area based. Recreation effects on habitats and species differ with the type of recreation and whether it is linear or area based under the specified travel regulations and particular landscape conditions (figures 7.4 and 7.5). Effects of linear-based recreation on habitats and species resemble effects associated with highways, roads, and motorized trails (Gaines et al. 2003). By contrast, area-based recreation affects habitats and species differently, in that effects typically manifest over a larger area where recreation use is allowed. For example, snowmobiles not restricted to travel on specified trails or

Table 7.3.—*Major types of recreation on national forests and grasslands, categorized as linear-based, area-based, or both, and some example effects and supporting references.*

Type of recreation	Linear- or area-based	Example effects	Supporting references
All-terrain vehicle riding	Both	Increased movement rates and flight by elk near trails.	Preisler et al. 2006, Wisdom et al. 2004a
		Habitat degradation and loss from introduction of nonnative plants.	The Wilderness Society 2006
		Songbird nest desertion and abandonment and reduced predation on shrub nests < 100 meters from off-highway vehicle trails.	Barton and Holmes 2007
		Avoidance of use area by elk.	Preisler et al. 2006
Backcountry skiing	Area	Increased movement rates and energetic expenditure in moose exposed to backcountry skiing.	Neumann et al. 2010
Backpacking	Both	Habitat elimination as caused by development and infrastructure.	Boyle and Samson 1985
Birdwatching	Area	Fewer numbers of fledgling and nestling birds in disturbed areas.	Gehlbach and Gehlbach 2000
Campground use	Area	Increased predation of passerine bird species by jays and corvid species, resulting in population sink.	Neatherlin and Marzluff 2004
Cross-country/Nordic skiing	Both	Ungulate disturbance and flight behavior without habituation or avoidance.	Cassirer et al. 1992, Ferguson and Keith 1982
		Avoidance of use area by native ungulates.	Ferguson and Keith 1982
Downhill skiing	Both	Habitat elimination caused by development and infrastructure.	Kariel and Kariel 1988
		Species avoidance of ski areas or increased stress levels near areas.	Krebs et al. 2007, Thiel et al. 2008
Fishing	Both	Increased mortality of bear species associated with chronic, negative interactions with humans in mutual use areas along salmonid-bearing streams.	Suring and Del Frate 2002
Helicopter skiing	Area	Disruption of wild ungulate behavior.	Frid and Dill 2002
Hiking	Both	Increased movement rates and flight by ungulates near trails.	Brillinger et al. 2004, Miller et al. 1998, Taylor and Knight 2003, Wisdom et al. 2004a
		Decreased use by brown bears in sites close to trails or with higher trail density.	Goldstein et all. 2010, Suring et al. 2006
		Prey handling, maintenance behaviors declined, while contact vocalizations increased (Mexican spotted owls, Strix *occidentalis lucida*).	Swarthout and Steidl 2003
Horseback riding	Both	Increased movement rates and flight by elk near trails.	Brillinger et al. 2004, Wisdom et al. 2004a
Hunting	Both	Increased mortality of bear species associated with chronic, negative interactions in areas of mutual use with hunters.	Peek et al. 1987
		Bear avoidance of areas near to open roads because of the risk of human-caused mortality.	Brody and Pelton 1987
Mountain biking	Both	Increased movement rate and flight by ungulates near trails.	Brillinger et al. 2004, Taylor and Knight 2003, Wisdom et al. 2004a
Mountain climbing	Area	Disruption of cliff-nesting bird and large mammals that use steep topography.	Boyle and Samson 1985, Camp and Knight 1998b
Para-gliding	Area	Displacement of native ungulates.	Schnidrig-Petrig and Ingold 2001
Ocean or lake boating and kayaking	Area	Displacement of nesting shorebirds and marine mammals.	Hockin et al. 1992, Morse et al. 2006
Rock climbing	Area	Disturbance of plant communities, avian nests, bat roosts, and amphibians and reptiles along and adjacent to climbing routes.	Camp and Knight 1998a, b; Goode et al. 1995; Richardson and Miller 1997; Boyle and Samson 1985

Table 7.3.—*Major types of recreation on national forests and grasslands, categorized as linear-based, area-based, or both, and some example effects and supporting references (continued).*

Type of recreation	Linear- or area-based	Example effects	Supporting references
Snowmobiling	Both	Displacement of native ungulates.	Colescott and Gillingham 1998, Poe et al. 2006
Snowmobiling	Both	Increased stress responses in medium to large mammals or increased mortality.	Creel et al. 2002, Persson et al. 2008, Squires et al. 2007
Spelunking	Area	Elimination of bat roosts and potential extirpation of colonies in high-use areas of caves.	Boyle and Samson 1985
Trapping	Both	Overharvest of mammal species that are easily trapped such as marten, fisher, and wolverine.	Douglas and Strickland 1987, Krohn et al. 1994, Squires et al. 2007

snow-covered roads would be limited only by steepness of terrain. Consequently, large areas would be affected by snowmobiles in landscapes dominated by gentle terrain (figure 7.5). Similarly, helicopter skiing would affect all areas that could be skied from the point of access.

Recreation effects are multifaceted and often not easily recognized (Gaines et al. 2003, Knight and Gutzwiller 1995) (tables 7.1 and 7.3; chapter 4, figure 4.4). The increased human contact with many species of wildlife can result in negative interactions, such as increased mortality of brown bears near campgrounds or hiking trails in which contact with humans is more frequent (Merrill et al. 1999), or increased mortality of bats in caves in which spelunking activities occur (Nagorsen and Brigham 1993). Some species are relatively adaptable to recreational disturbance, however. For example, the probability of flushing for vesper sparrows (*Pooecetes gramineus*) was only 0.10 for a pedestrian walking alone on a trail 27 m (89 feet [ft]) away (Miller et al. 2001). Many effects are difficult to recognize, such as increased nest predation by corvids on other birds near campgrounds or human settlements, owing to enhanced survival of corvids in sites with human-subsidized food sources such as garbage (Leu et al. 2008, Luginbuhl et al. 2001, Marzluff and Neatherlin 2006). Consequently, many types of recreation often have been ignored as part of human disturbance monitoring on NFS lands, but they clearly warrant more attention because of their widespread, multifaceted effects on habitats and species (table 7.3).

Monitoring

In this second example, the human disturbance selected for monitoring (step 1) is winter snowmobile use of the same landscape in which summer motorized routes were monitored for example 1 (figure 7.5). Rationale for selecting snowmobile use for monitoring is a combination of factors described previously for process step 1 (section 7.3).

The appropriate spatial extent for management is the watershed (step 2), or 5th hydrologic unit code (Wisdom et al. 2000), because this is the spatial extent at which forest activities are planned, implemented, and monitored in this case. Spatial grain is dictated by the 10-m (33-ft) resolution digital elevation map used to characterize slopes in the watershed and the vector layer of roads available from the ranger district in which the watershed is located. Slope estimates and road locations from these sources are assumed to be accurate to within 1 to 2 percent and 3 to 7 ft of true values, respectively, based on **accuracy assessments** associated with spatial layers.

Past regulations allowed snowmobile use over the entire area, with no restrictions regarding the number of snowmobiles allowed in the watershed. In the past, snowmobile use was sparse, but anecdotal evidence suggests that use has increased substantially since forest plan implementation. Consequently, context and targeted monitoring of actual snowmobile use is warranted (step 3), given the potential effects on habitats and species and new management direction for snowmobile use established in the revised forest plan.

The metrics identified for monitoring (step 4) are (1) the percentage of watershed area over which snowmobiles can traverse and (2) the daily rate at which snowmobiles enter the watershed. These two metrics were selected because management direction in this watershed has established thresholds based on these metrics for managing snowmobile use in watersheds in which emphasis species sensitive to human activities during winter are featured in management. The first threshold is the area within a watershed that can be traversed by snowmobiles; specifically, if more than 50 percent of the watershed can be traversed by snowmobiles, the watershed will be monitored for a second threshold. The second threshold is that snowmobile use will average no more than six to eight machines per weekend day and no more than four to six machines per weekday, as estimated by vehicles and snowmobile trailers in parking lots that provide access to such watersheds. If these two thresholds are exceeded, then snowmobile use will be restricted in the future to designated linear routes to minimize effects on emphasis species sensitive to winter motorized use.

To assess these thresholds as part of monitoring (step 5), a digital elevation map (DEM) is first used to identify all areas with slopes less than 30 percent, which defines areas assumed to be consistently traveled by most snowmobile users (figure 7.5). Results indicate that typical snowmobile users can traverse 78 percent of the watershed (table 7.3). This result, in turn, requires monitoring the number of snowmobiles entering the watershed to evaluate the second threshold.

At least two time points are used to monitor number of snowmobiles entering the watershed (step 6). Time point 1 is the winter during the first year of forest plan implementation, when no restrictions on snowmobile use are in effect because no data related to management have been collected. Time point 2 is 5 years after forest plan implementation. Counts of vehicles with snowmobiles in parking lots that access the watershed during time point 1 indicate that daily use averages one to two machines per weekday and two to three machines per weekend day (step 7). At time point 2, counts of vehicles at the same parking lots average two to three machines per weekday and four to six machines per weekend day. As a result, no change in management direction is warranted. Continued monitoring of snowmobile use is deemed appropriate, however, because counts at time point 2 have increased relative to time point 1 and are slightly less than the second threshold (step 8). Results from this monitoring process can then be considered in tandem with results from monitoring of other human disturbances, such as housing developments on adjacent ownerships (step 9, next sections and section 7.5.4).

Estimating Effects

Monitoring recreation activities and estimating their effects are challenging because of the many types of recreation and different ways in which recreation is managed. Knowledge of whether a certain type of recreation is linear or area based, however, helps guide the choice and use of a monitoring approach. For example, monitoring use of snowmobiles and estimating effects can be accomplished under two sets of management regulations: (1) all or most areas open to snowmobiles from a specific access point (area-based use, figure 7.5) or (2) all areas closed to snowmobiles except those trails designated as open (linear-based use, figure 7.4). In our monitoring example, snowmobile use was area based but could have changed to linear based had management triggers been exceeded based on monitoring results. In the latter case, the linear-based effects zones for winter snowmobile use would be similar or equivalent to those for summer motorized use, depending on the degree of similarity of linear routes open to motorized uses in the summer versus winter.

In the two contrasting examples shown in figures 7.4 and 7.5, management that restricts summer motorized use to linear routes results in a substantially smaller landscape effects compared with winter area-based travel. Under area-based travel, snowmobile use is restricted only by the technological capabilities of the machine, combined at times with vegetation that restricts travel, resulting in a substantially larger use area and, in turn, a greater area of negative effects on species and habitats, in contrast to linear-based use. Under linear-based summer motorized use, approximately 50 percent of the landscape is within 0.5 mi of a linear route open to motorized vehicles at time point 2 (table 7.3, figure 7.4b). By contrast, area-based snowmobile use in this same landscape results in nearly 100 percent of the landscape within 0.5 mi of areas open to motorized use (table 7.2, figure 7.5). Consequently, resulting effects on wildlife would likewise be different, with a more narrow effect zone under linear-based use and an extremely wide zone under area-based use (figures 7.4 and 7.5). Emphasis species that avoid snowmobiles or experience increased stress associated with snowmobile use are likely to be negatively affected by the higher frequency of snowmobiles entering the watershed, combined with the large area over which snowmobile use is possible, in an area-based management strategy (e.g., Creel et al. 2002).

The contrast between linear-based versus area-based disturbances in the first two examples typifies the use and effects associated with monitoring any motorized travel. That is, use will be restricted to a smaller portion of the landscape under linear-based travel and greatly expanded under area-based travel, with resultant effects that are substantially more negative when travel is area based. The example also applies conceptually to terrestrial, nonmotorized uses such as mountain biking, backpacking, and horseback riding, which are rarely restricted to linear routes, but typically are concentrated along linear routes.

The previous example features additional monitoring to directly estimate snowmobile use or other forms of motorized use at access points such as parking lots (Poe et al. 2006). Further monitoring of actual use can be achieved through surveys of users, aerial counts in use areas, cameras, or traffic counters installed at key use points along the linear routes or common use areas.

The potential interactions of climate change with effects of recreation can be strongly positive or negative. If, for example, climate change is projected to substantially decrease winter snowpack in the watershed in which snowmobile use occurs, this effect may reduce the length of time that snowmobile use may occur each winter, thus reducing the effect of this recreation activity on emphasis species that may be sensitive to this activity. By contrast, if climate change is projected to increase winter snowpack in the watershed, then snowmobile use is likely to occur over a longer period each winter, increasing the potential effects on sensitive emphasis species.

7.5.3 Example 3—Housing Developments Within and Near National Forests

Loss of open space on private lands near national forests was identified by the Forest Service as one of four key threats to NFS lands (USDA Forest Service 2006b, 2007). Actions that eliminate open space, such as housing and other human developments, can directly affect ecosystem services provided by wildlands, such as wildlife and aquatic habitats, timber, and recreation (Stein et al. 2005, 2007). Housing construction in less populated sites outside urban areas has accelerated in recent years, especially near public lands, and is expected to continue (Hansen et al. 2005, Radeloff et al. 2010, Talbert et al. 2007, Wade and Theobald 2010), especially in Southern and Western States (Hammer et al. 2009). For example, the number of housing units within 50 kilometers (km) (31 mi) of national forests increased from 9.0 million units in 1940 to nearly 35 million units by 2000 (Radeloff et al. 2010). In some areas, however, such as the southern Rocky Mountains, nearly one-half of the lands adjacent to public lands are private grazing lands owned by ranchers holding Federal grazing permits. This juxtaposition offers opportunities for cooperation to retard the conversion of ranchlands to rural housing (Talbert et al. 2007).

Any human habitation and associated structures, such as outbuildings and transmission lines, can lead to habitat loss and degradation. Common effects include (1) elimination and fragmentation of wildlife habitat, (2) spread of invasive or nonnative species into plant and animal communities, and (3) increased risk of wildfire from higher fuel loads and greater potential for ignitions (Butler et al. 2004; Gavier-Pizarro et al. 2010a, 2010b; Hansen et al. 2005; Plantinga et al. 2007; Radeloff et al. 2005; Stein et al. 2005, 2007; Theobald et al. 1997). Human habitation also increases the risk of fire in the wildland-urban interface (WUI), thus adding to the potential loss of habitat. Fire risk in the WUI is likely to increase substantially in the future (Cardille et al. 2001, Syphard et al. 2009).

Human disturbances associated with housing development can also lead to avoidance of otherwise suitable habitat by wildlife (Hansen et al. 2005, Theobald et al. 1997, Vogel 1989). Traditional wildlife migration routes or travel corridors may be altered following construction of housing in rural areas (Sawyer et al. 2005), and human-subsidized predators, such as dogs and cats, near housing developments can alter wildlife behavior, resulting in changes in habitat use patterns or activity levels (Lenth et al. 2008, Maestas et al. 2003). Moreover, many species avoid roads open to motorized use (Forman et al. 2003, Wisdom et al. 2000), which are often constructed as part of housing development

(Hawbaker et al. 2005, Mitchell et al. 2002). Recreational use of public lands near housing developments, in general, is greater than in undeveloped areas and can diminish use of these areas by wildlife species that are sensitive to disturbance (Theobald et al. 1997).

Increases in human population and housing density within or near public lands also may directly reduce or eliminate local populations of wildlife species, with concomitant decreases in biodiversity or biotic integrity (Germaine et al. 1998; Glennon and Porter 2005; Hansen et al. 2005; McKinney 2002, Rottenborn 1999). Negative effects on wildlife population can be caused by predation from domestic cats and dogs; poaching; collisions with vehicles; or human-wildlife conflicts resulting in removing or euthanizing wildlife (Coleman and Temple 1993; Kretser et al. 2008; Lepczyk et al. 2003; Maestas et al. 2003). All of these negative effects occur at a higher frequency on public lands near housing developments, in contrast to public lands with no housing nearby.

Housing density, in particular, affects many other environmental conditions, such as degree of invasion by nonnative plants, area affected by roads, and habitat fragmentation. Moreover, housing density provides a more accurate measure of land use change from human encroachment than does human population density. Household size has been trending lower for 70 years, so that a given increase in population now results in a larger increase in number of homes (Radeloff et al. 2005). In addition, the population census does not count seasonal residents; by contrast, the housing census does count seasonal homes. Taken together, these factors and others make housing counts and trends better suited for measuring human impacts on forest and rangeland resources than do human population counts and trends (Liu et al. 2003).

Housing developments in and near NFS lands can be monitored with the same types of metrics (i.e., distance, density, and frequency or rate) used for other estimates of human disturbance monitoring. For example, distance bands surrounding housing developments can be used to (1) estimate overlap of the bands with NFS lands (figure 7.6) or (2) estimate the density or number of houses within certain distances of NFS lands (Gimmi et al. 2011, Radeloff et al. 2010). In other cases, the frequency of recreational or motorized use of NFS lands within certain distances of houses or associated with different levels of housing density can be monitored as a more direct measure of human activities associated with housing.

Monitoring

The disturbance agent in this monitoring example is housing development on private lands near and within NFS lands (step 1, figure 7.6). This disturbance has been increasing in this national forest, especially in the form of vacation homes, and is of special concern to management because of predicted impacts of increased recreational use on species of concern. In this example, all housing units, whether primary or secondary homes, are included in monitoring. The proposed monitoring is context based (step 2), in that the Forest Service cannot explicitly manage development on private lands. The agency may be able to use knowledge of this type of development (e.g., existing and projected housing densities), however, to better manage wildlife habitat and populations on NFS lands influenced by this disturbance agent. For example, corridors for movement or connectivity between metapopulations could be identified, established, or enhanced on public lands as mitigation for nearby housing effects on private lands.

The spatial extent for monitoring housing is the watershed (step 3), which is the extent at which forest activities have been planned and implemented in this example. In many cases, a watershed or other large spatial extent contains a mix of public and private lands, as is the case in our example. Monitoring housing development on all private lands, inside and outside the watershed boundary, is therefore important. In our example, any house within 5 mi of NFS lands in the watershed is included in the monitoring. The actual distances chosen for monitoring, however, can be much greater and depend on the specific monitoring objectives. If, for example, the cumulative effects of larger urban areas are of interest, then monitoring the development of housing and different densities and types of developments at greater distances (e.g., 30 mi) from NFS lands may be important to consider as part of the monitoring design.

In our example, spatial grain is dictated by two main data sources used for monitoring housing units: (1) maps based on U.S. Census Bureau data on housing density in the vicinity of the watershed and (2) aerial photographs used to identify houses within the watershed and up to 5 mi from the watershed boundary. A grain of 1 to 2 m (3.3 to 6.6 ft) is adequate for identifying houses from remote sensing imagery, such as National Agriculture Imagery Program (NAIP) photography (Leinwand et al. 2010; also see text in the following section and chapter 4, section 4.5.1). If census block data are used, the block is the minimum mapping unit (Warnick et al. 2005).

The metric selected to assess effects of housing in this example is the area of NFS lands within distance bands surrounding each housing unit (step 4; figure 7.6). This metric is a measure of the proximity of any housing and associated effects in relation to NFS lands in the watershed. Data sources for this metric (step 5) include spatial data on housing density available from the U.S. Census Bureau and a forest-generated map, based on interpretation of aerial photography as described previously. An accuracy assessment of these methods of mapping house locations indicates that most houses can be identified on aerial photographs, but using aerial photographs may underestimate the number of houses. Use of aerial photographs to estimate number of houses is similar to spatial depictions of road locations, which typically underestimate the total number of roads present. Nonetheless, as with road layers, estimates of housing density are highly correlated with the true number of houses present in a given area and, thus, are useful in monitoring trends over time, assuming that houses are mapped with the same level of accuracy over time (i.e., degree of mapping bias remains unchanged over time). This assumption would need to be tested as part of the monitoring effort.

Monitoring in this example is at 5-year intervals (step 6). The first period of data collection, time point 1, was 5 years before the current time. Time point 2 is the current period.

Monitoring results for time point 1 indicate that a large percentage (84 percent) of the watershed is at least 1.0 mi from the nearest house (step 7; table 7.2, figure 7.6a). Results for time point 2 indicate that a much smaller percentage of the watershed is in this distance band, with only 52 percent of the watershed more than 1.0 mi from housing. New housing developments that are located on private inholdings, within the watershed and adjacent to the watershed boundary, account for the increase in area affected by housing (table 7.2, figure 7.6b). These results indicate a trend of increasing rural housing development.

Results from monitoring the area in distance bands relative to the nearest house indicate that continued monitoring of human development is warranted, given the rapid encroachment of housing near NFS lands in this watershed. Management direction in this watershed may need to be altered to accommodate the decreasing habitat quality for emphasis species sensitive to human disturbance (step 8). We combined these results with those for monitoring linear routes open to motorized use and areas used by snowmobiles in the watershed to better understand the cumulative effects from all three human disturbances (step 9, section 7.5.4).

Other methods and larger spatial extents, such as a district or one or more national forests, may also be used to monitor human developments, given that the potential effects are local (e.g., stand and watershed) and regional (e.g., district, forest, and region) in extent. For example, Stein et al. (2007) used three classes of housing density to evaluate trends in housing development adjacent to all national forests in the United States—the rural I class (less than or equal to 16 houses/mi^2), the rural II class (17 to 64 houses/mi^2), and the exurban/urban class (more than 64 houses/mi^2). One approach to using these categories is to quantify the area in each of these three zones within a specified distance; e.g., 15 mi from the boundary between NFS lands and private lands. Shifting proportions of these categories, such as increases in the area in exurban/urban, would indicate the need for more explicit monitoring of housing and associated roads in private lands adjacent to NFS lands. Radeloff et al. (2010) used two buffers or distances, 1 km (0.6 mi) and 50 km (31 mi), to report housing growth near all national forests, in absolute numbers of houses and decadal growth rates.

Estimating Effects

After spatial data on housing are obtained, either from existing data or through imagery, as described previously, estimating the area affected by houses can be accomplished in a Geographic Information System (GIS) by creating circular buffers or distance bands around each point location for houses (figure 7.6). The radius of the buffer reflects the disturbance zone, or distance to which effects of housing developments on habitat or behavior of the emphasis species are believed to occur (Leinwand et al. 2010, Odell et al. 2003, Theobald et al. 2007). The size of the disturbance zone, similar to analyzing road effects, depends not only on the emphasis species but also on housing proximity, housing density, and the spatial pattern of housing; that is, whether houses are clustered or distributed uniformly throughout the monitoring area (Rowland et al. 2000, 2005; Theobald et al. 1997). Emphasis species will vary in their response to housing development. For example, deer (*Odocoileus* spp.) in Montana avoided houses up to 2,400 m (1.5 mi) away, and relative use by deer declined substantially when housing density exceeded 10/mi^2 or when 1 to 10 houses were within 800 m (0.5 mi) (Vogel 1989). By contrast, gray foxes (*Urocyon cinerioargenteus*) in areas of New Mexico tolerated rural housing densities as high as 50 to 125 homes/km^2 (130 to 325 homes/mi^2) (Harrison 1997). The user must also decide if pixels located within multiple disturbance zones (i.e., influenced by more than one house) need to be weighted more in calculations of total area affected. If little data exist about the disturbance zone for a species, a range of radii can be used to generate maps of various effect scenarios.

The total area of NFS lands affected by housing then can be quantified within an area tailored to the monitoring objectives. For example, if habitat for an emphasis species occurs on a local management unit close to houses on nearby private lands and estimated effects extend up to 1.0 mi from houses, then the analysis area needs to extend inward at least 1.5 mi from the boundary between the local management unit and private lands. The distance from the boundary for which effects are summarized can be adjusted to meet monitoring objectives and account for other potentially synergistic disturbances, such as traffic on roads.

A key challenge for monitoring housing developments and associated effects is to accurately identify the location of all houses. For example the U.S. Census Bureau does not record specific locations of housing units within each parcel or census block; thus, the distribution of housing units within the blocks (e.g., random, even, or clustered) is unknown. The coarse spatial resolution of census data is problematic, because the spatial pattern of development can strongly influence the potential area affected by this disturbance (Theobald and Hobbs 2002, Theobald et al. 1997). Therefore, some knowledge of prevalent housing patterns in the vicinity is useful. Housing density data from county assessor offices, in general, are even more coarsely georeferenced, typically only to the nearest section (i.e., 640 acres) or quarter-section; however, they may provide broad-scale information for baseline monitoring or help stratify the area for sampling housing density. For example, Glennon and Porter (2005) used tax parcel data from the State of New York to determine residential housing density within sampling blocks in Adirondack Park while investigating biotic integrity of bird communities in relation to human development.

Housing density can be monitored with existing data, obtainable from a variety of public sources such as (1) decennial or annual American Housing Survey data collected in conjunction with census block data (http://www.census.gov/housing/ahs/) or (2) information from county assessor offices, which maintain building records for tax purposes (Saving and Greenwood 2002, Theobald et al. 1997, Warnick et al. 2005) (step 4). Census-derived data on housing densities are georeferenced to census blocks (smallest unit), which differ in size across the country and may be too coarse-grained to meet local monitoring objectives (Warnick et al. 2005). In addition to the decennial census data, estimates of housing density are included in the Census Bureau's annual population survey. If existing and future census data meet the goals of the monitoring program, then no new data on housing are needed.

To obtain new data on density of housing and related structures for a monitoring program, we recommend using a combination of remotely sensed data and GIS software (Warnick et al. 2005). An advantage of obtaining data from remote sensing is that all structures, not only houses, can be accounted for. Remote sensing imagery also can be used for targeted sampling in key areas of concern, in which housing growth is of special interest. For example, NAIP imagery (chapter 4, section 4.5.1) can be used in tandem with either hand-digitizing or image-processing software to count housing units visible on the image (Laes et al. 2007, Warnick et al. 2005; chapter 4, section 4.5.2, Image counts and observations, and figure 4.1). Laes et al. (2007) compared manual digitizing versus semiautomated image-processing software using 1-m (3-ft) natural color NAIP photography to estimate the number of structures and found that manual digitizing was more accurate and repeatable. Semiautomated approaches work well when structures are consistent in color, shape, and surrounding vegetation patterns, as in many suburban subdivisions. Populated areas within the WUI, however, often are characterized by dispersed structures of many types, embedded in a variety of different vegetation patterns. One difficulty in identifying structures with any image source is that trees in densely forested environments can obscure the structure from view, which often occurs in the WUI (Laes et al. 2007, Saving and Greenwood 2002, Warnick et al. 2005). LIDAR (see chapter 4, section 4.5.1) is another potential source of remotely sensed data for locating housing structures (Warnick et al. 2005); however, initial tests using this method with LIDAR Analyst were somewhat unsatisfactory owing to high omission errors (Laes et al. 2007).

The potential interactions of climate change with housing development can be strongly positive or negative on habitats for emphasis species. For example, if climate change is projected to significantly increase the duration of summer drought and warmer temperatures in the watershed, the vulnerability of associated dry forest and grassland communities to wildfires could increase dramatically. Frequency of human-ignited fires is higher in areas of human habitation (Syphard et al. 2009). Thus, an increase in housing near NFS lands under this climate scenario could magnify effects of wildfire on emphasis species whose habitats are not fire-dependent. Species whose habitat requirements include recent burns and early seral stages, however, may benefit from the interactive effects of climate change with housing development.

7.5.4 Consideration of Effects From Multiple Human Disturbances

Monitoring and evaluating the combination of different human disturbances operating in a given area are important because the cumulative effects from multiple disturbances may be substantially greater than the effects from individual disturbances. One method of analyzing the combination of results from monitoring multiple human disturbances involves a variation of human footprint analysis (Leu et al. 2008, Sanderson et al. 2002). This method includes six steps.

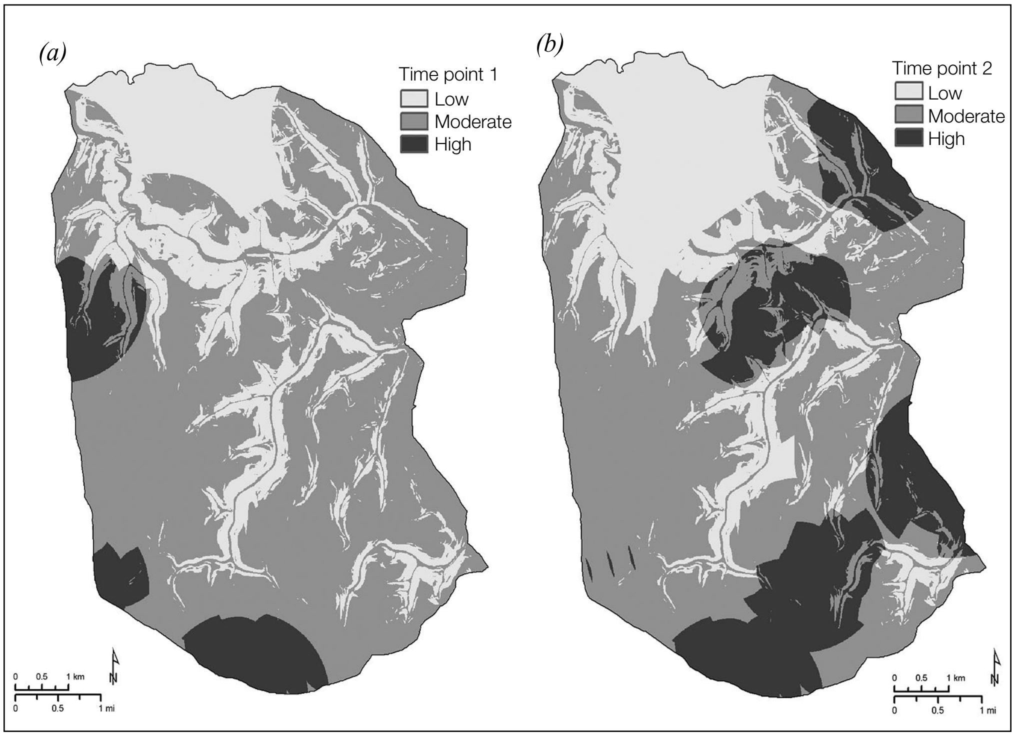
1. Rank conditions from best to worst for a given human disturbance, area, and time. For example, assign ranks to the distance bands buffered from linear routes or housing developments for a specific watershed and time, with the ranks representing different effect zone categories (e.g., category 1 representing the worst scenario; i.e., the distance band closest to a linear route or house, and increasingly higher ranks representing progressively less effect for more distant bands).
2. Overlay maps of the rankings from multiple disturbances on one another for the watershed and time point, such as a watershed map of the ranked distance bands for nearest linear routes with a watershed map of the ranked distance bands for housing.
3. Sum the ranks among all disturbances for each pixel in the landscape. For example, a given pixel may be immediately adjacent to an open linear route and have a ranking of 1 but be more than 2 mi from the nearest house and have a ranking of 5, resulting in a cumulative rank of 6 when considering the combined effects of human disturbance for the pixel.
4. Group the cumulative ranks into categories of environmental conditions or effects for the area and time, and map the categories. For example, pixels with a cumulative rank of 2 through 4 (depending on the number of disturbances considered simultaneously), considering the combination of linear routes and housing development, might be grouped as a condition of high effect, with progressively higher ranks grouped into conditions of moderate or low effect.
5. Calculate the percentage of area in each environmental condition for the time point and repeat the process for one or more additional time points.
6. Evaluate the trend in conditions across time, such as whether the percentage of area in a condition of low or high effect has increased or decreased substantially, indicating whether the cumulative effects from the combination of disturbances have increased or decreased over time.

We applied these steps to evaluate the combined monitoring results from our three examples of linear routes, snowmobile use, and housing developments (table 7.4, figure 7.7).

Table 7.4.—*Combined effects of three human disturbance agents in a hypothetical watershed at two time points. Effect categories are as follows—low (pixels with cumulative ranks ranging from 11 through 15), moderate (cumulative ranks ranging from 7 through 10), and high (cumulative ranks ranging from 3 through 6); see text for details.*

Effect category	Percentage of watershed	
	Time point 1	Time point 2
Low	29	28
Moderate	63	52
High	8	20

Figure 7.7.—*Sum of ranks from effects zones based on linear routes, snowmobile use, and housing developments for time point 1 (a) and time point 2 (b). The highest effect (i.e., greatest disturbance) zone is assigned a rank of 1, with increasing ranks for lower effect (defined by the number of the zone farthest from the human disturbance). The ranks in each pixel were summed, and pixels were then placed into three equal categories of low, moderate, or high effect.*



For each of the two time points, we assigned a rank of 1 (highest effect) to the distance band closest to linear routes, with the next-closest band assigned a rank of 2, and so on, through the farthest (fifth) distance band (rank = 5). We assigned these same ranks to distance bands in relation to housing developments. Similarly, we assigned a spatial rank of 1 (highest effect) for areas traveled by snowmobiles and a spatial rank of 5 for areas inaccessible to snowmobiles. For each time point, we then summed the ranks from the three human disturbances for each pixel in the watershed; grouped pixels into categories of low, moderate, or high cumulative effects; mapped the groups (figures 7.7a and 7.7b); and calculated the percentage of area of the watershed in low, moderate, and high cumulative effects categories for each time (table 7.4).

Trends in the three cumulative effects categories show that area in moderate effect declined and area in high effect increased (table 7.4, figures 7.7a and 7.7b). Thus, cumulative effects have increased over time. This increase in cumulative effects can be attributed to an increased amount of housing development because this disturbance was the only agent that increased in effect from time point 1 to time point 2. By contrast, linear routes declined in effect from time point 1 to 2 and snowmobile use remained the same across the two times.

These results have important management implications. First, housing development occurs on private lands, not public lands, and thus its effects cannot be mitigated directly by the Forest Service. Instead, the increased cumulative effects stemming from increased housing development can be mitigated only through further reductions in linear routes or reductions in snowmobile use, each of which is under management control of the Forest Service. Second, the importance of monitoring the effects from forest management (linear routes and snowmobile use) as well as off-site human activities (housing development) is obvious. That is, without monitoring the changes in housing development in relation to NFS lands, results from monitoring the other human disturbances would have suggested that trends in cumulative effects were positive or benign, with substantially different implications for Forest Service management. Third, many different types of human disturbances warrant monitoring, because a variety of human disturbances now affects most NFS lands. That is, the traditional effects on public lands from silviculture, livestock grazing, mining, and fire management remain as important human disturbances to monitor, but a plethora of emerging or common additional human disturbances are now exerting widespread effects on habitats and species on private and NFS lands in an interactive way (Czech et al. 2000). These additional human disturbances include linear routes open to motorized uses; all forms of recreation; housing developments; energy developments; establishment of NNIS; and power lines, communication towers, and related infrastructure.

Consideration of combined effects from multiple human disturbances, as with monitoring of individual disturbances, typically requires longer periods and more than two time points to accurately document trends. Our examples in this chapter, using two time points for evaluation, illustrate a monitoring process that usually requires estimates over multiple points in time, or over longer periods of continuous monitoring. Without monitoring conducted multiple times and over an appropriate temporal extent, detecting a meaningful trend of the targeted human disturbances may be impossible.

7.5.5 Conclusions

One key responsibility of land management agencies is to monitor and manage human activities. Most wildlife monitoring programs in land management agencies, however, have focused solely on monitoring either populations or the vegetation components of habitat. These past approaches have typically overlooked the significant role played by human disturbance agents in changing the quantity and quality of habitat. Past approaches also have overlooked the many direct effects of human disturbances on populations. This chapter addressed this topic in a manner directly relevant to management. We illustrated, through practical and relevant examples, how metrics of distance, density, and rate can be used to monitor human disturbances of interest in relation to wildlife species and their habitats. These examples, and the associated methods, can be efficiently incorporated into new monitoring designs for Forest Service management to address potential effects of a variety of human disturbances on species and habitats.

Human disturbance monitoring for management of wildlife species and their habitats, however, is a challenging and complex process. The large number of potential species to be monitored, the varied and many types of human disturbances that affect these species, and the different spatial and temporal scales at which monitoring occurs, all are factors that add to the challenge and complexity. Further complicating these challenges is the lack of resources needed for the work. As with many long-term management issues, it is difficult to implement monitoring programs that must occur over multiple time points that span multiple funding cycles. Despite these challenges, the long-term investment in such a monitoring program is expected to result in more effective, efficient, and defensible management of habitats for emphasis species. Moreover, given the legal, sociopolitical, and economic issues that typically are associated with managing emphasis species, the investment in human disturbance monitoring is well justified.