Estimating the cumulative effects of development on wildlife habitat

David M. Theobald [a,*], James R. Miller [b], N. Thompson Hobbs [a,c]

[a] Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, CO 80523, USA
[b] Graduate Degree Program in Ecology / Department of Biology, Colorado State University, Fort Collins, CO 80523, USA
[c] Habitat Research Section, Colorado Division of Wildlife, 317 W Prospect Rd., Fort Collins, CO 80526, USA

Abstract

The cumulative effects problem in natural resource management and land use planning stems from the difficulty of demonstrating that while each single land use change results in a negligible impact, the accumulation of these individual changes over time and within a landscape or region may constitute a major impact. This paper details a general approach to estimate the cumulative effects of land use change on wildlife habitat using Summit County, CO, USA as a case study. Our approach is based on a functional relationship between effect on habitat and distance from development. Within this building-effect distance, habitat is assumed to be degraded, producing a disturbance zone. We sum the total area within the disturbance zone and track how it changes over time and in response to different land use planning actions. This method is sensitive to both housing density *and* spatial pattern, so that the relative effects of clustered development can be evaluated. Two factors are important in understanding how development potentially degrades habitat: alteration of habitat near buildings and roads and landscape fragmentation. Our results show clustered development reduces the negative impacts on wildlife habitat. For large building-effect distances, spatial pattern was found to be a stronger indicator of disturbance than density. Efforts to decrease habitat disturbance by lowering development density should include the regulation of subdivision pattern in addition to decreasing density. © 1997 Elsevier Science B.V.

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1. Introduction

Land use planning decisions are generally made, especially at the local or county governmental level, within a framework which recognizes two approaches to planning: comprehensive or master planning (long-term); and development review (short-term). Comprehensive plans provide a consistent land use policy in an attempt to ensure meeting general public goals such as 'maintenance of quality of life.' These plans then guide day-to-day development review and decision making. Making good decisions singly, however, does not necessarily guarantee that overall land use goals will be met. This is commonly known as the cumulative effects problem, or the 'tyranny of small decisions made singly' (Kahn, 1966), which results from the difficulty of demonstrating that while each single land use change re-

* Corresponding author.

sults in a negligible impact, the accumulation of these individual changes over time and within a landscape or region may constitute a major impact. While a formal cumulative impact analysis requires evaluating indirect and synergistic effects (Stakhiv, 1988), simply accumulating many individual decisions over space and time can provide substantial insight into the likely cumulative results of these decisions.

Understanding and evaluating the cumulative effects of land use decisions on wildlife habitat is thus an important and challenging problem. This paper details a general approach to estimating the cumulative effects of land use change on wildlife habitat. Our approach is rooted in the SCoP (A System for Conservation Planning) project (Hobbs et al., 1997), which provides planning tools to aid county officials, citizens, and developers in making informed decisions regarding the potential effects of residential development on wildlife habitat. SCoP was developed in response to the rapid population growth rates that are causing substantial agricultural to residential land use changes in rural Rocky Mountain counties, where population increased three times faster than the rest of the United States from 1990 to 1995 (an annual rate slightly greater than 3%) (Theobald and Riebsame, 1995). Even though the proportion of private land in these counties may be as little as 5%, private lands contain a disproportionate amount of high quality wildlife habitat (Knight, 1994). The resulting residential development causes extensive changes in land use and cover that constitute the foremost threat to intact, high quality wildlife habitat. The loss, degradation, and fragmentation of wildlife habitat resulting from rapid residential development and associated infrastructure (roads, utilities, etc.) at the urban/rural, and even rural/wildland, interface is a prime example of the cumulative effects problem.

In this paper, we first identify factors associated with residential development that contribute to habitat degradation. Next, we examine common development patterns and compare clustered and dispersed subdivisions to illustrate the importance of pattern in determining impacts. We then introduce the concept of a disturbance zone, which is a function of both development density and spatial pattern, and develop a functional relationship between density, with pattern variations, and area of habitat disturbed. This hypothetical model is further evaluated and modified in light of empirical data on building locations and patterns. Finally, we suggest some implications of the cumulative impacts of development and the aggregation of development patterns at landscape and regional scales.

2. Effects of development on wildlife and wildlife habitat

Development affects wildlife habitat directly and wildlife indirectly. Native vegetation is often removed during construction of buildings and roads and as a result of landscaping activities. The structure of native vegetation is also frequently altered. For example, trees within 50 meters of a house are thinned to create a 'defensible space' against wildfire (Colorado State Forest Service, no date). Alteration of native vegetation may determine what wildlife species are found in an area. For example, the diversity of native bird species in urban areas has been found to be largely dependent on the amount of native vegetation present (e.g., Mills et al., 1989; Sears and Anderson, 1991). The amount of fencing generally increases with development, which tends to inhibit species movement. While fences that enclose pets are beneficial, other fences, especially those around the property perimeter and of chain-link construction, inhibit the movement of many mammal species.

Development may affect wildlife indirectly through human activities. Seemingly benign recreational activities such as hiking may cause some species to alter their activity and feeding patterns, which may have nontrivial consequences. Animals typically take flight, or 'flush,' in response to a human presence, incurring energetic costs associated with heightened metabolic rates (stress) and evasive movement (Gabrielson and Smith, 1995). For many species of birds, flushing may result in nest evacuation or abandonment (White and Thurow, 1985; Hockin et al., 1992) or nest predation. Some wildlife may exhibit a learned 'avoidance behavior' (Whitcomb et al., 1981) and maintain some distance from development. Flushing distances can range from 15 to 300 m for elk (Schultz and Bailer, 1978; Cassirer

et al., 1992), 100 to 300 m for mule deer (Ward et al., 1980; Freddy et al., 1986), 15 to 45 m for some waterbirds (Rodgers and Smith, 1995), and 40 to 300 m for grassland raptor species (Holmes et al., 1993). The distance from disturbance at which an animal flees depends on the nature of the disturbance, individual animal, habitat type, and season. Flushing distances can be used to establish 'buffer' or set-back distances, a minimum distance at which a species is unlikely to take flight. One method to calculate the set-back distances for colonial waterbirds uses the mean flushing distance, plus one-half the mean, plus 40 m (Rodgers and Smith, 1995).

Small to mid-sized predators (e.g., cats, dogs) often exist at high densities in human-dominated environments because of the variety of structures that serve as shelter and the abundance of feeding opportunities (Hoffman and Gottschang, 1977; Haspel and Calhoon, 1989). These 'subsidized predators' feed on small mammals, amphibians, reptiles, and songbirds, and can have a substantial impact on native species (e.g., Churcher and Lawton, 1987; Coleman and Temple, 1993). These animals may continue to take wildlife long after the prey base can no longer sustain a predator that relies on wildlife alone for food (Soulé et al., 1988).

Development does not affect all species equally. Not surprisingly, species with a long history of coexistence with humans (e.g., house sparrow, *Passer domesticus*, and house mouse, *Mus musculus*) and those able to take advantage of unique feeding or nesting opportunities (e.g., raccoon, *Procyon lotor*, and house finch, *Carpodacus mexicanus*) tend to thrive in developed areas. Other species tend to be displaced by development, either because their habitat requirements are not met (Beissinger and Osborne, 1982), or as a result of increased human presence and attendant habitat modification (Engels and Sexton, 1994).

Although species that thrive in human-dominated environments have been termed 'generalists,' the situation is not so simple. The gray fox (*Urcoyon cinereoargenteus*), usually considered to be opportunistic-generalist species, avoid using suitable habitat in areas with housing densities as low as 1 unit per 13 ha (1 per 33 acres) (Harrison, 1997). Furthermore, even though a species may occupy a particular developed area frequently, it does not necessarily follow that the species thrives there. For example, elk (*Cervus elaphus*) are commonly found in rural residential areas adjacent to wildlife refuges (e.g., Estes Park, CO) because of prohibition of hunting and the high-nutrient forage available. It is not clear, however, that these apparent gains counter increased incidence of disease and increased stress levels. Until proven otherwise, we presume that habitat similar to that in which a species evolved best supports the overall health and vigor of a species.

The impacts of development on wildlife are poorly documented, and much of the research that has been done focuses on game species. Thus, we are forced to extrapolate from relatively short-term (2–3 yrs) studies on game species in nondeveloped areas. Our strategy for developing a reasonable approach that captures the main effects associated with development (and associated human activities) is based on well established ecological principles, has few data requirements, can be parameterized for individual species, and can be refined in light of future research.

3. Development density and pattern

Our approach is based on a functional relationship between the effect of development on habitat and distance from the source of disturbance. For example, Vogel (1989) found that deer avoided developed areas, and this avoidance zone extended as far as 1 km. Based on the premise that the magnitude of human-related effects decreases with distance from the source of disturbance, we assume that within some distance of a housing unit (e.g., 50–500 m) the habitat value is degraded. This *building effect* is the distance within which wildlife habitat is adversely affected. It is similar to the edge effect concept, where changes in the environmental conditions at the patch edge reduce the effective area for patch-interior species (Paton, 1994). This results in a *disturbance zone* with a radius equal to the assumed building-effect distance. A disturbance zone is also associated with roads as they also cause fragmentation and degrade habitat (e.g., Lyon, 1983). The disturbance zones associated with housing and roads are correlated, i.e., clustered subdivisions have

shorter roads and overall lower disturbance zone area, and low-density dispersed subdivisions have much longer road length, but also maximum overall disturbance zone area. This road effect is, however, more difficult to measure than the building effect because each individual driveway and access road would need to be mapped and measured. Therefore, using the building effect alone is a conservative measure.

Clearly, the impacts on habitat near a house or road (e.g., at a distance of 10 m) are greater than those further away. Rather than specifying a particular building-effect distance, we examine the relationship of development patterns and disturbance zones using a range of building effect values. Furthermore, we use this approach to produce a relative measure by comparing one development pattern to another assuming the same building-effect distance.

Two components of development are critical in understanding the potential impacts on habitat: density and pattern. The idea that a clustered development pattern minimizes impacts is hardly new, for instance, clustered development was heralded in the 1960s as a way to reduce sprawl and to minimize loss of productive agricultural land (Whyte, 1964). However, it is still very important to illustrate the 'folly of large lots' (Arendt, 1994), as people may not understand how density and pattern interact. For instance, a building-effect distance of 100 m creates a disturbance zone that is only 22% of a 14.1 ha (35 acres) parcel, but at 200 m, the disturbance zone occupies 88% of the parcel!
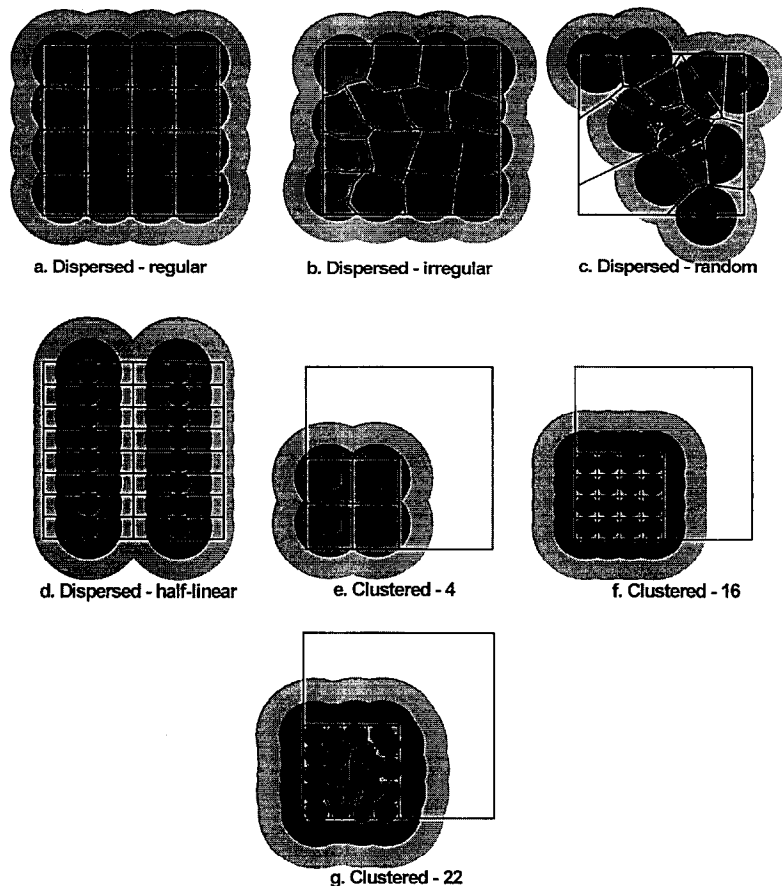

Fig. 1. Typical spatial patterns of residential subdivisions. Each subdivision is 258 ha (640 acres) and includes 16 parcels unless noted otherwise. The white mark is the building location, surrounded by 100 m (dark shade) to 500 m (light shade) zones of disturbance.

Table 1

Landscape measures for hypothetical subdivisions depicted in Fig. 1. 'Percent effected' is proportion of 64.7 ha (160 acres) within disturbance zone, the radius of which is set by the 'building-effect distance'

Pattern	Total edge of subdiv. (m)	Perimeter/area	Percent effected with building-effect distance of				
			100 m	200 m	300 m	400 m	500 m
Dispersed-regular	25824	0.0099	19.2	76.3	99.9	100.0	100.0
Dispersed-irregular	26624	0.0102	19.2	74.1	99.7	100.0	100.0
Dispersed-random	26244	0.0100	15.8	44.8	70.7	83.8	89.7
Dispersed-half	32280	0.0123	19.1	47.2	72.7	97.8	100.0
Clustered 4	12912	0.0049	4.8	19.2	30.3	37.5	45.1
Clustered 16	19360	0.0074	19.2	31.1	38.2	45.8	54.1
Clustered 22	21966	0.0084	22.7	31.6	38.6	46.2	54.4

3.1. Hypothetical subdivisions

A brief examination of a series of hypothetical subdivisions illustrates how different subdivision patterns result in different amounts of area affected, as well as the ways in which they are fragmented. Here, we examine seven hypothetical subdivision patterns, ranging from dispersed to tightly clustered (Fig. 1). For each hypothetical subdivision, three indices were calculated. *Disturbance zone area* is a measure of the area of disturbed habitat. Assuming buildings were located at parcel centroids, disturbance zones with associated building-effect distances of 50, 100, 200, 300, 400, and 500 m were calculated. *Length of*

edge, or the perimeter of all parcel boundaries in a subdivision, is a measure of connectivity and landscape flow (Forman and Godron, 1986), and high values indicate low connectivity and high landscape fragmentation. *Perimeter to area ratio* is a measure of shape, and high values indicate a more convoluted shape.

The dispersed-regular pattern (Fig. 1a) resulted in the most regularly-shaped parcels, shown by both the low edge length and low perimeter/area index, though the dispersed-random (Fig. 1c) and dispersed-regular were surprisingly similar (Table 1). Disturbance zone area increases rapidly with building-effect distance; at distances beyond 200 m, es-
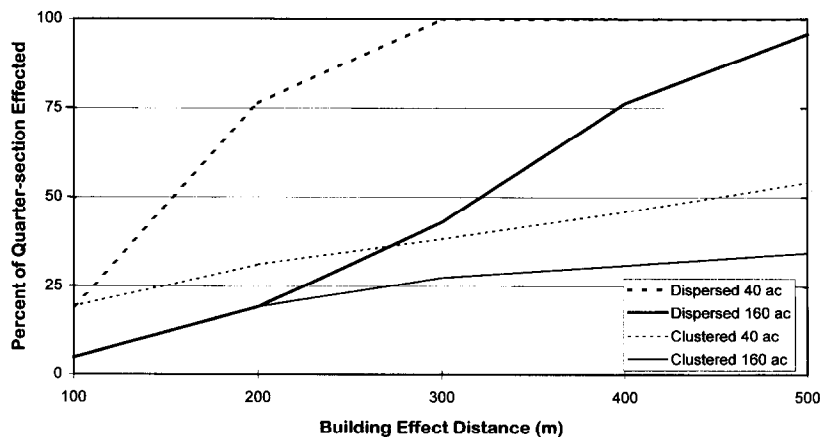

Fig. 2. The proportion of a quarter-section (258 ha or 160 acres) disturbed as a function of building-effect distance for hypothetical 16.1 ha (40 acres) and 64.7 ha (160 acres) dispersed and clustered subdivision patterns including overlap from adjacent quarter-sections. The quarter-section subdivision with 4 parcels (Dispersed 4) has a lower percent effected by disturbance zone than one with 16 parcels (Dispersed 16). However, the percent effected for the clustered quarter-section subdivision pattern (assuming 25% developed area) with 16 units (Clustered 16) is only slightly higher at low building-effect distances than the dispersed pattern with 4 units (Dispersed 4), and *less* at building-effect distances greater than 275 m.

a. Parcels and building disturbance zones

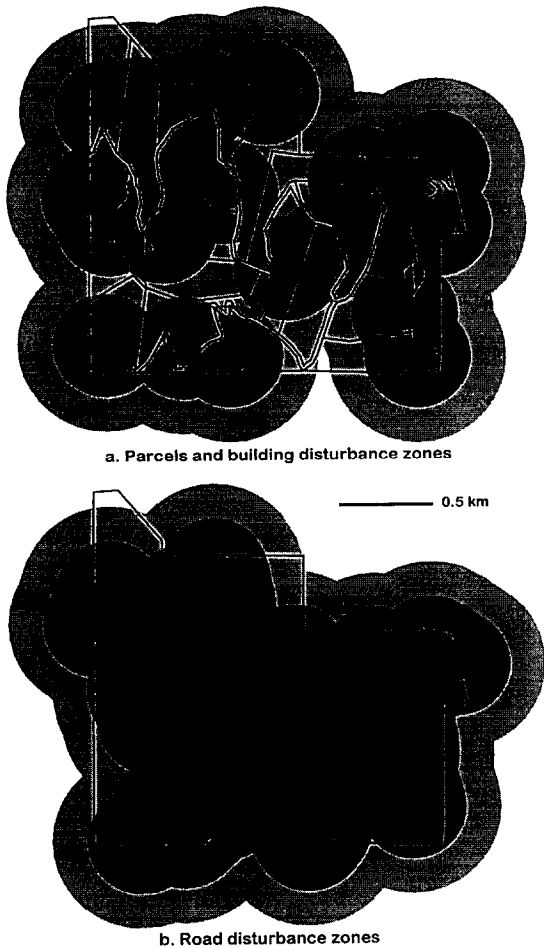———— 0.5 km

b. Road disturbance zones

Fig. 3. Disturbance zones produced by the building and road effects on the dispersed subdivision pattern from the East River Valley, Gunnison County, CO, USA. Zones of disturbance at 100 m (dark), 300 m (medium), and 500 m (light) and parcel boundaries are shown.

ment the landscape. The overall fragmentation of the dispersed-regular and dispersed-irregular patterns is small at low building-effect distances, but increases rapidly with increased building-effect distance. The dispersed-random is slightly fragmented at low and medium distances while the dispersed-half pattern is highly fragmented. An unexpected result is that the dispersed-random pattern provides both more compact-shaped parcels and lower overall disturbance zone than the dispersed-regular pattern.

a. Parcels and building disturbance zones
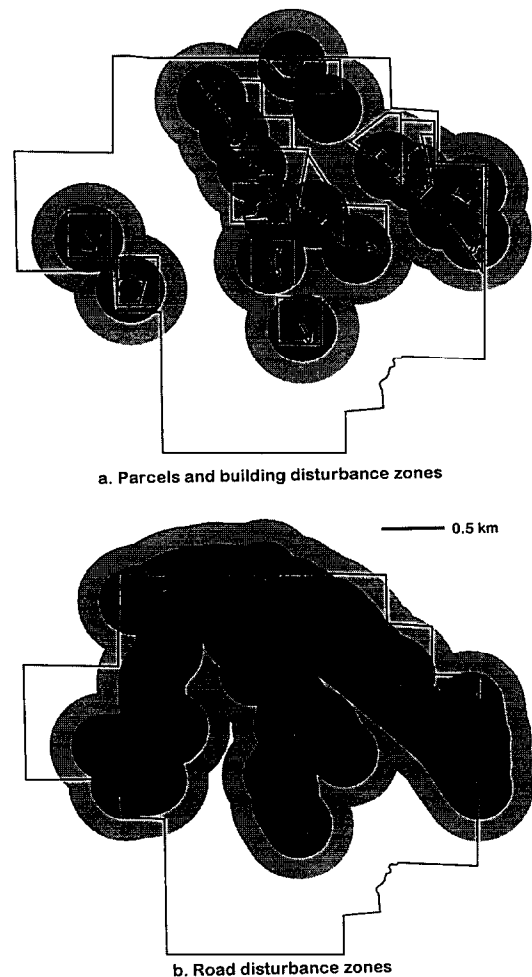
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sentially no effective habitat exists for the dispersed-regular, dispersed-irregular (Fig. 1b), and dispersed-half-linear (Fig. 1d). The dispersed-random has a compact shape and low edge, and at least some of the habitat remains outside the disturbance zones. The clustered patterns have a much lower edge length and a much more compact shape that is independent of building density, and have substantially less disturbance zone area.

In addition to disturbance zone area, the spatial configuration of building sites is important in determining how the disturbance zones coalesce to frag-

Table 2
Measures for the dispersed and clustered subdivisions located in the East River Valley, CO, USA, and depicted in Fig. 3 and Fig. 4. 'Total area' is the total subdivision area, while 'parcel area' is the total area in building parcels, less open space. 'Total edge length' is the total length of all subdivided parcels within the subdivisions. 'Perimeter/area' is a measure of parcel shape complexity

Subdivision type	Number of parcels	Total area (ha)	Total edge length (km)	Parcel area (ha)	Parcel edge (km)	Perimeter /area	House density (ha/unit)
Dispersed	19	310	60.0	290	42.36	0.0145	16.3
Clustered	15	1027	60.9	227	26.36	0.0115	68.4

Since building sites are usually located near a parcel boundary to minimize the access distance rather than being in center of a parcel as assumed, these results likely *underestimate* landscape fragmentation and *overestimate* disturbance zone area. Data on individual building locations and the clustered pattern formed by different building-effect distances are needed to establish the degree of clustering/dispersion that occurs with different types of development. Furthermore, vegetation types and topography also substantially influence the layout of subdivision parcels–especially building location.

These hypothetical subdivisions illustrate the interplay between different development patterns and building-effect distances. Generally, disturbance zone area increases rapidly with building-effect distance, and subdivision pattern is generally a stronger indicator of total disturbance zone area than density. For example, the total disturbance zone area is clearly the largest for the dispersed-regular subdivision with 16.1 ha (40 acres) parcels, while it is generally lower for the dispersed-regular subdivision with 64.7 ha (160 acres) parcels, though the difference narrows rapidly as the 500 m building distance approaches (Fig. 2). However, both the clustered subdivision with 4 and 16 units (and a 25% developed area) have substantially less impact, staying near or below 50%

Table 3
Proportion of subdivision in the disturbance zone for the dispersed and clustered subdivisions from the East River Valley, CO, USA. This shows the percent of the subdivision within the disturbance zone, the radius of which equals the 'building effect'

Pattern	Percent effected by building effect distance of				
	100 m	200 m	300 m	400 m	500 m
Dispersed	19.5%	55.8%	84.6%	97.1%	99.5%
Clustered	5.1%	19.1%	35.2%	50.7%	61.6%

effected area even at a distance of 500 m. Thus, a clustered subdivision (25% developed area), even with 4 times the number of total units, results in a substantially lower total disturbance zone area than a dispersed-regular patterned subdivision.

3.2. Comparison of a clustered and dispersed subdivision

Disturbance zones for a dispersed (Fig. 3) and clustered (Fig. 4) subdivision from the East River Valley, Gunnison County, CO, USA illustrate the effect of pattern on habitat impact (Table 2). The disturbance zone area for the dispersed subdivision constitutes over 50% of the subdivision at 200 m and 97% at 400 m (Table 3). At 100 m, the disturbance zones are islands in the habitat matrix, but by 200 m the habitat matrix is highly fragmented, and at 300 m and greater, little habitat remains (Fig. 3). Fragmentation may be more pronounced if there is a physical manifestation of the parcel boundaries, such as a fence or manipulation of vegetation (e.g., grazing, mowing, or chemical application).

The disturbance zone area for the clustered subdivision pattern is smaller than in the dispersed subdivision, constituting only 5% and 19% of the total area at 100 and 200 m (Table 3). Even at 500 m, only 61% is covered by the disturbance zone. However, areas of high building concentrations impede species movement at relatively low building-effect distances (Fig. 4).

4. Density /disturbance functional relationship

Estimating the disturbance zone areas for actual subdivisions using the approach illustrated above requires spatially-explicit building location data. Al-

though calculating the disturbance zone area directly from building location data is more accurate, these data are seldom available during comprehensive planning, and obtaining it from aerial photography is often cost prohibitive. Therefore, we extend the disturbance zone approach by developing a functional relationship between development density and disturbance zone area. County assessor offices usually maintain a database for tax assessment purposes that contains, for each parcel, the number of units and the Public Land Survey System location: township, range, section. Thus, the number of units per section (258.9 ha or 640 acres) or quarter section (64.7 ha or 160 acres) usually can be determined. Utilizing a density measure calculated for quarter sections, rather than absolute building locations, is also a more appropriate scale of analysis because it captures the general trends we are concerned with, while site-scale differences are the result of individual preferences and circumstances. Finally, most land use planning tools regulate density, not building location within a parcel.

4.1. Theoretical model

We examined how cumulative disturbance zone area varies with different development densities, building-effect distances, and building location patterns (i.e., clustered vs. dispersed) to produce a development density/disturbance zone area function. We constructed 858 GIS maps of quarter-section size (64.7 ha, 160 acres), with each map representing a unique combination of three factors: housing density, building-effect distance, and pattern. Density varied from 64.7 ha/unit to 0.4 ha (1 acre)/unit. Building-effect distances varied from 50–500 m. To assess how pattern influenced total disturbance zone area, we separated the hypothetical quarter section into developed and undeveloped portions—assuming that all units (at a given density) would be dispersed within the developed portions. The proportion of the developed area ranged from 25 to 100% of the quarter section. All parcels are packed into the developed area located in the lower left corner of each quarter section.

The total disturbance zone within each quarter section (excluding portions of the disturbance zones outside of the quarter-section borders) was calculated

for each combination of density, building-effect distance, and pattern. Generally, each combination produced a nonlinear function, with very rapid increases in the proportion of the quarter section within the disturbance zone at low densities, which leveled off quickly as density increased. This matches our prediction that even at low densities, development causes substantial wildlife habitat disturbance and disturbance increases rapidly with small increases in density. As expected, the density at which substantial disturbance occurs decreases rapidly as building-effect distance increases. For example, the percent impacted at 2.0 ha (5 acres)/unit density and 50 m building effect ranges from about 25% to 40% by varying the developed proportion from 25% to 100%. At 100 m building effect, the percent impact ranges from 32% to 98% (Fig. 5). Highly-clustered patterns result in maximum impacts as low as 35% at 100 m building-effect distance, while dispersed patterns result in 100% impact at 100 m at densities as low as 2.8 ha (7 acres)/unit.

These results suggest that the disturbance zone is sensitive to assumptions about building pattern. Because of this sensitivity and because there is little empirical research on actual development patterns in rural areas, we incorporated empirical measures of development pattern into the theoretical model. We calculated the disturbance zone area based on individual building locations for each quarter section in the East River Valley, in 1964, 1978, 1990, and 1994. Overlapping portions of disturbance zones that originated in an adjacent quarter section were included when calculating total area of disturbance zone in a quarter section. The East River Valley has been extensively subdivided, especially since 1975 by 14.1 ha (35 acres) ranchettes (Theobald et al., 1996).

4.2. Empirical results and adjustments

The relationship between density and percent impact defined in the theoretical model is similar to the relationship found in the East River Valley, with the observed density/impact generally fitting within the theoretical range. Some important discrepancies were discovered, however, resulting in revision of the original model. In particular, at very low building-effect distances (i.e., 50 m), the theoretical model
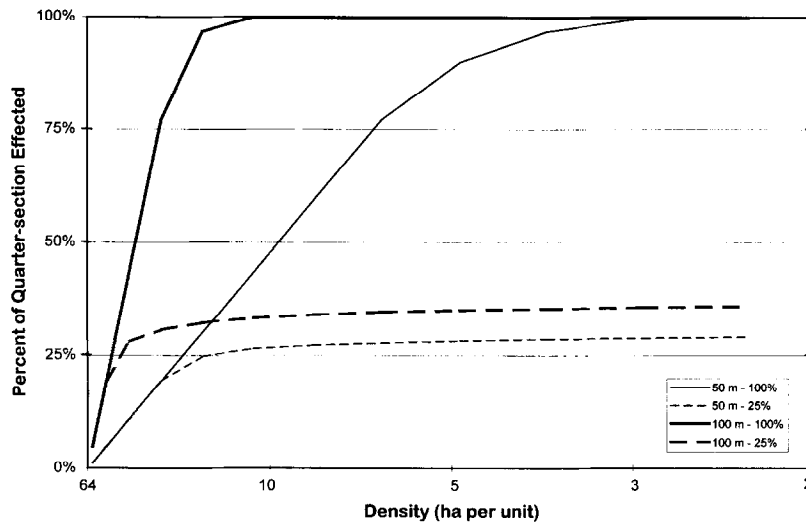
Fig. 5. Proportion of quarter-section within the disturbance zone (i.e., percent effected) as a function of building density for 50 m and 100 m building-effect distances and 25% and 100% development areas.

overestimated the disturbance zone area. Overestimation occurred because the empirical pattern was found to be much more clustered than anticipated in the theoretical model. Also, the amount of area disturbed is especially sensitive to pattern at low building-effect distances because very little aggregation of disturbance zones occurs. This makes intuitive sense, especially in mountain valleys where private land is a thin ribbon along the valley bottom and buildings, especially older farms and ranches, are located adjacent to the road, creating a 'linear clustered' pattern. At 200 m building-effect distance, the observed data fit fairly well within the ranges identified by the theoretical model, though the range of disturbance zone percentages (about 30%) is much greater than the narrow range (about 5%) identified by the theoretical model (Fig. 6). At larger building-effect distances, the theoretical models underestimate the percent impact, even compared to the 100% developed theoretical models. This apparent discrepancy occurs because at relatively large building-effect distances, the effects of neighboring development spill over into adjacent quarter sections. Thus, it appears that neighboring quarter-section densities have a fairly strong impact on the estimated disturbance zone area, especially at large building-effect distances.

In light of the empirical results, we adjusted our model in the following ways. First, estimating the

percent developed area (in the theoretical model) as a surrogate measure of clustered/dispersed pattern was problematic, especially in determining the pattern of existing development. Therefore, we fitted a power curve through the empirical data so that the estimated percent impact is an average value for a quarter section of a particular density. Second, to reflect the decreased impacts associated with a clustered development pattern, we simply decreased the disturbance zone proportion to the lowest observed value from the empirical data set. This revised approach more realistically models existing development patterns, incorporates portions of disturbance zones that originate in neighboring quarter sections, and is straightforward and computationally efficient to implement. Finally, this method resulted in lower estimates of disturbance zone area.

4.3. Fragmentation

In addition to reducing habitat area, development fragments habitat by dividing it into smaller, spatially disjoint landscape units. A highly fragmented landscape is less likely to have large, intact habitat units. Furthermore, fragmentation isolates species and inhibits movement and reduces the probability of recolonization in the event that a species disappears from a given patch of habitat. Furthermore, mountain
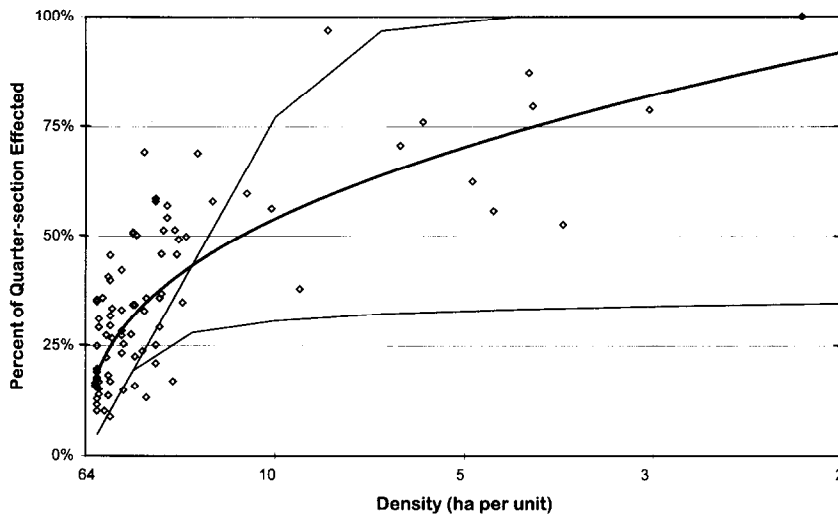
Fig. 6. Empirical and theoretical disturbance zone data for 200 m building effect. The heavy line is fitted to the empirical density-disturbance data marked by diamonds, while the thin lines are 25% and 100% bounds based on theoretical subdivision patterns.

landscapes are predisposed to fragmentation because of the dendritic public/private land ownership pattern common throughout the mountainous western US (Theobald and Riebsame, 1995; Riebsame et al., 1996). The development pattern of the East River Valley demonstrates the fragmenting effects of development. At a relatively early stage of development (1964) and at low building-effect distances, habitat is perforated by small islands of development. Later, disturbance zones begin to coalesce, and in 1994, only a few small areas remain open to provide cross-valley connectivity for wildlife.

Fragmentation and overall area of disturbance are not necessarily correlated. For example, a dispersed, low-density development pattern causes maximum areal disturbance, because disturbance zones do not coalesce until a relatively large building-effect distance is reached. At a relatively low building-effect distance, development perforates the landscape, but connectivity is relatively high, until a threshold is reached when disturbance zones begin to coalesce and connectivity is rapidly compromised. A clustered, low-density development pattern causes minimal areal disturbance, but at even short building-effect distances connectivity is compromised within the developed area. A large number of clustered development patterns scattered throughout a valley would create holes in the habitat matrix, but overall connectivity would remain high. Perhaps most troubling, in terms of maintaining intact habitat, is that linear clustered development patterns result in both large overall disturbance zone areas *and* fragmentation, even at short building-effect distances.

4.4. Application of disturbance zone

We evaluate the effect of development on wildlife habitat by calculating the proportion of each quarter section effected by development. This expected impact layer is then applied to a map of habitat value depicting wildlife habitat patterns. The relative effects of different development alternatives are evaluated by summing the development-weighted habitat quality values over the study site.

While the methodology described here was developed to support comprehensive planning, it also can be used at the site scale. More refined estimates of impact can be made since locations of buildings, roads, and utility infrastructure and wildlife habitat patches and other environmental constraints are known. The building-effect distance could reflect slope and cover characteristics important to wildlife species, so that the building-effect distance would be greater in adjacent areas without cover and be shorter in areas with cover. A further extension would be to adjust effects to reflect the location of disturbance

zone in relation to patch boundaries, so that a zone within a patch interior might have a stronger impact than a zone at the patch edge.

5. Conclusion

We have presented an approach for estimating the area of habitat disturbance generated by development, given different development densities and patterns, as well as different assumptions about wildlife sensitivities. Our approach does not address thorny issues such as differential sensitivities of wildlife species to human disturbance, shifting species composition, or the potential for development to improve habitat in some ways, nor does it attempt to differentiate types of disturbance with different types of development (e.g., condo units with full-time residents vs. seasonally occupied large homes). However, it does provide a tractable, understandable, and, ultimately, useful method that improves our ability to evaluate development impacts on wildlife habitat. We also assumed that housing density is a surrogate for disturbance associated with roads. Further research is needed to identify similarities and differences between effects associated with housing density and road density and the extent of spatial correlation. It must be emphasized that the value of this approach is in comparing relative impacts of various development patterns, given different assumptions about density, pattern, and disturbance intensity.

Clustering development reduces disturbance of development on wildlife habitat. In fact, subdivision pattern was found to be a strong indicator of total disturbance zone area and, for long building-effect distances, a stronger indicator than subdivision density. This finding suggests that efforts to minimize habitat impacts by decreasing development density (e.g., Powers, 1994) should also require clustering of parcels. However, development can be clustered in a way that reduces overall disturbance area, but that still fragments the landscape to a considerable degree. Many clustered development designs place buildings around 'pods' or cul-du-sacs, reducing the overall disturbance zone area, but landscape fragmentation is high if islands of habitat contained inside the development, are too small to support a viable population and inaccessible to the surrounding habitat. Landscape connectivity is also compromised

when linear clustering (e.g., development along a linear feature such as a riparian area or road) occurs perpendicular to the direction of landscape movement. Thus, two factors are important in understanding how development potentially disturbs habitat: total area of habitat disturbed near buildings and roads; and landscape fragmentation and inhibition of wildlife movement across the landscape.

As development proceeds in a valley or landscape, negative impacts will likely occur at an increasing rate. At low levels of overall development in a valley, development impacts appear to be slight because of species immigration from large expanses of habitat adjacent to the developed areas. As development proceeds and subdivisions form increasingly large clumps of development, immigration from adjacent habitat will be reduced, and the likelihood that a development obstructs a wildlife corridor will increase. While clustered subdivisions reduce total disturbance zone area, the positioning of adjacent clustered subdivision should be considered to limit fragmentation effects at a coarser scale. That is, the same issues important in determining negative impacts associated with different subdivision patterns apply at a broader scale as well. In particular, rules which result in the clustering of clustered subdivisions that minimize overall habitat fragmentation are needed.

Acknowledgements

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