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Clustering Timber Harvests and the Effect of Dynamic Forest Management Policy on Forest Fragmentation

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ABSTRACT

To integrate multiple uses (mature forest and commodity production) better on forested lands, timber management strategies that cluster harvests have been proposed. One such approach clusters harvest activity in space and time, and rotates timber production zones across the landscape with a long temporal period (*dynamic zoning*). Dynamic zoning has been shown to increase timber production *and* reduce forest fragmentation by segregating uses in time without reducing the spatial extent of timber production. It is reasonable to wonder what the effect of periodic interruptions in the implementation of such as strategy might be, as would be expected in a dynamic political environment. To answer these questions, I used a timber harvest simulation model (HARVEST) to simulate a dynamic zoning harvest strategy that was periodically interrupted by changes in the spatial dispersion of harvests, by changes in timber production levels, or both. The temporal scale (period) of these interruptions had impacts related to the rate at which the forest achieved canopy closure after harvest. Spatial dynamics in harvest policies had a greater effect on the amount of forest interior and edge than did dynamics in harvest intensity. The *periodically clustered* scenarios always produced greater amounts of forest interior and less forest edge than did their *never clustered* counterparts. The results suggest that clustering of harvests produces less forest fragmentation than dispersed cutting alternatives, even in the face of a dynamic policy future. Although periodic episodes of dispersed cutting increased fragmentation, average and maximum fragmentation measures were less than if clustered harvest strategies were never implemented. Clustering may also be useful to mitigate the fragmentation effects of socially mandated increases in timber harvest levels. Implementation of spatial clustering during periods of high timber harvest rates reduced the variation in forest interior and edge through time, providing a more stable supply of forest interior habitat across the landscape.

Key words: timber harvest; aggregation of harvests; dynamic zoning; spatial simulation model; forest interior; forest fragmentation; forest management policy; forest management planning.

INTRODUCTION

Forest management occurs in the context of dynamic systems, including not only ecological systems, but also social and political systems (Wiersum 1995). Societal expectations for the management of forest resources are in constant tension, as people value both relatively undisturbed forests and the forest products needed to support desired lifestyles. This tension especially affects the management of public lands and is manifested in the somewhat independent evolution of policy in the administrative and legislative sectors of governments. Consequently, policies may oscillate in the short term, even as they are steadily evolving over the long term (Keiter 1996).

One of the potential ecological consequences of timber harvest is a reduction in the amount of habitat for forest interior species. Many interior

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species are thought to be sensitive to the size of forested blocks (Blake and Karr 1987; Freemark and Collins 1992), and internal edges may provide improved habitat for generalist predators and brood parasites (Gates and Gysel 1978; Brittingham and Temple 1983; Small and Hunter 1988; Robinson and others 1995). The practice of dispersing cutting units has been implicated as a major contributor to the reduction in forest interior habitat and the increase in linear edge (Franklin and Forman 1987; Gustafson and Crow 1994; Wallin and others 1994). Typically, a large area is identified where timber cutting is allowed on all land not otherwise set aside from cutting or unsuitable (*timber production zone*), and this zone implicitly is to be used for timber production in perpetuity (*static zoning*). Harvests are dispersed throughout this area during each management cycle. Progressive cutting across the landscape has been proposed as an alternative to the traditional approach of dispersing cutting units across the landscape (Li and others 1993). Under this strategy, timber harvesting would proceed somewhat systematically across the landscape. Openings produced by harvest would be clustered in both time and space, allowing more interior habitat to be sustained on the landscape as a whole. The practical application of this approach is complicated by discontinuous ownership of the landscape and the variability in the suitability of stands for harvest at any given point in time. A potential solution to this complication is a *dynamic zoning* strategy, in which timber production is concentrated in a relatively small portion of the timber production zone for a limited time, and this subzone is moved sequentially across the timber production zone at 30- to 50-year intervals (Gustafson 1996). The base timber production zone is identical under both the static and dynamic zoning strategies, but dynamic zoning has the effect of clustering harvest openings within the larger landscape, while allowing flexibility in the placement of individual harvest treatments within the subzone. Dynamic zoning may also lower costs of production by clustering operational activities (for example, road improvement and access control), and localize disturbance impacts (for example, stream sedimentation).

Dynamic zoning serves to cluster the spatial configuration of timber extraction. Simulation studies have shown that it is possible to increase timber production *and* reduce forest fragmentation across the landscape as a whole, simply by changing the spatial and temporal configuration of timber extraction (Gustafson 1996). In fact, a tightly clustered harvest strategy produced amounts of forest interior and edge comparable to that of the dispersed alternative with half the rate of harvest. Forest interior is minimal within active timber production zones, but the clustering of cutting activity produces marked increases of interior elsewhere on the landscape. Although adjacency restrictions (that is, a harvest must not be located adjacent to an existing harvest opening until regeneration has progressed sufficiently) generally serve to disperse cuts and increase fragmentation, their effect is minimal under dynamic zoning, because the dispersion is contained within a portion of the landscape where fragmentation is high anyway.

A dynamic zoning strategy essentially initiates a long-term (1–2 rotations) spatially explicit timber harvest plan. It is reasonable to wonder what the effect of periodic interruptions in the implementation of this plan might be, as might be expected in a dynamic political environment where long-term policy stability is not possible. Managers of publicly owned forests are particularly sensitized to the fact that management policies may change in unexpected ways. Historical examples include the shift from maximizing forest edge (to increase populations of game species) toward minimizing fragmentation, and the recent dramatic reduction in harvest rates on federal forests in the Pacific Northwest of the United States (Haynes and others 1995). Possible future policy changes might result from some international crisis (for instance, interruption in the supply of imported timber) or a change in administration of the executive entity overseeing a public forest. Ideologically based changes in management policy resulting from election cycles are potentially oscillatory. If a dynamic zoning (clustered harvests) policy were periodically interrupted by a dispersed cutting policy, or if timber production quotas were periodically altered dramatically, what would be the effect on measures of forest fragmentation? Can a dynamic zoning strategy reduce average measures of fragmentation even when periodically punctuated by dispersed cutting policies?

The objectives of this study were (a) to quantify the changes in forest fragmentation (forest interior and forest edge) as a function of periodic policy changes, (b) to determine which aspect of management policy (spatial dispersion of harvests, harvest rate, and temporal period of policy changes) has the greatest effect on forest fragmentation, and (c) to determine whether spatial clustering can compensate for periodic increases in harvest rates, to aid in the preservation of forest interior habitat. The study was designed to determine the spatial pattern consequences of generalized alternative policy scenarios rather than find an optimal scenario to produce some desired spatial pattern. Simulation models are

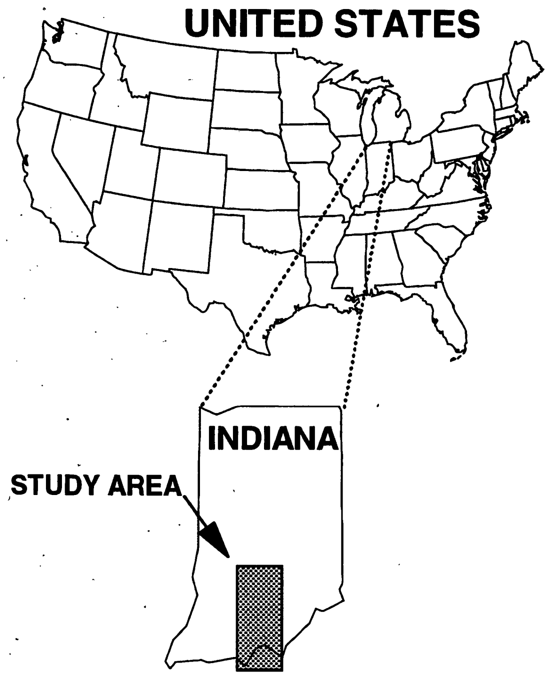

Figure 1. Location of the study area.

well suited to illuminate the statistical range of expected landscape patterns for given broad management strategies. Alternatively, optimization models can be used to design tactical management activities by maximizing some objective criterion, such as amount of forest interior (Hof and Raphael 1997). I used a timber harvest simulation model (HARVEST) to simulate a dynamic zoning harvest strategy that was periodically interrupted by a dispersed cutting policy, by changes in timber production levels, or both.

Methods

Study Area

The study was conducted on a rectangular study area (1,058,046 ha) that included the entire Hoosier National Forest (HNF) Purchase Area, located in southern Indiana, USA (Figure 1). The HNF was used to provide a realistic ownership and timber production zone pattern for assessing alternative harvest strategies. Ownership boundaries were digitized from 1:24,000 scale paper maps produced by the US Geological Survey (USGS) for the Forest Service. I used the timber production zone boundaries from the 1991 HNF Amended Plan (USDA Forest Service 1991), which were manually transferred from the Forest Plan maps (approximate scale, 1:127,000) to 1:100,000-scale USGS maps and digitized. HNF land within these boundaries was considered suitable for timber harvest and is represented with black shading in Figure 2. A forest-cover map of the entire Purchase Area was generated from USGS–Land Use Data Acquisition (LUDA) data, and all layers were gridded to a common cell size of 100 × 100 m. I used this map as the starting landscape condition, which ignores existing harvest openings and assumes an initial unharvested landscape. Consequently, the initial forest condition appeared less fragmented than it is in reality.

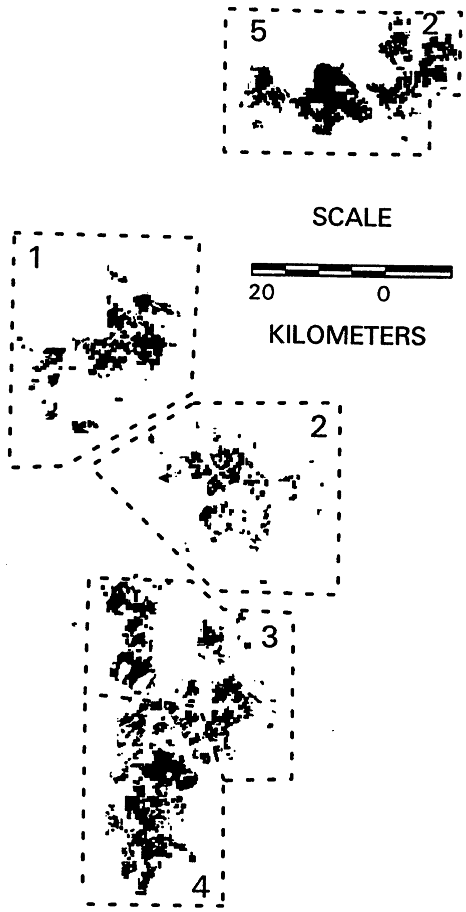

Figure 2. Map of the Hoosier National Forest (HNF) timber land base on which harvests were simulated, based on timber production zones in the 1991 HNF Amended Forest Plan (USDA Forest Service 1991). The black shading represents land on which timber harvests were simulated, which is about 65% of the land owned by the HNF. The dashed lines represent the subzones used for the clustered alternatives. The numbers indicate the order in which timber harvest was allowed on the subzones for the clustered alternatives.

Timber Harvest Model

HARVEST is a timber harvest simulation model designed to evaluate quickly the spatial pattern consequences of alternative timber management scenarios. The user controls a number of parameters commonly found in National Forest Plan standards and guidelines that can be used to determine the spatial attributes of harvest units that produce forest openings (clear-cuts, shelterwood, and group selection) (Gustafson and Crow 1994, 1996). The model produces landscape patterns that have spatial attributes resulting from initial landscape conditions and the simulated timber management activities. The model does not attempt to optimize timber production or spatial pattern. Instead, the model stochastically allocates harvest units, using the parameters of the standards and guidelines, and the timber production zone (or subzone) boundaries. Modeling this process allows experimentation to link variation in management strategies with the resulting pattern of forest openings. HARVEST is useful for exploring strategic issues (for example, evaluating broad alternatives) rather than tactical issues (for instance, designing timber sales).

HARVEST allows control of harvest size distributions, the total area of forest to be harvested, and the rotation length (by specifying the minimum age where harvests may be allocated). HARVEST selects harvest locations randomly within currently active timber production zones, checking first to ensure that the forest is old enough to meet rotation length requirements. Cells are added to a harvest unit until its size reaches a size drawn from a normal distribution of harvest sizes with a user-specified mean and variance. Before a cell is actually harvested, a check is made to verify that the cell is older than the rotation age and not in violation of any spatial constraints that have been specified by the user (for example, adjacency restrictions or outside timber production zone). The spatial configuration of areas where timber harvests are allowed is controlled by using a Geographic Information System (GIS) to mask areas on the input map that are not to be harvested.

A number of simplifying assumptions were made in the development of HARVEST to reduce input data requirements and enable it to simulate harvest activity quickly over a relatively large area ($>10^6$ ha). The first is that harvest allocations within timber production zones typically take a spatially random distribution over the period represented by the time step of the model run. However, this assumption does not nullify the spatial constraints most important in strategic management planning: harvest allocations are constrained by the locations of existing stands that are older than the rotation length, by the boundaries of management zones, and by buffer requirements (distance of uncut forest that must be left around harvest units). The spatially random assumption is based on an analysis of stands reaching rotation age and on past harvest allocations. Using nearest-neighbor analysis (Davis 1986) on 10 subsets of HNF stand maps (mean size of subsets, 3366 ha; SD = 1062 ha), the observed mean nearest-neighbor distance between stands of similar age was compared with the distance expected if stands were randomly distributed, and a z statistic was computed. The null hypothesis that stands are randomly distributed could not be rejected at the 95% confidence level for 8 of the 10 subsets [see Gustafson and Crow (1996)].

The ability of HARVEST to produce patterns similar to those produced by actual timber management has been demonstrated on three landscapes (size range 34,053–49,515 ha) on the HNF (Gustafson and Crow forthcoming). Beginning with a forest age map and the timber production zone boundaries as of 1968, two decades of harvest activity were simulated by using the total area and size distribution of stands actually regenerated in each decade. The amount of forest interior and edge predicted by HARVEST (based on three replicates) was compared with the amounts derived from the 1978 and 1988 age maps ($n = 6$). HARVEST predicted the amount of forest interior between 0.2% and 2.8% of the range possible (given the pattern of nonforested land) in each case except one, where the mean prediction departed from the actual by 5.3% (Gustafson and Crow forthcoming). Predicted amounts of forest edge deviated even less from the actual amounts. This is not surprising since edge is related more to the size of harvests than to their spatial location, and HARVEST is able to match closely the size distribution of the actual harvests. These results suggest that the simple rules used by HARVEST can mimic the landscape patterns produced by forest planners who typically allocate harvest units under complex constraints.

Experimental Design

The land base harvested in the simulations was determined by the Management Area boundaries specified in the 1991 HNF Amended Plan (USDA Forest Service 1991). Timber production was simulated on approximately 65% of the HNF land base and only on land owned by the HNF (Figure 2). Harvest was never simulated on land reserved from harvest under the 1991 Amended Plan. The total land base that was harvested (timber harvest land base) over a period of 12 decades was identical among all alternatives (48,884 ha). The timber production zones in the HNF have an extensive road network, so road access was not considered to be a limitation for the placement of harvest units. Timber harvest parameters were chosen to fall within the

Table 1. Temporal Sequence of Experimental Treatments for the Four Simulated Scenarios, When Periodic Policy Changes Occurred Within a 2-Decade Period[a]

	Never Clustered, High Intensity		Never Clustered, Dynamic Intensity		Periodically Clustered, High Intensity		Periodically Clustered, Dynamic Intensity	
Decade	Intens[b]	Dispers[c]	Intens[b]	Dispers[c]	Intens[b]	Dispers[c]	Intens[b] (ha)	Dispers[c]
1	2600	D	1300	D	2600	C	2600	C
2	2600	D	1300	D	2600	C	2600	C
3	2600	D	2600	D	2600	D	1300	D
4	2600	D	2600	D	2600	D	1300	D
5	2600	D	1300	D	2600	C	2600	C
6	2600	D	1300	D	2600	C	2600	C
7	2600	D	2600	D	2600	D	1300	D
8	2600	D	2600	D	2600	D	1300	D
9	2600	D	1300	D	2600	C	2600	C
10	2600	D	1300	D	2600	C	2600	C
11	2600	D	2600	D	2600	D	1300	D
12	2600	D	2600	D	2600	D	1300	D

[a] *The sequences for a 1-decade period are not given, but followed a pattern analogous to that shown here.*
[b] *Intensity of cutting expressed as area of forest (ha) cut per decade.*
[c] *Dispersion of harvest openings: D, dispersed; C, clustered.*

parameter space of the original HNF Management Plan (USDA Forest Service 1985) and the 1991 Amended Plan (USDA Forest Service 1991), with opening sizes ranging between 3 and 8 ha. Only harvest methods that produce forest openings (analogus to clear-cut, shelterwood, and seed-tree treatments) were simulated, and harvest placement was not constrained by adjacency prohibitions.

The experimental treatments involved periodic changes in (a) the strategies governing the spatial dispersion of harvests, (b) the intensity (area cut per decade) of harvest, and (c) the temporal period (interval) at which these changes occurred.

The two strategies governing spatial dispersion of harvests were a dynamic zoning strategy (clustered harvests) and a dispersed harvest strategy. The dynamic zoning strategy was implemented by dividing the timber harvest land base into five subzones, and harvest was allowed only within a single subzone (active subzone) at any given time (beginning with subzone 1; Figure 2). The active subzone was rotated sequentially among subzones every 3 decades, so that all five subzones would be harvested over a period of 15 decades. Thus, each subzone was harvested for 3 decades and reserved from harvest for 12 decades. Experimental treatments were devised to introduce temporal variation in the application of the spatial clustering strategies (Table 1) by periodically interrupting the dynamic zoning strategy with a dispersed strategy. The dispersed harvest strategy was simulated by allowing harvests anywhere within all five subzones. Under the *periodically clustered* scenarios, the spatial clustering of harvests (that is, the restriction of harvesting to a specific subzone) was periodically interrupted by a dispersed harvest policy. Alternatively, the *never clustered* scenarios featured a dispersed strategy throughout the 12 decades. For comparative purposes, I also simulated the dynamic zoning scenario without interruption, referencing it in the results as the *always clustered* scenario.

The intensity of harvest could also vary periodically (Table 1). Under the *dynamic intensity* scenarios, the area harvested was periodically doubled and then halved (1300 ha/decade and 2600 ha/decade) whereas, under the *high intensity* scenario, harvest rate was a constant 2600 ha/decade. Finally, an interaction experiment was included to assess whether periodic increases in harvest rates can be compensated for by spatial clustering to mitigate increases in fragmentation. In this *periodically clustered, dynamic intensity* scenario, when the harvest rate was high, harvests were clustered, and when the harvest rate was low, harvests were dispersed.

For each scenario, the length of time (period) between these periodic changes in strategy was also simulated with two levels (1 decade and 2 decades). Thus, a complete factorial design was implemented, with two levels of spatial variation (constant and dynamic), two levels of harvest intensity variation (constant and dynamic), and two levels of temporal period (1 decade and 2 decades). Three replicates of each factorial combination were produced.

Analysis

At each decade, I used a GIS to measure the amount of forest interior habitat [forest > 300 m from an opening or edge (DellaSalla and Rabe 1987; Andren and Angelstam 1988)] on the entire study area. A simple FORTRAN routine was written to calculate linear forest edge. Cleared sites in the HNF generally achieve canopy closure in 12–20 years (T. Thake personal communication 1993), so harvested cells were assumed to create openings in the forest for 20 years and were assumed to return then to a closed-canopy condition. The total amount of interior and edge was plotted over simulated time for each of the alternative scenarios, using the means of the three replicates.

To evaluate the relative effects of spatial and harvest intensity dynamics, and the temporal period of these dynamics on forest interior and edge, analysis of variance (ANOVA) was used to test for treatment effects (average amount of forest interior and edge over simulated time) reflecting spatial dynamics (*spatial*), harvest intensity dynamics (*intensity*), and temporal period (*period*). Decade 1 was excluded from the analysis because the spatial pattern of forest openings in the first decade was transitional between the unharvested starting conditions and the equilibrium trends established by the second decade (Figures 3 and 4).

RESULTS

The amount and spatial pattern of forest interior were markedly different between many of the scenarios (Figure 5). The replicates produced little variability in the amount of forest interior and edge at any point in simulated time, being generally less than the width of the symbols in the plots and not shown. The temporal period of the management dynamics had a marked effect on the variation in forest interior and edge over time (Figures 3 and 4). The curves representing a 1-decade period (Figures 3a and 4a) resemble what one would expect if a smoothing algorithm were applied to the curves representing a 2-decade period (Figures 3b and 4b). This is related to the relationship between the length of the temporal period and the time it takes for canopy closure to occur (in this case, 2 decades). When the period is less than the canopy closure time, openings persist between policy changes, acting to dampen oscillations in spatial pattern. When the period is greater than or equal to the canopy closure time, there is sufficient time for the spatial pattern produced by previous policies to be erased by forest regeneration, allowing the pattern produced by the new policy to manifest itself.

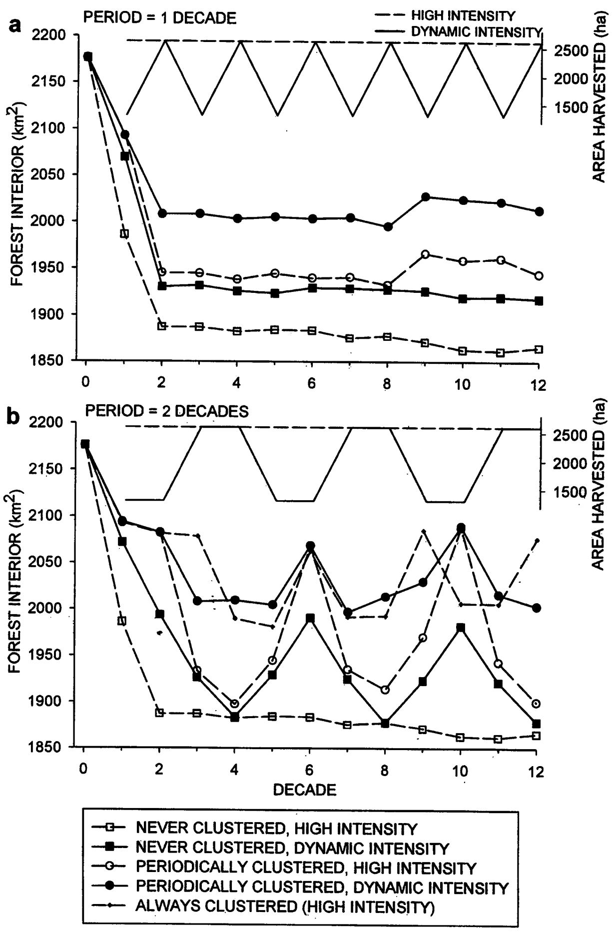

Figure 3. Amount of forest interior produced by dynamic timber harvest policies over simulated time on the entire study area. Harvest rates are plotted on the right axis. The temporal period of policy changes was 1 decade a and 2 decades b. The *always clustered, high intensity* alternative in b is the 120-year-hiatus scenario of Gustafson (1996) and is shown for comparison. The standard deviation from each plotted point is generally less than the width of the symbols and is not shown.

The effect of periodic spatial dynamics on forest interior can be visualized by comparing curves having symbols with the same fill (that is, solid or open; Figure 3), representing scenarios with differing spatial policies. Note that *periodically clustered* scenarios always produce greater amounts of forest interior than do their *never clustered* counterparts. The *always clustered* scenario (Figure 3b) illustrates the level of forest interior that can be achieved with an uninterrupted dynamic zoning policy, even when a high intensity of harvest is sustained throughout the simulations.

The effect on forest interior of periodic changes in harvest intensity can be visualized by comparing curves having symbols with the same shape (Figure 3), representing scenarios with differing harvest

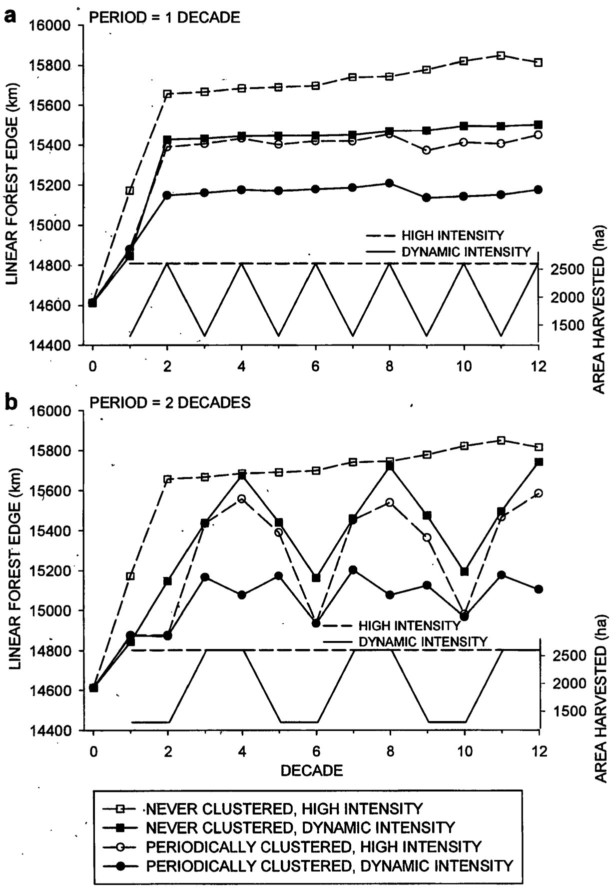

Figure 4. Amount of forest edge produced by dynamic timber harvest policies over simulated time on the entire study area. Harvest rates are plotted on the right axis. The temporal period of policy changes was 1 decade **a** and 2 decades **b**. The standard deviation from each plotted point is generally less than the width of the symbols and is not shown.

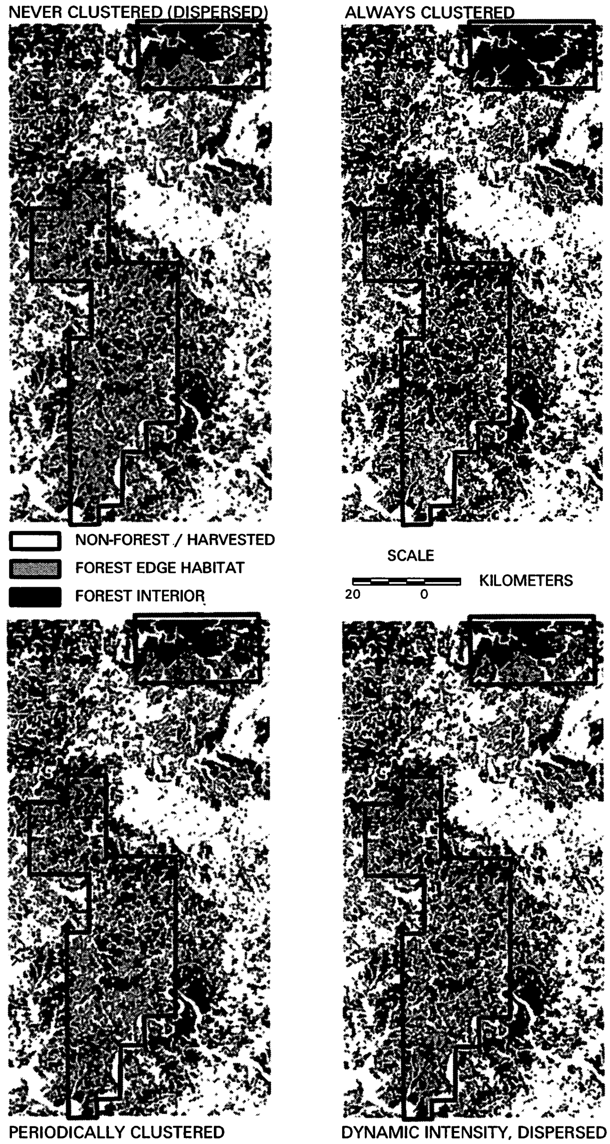

Figure 5. Forest interior in the study area at the end of 12 decades of simulated harvest for four selected scenarios. In the two *clustered* cases, the subzone most recently harvested was subzone 4 (see Figure 2) located in the southern-most part of the Hoosier National Forest (HNF). Harvest intensity was high (2600 ha/decade) in all but the *dynamic intensity* case, where intensity oscillated with a period of 1 decade. In the *periodically clustered* case, the harvest strategy oscillated between dispersed and clustered with a period of 1 decade. The solid lines represent the approximate location of the HNF Purchase Boundary, and simulated harvests occurred only on HNF land (see Figure 2) within those boundaries.

intensity policies. As might be expected, periodic reductions in harvest rate result in more forest interior.

The *periodically clustered, dynamic intensity* scenario (Figure 3) illustrates the effect of attempting to compensate for increased timber harvest rates by spatially clustering those more numerous openings. When compared with the *never clustered, dynamic intensity* case, it is evident that higher amounts of forest interior are maintained by spatial clustering of harvests. When the temporal period was 2 decades (Figure 3b), the *periodically clustered, dynamic intensity* scenario also reduced the variability in forest interior through time.

The effect of periodic spatial dynamics on forest edge can be visualized by comparing curves having symbols with the same fill (Figure 4), representing scenarios with differing spatial policies. Here, *never clustered* scenarios always produce the same or greater amounts of forest edge than do their *periodically clustered* counterparts. This is because adjacency constraints were not applied in these simulations, allowing openings to coalesce when harvests were clustered, reducing edge-to-area ratios. If adjacency

Table 2. Analysis of Variance Comparing the Effects of Spatial Dynamics in Harvest Policies (*spatial*), Harvest Intensity Dynamics (*intensity*), and the Temporal Period of Those Dynamics (*period*) on the Area of Forest Interior and Linear Forest Edge Maintained on the Landscape[a]

		Forest interior (km^2)				Forest edge (km)			
Source	*df*	SS	*F*	$P > F$	R^2	SS	*F*	$P > F$	R^2
Spatial	1	1.675E + 5	156.6	0.0001		2.724E + 8	160.7	0.0001	
Intensity	1	6.998E + 4	65.4	0.0001		1.560E + 8	92.0	0.0001	
Period	1	2.965E + 3	2.8	0.0997		5.025E + 6	3.0	0.0888	
Error	84	8.986E + 4				1.424E + 8			
Total	87	3.303E + 5			0.73	5.757E + 8			0.75

[a]*Analysis included three replicates of simulations conducted for 12 decades.*

restrictions were applied, temporal variability in the amount of edge would be minimal (Gustafson and Crow 1996). The effect of periodic changes in harvest intensity on forest edge can be visualized by comparing curves having symbols with the same shape (Figure 4), representing scenarios with differing harvest-intensity policies. It is clear that periodic reductions in harvest rates reduce the amount of forest edge produced (Gustafson and Crow 1994).

Spatial dynamics in harvest policies appear to have a greater effect on the amount of forest interior than do dynamics in harvest intensity. Examination of the ANOVA sums of squares shows that the spatial dynamics of harvests (*spatial*) explains 50.7% of the total variance of forest interior, whereas harvest-intensity dynamics (*intensity*) explains 21.2% of the variance (Table 2). *Period* explains only 0.9% of the variance. Although different temporal periods produce marked decade-to-decade variation in forest interior, the mean response is only marginally different between a period of 1–2 decades. Similarly, *spatial* explains 47.3% of the total variance of forest edge, whereas *intensity* explains 27.1% of the variance (Table 2).

Discussion

The utility of simulation models lies in their ability to manifest the consequences of assumptions as a function of variation in the input parameters. Models also allow control of effects that are difficult to control in empirical experiments. Here I assumed that timber harvest allocations over the course of a decade are spatially random within timber management zones, and that harvests produce openings that perforate the forest interior for 20 years. Some features of the study area may not be duplicated in other managed forests (for example, extensive existing road network). By varying inputs (spatial constraints on harvest allocations and harvest rates), I was able to use the HARVEST model to evaluate the relative consequences of alternative harvest policy dynamics on forest spatial pattern. Although it is not appropriate to use HARVEST to predict the precise location of future forest openings, the simulations clearly showed the landscape effect of periodically changing certain input parameters, and illuminated consequences that were not intuitively obvious prior to the simulation exercise.

The answer to the original question, "Can a dynamic zoning strategy reduce average measures of fragmentation even when periodically punctuated by dispersed cutting policies?" appears to be "yes." These results consistently suggest that clustering of harvests produces less forest fragmentation than dispersed cutting alternatives, even in the face of a dynamic policy future. A continuously implemented dynamic zoning strategy can produce a marked increase in contiguous forest, even when harvest rates increase (Gustafson 1996). Although periodic episodes of dispersed cutting increased fragmentation, average and maximum fragmentation measures were less than if clustered harvest strategies were never implemented. This suggests that embarking on a course of dynamic zoning may be prudent, even in the face of future policy uncertainty. Clustering may also be useful to mitigate the fragmentation effects of increases in timber harvest levels. Implementation of spatial clustering during periods of high timber harvest rates can reduce the variation in forest interior and edge through time, providing a more stable supply of forest interior habitat across the landscape.

The temporal scale of policy shifts has obvious consequences on the resulting spatial pattern of forest through time. My results indicate that when the period is less than the canopy closure time, openings persist between policy changes, acting to dampen oscillations in spatial pattern. It is not possible to predict future political trends, although recent experience suggests that forest policy changes may be dramatic and occur within a relatively short period. A consistent, dynamic zoning strategy is likely to reduce forest fragmentation markedly while allowing relatively high amounts of timber to be extracted (Gustafson 1996). If policies are in fact dynamic in the future, however, perhaps a short-period dynamic is to be preferred, because this allows the supply of forest interior and edge to be more stable. Although short-period policy dynamics never allow large areas of interior to develop, stability in the amount of forest interior may help stabilize populations of organisms that depend on interior habitat. These results also suggest that spatial clustering of harvests improves average fragmentation levels through time, regardless of the temporal period of policy changes.

Political and social change is a fact of life. Managers of forests must allow for changing social mandates as they formulate plans to sustain the goods and benefits associated with the forested land they manage. To manage change, one must first understand the consequences of change. Simulation models such as HARVEST are potentially useful tools to help understand the consequences of management alternatives and the impact of future social change.

The HARVEST model, documentation, and source code are available at no charge on the World Wide Web at http://www.ncfes.umn.edu/products/harvest/harvhome.htm.

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REFERENCES

Andren H, Angelstam P. 1988. Elevated predation rates as an edge effect in habitat islands: experimental evidence. Ecology 69:544–7.

Blake JG, Karr JR. 1987. Breeding birds of isolated woodlots: area and habitat relationships. Ecology 68:1724–34.

Brittingham MC, Temple SA. 1983. Have cowbirds caused forest songbirds to decline? Bioscience 33:31–5.

Davis, JC. 1986. Statistics and data analysis in geology. New York: John Wiley and Sons.

DellaSalla DA, Rabe DL. 1987. Response of least flycatchers *Empidonax minimus* to forest disturbances. Biol Conserv 41: 291–9.

Franklin JF, Forman RTT. 1987. Creating landscape patterns by forest cutting: ecological consequences and principles. Landscape Ecol 1:5–18.

Freemark K, Collins B. 1992. Landscape ecology of birds breeding in temperate forest fragments. In: Hagen JM, Johnston DW, editors. Ecology and conservation of neotropical landbirds. Woods Hole (MA): Manomet Bird Observatory. p 443–54.

Gates JE, Gysel LW. 1978. Avian nest dispersion and fledgling success in field and forest ecotones. Ecology 59:871–83.

Gustafson EJ. 1996. Expanding the scale of forest management: allocating timber harvests in time and space. Forest Ecol Manage 87:27–39.

Gustafson EJ, Crow TR. 1994. Modeling the effects of forest harvesting on landscape structure and the spatial distribution of cowbird brood parasitism. Landscape Ecol 9:237–48.

Gustafson EJ, Crow TR. 1996. Simulating the effects of alternative forest management strategies on landscape structure. J Environ Manage 46:77–94.

Gustafson EJ, Crow TR. HARVEST: linking timber harvesting strategies to landscape patterns. In: Mladenoff DJ, Baker WL, editors. Spatial modeling of forest landscape change: approaches and applications. Cambridge: Cambridge University Press. Forthcoming.

Haynes RW, Adams DM, Mills JR. 1995. The 1993 RPA timber assessment update. Fort Collins (CO): USDA Forest Service, Rocky Mountain Forest and Range Experiment Station; GTR-RM-259.

Hof J, Raphael MG. 1997. Optimization of habitat placement: a case study of the northern spotted owl in the Olympic Peninsula. Ecol Appl 7:1160–9.

Keiter RB. 1996. Toward legitimizing ecosystem management on the public domain. Ecol Appl 6:727–30.

Li H, Franklin JF, Swanson FJ, Spies TA. 1993. Developing alternative forest cutting patterns: a simulation approach. Landscape Ecol 8:63–75.

Robinson SK, Thompson FR, Donovan TM, Whitehead DR, Faaborg J. 1995. Regional forest fragmentation and the nesting success of migratory birds. Science (Washington) 267: 1987–90.

Small MF, Hunter ML. 1988. Forest fragmentation and avian nest predation in forested landscapes. Oecologia (Berl) 76:62–4.

USDA Forest Service. 1985. Land and resource management plan, Hoosier National Forest. Bedford (IN): USDA Forest Service, Eastern Region, Hoosier National Forest.

USDA Forest Service. 1991. Plan amendment, land and resource management plan, Hoosier National Forest. Bedford (IN): USDA Forest Service, Eastern Region, Hoosier National Forest.

Wallin DO, Swanson FJ, Marks B. 1994. Landscape pattern response to changes in pattern generation rules: land-use legacies in forestry. Ecol Appl 4:569–80.

Wiersum KF. 1995. 200 years of sustainability in forestry: lessons from history. Environ Manage 19:321–9.