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NATURAL FIRE REGIMES AS SPATIAL MODELS FOR MANAGING BOREAL FORESTS

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Abstract

Because organisms have adapted to the natural disturbance regimes of forest ecosystems such as fires and windfalls, conservationists often suggest that timber harvesting systems be designed to imitate natural disturbance regimes. Using the crown fires that shape true boreal forest ecosystems as spatial models for harvesting would require very large clearcuts; in two studies, mean fire size was 12 710 ha (in Labrador) and 7 764 ha (in Quebec). Most conservationists would be reluctant to advocate such large clearcuts and it is not easy to justify them from the perspectives of various ethical systems. A solution is proposed in which moderate-sized clearcuts would be clustered into portions of land areas bounded by water-bodies. These water-bounded areas have an average size of 770 ha in Labrador and 322 ha in Quebec.

Key words: Canada, boreal forest, forest fire, clearcuts, environmental ethics.

INTRODUCTION

People have long been critical of the ways forests are managed, but in recent years issues such as deforestation, global climate change, forest fragmentation, and loss of biodiversity have heightened criticism and given rise to new ideas about forest management (Harris, 1984; Maser, 1988; Franklin, 1989; Hansen *et al.*, 1991). One such idea is that timber harvesting systems should be designed to imitate the natural disturbance regimes, such as fire and windfall, which shape the structure of forest ecosystems. For example, Runkle (1991) suggested that to cut temperate deciduous forests in an environmentally sensitive manner, harvest openings should be patterned after tree fall gaps. Hunter (1990) linked maintenance of biodiversity to silvicultural imitation of the size-frequency distribution of natural disturbances. He noted that, for any given type of disturbance, small-scale disturbance events usually outnumbered larger events, and that imitating this pattern would maintain spatially diverse forest landscapes that would provide suitable habitat for a wide range of organisms with varying spatial requirements.

The assumption underlying these ideas is that the biota of a forest are adapted to natural disturbances, and thus could more easily cope with ecological changes associated with timber harvest if these changes resembled those of a natural disturbance. The idea of matching manipulations of forest stands to natural disturbances is not really new; it is a cornerstone for some of the earliest forms of scientific silviculture which focused on stands of commercially valuable trees (Smith, 1986). The idea seems somewhat novel now primarily because much of the current silviculture is divorced from careful, limited manipulation of a natural ecosystem, and instead focuses upon timber production as a woody analogue of agriculture.

Natural disturbance regimes can serve as models for harvesting systems in three basic ways. First, one could match the frequency of harvesting to the periodicity of natural disturbance regimes. Usually the goal of maximizing timber production means that trees are cut at younger ages than they would die naturally, and thus old forests and their associated biota are relatively uncommon. Second, one could match the size of openings created by harvesting, and their distribution on the landscape, to the patterns of openings created by fire, wind, and the decay and fall of individual trees. In practice, economies of scale often favor harvest openings that are much larger than natural openings and this may exacerbate forest fragmentation and the loss of mature forest habitat. Finally, one could attempt to leave residual organic matter on a harvest site that would resemble the residual material left after a natural disturbance. This could include both dead material such as snags, logs, and slash, as well as live trees, seedlings, and seeds. Harvest systems vary enormously in this respect, from those that only remove a few crop trees to those that remove the vast bulk of above-ground biomass. The general trend is toward more complete utilization of biomass.

In this paper I will address the second of these three points: the size and distribution of natural disturbances as a spatial model for timber harvesting. The paper will focus on boreal forests where the natural disturbance regime is dominated by fires that are frequent (typically, any given place burns every 50–150 years) and of catastrophic intensity, i.e. the great majority of trees are killed (Heinselman, 1981; Cogbill, 1985). These fires are often very large, much larger than most timber harvests, and thus they provide an interesting challenge to the idea that environmentally sensitive forestry should match the spatial scale of harvesting regimes to the spatial scale of natural disturbance regimes.

METHODS

Data on the size distribution of boreal fires in regions essentially unchanged by people were obtained from two published sources, Foster (1983) and Payette *et al.* (1989). I am unaware of other papers with comparable data from either Nearctic or Palearctic boreal forests. The Foster study area was in southeastern Labrador, extending west from the coast to *c.* 60° W, and north from 52° N to the Mealy Mountains and the coast at *c.* 53°30'; it covered *c.* 48 000 km^2. His data on fire sizes for 1870–1980 were obtained from aerial photographs, fire maps compiled by the Newfoundland Forest Service, and aerial surveys. The Payette *et al.* (1989) data covered 1920–1984 and were from northern Quebec in an area between 55–59° N and 74–76° W. I restricted my review of the Quebec data (and further analyses described below) to an area of *c.* 5 670 km^2 described by Payette *et al.* (1989) as northern boreal forest, south of approximately 55°24' N. They delineated older fires from archival aerial photographs, and fires since the mid-1950s from aerial surveys. The methods used in both studies may underestimate the number of small fires because a large fire would obliterate evidence of a smaller, previous fire, and because small fires would be more easily overlooked (D. R. Foster, pers. comm.). In both studies the reported fire sizes refer to the area encompassed by a fire's outer boundary and do not exclude unburnt patches, known as skips, within this boundary. In a study of 69 boreal forest fires in Alberta, the mean total area of skips increased with fire size from 0% for fires <40 ha to 5·2% for fires >2000 ha, with a maximum value of 18% (Eberhardt & Woodard, 1987).

I analyzed 1 : 50 000 scale topographic maps of the regions studied by Foster (1983) and Payette *et al.* (1989) (Surveys and Mapping Branch, Department of Energy, Mines and Resources, Ottawa, Canada) to look for (1) relationships between physiographic patterns and fire patterns; and (2) an alternative model for landscape patterns of timber harvesting. Because the landscapes in both areas were heavily dissected by lakes and rivers, I measured the size-frequency distribution of areas bounded by water-bodies. For each region, 100 points were located in a stratified random manner by dividing each region into 100 cells of approximately equal size, and then randomly locating a point in each cell. Points that fell in a water-body were relocated. Around each of these points, eight vectors were marked corresponding with the eight major compass directions (N, NE, E, etc.). Along each vector the distance to the nearest lake, river, or stream was measured to the nearest 50 m. All streams visible on 1 : 50 000 scale aerial photos were mapped (Surveys and Mapping Branch, pers. comm.); almost all of them connected lakes and thus were probably perennial features. The eight vectors were used to draw an irregular octagon with the length of each vector being the distance from the octagon centre to the angle between two sides. The size of each octagon was determined using trigonometry to determine the sizes of the eight irregular triangles that comprised it. Finally, the size-frequency distributions of the 100 octagons for each region were plotted.

RESULTS AND DISCUSSION

Fire regimes

In both Labrador and Quebec relatively small fires generally outnumbered larger fires (Fig. 1), although in Labrador there were relatively few very small fires of less than 100 ha. Ecologically, the total area burnt by fires of different sizes is probably more significant than the number of fires. Figure 2 shows that fires between 10 000 and 100 000 ha have the greatest total coverage. The overall average fire size was 12 710 ha ± 3021 ha SE in Labrador versus 7764 ha ± 2851 ha SE in Quebec. These data are consistent with a general review of North American boreal forest fires (Heinselman,

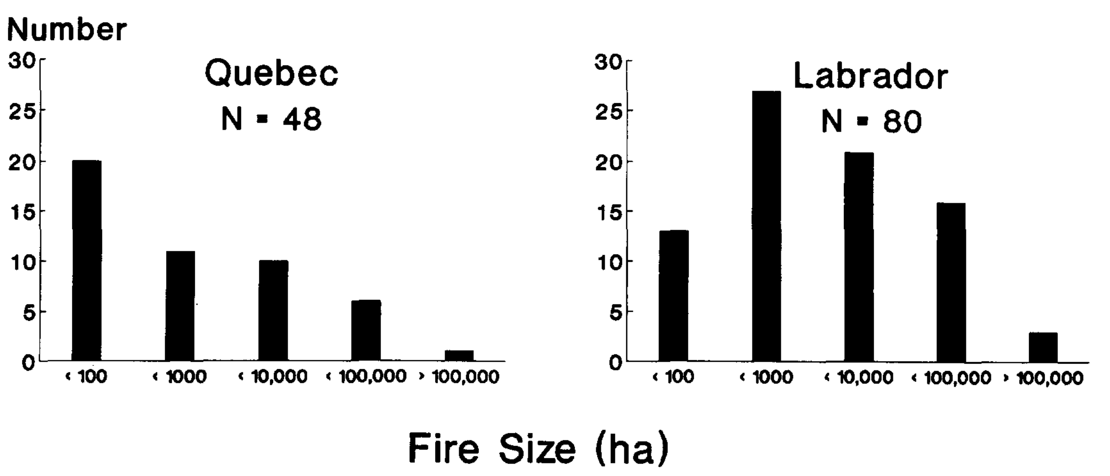


Fig. 1. Size-frequency distributions of boreal forest fires in Quebec (Payette *et al.*, 1989) and Labrador (Foster, 1983).

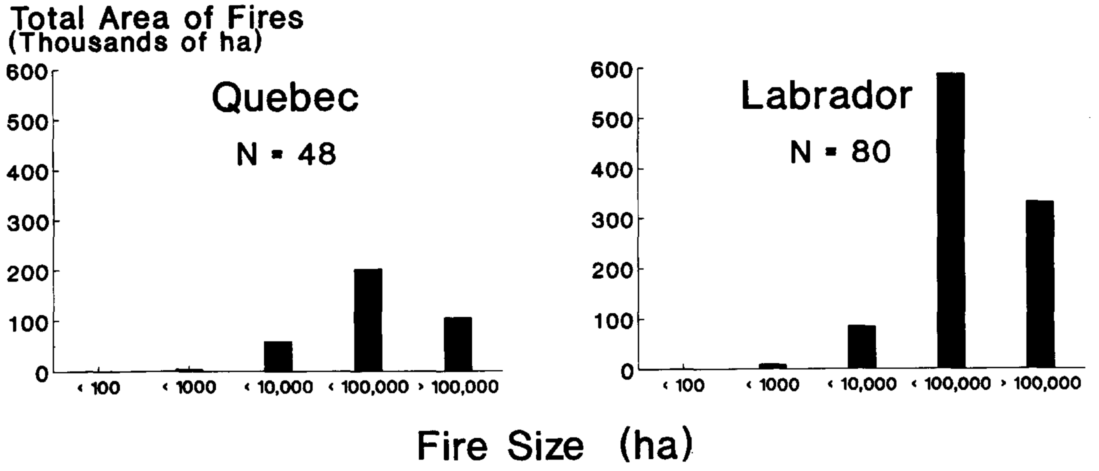


Fig. 2. Data from Fig. 1 transformed to show the total area of fires in each size class.

1981): 'fires are large in area—often thousands of hectares and sometimes hundreds of thousands of hectares'.

Note that these data and Heinselman's statement refer to the true boreal forest (*sensu* Rowe, 1972), as distinct from some other types of northern conifer forests. For example, in subalpine coniferous forests, fires cannot spread as readily because of the mountainous terrain (Kilgore, 1981). Sub-boreal forests found in New England and the Maritime Provinces provide a second example; they are more complex in terms of age structure and species composition and thus do not experience large fires as frequently as the true boreal forests (Lorimer, 1977; Wein & Moore, 1979; Seymour, 1992; Seymour & Hunter, 1992). The difference between the Labrador and Quebec fire regimes probably reflects local variations that occur throughout the boreal region depending primarily on weather, physiography, and vegetation. Within his study area, Foster (1983) found that fewer, smaller fires occurred in lowland plains with many wetlands, and that the largest fires occurred in hillier areas, especially in young stands that had burnt relatively recently. Suffling *et al.* (1988) described significant variation in percent of land area burnt each year along an east–west cline in Ontario. Bergeron (1991) described how boreal fire regimes varied depending on isolation by water, climate, and other factors.

Physiographic patterns

In Quebec the water-bounded areas had a mean size of 322 ± 31 ha and 72% of them were between 100 and 1000 ha (Figs 3 and 4, Table 1). The Labrador water-bounded areas were about twice as large (mean area = 770 ± 61 ha), but still far smaller than the fires. Mean fire size was 17× larger than mean water-bounded area size in Labrador, and 24× larger in Quebec. Obviously, some fires can leap over water barriers; examples can be seen in the maps of Foster (1983) and Payette *et al.* (1989). If water-bodies were usually effective barriers to fire-spread, fires would *not* just be roughly the same size as water-bounded areas; they would be significantly smaller. (This statement assumes that a fire could start anywhere within a water-bounded area and then would be spread by the wind in one general direction, unlikely to turn back on itself.) On the other hand, some fires are stopped by water barriers (e.g. Foster (1983) writes of unburnt forest on the downwind side of water-bodies), and the data suggest that there might be some relationship between fire sizes and the sizes of water-bounded

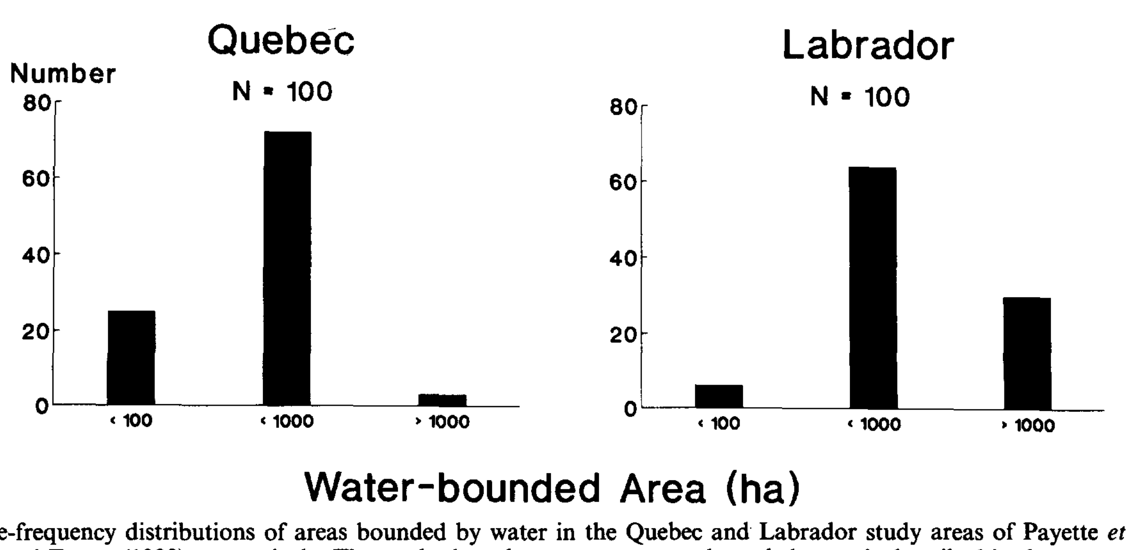


Fig. 3. Size-frequency distributions of areas bounded by water in the Quebec and Labrador study areas of Payette *et al.* (1989) and Foster (1983), respectively. The method used to measure water-bounded areas is described in the text.

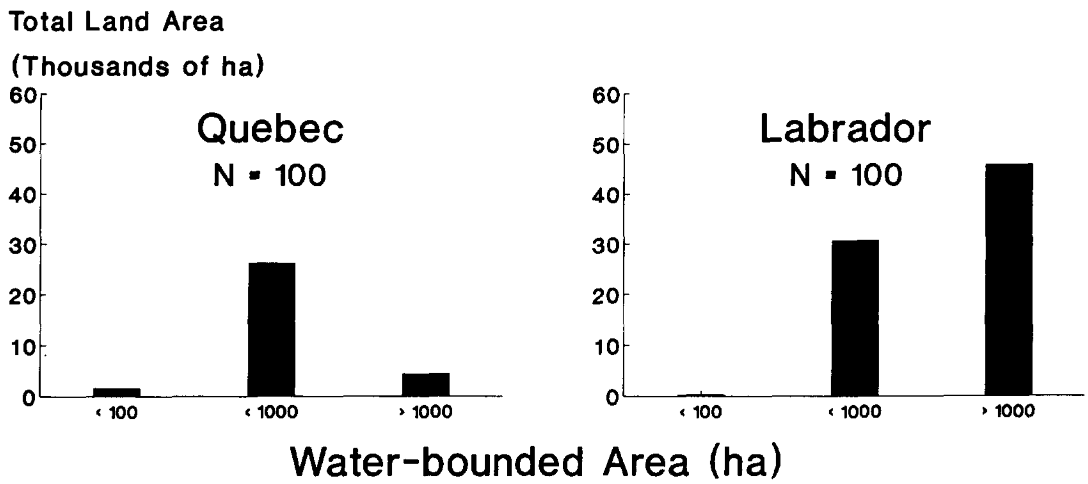


Fig. 4. Data from Fig. 3 transformed to show the total area of water-bounded areas in each size class.

areas. In Labrador both fire sizes and water-bounded areas were roughly twice as large as in Quebec, by factors of 1·6 and 2·4, respectively.

With a sample size of only two regions, this analysis obviously is not conclusive. For example, differences between the Quebec and Labrador fire regimes could be more closely tied to differences in climate than to differences in physiography. Furthermore, to understand the relationship between water barriers and fire, other factors should be considered such as the relationship between the direction of prevailing winds during drought periods and the orientation of water-bodies, and the differential permeability of different-sized water barriers. However, for the purposes of this paper it is sufficient to know that water-bounded areas are significantly smaller than fires.

Spatial models for timber harvesting

Adapting the size distribution of timber harvests to the local fire regime should involve imitating a whole spectrum of fire sizes such as those depicted in Fig. 1, not just matching a mean fire size. This is important if the spatial diversity of a landscape, and potentially its biological diversity, are to be maintained. For example, harvests at the large end of the spectrum would, all other things being equal, develop into forest stands with the relatively low edge : areas ratios preferred by forest interior species, while smaller harvests would favour edge species (Franklin & Forman, 1987; Rolstad & Wegge, 1989; Hunter, 1990). Some caribou *Rangifer tarandus* biologists advocate large-scale timber harvest because they believe that small-scale cutting leads to increased moose *Alces alces* populations, which lead to increased wolf *Canis lupus* populations, with consequent lower caribou populations (D. Welsh, pers. comm.).

Timber harvests that imitated boreal fires would kill the large majority of trees over large areas and thus they would be clearcuts. Of course, given the widely-held negative views of clearcuts, many people would question the wisdom of imitating natural disturbance regimes if this required clearcuts measuring thousands of hectares. They would argue that a clearcut cannot be completely identical to a fire. One could cut at intervals that matched the time between fires; one could burn slash; one could leave residual patches that matched unburnt fire skips; but there would still be some differences. Notably, removing timber from a site is unavoidably different from charring boles and leaving them in place. Perhaps more importantly, timber harvesting requires road construction, and increased access can lead to overexploitation of a wide range of biota. These differences may be a basis for an argument against clearcutting in general, but they are not a useful way to approach the question: given that a fixed area of boreal forest will be clearcut, is it better to have fewer, larger clearcuts, or more, smaller clearcuts? This is a valid question because (1) currently, clearcutting is used almost exclusively to harvest true boreal forests and this is unlikely to change in the foreseeable future; and (2) reactions against clearcutting in general have led many people to suggest that clearcuts be regulated by controlling their size.

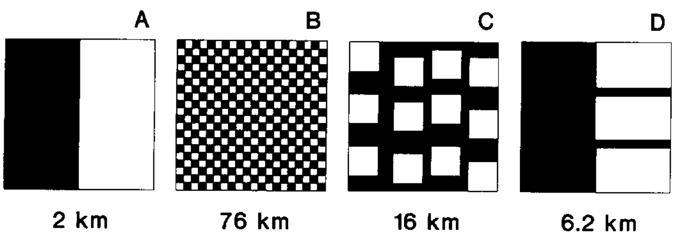
Table 1. Water-bounded areas (ha) in Labrador and Quebec

Labrador									
10	137	242	365	430	588	846	1 041	1 251	1 756
25	151	251	382	438	595	850	1 057	1 282	1 793
33	182	262	384	462	603	910	1 058	1 342	1 808
37	201	271	394	472	714	922	1 059	1 348	1 819
77	209	277	395	474	749	922	1 065	1 348	1 838
100	219	328	410	498	761	937	1 093	1 364	1 859
102	219	345	417	506	790	952	1 103	1 451	1 869
103	200	345	424	526	790	971	1 210	1 475	2 128
120	233	350	428	553	791	978	1 238	1 685	2 765
124	235	354	430	563	822	1 015	1 241	1 754	2 946
Quebec									
24	62	81	125	180	235	285	376	557	722
27	63	82	127	185	238	291	398	569	742
34	68	89	138	185	239	292	404	584	807
44	74	92	143	188	244	295	417	597	852
49	74	99	146	189	246	310	419	603	887
52	77	105	148	189	256	318	419	626	897
55	77	106	157	202	274	326	435	667	930
56	77	110	167	204	279	353	438	691	1 039
56	78	116	176	216	281	356	466	698	1 272
62	79	122	177	234	283	361	498	712	2 101

A compromise strategy

There may be an alternative solution that partially imitates large natural disturbances while accounting for the fact that people are uncomfortable with very large cuts. Figure 5 shows two extremes of one 200-ha cut (A) versus 200 1-ha patch cuts (B), plus the strategy currently favored by many people, i.e. many relatively small clearcuts (C). Figure 5(D) depicts an alternative strategy: clustering moderate-sized clearcuts into large units separated by strips. This would have some advantages. First, it may roughly imitate the skips left by natural fires. These are often linear features along water-bodies or wetlands, called stringers (Heinselman, 1981; Foster, 1983; Payette *et al.*, 1989). These strips may (1) serve as travel and dispersal corridors for forest species; (2) provide seed sources for natural revegetation; and (3) reduce the visual impact of clearcuts. Second, this strategy would not necessarily exclude large-scale disturbances if large fires continued to occur after an area was exploited for logging, and burned both previously logged and unlogged stands. This depends upon the extent to which people decide to control wild fires, and are effective in doing so. Finally, this strategy may substantially diminish the negative effects of fragmentation and edges by concentrating them; note the length of internal edge in each figure. However, the relevance of fragmentation and edge effects to landscapes dominated by boreal forests is poorly understood because most of the information on this issue comes from temperate regions in which forests are isolated in agricultural matrices (Hunter, 1990, 1992).

It must be emphasized that Fig. 5(D) is schematic. In practice, one should avoid convergence on a single clearcut size, and should shape cuts to fit site conditions, particularly with respect to the location of buffer strips between cuts. It may be useful to consider the size distribution of water-bounded areas (Fig. 3). For example, consider a 600-ha area bounded by lakes and rivers. After protecting major riparian areas with a wide buffer, say 100 m, the area available for clearcutting might be reduced to 500 ha. If it were decided that on one cutting cycle only half the total area should be cut, then 250 ha remain. Within this 250 ha one might choose to cluster cuts of *c.* 1, 2, 4, 8, 15, 40, 60, and 100 ha (leaving 20 ha for buffers between cuts). The specific shape and location of each cut would be adapted to site conditions with a goal of perpetuating the whole range of stand types that characterized that forest. Finally, differences in the socioeconomic environment—for example, landownership patterns—may need to be accommodated.



Internal Edge

Fig. 5. Four schemata representing scenarios under which half of a 400-ha tract might be clearcut. Scenarios (A) and (B), the extreme cases of one 200-ha cut versus 200 1-ha cuts; Scenario (C), a commonly advocated strategy of scattering small clearcuts throughout the tract; Scenario (D), intermediate-sized clearcuts clustered in half the area. For each scenario the total length of internal edge is shown, i.e. ignoring the perimeter of the 400-ha area. See Franklin and Forman (1987) for a similar analysis.

In summary, Fig. 5(D) does not represent an ideal prescription for managing boreal forests. There may well be circumstances under which management resembling Fig. 5(A), (B), or (C) is more appropriate. Figure 5(D) simply represents a compromise between a goal of having boreal forest harvest systems imitate natural disturbance regimes and one of accommodating human value systems which see large-scale harvesting as catastrophic.

An ethical perspective

Whether or not to imitate natural disturbance regimes is as much a question for ethicists as for scientists. In this final section I will examine this question using Callicott's (1990) review of conservation ethics in which he describes three different value systems: the resource conservation ethic, the romantic-transcendental preservationist ethic, and the ecological-evolutionary land ethic, personified by Gifford Pinchot, John Muir, and Aldo Leopold, respectively.

For a resource conservationist like Gifford Pinchot (first chief of the US Forest Service) there are only two things on earth, people and resources, and resources are to be used for the 'greatest good for the greatest number of people for the longest time'. From this perspective, the critical issues are that timber harvesting be sustainable to benefit future generations, and efficient. Clearcutting in boreal forests probably meets these two criteria, but a resource conservationist would not necessarily favor clearcuts measured in thousands of hectares because (1) the curve of economies of scale (timber harvesting costs decreasing with increasing cut size) would be quite flat before reaching cuts this large; and (2) aesthetics are one of the 'greatest goods' and the 'greatest number of people' do not like large clearcuts.

For a romantic-transcendental preservationist such as John Muir (one of the first advocates of preserving wilderness), nature is a temple that can only by sullied by the intervention of people. With this value system, imitating natural disturbances is a moot point because all forms of timber harvesting are an intrusion upon nature. Here one's primary goal would be to maximize the amount of wilderness area, and concomitantly this would mean obtaining needed timber production from as small an area as possible.

An advocate of Aldo Leopold's ecological-evolutionary land ethic thinks of people as 'citizen-members' of natural ecosystems with both the right to alter those ecosystems, and the responsibility to assure the well-being of all other member species. Leopold's philosophy is fundamentally different from Pinchot's (people as citizen-members versus a people–resources dichotomy), but his prescription for harvesting boreal forests may or may not look very different from that of Pinchot. It is possible that Leopold would assume that as citizen-members we have the right to diverge from nature in favor of small clearcuts. It is more likely that he would argue that we ought to adjust our aesthetics and accept clearcuts designed to imitate boreal fires (J. B. Callicott, pers. comm.). When one reads of Leopold's (1991) distaste over the carefully manicured forests of Germany, it is obvious that his sense of aesthetics is closely informed by what is natural for a given ecosystem, rather than what is considered aesthetic in the tradition of landscape painting (J. B. Callicott, pers. comm.).

In summary, while I cannot find an unambiguous philosophical basis for making boreal clearcuts as big as fires in Callicott's (1990) review, or others (e.g. Nash, 1976; Rolston, 1979), it is likely that Leopold would support this approach. But would Leopold be able to convince others to adjust their aesthetics? The answer is probably either 'no', or 'with great difficulty'. Most people, including philosophers, find it impossible to avoid looking at the world anthropocentrically. In terms of human spatial scales and human life spans, a 5000-ha clearcut would stretch to the horizon and last almost forever, and thus seem like a catastrophe best avoided. To view ecosystems from a larger spatial and temporal perspective requires more than just a basic knowledge of ecology and evolution; it requires a profound understanding.

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