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FORESTS - WILD AND MANAGED: DIFFERENCES AND CONSEQUENCES
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Dr. Gordon Grant

U.S. Forest Service, Pacific Northwest Research Station

HYDROLOGIC, GEOMORPHIC AND AQUATIC HABITAT IMPLICATIONS OF OLD AND NEW FORESTRY

Abstract

The effects of timber harvest activities on hydrology, geomorphology and fisheries have been a subject of research for many decades. It still is difficult, however, to make categorical statements as to what those effects are.

There is now a growing recognition that it is not just the presence or absence of logging within a watershed that is significant, but the overall pattern of land use through space and time that determines what effects logging will have. This introduces an entirely new level of complexity into the problem. Intelligent stewardship of forest resources requires that we attempt to address the implications of alternative harvest strategies on stream and riparian resources.

Unfortunately, we have little basis from either field observations or modeling to allow us to predict how alternative cutting scenarios will affect the input or movement of water, sediment and wood with consequences for riparian and aquatic ecosystems. In this paper a general framework is presented for analyzing hydrologic, mass erosion, and aquatic habitat effects of alternative harvest strategies and present some preliminary results of modelling the effect of such strategies. Three scales of interest are examined: individual clearcuts, approximately 100 acres in size, aggregates of units of 2,000 to 3,000 acres and multiple aggregates which are medium sized watersheds of 10,000 to 20,000 acres. The effects of both minimum fragmentation and staggered-setting harvest scenarios are explored. The paucity of field, modelling or historical data underscores the need for a major research initiative in this area.

INTRODUCTION

Today, I'd like to present some broad perspectives, and a conceptual framework, for viewing the effects of alternative cutting patterns at a variety of scales on the hydrology, geomorphology and aquatic resources of the forest.

Now, those of you who are students in the audience know that when someone starts talking about conceptual frameworks, it usually means that they have no data. And in my case that happens to be true. In fact my talk brings to mind Mark Twain's oft-quoted refrain that there is something marvelous about science: one gets such wholesale returns of conjecture out of such a trivial investment of fact.

I want compare two alternative strategies or ways of prescribing and laying out harvest activities at a landscape level. I'll refer to these two as the minimum fragmentation alternative in which harvest units are aggregated over a landscape so as to minimize the fragmentation of the remaining stand. This is in contrast to the dispersed or staggered setting alternative where activities are dispersed over the landscape, generally creating more fragmentation in the remaining forest. In the States these alternatives have been called "new" and "old" forestry respectively, but these terms are inappropriate in British Columbia where, as Jerry mentioned last night, you don't need any more big clear-cuts. In any case I will contrast these alternatives at a variety of scales looking sequentially at the effects on hydrology, mass erosion , and fisheries.

The aggregation process that I am referring to has a certain scale dependence attached to it. That is, I am assuming aggregation is occurring of individual harvest units into larger cutover blocks at a scale of approximately 2,000 acres or so. These are not large clear-cuts compared to some of the blocks you have here in B. C.. Perhaps in the question period we can have some discussion about what the actual implications might be from larger clear-cuts.

To begin with, however, I'd like to emphasize that when one talks about Old and New Forestry, there's a certain tendency to view practices conducted in the past as being somewhat anachronistic. And I think this is a fallacy: what we need to do is understand the logic that initially attended the application and the development of those practices.

In the case of the philosophy of staggered settings or dispersion of units, which has certainly motivated the practices on U.S. federal lands over the last thirty to forty years, there was a certain logic that went with it. That logic is summarized in Fig. 1. From 1950 to 1990 there was a set of concerns having to do with natural regeneration of seedlings, the efficient development of a road network, concerns about producing edge habitat for large game species in the forests, and a set of watershed concerns that had to do with dispersing impacts so as to minimize the effects of peak flow increases and mass erosion.

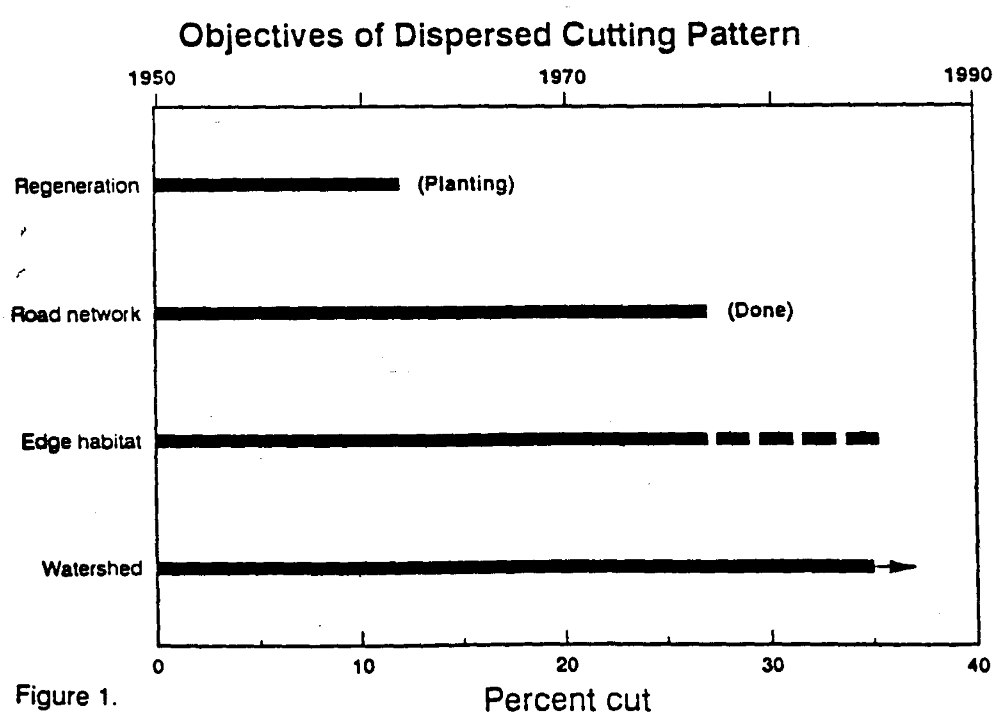

Figure 1.

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Note that many of these original objectives have been achieved. Natural regeneration was replaced in the late 1950's by direct reforestation and planting. The road network had largely been completed by the late 1970's. Edge habitat concerns have been achieved and replaced by concerns about other species, such as Spotted Owls, that require interior, rather than edge forest habitat, so that objective has changed as the pattern of the forest and our knowledge about the habitat needs of other forest dwellers has changed.

The one objective that has been maintained throughout this period are the watershed concerns. So we need to consider the implications of different management-imposed patterns on watershed values.

As Jerry pointed out in his talk last night, and as Miles indicated in his talk, there are different scales of interest that are being considered by the concept of New Forestry. We are interested in how harvest practices at the stand level can be used to create or maintain diverse values. We are also interested in how the landscape level pattern develops and affects ecological values. A third set of issues which are subsumed under the heading of New Forestry have to do with maintenance and protection of riparian zones and channels, and viewing these in a drainage basin geomorphic context and as important connecting corridors in the landscape.

I'm going to be focussing on the effects of alternative cutting patterns on those stream and riparian values over a range of scales. I'll be looking at these effects at three scales: *individual units* which may be on the order of 100 acres or so; *aggregates of units* which in many parts of the Pacific Northwest correspond to third-or fourth-order drainage basins -- these might be on the order of 2,000 to 3,000 acres, and then *multiple aggregates*. The latter scale involves larger fifth, sixth-order drainage basins of 10,000 to 20,000 acres in size.

So I will consider the effects of two different landscape patterns, staggered or dispersed setting and minimum fragmentation on hydrology, mass wasting, and aquatic habitat in turn at each of these three scales.

HYDROLOGIC EFFECTS

Looking first at the hydrologic effects, I will be emphasising peak flows as a major geomorphic agent that can affect channel stability, riparian zones and aquatic habitat. Studies conducted over the last twenty years in Oregon, Washington and elsewhere, have indicated that the harvest activities can increase the frequency or magnitude of peak flows. This increase has to do with two main factors: first, the increased efficiency of the drainage network that comes from the development of roads and compacted ground. This effect can be indexed by the area of roads and compacted surfaces occurring within a basin (Harr *et al.* 1975). This is because water is routed more efficiently and faster over compacted surfaces, resulting in more rapid delivery and larger peak flows in stream channels.

Another factor that Jerry discussed at some length last night has to do with the rain-on-snow effect. We know that by opening or removing the canopy in clear-cuts we increase the sensitivity of the landscape to rain-on-snow events because we both increase the amount of snow accumulated in clear-cuts and we also increase the rate of snow melt during rain-on-snow events (Harr 1981, Christner and Harr 1982). These two processes represent important effects of timber harvest in general on the hydrologic system.

The evidence to support this comes from some studies conducted in both the Coast and Cascade ranges of Oregon by Dennis Harr (Fig. 2). These watersheds are no more than second- or third-order and range up to several square kilometers in size. There is an approximate linear increase in peak flow as a function of the percent of basin area compacted (Fig. 2). That's the first effect I mentioned. The evidence for increased peak flow from harvested basins due to augmented rain-on-snow events is a little bit more ambiguous, but also can be interpreted from some studies done by Dennis Harr and Jerry Christner on the Willamette National Forest in Oregon (Christner and Harr 1982). What they did was plot the cumulative peak flows for a series of storms over time between two neighbouring basins. For example, the cumulative peak flows for Lookout Creek and Blue River are shown in Fig 3A.

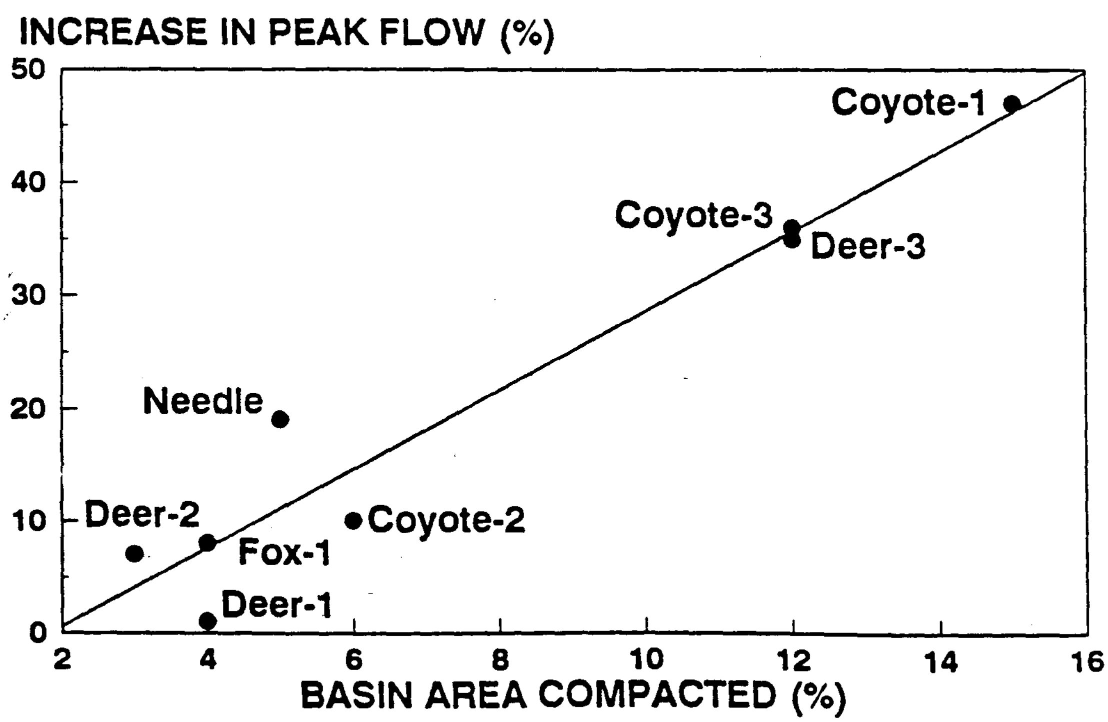
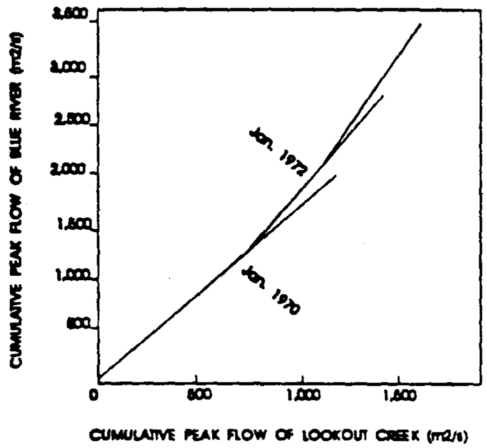
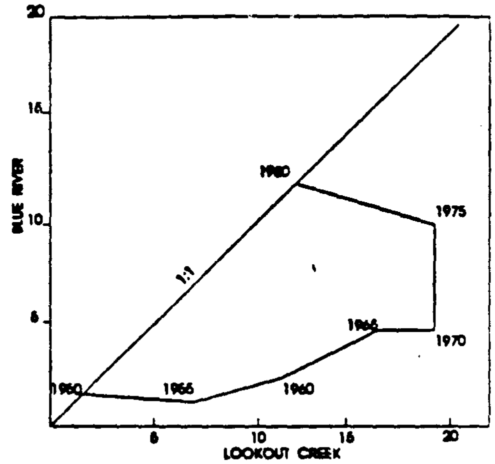


Figure 1.



Double-mass plot of cumulative peak flows of Blue River and Lookout Creek. Curve was fitted by eye.

Figure 3A



Percent of Blue River and Lookout Creek watersheds below 1,200-m elevation in forest stands, 25-yr-old stands.

Figure 3B

Note the fact that the slope of the relationship in peak flows appears to shift when the level of harvest activities in Blue River, which had been relatively modest up to the 1970's, increased from about five percent of the basin area cut to about fifteen percent or more cut (Fig. 3B). There is a deflection in the peak flow curve indicating that the relative magnitudes of peak flows in Blue River had increased relative to Lookout Creek. Most of these peaks were generated during rain-on-snow (Harr 1981). The same kind of pattern was visible on other fifth- to sixth-order (ten to 100 square kilometre) basins. Although that's about the extent of the studies that have been done to date, it's suggestive enough to give us pause in considering some of these issues.

How might these hydrologic effects manifest themselves across the range of scales I have identified here under a staggered setting as opposed to a minimum fragmentation approach? At the scale of the individual unit, we expect no difference; that is in either case, the unit is either cut or not cut, so we expect the same kind of hydrologic response (Fig. 4).

At the scale of the aggregate of units, again reminding you that's approximately a third- or fourth-order basin of several thousand acres -- I guess I should back up and say the model that I am proposing here is one in which the aggregate scale might be entered and cut over a period of 25 years. Over that period, under the minimum fragmentation approach, the entire watershed would be entered and cut. Under a staggered setting approach, there would be multiple entries into that same ground, but the entire watershed would not be cut (Fig. 4). But over an entire rotation, the watershed, the larger watershed in which this smaller aggregate was embedded, would be entered and completely cut; the same under both scenarios.

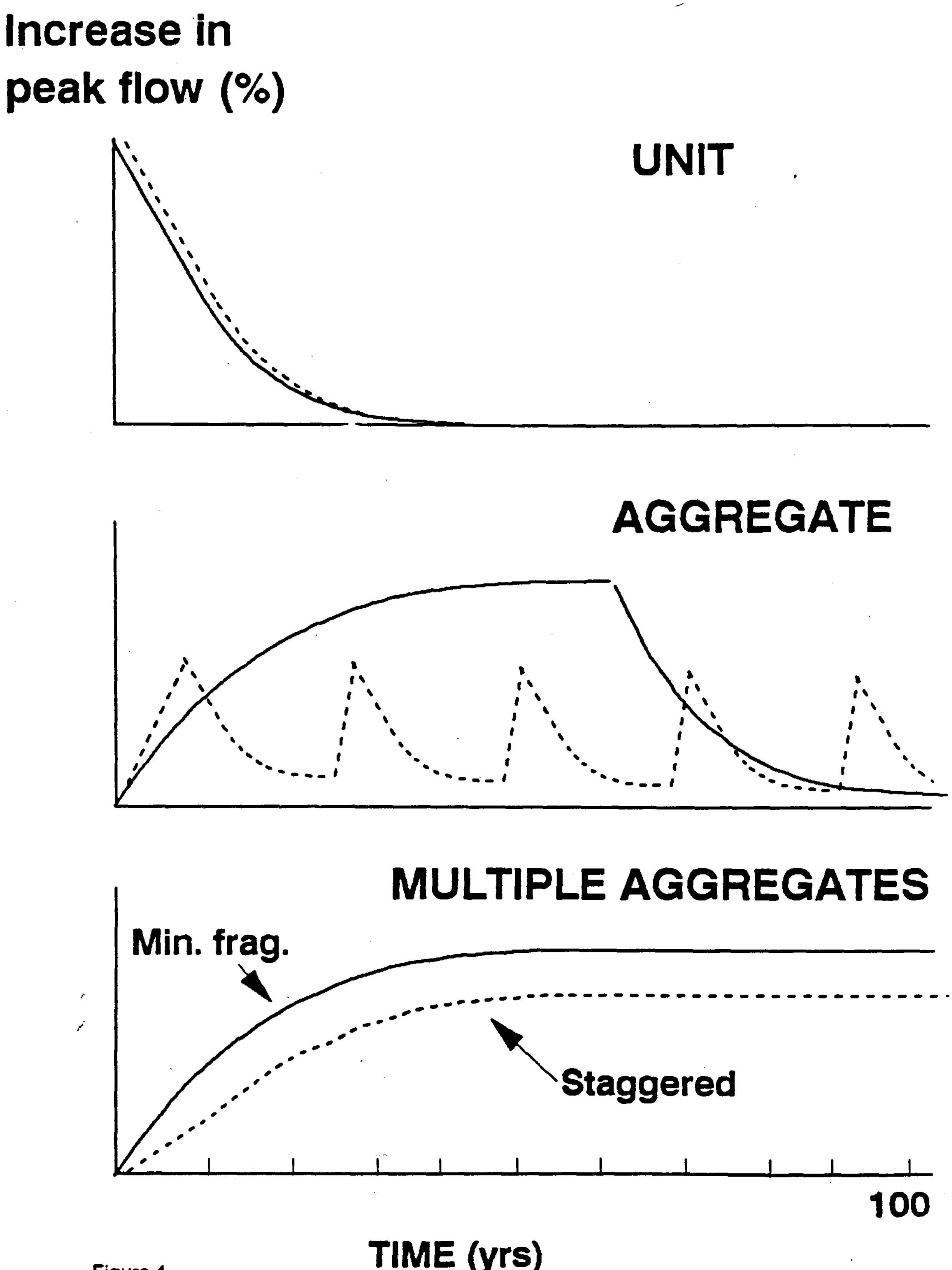

Increase in
peak flow (%)
UNIT
AGGREGATE
MULTIPLE AGGREGATES
Min. frag.
Staggered
100
TIME (yrs)

Figure 4.

So at the scale of the aggregate we might expect to see. under the minimum fragmentation approach, a steady increase in the magnitude of the peak flow increase with time. This comes from integrating the individual harvest unit curves over the entire period. So at the very end of 25 years the effects from the first clear-cut are completely gone. The reason for this is that with time the sites recover, the canopy closes, the compacted ground becomes presumably less compacted. But note that there's no absolute scale on this axis. We really don't know what the magnitude of these decreases really are.

So, peak flows under the aggregate approach increase with time to some steady state and then drop off. Under the staggered setting, we might see short spike increases in peak flow corresponding to multiplies entries, then followed by decreases (Fig. 4). If we then integrate that signal followed over the entire 20,000-acre watershed, we might expect to see that there is likely to be some difference between those two alternative approaches. Peak flows under the minimum fragmentation alternative might be expected to be larger, but the relative magnitude of that increase would be more modest than that experienced at the smaller aggregate scale.

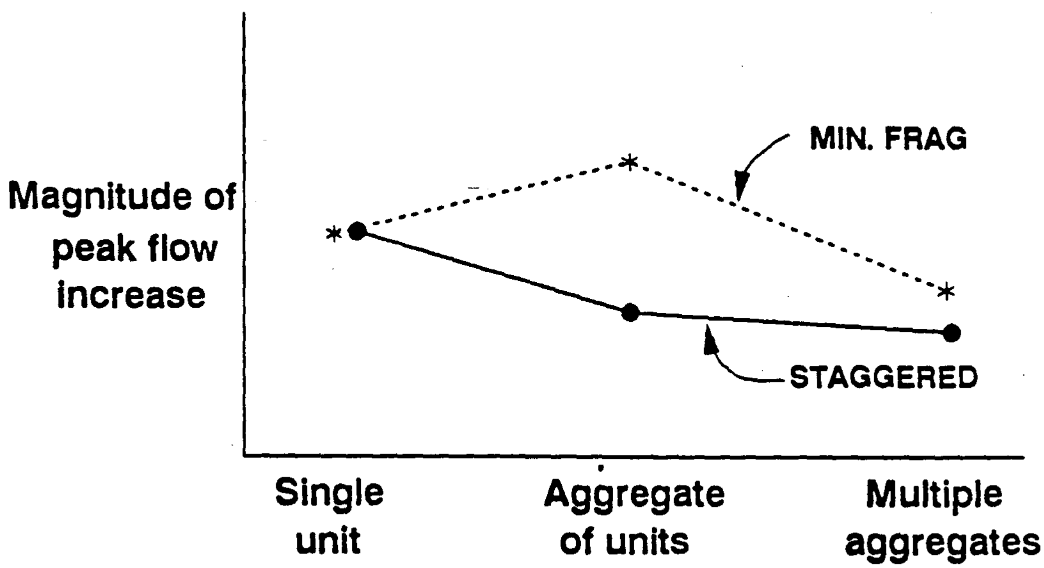


Figure 5.

This is sumarized in Fig. 5. The relative magnitude of peak flow increase is shown on the vertical axis. At the single unit scale, the same behavior is seen under both scenarios. At the aggregate of units scale there is a large difference in performance, in terms of potential for generating higher peak flows under a minimum fragmentation approach, and then a more modest difference between the scenarios at the multiple aggregate scale. I'll come back to this at the end when I discuss some modelling efforts.

MINIMUM FRAGMENTATION SCENARIO

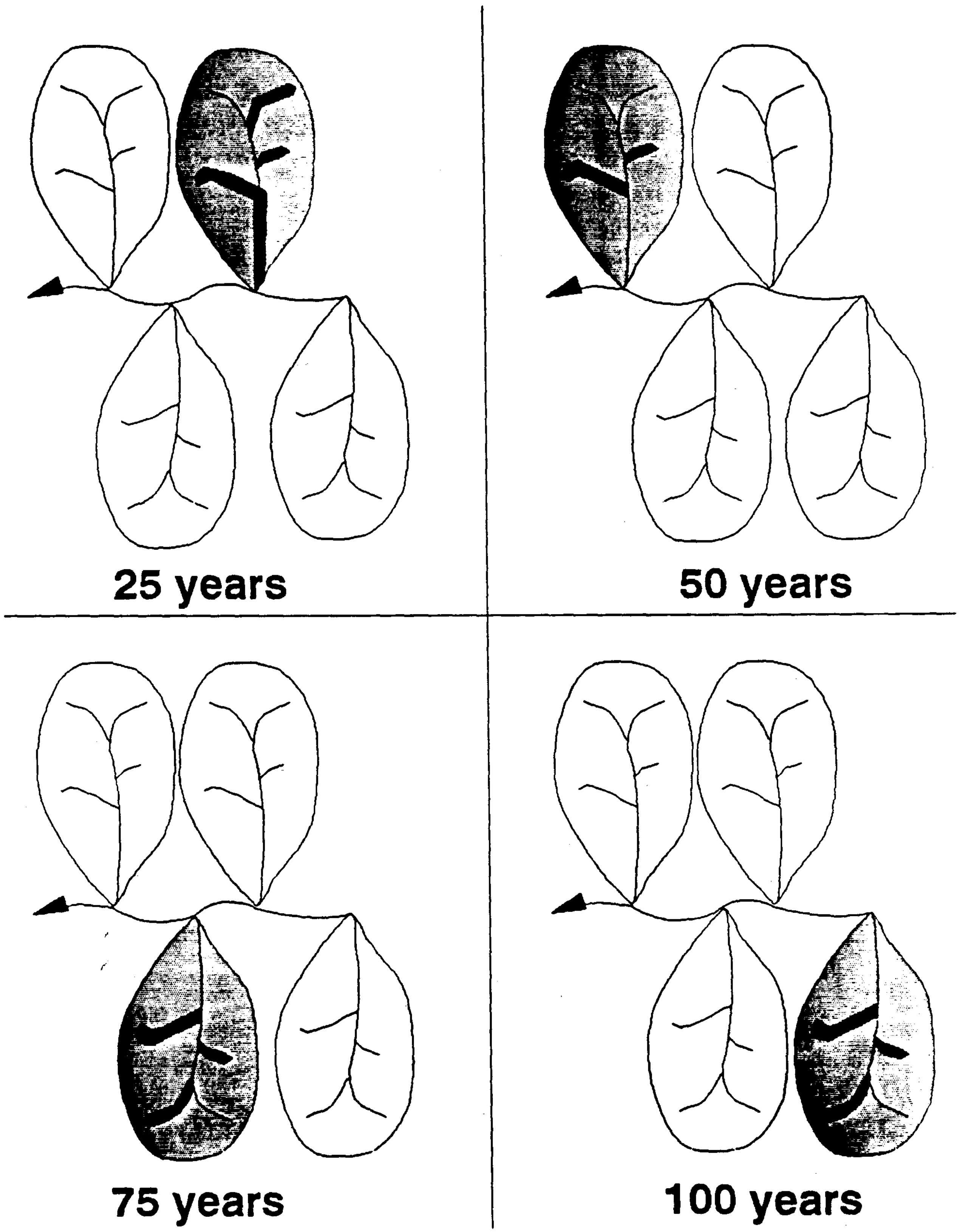


Figure 6.

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STAGGERED SETTING SCENARIO

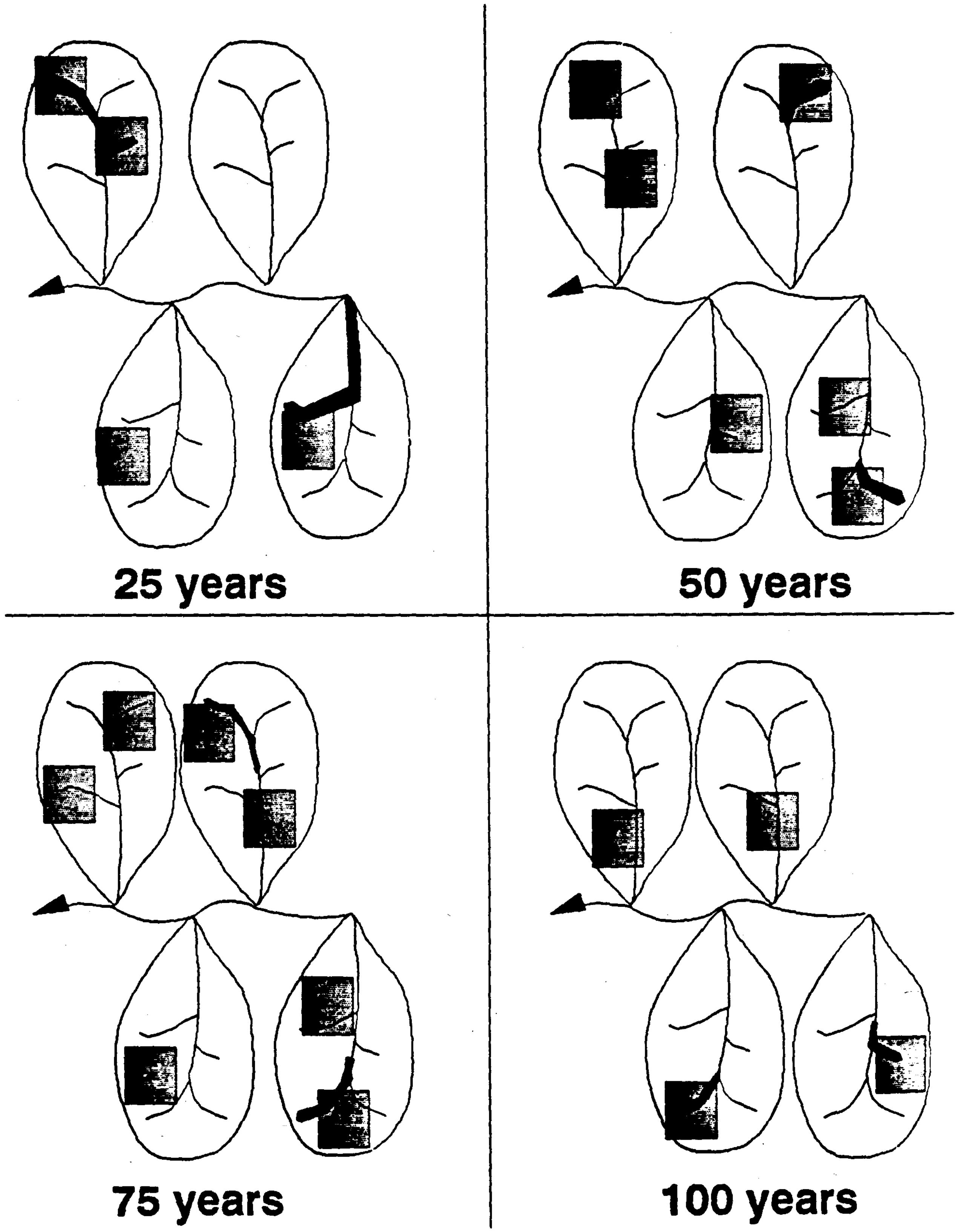


Figure 7.

Whether or not the magnitude of increases in peak flows under these various scenarios has any significance as far as the channel is concerned may have more to do with the nature and character of the stream system than with the absolute magnitude of the peak flow. For example, if you imagine a channel in which the entire channel is incised into bedrock, even major increases in peak flows may work very little change in the character and geometry of the channel. The effect would be expected to be greater in a self-formed alluvial system where increased peak flows in the stream may translate into increased competence to move bed material. This may result result in changes in the channel geometry with attendant implications for channel stability, aquatic habitat and so forth.

So we need to remember there's a geomorphic context to these changes that needs to be addressed, as well as assessing whether there will be changes at all.

MASS EROSION EFFECTS

Turning now to the question of the effects of mass erosion under these two different alternatives, we note that the effect of cutting frequency at a site is strongly controlled by the percent of time that that site has increased sensitivity to landsliding. You can think of this as a window of vulnerability. And this window of vulnerability is strongly controlled by the physiographic or biogeoclimatic region that one is in.

For example, the timing of increased landsliding following harvest depends on whether you are in the Coast range, the Cascades, or the Idaho Batholith. In the case of the Coast range, almost two-thirds of the slides occur within zero to three years after harvest.

There is a more even distribution of sliding within the first ten years in the Cascades and in the Idaho Batholith we see even later occurrence of sliding following harvest. The reason for this is relatively easily explained in terms of the wetter climate to the west which leads to faster decomposition rates, hence loss of residual rooting strength in the Coast range. In addition, as we go more eastward, we also encounter more deeply-rooted vegetation which also tends to hold the ground.

So we need to keep this kind of regional perspective in mind when contrasting the effects of harvest activities on mass erosion. But keeping that in mind, how might we contrast these two different anthropogenic disturbance regimes that we are imposing? Well, we can look at the effects of sliding and associated debris flows at a basin scale (Fig. 6). Under the minimum fragmentation approach, these sub-watersheds would be sequentially entered at approximately 25-year intervals, and thus, there would be an effect of concentrating landslide and debris flow activity in particular parts of the drainage basin at any one time. If one were standing in one of the sub-basins, one would experience a greater probability of seeing effects of erosion, debris flows and so forth if it was that basin's turn to be harvested. The rates of slide and debris flows would drop down to more of a background forest rate in the intervening 75 years between entries (assuming a 100 year rotation).

This should be contrasted against the kind of picture that would emerge under a dispersed strategy where the entire basin would be susceptible to slides and debris flows, at least in some portion, over the entire period of entry (Fig. 7). So, the effects of these two different alternatives is to either concentrate or disperse the probability of increased mass erosion at a given site.

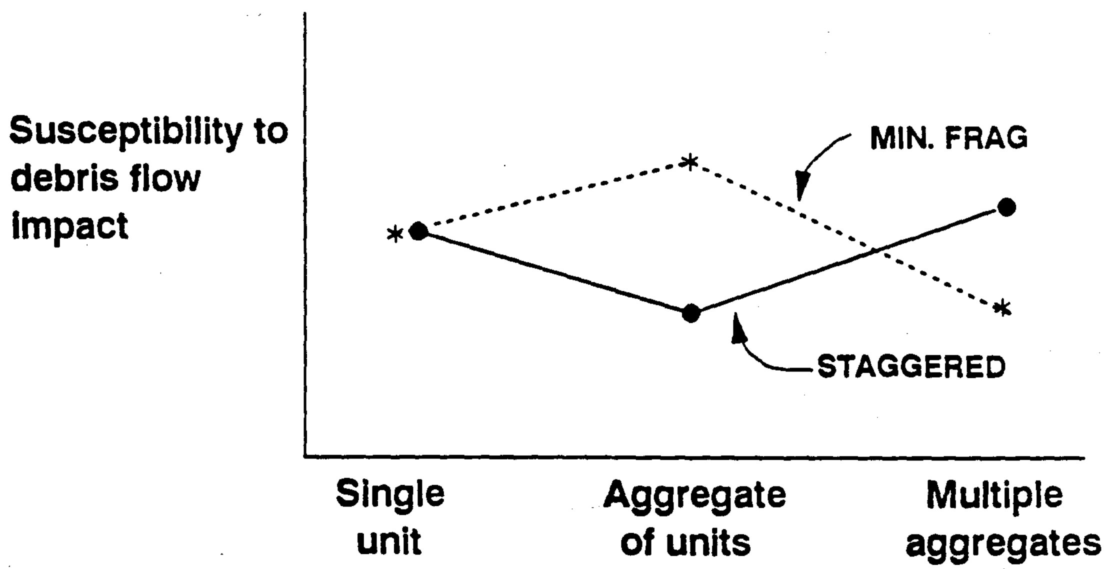


Figure 8.

If we contrast these effects at the different scales as before (Fig. 8), we see again that at the scale of the single unit no difference exists between the two different strategies. At the scale of the aggregate unit, we might expect to see a much higher incidence of susceptibility to debris-flow impact during the period when that unit was being entered and for the window of vulnerability following entry. Following that, we might expect a much lower probability of mass erosion than under a staggered setting approach because of the long recovery period without harvest activity.

But if we extend that analysis now to the full basin, there is a flip-flop between the likelihood of experiencing a debris flow at a given site. Under the staggered setting scenario, continuous operations over the entire watershed might lead to a greater probability of debris-flow impact at a site than under minimum fragmentation approach where our effects are concentrated in individual sub-basins.

We can look at the same picture through time to see how these events are distributed over the course of an entire rotation (Fig. 9). An important assumption is that under both the minimum fragmentation and staggered setting scenarios, at the end of 100 years or so, we've cut the whole place. In other words the rotation age is constant under both scenarios, so that we might expect that at the end of that period we would see approximately the same number of slide events in both cases, assuming the same frequency of slide triggering storms. The timing of those slides, however, is very different under the two scenarios. If we consider only the aggregate scale, there is a pulse of activity as the basin is entered under the minimum fragmentation alternative. The staggered setting scenario leads to a lower magnitude but more frequent sequence of mass erosion events over the entire length of rotation.

The only way to effectively change the total number of slide events is to change the rotation age. That is, if we want to reduce the total number of slides and if we believe in this relationship between harvest and increased susceptibility to sliding, one way to change that is to go to a longer rotation, in which case we're operating over the same piece of ground over a longer period of time. The effective result of that is to reduce the slide rate.

EFFECTS ON FISHERIES

This pattern and timing of mass erosion events has some implications for fisheries. As I am not a fisheries biologist, this section is going to be even more speculative than the others. There are a number of implications in terms of how fish might view these different basins under these different management scenarios. There might be greater opportunity for refugia, for example, under the minimum fragmentation alternative due to the concentration of activity in particular parts of the basin. Under these conditions, fish could utilize those parts of the basin that were not being disturbed.

In addition to directly disturbing fish communities, one of the effects of mass erosion events, is to transform the channel structure. We have evidence, for example, that following debris-flow passage there is a much more homogeneous channel structure, without the clear definition of pools, riffles, cascades and so forth that we see in a system that has not experienced recent debris-flow. And since we know that fish are keyed into these kinds of habitat units, we might expect to see a different kind of mix of fish depending upon the diversity of structural habitat.

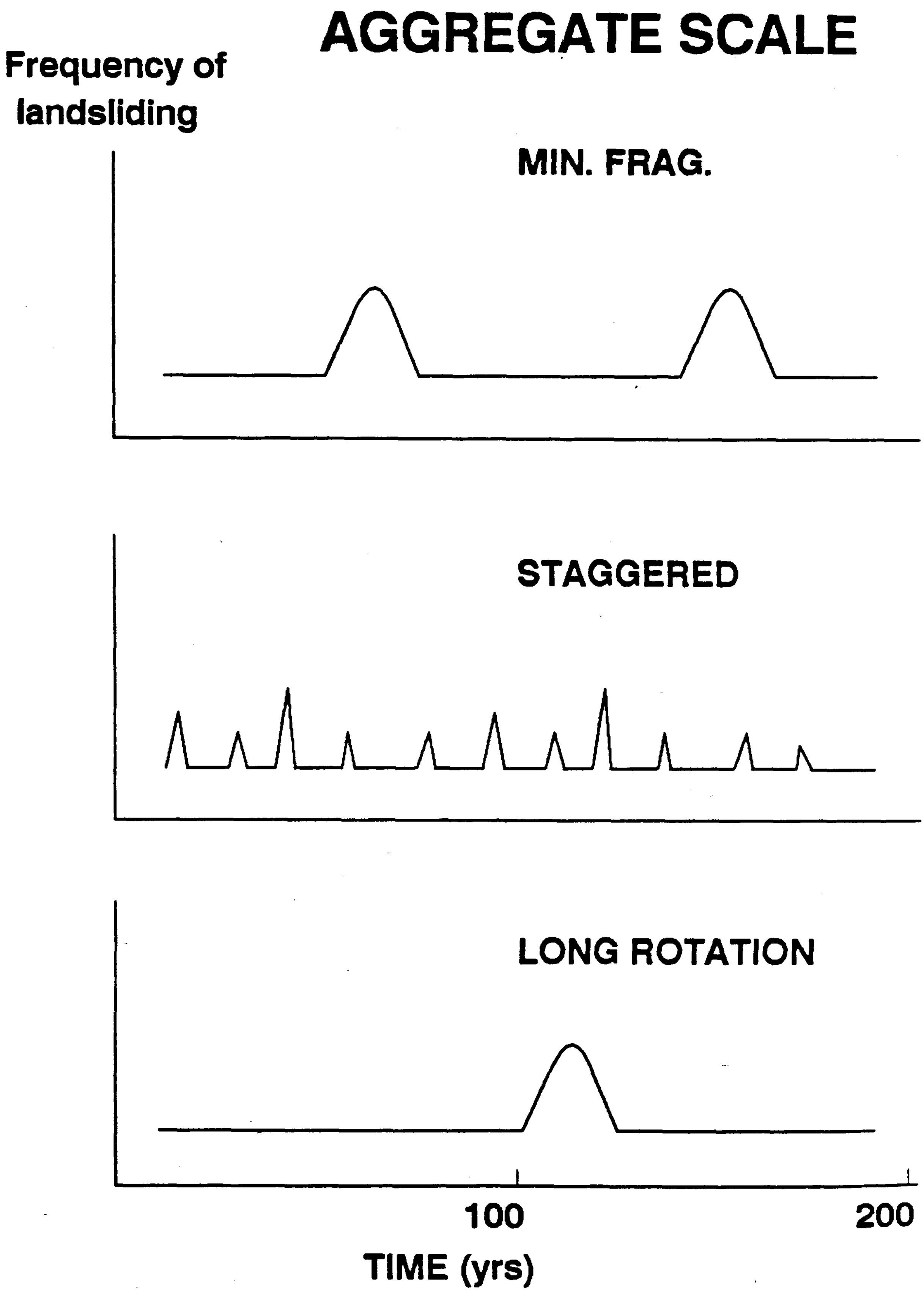

AGGREGATE SCALE
Frequency of landsliding
MIN. FRAG.
STAGGERED
LONG ROTATION
100
200
TIME (yrs)

Figure 9.

Work at our laboratory by Gordie Reeves, Fred Everest and others suggests that there are some very different patterns of fish community structure as a function of the disturbance regime. Loss of certain kinds of channel structure tends to push the the fish community towards a single species as opposed to a more complex mix. So continuous debris-flow activity in a particular part of the basin might tend to homogenize channel structure in such a way that we lose some of the complexity we need to maintain a complex fish community.

This diversity of habitat might vary over these three different scales (Fig. 10). At the scale of the aggregate units under a minimum fragmentation approach, concentration of debris flow activity in a single basin over a short period of time might result in a more homogeneous channel structure for that period of time. In contrast, under a staggered setting approach at that same scale less frequent debris-flow activity would lead to a more heterogeneous mix of channel environments.

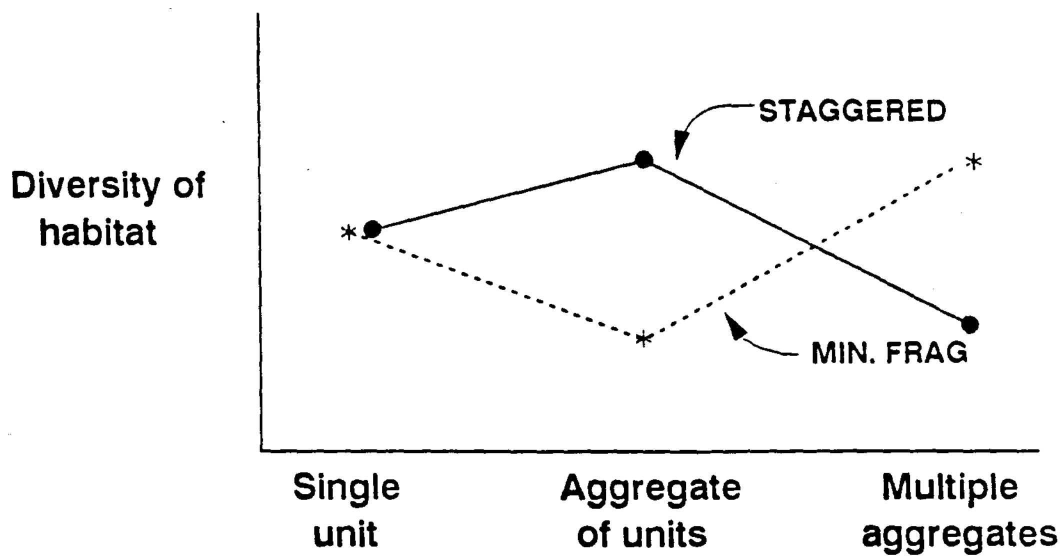


Figure 10.

At the basin scale again we see that flip-flop occurring, where what looks like heterogeneity at this scale becomes homogeneity at the multiple aggregate scale. Under the staggered setting approach, we're operating continuously over the whole basin so that we're disturbing the whole basin in a more or less uniform fashion. And this is likely to be different than under the minimum fragmentation approach -- a greater contrast in the range of channel habitats is likely to be present.

I've been focussing primarily on the frequencies and magnitudes of channel disturbance events. Another factor is the timescale of recovery. There are different timescales here depending on whether one is interested in recovery of the channel form, that is the actual geometry of the channel; recovery of channel processes; and also biologic recovery, that is the timescale required for biological communities to re-establish themselves.

Stan Gregory and others have been looking at the re-establishment of fish communities following debris flow in the Cascades. Their work suggests that fish community recovery can occur fairly quickly; that is, fish can recolonize a debris flow impacted stream within a few years if the channel structure has not been entirely lost.

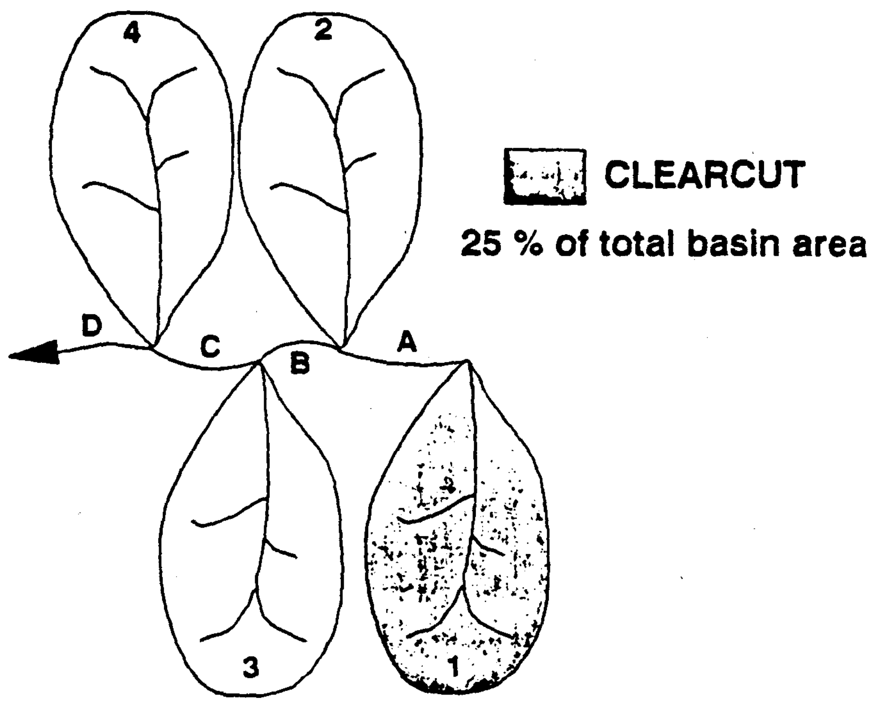
So these are issues that one needs to keep in mind in addressing this whole problem. Another issue is that the model I've been presenting up to now assumes that harvesting would be concentrated within watersheds. One could somewhat minimize or mitigate the effects I've discussed by actually draping units over watershed divides, thereby distributing impacts over one, two or more watersheds. So there are some management options here in terms of how you actually put these things out on the ground.

UNCERTAINTIES AND FUTURE DIRECTIONS

There are some big unknowns. Much of this is a big unknown in itself, as you can tell from the paucity of data, but I'd like to emphasize a couple of issues. One is that we really don't have any understanding of what the effects of alternative structures at the stand level might have on any of this. Jerry mentioned last night that we have to think of these things as a package, that it's not just landscape level concerns or stand level concerns. We have to think of these different scales simultaneously. And what that means is there will be hydrologic effects that vary in terms of the amount of green retention and in terms of the distribution and pattern of trees that we leave on a site. We may therefore be able to influence the hydrology one way or the other. We may also be able to influence the tendency for mass erosion events. And these are as yet completely unexplored topics.

Another big unknown has to do with the whole complex nature of water and sediment rout' ; in mountain streams. We really understand very little about how water and sediment move through steep, rough channels. Most of the work has been done in lowland streams and the models really don't apply to the upland. So this is another area where we're focusing some effort.

MINIMUM FRAGMENTATION SCENARIO



STAGGERED SETTING SCENARIO

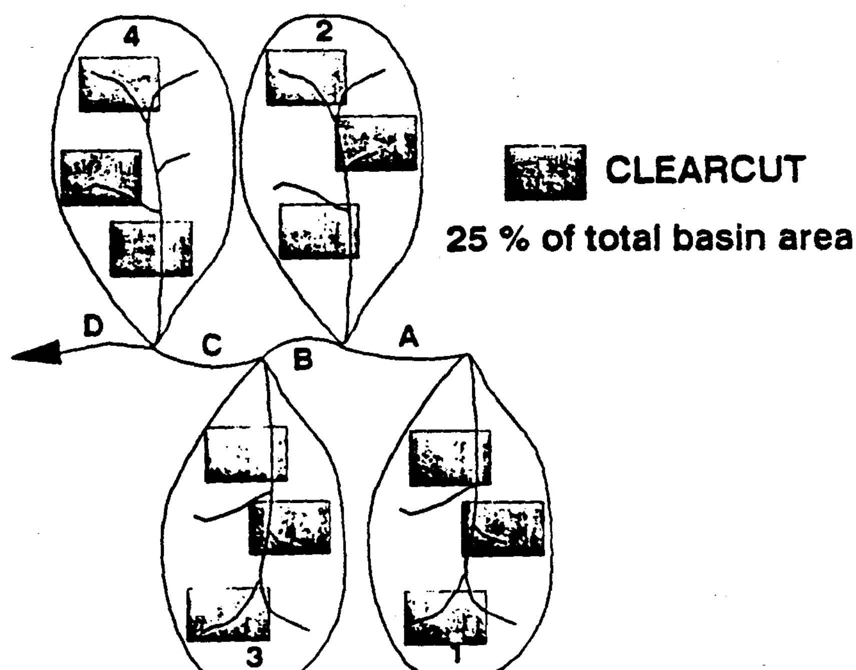


Figure 11.

Grant 1990

And then there is the whole issue of synergistic or complex response; that is the fact that we may have joint increases in both discharges and mass erosion events. How is that going to affect the channel? We really don't know.

Some directions for future research: first we need to be emphasizing process based landscape models. The phenomena we're considering operate at a scale that we've little experience doing science at - large watersheds. How do we do science at this level? Well, one way to do it is to emphasize computer simulations. We are just now putting these kinds of large landscape level models together, to look at hydrology, basin-scale hydrologic processes and routing of sedimentary and organic material.

We need to do a better job of looking at our historical studies. We have a wealth of data residing in our long-term stream records, in our aerial photographs. Much of this has been under-utilized and/or not utilized at all. We really need to take some good retrospective looks to see what the nature and results of the land-use experiment that we've been conducting over the last thirty years really is.

Finally, we need to consider incorporating and initiating some large-scale field experiments. And, again, this raises a set of logistical and technical and scientific problems as to how one does science over a large landscape in any kind of consistent way. The statisticians shudder at the idea of doing comparisons among 20,000 acre basins.

I just want to briefly summarize some preliminary results from a simple model just to show how the effects of pattern might make a difference. The assumptions in this model are that hydrologic effects are driven primarily by compaction and that compaction is a linear function of the percent of basin area harvested. Let's take a simple case of two watersheds: one harvested under a minimum fragmentation approach and the other under a staggered setting approach. In both cases, 25 percent of the basin is harvested (Fig. 11). We route a peaky-looking china hat hydrograph through both basins and compare size of the resultant peak flows. If we compare the hydrographs at the downstream end of the basin there is an approximate doubling of the percent increase in peak flow under the minimum fragmentation approach (Fig. 12). These numbers should not be taken as anything more than just evidence that pattern does count.

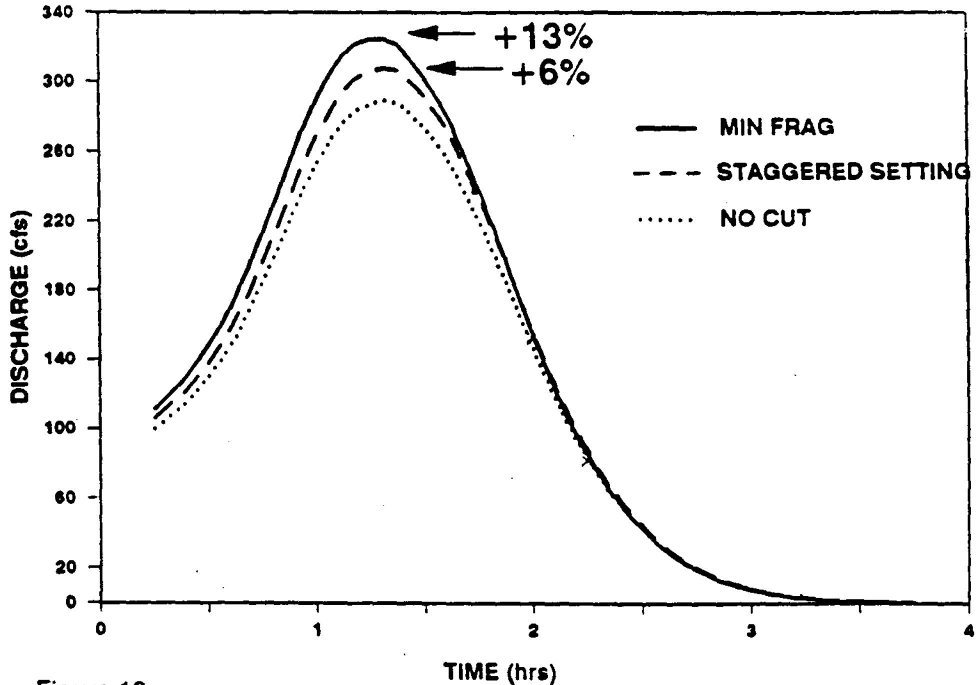


Figure 12.

Here are some concluding thoughts. First, I've tried to emphasize the importance of scale as a factor. Effects that are manifest at one scale do not show up at other scales, or the effects are reversed. We need to keep this in mind. At some scales, aggregating cutting units may increase peak flows and concentrate mass wasting events. The frequency of these mass erosion events is influenced by both the rotation age and the so-called window of vulnerability.

The fisheries impacts are also scale-dependent and need to be considered at both the population and community level.

We must consider the geomorphic context, both regional and at the channel level in interpreting our effects. There are management options as to how we actually create these patterns. Finally, we must emphasize a coordinated approach of field, modelling, and historical studies if we are to reduce the level of speculation and increase the store of facts with respect to the effects of forest pattern on geomorphic and aquatic resources.

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