Scale of Severe Channel Disturbances Relative to the Metapopulation Structure of Bull Trout

Charlie Luce, Bruce Rieman, Jack King, Jason Dunham

USDA Forest Service Rocky Mountain Research Station, Boise, Idaho www.fs.fed.us/rm/boise

Severe disturbances to channels, like debris flows or hyperconcentrated flows, can kill or remove all fish in a stream. Severe disturbances are not new features in the landscape, and fish have evolved strategies to persist in the face of major disturbances.

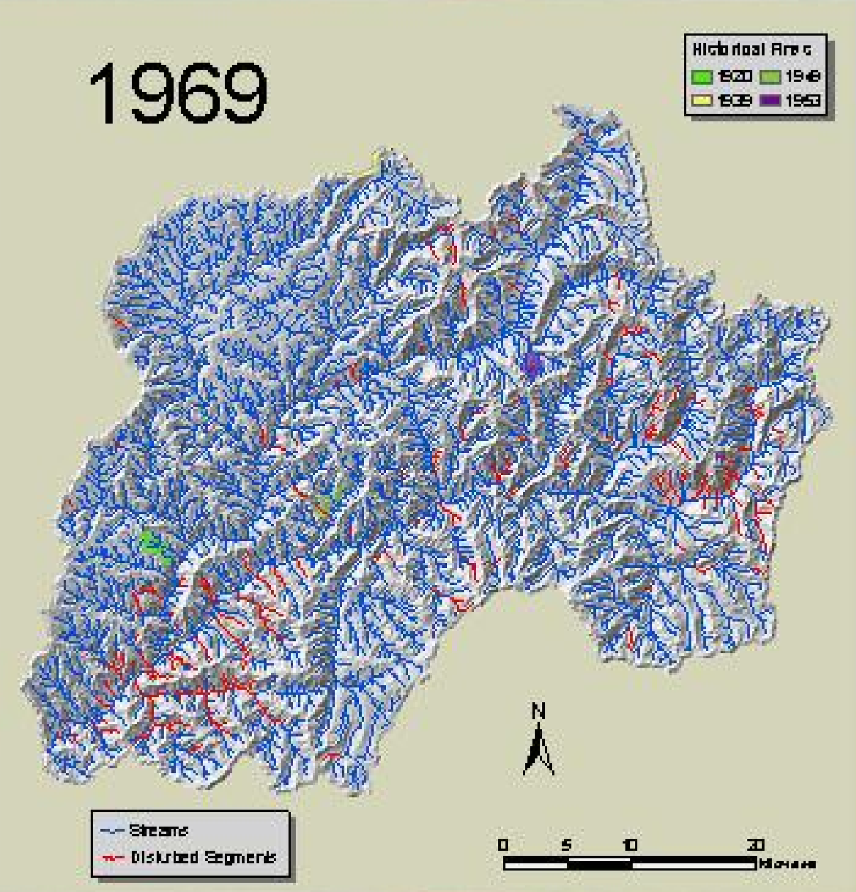
Variation in life history and the spatial structuring of fish populations are two important factors contributing to persistence. For example, some fish in a local population may move extensively, thus reducing the likelihood that all members of a population are in a stream when a major event strikes. These individuals can recolonize areas where populations have been lost. Members from nearby local populations may also be important for recolonizing impacted streams. A metapopulation comprises a group of local populations that may support each other in this manner.

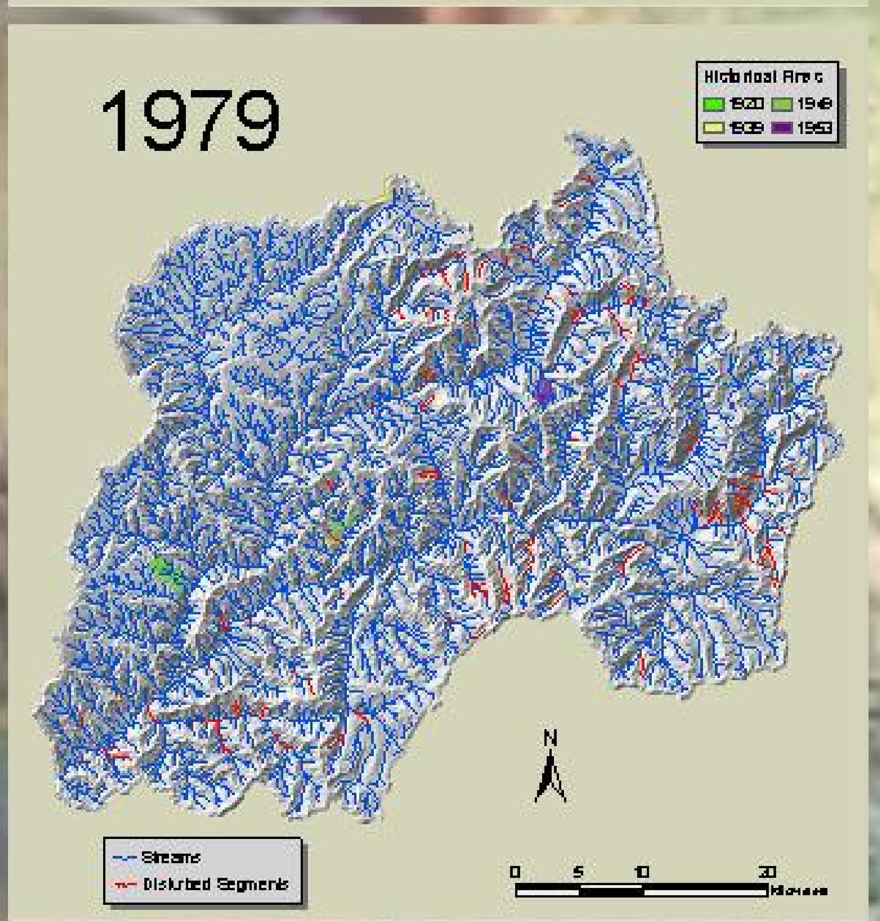
Metapopulation theory implies that if the scale of disturbance is smaller than the scale of habitats occupied by local populations, then it is relatively inconsequential to persistence. One key prediction is that larger habitats will have greater population stability (e.g., persistence), due to a lower probability of a system-wide severe disturbance. Our objective was to compare the scale of physical disturbance to that of biological process implied by a metapopulation structure.

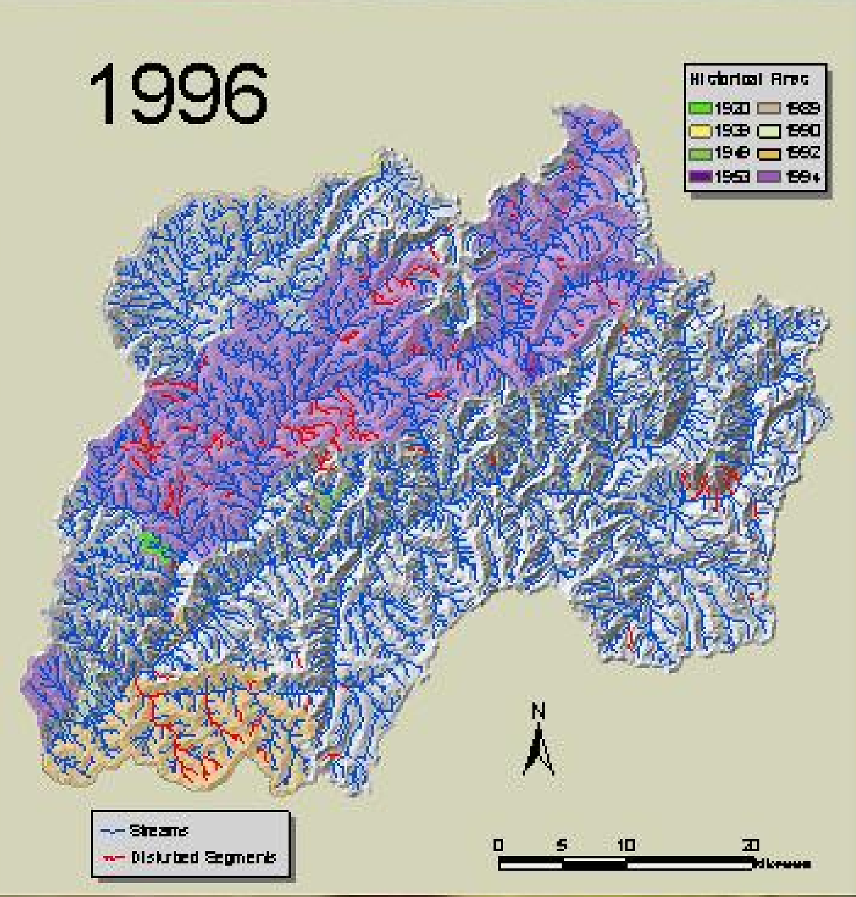
Debris flows, hyperconcentrated flows and other severe channel disturbances were mapped from 1:15,800 aerial photographs of the Middle Fork Boise River basin. In these photos (reproduced at full scale below), severely disturbed channels are much brighter than undisturbed channels.

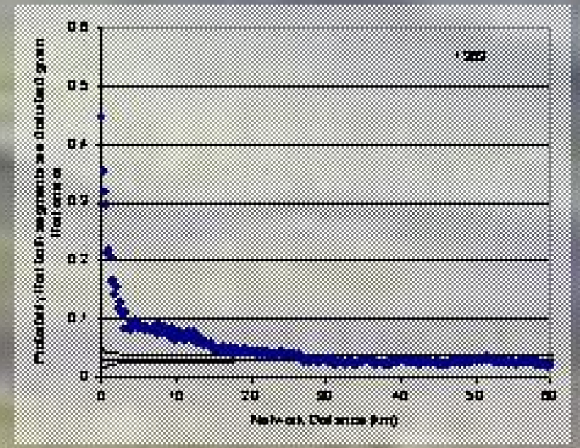
Maps were made from photos flown in 1969, 1979, 1988, and 1996. Maps are shown for only three years to conserve space, as the 1979 and 1988 maps are similar.

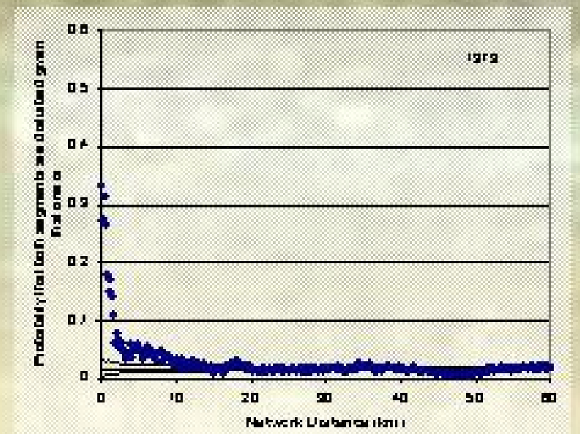
The data were analyzed by calculating the probability of a pair of stream segments both being disturbed in a scene conditioned on one of the pair being disturbed. The pairs were grouped into bins of distance along the stream network between segments. In a sense, the resulting graphs show correlation in disturbance as a function of distance. The broad line at the bottom of the graphs is the global mean conditional probability flanked by 5% significance estimates based on a binomial distribution for each bin.

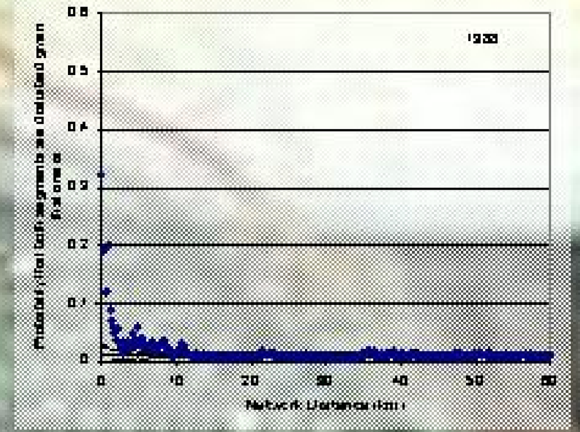


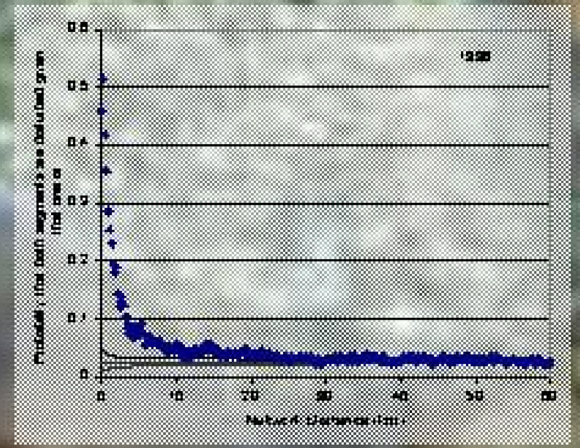










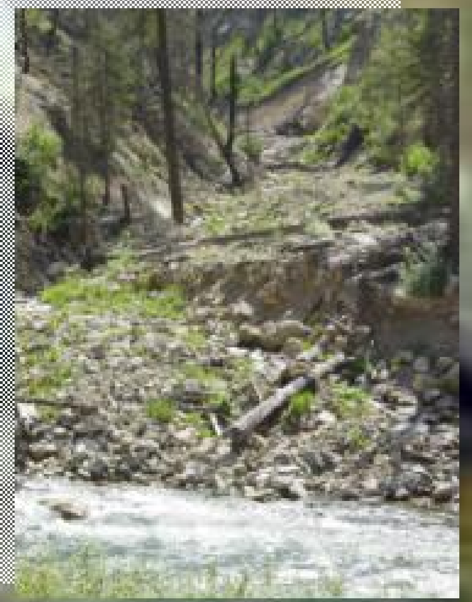


Looking at the group of maps together, there are several interesting observations. First, in years with more disturbance, there appears to be a greater degree of grouping of the disturbance. Second, at the extent of the Middle Fork Boise basin, there seem to be only a few clusters. Third, in any given scene, only a small portion of the basin is affected at any time. In 1969, the scene with the most disturbance, about 6% of the segments representing about 8% of the total length were disturbed. Finally there are a few areas on the map showing little disturbance history while other areas show a repeated history. The large region in the north has less gradient and relief than the rest of the basin.

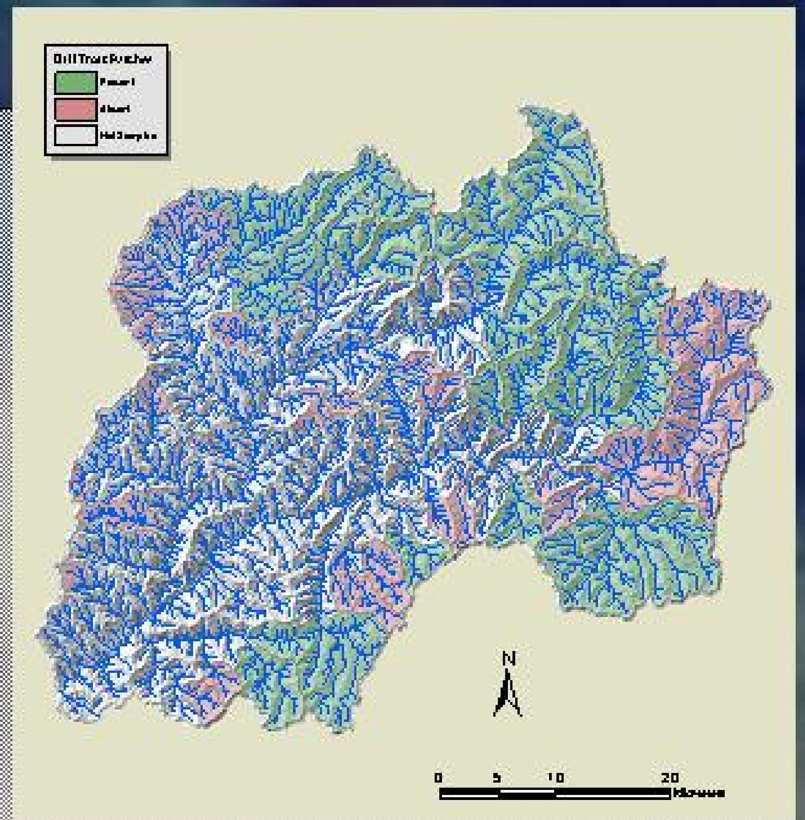
The 1969 map shows disturbances primarily related to the 1964 flood event that affected much of the Pacific Northwest. For this severe disturbance, there was some clustering of impact, and the analysis suggests between a 5 and 10 km characteristic length scale for clusters of disturbed channel.

The 1979 and 1988 maps and analyses show much less spatial clustering and much less disturbance overall. Individual stream segments appear to be disturbed randomly across the basin. Thunderstorms are a relatively common occurrence in the region and may have caused these spatially disparate channel disturbances.

The 1996 scene again shows a large extent to disturbance basinwide, and a higher degree of clustering. The characteristic length scale is again in the 5-10 km range. Interestingly enough, most of the disturbances seen in this scene are related to severe thunderstorms as well, but the large area burned by fire may have allowed each thunderstorm to affect a wider area. Most of the damage occurred from two thunderstorms, one in 1993 following the 1992 wildfire, and one in 1995 following the 1994 wildfire.

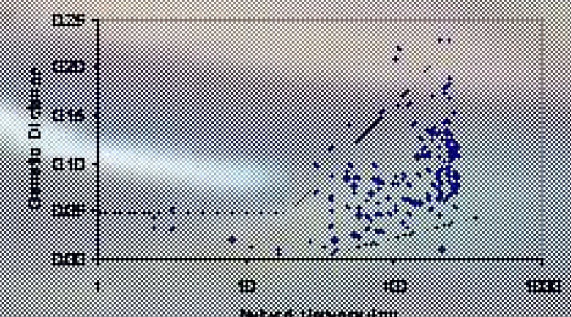


Although bull trout may move widely, critical spawning and rearing habitats are constrained to cool streams. The colored watersheds on the adjacent map encompass our predictions of the thermally suitable stream networks for bull trout in the Boise River basin. Demarcation of basins based on elevation as a proxy for temperature provides a network of habitat patches on which metapopulation processes are presumed to operate.

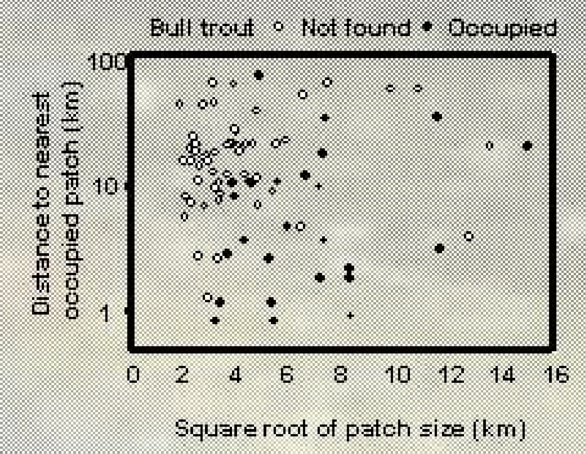


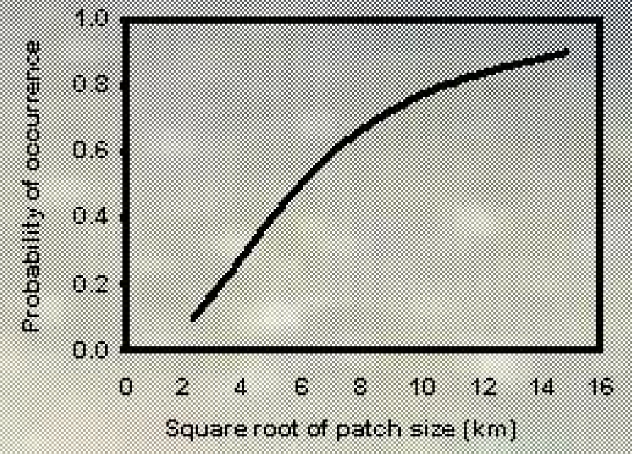
Larger patches tend to contain bull trout, while smaller and more isolated patches rarely do. One explanation for such a pattern is that larger patches are less vulnerable to contiguous severe disturbances. A length scale of 8-10 km is suggested for both the patch size and the distance between patches.

Genetic divergence of fish among stream segments can be used to determine the scale of population structuring or gene flow among bull trout throughout the basin. Genetic distance estimated from variation in microsatellite DNA suggests that gene flow is high at the scale 10-20 km declining with distance beyond that.



The patterns of patch occupancy and disturbance are consistent in scale with the patterns of gene flow that would be expected within and among those patches functioning as a metapopulation.





Extinction of a metapopulation will result when all member populations are simultaneously extirpated. The evidence presented here from two recognizably severe disturbance causing mechanisms suggests that individual fish populations are robust to some of the more extensive natural disturbances seen in recent history. The largest disturbances in the observed record tend to have scales smaller than those associated with structure in fish populations as defined by patch size and genetic divergence.

The cartoon on the right shows how disturbances with characteristic scale smaller than a patch might play out. In essence small patches are much more likely to experience a complete disturbance (i.e. most or all available habitat within a patch) than large patches. Small patches should therefore be much less likely to support a population at any point in time. Our observations from other work and the patterns of gene flow indicate that recolonization through dispersal from nearby, persistent, populations can occur within one or two decades. Small patches in close proximity to large patches might also be more likely to support a population at any point in time because they are more likely to receive the demographic support through dispersal of individuals from those larger patches.

This information has important implications for reserve design, where reserves need to be spaced sufficiently far apart to minimize the likelihood of simultaneous destruction. There is also important information for evaluating risks of management that reduces habitat patch size through fragmentation (e.g. culverts) or stream warming by riparian harvest. Natural processes that shrink patch size such as fire in riparian forests and global warming may well influence potential fate of fish populations like bull trout in the Boise River Basin.