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# An improved design for assessing impacts of watershed practices on small streams[1]

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With 1 figure and 2 tables in the text

Assessment of impacts of watershed management practices (logging, grazing, etc.) on stream ecosystems is an important problem facing resource managers. Considerable effort has been put into studies of such effects, yet results have too often been equivocal. Difficulty may arise from the complexity of multiple pathways through which these practices may influence stream ecosystems. We suggest that another source of difficulty may lie in the design of the various studies. In this paper we review four approaches to assessing impacts of watershed practices that have been taken in Oregon and suggest the most efficient design in terms of time, effort, and power to discriminate effects.

Study designs differ in the way they address a research problem. Each study must strike a balance between the level of precision and generality that it attains. Furthermore, limitations on time, funds, and manpower dictate that one choose the design that most efficiently allocates effort, and that best suits the study objective.

The approaches can be classified in four categories according to whether they involve study before treatment (before-after) or not (post-treatment) and whether they involve one or two streams (intensive) or many (extensive). Extensive studies are usually of short duration. Intensive studies must, by nature, extend over at least several years to account for natural variation. The total effort may be about the same; extensive studies involve single observations at many sites, and intensive studies involve many observations at the same site.

## Comparison of designs

Perhaps the most common design, and the one most conventionally accepted, is the long-term watershed study (intensive before-after), designed after traditional hydrologic studies. The Alsea Watershed Study in Oregon involved a 15-yr investigation of three adjacent watersheds (HALL & LANTZ 1969). Fish populations and physical characteristics were monitored for 7 yrs, then timber was harvested in two watersheds, the third remaining unlogged as a control. Significant changes occurred in the watershed that was completely clearcut, including increased stream temperature, reduced dissolved oxygen, and increased sedimentation. Responses of the fish populations to these changes differed by species. Based on analysis of juvenile populations rearing in the streams, no effect on the coho salmon *(Oncorhynchus kisutch)* was detected, whereas the cutthroat trout *(Salmo clarki)* population was reduced to about one-third of its pre-logging abundance for the duration of the 7-yr post-logging phase (MORING & LANTZ 1975).

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The principal advantage of the intensive before-after study is the ability to assess year-to-year variation in fish populations and habitats and to put impacts of management practices in the context of this variation. It is also possible to assess rate of recovery from a disturbance. No assumptions are required about pre-treatment conditions.

Disadvantages of the long-term approach, however, are many. The design is not really an experiment, but a case study, with results of questionable applicability in other watersheds differing in geology, soils, hydrologic regime, or fish species. The results are vulnerable to unusual events, such as extreme weather, especially if the event coincides with the treatment. In the Alsea Study, for example, a storm with recurrence interval of about 100 yrs preceded treatment by 1 yr, whereas the rainfall in the 2 yrs immediately following logging was below average. The long time required to obtain results is another severe limitation. Including planning lead time, up to 20 yrs might be required for completion of this type of study. The watershed practices being evaluated might well be obsolete by the time recommendations are made. In addition, if there are serious adverse influences on the fish populations, considerable damage will have been done in other streams subject to these practices during the study period. Finally, it is difficult to maintain intensity and continuity of involvement by research personnel over such a long period.

A second approach attempted in Oregon could be termed extensive before-after comparison. As an adjunct to the Alsea Study, 12 watersheds in Western Oregon were selected for short-term study, one summer before and one summer after logging (MORING & LANTZ 1974). The results were variable, in part because several different patterns of timber harvest were included among the 12 watersheds. Where comparable estimates could be made, juvenile coho salmon populations increased in five streams and decreased in three. These inconsistent results may well be due to substantial year-to-year variation in population size, as observed in the Alsea Study. Cutthroat trout populations decreased in all four watersheds where good comparisons could be made, and declines were most severe (up to 50 %) in the two watersheds where the treatment was extreme (clearcutting without a buffer strip) (MORING & LANTZ 1974). Thus the results of this extensive study are generally in agreement with those of the Alsea Watershed Study.

Advantages of this second approach include: 1. the broader perspective gained on the severity of problems across a geographic area (for example we found that the changes in stream temperature and surface dissolved oxygen noted on the clearcut watershed in the Alsea Study were extreme compared to those observed in the other 12 coastal watersheds); 2. increased generality that allows wider application of findings to other areas and other situations; and 3. the shorter time required to obtain results, as little as 3—4 years.

The principal disadvantage lies in the lack of long term perspective, since only immediate effects can be monitored. There is little or no provision for assessing natural year-to-year variation, relative to magnitude of treatment effects. Further, results are vulnerable to unusual weather events, since all treatments occur in the same year.

The third approach could be called intensive post-treatment analysis. As part of the Coniferous Biome Study, we inventoried cutthroat trout populations in a stream that had been clearcut 6 years prior to the beginning of our work. The "control" was an upstream unlogged area closely adjacent to the logged section. The study began in 1972 and continued through 1976 (Aho 1977; Murphy 1978).

Trout populations differed in the two sections of stream and these differences were remarkably consistent. For 4 years in succession the number and biomass of cutthroat trout in the lower clearcut area were substantially greater than those in the upper forested area (Table 1). This result is in direct contrast to detrimental effects noted in Coast Range studies.

Table 1. Number and biomass ($g/m^2$) of cutthroat trout in 200 m clearcut and forested sections of Mack Creek. Populations were estimated at low water, usually during October.

| Year | Clearcut | | Forested | |
|---|---|---|---|---|
| | No. | Biomass | No. | Biomass |
| 1973 | 672 | 12.2 | 415 | 6.2 |
| 1974 | 419 | 10.1 | 264 | 3.8 |
| 1975 | 410 | 6.9 | 199 | 2.6 |
| 1976[a] | 100 | 9.9 | 55 | 4.4 |

[a] estimate for 35 m section

The intensive post-treatment analysis has the advantage of reducing the time required for results, compared to a before-after watershed study, while retaining the ability to assess year-to-year variation. It can provide a time perspective after logging comparable to the intensive before-after analysis.

The technique suffers from a major disadvantage in that it requires the assumption that the two areas were essentially identical prior to logging; one cannot with certainty attribute differences between sites to the watershed practice. A consideration complicating interpretation of results is that the control area must always be located upstream from the treatment, as sediment from logging might adversely affect any downstream area near enough to be considered a valid control. Any downstream trend in abundance would confound analysis of treatment effects to some degree, although if the two areas are located close together, this complication could be minimized. Finally, this design provides no geographic perspective and results have questionable applicability in other situations.

The fourth approach, extensive post-treatment analysis, involves the comparison of many logged and forested sections of streams sometime after logging. In our second study in the Oregon Cascades nine pairs of study sites, each consisting of a logged section and an adjacent, upstream, undisturbed section, were studied during one summer (Murphy 1978).

As in the intensive analysis, this study found that trout biomass was greater in clearcut than forested sections (Table 2). The hypothesized causal mechanism

Table 2. Biomass (g/m²) of cutthroat trout and Pacific giant salamander in paired clearcut-forested sections of streams in the Oregon Cascades during summer 1976.

| Stream | Drainage area (km²) | Clearcut | | Forested | |
|---|---|---|---|---|---|
| | | Trout | Salamander | Trout | Salamander |
| McRae I | 0.4 | 0.0 | 51.4 | 0.0 | 26.1 |
| Arnold | 0.8 | 0.0 | 13.7 | 0.0 | 10.5 |
| Lookout I | 1.2 | 0.4 | 24.6 | 0.0 | 24.3 |
| Mack | 5.4 | 6.1 | 26.2 | 2.4 | 16.8 |
| Lookout II | 7.8 | 9.6 | 12.5 | 6.0 | 14.3 |
| Cook | 11.9 | 7.7 | 8.5 | 5.6 | 16.8 |
| McRae II | 12.7 | 4.5 | 0.2 | 3.3 | 1.8 |
| Walker | 13.0 | 2.8 | 43.8 | 2.6 | 14.1 |
| Lookout III | 17.1 | 7.7 | 0.4 | 2.8 | 3.5 |

is greater food availability, operating through increased primary production in the opened sections of stream (Lyford & Gregory 1975).

In addition, we found the Pacific giant salamander *(Dicamptodon ensatus)* to be the dominant predator in most sites, often greatly exceeding the trout in biomass (Table 2). The effect of clearcutting on salamander biomass was related to gradient. Within paired sites, salamander abundance was greater in clearcut than forested sites in high gradient areas, but lower in clearcut than forested sites in low gradient areas (Fig. 1). The apparent mechanism was an interaction (between gradient, large organic debris, and sediment) that affected the abundance of surficial crevices in the substrate, a favored salamander habitat.

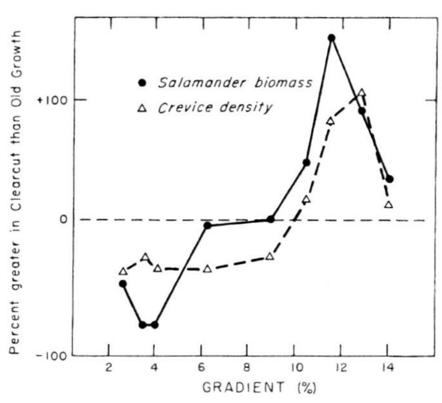


Fig. 1. Biomass of salamanders and density of surface crevices (> 25 cm³) compared between paired clearcut and old growth sites, in relation to channel gradient.

The greatest advantage of the extensive approach is the wide perspective (both temporal and spatial) and generality gained from examining watershed practices in a variety of situations. The consistent difference between the effects of logging on the cutthroat trout in the Coast Range and the Cascades emphasizes the need for the wide perspective and generality provided by the extensive approach. The method also provides the ability to assess the role of the physical setting of a watershed in modifying effects of logging on stream biota. The extensive post-treatment design of our Cascade study provided an opportunity to identify the critical relation between logging practices and salamander abundance that might not otherwise have been evident. This method requires the least time of the four designs, yet can provide a much longer time perspective than any other design, even the long-term watershed study. This feature is particularly desirable in evaluating forest management practices, impacts of which are usually most dramatic in the first year or two following treatment, but may be less significant if considered over the 60—100 yr period before the next timber harvest.

The main disadvantage is the lack of data on pre-treatment conditions, which forces the assumption that, on the average, there was no difference between adjacent sites before treatment.

## Discussion

Of the four designs we have tried, the extensive post-treatment design employing paired-site comparisons provided the most useful information about impacts of watershed practices on streams. By studying a large array of watersheds treated in different ways or at various times in the past, one can assess the severity of effects from different treatments, or the length of time that an impact may persist.

There have been few other extensive post-treatment analyses, mostly stimulated by a substantial management problem. Most notable of these have been on the South Fork Salmon River (PLATTS 1974) and the Clearwater River in Washington (CEDERHOLM & LESTELLE 1974). These studies, however, have mainly emphasized parametric correlation among independent samples. This is not as powerful a technique as one using paired-site comparisons; pairing can often reduce variance and significantly increase precision (SNEDECOR & COCHRAN 1967). Pairing is most applicable, however, where impacts are localized and may not be as effective where general effects over whole watersheds are involved.

Perhaps one explanation for the lack of application of the extensive post-treatment analysis is its relatively high cost, concentrated in a short period. For example, the total budget of the Alsea Watershed Study, spread over 15 yrs, was in excess of $ 1 million, while the first year annual budget was only about $ 20,000. Additional funding and participation by other agencies did not develop until the project was well underway. It is questionable whether administrators could have been persuaded to budget the total amount over a 2 or 3 yr period, which is probably the optimum time frame. The substantial planning and supervision required to coordinate a short-term extensive field program of this magnitude may also be a deterrent.

The most popular design has been the long-term watershed analysis (intensive before-after). Among those involving substantial study of effects on fish populations, in addition to the Alsea Study, are Hollis, Alaska (SHERIDAN & MCNEIL 1967), Casper Creek, California (BURNS 1972), and Carnation Creek, British Columbia (NARVER & CHAMBERLIN 1976). Results of these studies, however, have been difficult to interpret, in part because of large natural variation in population size. PELLA & MYREN (1974) have cogently pointed out many of the pitfalls in interpretation of watershed studies. In particular they caution against the Type II statistical error, failing to reject the null hypothesis when in fact a difference exists. For a hypothetical study of salmon abundance (5 yrs before and after treatment), given the variance observed in some Alaskan streams, a t-test would show no difference in 3 of 4 cases in which the average abundance was in fact reduced by 50 per cent.

In a strict statistical sense one could argue that it is futile to attempt a study of effects of watershed practices on streams, because of the difficulty in establishing valid controls and the large inherent variation (PELLA & MYREN 1974). This argument, however, is based largely on analysis with parametric statistical tests. We suggest that, because of very small sample size in most watershed studies, even extensive ones, the assumption of normality required by parametric tests is open to serious question. Non-parametric methods require less precision, have fewer assumptions, and are more general than parametric methods (SIEGEL 1956; ELLIOT 1971). Thus designs utilizing non-parametric methods, especially those taking advantage of paired samples, should be more powerful in detecting effects of watershed practices than conventional designs based on parametric analyses.

Where applicable, the extensive post-treatment design with paired-site comparisons should significantly improve a study's ability to assess impacts of watershed practices on small streams. This is especially true when impacts are localized within reaches of streams and adjacent disturbed and undisturbed reaches provide valid comparisons. Where general effects over whole watersheds are of concern, pairing may not be as effective, although for small watersheds, one might compare adjacent logged and undisturbed watersheds that are similar in size, slope, and geology. The best strategy would be a combination of extensive and intensive designs, employing paired-site comparisons in both. Such complementary studies would place results of each in perspective. The extensive design would provide spatial and temporal perspective, while the results of an intensive study would present impacts of watershed practices in the context of natural variation in stream ecosystems.

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