# Effects of Urbanization on the Biological Integrity of Puget Sound Lowland Streams: Restoration With a Biological Focus.

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## INTRODUCTION

With millions of dollars in federal funds recently allocated for salmon recovery and a public increasingly active in river conservation, hundreds of urban stream restoration projects are being installed around the Puget Sound Lowlands. What is worrisome is a deficiency of consistent pre- and post-project monitoring to guide project placement and design, and to evaluate what techniques are working where. The mission underlying the majority of these projects is salmon recovery, yet very rarely are salmon or any other element of stream biota directly monitored to assess restoration success.

Because declining biological conditions in running waters have many potential causes, a broad perspective is needed for their protection. The overall objective of this study is to apply tools of biological monitoring to urban stream management and restoration. The specific method of biological assessment utilized is the benthic index of biological integrity (B-IBI), a multimetric index based on attributes of stream benthic invertebrates (Karr and Chu 1999). This study has three components: 1) analysis of B-IBI variability relative to land cover change at multiple spatial scales, 2) evaluation of the diagnostic properties of B-IBI (e.g., how do metrics of this index respond to different channel impact types?), and 3) assessment of biological response associated with in-stream restoration projects.

## METHODS

### Study site selection

Between 1997 and 1999, benthic invertebrates were collected from 16 second and third-order streams in King and Snohomish counties (Table 1). In total, 45 study sites were selected that reflected a gradient of urban development. Two basins (Little Bear and Swamp Creek) were sampled at nine and ten sites respectively to examine within-basin variation in biological condition. Substrate data were provided by a concurrent study at 18 invertebrate monitoring sites (Konrad 2000). Hydrologic analysis was limited to 11 monitoring sites located in close proximity to gauging stations without intervening tributary input. Restoration efforts at five King County streams were selected to evaluate the response of invertebrates to LWD placement, a common restoration technique in Pacific Northwest streams (Larson 1999).

**Table 1.** Study basin area, land cover, and sampling intensity.

| Basins | area ($km^2$) [1] | % urban [1] | No. of sites |
|---|---|---|---|
| **Lk. Washington / Cedar River** | | | |
| Thornton Creek | 25 | 91 | 4 |
| Scriber Creek | 15 | 84 | 1 |
| Swamp Creek | 58 | 70 | 10 |
| North Creek | 57 | 67 | 1 |
| Little Bear Creek | 40 | 54 | 9 |
| Big Bear Creek | 61 | 41 | 5 |
| Struve Creek | 4 | 48 | 1 |
| Seidel Creek | 7 | 19 | 1 |
| Forbes Creek | 5 | 85 | 2 |
| Laughing Jacobs Creek | 16 | 59 | 4 |
| May Creek | 30 | 36 | 1 |
| Rock Creek | 43 | 22 | 1 |
| **Green River** | | | |
| Jenkins Creek | 69 | 43 | 1 |
| Big Soos Creek | 42 | 61 | 1 |
| Soosette Creek | 14 | 63 | 2 |
| **Puget Sound** | | | |
| Miller Creek | 22 | 85 | 1 |

[1] values correspond to sample site furthest downstream

## Benthic macroinvertebrates

Invertebrates sampling at each site was performed in September, using a Surber sampler to collect three samples along the mid-line of a single riffle. Invertebrates were preserved in the field in a solution of 70% ethanol and returned to the lab for identification under microscopy. Following procedures first outlined for fish (Karr et al. 1986), and later for invertebrates (Fore et al. 1996), metric scores of one, three, or five were assigned to each of ten raw metric values. These scores were then summed to provide a site and time specific B-IBI that ranged from 10 (very poor) to 50 (excellent).

## Land cover analysis

Extent of urbanization in each study basin was calculated over three spatial scales: sub-basin, riparian, and local (Figure 1). The GIS land cover layer used in this analysis was a 1998 satellite classification with a mapping resolution of 30m (Botsford et al. 1998). Sub-basin delineation, stream buffering, and map overlays were performed in ArcInfo and ArcView to determine land cover distribution for each sample site. Graphical analysis and simple linear regression were used to evaluate land cover urbanization relative to B-IBI.

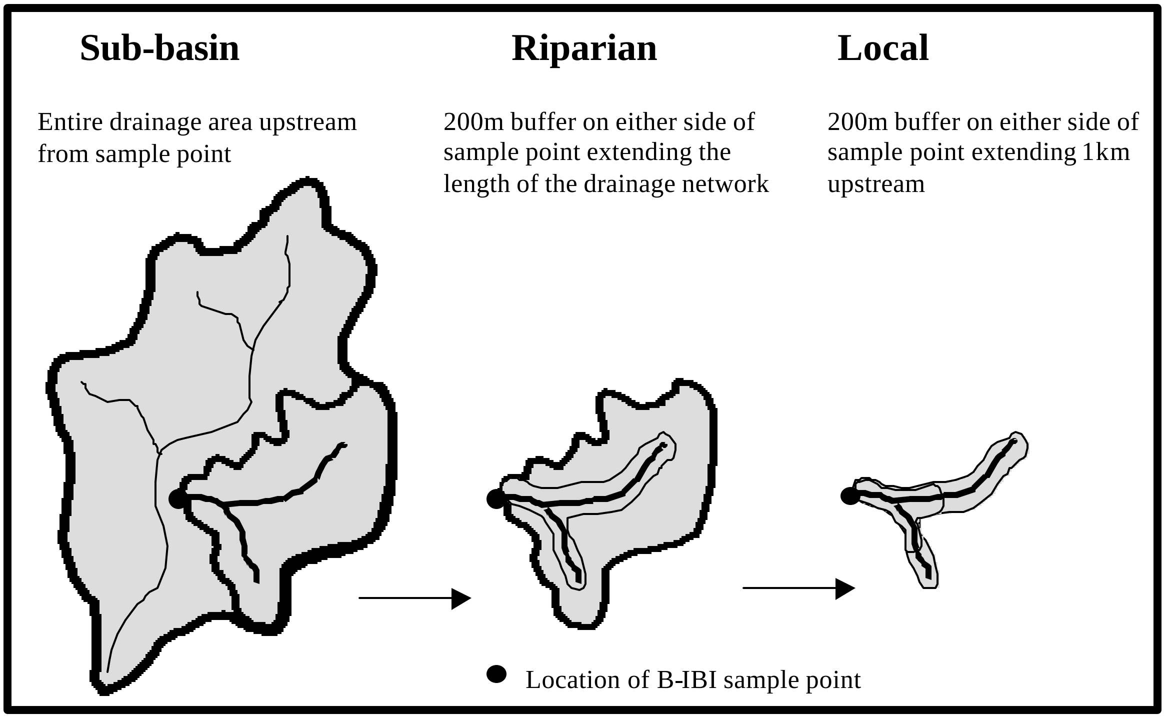


**Figure 1.** Diagram of GIS-based landscape analysis. Buffer widths dimensions were selected so as to be broad enough to include those functions commonly cited in association with riparian corridors, but not unrealistically narrow given the relative accuracy of geographical datasets used in basin delineation and buffer analysis.

### Substrate and flow evaluation

Seven parameters that characterized the stream substrate and hydrology were evaluated in relation to biological condition. Size distribution of surface substrate was characterized by a Wolman pebble-count (Konrad 2000). Hydrologic data were downloaded from continuous recording hydrologic gauging stations, and provided by King County Hydrologic Information Center and Snohomish County Surface Water Management. Graphical analysis and simple linear regression were used to analyze the relationships between B-IBI and selected metrics to substrate and flow.

### Restoration project assessment

B-IBI assessment was conducted in collaboration with concurrent evaluation of physical project condition (Larson 1999). Pre-construction invertebrate data were available for only one project (Soosette Creek; Greenberg 1995). In order to determine if restoration efforts were successful in improving biological condition, monitoring sites were located immediately upstream (control) and downstream (treatment ) of projects. At three of these paired sites, an additional mid-stream site was sampled to test for localized effects. A paired t-test was used to compare control and treatment B-IBI.

## RESULTS

### B-IBI

Invertebrate biota of nearly all sites sampled in this study indicated mild to severe stream degradation. Although B-IBI varied from 10 (Thornton Creek) all the way up to 48 (Rock Creek; Figure 2), only 10% of sites sampled across the study were comparable or only slightly divergent from reference condition for the region. On Little Bear, biological condition was good in the headwaters with a B-IBI of 40, but this score rapidly dropped down to 16 over a distance of approximately 10 km. In contrast, B-IBI varied relatively little between a high of 32 and a low of 22 along a 14 km. length of Swamp Creek. Overall, highest B-IBI's (>38) were concentrated in less developed headwaters and unincorporated areas of King and Snohomish counties, while scores of 16 or less were located in areas of high residential and/or commercial development.

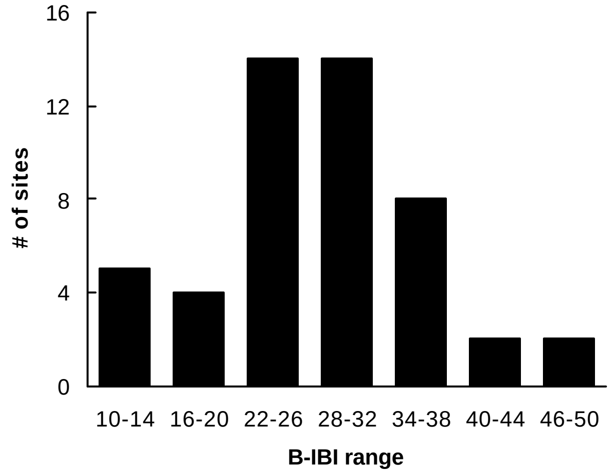


**Figure 2.** Distribution and range of B-IBI across all study sites (median = 28, mean = 27.4, standard deviation = 8.9).

### Land cover

The distribution of land cover among the 16 basins of this study reflects current development trends around the Puget Sound lowlands—conversion of forested lands to urban and suburban centers (Figure 3). Of the various groupings of land cover measures tested, a combination of all urban land cover categories was best correlated with B-IBI ($r^2 > .49$, $p < 0.001$), and is used throughout this study in relation to biological and physical stream response. Because riparian and sub-basin land cover were so closely correlated ($r^2 = .95$, $p < 0.001$), the remainder of this study focuses on B-IBI response at the sub-basin and local scales.

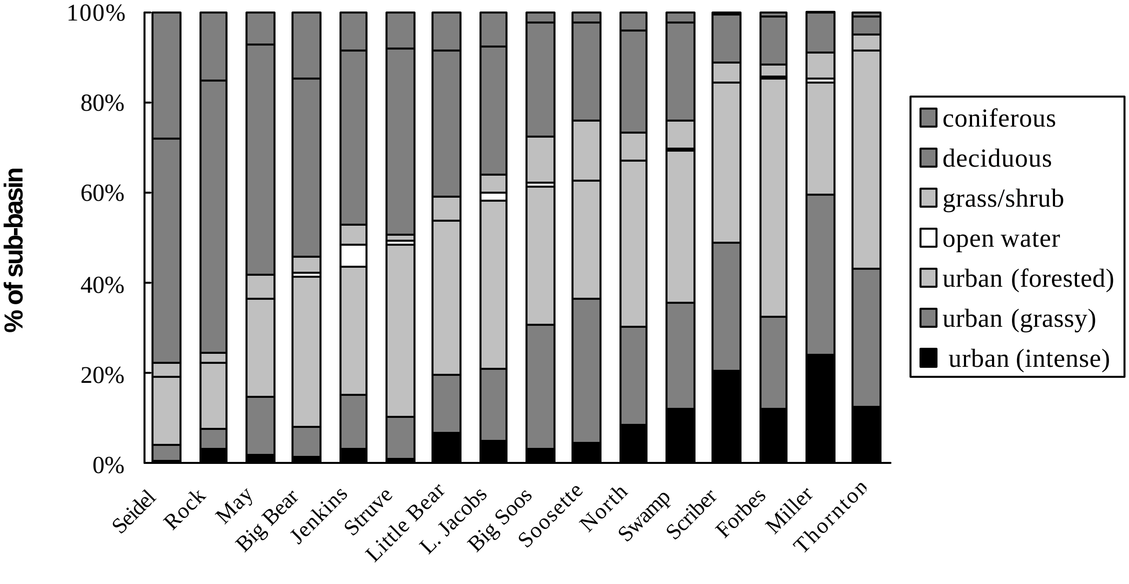
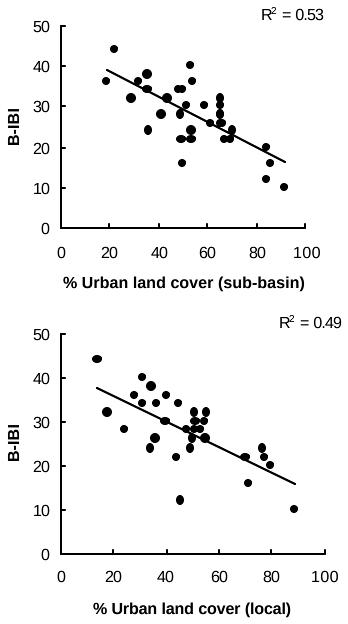


**Figure 3.** Distribution of land cover categories within study basins. Basins are ordered from least to most urban. With the exception of open water, all seven land cover categories are present in each of the 16 study basins. Combined forested categories range from 5-78% of the total area of the basin, and combined urban categories from 19-91%.

## B-IBI v land cover

Across study sites in all 16 basins, both sub-basin and local land cover were strongly correlated with B-IBI (Figure 4). When these two scales are combined in a multiple regression model, urban land cover explains 59% of variability in B-IBI ($p < 0.001$). B-IBI variability within the intensely sampled Swamp and Little Bear Creek basins tells a slightly different story. At the sub-basin scale, Swamp Creek was *more* urbanized than Little Bear, with 70% vs. 54% urban land cover, respectively. But at the local scale, the reverse pattern was observed: all sample sites on Swamp Creek were *less* urbanized than the six sites on lower Little Bear. In Little Bear Creek, B-IBI variability was strongly related to local land cover change (Figure 5a). In Swamp Creek, neither sub-basin nor local urban land cover varied substantially (Figure 5b), an observation that is concordant with limited variability in B-IBI.



**igure 4.** B-IBI *v* urban land cover across all sites.

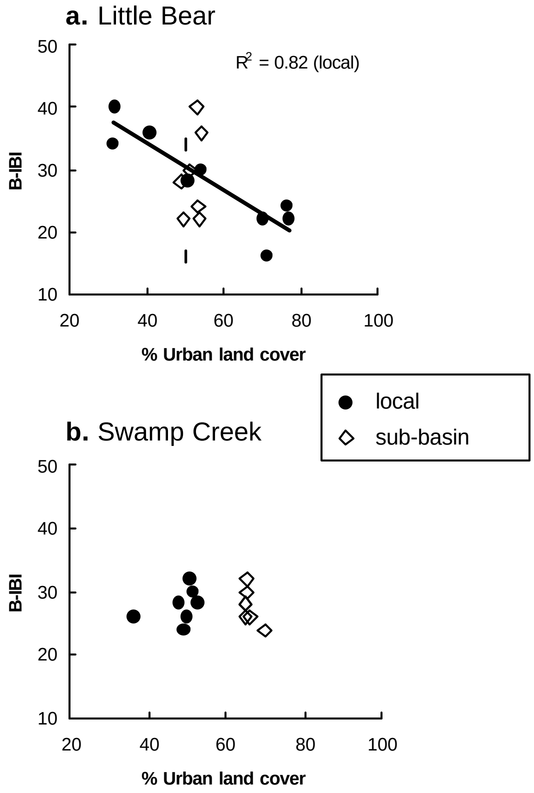


**Figure 5.** B-IBI *v* urban land cover in Little Bear and Swamp Creek. Note that for Swamp Creek, the most downstream site is excluded; local land cover could not be accurately determined here due to discrepancies between geographical datasets.

### B-IBI v substrate and flow

Pattern in B-IBI and metrics across sites was also explained to some degree by local channel features. Of the channel parameters tested, three were statistically related to biological response and/or to the extent of upstream urbanization: relative roughness (84th-percentile pebble diameter divided by bankfull depth) and two measures of discharge flashiness. Two measures of particle size distribution ($D_{16}$ and $D_{50}$) were better predicted by sub-basin area than urban land cover, suggesting that variation in particle size was more a factor of natural basin differences than anthropogenic impacts. Neither measure of peak flow explained any degree of variability in B-IBI or metrics; invertebrates seem to respond more to the degree of flow *fluctuation* than to the sheer magnitude of peak events.

### Restoration project evaluation

Addition of LWD had little demonstrable effect on biological condition as measured by B-IBI (Larson, 1999; see the Winter 2000 issue of the *Newsletter*). Additional sampling in 1999 still showed no improvement in biological condition nor was there an improvement when samples were collected within project boundaries. Overall, B-IBI was much better correlated with the level of local urban land cover than with the presence or absence of a LWD project. Only post-treatment B-IBI on Soosette Creek scored significantly higher than either the upstream control site or pre-project collection. But here, the “control” site on this creek was considerably more urbanized than the treatment (53% vs. 13%), and thus serves as a poor comparison by which to judge the effects of LWD addition. Biological improvement observed on Soosette Creek may also be due to natural downstream recovery over the last decade.

## DISCUSSION

### Biological condition of Puget Sound lowland streams

Extensive and diverse activity throughout the Puget Sound basin has altered the region’s landscapes—with especially devastating effects on stream biota. Half of the stream sites sampled in this study were in poor biological condition; almost all sites lacked even a single “intolerant” taxon and at the most urbanized sites no stoneflies were found. Although the sites from this study were not randomly selected, such degraded conditions are typical of many streams in and around major metropolitan areas in the region (Kleindl 1995). The survival of wild salmon in the Pacific Northwest depends on many factors, crucial among them being high quality streams for spawning and rearing of young.

### Measuring urbanization¾ the importance of spatial scale

Because humans modify watersheds in many ways, a broad definition of anthropogenic disturbance is appropriate for use in conjunction with biological assessment. None of the measures of land cover tested in this study were perfect fits with B-IBI, but overall, a grouping of equally weighted urban land cover categories explained a high degree of variability in B-IBI. This simple yet broad definition of urbanization is more inclusive of a variety of potential impact types than what is captured by impervious area models. Taking a broader definition of disturbance refers also to examining how urban development influences stream condition over multiple spatial scales. B-IBI in the urban streams of this study responded strongly to land cover change over both the entire sub-basin and local scale. Rarely is land cover homogenous across urbanizing basins and as a consequence biological condition may also vary substantially along a length of stream.

### Diagnostic properties of B-IBI

B-IBI responded predictably across a gradient of urbanization, but it was also sensitive to changes in substrate and flow conditions. In particular, channel roughness and hydrologic flashiness were both correlated with B-IBI. High values of relative roughness, as observed on Rock Creek, may indicate a greater diversity of flow conditions (e.g., availability of slow-water refugia) during high flow events. In terms of flow regime, Rock Creek was also one of the least flashy sites. Stream invertebrates are adapted for life in strong currents, but few are able to exist under conditions of extreme and unpredictable flow fluctuation. The two most urban basins in this analysis were also the flashiest; biological condition at sites on these creeks was severely degraded.

### Are current models of restoration working?

Overall, B-IBI did not detect any substantial positive effect on biological condition from the restoration activities at the time scales sampled. Biologically, placing logs devoid of bark, roots, branches, or leaves into urban streams is not equivalent to natural recruitment, where wood is but one benefit of a forested riparian corridor and comes in a variety of forms, sizes, and configurations. In order to achieve meaningful long-term biological recovery, restoration efforts must take a broad focus to address why wood is lacking from urban streams in the first place, and what else is amiss. This entails looking beyond local scale in-stream habitat manipulation to address factors operating across the entire basin.

### Riparian corridor conservation

As both a conservation and restoration strategy, protection and reforestation of riparian areas is critical for preventing severe stream degradation, but alone these measures are not adequate to maintain biological integrity in streams draining highly urban basins.
In Little Bear Creek, high B-IBI was associated with sites located in headwater reaches of intact riparian corridor. Further downstream, B-IBI decreased dramatically as local riparian vegetation was replaced by development. Neighboring Swamp Creek was more urbanized at a sub-basin scale but less so along the stream margin. Although B-IBI throughout this stream never indicated the severe degradation observed on lower Little Bear, sites on Swamp creek also never scored particularly high. In some of the most urban basins of this study (e.g., Forbes and Miller Creek), B-IBI was still very poor even in reaches with some degree of forested corridor.

## CONCLUSIONS

The underlying goal of many urban stream management and restoration practices in the Pacific Northwest is biological. Instead of defining “critical thresholds” of basin development to generate formulas for stream protection, the biological condition of the streams that drain those basins should be examined directly. Routine biological assessment is also critical for deciding how most effectively to spend limited restoration dollars. This study looked at a small sub-set of one type of restoration project: placement of large woody debris in small lowland streams. The results presented here can by no means be generalized across all types of restoration projects in the Pacific Northwest. But that is precisely the problem; at present, we don't know what's working and what is not so as to learn by example. By ignoring the biology of those urban streams we seek to restore, we make the same mistake that has contributed to the current state of Puget Sound Lowland streams and rivers.

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