Sustainable river restoration in urban streams - using biological indicators to establish environmental flow targets in the Pacific Northwest

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ABSTRACT: Managing sustainable aquatic ecosystems requires restoration of ecological processes; such as the natural flow regime, as well as restoration of specific habitat structure and biological attributes. A general understanding of the ecological effects of altered flow regimes currently exists, but the lack of data on specific ecological responses to flow alteration has frequently hampered restoration efforts. In the Pacific Northwest, few attempts have been made to restore significant components of the natural flow regime, particularly in urban streams. To support river restoration and salmon recovery, King County is developing analytical tools for evaluating the ecological effects of altered flows on river and stream ecosystems. A first step in this multi-phased project is to use existing information to describe direct and indirect links between flow and ecosystem attributes. Based on a review of the literature, we identified candidate indicators of hydrologic alteration and ecosystem response that could be used to guide restoration. Using available biological and hydrologic data we tested candidate indicators to determine if flow-biology relationships could be identified and used as guidance in restoration programs.

1 INTRODUCTION

Altered flow regimes due to river regulation and water development projects are a major factor in the deterioration of riverine ecosystems and the imperilment of aquatic biota (Petts 1996, Richter et al. 1996, Poff et al. 1997, Bunn and Arthington 2002). Restoration of healthy river systems requires restoring critical aspects of the natural flow regime and/or mitigating the most damaging aspects of altered flows (Stanford et al. 1996, Poff et al. 1997). Understanding and predicting the ecological impacts of altered (and restored) flow regimes has two components: (1) identifying the ecologically important characteristics of the natural flow regime, and (2) evaluating the relationships between flow alterations and ecological responses.

Numerous recent reviews and studies have evaluated flow-ecology relationships, however, most are relevant to larger river systems and river regulation for flood control, navigation, hydroelectric power, or irrigation. The effects of altered flow regimes related to urbanization, and in particular, urbanization in small streams, are much more poorly understood (Paul and Meyer 2001, Bunn and Arthington 2002).

King County in western Washington, USA, is one of the most intensely urbanized counties in the Pacific Northwest. Two of the largest cities in the state occur in the County (Seattle and Bellevue) and the area is experiencing rapid population growth. Despite the growing population, the County still contains some relatively undeveloped and predominantly forested areas. The County's streams have historically supported all five Pacific salmon species, which are important cultural and economic resources in the region. Due in part to the recent listing of some Puget Sound salmon evolutionarily significant units (ESU's) under the Endangered Species Act (ESA), increasing resources and attention are being paid to managing rivers to restore and protect salmonids and other native species. Public agency managers with responsibilities for river restoration and management need better tools for assessing the ecologically important characteristics of flow regimes and how changes in flow regimes affect the biological condition of streams.

To provide County managers with analytical tools for evaluating and managing flows, we are investigating the use of an indicator-based approach to assessing ecological responses to hydrologic alteration in the County's streams. To provide guidance for management and restoration we asked: (1) can we identify ecologically important aspects of flow regimes that are affected by urbanization? (2) Are there predictable biological responses to these flow changes that could be used to identify systems in biologically 'good', 'fair', and 'poor' condition?

We report here on the first three steps of this investigation: (1) selecting candidate indicators of ecological response to hydrologic alteration relevant to Puget Sound Lowland (PSL) urban streams; (2) testing whether these indicators respond to flow alteration in predictable ways; and (3) developing general management guidance for restoration based on a preliminary set of the indicators.

2 METHODS

2.1 *Literature Review*

To select candidate indicators, we reviewed recent (post-1997) literature to identify relationships between urbanized flow alterations and ecological responses. We focused on looking for relationships documented in stream systems similar to those in the Puget Sound region - predominantly rain-fed, moderate to low gradient, low elevation, second to fourth order streams, in a winter-wet/summer dry climate. We screened a number of reviews on hydrologic indices to reduce redundancy, but also to incorporate a full suite of hydrologic measures that capture magnitude, duration, frequency, timing and rates of change of flows (Richter et al. 1996, Olden and Poff 2003). We attempted to find candidate indicators for important ecological processes, such as connectivity with side channels and floodplain wetlands, as well as the condition of key species or taxonomic groups, such as juvenile salmonids or aquatic insects. After a set of candidate indicators was identified, we defined specific measures (metrics) for each indicator.

2.2 *Testing Indicators Using Data from PSL Streams*

Data availability limited our initial test to small streams where biological data on benthic macroinvertebrate communities has been collected. To test for relationships between hydrologic and biological measures we identified seven stream systems with different degrees of urbanization. We assumed that degrees of urbanization result in a range of hydrologic conditions from relatively unaltered flows to highly altered flows. Stream basins were divided into sub-basins based on hydrology and locations of biological data sites. A total of 42, 2nd to 4th order, sub-basins were identified, 20 along mainstem channels and 22 along smaller tributaries. To generate values for the hydrology metrics we used hydrologic simulation models (HSPF) to simulate values for the hydrology metrics under fully forested (i.e., historic or baseline) and current land-cover (i.e., scenario) conditions for each sub-basin. Current land-cover values were derived from 1995 land-cover for each stream sub-basin. We calculated values for baseline and scenario conditions, as well as the ratio of scenario to baseline for each sub-basin. This allowed us to compare current hydrology (scenario) with current biological condition, and to compare the degree of hydrologic change (ratio of scenario to baseline) to current biological condition.

Gauge data were not used for hydrology because they describe incremental changes over time associated with urbanization. Gauge data cannot be readily used to understand change from a pre-urbanized state (i.e., there is nothing analogous to pre- vs. post-dam conditions).

Benthic macroinvertebrate sampling data that has been collected as part of the benthic index of biological integrity or BIBI (Kleindl 1995, Karr and Chu 1999) is the most comprehensive biological data set for the County. These data can provide a composite index of biological integrity (Karr and Chu 1999). Biological metrics, such as community composition, functional feeding group, and life history measures can be derived from these data as well. We compiled data sets collected by three groups using the same protocols within the County's streams, by King County, the University of Washington, and Snohomish County. Biological sampling was conducted from 1995 to 2002; however, sampling was not conducted for all years at all sites. Most of the sampling sites had two to three years of data. Most hydrologic sub-basins contained one biological sampling site but some sub-basins contained multiple sites. We compared biological values for individual sites and years within each sub-basin to hydrology, as well as comparing sub-basin mean biological values to hydrology.

Preliminary exploratory analyses were conducted to identify sub-sets of the biological and hydrology metrics to explore in future analyses. Relationships between biological measures and hydrology were evaluated first graphically with bivariate plots for each hydrology-biology metric pair. Data were then further explored using multivariate techniques such as multiple regression and Discriminant Function Analysis.

3 RESULTS

The gradient of urbanization in our seven stream basins was reflected in the corresponding range in hydrologic alteration. The hydrograph for water year 1989-1990 is virtually identical for baseline and scenario conditions in the predominantly forested Issaquah Creek basin (Fig. 1). In the highly urbanized Miller Creek basin, the scenario hydrograph shows increased magnitude and frequency of peak flows, increased number of moderate to high peaks especially during early fall and late spring, decreased high flow durations, and increased rates of rise and fall during peak events (Fig. 2).

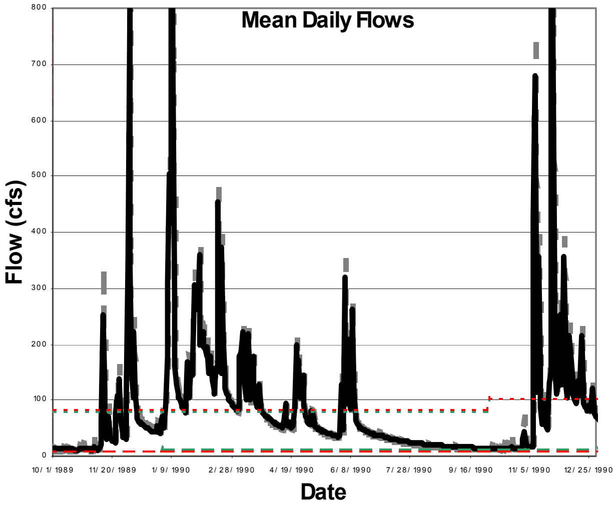

Figure 1. Baseline (fully forested) and scenario (current land use) hydrograph for water year 1989-1990 (October 1 to December 30) in Issaquah Creek. Solid black lines are daily flows under fully forested conditions; dashed gray lines are daily flows under current land use conditions. Baseline and scenario hydrographs are nearly identical. Streams in predominantly forested basins have sustained periods of high flow with broad storm peaks in late fall, winter and early spring, while summer flows are low with no storm peaks.

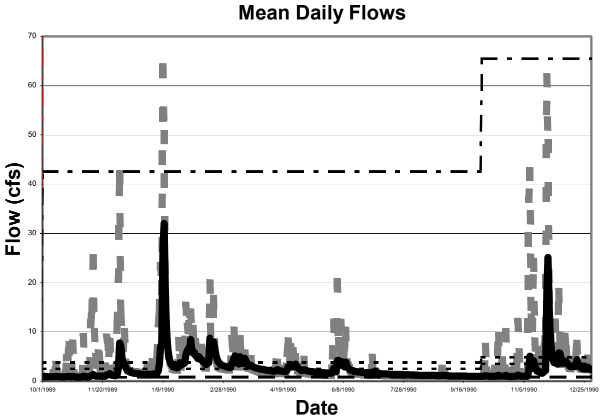

Figure 2. Baseline (fully forested) and scenario (current land use) hydrograph for water year 1989-1990 (Oct. 1 to December 30) in Miller Creek. Solid black lines are daily flows under fully forested conditions; dashed gray lines are daily flows under current land use conditions. Typical hydrograph for urbanized streams: increased frequency and magnitude of peak flows, increased frequency of peaks during normally quiescent summer and early fall periods, and increased rise and fall rates.

Some of the biological metrics were significantly related to changes in hydrology (Fig. 3). However, the relationships could not be characterized by simple linear regressions or correlations. These patterns of biology-hydrology relationships are typical of ecological responses to multiple limiting factors (Fig. 4) (Cade et al. 1999, Huston 2002).

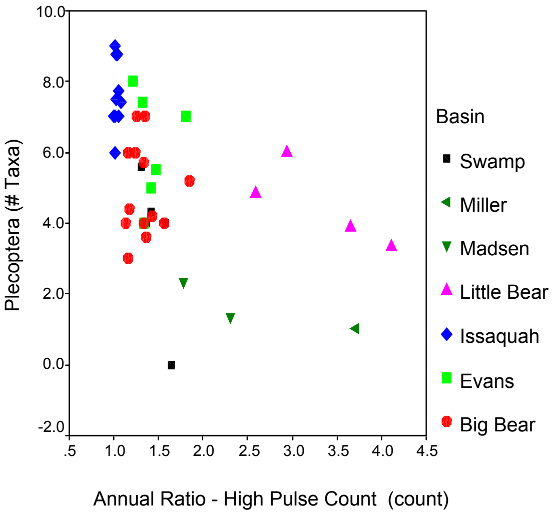

Figure 3. Change in number of Plecoptera taxa with increased hydrologic alteration (ratio of scenario to baseline high pulse counts). A ratio of 1.0 indicates no difference between baseline and scenario, so that hydrologic alteration is minimal.

4 CONCLUSIONS

If hydrology or hydrologic change is the only limiting factor driving biological response, then correlations between biological measures and hydrology should be strong, and hydrology would be a good estimator of biological condition. However, many environmental factors are likely to be limiting for aquatic organisms. Additional factors may have been limiting at the times or locations when biological data were collected; as additional factors become limiting at some times or places, the predicted correlation between hydrology and biology should become weaker. If other potentially limiting factors can be identified and measured, then variability in biological responses not due to hydrology can be explained statistically. Using statistical approaches such as quantile regression, we may be able to quantify the biological response under conditions of multiple limiting factors, including hydrology. As the next steps in this project, we will be investigating the use of statistical approaches, as well as measuring additional environmental factors to develop better predictions about the response of biology to hydrologic change.

Our results using benthic macroinvertebrate metrics in relation to hydrologic change can be used to develop general guidance for stream restoration in the short term. Given the factor ceiling patterns that are consistent in this data set, hydrologic change can be interpreted in terms of the maximum biological value that can be expected given a degree of hydrologic change (Fig. 5). Trends in the overall biological condition as measured by the BIBI score can be

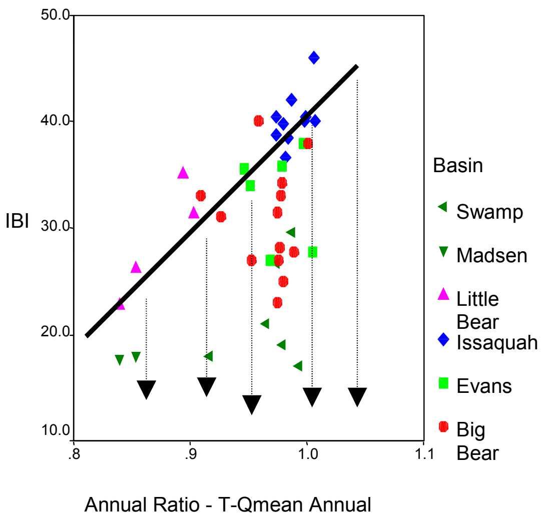

Figure 4. Limiting factor or factor ceiling distribution. The maximum values of the dependent variable (BIBI or index of biotic integrity) are defined by the independent variable (degree of hydrologic change); lower values of the BIBI are affected by other limiting factors. A BIBI score ≥ 40 indicates relatively unaltered sites with high taxa richness, similar to reference conditions. A BIBI score ≤ 20 indicates a degraded site dominated by few taxa. TQ mean is a measure of 'flashiness' and is the % of day over a year that the daily flow rises above the mean annual flow. A lower value of TQmean is associated with high peak, flashy hydrographs in urbanized streams in the PNW; a ratio of 1.0 indicates no hydrologic alteration.

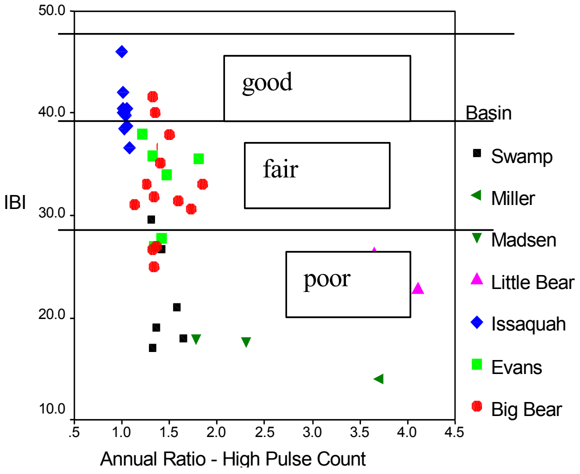

Figure 5. Relationship between ratio of scenario to baseline high pulse counts and BIBI score. Higher ratios indicate systems with an increase in the number of high pulse counts; BIBI scores of ≥ 35 are considered good sites, while scores below 20 are considered to be in poor biological condition. The maximum BIBI score attainable when the number of high pulse counts in a year has increased 4 X over baseline is about 20; the maximum BIBI score under baseline conditions is greater than 40.

related to the degree of hydrologic change from baseline. Degree of hydrologic change can be interpreted in terms of the relative biological condition – 'good', 'fair', or 'poor' (Fig. 5). In addition, trends in richness or abundance of specific taxa, functional feeding groups, or life history strategies can be related to hydrologic change. These trends can be interpreted in light of the general functional relationships between particular groups of taxa and ecological conditions. For example, decreases in taxa richness or abundance of shredders can impact detritus-based food webs, and organic matter cycling, especially in small streams where shredders are a dominant group (Hawkins and Sedell 1981, Wallace et al. 1991).

These relatively simple biological metrics can be used by river managers to determine the potential for restoration, and the most appropriate type of restoration for a given stream basin. For example, in basins in the lower right hand corner of Figure 5, habitat restoration projects are likely to be ineffective unless restoring components of the natural flow regime can decrease the frequency of high pulses. Basins towards the left side of the graph are good candidates for habitat or water quality mitigation projects because their potential for improved biological condition is not limited by hydrologic changes.

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