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Flow pulses and fine sediments degrade stream macroinvertebrate communities in King County, Washington, USA

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ABSTRACT

Determining the causes of biological impairment in urban stream settings presents unique challenges because there are many potential stressors associated with human development. A rigorous, scientifically based process is more likely to identify influential stressors that can be reduced to improve stream condition. We used the U.S. Environmental Protection Agency's (U.S. EPA) CADDIS (Causal Analysis/Decision Information System) stressor identification process to assess eight candidate causes in the urban Soos Creek Basin in Washington State. The eight candidate causes capable of negatively affecting the abundance and diversity of benthic macroinvertebrates are: flow alteration, increased fine sediments, reduced habitat complexity, elevated water temperature, low dissolved oxygen, elevated nutrients, increased ionic concentration, and toxic pollutants. We assembled multiple lines of evidence, as well as the consistency of that evidence and agreement with other assessments. We evaluated the influence of natural and cumulative anthropogenic stressors on macroinvertebrate communities by comparing various chemical, physical, and biological measures at sites in the Soos Creek Basin with regional reference sites. Of the stressors evaluated, flow alteration, increased fine sediments, and loss of habitat complexity were the most probable causes of biological impairment, with multiple biological metrics responding predictably across levels of impairment. Key findings from this study include: the use of specific community alterations as evidence in causal assessment, demonstration of links in a complete causal pathway, and the use of multiple models to show which pathway is likely stronger. In addition to the value to the specific case, the analyses increased our understanding of the responses of stream invertebrate communities in urban environments. Ultimately, demonstrating the utility of causal assessment in a practical situation provides greater confidence that mitigation efforts aimed at improving biological health of urban stream communities will have detectable desired effects while also providing a baseline from which the effectiveness of management practices can be evaluated.

1. Introduction

Urban development and land conversion have measurable adverse impacts on biological communities (Vitousek et al., 1997). Along a gradient of urban development, alterations to biological communities can take many forms, ranging from the replacement of sensitive taxa by more tolerant ones to significant biodiversity loss (reviewed in Walsh et al., 2005). Streams in urban settings are subject to the combined impacts of multiple stressors arising from a variety of anthropogenic activities. The negative impacts of urbanization on stream systems are pervasive enough that they are collectively referred to as the 'urban stream syndrome' (Meyer et al., 2005, Walsh et al., 2005). Several potential stressors to stream systems resulting from urbanization include the loss of riparian habitat (Osborne et al., 1993, Morley and Karr, 2001), channelization and modifications to the natural flow regime (Konrad and Booth, 2005; Rosburg et al., 2017), increased inputs of nutrients and a variety of other chemicals (Paul and Meyer, 2001). These stressors, alone or collectively, can modify the physical and chemical parameters of a stream, ultimately leading to a significant alteration to the resident biological communities.

In highly diverse systems such as streams, describing the response to anthropogenic stressors of each individual taxon within the community can be impractical if not overwhelming, except perhaps in the case of endangered species. Yet more efficiently, important ecological insights into alterations to community composition can be gained through studies of functional traits (McGill et al., 2006; Poff et al., 2006; Messier et al., 2010). With increasing environmental stress, environmental filtering can shift composition within a community from one dominated

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by sensitive taxa to one dominated by more tolerant ones; in streams, these shifts can be measured through the response of diversity and trait-based metrics (Poff et al., 2006).

In the United States, individual states are mandated by the Clean Water Act, to evaluate, restore and maintain the chemical, physical and biological integrity of the Nation's waters (Section 101(a), CWA, 33 U.S.C. § 1251(a)). Historically, waters determined to be 'impaired' for physical or chemical parameters are listed on a state's 303(d) list and a Total Maximum Daily Load (TMDL) is developed to address ways of improving conditions for specific listings. However, less commonly included in the TMDL process is the incorporation of biological assessment, or the evaluation of resident biological communities (hereafter referred to as bioassessment). The science of bioassessment has developed over multiple decades, yet despite the mandate in the Clean Water Act to address biological integrity, progress in the successful incorporation of bioassessment within the framework of a TMDL has been slower than for more traditional water quality parameters (Karr and Yoder, 2004), despite increasing global threats to freshwater biodiversity (Vörösmarty et al., 2010).

In the state of Washington, biological integrity of stream segments can be evaluated with an index of biological integrity (B-IBI) for macroinvertebrates and potentially listed on the state's 303(d) list of impaired waters (https://ecology.wa.gov/Water-Shorelines/Water-quality/Water-improvement/Assessment-of-state-waters-303d/Assessment-policy-1-11). The B-IBI is a multimetric index comprised of ten community diversity measurements (Karr, 1998; Morley and Karr, 2001; more information at: http://pugetsoundstreambenthos.org/About-BIBI.aspx). These metrics have been demonstrated to give reliable signals of biological condition across a variety of scales and circumstances (Karr, 1999). Because of the integrative nature of multimetric indices such as the B-IBI, the component score alone is only informative for determining whether a site may be biologically impaired. However, the individual metrics comprising the B-IBI, in conjunction with supplemental metrics summarizing the biological traits of the component communities they describe, have the potential to create suggestive patterns between the biological community and specific environmental factors. In other words, the collection of organisms at a site, summarized into a variety of diversity and functional metrics, has the potential to suggest causal patterns of impairment (Karr and Yoder, 2004; Statzner and Bêche, 2010).

Here we describe the use of chemical and physical data in conjunction with biological data to assess causes for altered biological condition in streams from the Soos Creek Basin (King County, Washington, USA). In 2012, multiple streams and stream reaches within the basin (i.e., Big Soos, Little Soos, and Jenkins Creeks) were listed for biological impairment based on B-IBI scores (ECY, 2012). Additionally, the Washington State Department of Ecology (ECY) identified basin-wide impairments for elevated temperature and reduced dissolved oxygen based on criteria for spawning salmonids (ECY, 2012). Along with the separate listings for elevated temperature and reduced oxygen, a TMDL assessment is being prepared that will provide specific guidance for addressing any biological impairments in the Soos Creek Basin. Before steps can be taken to address the sources of biological impairment, the causes of impairment need to be elucidated.

We performed a Stressor Identification (SI) analysis to determine the most probable causes of altered biological conditions at listed sites so direct management strategies could be implemented within the TMDL. Within the Puget Sound, increasing development is leading to more urbanization and impervious cover, which has contributed to alterations in the natural flow regimes for many streams (Rosburg et al., 2017). Also within the region, a relationship between B-IBI and hydrologic alteration (e.g. high pulse count [HPC]) has already been demonstrated (DeGasperi et al., 2009), so flow alteration was one of several likely causes of biological impairment. As such, we predicted biological impairment would be linked with hydrologic alteration, namely in the form of a negative relationship between flashy flow and B-IBI scores as well as with several biological metrics. We also hypothesized that sites determined to be biologically impaired would differ from regional sites with minimal human impacts in predictable ways, namely an increase in organisms tolerant to various stressors (e.g. temperature, organic pollution, sensitivity to fine sediments, etc.). We were cognizant to evaluate all potential causes of impairment in the Soos Creek Basin using all available data. Our aim was to determine the most probable causes of biological impairment in the Soos Creek Basin while simultaneously demonstrating the applicability of the SI process within the framework of a TMDL (U.S. EPA, 2000, 2007).

2. Materials and methods

The U.S. EPA (2000, 2007) SI process, as described on the CADDIS (Causal Analysis/Diagnosis Decision Information System) website (www.epa.gov/caddis) provides guidance for identifying environmental stressor(s) impacting biological communities using relevant available chemical, physical, landscape, or other biological data. The SI process provides a standardized, unbiased, and comprehensive structure for organizing evidence supporting the derived conclusion, allowing results to be compared with other assessments and ensuring the overall process is repeatable. Ultimately, the assembled lines of evidence among alternate causal hypotheses are weighed and compared (Cormier et al., 2010). In this way, SI guidance can assist in establishing the causal linkage(s) between a pollutant and the biological impairment, thus providing a basis for the development of a TMDL.

2.1. Watershed description

The Soos Creek watershed occupies approximately 70 square miles of glacial deposits, foothill ridges, and flat valley land in western Washington State (Fig. S1.kmz here). The 4 main headwater tributaries in the watershed are Soos Creek (26.4 linear stream km), Little Soos Creek (7.7 km), Jenkins Creek (10.3 km), and Covington Creek (17.1 km), which combine to form Big Soos Creek, a tributary to the Green River that leads to Puget Sound. As of 2012, there were 7 locations in the Soos Creek basin determined to be biologically impaired (I sites) and listed on the state's 303(d) list.

Upper portions of the watershed have flat or rolling terrain characterized by extensive wetlands and an elevated water table. Uniquely, the most developed areas of the watershed are in the headwaters of tributaries. Elevation decreases stepwise from 112 meters above sea level to 6 meters with headwater plateaus yielding to steep gradient reaches that terminate in low gradient valleys below.

Hydrology in the Soos Creek watershed is typical of the Puget Lowlands: spring and winter precipitation feeds large runoff and stream discharge events concurrent with Cascade Mountain snowpack storage at elevations, while reduced summer flows are maintained by snowmelt and base flows from groundwater. Glacial geology consists of a mix of low permeability Pleistocene continental glacial till (Vashon Stade) with veins of high permeability Fraser-age glacial outwash that mirror surface water features.

Land use and land cover are dominated by medium and low intensity development with limited mixed and evergreen forest coverage, particularly in areas draining to the stream reaches with a biological impairment. Six municipalities intersect the Soos watershed resulting in complete coverage under the state's municipal stormwater permit program. Additional other point source discharges related to construction (31), industrial (3), and mining permit activities (6) were also present at the time of this assessment.

2.2. Biological data

Within the U.S. EPA Puget Lowland level III ecoregion (Omernik, 1987), 10 "reference" (R), or 'minimally impacted' sites were chosen for comparison with sites from the Soos watershed. These sites were