Building Cities in the Rain
Working Group
February 24, 2015
Meeting Summary

Participants: Larry Schaffner, Thurston County (by phone); Bob Vadas, Washington State Department of Fish and Wildlife (by phone); Erika Harris, Puget Sound Regional Council; Anne Dettelbach, Dan Gariepy and Abbey Stockwell, Department of Ecology; Andy Rheaume, City of Redmond; Bruce Wulkan, Puget Sound Partnership; Doug Navetski, King County; Paul Crane, City of Everett; John Palmer, EPA; Kerry Ritland, City of Issquah; Heather Trim and Cailin Mckenzie, Futurewise; De'Sean Quinn, South Central LIO; Anthony Boscolo and Heather Ballash, Washington State Department of Commerce.

Current Operating Assumptions
Based on the February 3, 2015 meeting, the group agreed to add the following operating assumption:

> 11. Sending areas will not be "written off". Local governments will still be required to hold the line in those areas and the program must include backstops to make this happen. A local government must prioritize the ones to fix first, or it won't have anything to show after many years of investment.

Bicycle Rack Issues
The group reviewed and reaffirmed the Bicycle Rack (aka Parking Lot) Issues, with one clarification to the first observation as follows:

- Guidance should include a backstop that prevents a watershed that is lightly~~low~~ impaired with parkland and low density development from being designated as a receiving area as these watersheds present minimal ecological lift potential.

Local Data for Flow Control Prioritization Survey
The group spent the rest of the meeting reviewing the results of the Local Data for Flow Control Prioritization survey. The purpose of the survey was to get a sense of what data is needed versus nice to have to prioritize watersheds for flow control transfers.

It was noted that the watershed prioritization process will be based on actual data v. modeling, as it will be used for prioritizing actual receiving watersheds. [Redmond found that modeling is appropriate for designing the capacity of the facility.

Each data type included in the emailed survey was reviewed and discussed as to whether it is essential to have, nice to have, or not needed to prioritize watersheds for flow control transfers. The group agreed that they would do this same exercise for water quality/runoff treatment and LID transfers. The exercise at this meeting was just for flow control transfers.

The group agreed that, after this exercise, they would then discuss what data would be recommended for an initial step/first tier screen, and what would be secondary/second tier screen. The City of Redmond has four types of watersheds prioritizations – protected, highest restoration, restoration, and restoration/development. Local knowledge is important to the WSDOT program, that is characterized by three tiers.

1. ***Is land cover data (e.g. %forest, pasture, landscape, ~~effective~~ total impervious surface) needed to prioritize watersheds?***

Essential to have: Land cover is very important data. It tells what the current impact is in the watershed is now. However, the group agreed that it could be "total" rather than "effective" impervious surface, as effective impervious surface data is very hard to obtain and costly.

Bob Vadas noted that there is biotic criteria associated with this data. See the attached *2011 Jan 7 Fish Hydrology Metrics*. Also, see:

- Horner, R.R., and C.W. May. 1999. Regional study supports natural land cover protection as the leading best management practice for maintaining stream ecological integrity. Proceedings of the Comprehensive Stormwater and Aquatic Ecosystem Conference. Auckland, New Zealand. 12 pp. *http://stormwater.cecs.ucf.edu/research/bioassessment/pugetsoundfinalreport.pdf*
- Booth, D.B., and L.E. Reinelt. 1993. Consequences of urbanization on aquatic systems — measured effects, degradation thresholds, and corrective strategies. Pages 545–550 in U.S. Environmental Protection Agency (ed.). Proceedings Watershed '93: a national conference on watershed management. Alexandria, VA (http://www.sciencetime.org/ConstructedClimates/wp-content/uploads/2013/01/BoothReinelt1993.pdf).

Question: Are we looking at future capacity based on GMA population projections? Sending areas will be Regional Growth Centers, where most of the population is expected to be accommodated. We are talking about prioritizing the receiving areas. However, potential change in the receiving watershed through zoning is important. That is data that should be added to the list as essential to have (see Question #30 below).

2. ***Is land use data (e.g. %commercial, industrial, roads, single-family residential, multi-family residential, parks and undeveloped land) needed to prioritize watersheds?***

Nice to have: This is based on existing land use and is already captured under #1. It is nice to have for flow control, but will be more important for runoff treatment because of the difference between runoff from different land uses – e.g. industrial versus residential.

Note: Land use/land cover data are often included/available in the same dataset.

Side Note: It would be helpful to streamline by combining the GMA updates and this process. Unfortunately, many jurisdictions are doing the absolute minimum for their GMA updates due to lack of state funding.

3. ***Is watershed area data (acres inside City limits) needed to prioritize watersheds? This includes stormwater conveyance and topographic based watershed.***
4. ***Is total watershed area data (acres inside and outside of City limits) needed to prioritize watersheds? This is total acres of stream area inside and outside the City.*** (These two questions were taken together.)

Essential to have: If the city knows the amount of the watershed that is inside and outside the city, then it knows the amount of regulatory control it has over the land impacting the stream. It is not expensive data and is readily available.

Note: If much of the the watershed is outside the city, prioritizing the whole watershed would require an interlocal agreement between the city and the adjacent jurisdiction.

5. ***Is total stream length in the City data needed to prioritize watersheds? This is limited to the City limits.***
7. ***Is total stream length data needed to prioritize watersheds? This is not limited to the city limits; it includes streams in other jurisdictions.*** (These two questions were taken together.)

<u>Nice to have</u>: Redmond used stream length inside and outside the city because the goal is to restore the stream. Also, it is helpful for state funding. However, while it was informative, it didn't have a lot of weight in the prioritization. WDFW hasn't used stream length because there is no criteria associated with it. The watershed area does a better job of telling how much habitat there is for fish.

6. ***Is Class II (Type F [1]under DNR stream typing) Stream length in City data needed to prioritize watersheds? This is limited to the City limits.***
8. ***Is Class II stream length data that is not limited to the city limits (includes streams in other jurisdictions) needed to prioritize watersheds?*** (These two questions were taken together.)

<u>Nice to have</u>: The Endangered Species Act applies to actual and potential fish use. It helps us understand where fish are and where they need to be. Potential fish use is important per questions 9 - 12.

9. ***Is significant salmon use data needed to prioritize watersheds? Redmond used observed significant salmonid use greater than 50/100 linear feet of channel, taken from Wild Fish Conservancy stream surveys in 2004 and 2005.***
10. ***Is Chinook Salmon data needed to prioritize watersheds?***
11. ***Is Coho use needed to prioritize watersheds?***
12. ***Is other salmonid use <u>relevant to the jurisdiction</u> needed to prioritize watersheds?***

(These four questions were considered together.)

<u>Essential to have</u>: Need to know that fish are there if are prioritizing for restoration. Of this suite of data types, Chinook use is the best indicator of (high) flow issues. Current fish use is easy data to obtain because all of the WRIAs have the information in their plans. Question 12 data is revised to add "relevant to the jurisdiction". Steelhead should be added as a separate data point. Other salmonid use may be added based on what is present in the jurisdiction. See the attached *2011 Jan 7 Fish Hydrology Metrics*.

<u>Nice to have</u>**: *Potential fish use*** would be nice to have. Percentage of creek system that is potentially fish-bearing vs. what is fish-bearing would be helpful, but it would require knowledge of what types of fish barriers exist (natural vs. human-made). Cities and counties may have done a physical barrier inventory. Coho and cutthroat can get farther upstream, so their ratio is good to calculate to assess stormwater impacts (as they're typically winter vs. spring spawners, respectively). The species also differ on how they can get beyond barriers. <u>[Note: Heather's notes reflected this as nice to have. However, further discussion with Bob Vadas and Scott Stolnack after the meeting indicated they recommend it is essential to have. This will be on the agenda to discuss at the next meeting. Further note: The group agreed at the March 16 meeting that this data is essential to have – see March 16 meeting summary.]</u>

[1] Type F streams include actual or potential fish use.

Notes:

- Some expressed that presence of fish should be enough. It is a balance of level of detail and cost.
- Physical data can come first, and then biological data.

13. Is <u>naturally occurring</u> large woody debris per 100 linear feet data needed to prioritize watersheds? (see notes in Redmond plan for more info)
14. Is tree canopy percentage cover in buffers needed to prioritize watersheds?
15. Is data on the percentage of 300-foot buffers that is vegetated needed to prioritize watersheds? (All vegetation excluding landscaped and mowed or plowed land is included - trees, shrubs and unmoved grasses. Limited to city limits.)
16. Is data on the percentage of 100-foot buffers that is vegetated needed to prioritize watersheds? (All vegetation excluding landscaped and mowed or plowed land is included - trees, shrubs, and unmowed grasses. Limited to city limits.)
(These four questions were considered together.)

<u>Nice to have</u>: Question #13 should be refined to naturally occurring versus restored large woody debris.

Notes:

- Regarding Question 14, smaller streams tend to have higher percent tree canopy cover which weights small vs larger streams.
- After the meeting, Bob Vadas indicated that he would like to revisit whether Question #16 should be essential or nice to have based on data regarding the value of 100 foot buffers.

17. Is Benthic Index of Biotic Integrity (BIBI) data needed to prioritize watersheds?

<u>Essential to have (where appropriate to measure aquatic health)</u>: It is essential for fresh water but not available for salt water. It cannot be collected in all streams, so other measures of aquatic health/environmental integrity may be needed. It is a good metric on a yearly scale for the general health of a stream and shows a good correlation with impervious surfaces and flow metrics. If not BIBI, a jurisdiction will need to find some other measure of aquatic health – the guidance will need to provide examples.

Again, see:

- Horner, R.R., and C.W. May. 1999. Regional study supports natural land cover protection as the leading best management practice for maintaining stream ecological integrity. Proceedings of the Comprehensive Stormwater and Aquatic Ecosystem Conference. Auckland, New Zealand. 12 pp. *http://stormwater.cecs.ucf.edu/research/bioassessment/pugetsoundfinalreport.pdf*
- Booth, D.B., and L.E. Reinelt. 1993. Consequences of urbanization on aquatic systems — measured effects, degradation thresholds, and corrective strategies. Pages 545–550 in U.S. Environmental Protection Agency (ed.). Proceedings Watershed '93: a national conference on watershed management. Alexandria, VA (http://www.sciencetime.org/ConstructedClimates/wp-content/uploads/2013/01/BoothReinelt1993.pdf).

Also, see the attached Matzen and Berge paper that Bob mentioned at the meeting. This paper focuses on fishes and why they provide complimentary information to B-IBI (as the latter data are restricted to riffles, but provide less stream-size dependent results than F-IBI)."

18. Is known water quality impairments data (waterbody is identified on the Ecology 303(d) list as a category 5 or 4B due to impairment from the indicated water quality parameter) needed to prioritize watersheds?
19. Is high temperature data needed to prioritize watersheds?
20. Is low dissolved oxygen data needed to prioritize watersheds?
21. Is high fecal coliform bacteria concentration data needed to prioritize watersheds?
(These four questions were considered together.)

<u>Nice to have</u>: This list represents the commonly known water quality impairments. Water quality impairment data, where available, will likely be required by Ecology. Participants indicated that these data should be used later in the prioritization process, not as a first screen. Temperature and dissolved oxygen impariment information may have the most direct nexus to flow control because low summer flows can be associated with high stream temperatures and low dissolved oxygen levels.

22. Is percent effective impervious surface data needed to prioritize watersheds? (Same value as in land use section – not considered as is a repeat of Question #1)

23. Is percentage of high Annual Average Daily Traffic right-of-way data needed to prioritize watersheds? (Redmond traffic count data used to select right-of-ways where AADT is 7,500 or greater)

<u>No, it is not needed</u>: This data is not relevant for flow control.
Notes:

- Public right-of-way (ROW) versus private may make a difference because local government has control over the ROW.
- Square miles of road density versus watershed can have fish impacts. It could be an alternative to BIBI. See the attached *2011 Jan 7 Fish Hydrology Metrics* which contains five measures from GIS maps.

24. Is data on the percentage of watershed inside the City needing flow control retrofit needed to prioritize watersheds? (Redmond calculated the percentage using the entire watershed area within the city minus areas that are currently forested, flow control exempt, or areas contributing runoff to a flow control facility designed to attenuate flows to match forested hydrology from 1/2 the 2-year through the 50-year storm event.)

<u>Essential to have</u>: This data indicates the environmental lift potential from installing stormwater retrofits. It could be the age of infrastructure development in the area – e.g. development after year X. This is a good indicator, but not all cities have this information.

Note: The question will be rewritten to be more clear with a better explanation for the next meeting.

25. Is data on the percentage of watershed inside the city needing basic water quality treatment retrofit needed to prioritize watersheds? (Redmond calculated the percentage using the entire watershed area within the city minus areas that currently contribute runoff to a basic treatment facility or are currently forest or pasture.)

No, not needed: Same idea of ecological lift, but not needed for flow control. This is for water quality.

26. Is the number of outfalls and ditches data that is needed to prioritize watersheds?
27. Is the number of outfalls and ditches per 1,000 linear feet data that is needed to prioritize watersheds?
28. Is the number of culvert crossings per 1,000 linear feet Class II data that is needed to prioritize watersheds? (Mapped culvert crossings - street, driveway, or utility - per 1,000 linear feet on mapped Class II stream channels in each watershed within the city limits. Does not include trail bridges, long storm pipes, pipe outfalls, or piped sections of stream headwaters.)
29. Is the number of mapped ditch outfalls (or pipes smaller than 12") potentially draining from pollution generating surfaces within city limits data that is needed to prioritize watersheds?
(These four questions were considered together.)

No, not needed: This data is not needed for prioritization. But it can be used for siting retrofit projects.

30. What types of data not listed above are also needed for prioritizing a watershed for flow control transfers?

Zoning is important because future development impacts to the watershed must be considered.
May need to include other measures of ecological integrity (in lieu of BIBI scores). Shellfish bed closure data, like known water quality impairments, is important to consider where available.

Next meeting dates:

- March 16, 10:00 a.m. – 1:00 p.m., City of Tacoma Central Wastewater Treatment Facility
- March 31, 10:00 a.m. – 1:00 p.m., Puget Sound Regional Council
- April 20, 10:00 a.m. – 1:00 p.m., City of Tacoma Central Wastewater Treatment Facility

Summary of Ecosystem Processes Metrics (for Aquatic System Integrity)[a]

High ratings: channel stability, stream habitat, wetland water level fluctuation	⟷	Low ratings: channel stability, stream habitat, wetland water level fluctuation

Aquatic integrity: % basin or watershed natural landcover[b]

>90%	80-89%	70-79%	60-69%	<60%

Aquatic integrity: watershed/catchment percent effective impervious area (EIA)[c]

<4% (≤3.5% TIA)	4-6% (10-14% TIA)	7-8% (15-17% TIA)	9-10% (18-20% TIA)	>10% (>20% TIA)

Aquatic integrity: accessible-habitat losses (for anadromy in current vs. historic conditions, % of stream length)

<15%	15-20%	20-30%	30-60%	>60%

Riparian integrity: % natural vegetation within riparian corridor[d,e]

>85%	51-85%	43-50%	25-42%	<25%

Riparian integrity: number of break crossings (from roads, trails, powerlines, etc.) per stream mile

Assume 0 to <<3.2	~3.2	>>3.2

Road density (mi/mi^2 of the watershed or basin area)[f]

<1	1-1.9	2-2.4	2.5-3	>3

[a] *See Appendix B tables for supporting information and citations.*

[b] *Based primarily on forest land-cover values; however note for practical application, percent natural land cover can be meaningful (e.g., see Pierce County's use of percent natural land-cover* ***web link*** *). For forest, trees should be >25 years old and ≥33 feet tall; best integrity is when >>15% of stand is late successional (especially old-growth conifers), moderate integrity includes ~15% late successional, and low integrity is <<15% late successional forest.*

[c] *TIA is based on Alley and Veen (1983) and Dinicola (1990); 10% TIA is ~4% EIA and 20% TIA is ~10% EIA, but ≤3.5% TIA is based on Reinelt and Taylor (2001) and isn't a conversion for <4% EIA.*

[d] *From Knudsen and Naef (1997).WDFW recommended riparian habitat area widths developed to meet the goal of maintaining or enhancing the structural and functional integrity of riparian habitat and associated aquatic systems needed to perpetually support fish and wildlfie populations on both site and landscape levels. These RHA widths are:*

Type 1&2 streams; shorelines of the state, or statewide significance:	*250 ft*
Type 3 streams; other perennial/fish streams 5-20 ft wide:	*200 ft*
Type 3 streams; other perennial/fish streams <5 ft wide:	*150 ft*
Type 4&5 streams; or intermittent w/ low mass-wasting potential:	*150 ft*
Type 4&5 streams; or intermittent w/ high mass-wasting potential:	*225 ft*

[e] *Useful criteria to differentiate high (from low) mass-wasting potential for logging activities include sideslope values of ≥25-30%, ≥50%, and >65-70%; and/or the predominance of sandstone bedrock (Oman and Palensky 1995; Hooper 1998; May and Peterson 2003; Stanley et al. 2005; Turner et al. 2010).*

[f] *Based on NMFS (1996), and USFWS (1998), road densities <1-2 mi/mi^2 (all outside of the valley bottom) are best for salmonids (with Bull Trout being especially sensitive); road densitiies 2-3 mi/mi^2 (some in the valley bottom) are rated a medium condition; and road densities of >2.4 to 3.0 mi/mi2 (many in the valley bottom) are worst for salmonids.*

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[Article]

Assessing Small-Stream Biotic Integrity Using Fish Assemblages across an Urban Landscape in the Puget Sound Lowlands of Western Washington

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Abstract.—We developed a fish index of biotic integrity (FIBI) to evaluate the relationship between urbanization and fish assemblages. The FIBI was developed with data collected from 70 sites in 30 basins and tested with a validation data set from 71 sites in 18 basins within the greater Lake Washington watershed. Fish assemblage data were evaluated at each site according to species-specific attributes and the level of human disturbance (total impervious area [TIA], impervious and vegetative coverage, mixed development, and road density) within each sampling basin. In this study TIA proved to be the most useful measure of urbanization. Approximately 50 metrics were evaluated and six were included in the final FIBI based on their response to urbanization. Each metric was scored according to standardized criteria, and the scores of all of the metrics were summed to create a final index score for each sampling location. A relationship between FIBI and TIA was expected, prompting the use of linear regression as a tool to evaluate the FIBI against five disturbance measures; correlation coefficients ranged from 0.13 to 0.68, with an overall trend of decreasing biotic integrity with increasing urbanization. Comparisons of data collected over a 10-year period from the same sampling locations demonstrated decreases in biotic integrity at most sites corresponding with an observed increase in urbanization. The FIBI developed in this study can serve as a useful management tool (in conjunction with other indicators of the condition of fish communities across Puget Sound lowland streams) as well as a metric with which to describe conditions to the public in an easily understood manner.

Many freshwater ecosystems around the world have been altered by anthropogenic effects, including agriculture, industrial logging, and urbanization (Meehan 1991; Doppelt et al. 1993; Naiman et al. 1995; Paul and Meyer 2001; Schindler 2001; Van Sickle et al. 2004; Donald and Evans 2006). Global concern for environmental degradation and sustainable development has resulted in an increased effort to monitor and assess environmental conditions (Karr and Chu 1999; USEPA 2000; Wang et al. 2000; NRCS 2003). Such concern is warranted when estimates reveal that in the United States alone almost half of the rivers and streams fail to meet water quality standards when biological indicators are used (Doppelt et al. 1993) and estimates in the early 1980s suggested that approximately 81% of the streams with fish communities were degraded (Judy et al. 1984). Successful monitoring and assessment of environmental conditions require effective tools that are easily understood by managers and the public. Ecological indicators are one such tool used to characterize the condition of watershed health, including chemical, physical, and biological components.

In contrast to physical and chemical attributes, it is difficult to quantify the integrity and stability of aquatic ecosystems because they are responding to complex mixtures of biotic and abiotic processes (Karr 1981; Fausch et al. 1990; Simon and Lyons 1995; USEPA 2000; Hued and Bistoni 2005). Since the 1980s, researchers have sought biological indicators that could be used to describe the response of complex organisms to current conditions and cumulative effects (Karr 1981; Karr and Chu 1999). Particular importance lies in understanding the attributes of a biological community that are indicative of its overall condition. An index of biotic integrity (IBI) is used to integrate multiple measurements of biological attributes (metrics) to assess the condition at a specific location (Karr and Chu 1999). Fish are ideal indicators because they are sensitive and visible components of freshwater ecosystems and respond predictably to both abiotic and biotic factors (Angermeier and Karr 1986; Fausch et al. 1990; Simon and Lyons 1995).

The physical characteristics of sampling locations may influence the characteristics of the fish assemblage. For example, fish assemblages are assumed to vary between low and high gradient streams. High gradient streams are typically associated with lower species diversity and low gradient streams are associated with higher species diversity (Li et al. 1987; Kruse et al. 1997). In addition, lower-order streams generally have lower species richness than

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higher-order reaches in the same basin (Platts 1979; Li et al. 1987). Some exceptions result from cold groundwater influences in low gradient streams that could cause the ecosystem to appear more like a higher gradient system, due to the inverse relationship between temperature and primary productivity (Vannote et al. 1980; Li et al. 1987; Wehrly et al. 2003).

Fish species attributes have been used to define the relationship between the ecological function of an assemblage and environmental conditions (Goldstein and Meador 2005). In a fish index of biotic integrity (FIBI), each metric is used to identify an aspect of the fish community that responds in a unique manner to stressors in the aquatic ecosystem (Zaroban et al. 1999), assuming that any two assemblages exposed to the same stressors will have similar structures (Goldstein and Meador 2005). This also assumes that the appropriate scale has been chosen to evaluate the effect of the stressors on the fish assemblage (Jones et al. 1996).

The IBI was first developed using fish communities in small, warmwater streams as a way to describe biotic integrity and ecosystem health (Karr et al. 1986; Simon and Lyons 1995) and has since been successfully applied to benthic macroinvertebrates (Karr and Chu 1999; Hawkins et al. 2000). Metrics typically measure assemblage attributes related to species richness, tolerance to specific stressors (turbidity, siltation, low dissolved oxygen, and temperature), trophic guilds, reproductive strategies, habitat preferences, abundance, and individual health (Karr et al. 1986; Fausch et al. 1990; Lyons et al. 1995; Hughes et al. 2004). The IBI concept has subsequently been applied in lakes, rivers, and streams throughout the world (Simon and Lyons 1995; NRCS 2003; Pont et al. 2006). Applications of the IBI in other areas show that the concept is widely adaptable, but metrics must be modified, added, or deleted to reflect regional differences in fish distribution and assemblage characteristics (Simon 1998; Zaroban et al. 1999). Like any index of biotic integrity, a FIBI is a particularly useful tool in assessing stream health as long as the metrics and indicators used are well suited to the watershed, and both desired and current conditions are represented by the range of values in the metrics.

In the Pacific Northwest (PNW), freshwater systems are characterized by coldwater streams with relatively low biological diversity of fish and amphibians, making development of an IBI based on species richness difficult (Sparling et al. 2001). Unlike in warmwater Midwestern streams, little variation is observed in habitat preferences, trophic guilds, or reproductive strategies of fish in the PNW (Hughes et al. 2004). For these reasons FIBIs have received limited attention in the PNW except for two studies conducted on rivers (Hughes and Gammon 1987; Mebane et al. 2003) and a fish and amphibian IBI developed for coldwater coastal streams in Washington and Oregon (Hughes et al. 2004). Combined, these studies have covered portions of Idaho, Oregon, and most of Washington with the exception of the Puget Sound Lowland (PSL) ecoregion.

Recent declines of Pacific salmon *Oncorhynchus* spp. and subsequent listings of species under the authority of the Endangered Species Act (USFWS 1999; NMFS 2000) have prompted land use managers in the Puget Sound region to seek effective tools for assessing the current conditions of freshwater fish habitats in an effort to more fully integrate restoration and recovery efforts at watershed scales. The use of biological indicators has been championed as an answer to the discrepancy of declining environmental conditions in the midst of extensive water quality monitoring (Karr and Chu 1999). In the Puget Sound region, a BIBI (benthic IBI) has been used extensively as an indicator of stream health by federal, state, and local agencies. Although benthic macroinvertebrates are an important indicator of ecosystem condition, they do not respond to landscape changes in the same manner as vertebrates, particularly fish species, and may not be appropriate surrogates for monitoring changes in fish habitat (Fitzpatrick et al. 2001, 2004). The purpose of this study was to develop a FIBI for small PSL streams to better understand the response of fish communities in lotic systems to urbanization in the greater Lake Washington watershed (GLWW).

Methods

Study area.—The GLWW is located in Washington State between the Olympic and Cascade mountains and is part of the PSL ecoregion, which has a mean annual temperature of 9°C, a mean summer temperature of 15°C, and a mean winter temperature of 3.4°C (Ricketts et al. 1999). Mean annual precipitation of the PSL ecoregion ranges from approximately 800 to 900 mm (Ricketts et al. 1999). The physical geography of the region is directly related to multiple glacial events as recent as approximately 15,000 years ago that left behind a depressed valley of glacial till, glacial outwash, and lacustrine deposits. The GLWW drains an area of 1,274 km^2 (Figure 1), with the majority of stream flow originating from rainfall, and a very small percentage originating from seasonal snowmelt in the Cascades (WCC 2001).

Approximately 1.4 million people live within the GLWW, making it the most populous and densely developed watershed in the PNW (WCC 2001). Like many areas in the PNW, the GLWW has been

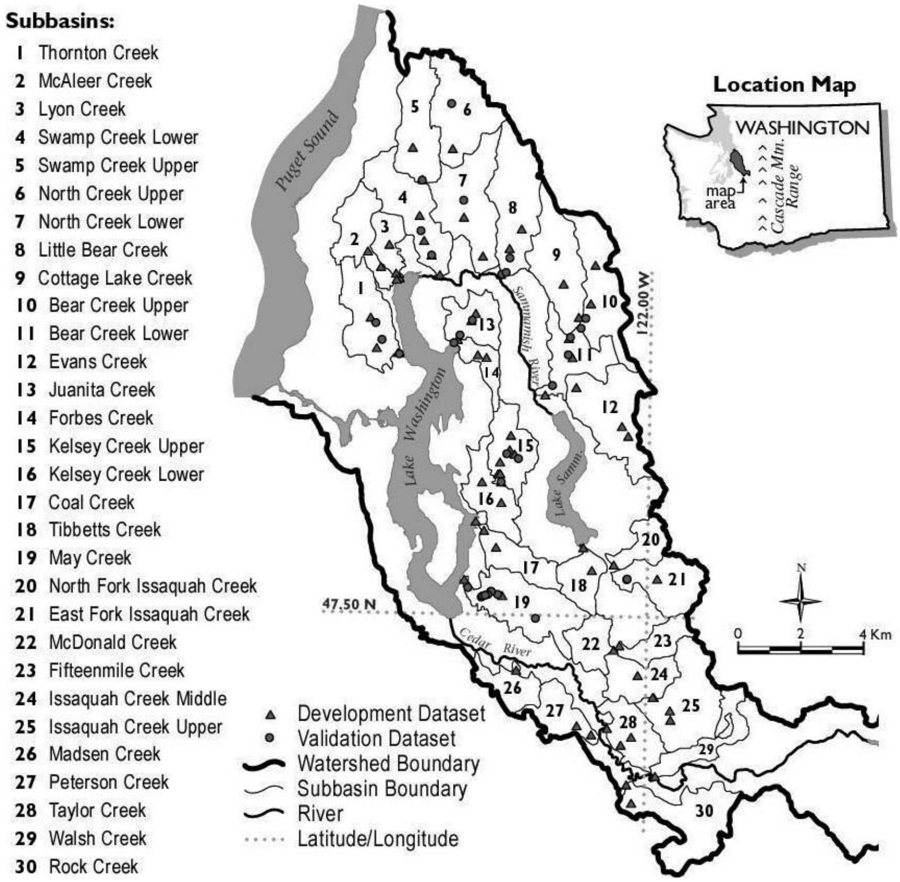

FIGURE 1.—Location of study subbasins and fish sampling sites in the greater Lake Washington watershed.

dramatically altered over the last 150 years by human activity. Within the watershed, land use ranges including a protected water supply, parks and open spaces, agriculture, high- and low-density housing, and areas of intense urbanization. The urban gradient across this watershed is further reflected in total impervious area (TIA) measurements in stream basins, which range from 0% to 57%. The TIA measures built surfaces, which include roads and buildings, or bare ground, which includes unpaved roads and trails that are presumed not to soak up water (Booth et al. 2004). In addition, the natural drainage system of Lake Washington was substantially altered in the early 20th century with the Cedar River's diversion into Lake Washington and the construction of the Hiram M. Chittenden Locks creating an artificial channel from Lake Washington to the Puget Sound.

While there are some differences in geology, hydrology, and topography among individual basins, Booth et al. (2004) consider physiological and biological features to be similar throughout the PSL. Native fish assemblages in the PSL consist primarily of salmonids (salmon, trout, char, grayling, and whitefishes), cottids (sculpins), cyprinids (minnows), gasterosteids (sticklebacks), petromyzontids (lampreys), osmerids (smelts), and catostomids (suckers) (Wydoski and Whitney 2003). Within in the GLWW, native populations of salmonids have been affected by the operation of salmon hatcheries in the watershed since 1936. Many nonnative species co-occur in the Puget Sound lowlands, the majority of these are centrarchids (black basses and sunfishes), but also include salmonids, ictalurids (catfishes), cyprinids (carp), and percids (perches) (Wydoski and Whitney 2003).

Fish collection.—Fish were collected with DC by means of a Smith-Root Type VII backpack electrofisher. A minimum of two passes were used to collect fish in each sampling event. Surveys were conducted in an upstream direction. Fish were enumerated, identified to species in most instances, and released in situ. Data were collected during the summer period from 1993 to 2003 in stream basins across the GLWW (Figure 1).

TABLE 1.—Species-specific attribute classifications of fish species found in small streams of the greater Lake Washington watershed (modified from Hughes et al. 1998 and Zaroban et al. 1999).

Family	Species	Family origin[a]	Species origin[a]	Hughes et al. 1998			
				Foraging[b]	Habitat[c]	Tolerance[d]	Reproduction[e]
Catostomidae	Largescale sucker *Catostomus macrocheilus*	N	N	O	B	I	L
Centrarchidae	Black crappie *Pomoxis nigromaculatus*	A	A	T	W	T	PN
	Bluegill *Lepomis macrochirus*	A	A	I	W	T	PN
	Largemouth bass *Micropterus salmoides*	A	A	T	W	T	PN
	Pumpkinseed *Lepomis gibbosus*	A	A	I	W	I	PN
	Smallmouth bass *Micropterus dolomieu*	A	A	T	W	I	LN
Cottidae	Sculpin species[g]	N	N	I	B/H	I	CN
Cyprinidae	Dace species[h]	N	N	I	B/H	I	L
	Peamouth *Mylocheilus caurinus*	N	N	I	W	I	L
Gasterosteidae	Threespine stickleback *Gasterosteus aculeatus*	N	N	I	W/H	I	VN
Petromyzontidae	Lamprey species[i]	N	N	FS	B/H	S	NLN
Salmonidae	Chinook salmon *Oncorhynchus tshawytscha*	N	N	T	W	S	NLN
	Coho salmon *Oncorhynchus kisutch*	N	N	T	W	S	NLN
	Cutthroat trout *Oncorhynchus clarkii*	N	N	T	W/H	S	NLN
	Steelhead–rainbow trout *Oncorhynchus mykiss*	N	N	T	W/H	S	NLN

[a] N = native, A = alien.
[b] O = omnivore, FS = filterer specialist, I = invertivore, T = top carnivore.
[c] B = benthic, W = water column, H = hider.
[d] I = intolerant, S = sensitive, T = tolerant.
[e] NLN = nonguarding lithophil (gravel–cobble) nester, LN = lithophil nester, L = lithophil, V = vegetation, P = psammophil (sand–fine gravel), CN = cavity nester, VN = vegetation nester, PN = psammophil nester.
[f] I = invertivore, O = omnivore, I/P = invertivore/piscivore, P = piscivore, FF = filter feeder (characterizes most of freshwater life).
[g] Includes coastrange sculpin *Cottus aleuticus*, mottled sculpin *C. bairdi*, prickly sculpin *C. asper*, shorthead sculpin *C. confusus*, and torrent sculpin *C. rhotheus*.
[h] Includes longnose dace *Rhinichthys cataractae* and speckled dace *R. osculus*.
[i] Lamprey species include Pacific lamprey (*L. tridentata*), river lamprey (*L. ayresi*), and western brook lamprey (*L. richardsoni*).

The FIBI was developed with fish assemblage data (guidance data set) collected from 70 sampling sites in 30 subbasins within the study area (Ludwa et al. 1997; Figure 1). These data include 39 sites in second-order streams and 31 sites in third-order streams. The data used for validation of the FIBI (validation data set) included 71 sampling sites in 18 subbasins, and consisted of 25 sites in second-order streams and 46 sites in third-order streams.

Benthic index of biotic integrity (BIBI) data.—The BIBI data collected in 2002 (King County 2004) were from the same subbasins where fish sampling occurred as well as additional subbasins within the GLWW. Both the BIBI and FIBI scores were regressed against disturbance measures to evaluate the similarity in responsiveness.

Geomorphic characterization.—Sampling sites were classified according to their geomorphic characteristics to identify comparable sets of fish assemblage data (Karr and Chu 1999). Stream order, gradient, and confinement data from the Salmon and Steelhead Habitat Inventory and Assessment Program (SSHIAP [NWIFC 2004; WDFW 2004]) were used for each sampling site. These data were overlaid in a geographical information systems (GIS) data layer with fish sampling sites that met the selection criteria. For sampling sites in channel segments not defined by the SSHIAP layer, stream order was determined from King County's watercourse GIS data layer using the methods from Strahler (1952).

Landcover.—We used surrogate measures of human influence from three sources. Sixteen landcover classifications were identified from 1995 Landsat imagery (King County 2002). Measures of TIA and impervious cover were available from Leonetti et al. (2005), as calculated from 2001 Landsat imagery. Road density was calculated in the Spatial Analyst extension in ArcView GIS 3.2 (ESRI 1999) with protocols adopted from Alberti et al. (2007). Five disturbance measures were used in the study: TIA, vegetative land use (sum of scrub and shrub, grass, and deciduous and coniferous forest), impervious cover, mixed development (sum of high and medium development), and road density.

Index development.—Species-specific attributes from five categories were the basis for the metrics used in this study as well as for evaluating metrics related to abundance. The five categories of species-specific attributes included the origin (whether a native or alien species), pollution tolerance, trophic guild, habitat (including temperature) preference, and reproductive strategy (Table 1; Hughes et al. 1998; Zaroban et al. 1999).

TABLE 1.—Extended.

	Zaroban et al. 1999			
Family	Temperature	Habitat[c]	Forage[f]	Overall tolerance[d]
Catostomidae	Cool	B	O	T
Centrarchidae	Warm	W	I/P	T
	Warm	W	I/P	T
	Warm	W	P	T
	Cool	W	I/P	T
	Cool	W	P	I
Cottidae	Cool	B	I	I
Cyprinidae	Cool	B	I	I
	Cool	W	I	I
Gasterosteidae	Cool	H	I	T
Petromyzontidae	Cool	H	FF	I
Salmonidae	Cold	W	I	S
	Cold	W	I	S
	Cold	W	I/P	S
	Cold	H	I/P	S

Potential metrics were identified from biological attributes and studies that were either conducted in the PNW or suggested metrics for this region (Table 2). Many potential metrics were identified from the scientific literature, others were modified from previous studies (May 1996), and several new metrics were developed to specifically address PSL conditions across an urbanized gradient. The response of each species-specific attribute to human influence was predicted before metrics were evaluated based on ecological principles and used as a criterion for metric selection.

Data analysis.—Scatterplots and linear regression were used to compare the five disturbance measures with metrics of species-specific attributes and their predicted response with the purpose of selecting metrics for inclusion in the final index. If at least 20% ($r^2 > 0.2$) of the variation in the metric was explained by one of the disturbance measures and the metric responded to disturbance as ecologically expected, it was considered for inclusion in the final index. Metric scores were summed together adding one metric at a time and the sum was regressed against TIA. If the r^2 increased, the metric was left in the index, and if it decreased, the metric was removed.

Several tests were used to evaluate the FIBI. The significance of the geomorphic characteristics was tested using linear regression and analysis of variance (ANOVA). Nonconstant error variance was tested using a version of the Breusch–Pagan test. The Shapiro–Wilks test for normality was used to test whether the residuals were normally distributed. Robust regression was used to test for influential outliers. The ability of the FIBI to detect changes over time was tested using a paired *t*-test to compare mean differences in site FIBI scores from year to year.

Results

Species Collected

A total of 20 fish species representing seven families were collected. However, species of dace, sculpin, and lamprey were each consolidated by genus because not all studies identified to the species level, thereby reducing the total number of identified "species" to 15 (Table 1). Of these 15 fish species, five were not native to the PSL. The total number of species captured in each sampling event ranged from one to nine.

Metric Selection

Approximately 50 potential metrics were evaluated for use in the FIBI (Table 2). Metrics were either selected from a literature review or derived from concepts found in the literature. New metrics included the percent of cutthroat trout individuals, the percent of coho salmon individuals, the presence or absence of sculpins, trophic guild diversity (using the Shannon–Wiener diversity index), the percent of individuals of the most abundant species, the percent of individuals of the two most abundant species, the ratio of coho salmon to cutthroat trout (juveniles), and density (number of individuals per meter of stream reach sampled).

The guidance data set was used to evaluate the 50 potential metrics. The linear regression analysis produced 11 candidate metrics that were considered for inclusion in the final index. One candidate metric was the percent of individuals in the most abundant species. The other 10 candidate metrics were the percentage of invertivore, invertivore–piscivore, intermediate-tolerance, benthic, sculpin, coho salmon, cutthroat trout, cutthroat trout and trout less than 80 mm, trout less than 80 mm, and trout individuals. The metric for tolerant individuals, a commonly used FIBI metric (Table 2), was not used in this study because there were too few tolerant species to provide a useful response. The metric for sensitive individuals, another common FIBI metric, was eliminated because cutthroat trout are classified as sensitive by Hughes et al. (1998) and Zaroban et al. (1999), but respond positively to urbanization rather than negatively (Table 3).

We chose TIA to select metrics for inclusion in the FIBI because TIA has been commonly used in PSL studies (Alberti et al. 2007; Booth et al. 2004) and because it represents a wide range of disturbance, an attribute favored by Karr and Chu (1999) for index development. Linear regression analysis of our data showed that metrics using the attribute classifications proposed by Zaroban et al. (1999) produced stronger

TABLE 2.—Species-specific metrics evaluated in the development of the Puget Sound lowland fish index of biotic integrity, by study; no. = number.

Attribute type	Karr et al. (1986)	Hughes et al. (1998)	USEPA (1993)	Mebane et al. (2003)	Hughes et al. (2004)	This study
Species richness	Total no. of fish species	No. of native species	No. of native species	No. of alien species	% Alien species	% Native individuals
		No. of native families	No. of native families	% Alien individuals		% Individuals of the most abundant species
		% Alien individuals	% Exotic/alien			% Individuals of the two most abundant species
			No. of species/stocks of special concern			
Abundance	No. of individuals in sample	Total no. of individuals		% Sculpin individuals	% Anadromous individuals	% Coho salmon individuals
						% Cutthroat trout individuals
						Coho salmon to cutthroat trout ratio
						Density (no./meter sampled)
Tolerance	No. of intolerant/sensitive species	No. of sensitive species	No. of sensitive species	% Sensitive native individuals	No. of tolerant individuals	% Intermediate tolerant individuals
		% Tolerant individuals		% Tolerant individuals		
Trophic guild	Proportion of omnivore individuals	% Omnivore individuals	% Omnivores			% Invertivore/piscivore individuals
	Proportion of insectivore individuals	% Filter-feeding individuals	% Invertivores			% Piscivore individuals
	Proportion of piscivore individuals	% Native top carnivore individuals	% Top carnivores			
Habitat		No. of native benthic species		No. of native coldwater species	No. of native coldwater species	% Water column individuals
		No. of native water column species		% Native coldwater individuals	% Coldwater species	% Hider individuals
		No. of hider species		% Coldwater individuals	No. of native coldwater individuals	% Benthic individuals
					% Coolwater individuals	
Reproductive strategy		No. of native nonguarding lithophil nester species				

responses to TIA than metrics using the attribute classifications proposed by Hughes et al. (1998) (Table 3). All species-specific attributes used in the metric selection in this study were therefore based on Zaroban et al. (1999).

Before a scoring scheme could be developed, the effect of geomorphic characteristic of the sites needed to be determined. Therefore, each metric was regressed against TIA controlling for one geomorphic characteristic at a time. Three measures of physical characteristic were tested independently by means of multivariate regression analysis and ANOVA: gradient, stream confinement, and stream order. This analysis showed that confinement and stream gradient based on site SSHIAP data were not statistically important for any metrics at the 95% confidence level while controlling for TIA. Stream order was statistically significant ($n = 70$, $P < 0.05$) for five metrics (percent benthic

TABLE 3.—Responses of species-specific attributes from two studies (Hughes et al. 1998 and Zaroban et al. 1999) to percent total impervious area in terms of linear regression coefficients ($n = 141$); asterisks denote statistical significance.

Attribute type	Metric	Hughes et al. (1998)	Zaroban et al. (1999)
Forage	Filter specialist	0.047*	
	Filter feeder		0.047*
	Invertivore	−0.10	−0.47*
	Invertivore/piscivore		0.40*
	Omnivore	0.019	0.019
	Top carnivore	3.6	
	Piscivore		−0.0063
Habitat	Benthic	0.035	−0.79*
	Benthic–hider	−0.79*	
	Hider		0.20*
	Water column	−0.50*	0.59*
	Water column–hider	1.3*	
Tolerance	Intermediate	−0.53*	−0.76*
	Sensitive	0.54*	0.73*
	Tolerant	−0.0046	0.028
Reproductive strategy	Cavity nester	−0.8*	
	Lithophil	0.024	
	Lithophil nester	0.015	
	Nonguarding lithophil nester	0.78*	
	Psammophil nester	−0.0046	
	Vegetation nester	0.014	
Temperature	Cold		0.49*
	Cool		−0.51*
	Warm		0.014
Total number of metrics		17	14
Number of statistically significant metrics		8	10

individuals, percent cutthroat trout and trout less than 80 mm, percent invertivore individuals, percent invertivore–piscivore individuals, percent intermediate-tolerance individuals). Because some of the metrics still responded to differences in stream order while controlling for TIA, two indices were developed: one that accounts for stream order and one that does not account for stream order in the scoring methods.

The values of each metric in the guidance data set were divided into quartiles. Each quartile was assigned an integer value between 1 and 4, where 1 represented the most disturbed condition and 4 represented the least disturbed condition. To identify the most appropriate set of metrics, scores from the 10 candidate metrics were summed in different combinations and regressed against TIA (stepwise regression). The combination of metrics that resulted in the strongest correlation with TIA was used as the final set of FIBI metrics. This analysis narrowed the number of candidate metrics to six: percent invertivore, percent invertivore–piscivore, percent sculpin, percent coho salmon, percent cutthroat trout, and the percent individuals of the most abundant species resulting in a minimum score of 6 and a maximum score of 24.

Linear regression of the FIBI scores against TIA, without accounting for stream order, were significantly negative ($r^2 = 0.66$, $n = 70$, $P < 0.05$). Linear regression of the FIBI scores against TIA, accounting for stream order, were significantly negative ($r^2 = 0.59$, $n = 70$, $P < 0.05$). A paired t-test was used to compare the means of the two sets of FIBI scores, one that controlled for stream order and one that did not. The t-test results indicated that we could not reject the null hypothesis that there was no difference between the means of the two samples ($n = 70$, $P = 0.96$). Therefore, the index presented in this study will not account for stream order in the scoring scheme (Table 4).

FIBI Scores

The metrics for each sampling event in the guidance and validation data sets were scored according to the scheme established using the guidance data set (Table 4). The FIBI scores from the guidance data set

TABLE 4.—Metric scoring based on the fish index of biotic integrity guidance data set ($n = 70$). Scores are determined by the percentage of the total number of fish sampled.

Metrics	Score 1	2	3	4
Percent invertivore individuals	<35	35–55	55–75	≥75
Percent invertivore/piscivore individuals	≥65	45–65	25–45	<25
Percent coho salmon individuals	<5	5–25	25–41	≥41
Percent cutthroat trout individuals	≥65	45–65	25–45	<25
Percent sculpin individuals	<05	0.5–10	10–40	≥40
Percent individuals of the most abundant species	≥80	65–80	50–65	<50

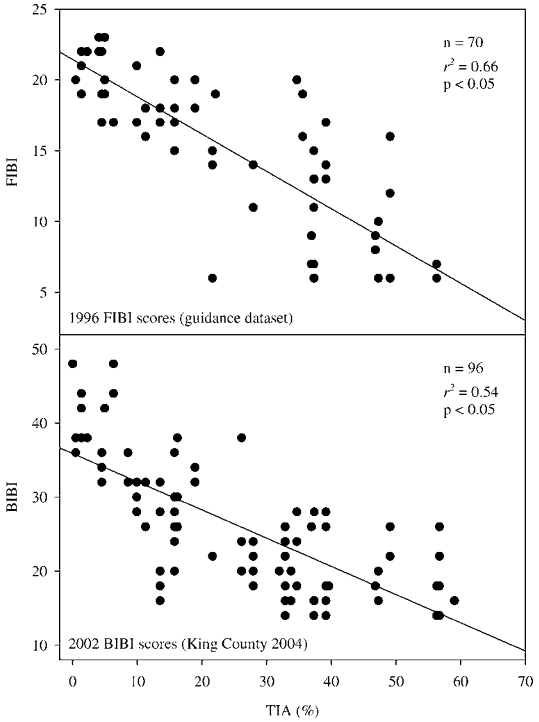

FIGURE 2.—Relationships between the guidance data set fish index of biotic integrity (FIBI) and 2002 benthic index of biotic integrity (BIBI) scores and total impervious area (TIA) in the greater Lake Washington watershed.

ranged from 6 to 23 across the GLWW and FIBI scores from the validation data sets ranged from 6 to 19 across the GLWW. Site scores showed an overall negative relationship between biotic integrity relative to TIA, and a broad range of biotic integrity was observed between 30% and 40% TIA (Figure 2). This observation suggested the need to test for violation of the assumption of constant error variance (homoscedasticity) and a normal distribution of the errors. Using a test for nonconstant error variance (a version of the Breusch–Pagan test), we can reject the null hypothesis with 95% confidence that the FIBI data are homoscedastic. According to the Shapiro–Wilks test, we cannot reject the null hypothesis with 95% confidence that the errors in the FIBI data are normally distributed. This analysis suggests that omitted variable bias may be an issue.

Site scores within each subbasin were averaged to assess the overall condition of the subbasin. In most subbasins, average FIBI scores reflected the relative expected condition based on TIA (Table 5). Subbasins with high amounts of TIA had the lowest FIBI scores, with some exceptions: Madsen Creek, North Fork Issaquah Creek, Swamp Creek (lower), and Swamp Creek (upper). Subbasins with low amounts of TIA had the highest FIBI scores, with some exceptions: Bear Creek (upper), Rock Creek, Walsh Creek, and East Fork Issaquah Creek. Where subbasins were sampled in more than 1 year, basin averages of FIBI scores decreased or stayed the same over time with the exception of two subbasins, North Creek (lower) and Swamp Creek (lower).

Index Validation

Comparison of scores from the same sites sampled at different times allowed for an evaluation of sensitivity to temporal variation. The FIBI scores from 22 sites sampled in both 1996 and 1997 were compared using a two-tailed *t*-test (paired two samples for means). According to the *t*-test, we cannot reject the null hypothesis that there is no difference between the means of the 1996 and 1997 FIBI scores ($n = 22$, $P = 0.23$). The FIBI scores from 18 sites sampled in both 1993 and 2003 were compared using a one-tailed *t*-test (paired two samples for means). According to the *t*-test, we can reject the null hypothesis that the mean of the 2003 scores is greater than or equal to the mean of the 1993 scores ($n = 18$, $P < 0.05$).

The FIBI scores were compared with four measures of urbanization besides TIA. Statistically significant relationships ($P < 0.05$) were found between the other four disturbance measures and FIBI scores: vegetative land use ($r^2 = 0.34$), impervious cover ($r^2 = 0.67$), mixed development ($r^2 = 0.13$), and road density ($r^2 = 0.68$). The FIBI was positively correlated with vegetative land use and negatively correlated with impervious cover, mixed development, and road density.

The FIBI scores from the guidance data set (1996) were compared with BIBI scores from 2002 (Figure 2). Though scores from the FIBI and BIBI cannot be directly compared, as expected, the response of BIBI data to TIA is similar to that of the FIBI in this study.

Discussion

In recent years, hydrologic alterations due to human influence on the landscape and the subsequent biological responses have been well documented in the PSL (May 1996; Ludwa et al. 1997; Serl 1999; Morley and Karr 2002; Booth et al. 2004; Alberti et al. 2007). However, outside of the development of a BIBI and the FIBI in this study, we do not have a tool for monitoring the health of fish communities in second- and third-order streams in the PSL. The greatest perceived challenge to developing a FIBI in the PSL has been the naturally low diversity of fish species, although this study along with the work of other researchers working in regions of low species diversity

TABLE 5.—Variation in fish index of biotic integrity scores within sub-basins and across years. Blank cells indicate that data were not collected; TIA = total impervious area.

Sub-basin (% TIA)	1993 Mean (SD)	*n*	1996 Mean (SD)	*n*	1997 Mean (SD)	*n*	1998 Mean (SD)	*n*	2003 Mean (SD)	*n*
Bear Creek watershed										
Cottage Creek (10)			19 (2.8)	2						
Evans Creek (14)			19 (2.6)	3						
Bear Creek, lower (19)			18.7 (1.2)	3			15.1 (2.3)	7		
Bear Creek, upper (5)			18 (1.4)	2			15.5 (3.5)	4		
Cedar River watershed										
Taylor Creek (4)			22.7 (0.6)	3						
Peterson Creek (5)			21 (2.8)	2						
Rock Creek (5)			19.5 (0.7)	2						
Madsen Creek (35)			20	1						
Walsh Creek (0.5)			20	1						
Issaquah Creek watershed										
East Fork Issaquah Creek (6)			17	1	16 (4.2)	2			17	1
North Fork Issaquah Creek (22)			19	1	18	1				
Issaquah Creek, middle (2)			22	1						
Issaquah Creek, upper (1)			21 (1.4)	4						
Fifteenmile Creek (1)			21	1	17	1				
McDonald Creek (5)			22	1	18	1				
Tibbetts Creek (11)			17 (1.4)	2						
East Lake Washington watershed										
Juanita Creek (47)	12.3 (4.9)	3	8.7 (0.6)	3					9.0 (2.6)	3
Forbes Creek (37)			6.0 (0.0)	2						
Kelsey Creek, lower (47)			8.0 (2.8)	2	11	1				
Kelsey Creek, upper (37)	13 (3.6)	3	9.9 (3.6)	7	9.4 (3.4)	5			6.7 (1.2)	3
Coal Creek (22)			11.7 (4.9)	3						
May Creek (16)	20.3 (2.5)	3	19 (1.4)	2					10.4 (3.6)	9
North Lake Washington watershed										
North Creek, lower (28)			12.5 (2.1)	2	16.7 (2.3)	3				
North Creek, upper (37)			13	1	13.5 (0.7)	2				
Swamp Creek, lower (39)	18.5 (0.7)	2	14.5 (1.7)	4	16 (0.8)	4			14 (1.4)	2
Swamp Creek, upper (36)	19	1	17.5 (2.1)	2	13 (0.0)	2			12	1
Little Bear Creek (16)	15 (3.6)	3	16.7 (1.5)	3					13 (3.5)	3
West Lake Washington watershed										
Lyon Creek (37)			7.7 (1.2)	3	8.6 (3.8)	3				
McAleer Creek (49)			11.3 (5.0)	3						
Thornton Creek (56)	12 (7.8)	3	6.3 (0.6)	3					8.6 (4.6)	3

demonstrate that this obstacle can be overcome through the use of metrics that are specific to the respective ecoregion (Harris and Silveira 1999; Bramblett et al. 2005; Pont et al. 2006).

The development of a FIBI for low-diversity streams in the PSL required looking outside the set of metrics originally developed by Karr (1981) and incorporating region-specific phenomena. Three metrics in this study were consistent with observations made in several GLWW studies, the proportion of cutthroat trout, coho salmon, and sculpin individuals. The proportion of cutthroat trout individuals increased in response to increasing urbanization, which is supported by the findings of several studies in the GLWW (Fresh 1994; May 1996; Serl 1999; Nowak and Quinn 2002; Karr et al. 2003; Seiler et al. 2004). Interestingly, cutthroat trout are considered to be a species sensitive to certain types of pollution, so the idiosyncratic response of cutthroat trout to urbanization confounded the ability of the pollution sensitivity metric to describe biotic integrity in this region. The proportion of coho salmon and sculpin individuals both decreased in response to increasing urbanization, which is consistent with other observations in the GLWW and further supports the metrics used in this study (Serl 1999; Karr et al. 2003).

The correlation between the FIBI developed for the GLWW and the five disturbance measures we evaluated demonstrates the ability of the FIBI to reflect changes resulting from urbanization and its usefulness as a tool to detect biological responses to human disturbance. As expected from the work of others (Wang et al. 1997; Gergel et al. 2002; Morley and Karr 2002; Booth et al. 2004; Morgan and Cushman 2005), TIA proved to be the most useful indicator of urbanization in this study. In general, the biotic integrity of fish assemblages in this study declined with increasing urbanization (e.g., TIA). Deviations from the expected response did occur, especially when TIA ranged between 30% and 40% (Figure 2), which suggests that TIA by itself cannot account for the full extent of human influence on stream health at the subbasin scale. Some sites in this study had FIBI scores that did not fit the expected conditions because small deviations in abundance of one species can result in a large change in the proportion of that species relative to other species collected. This bias is reduced in a multimetric index score when some sites score high in some metrics but low on others. It is difficult to show empirical biological responses in low diversity systems (Sparling et al. 2001), but the data used in this study did show multiple responses to environmental stressors consistent with other studies, including variability in the responses of different species to changes in their environments.

In the GLWW, most researchers have focused on the response of benthic macroinvertebrates to several surrogate measures of human influence using the BIBI as a measure of biological response and stream health to better understand the relationships between urban development patterns, hydrology, and ecosystem dynamics (May 1996; Morley and Karr 2002; Booth et al. 2004). Alberti et al. (2007) found statistically significant correlations (maximum $r^2 = 0.68$) between urban landscape patterns and BIBI that are similar to the relationships between urban development measures and FIBI reported in this study. The response of the FIBI to TIA is similar to the response observed in benthic macroinvertebrate assemblages (BIBI) at the same sampling locations (Figure 2; Morley and Karr 2002; Alberti et al. 2007; Booth et al. 2004; Karr et al. 2003). The apparent concordance between FIBI and BIBI responses to urbanization leads us to believe that a better understanding of the links between fish and benthic macroinvertebrates is possible.

One of the challenges of developing an IBI is accounting for natural variation. Temporal variation may result from year-to-year differences in spawning success, climate, or hydrology. Spatial variation may result from differences in localized habitat conditions, reflective of physical, chemical, and hydrological processes that are site specific as Wang et al. (2003) found with fish assemblages and Morley and Karr (2002) found with BIBI indices. Despite these challenges, the FIBI developed in this study appears to be sensitive to temporal variation, especially over longer time scales, and may be useful in describing regional trends. Trends over longer time periods are most evident when comparing FIBI scores from the same sites sampled in 1993 and 2003. However, FIBI scores compared across smaller time periods showed more variation, both increasing and decreasing relative to previous years. This underscores the importance of long-term monitoring in identifying regional trends for management decisions when using a FIBI. Care should be taken when interpreting ecological indicators operating on small spatial and temporal scales and the importance of relative differences across subbasins should be emphasized over specific scores at a given site.

Given the influence of natural spatial and temporal variation in fish assemblages, the FIBI still showed a statistically significant negative response to disturbance ($r^2 = 0.13$ to $r^2 = 0.68$, $P < 0.05$). The sensitivity of the FIBI to urbanization demonstrates the usefulness of the index as a management tool. The FIBI could be used, in conjunction with other ecological indicators, as a tool with which to prioritize restoration projects and identify areas that could be targeted for protection, restoration, or education and outreach based on the community structure of fishes at those locations, as has been suggested by Booth et al. (2004) based on the BIBI. When managers are faced with limited funding and a mandate to protect and restore aquatic ecosystems, the use of ecological indicators, such as the FIBI developed in this study, can illuminate the ecosystems where restoration or protection efforts will be most effective. Additionally, the sensitivity of the FIBI can serve to identify subtle regional trends of biotic integrity in small streams, such as habitat degradation that may not be noticed with other indicators (Karr 1981; Hughes and Gammon 1987; Wang et al. 1997, 2003; NRCS 2003; Hughes et al. 2004).

The most useful application of a FIBI is in summarizing and communicating complex biological information to managers and the public (NRCS 2003; Morgan and Cushman 2005; Pont et al. 2006). The public, in particular, relates more readily to fish as an indicator of stream condition as compared with other biological measures like diatoms and macroinvertebrates (Karr 1981), complex statistics, or abstract chemical and physical measures (NRCS 2003). However, ecosystems are complex and thus require the use of multiple indicators at appropriate spatial and temporal scales in establishing important management goals and making decisions; the use of one performance measure alone is myopic. Other factors should be considered in freshwater ecosystem management such as physical habitat structure, reestablishing natural processes, benthic macroinvertebrate communities, riparian condition, water quality, hydromodifications, and flow alteration. Our experience in the GLWW suggests that this approach could be useful in other ecoregions in developing a FIBI to improve the effectiveness of using biological indicators to understand the condition and trends of aquatic ecosystems.

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