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# Benthic Macroinvertebrate Status and Trends in the Bear Creek Study Area

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May 2017



**King County**

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Water and Land Resources Division

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# **Benthic Macroinvertebrate Status and Trends in the Bear Creek Study Area**

## **Prepared For:**

King County, Snohomish County, City of Redmond, City of Woodinville, NPDES Permit requirement (Phase I- S5.C.5.c and Phase II- S5.C.4.g) and Washington State Department of Transportation in support of the Bear Creek Watershed-Scale Stormwater Management Plan

## **Submitted by:**

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**King County**

Department of  
Natural Resources and Parks

**Water and Land Resources Division**



## Acknowledgements

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## Citation

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## EXECUTIVE SUMMARY

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This report is among a suite of reports prepared to support the watershed-scale stormwater planning process for Bear Creek. In particular, this report analyzes current conditions and trends of stream health in the Bear Creek Study Area (hereafter “study area”). Stream health is assessed in terms of the benthic index of biotic integrity (B-IBI). B-IBI is a multi-metric index commonly used throughout the Puget Sound region to evaluate stream health. King County and numerous regional partners and jurisdictions have monitored B-IBI scores in the study area and western Washington for over two decades, providing a rich source of regional stream health data.

This report examines current B-IBI scores and changes in those scores over the past two decades. Potential abiotic drivers of B-IBI variation are also considered. These include landscape and hydrological characteristics such as urbanization and stream flashiness. Analyses were conducted using B-IBI scores and abiotic data both from within the study area and within the Puget Sound Lowlands Ecoregion (hereafter “region”) in order to increase statistical power to detect trends and patterns tied to abiotic conditions.

### ***B-IBI current conditions and trends***

On a scale of 0–100, the average study area B-IBI score from 2013–2015 was 53.0 ( $\pm 2.7$  SE). This means that on average, the qualitative B-IBI score in the study area is considered “fair.” B-IBI scores varied across study area sites, ranging from a low of 10.3 (“very poor”) to a high of 81.4 (“excellent”). Over the available record of data, study area B-IBI scores showed no evidence of trend. This contrasts the regional pattern showing an increase of approximately  $\frac{1}{2}$  point per year.

### ***Drivers of B-IBI***

B-IBI was negatively correlated with both urban cover and road density in the surrounding landscape. These landscape features are important drivers of stream flashiness, which is generally negatively correlated with B-IBI scores. Within the study area, both urban cover and flashiness have increased over time.

### ***Conclusions***

B-IBI is highly variable throughout the study area, and more generally, throughout the region. Despite the observed trends, a wide range of B-IBI scores are found in streams that appear healthy (i.e., characterized by low urbanization and flashiness). This is consistent with the regional pattern in B-IBI scores, wherein a fraction of streams in undeveloped areas can have low scores, while a fraction of streams in urbanized areas can have high scores. This variation does not indicate that the B-IBI is uninformative. However, caution is urged in relating patterns to mechanisms and further evaluating success based on changes in scores over time. For example, measures of restoration success should be developed to account for this variation and the possibility that improved stream conditions will not lead to improved B-IBI scores.

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## 1.0 INTRODUCTION

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This report presents the current conditions and trends of biotic stream health in the Bear Creek Watershed (King County 2015a). In particular, biotic stream health is assessed using the Benthic-Indicator of Biotic Integrity (B-IBI). This report was written to support the development of the Bear Creek Watershed-Scale Stormwater Management Plan (King County 2015b).

B-IBI is a multi-metric index that calculates a single, numerical score designed to represent information about the ecological health of a stream. The B-IBI score in a given stream is determined by the community of macroinvertebrates detected there (Karr 1996; Morley 2000). Higher scores represent macroinvertebrate communities that are generally more diverse, for example in terms of the overall number of species, the number of so-called sensitive species, and the types of ecological functions those species perform. This approach to assessing biological stream health is based on the observation that attributes of benthic macroinvertebrate biodiversity systematically erode along a gradient of urbanization. Thus, as the habitat adjacent to a stream is converted from more natural (e.g., forested) conditions to include more urban cover, B-IBI scores can be expected to decline.

The B-IBI was initially developed as a way of providing a relatively quick assessment of biotic stream health. The idea was that a sample of the benthic macroinvertebrate community in a stream serves as a good indicator of the conditions experienced in that stream. One of the virtues of this approach is that it is phenomenological. That is, it captures community level degradation without having to first identify potential mechanisms associated with such degradation. For example, some impacts on streams (e.g., contamination or hydrological flashiness) may occur infrequently but induce substantial impacts on biota. The infrequent or “pulse” nature of these events makes them difficult to monitor and easy to miss. However, the change in biota induced by such events leaves a lasting mark on the stream. In this way, B-IBI is particularly effective at indicating degradation even when drivers of change are not readily apparent, such as urbanization.

However, by design, B-IBI itself does not necessarily point to specific mechanisms of degradation. For example, a low B-IBI score does not necessarily indicate whether a stream’s health is negatively impacted by hydrology, contaminants, temperature stressors, and/or local site habitat conditions.

Biotic stream health is variously defined in the literature. Here, we refer to the health of a stream as the extent to which conditions supports the ecosystem functioning and biodiversity typically observed in streams minimally or unaffected by human influence. This definition of stream health is intentionally broad and qualitative, reflecting the fact that there is no single measure of what constitutes a healthy stream.

Generally, we appreciate that streams in good “health” are those that are relatively free of contaminants, and maintain complexity for example in terms of structure (riffles, runs,

pools), thermal regimes, and habitat types. We also appreciate that healthy streams are generally free of non-native species. These various factors contribute to the availability and quality of the niches within streams that can support the ecological functions and communities of organisms we hope to protect.

In this report, B-IBI is assessed at a suite of sites distributed throughout much of the Bear Creek Watershed (see 2.1 Study Area). B-IBI is assessed in terms of the current distribution of scores in the study area, along with changes in scores over the past two decades. Scores are also analyzed at the level of the stream and in the contexts of land cover and stream hydrological conditions.

## 2.0 METHODS

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### 2.1 Study Area

In the context of the Bear Creek Watershed-Scale Stormwater Plan (King County 2015a, 2015b), the study area is defined as Bear Creek and lands that drain to Bear Creek, with the following exclusions:

- The Evans Creek basin (a tributary to Bear Creek) is not included
- The reach of Bear Creek downstream of the confluence with Evans Creek, along with small direct drainages and tributaries to this reach of Bear Creek
- Cottage Lake and the area that drains to Cottage Lake

A full description of the study area and the rationale for its delineation is available in King County (2015a).

### 2.2 Data Sources

#### 2.2.1 B-IBI Data

B-IBI data were acquired from the Puget Sound Stream Benthos Database (PSSB). The PSSB is an online repository and analytical tool for regional benthic macroinvertebrate data (<http://pugetsoundstreambenthos.org/>). Data in the PSSB have been collected and uploaded by multiple jurisdictions and organizations throughout the Puget Sound region. Macroinvertebrate data in the PSSB are used to compute B-IBI scores, providing an assessment of stream health in terms of the community of macroinvertebrates present at a given site. B-IBI scores are calculated in such a way as to maintain comparability of scores across sites and over time. B-IBI scores and the taxonomic data used to calculate them are publically available on the PSSB website.

B-IBI data were downloaded from the PSSB on December 27, 2016. Data were limited to sites located within the Central Puget Lowland, Eastern Puget Riverine Lowland, and Eastern Puget Upland ecoregions (hereafter referred to collectively as “region”). Scores for all available streams were acquired from the earliest year of record (1994) through 2015. Default options were used to specify how B-IBI scores were calculated. Specifically, when available, replicate samples were combined together prior to calculating the B-IBI score. B-IBI score was determined by the respective taxonomic resolution of each sample. Samples with > 500 organisms were randomly subsampled to reach a count of 500 prior to calculating a score. For each record, B-IBI scores were acquired using both the 10-50 scale (using the “Wissman, 1998” setting) and the 0-100 scale (using the “Fore, Wisseman, 2012” setting). Qualitative categories for score ranges are shown in Table 1.

**Table 1. B-IBI score categories and corresponding color codes for both the 10-50 and 0-100 scales.**

<b>Condition of Biotic Integrity</b>	<b>B-IBI<sub>10-50</sub> Score</b>	<b>B-IBI<sub>0-100</sub> Score</b>
Excellent	46-50	80-100
Good	38-44	60-80
Fair	28-36	40-60
Poor	18-26	20-40
Very Poor	10-16	0-20

Across the 21-year period of data, the PSSB contained over 6,000 individual B-IBI scores. These scores represented 1,398 different sites distributed across 582 Wadeable streams throughout the region. Different subsets of these data were utilized for different suites of analyses in this report depending on the nature of the question and the availability of covariates. For example, analyses of the influence of hydrology on B-IBI were limited to B-IBI sites with nearby stream gauges. These different pairings of B-IBI data and available covariates are outlined below in each relevant subsection. Details are provided in Table A1.

### 2.2.2 Land Cover Data

Land cover data were acquired from two different sources. First, estimates of road density within the contributing watershed of each B-IBI site were acquired from the 2006 National Land Cover Database (Fry et al. 2011). Second, estimates of urban cover were acquired from the 2011 Coastal Change Analysis Program (C-CAP) regional land data (NOAA 2011). These data were available separately for the years 1996, 2001, 2006, and 2011. A full description of the acquisition of these data and the delineation of the basin corresponding to each B-IBI site is described in King County (2015c).

### 2.2.3 Hydrological Data

Daily streamflow data were obtained from the King County Hydrologic Information Center (<http://green.kingcounty.gov/wlr/waterres/hydrology/>). These data were derived from in-stream gauges measuring daily flow volumes. All available gauge data were acquired. Gauges located less than 1000 feet from a B-IBI site—and with no intervening tributary—were paired to that site and any corresponding land cover data.

## 2.3 Analyses

All analyses were conducted in R v. 3.2 (R Core Team 2016).

### 2.3.1 B-IBI: Current Conditions and Trends

For each B-IBI site located within the study area (Appendix A1, Table A1), current B-IBI conditions were calculated as the average B-IBI scores from 2013- 2015. Temporal trends in B-IBI were analyzed over the period of record available, originating in 1995. These trends were analyzed using linear mixed models in which B-IBI was analyzed in response to the “fixed effect” of time (i.e., year) and site was included as a “random effect” to prevent pseudoreplication associated with non-independence of observations at a given site over time (Pinehiro and Bates 2000). This analysis was done for both the region and study area datasets to provide context for trends. Separately, linear models were used to analyze temporal trends at the stream level and in the context of different intensities of urbanization (i.e., low, medium, high) and in relation to hydrological metrics (see below).

### 2.3.2 Land cover

The proportion of urban land cover adjacent to each B-IBI site in the study area was analyzed over the four available time periods (1996, 2001, 2006, and 2011). Changes in the proportion of urban land cover were investigated at each site and at the aggregate level of all sites. Further, each B-IBI site was categorized in terms of the amount of urban cover. Specifically, B-IBI sites with < 15% urban cover were categorized as “low” urban cover. Sites with 15–30% urban were categorized as “medium” urban cover, while sites with > 30% urban cover were classified as “high” urban cover. These values were chosen because stream habitat degrades precipitously at 10–15% urban cover (Schueler 1994).

### 2.3.3 Hydrology

For each gauge, the four following metrics of stream flashiness were calculated: 1) high pulse count (HPC), 2) high pulse duration (HPD), 3) high pulse range (HPR), and 4) TQ mean (see Table 2 for definitions). In relation to these metrics, flashier streams are those with increased HPC and HPR but decreased HPD and TQM. In other words, flashy streams are those that have a relatively high number of shorter, high flow events occurring over a relatively higher proportion of the water year.

Metrics were calculated with respect to “water year,” defined as the period of time from October 1 through September 30 of the following calendar year. The water year is referred to numerically as the year in which this period ends. For example, the 2015 water year begins on October 1, 2014, and ends September 30, 2015.

**Table 2. Stream flashiness metrics definitions.**

<b>Flashiness metric</b>	<b>Definition</b>
High pulse count (HPC)	Number of high pulse events per year. A high pulse event occurs when daily flow exceeds twice the long-term (period of record) average daily flow. A single event covers all consecutive days when this condition is met. Thus, consecutive high pulse days comprise a single event.
High pulse duration (HPD)	Average annual duration (in days) of high pulse events
High pulse range (HPR)	Number of days between the first and last pulse event of the water year
TQ mean (TQM)	Fraction of time during a water year that average daily flow is greater than average annual flow

Principal component analysis (PCA) was used to reduce the number of stream flashiness metrics while capturing their predominant axes of variation. Linear regression models were fitted to each of the four stream flashiness metrics and their first two principal components. Linear regression models were also used to analyze the temporal trend in B-IBI over the period of record. Separate linear regressions were also used to analyze the response of B-IBI to the proportion urban cover and for most models, B-IBI was modeled as a normal response variable.

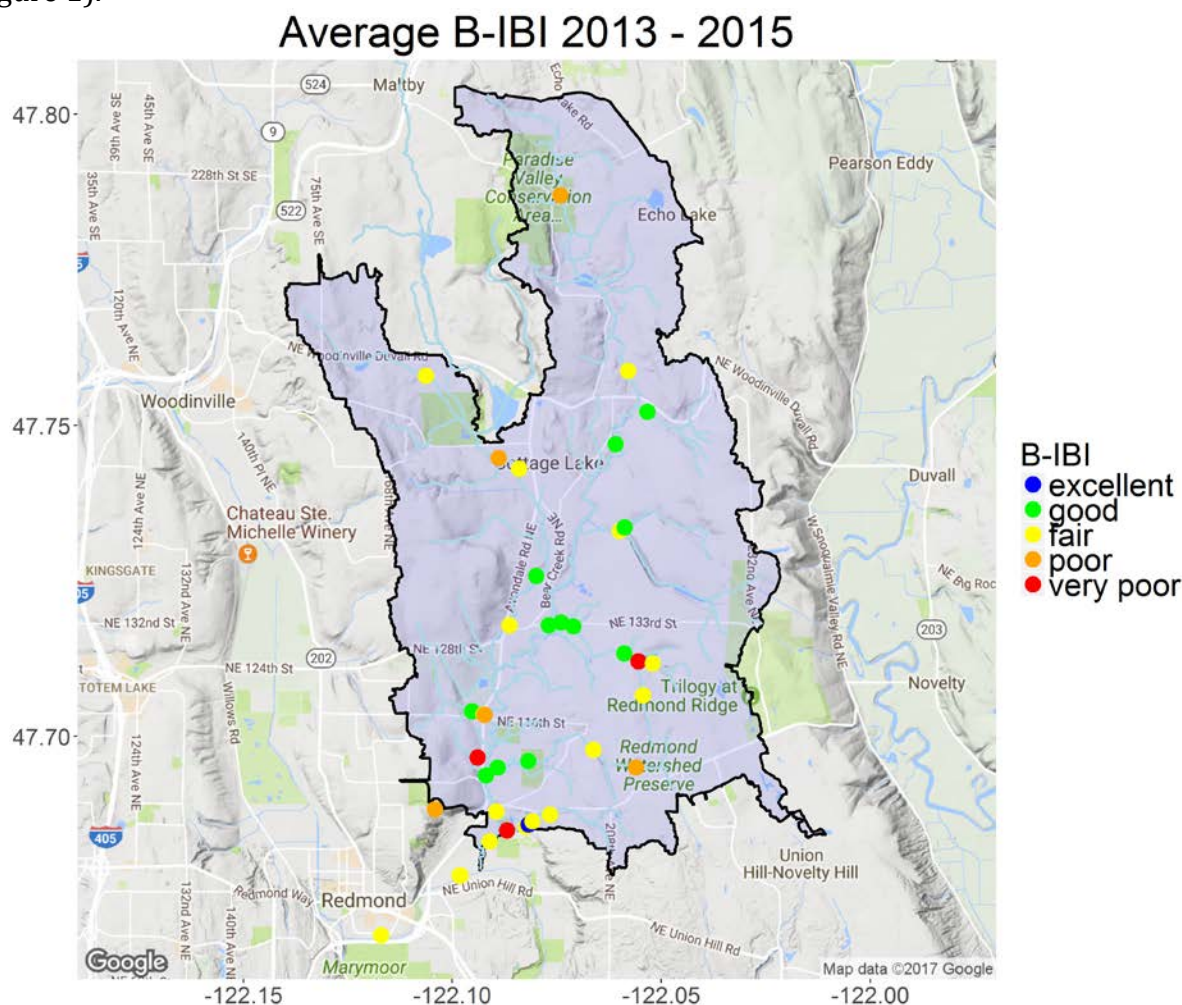


## 3.0 RESULTS

### 3.1 B-IBI Patterns

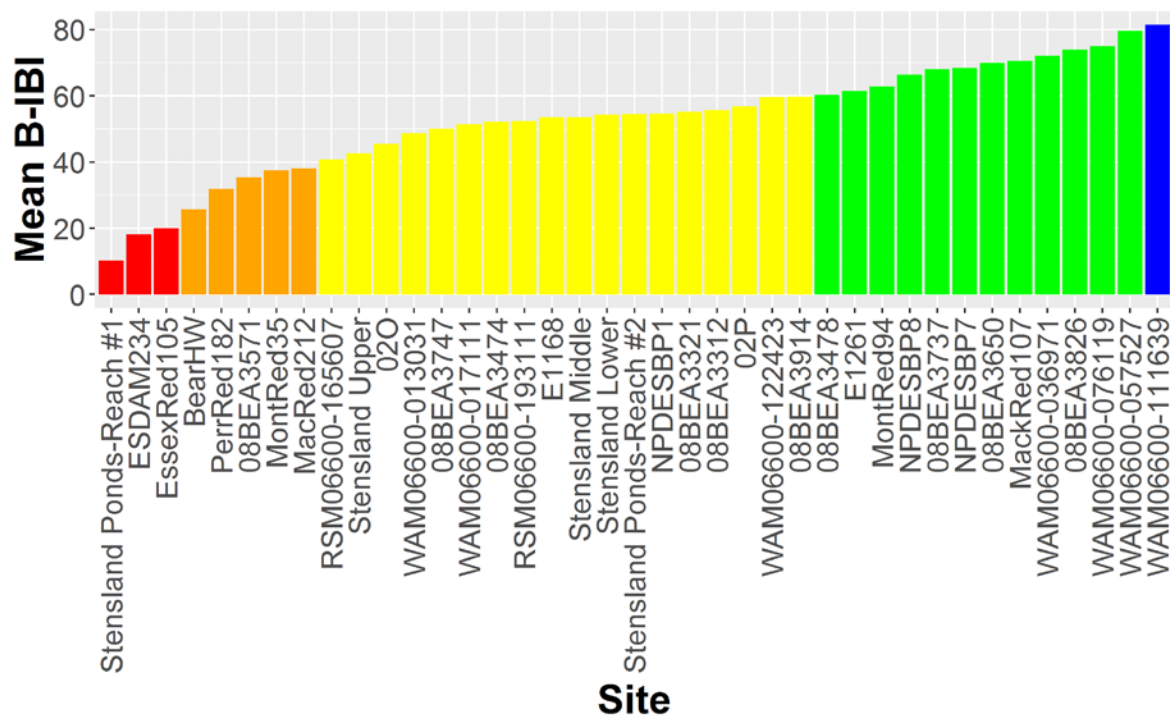
#### 3.1.1 Current B-IBI Status

From 2013–2015, B-IBI was highly variable across sites ( $F_{38, 53} = 4.88$ ,  $P < 0.001$ ). Specifically, individual site identity accounted for 78% of the variation in B-IBI scores. Throughout the study area, average B-IBI at all sites ( $n=39$ ) ranged from 10.3–81.4 (Figure 1).

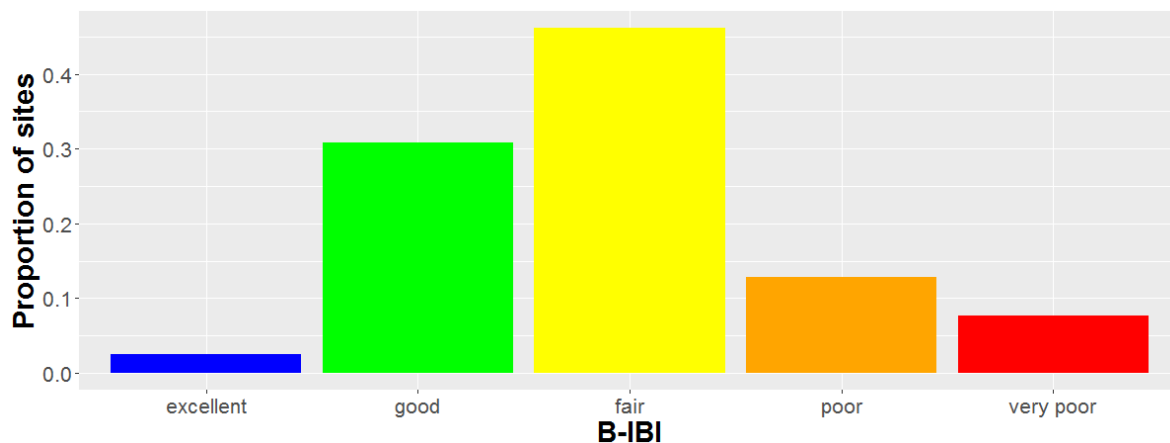


**Figure 1.** Distribution of average B-IBI categories in the study area. The proportion of each category is based on the average score from 2013–2015 for each study area site.

The average B-IBI score across all sites was 53.0 ( $\pm 2.7$  SE). Thus, on average, current B-IBI conditions across the study area are “fair.” Of the 39 B-IBI sites assessed, 46% of those were categorized as “fair” while 31% were “good.” 13% of sites were “poor” and 8% were “very poor.” One of the 39 sites was “excellent” (Figures 2–3).

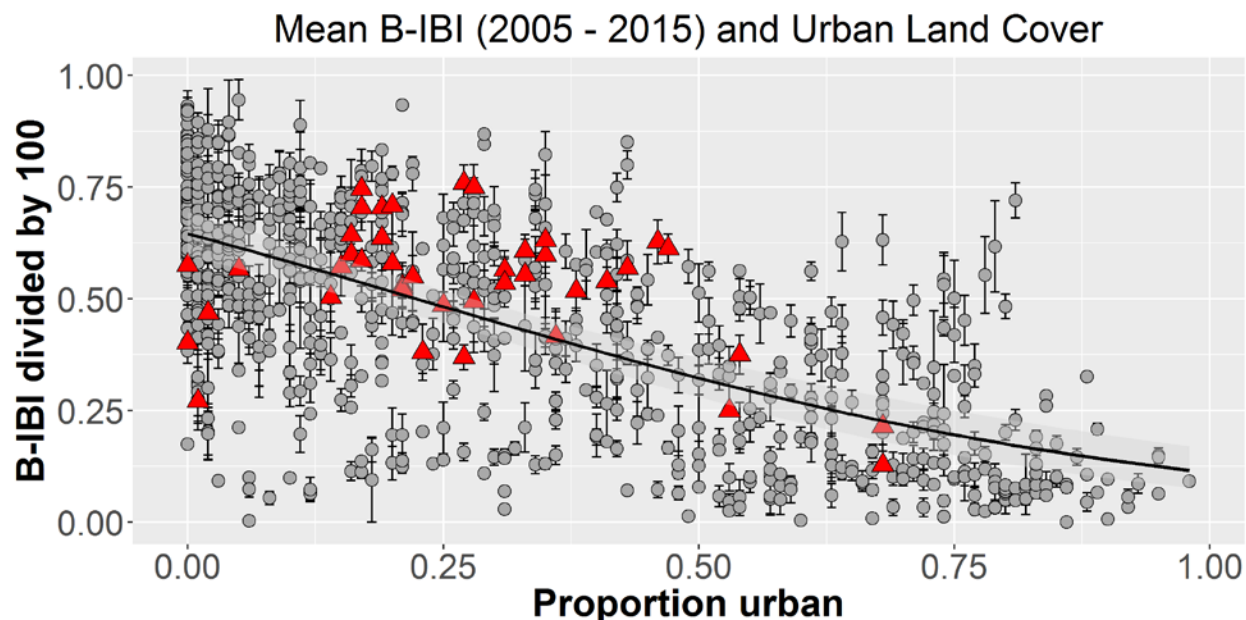


**Figure 2.** Current study area average B-IBI scores (2013-2015) by site. Colors correspond to B-IBI category (red = very poor, orange = poor, yellow = fair, green = good, and blue = excellent).

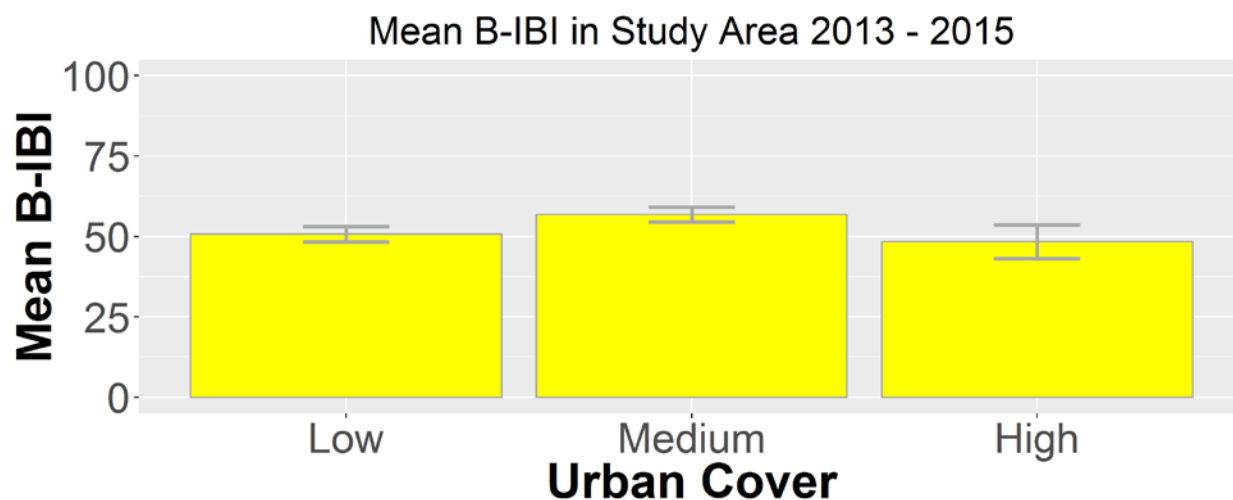


**Figure 3.** Proportional distribution of B-IBI categories in the study area (red = very poor, orange = poor, yellow = fair, green = good, and blue = excellent). Proportion is based on the number of sites in each category (2013–2015 average score) at a given site.

Regionally, B-IBI declined with increasing urban cover (Figure 4). In contrast, within the study area, there was no effect of urban cover on B-IBI score ( $F_{1,26} = 1.83$ ,  $P = 0.188$ ). Similarly, B-IBI score did not differ across the three categories of urban cover ( $F_{2,35.3} = 1.74$ ,  $P = 0.190$ ; Figure 5).



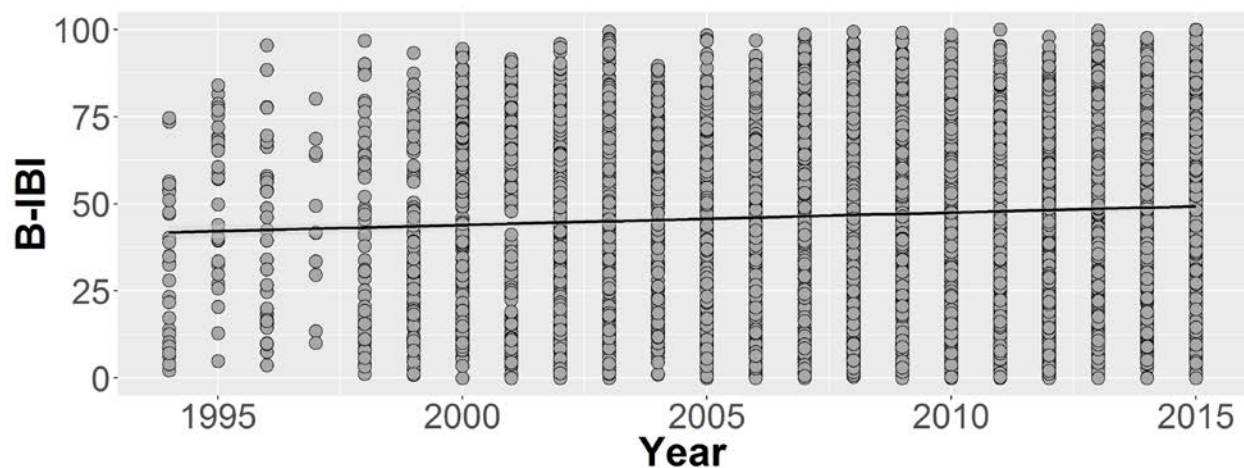
**Figure 4.** Mean B-IBI (2005–2015 [ $\pm 1$  SE]) in relation to proportion urban cover. B-IBI values were scaled by 100. A generalized linear model with a binomial error family was used to characterize B-IBI response to urban cover. Study area sites are indicated by red triangles, regional sites (across the Puget Sound Lowland ecoregion) are indicated by grey circles. Annual patterns are shown in Appendix C.



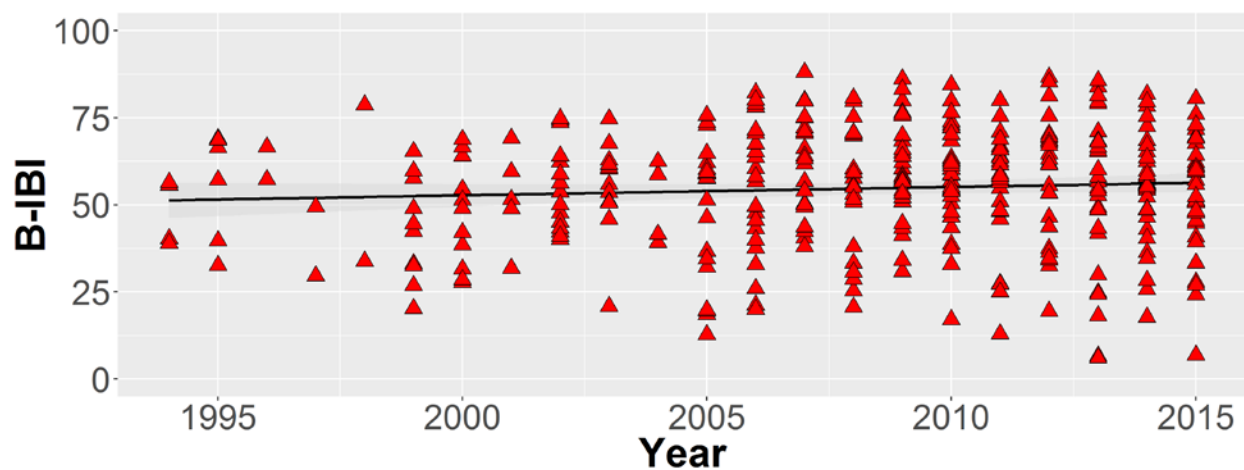
**Figure 5.** Mean B-IBI scores over time (2013–2015). Scores are grouped by each of three different levels of urban cover (low, medium, high).

### 3.1.2 Temporal Trends

Across the regional PSSB data set, B-IBI increased at the rate of about  $\frac{1}{2}$  point per year (Estimate = 0.53,  $F_{1, 5398} = 159$ ,  $P < 0.001$ ; Figure 6). In contrast, there was no detectable trend in scores within the study area (Estimate = 0.21  $F_{1, 362} = 1.94$ ,  $P = 0.165$ ; Figure 7).

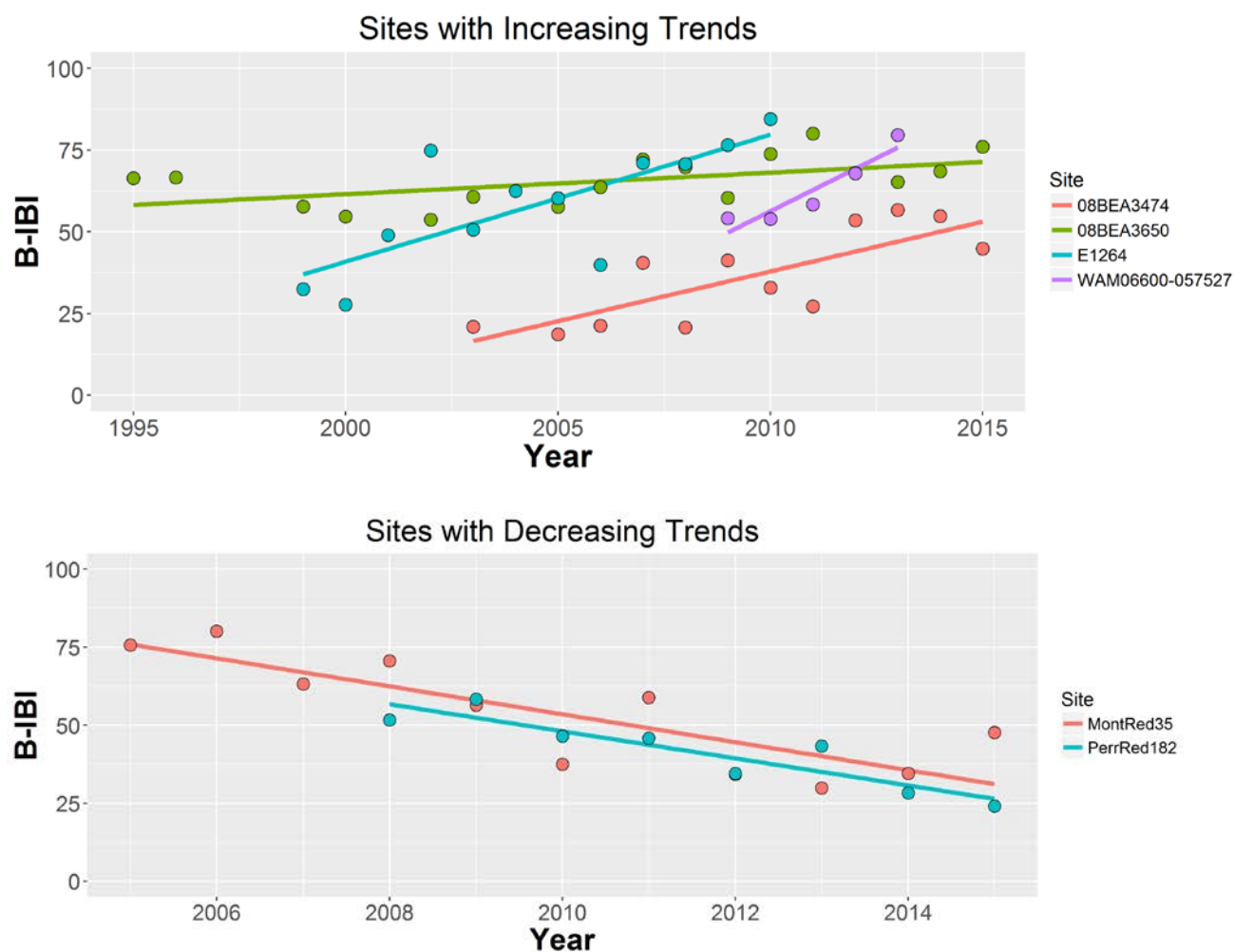


**Figure 6.** Regional B-IBI scores over time. Across available data, scores have increased at approximately  $\frac{1}{2}$  point per year over the past 22 years.



**Figure 7.** Study area B-IBI scores over time.

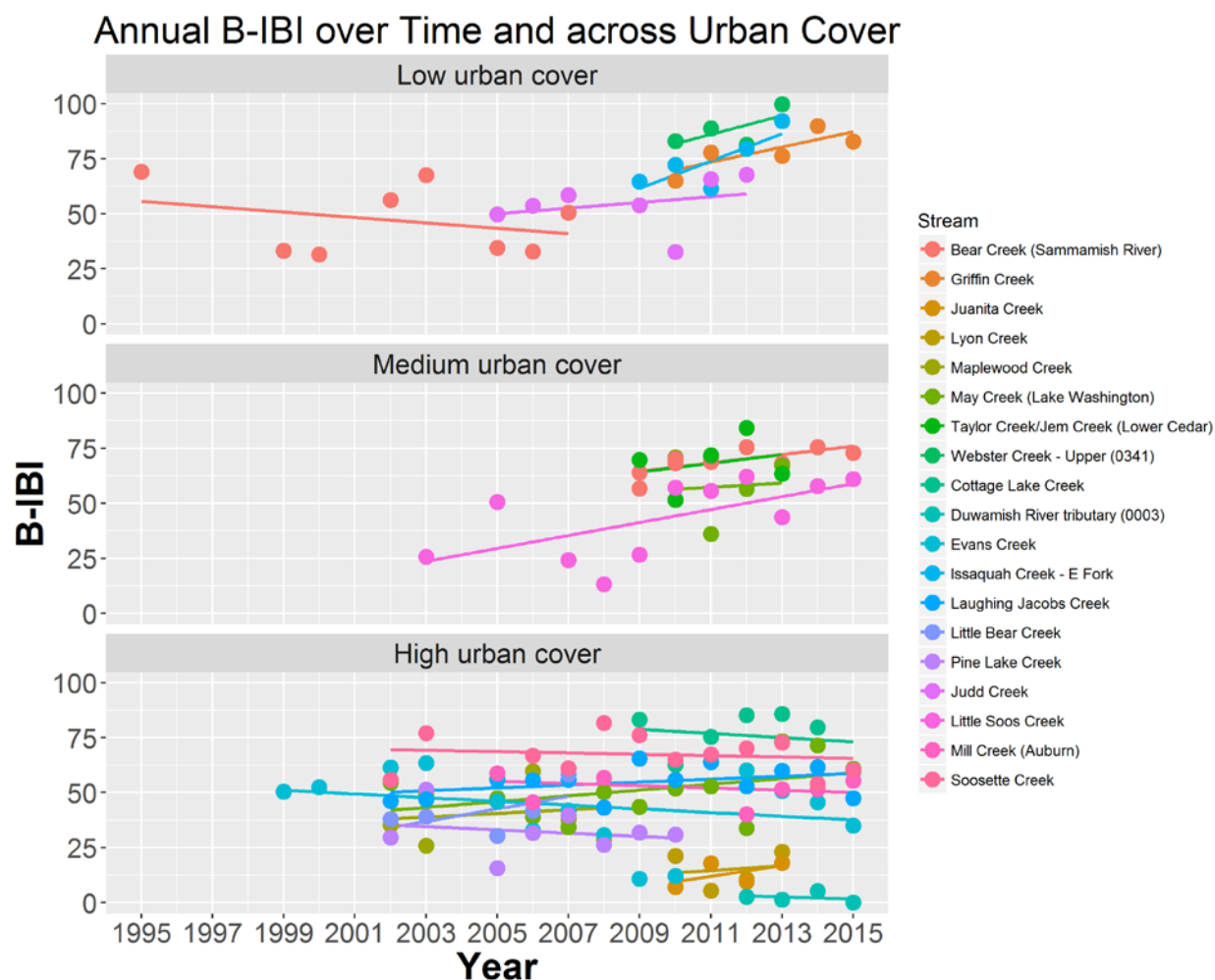
Within the study area, there was an interaction between site and time ( $F_{1, 47} = 2.53$ ,  $P < 0.001$ ). This interaction accounted for 73 % of variation in B-IBI. Thus, for some sites, B-IBI increased over time while at other sites, B-IBI decreased (Figure 8).



**Figure 8.** Sites where B-IBI scores have significantly increased (top panel) or decreased over time (bottom panel). Regression lines from linear models are shown for each site.

Plotting these trends across differences in land cover shows that the majority of sites with positive slopes in B-IBI scores occur in areas with low and medium urban cover (Figure 9). In contrast, the majority of sites located in areas of high urban cover have B-IBI scores with relatively flat or negative slopes over time.

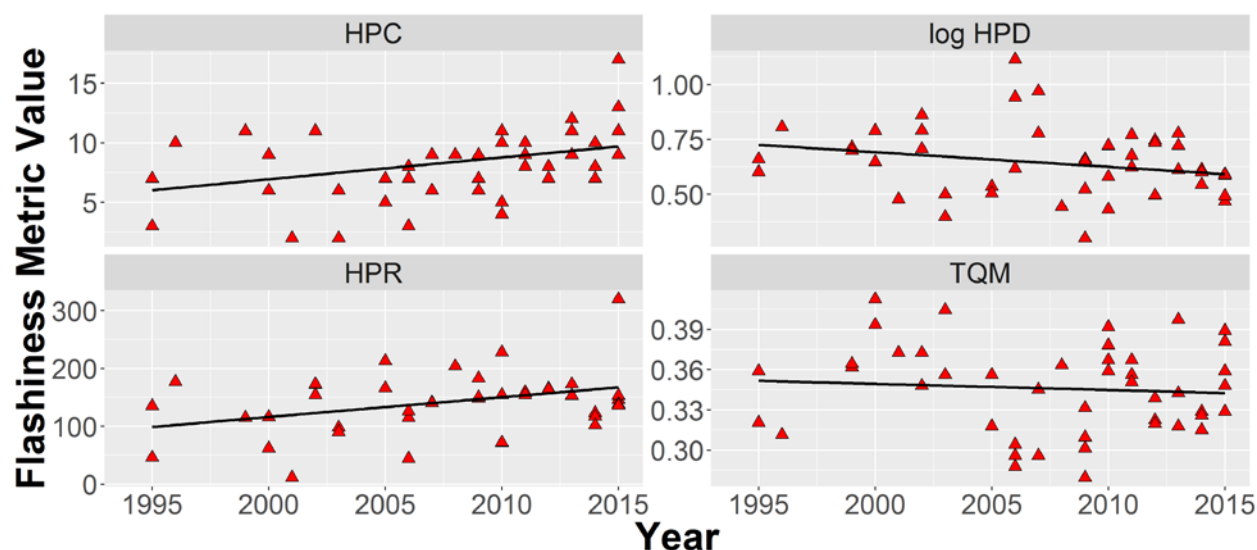




**Figure 9. Mean B-IBI scores across a gradient of urban cover over time (1991-2015) for each of three classes of urban cover: low (< 15%), medium (15–30%), and high (> 30%).**

## 3.2 Hydrology

Flashiness has generally increased over time in the study area (Figure 10). Specifically, from 1995–2015, HPC increased at an average rate of 0.2 counts per year ( $F_{1, 48} = 6.43$ ,  $P = 0.015$ ), while HPR increased by about three days per year ( $F_{1, 48} = 7.01$ ,  $P = 0.011$ ). Over that same period of time, there is marginal evidence that duration of high pulse events decreased by approximately one day per year ( $F_{1, 48} = 3.31$ ,  $P = 0.075$ ). There was no trend in TQM during that time ( $F_{1, 48} = 0.323$ ,  $P = 0.569$ ).



**Figure 10. Flashiness metrics over time in the study area.**

In the context of the PCA, 88% of the variation in hydrological flashiness is represented by the first two principal components (Table 3). High pulse count and HPR load strongly and positively on principal component 1 (PC1), whereas log HPD loads strongly negatively (Table 4). Thus, increasing values of PC1 represent increasing pulse counts and pulse ranges, but decreasing durations of those pulses. For PC2, only HPD and HPR load strongly, both in the negative direction (Table 4). Thus, increasing values of PC2 represent decreasing duration and range of pulses. In other words, high PC2 values represent streams characterized by short duration of pulse events that occur over a relatively small proportion of the water year.

**Table 3. Relative importance of principal components. PCA was conducted on all study area sites with paired B-IBI and hydrological data from 2010–2015.**

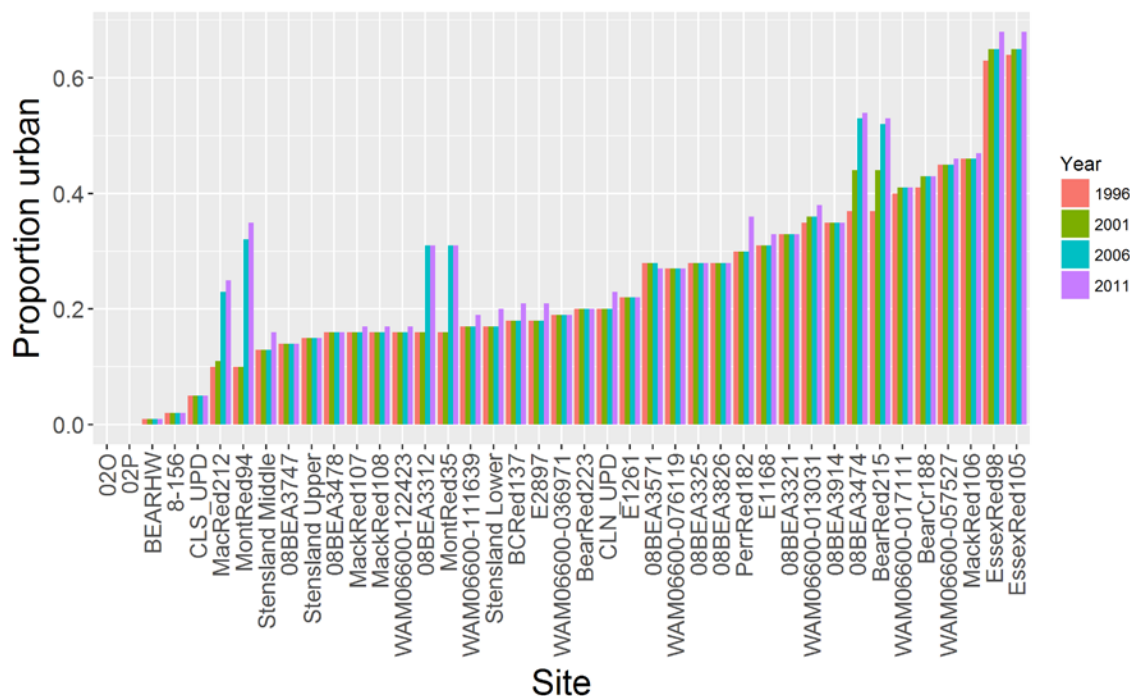
Variable	PC1	PC2	PC3	PC4
Standard deviation	0.544	0.361	0.193	0.148
Proportion of variance	0.611	.0268	0.076	0.045
Cumulative proportion	0.611	0.879	0.955	1

**Table 4. Loadings from PCA of hydrologic indices of flashiness. The square of the loading value (not shown) indicates the proportion of each variable's variance accounted for by the component.**

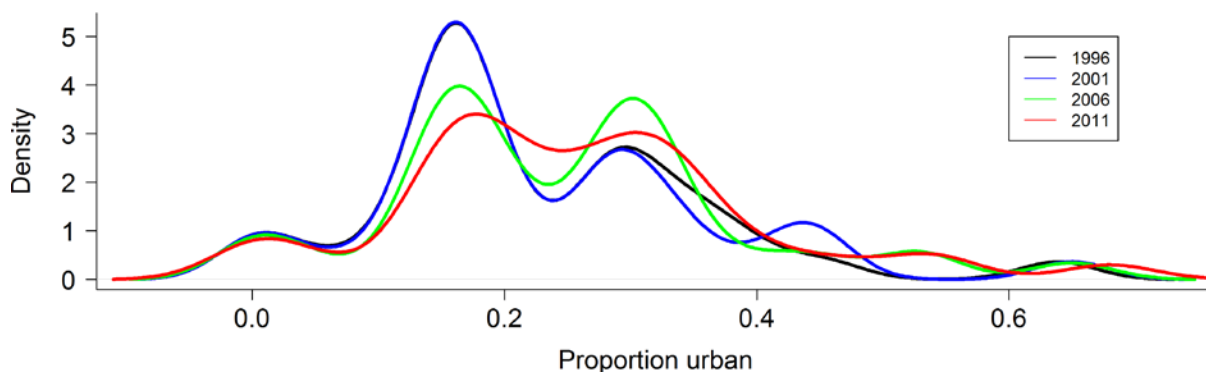
Variable	PC1	PC2	PC3	PC4
High pulse count	0.654	-0.131	-0.698	-0.258
High pulse duration	-0.511	-0.800	-0.310	-0.048
High pulse range	0.539	-0.581	0.609	0.013
TQ mean	0.142	0.067	0.211	-0.965

### 3.3 Land Cover at B-IBI Sites

The proportion of urban cover varied across B-IBI sites ( $F_{40, 120} = 89.7$ ,  $P < 0.001$ ) with an average value of 25% ( $\pm 1\%$  SE). Urban cover ranged from 0–68% (Figure 10). The proportion of urban cover at B-IBI sites increased from 1996 to 2011 ( $F_{1, 122.3} = 30.6$ ,  $P < 0.001$ ). During this time, urban cover increased by 0.3 % per year on average. This is evident in the shifting distribution of urban cover shown in Figure 11.



**Figure 11.** Proportion urban land cover at each site in the study area over time. Urban cover comprises the proportion of land within a 1 km buffer within the watershed that is classified as urban. Values are shown for each of four years (1996, 2001, 2006, 2011).

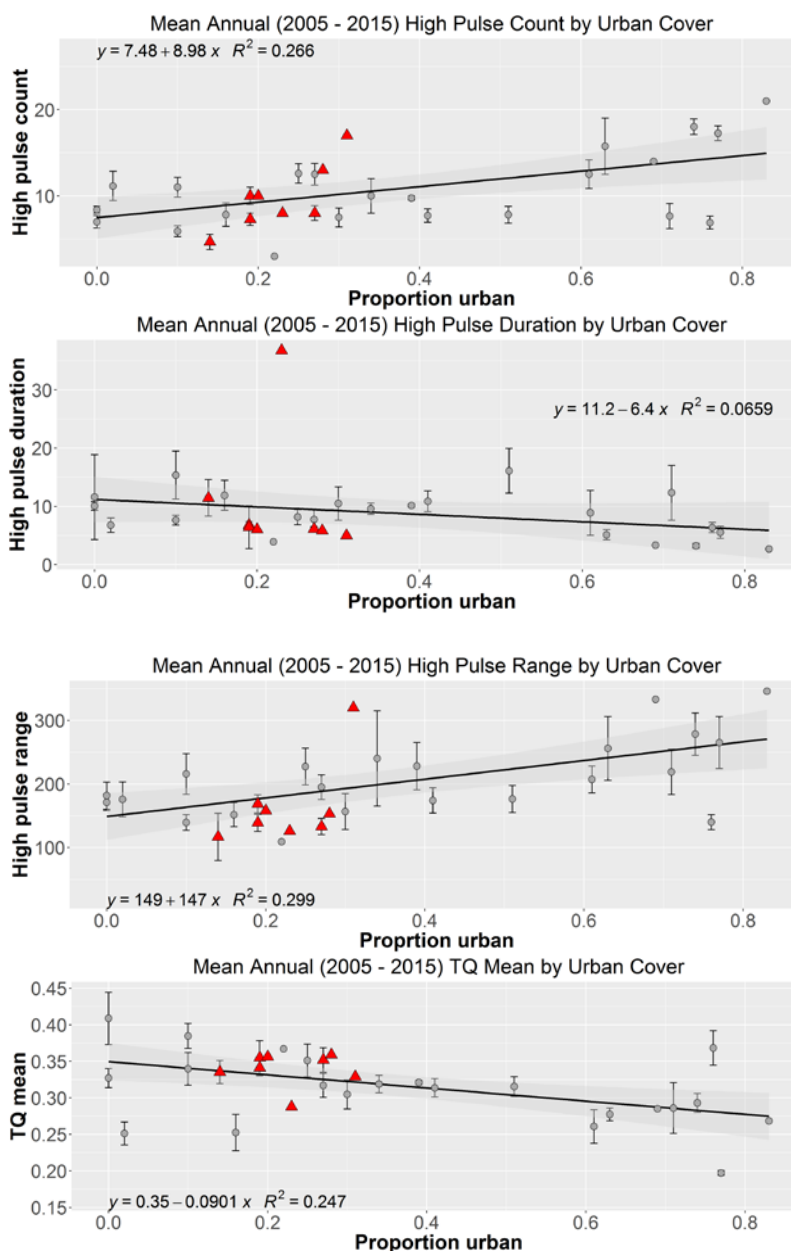


**Figure 12.** Distribution of urban land cover at B-IBI sites in the study area. Urban cover comprises the proportion of land within a 1 km buffer within the watershed that is classified as urban. The distribution is shown as kernel density estimated for each of four years (1996, 2001, 2006, 2011).

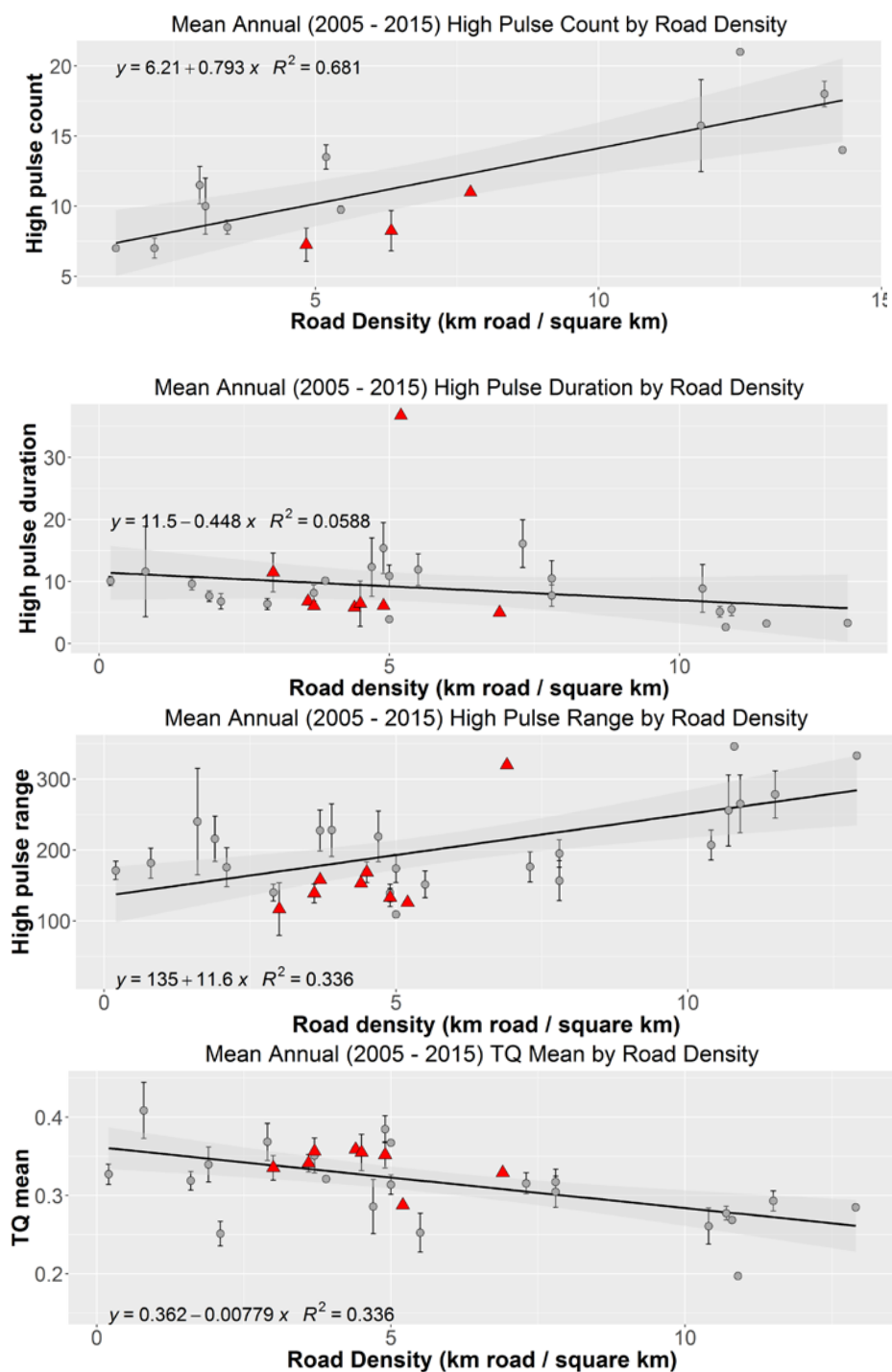


### 3.4 Influence of Land Use on Hydrology

Each of the four metrics of flashiness were assessed separately in relation to the proportion of urban cover and road density at nearby B-IBI sites (Figures 13-14). Fitted coefficients and  $R^2$  values from corresponding linear regressions are provided as text in the figure panels.



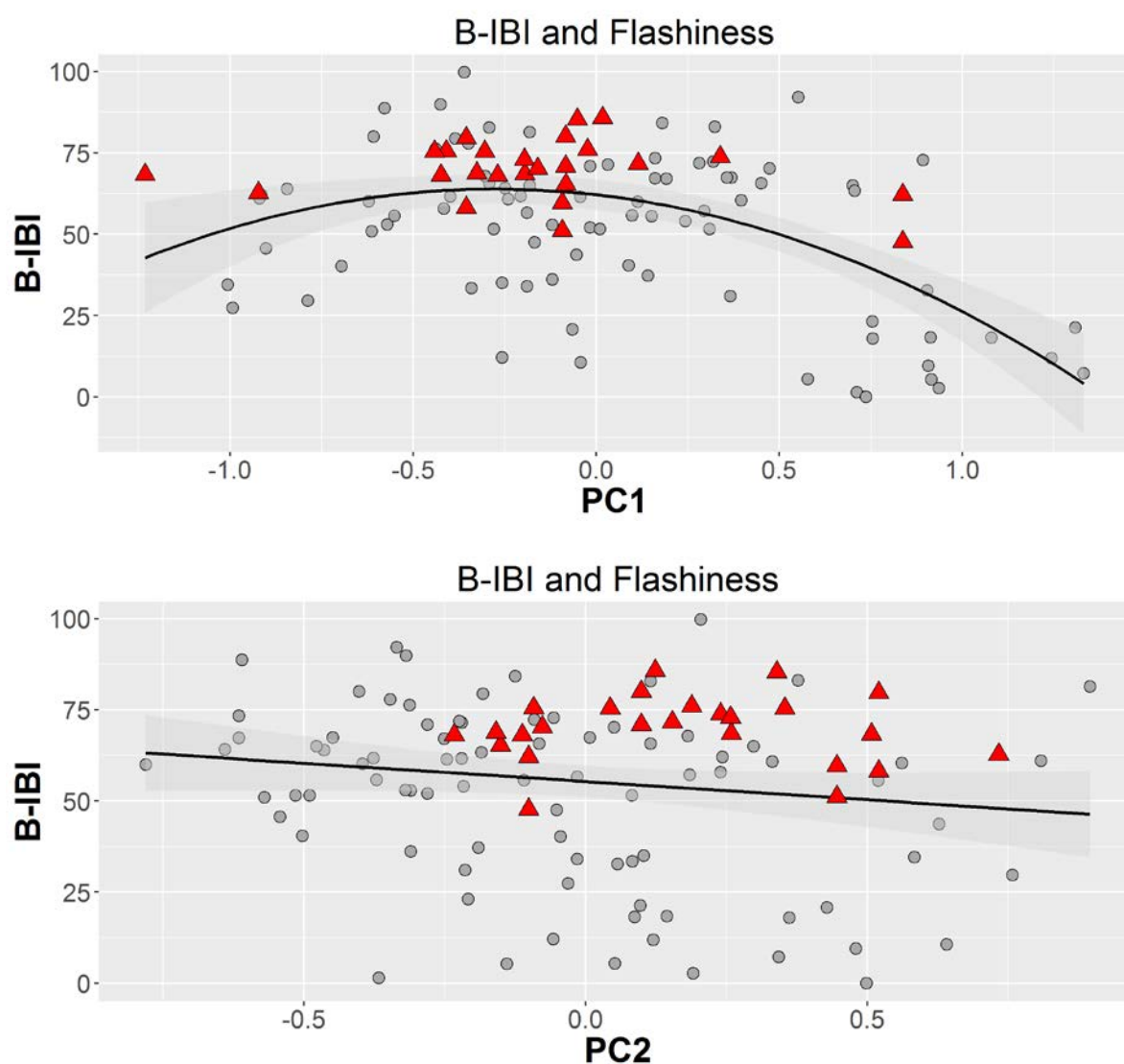
**Figure 13.** Mean ( $\pm 1$  SE) flashiness metrics (2005-2015) in relation to proportion of the landscape that is urban. Study area sites are indicated by red triangles; regional sites outside of the study area are indicated by grey circles. A linear regression is shown for each flashiness metric, with parameter estimates printed on each panel. Annual regressions are shown in Appendix D.



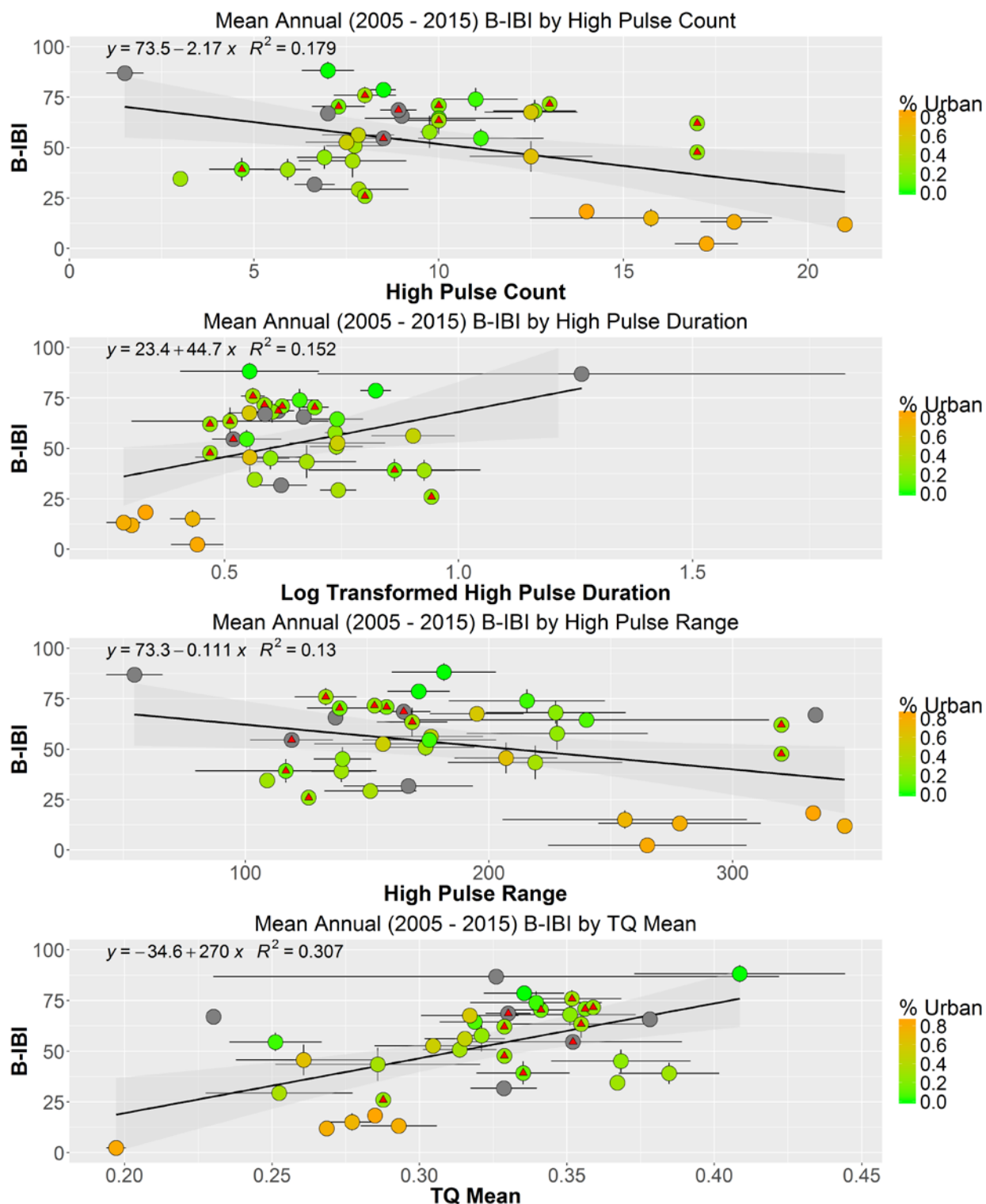
**Figure 14.** Mean ( $\pm 1$  SE) flashiness metrics (2005-2015) in relation to road density. Study area sites are indicated by red triangles; regional sites outside of the study area are indicated by grey circles. A linear regression is shown for each year, with parameter estimates printed on each panel. Annual regressions are shown in Appendix D.

### 3.5 Relationship between Hydrology and B-IBI

Increases in flashiness generally had a negative influence on B-IBI scores (Figures 15–16). However, in the context of PCA, the best fit model suggests that moderate levels of flashiness support the highest B-IBI scores, with more rapid declines in B-IBI scores occurring thereafter (Figure 15). When each metric is considered separately, the strength of the relationship between flashiness and B-IBI varies (Figure 16). Specifically, for the four different metrics,  $R^2$  values range from 0.13–0.31 (Figure 16). Notably, these relationships are characterized by high inter-annual variability (Appendix E). When viewed at the stream level, there are no consistently strong effects of flashiness on B-IBI (Figures 17–20). Rather, within any given stream, B-IBI scores show little variability with respect to flashiness. This stream effect on B-IBI is consistent across different levels of urban cover (Figures 17–20).



**Figure 15.** B-IBI in relation to principle components. All available data from paired gauges and B-IBI sites from 2010–2015 are shown. Study area sites indicated by red triangles; regional sites outside of the study area are indicated by grey circles.



**Figure 16.** Mean annual B-IBI (2005-2015) in relation to flashiness metrics. Sites are color coded according to proportion of urban cover. Study area sites are indicated by red triangles; points without red triangles represent regional sites. Sites lacking data on urban cover area indicated by grey circles. A linear regression is shown for each year, with parameter estimates printed on each panel. Annual regressions are shown in Appendix F.

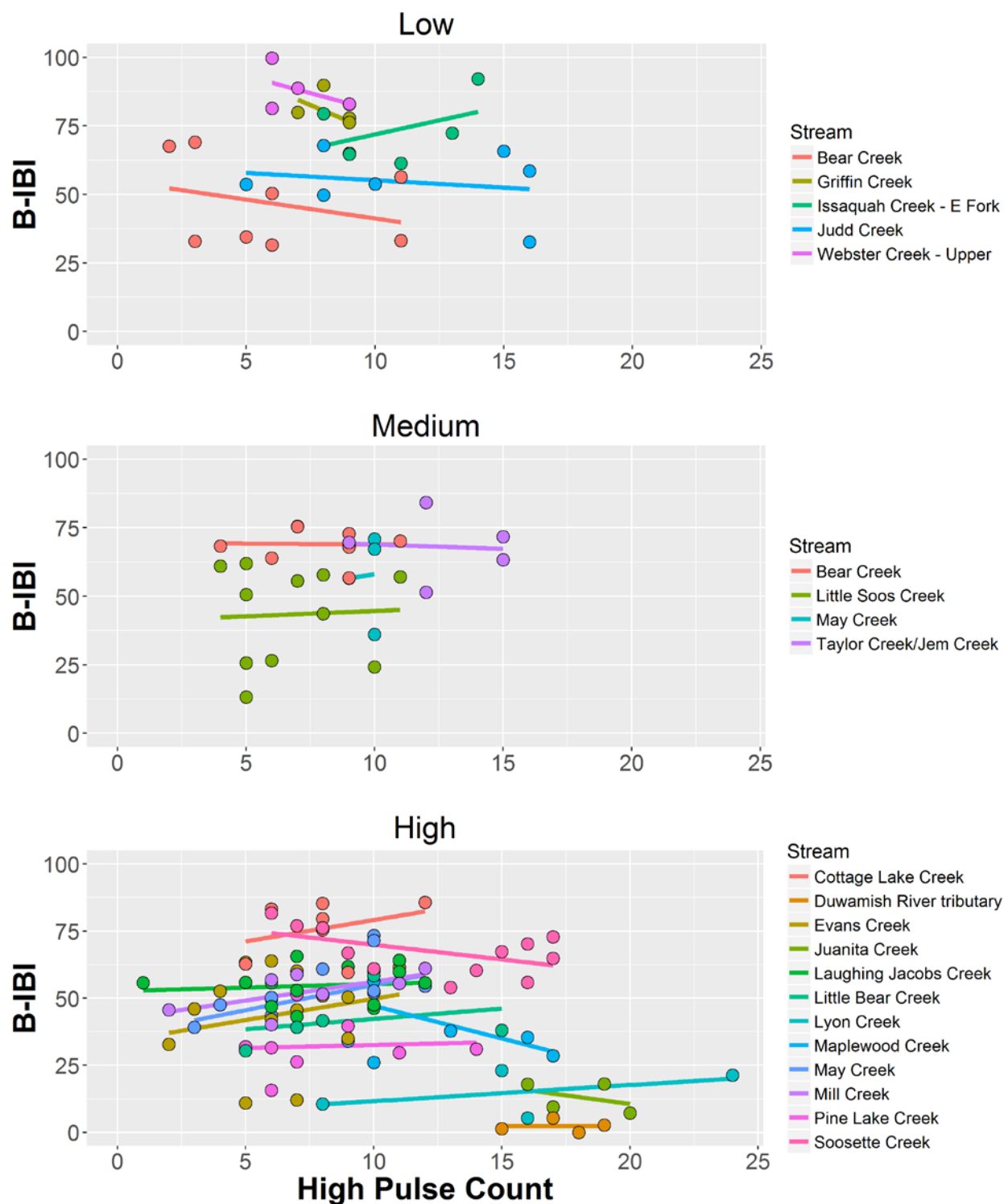


Figure 17. B-IBI in relation to high pulse count and across different levels of urban cover. Paired gauge and B-IBI site data are shown for all streams containing at least four years of paired data.

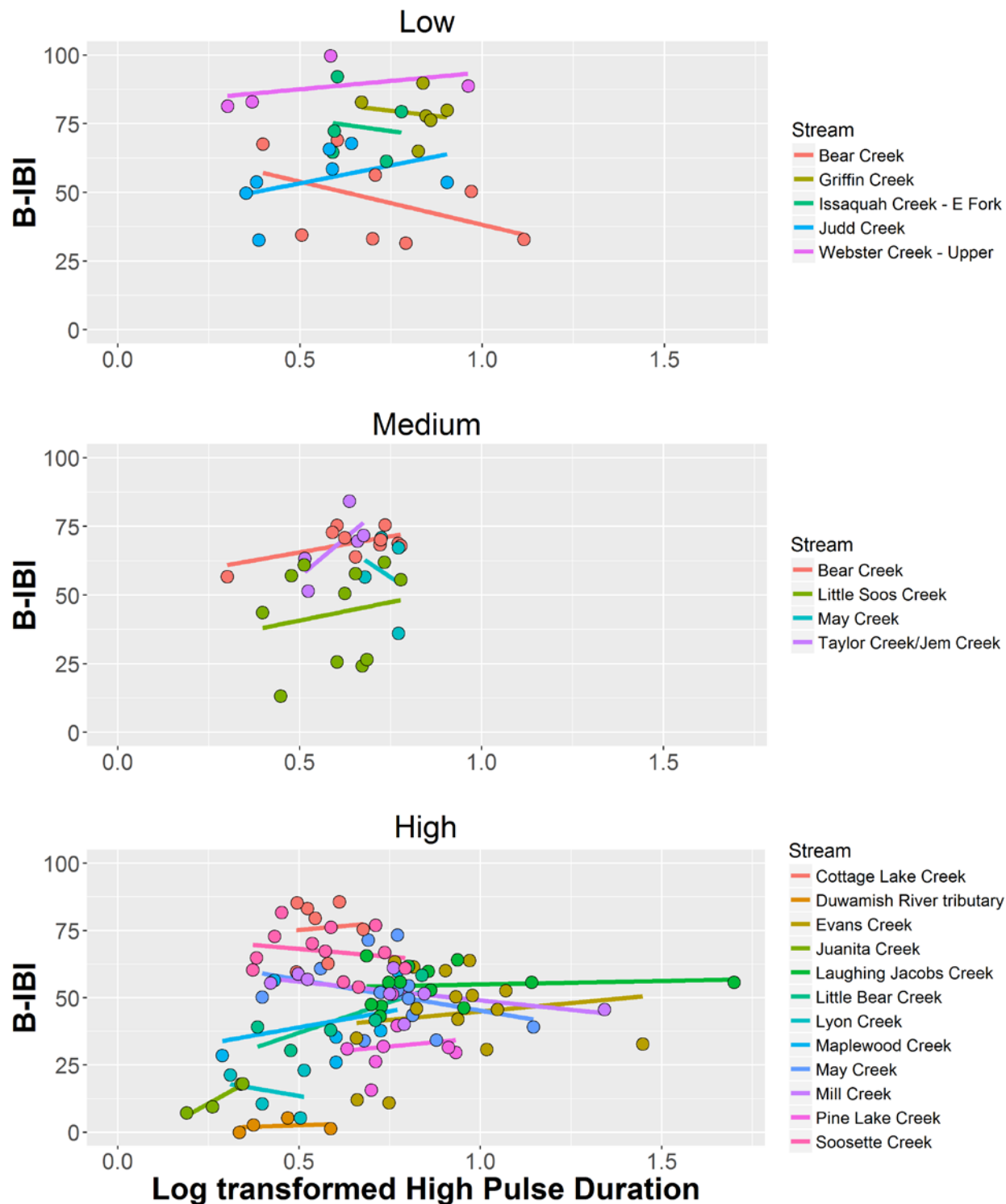
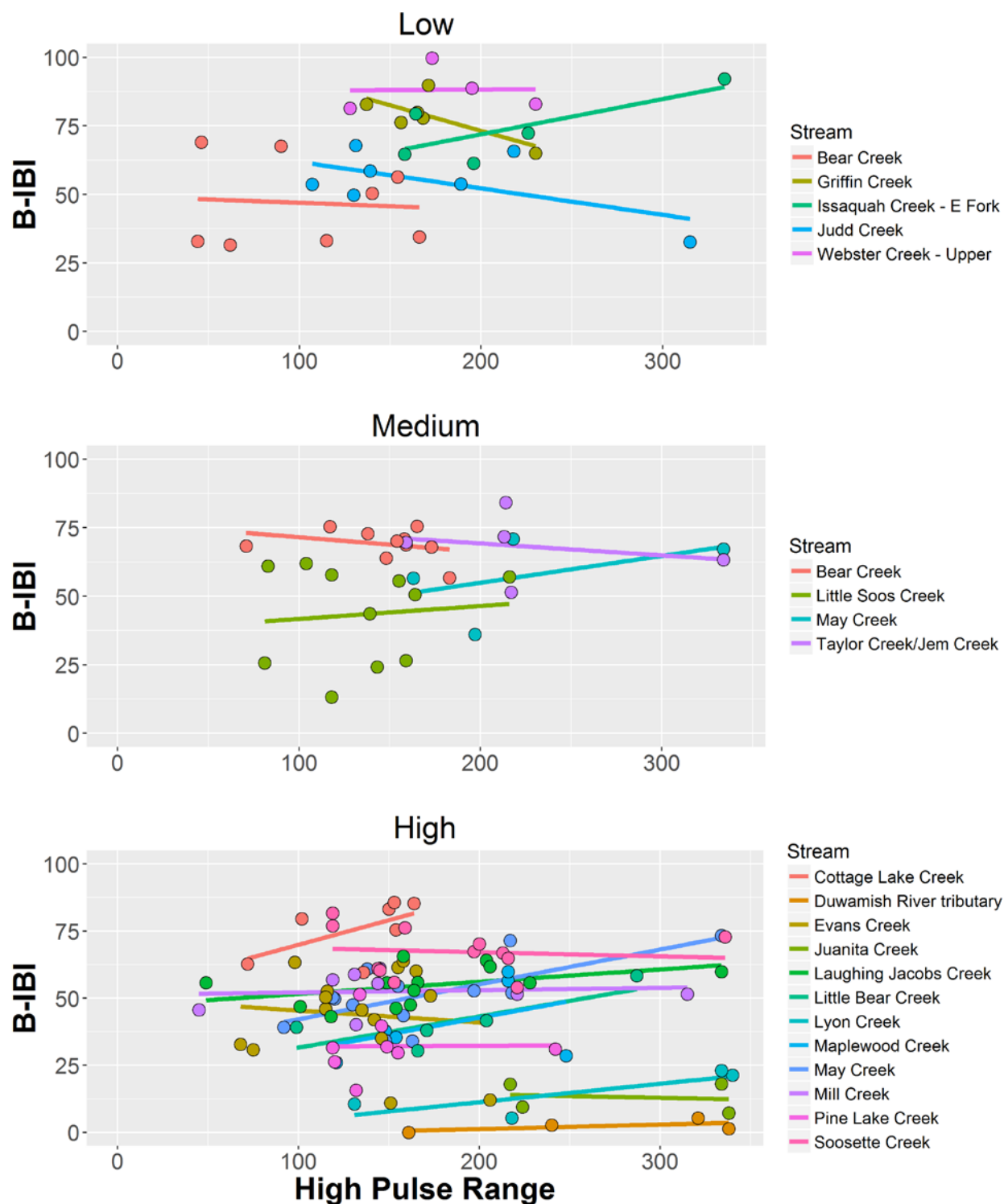
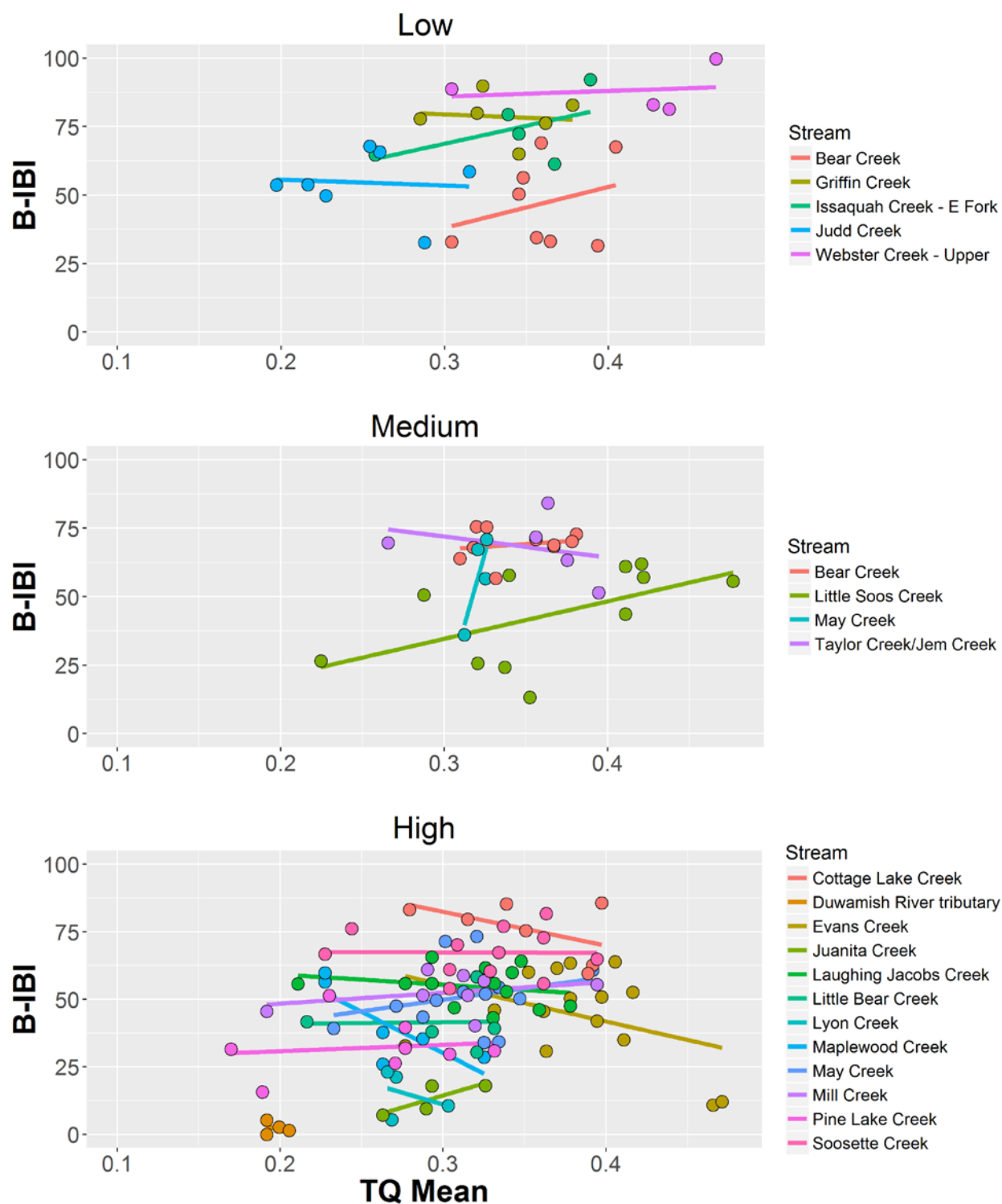


Figure 18. B-IBI in relation to high pulse duration and across different levels of urban cover. Paired gauge and B-IBI site data are shown for all streams containing at least four years of paired data.



**Figure 19.** B-IBI in relation to high pulse range and across different levels of urban cover. Paired gauge and B-IBI site data are shown for all streams containing at least four years of paired data.





**Figure 20. B-IBI in relation to TQ mean and across different levels of urban cover. Paired gauge and B-IBI site data are shown for all streams containing at least four years of paired data.**



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## 4.0 DISCUSSION

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An average B-IBI score across the study area of 53.0 (or “fair”) suggests that streams in the study area are impacted by urbanization. In general, the highest B-IBI scores—and therefore the most intact communities of stream benthos—occur in less developed landscape contexts (Karr 1996; Morley 2000). Indeed, the use of B-IBI as an indicator was developed on the basis of this very pattern, wherein macroinvertebrate diversity is observed to degrade along an urbanization gradient (Karr 1996). That is, B-IBI tends to be higher in streams where the surrounding landscape is characterized by large swaths of intact forest compared to sites characterized by urban cover.

In contrast to this well-established pattern, within the study area, no differences in B-IBI were detected across different intensities of urban cover (Figure 10). Thus within the study area, scores in more urban sites were on average no different than scores in less urban sites. This similarity of scores could be due in part to the definitions used to classify urban cover at sites as low, medium, and high. However, even when B-IBI was analyzed across a continuous predictor of urban cover, no effect of urbanization was found within the study area (Figure 4; Appendix C).

This homogeneous response to urban cover may reflect the limited number of sites within the study area containing more than 50% urban cover. As a result, there may be insufficient power to detect a negative trend within the study area. Similarly, five of the sites in the low urban category had substantially lower scores than predicted by the regional pattern (see points in Figure 4 corresponding to sites with < 10% urban cover). Inspection of aerial imagery indicates that four of these five sites (BearHW, 8-156, 02p, and 02o) are adjacent to large wetlands, which may explain their low scores. Similarly, the fifth site (CLS\_UPD)—while surrounded predominantly by forest within a 90m buffer—is situated in a heavily urbanized context within a buffer of several hundred meters, which may be a cause of the observed score. Therefore, these five sites may not be representative of typical low urban sites in the region.

The relative similarity of scores across urban intensities may also reflect the scale at which urbanization impacts macroinvertebrates relative to the scale of urbanization in the study area. That is, urbanization occurring in patches throughout the watershed could negatively affect B-IBI scores in nearby streams, even if those nearby streams are situated in more forested contexts. Indeed, the average proportion of urban cover at B-IBI study sites was 25%. Based on the PSSB dataset, 25% urban cover predicts a B-IBI score of 50 (Figure 4). In other words, the average B-IBI score in the study area is about what is expected from regional trends.

More generally, the average grade of “fair” in the study area may reflect the history of logging in the Puget Sound Lowlands region. The extensive harvest of forest habitat undoubtedly reduced stream benthos diversity and abundance on a regional scale, for example through the loss of terrestrial habitat utilized by adult life history stages for food and dispersal, the loss of instream habitat associated with woody debris inputs, and

negative impacts on hydrological conditions. With this presumptive loss of benthic species following the history of logging, it is reasonable to speculate that the regional species pool was depleted compared to species pools in areas that had never been logged. A somewhat obvious but perhaps underappreciated point is that B-IBI scores in a stream will be low if diversity in the region is low. This point bears a critical insight for guiding restoration approaches and expectations. Specifically, improvements in local stream quality following restoration may not necessarily lead to restored biotic stream communities if sources of the species comprising those communities are not regionally available to colonize restored sites. Connectivity among streams and across intervening landscapes will likely also influence the capacity to restore stream benthic communities.

Streams characterized by high flashiness tended to have lower B-IBI scores (Figures 14–15). However, a relatively low to moderate level of flashiness appears to support the highest B-IBI scores (Figure 14). Moreover, the relationship between individual flashiness metrics and B-IBI scores is characterized by substantial uncertainty. That is, there remains considerable unexplained variation in B-IBI scores in the context of stream flashiness (Figure 16). For example, average  $R^2$  values for the relationship between B-IBI and flashiness metrics range from 0.15–0.31. Thus, flashiness metrics explain 15 to 31% of the variation in these datasets, with TQ Mean providing the strongest relationship.

Within the study area, these relationships appear to differ from the regional dataset. For example, HPC appears to have no effect on B-IBI, whereas HPD appears to have a negative effect (opposite of that reported at the regional level). These patterns may in part be due to the small sample size for paired “gauge-B-IBI” sites available in the study area. Alternatively, these patterns may be reflective of conditions in the study area that differ from those at the regional level.

A substantial portion of variation in B-IBI is explained simply by the stream rather than any of the conditions of that stream. That is, individual stream B-IBI scores differ substantially from one another. Specifically, among all variables considered, stream identity is the best predictor of B-IBI score (explaining nearly 80% of the variation). Yet when we look within a stream, there is little evidence of consistent or strong effects of abiotic factors such as land use (Figures 17–20) or hydrology (Figures E6–E9).

In part, these patterns are resolved by differences in urban land cover (Figure 9). Specifically, on average, B-IBI over time increased in some of the low and medium urban sites, but generally decreased or remained unchanged in high urban sites. Notably however, even when this effect is accounted for, there is still substantial variation between sites, particularly at high urban sites. That is, sites located in high urban areas vary dramatically in their range of scores whereas within a site, scores do not change considerably over time.

## 5.0 CONCLUSIONS

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Most of the variation in B-IBI scores was observed to occur as a function of stream identity. While urban cover explained regional B-IBI variation, it did not explain B-IBI variation within the study area. The hydrological flashiness metrics explained some variation in B-IBI, but these effects were neither particularly strong on average, nor consistent from year to year. However, given that generally, low to intermediate levels of flashiness support the most diverse benthic stream communities, measures to limit extreme flashiness in the study area represents an important component to supporting the types of habitat conditions that support healthy streams.

A perhaps underappreciated component of stream health concerns our understanding of connectivity and fragmentation. In terrestrial contexts, the lessons of fragmentation are abundantly clear. For example, clear cut harvesting is known to induce a suite of consequences: habitat is lost, biodiversity is degraded, biotic communities shift toward more generalist species, and invasive species more easily make inroads into core habitat. However, in the context of streams, our understanding of adjacency effects (i.e., from urbanization of nearby landscapes) has tended to focus almost exclusively on the consequences within the stream including changes in flow regime, introduction of contaminants from runoff, and sedimentation. While each of these consequences clearly impacts stream health, it is unclear to what extent reversing these conditions will support increased diversity in the future, and the potential lag time that may be required before any biological changes are noticeable. Thus, careful consideration should be given to the measures of success and the period of time over which they are expected.

### 5.1 Caveats and Future Directions

While B-IBI can serve as a useful indicator of stream health, it is not necessarily well suited to identify particular mechanisms of degradation. This is because B-IBI is an index based upon a pattern of urbanization. That is, B-IBI is by design a function of urban cover. Thus, insights obtained by regressing B-IBI scores against urban cover—or against variables such as stream flashiness that are correlated with urban cover—should be treated cautiously. Indeed, B-IBI was not designed with such a purpose in mind. Notably however, the raw macroinvertebrate data that comprise B-IBI scores do lend themselves to identifying environmental stressors (e.g., “stressor analysis”). Such stressor analyses may prove useful in future work to distinguish among potential mechanisms driving low B-IBI scores.

Relatedly, while B-IBI is a good indicator of the degradation of stream health, it may not be a good indicator of the effectiveness of the restoration of stream health, particularly over short time periods. For example, there may be a time lag between improvement in stream habitat conditions and subsequent colonization by macroinvertebrates. Future work should consider the ability of macroinvertebrates to colonize restored sites, for example both naturally in the context of stream connectivity, and through restoration techniques such as assisted migration, wherein macroinvertebrates are transplanted from high-

scoring to low-scoring B-IBI sites. Ideally, experiments testing the effectiveness of assisted migration would be performed in conjunction with B-IBI monitoring.

An additional constraint on the capacity of B-IBI to indicate restored stream health is the nature of the relationship between improved conditions and macroinvertebrate diversity. Specifically, this relationship may not be linear. For example, there may be a threshold of stream quality that is required for benthic populations to become established successfully in formerly degraded sites. In this case, B-IBI scores would not be expected to increase proportionally with improvements to stream conditions.

Because little variation in B-IBI scores was explained by any of the hydrological flashiness metrics, their use as predictors of future B-IBI should be conducted cautiously. For example, if modifying flashiness through stormwater remediation is intended to achieve specific B-IBI restoration targets, such targets should reflect the limited strength of these relationships. Moreover, in light of the variability between flashiness and B-IBI, changes in flashiness metrics alone are unlikely to cause scores to increase substantially. However, supporting levels of flashiness that approach those seen in less disturbed sites is certainly an important component in any effort to support urban stream health.

The data used in this report were opportunistic in the sense that they were not designed specifically for the analyses that were conducted. Future studies should collect B-IBI data and hydrology data in a more complementary manner. Ideally, B-IBI and hydrology data would be collected at the same site, with a sufficient number of sites distributed throughout a range of streams conditions and intensities of urban cover.

## 6.0 REFERENCES

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- Ecology and King County. 2011. Control of Toxic Chemicals in Puget Sound – Assessment of Selected Toxic Chemicals in the Puget Sound Basin. Washington State Department of Ecology, Olympia, WA and King County, Seattle, WA. Department of Natural Resources. Ecology Publication No 11-03-055.
- Fry, J., G. Xian, S. Jin, J.A. Dewitz, C.G. Homer, L. Yang, C.A. Barnes, N.D. Herold, and J.D. Wickham. 2011. Completion of the 2006 National Land Cover Database for the Conterminous United States, PE&RS, Vol. 77(9):858-864.
- Karr, J. 1996. Rivers as Sentinels: Using the biology of rivers to guide landscape management. Pp in R.J. Naiman and R.E. Bilby, eds. *The Ecology and Management of Streams and Rivers in the Pacific Northwest Coastal Ecoregion*. Springer-Verlag, New York.
- King County. 2015a. Scope of Work and Schedule for the Bear Creek Watershed–Scale Stormwater Plan. Prepared by King County, Water and Land Resources Division. Seattle, Washington.
- King County. 2015b. A Monitoring Quality Assurance Project Plan for Bear Creek Watershed-Scale Stormwater Plan. Prepared by Jeff Burkey, Eric Ferguson, Katherine Bourbonais, Water and Land Resources Division. Seattle, Washington.
- King County. 2015c. Strategies for Protecting and Restoring Puget Sound B-IBI Basins. Prepared by Jo Opdyke Wilhelm, Kate Macneale, Chris Gregersen, Chris Knutson, and Debra Bouchard. Water and Land Resources Division. Seattle, Washington.
- Morley, S. 2000. Effects of urbanization on the biological integrity of Puget Sound lowland streams: Restoration with a biological focus, Washington, USA. Thesis, University of Washington, Seattle, WA.
- [NOAA] National Oceanic and Atmospheric Administration Coastal Services Center. 2011. The Coastal Change Analysis Program (C-CAP) Regional Land Cover. NOAA Coastal Services Center, Charleston, South Carolina. Accessed at [www.csc.noaa.gov/digitalcoast/data/ccapregional](http://www.csc.noaa.gov/digitalcoast/data/ccapregional).
- Pinheiro, J.C. and D.M. Bates. 2000. Mixed-effects models in S and S-PLUS. Springer-Verlag New York. USA.

- R Core Team (2016). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL <https://www.R-project.org/>.
- Schueler, T.R. 1994. The Importance of Imperviousness. Watershed Protection Techniques. 1(3): 100-111

## Appendix A: Record of B-IBI scores in the Study Area

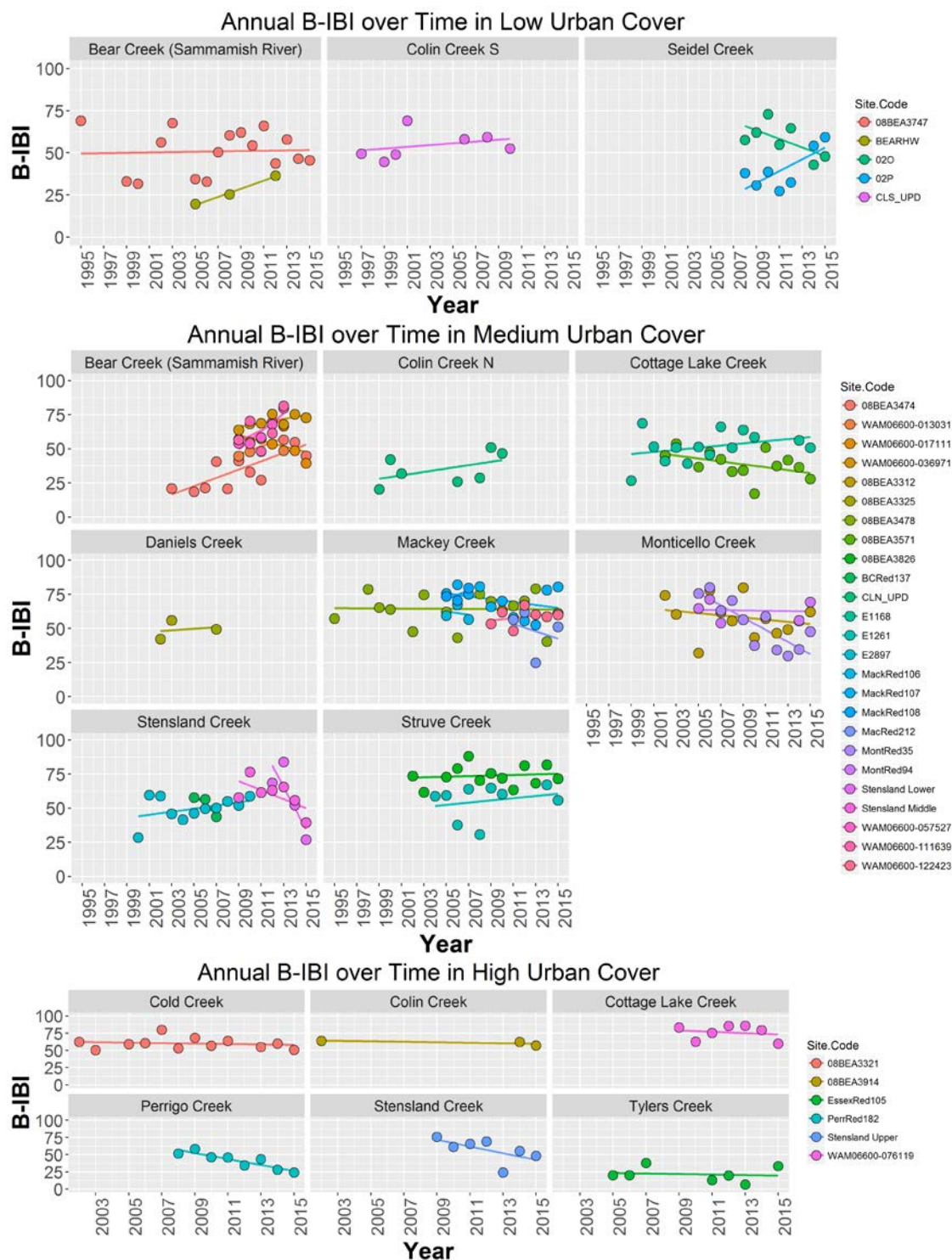


A-1 Period of record of B-IBI scores for sites within the study area. Shaded cells indicate years in which B-IBI scores are available for a given site.

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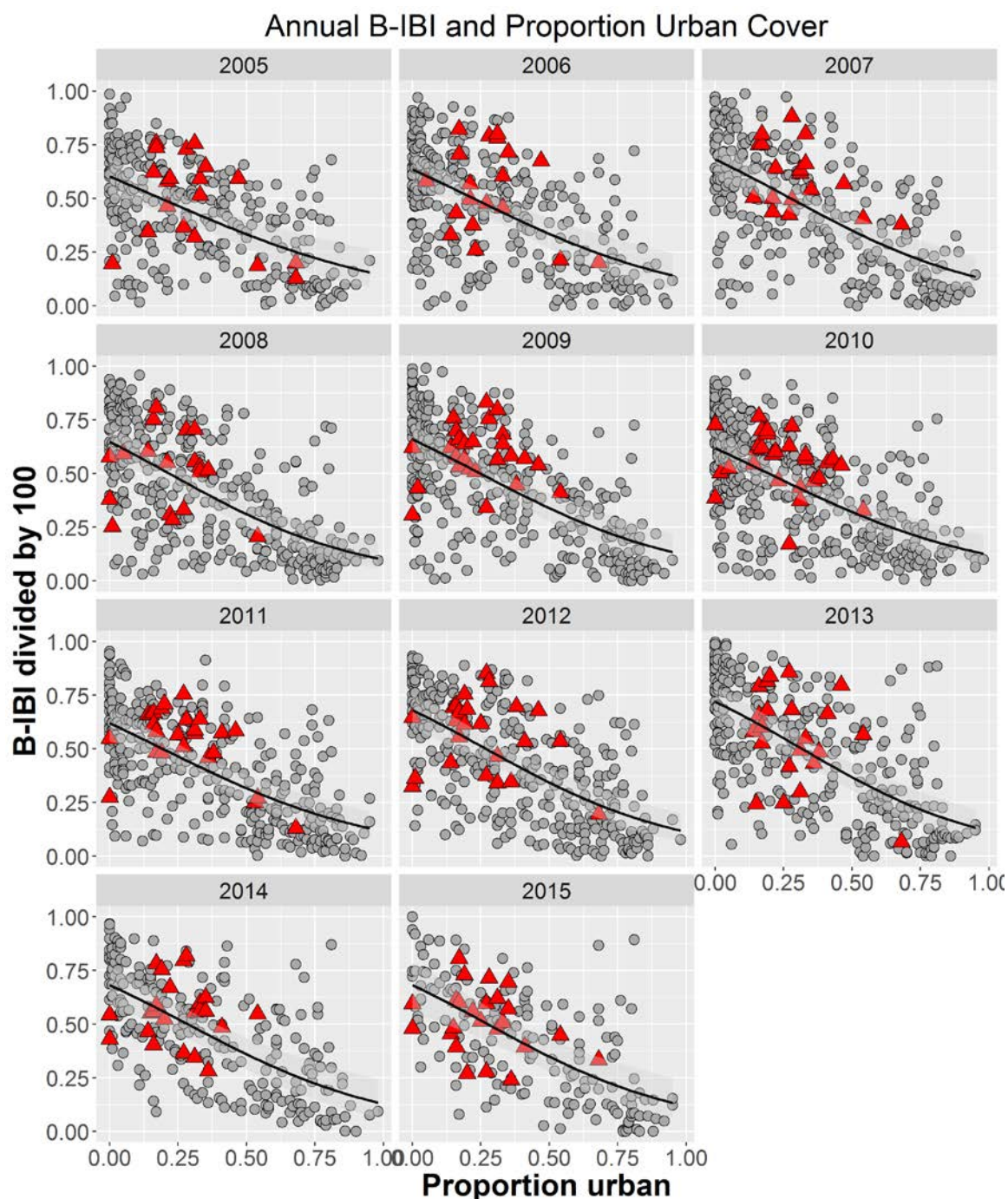
## Appendix B: Temporal B-IBI Trends



**B-1. Temporal trends in B-IBI at the site level and grouped by urban cover class (low, medium, high).**

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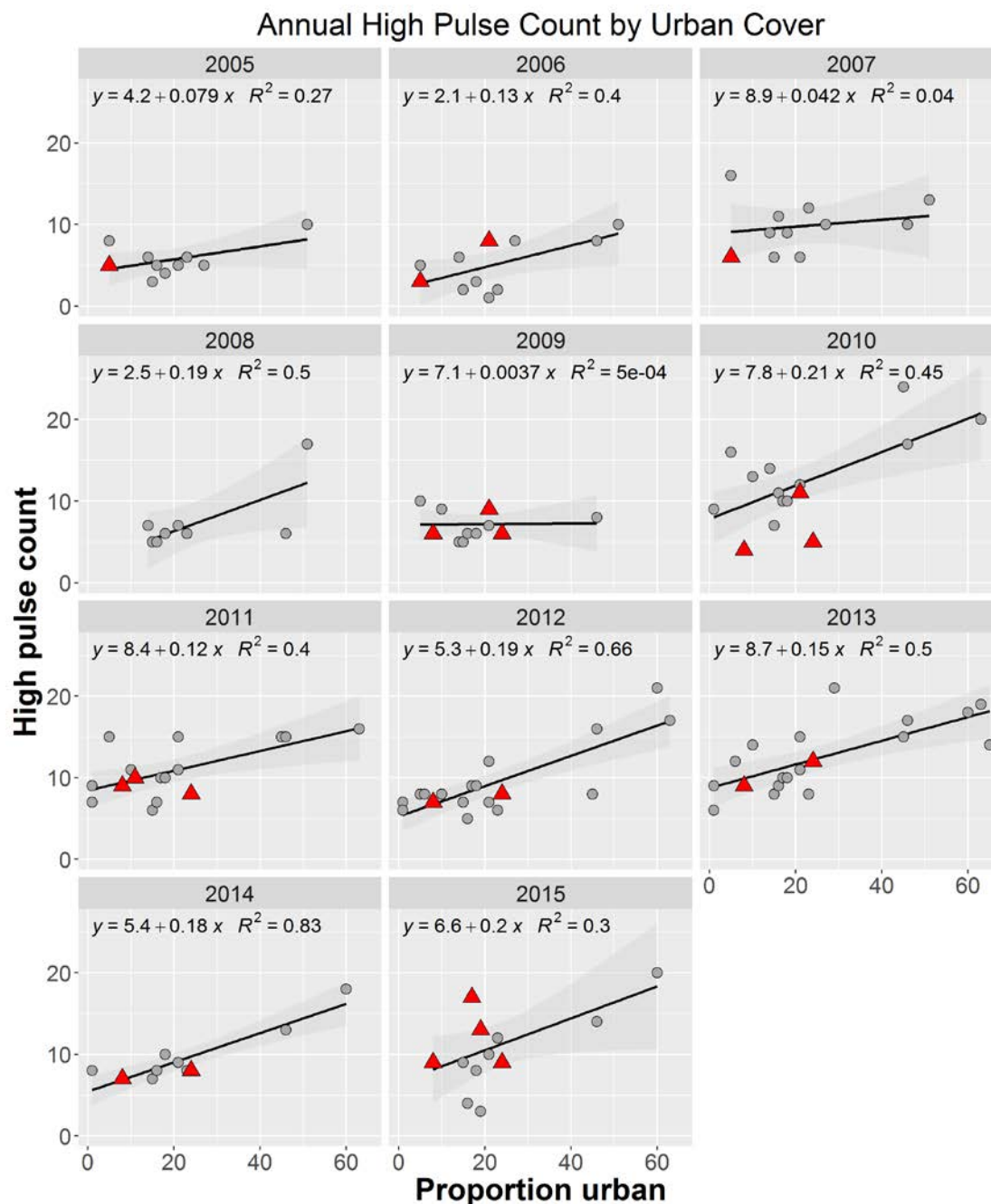
## Appendix C: B-IBI and Land Cover



**Figure A-1 Regional B-IBI in relation to proportion of the landscape that is urban (2005–2015).** Study area sites are indicated by red triangles; regional sites outside of the study area are indicated by grey circles. A generalized linear regression is shown for each year. The response averaged across years is shown in the body of the report in Figure 14.

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## Appendix D: Hydrological Metrics and Land Cover



**D-1 Regional HPC in relation to proportion of the landscape that is urban (2005-2015).** Study area sites are indicated by red triangles; regional sites outside of the study area are indicated by grey circles. A linear regression is shown for each year, with parameter estimates printed on the bottom of each panel. The average response is shown in the body of the report in Figure 15.



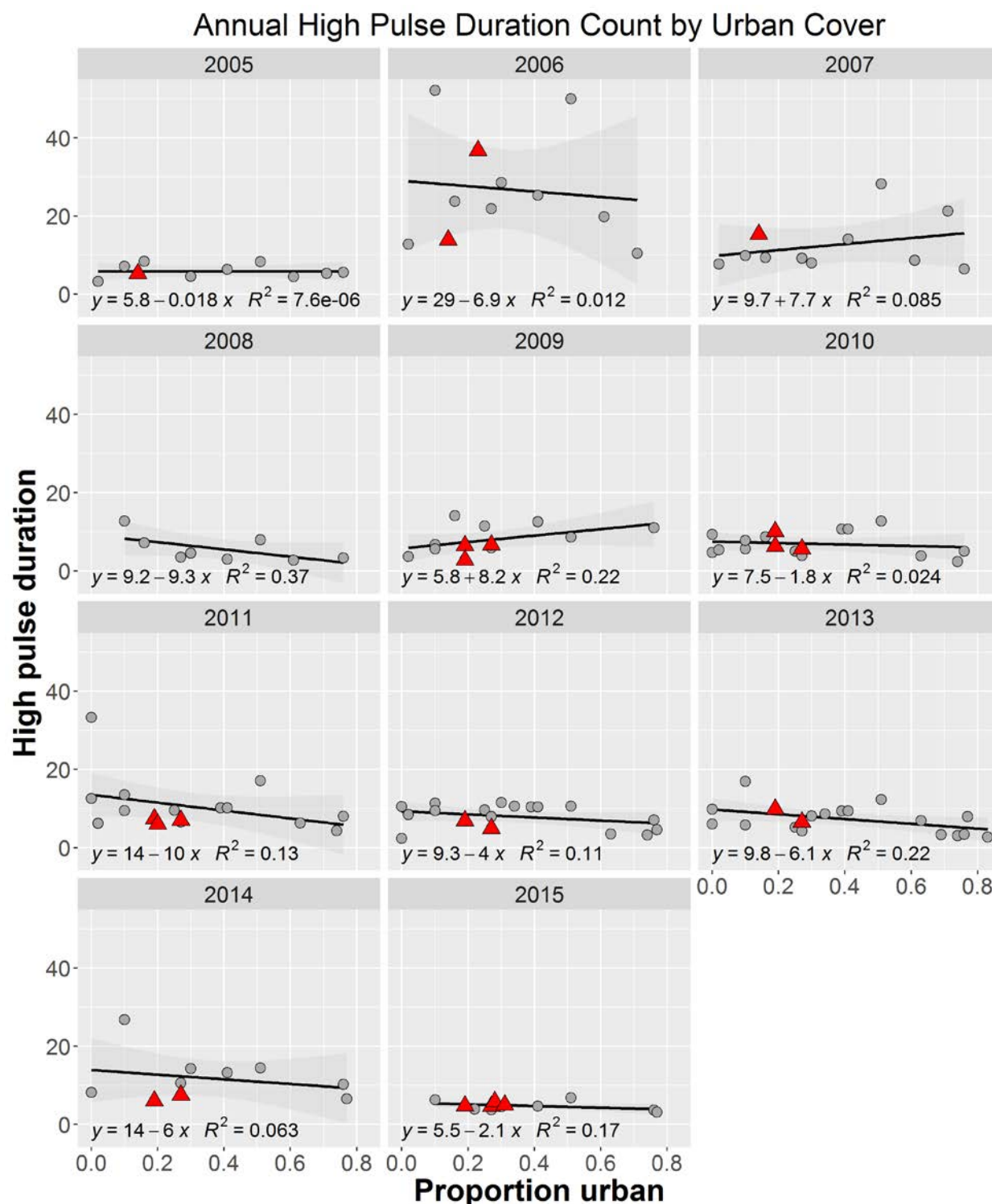
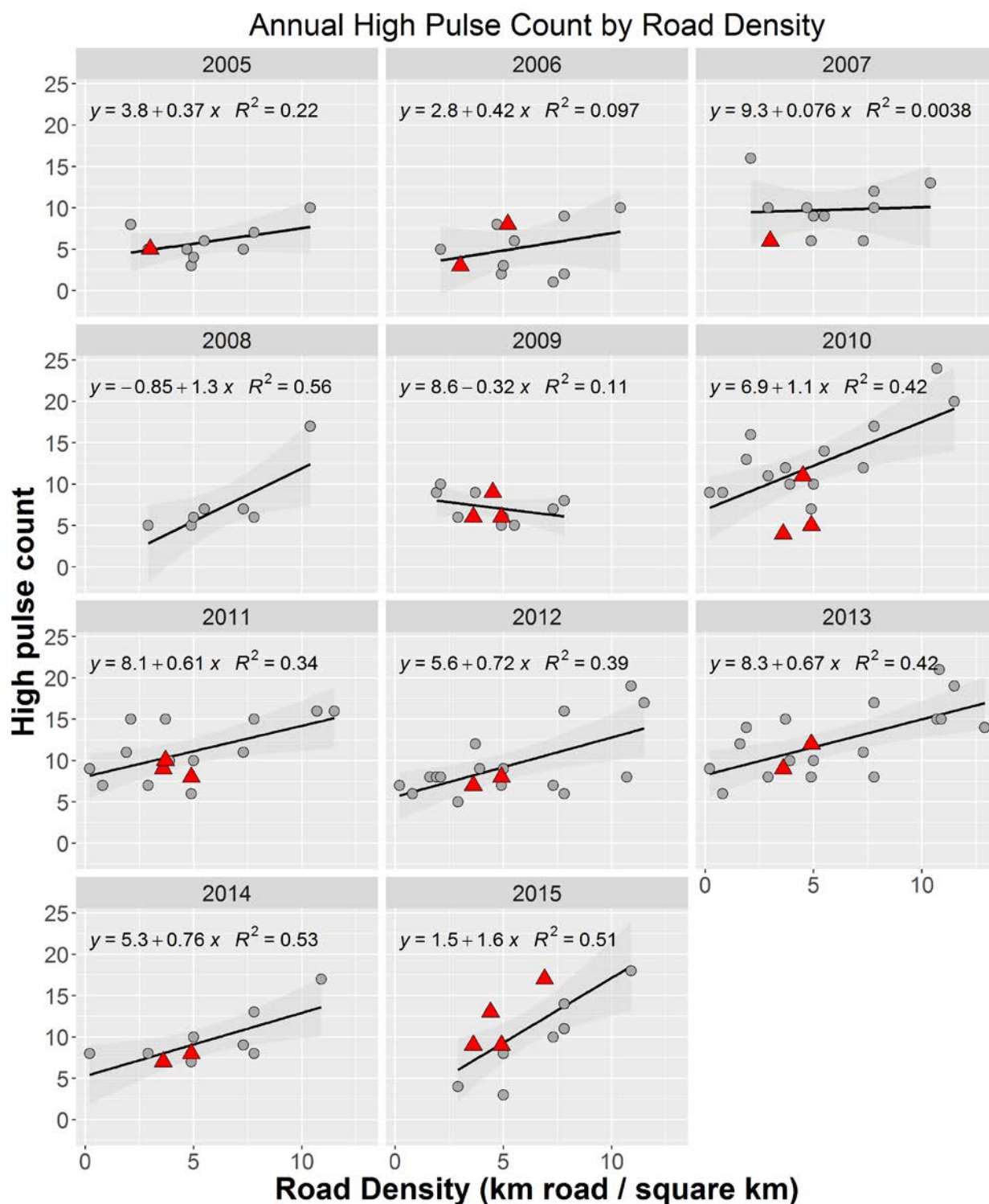


Figure D-2 Regional high pulse duration in relation to proportion of the landscape that is urban (2005-2015). Study area sites are indicated by red triangles; regional sites outside of the study area are indicated by grey circles. A linear regression is shown for each year, with parameter estimates printed on the bottom of each panel. The average response is shown in the body of the report in Figure 15.

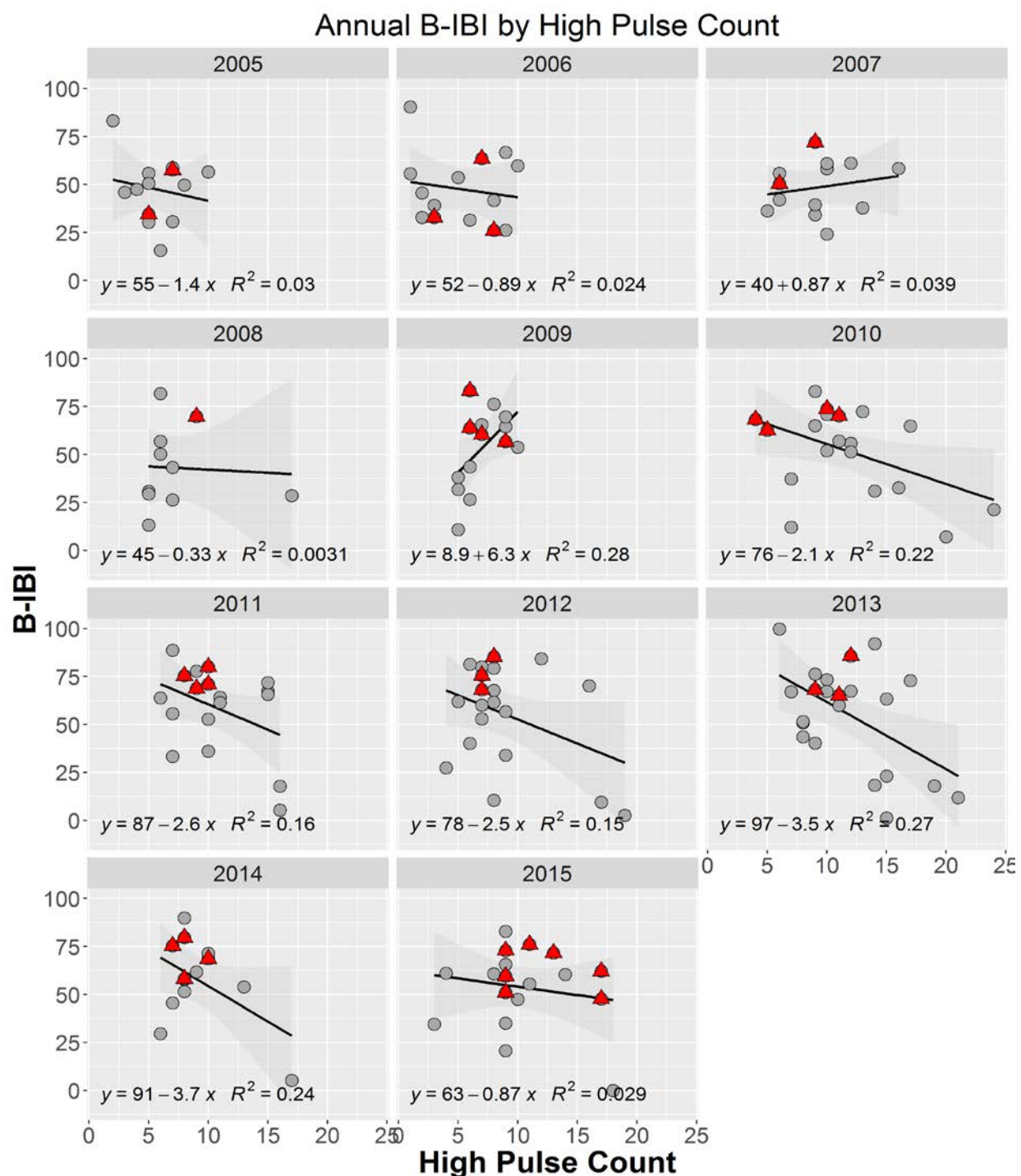


D-3 High pulse count in relation to road density in the surrounding watershed (2005–2015). Study area sites are indicated by red triangles; regional sites outside of the study area are indicated by grey circles. A linear regression is shown for each year, with parameter estimates printed on the bottom of each panel. The average response is shown in the body of the report in Figure 15.

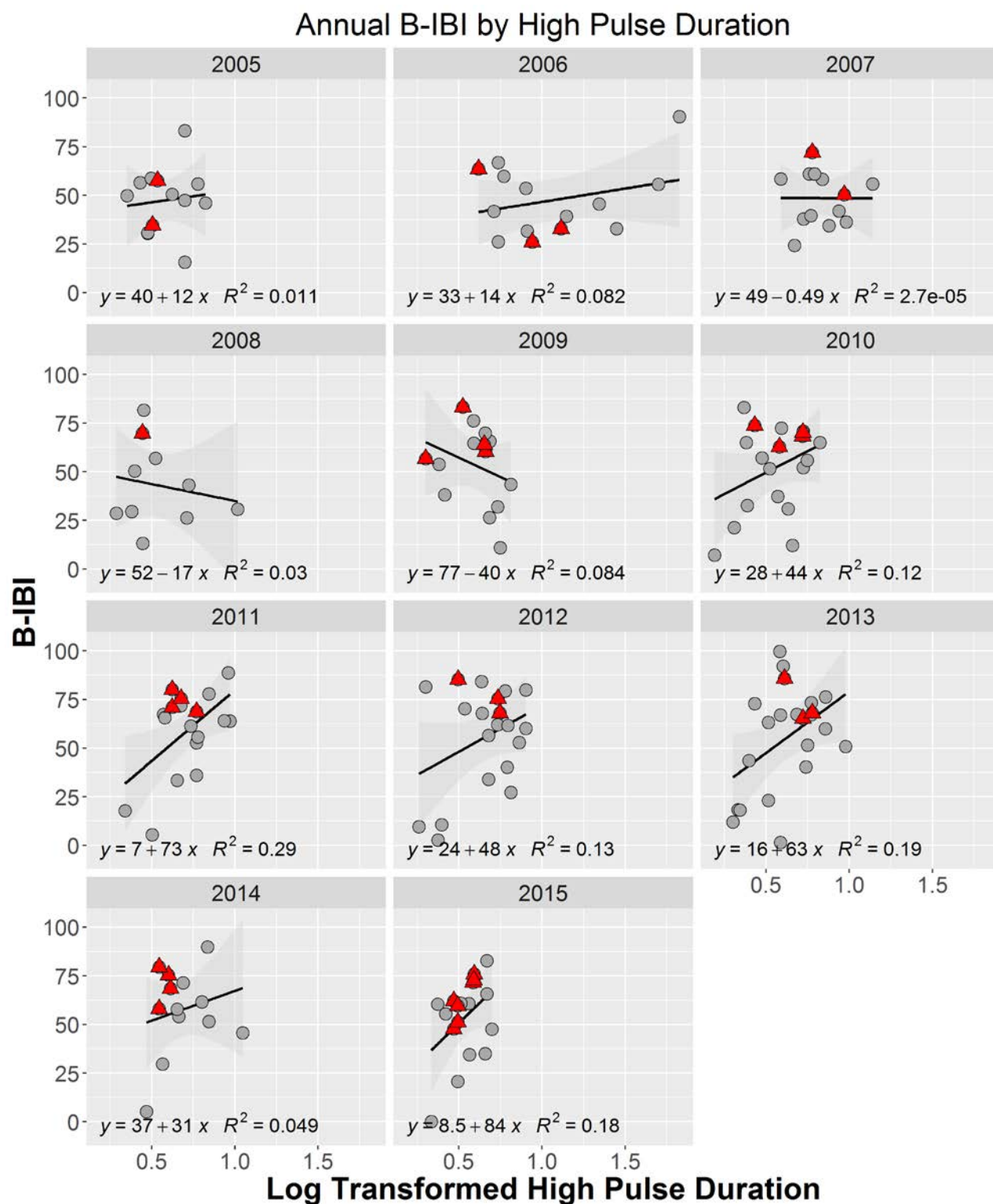
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## Appendix E: B-IBI and Hydrological Metrics



**Figure E-1. B-IBI in relation to high pulse count (HPC). B-IBI and HPC (2005–2015). Study area sites are indicated by red triangles; regional sites outside of the study area are indicated by grey circles. A linear regression is shown for each year, with parameter estimates printed on each panel.**



**Figure E-2. B-IBI in relation to log-transformed high pulse duration (HPD). B-IBI and HPD (2005–2015). Study area sites are indicated by red triangles; regional sites outside of the study area are indicated by grey circles. A linear regression is shown for each year, with parameter estimates printed on each panel.**

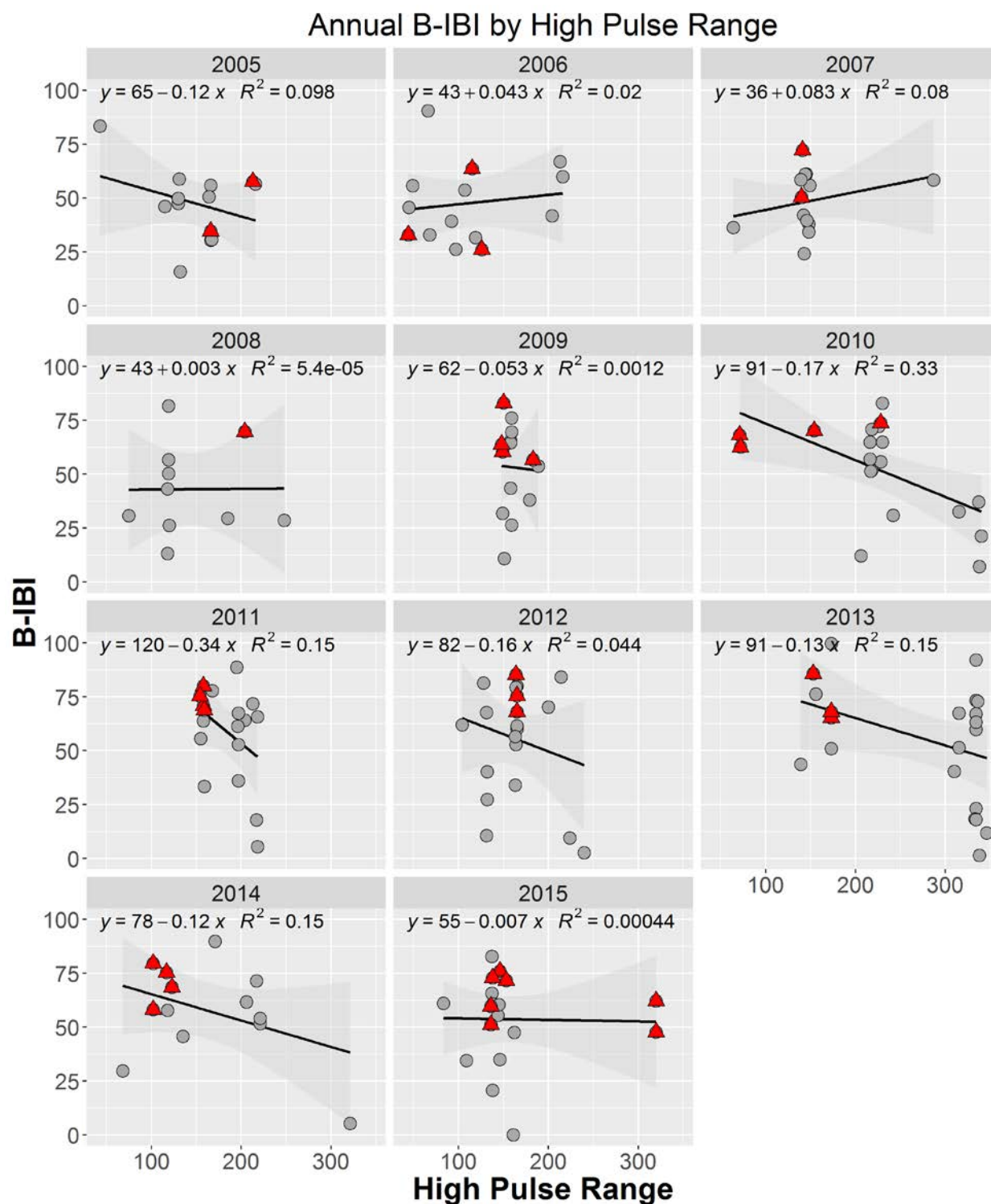


Figure E-3. B-IBI in relation to high pulse range (HPR). B-IBI and HPR (2005–2015). Study area sites are indicated by red triangles; regional sites outside of the study area are indicated by grey circles. A linear regression is shown for each year, with parameter estimates printed on each panel.

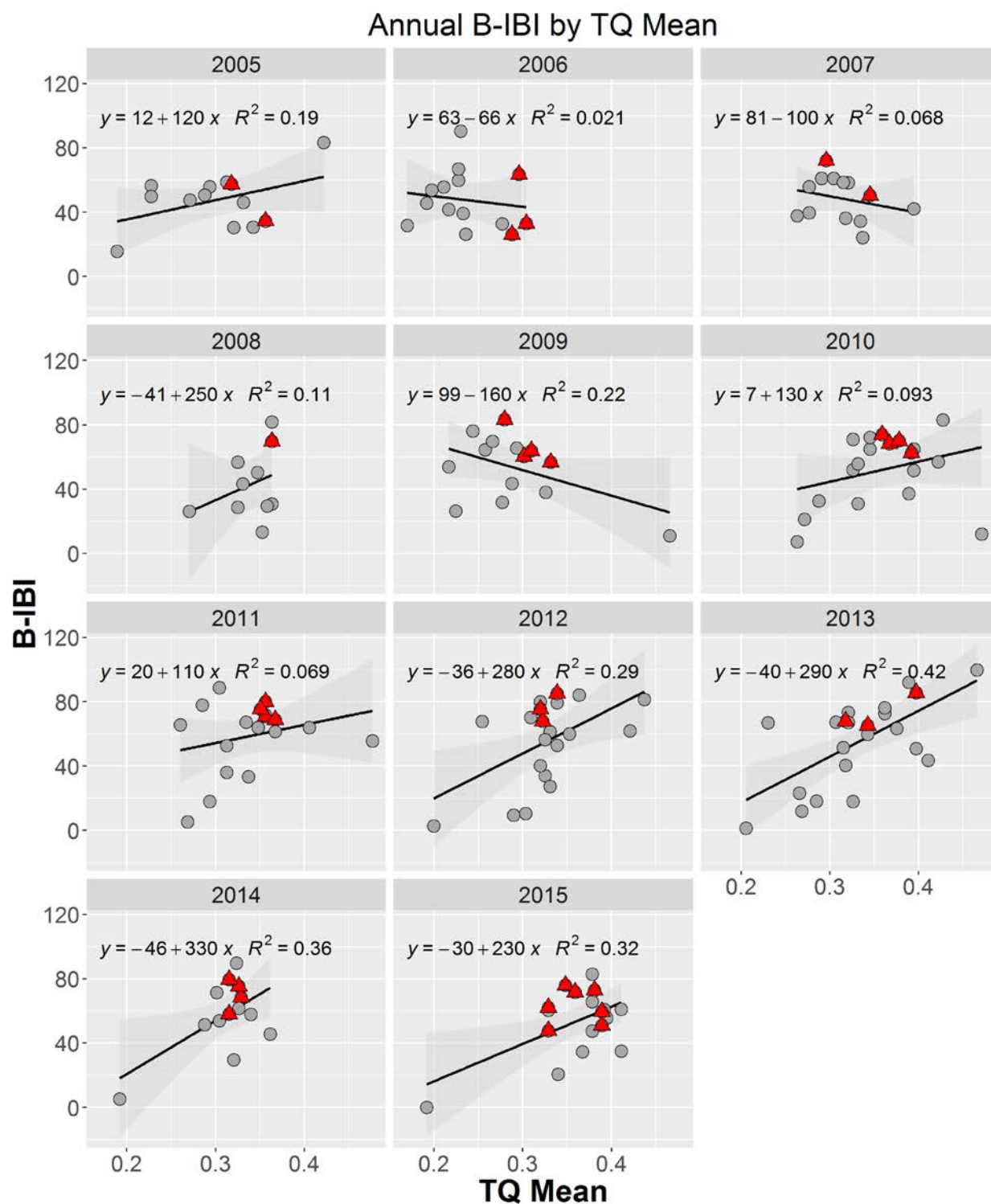
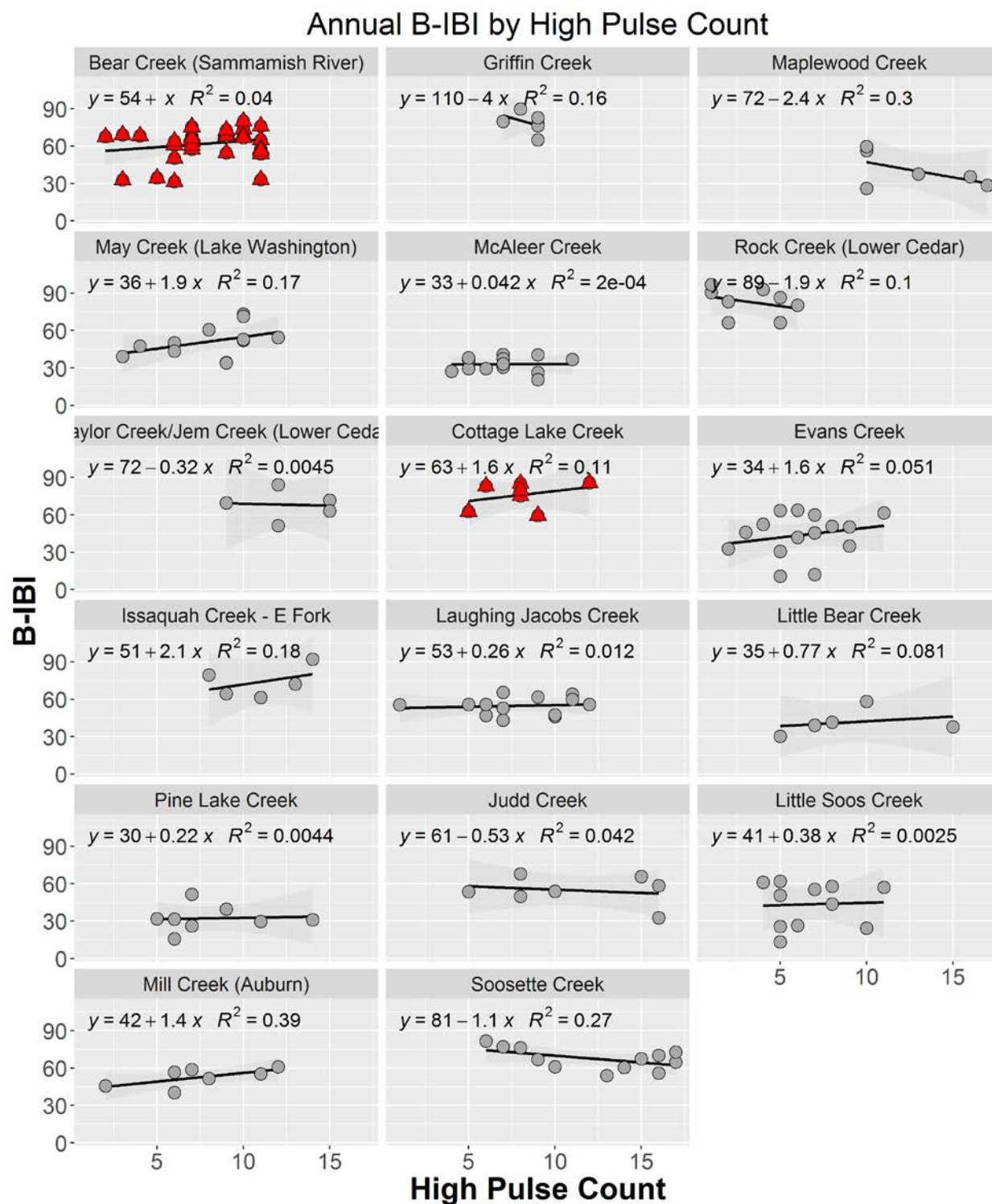


Figure E-4. B-IBI in relation to TQM (2005–2010). Study area sites are indicated by red triangles; regional sites outside of the study area are indicated by grey circles. A linear regression is shown for each year, with parameter estimates printed on each panel.





**Figure E-6. B-IBI in relation to high pulse count (HPC) and grouped by stream each available year for each stream. Study area sites are indicated by red triangles; regional sites outside of the study area are indicated by grey circles. A linear regression is shown for each year, with parameter estimates printed on each panel.**

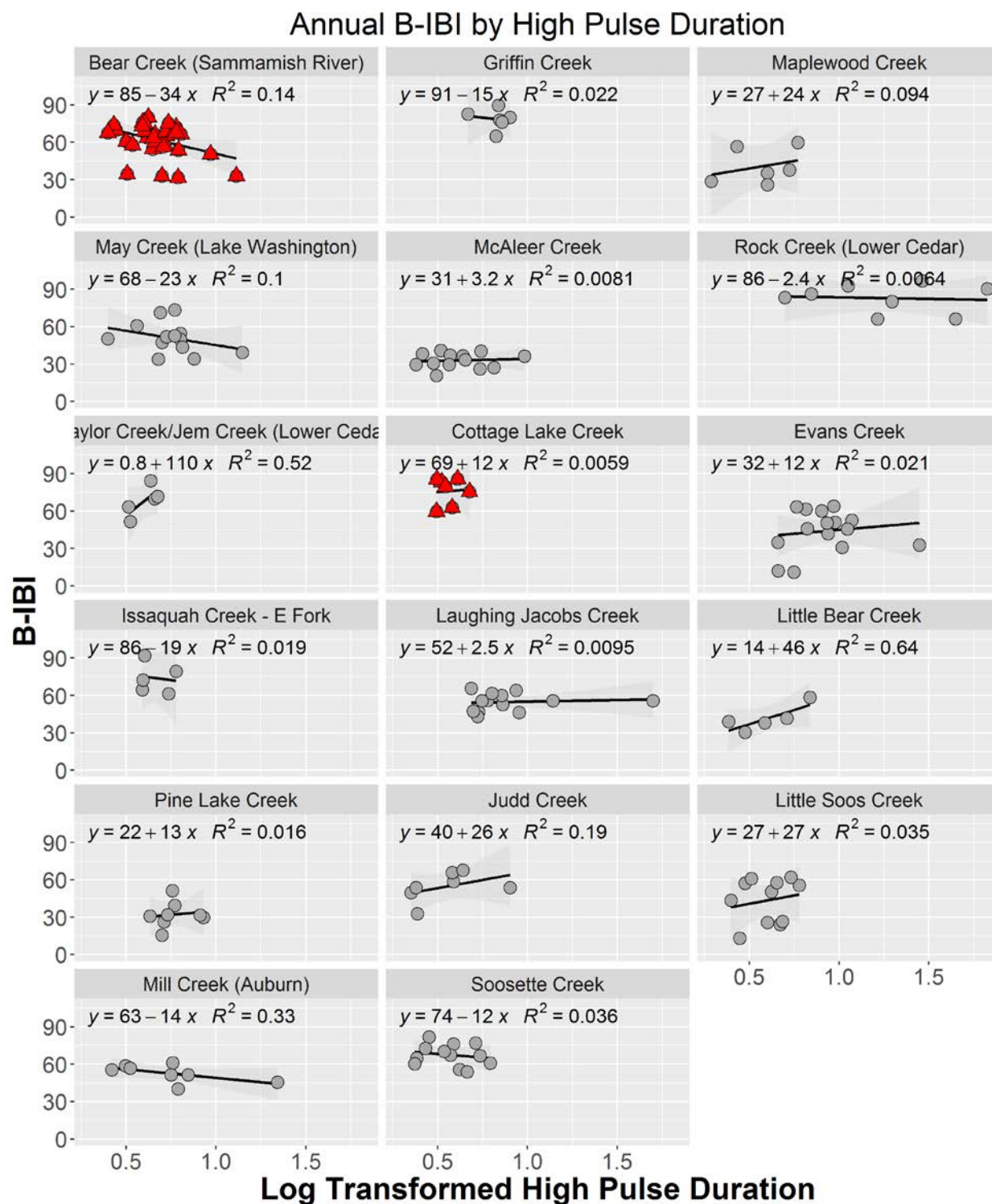
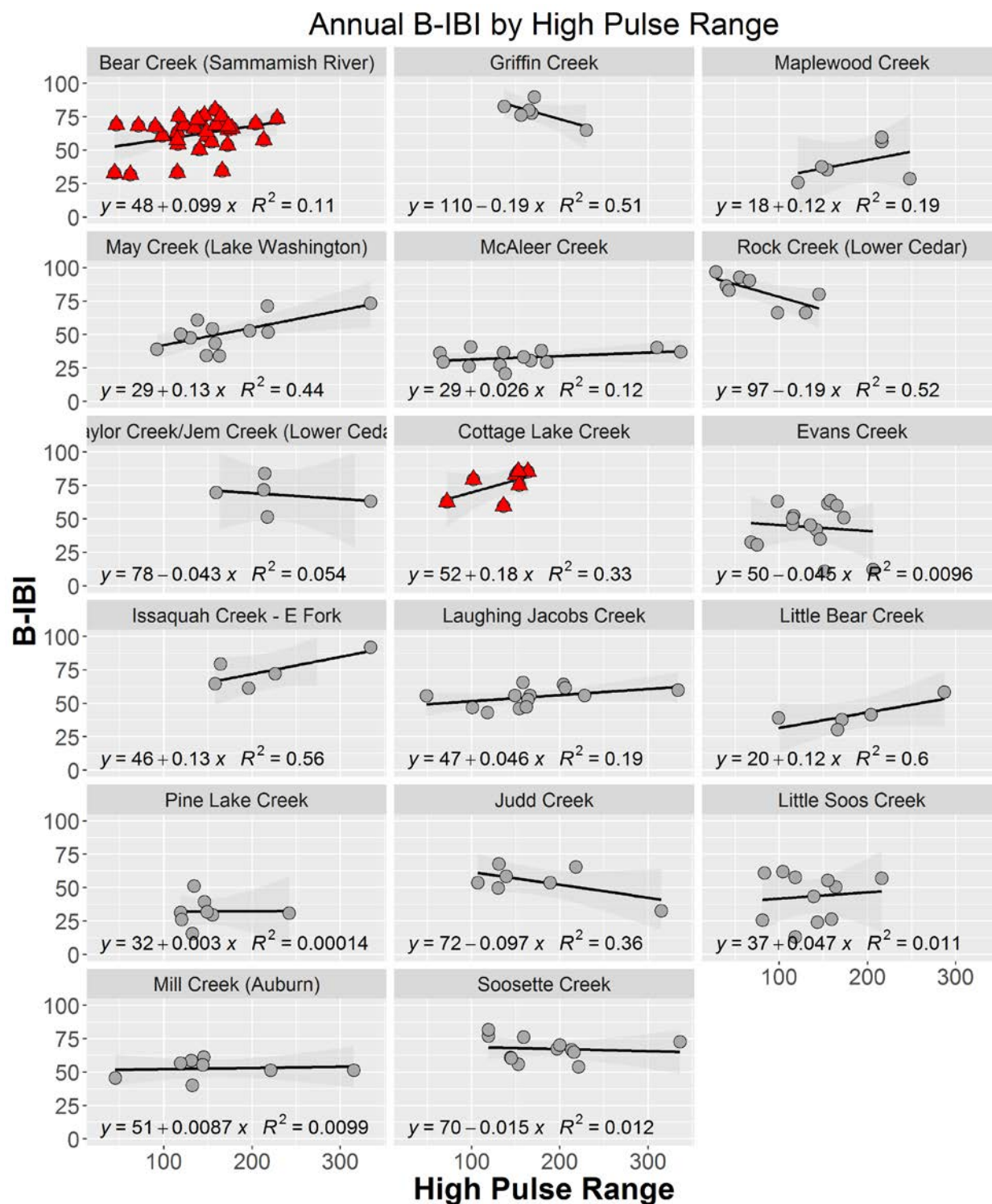


Figure E-7. B-IBI in relation to log transformed high pulse duration (HPD) grouped by stream for each available year for each stream. Study area sites are indicated by red triangles; regional sites outside of the study area are indicated by grey circles. A linear regression is shown for each year, with parameter estimates printed on each panel.



**Figure E-8. B-IBI in relation to high pulse range (HPR) and grouped by stream for each available year for each stream. Study area sites are indicated by red triangles; regional sites outside of the study area are indicated by grey circles. A linear regression is shown for each year, with parameter estimates printed on each panel.**



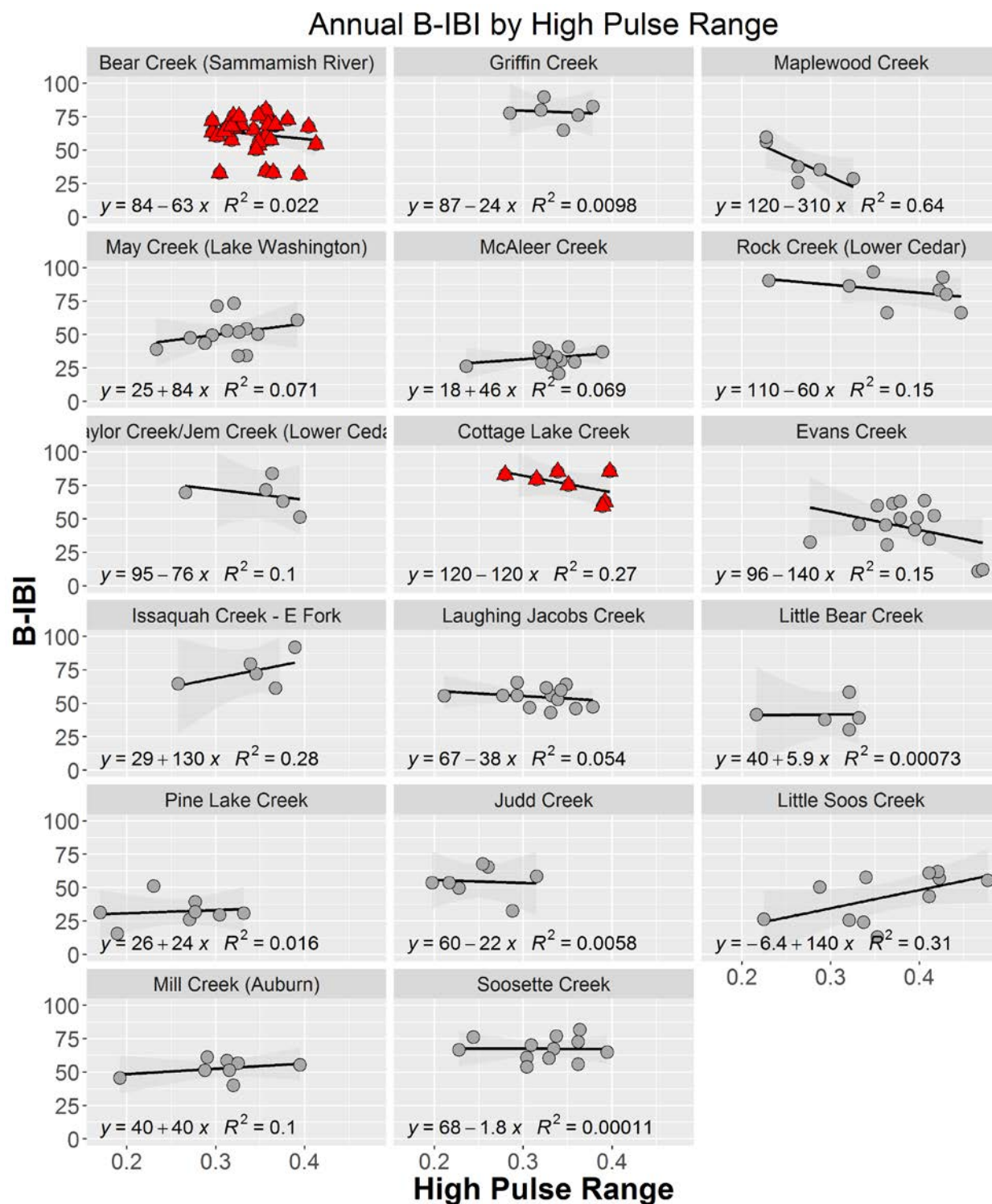
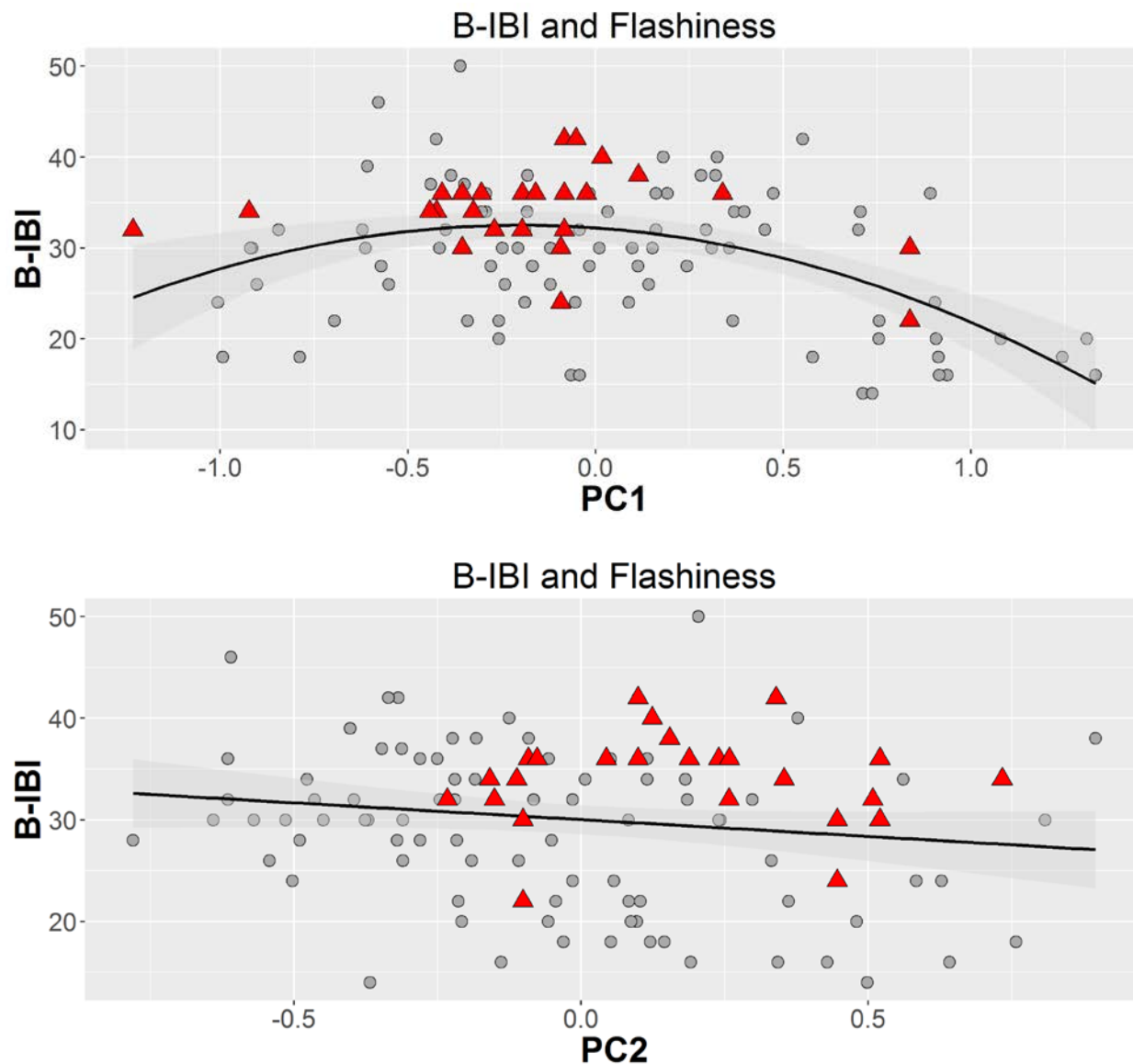


Figure E-9. B-IBI in relation to TQ Mean (TQM) and grouped by stream each available year for each stream. Study area sites are indicated by red triangles; regional sites outside of the study area are indicated by grey circles. A linear regression is shown for each year, with parameter estimates printed on each panel.



## Appendix F: Regressions of B-IBI on 10-50 Scale by Hydrological Metrics



**Figure F-1. B-IBI (10–50 scale) in relation to principle components. All available data from paired gauges and B-IBI sites from 2010–2015 are shown. Study area sites are indicated by red triangles; regional sites outside of the study area are indicated by grey circles.**

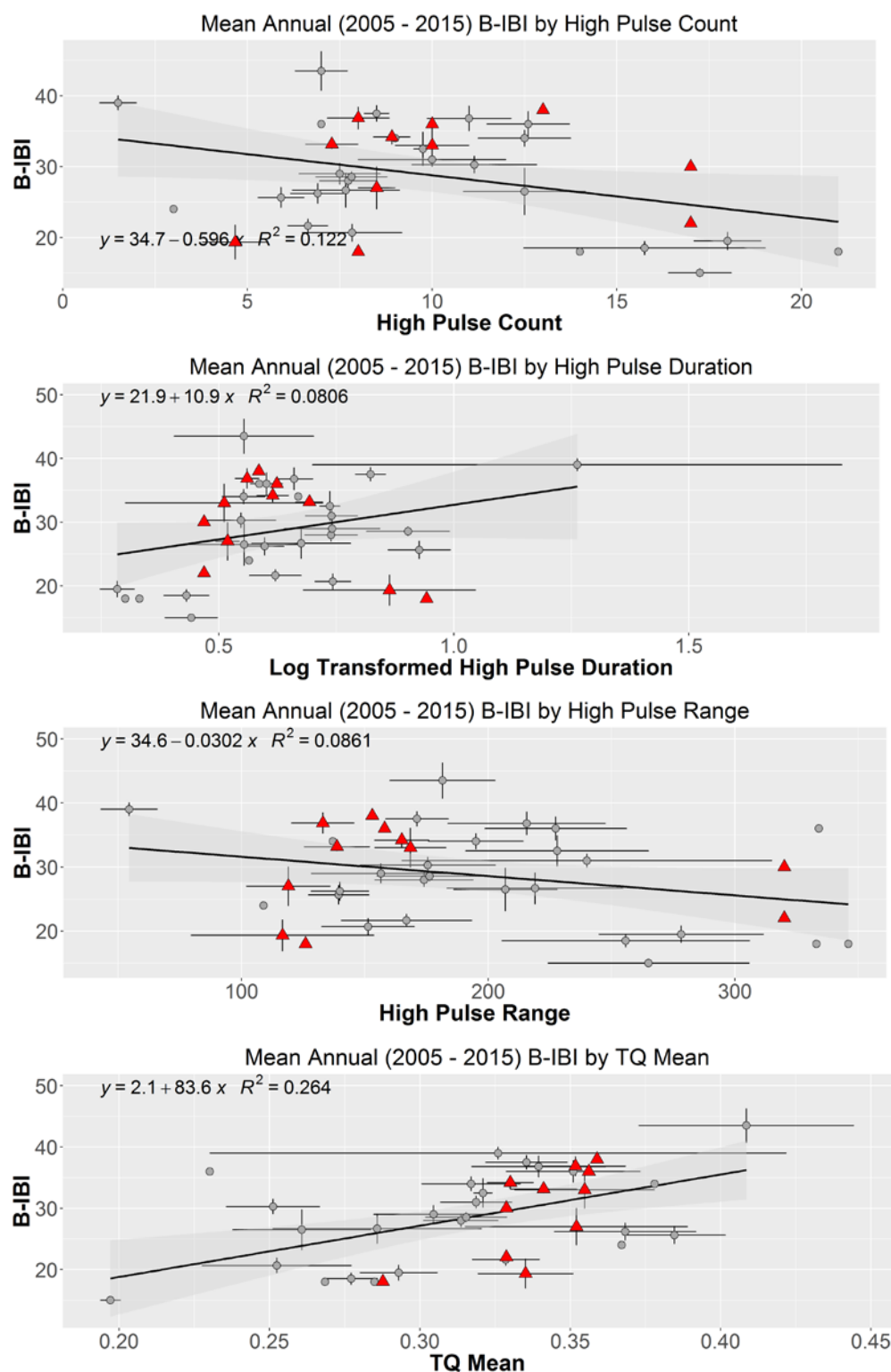
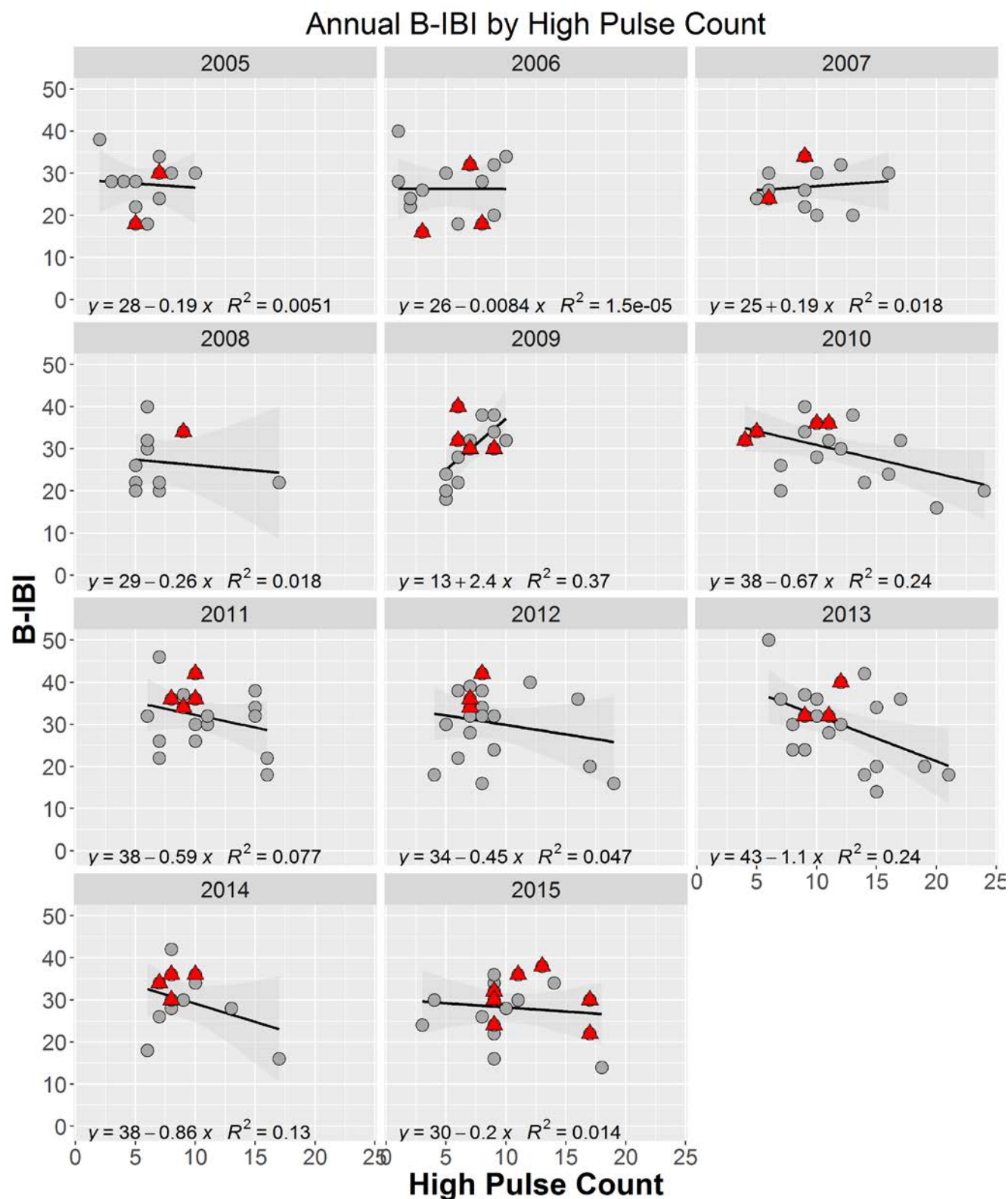
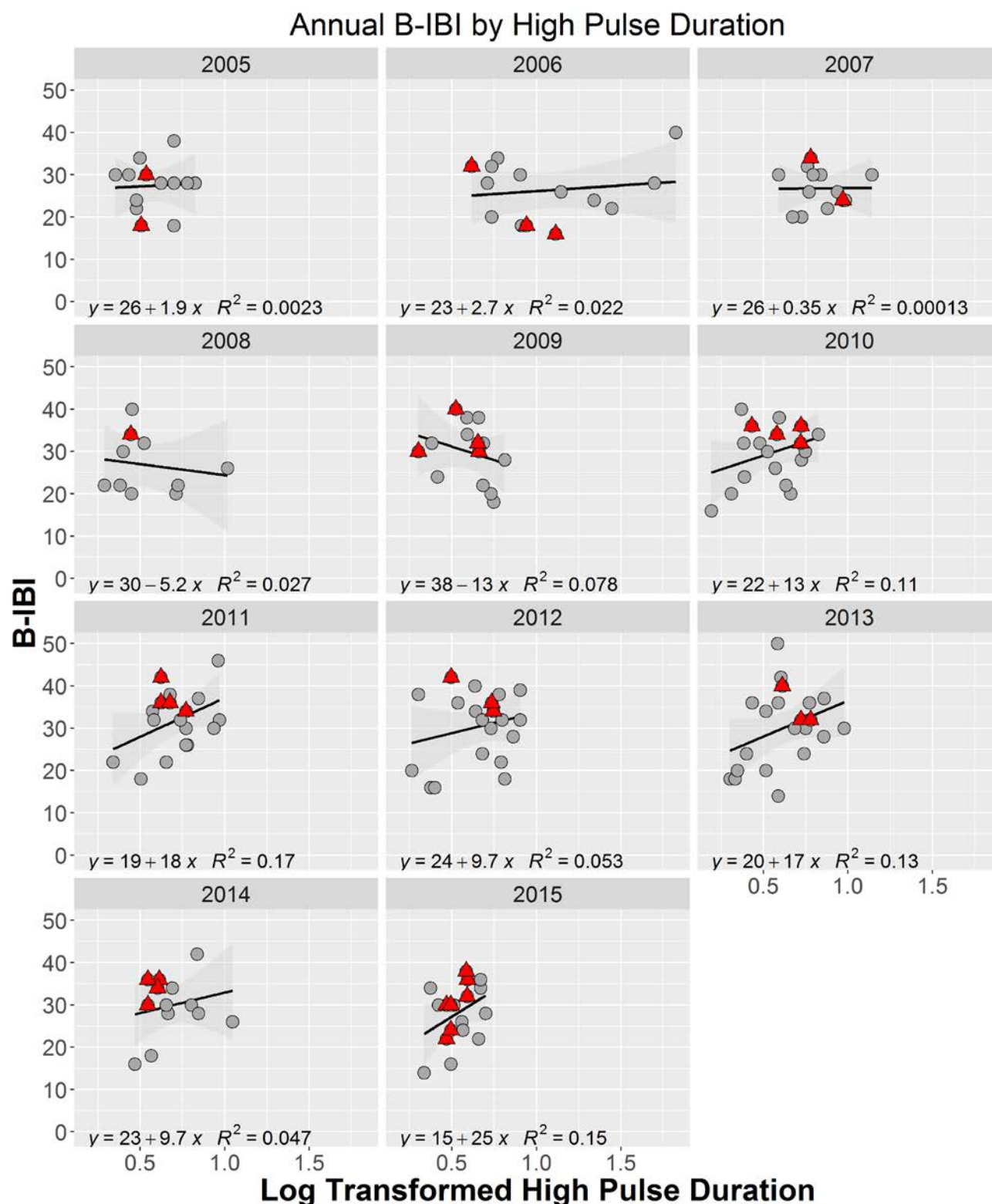


Figure F-2. Mean ( $\pm 1$  SE) B-IBI (10–50- scale) in relation to flashiness metrics (2005–2015) is shown. Study area sites are indicated by red triangles; regional sites outside of the study area are indicated by grey circles. A linear regression is shown for each metric, with parameter estimates printed on each panel.



**Figure F-3. B-IBI (10–50 scale) in relation to high pulse count (HPC) (2005–2015).** Study area sites are indicated by red triangles; regional sites outside of the study area are indicated by grey circles. A linear regression is shown for each year, with parameter estimates printed on each panel.



**Figure F-4. B-IBI (10–50 scale) in relation to log transformed high pulse duration (HPD) ((2005–2015. Study area sites are indicated by red triangles; regional sites outside of the study area are indicated by grey circles. A linear regression is shown for each year, with parameter estimates printed on each panel.**

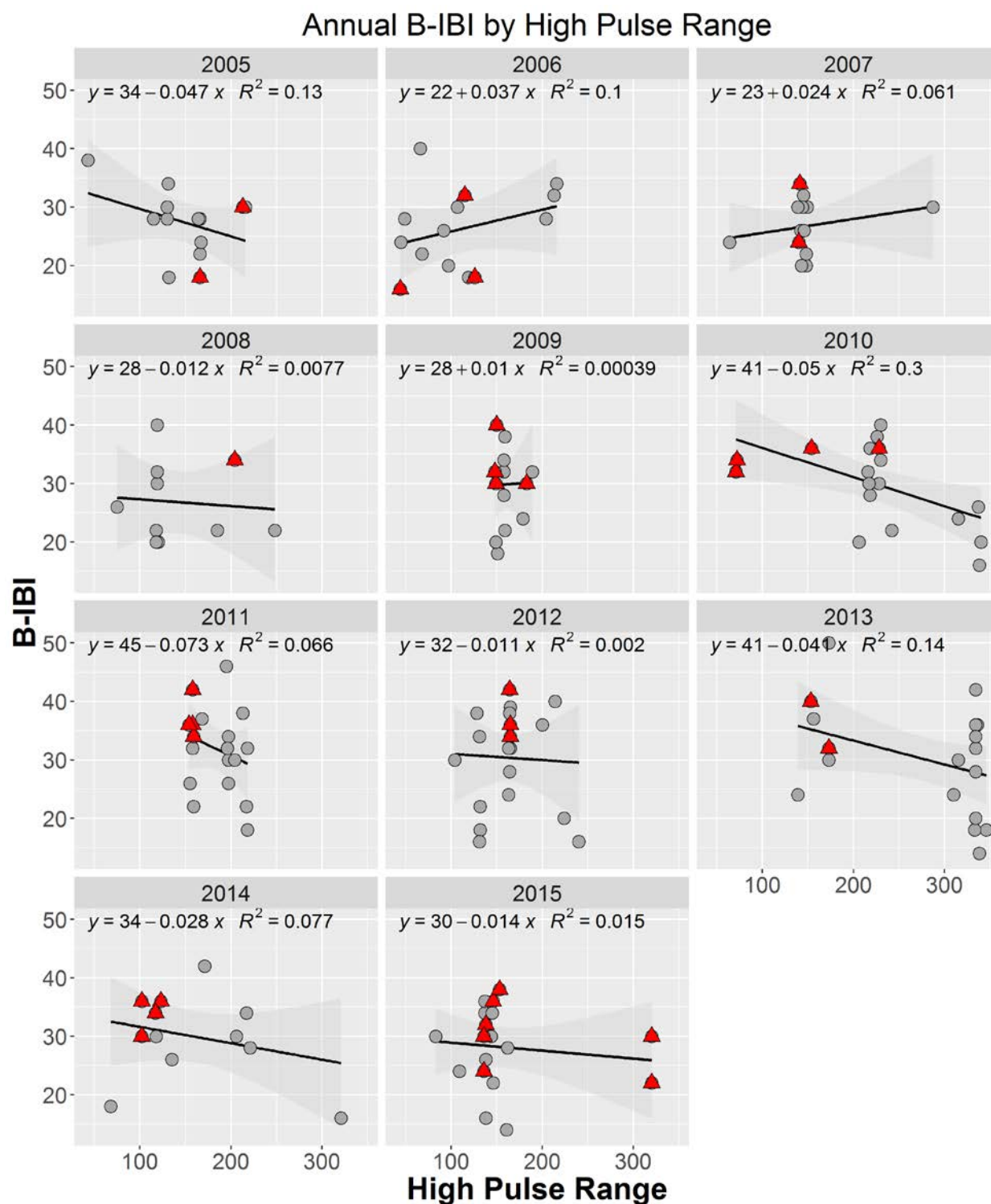


Figure F-5. B-IBI (10–50 scale) in relation to high pulse range (HPR) for each year (2005–2015). Study area sites are indicated by red triangles; regional sites outside of the study area are indicated by grey circles. A linear regression is shown for each year, with parameter estimates printed on each panel.



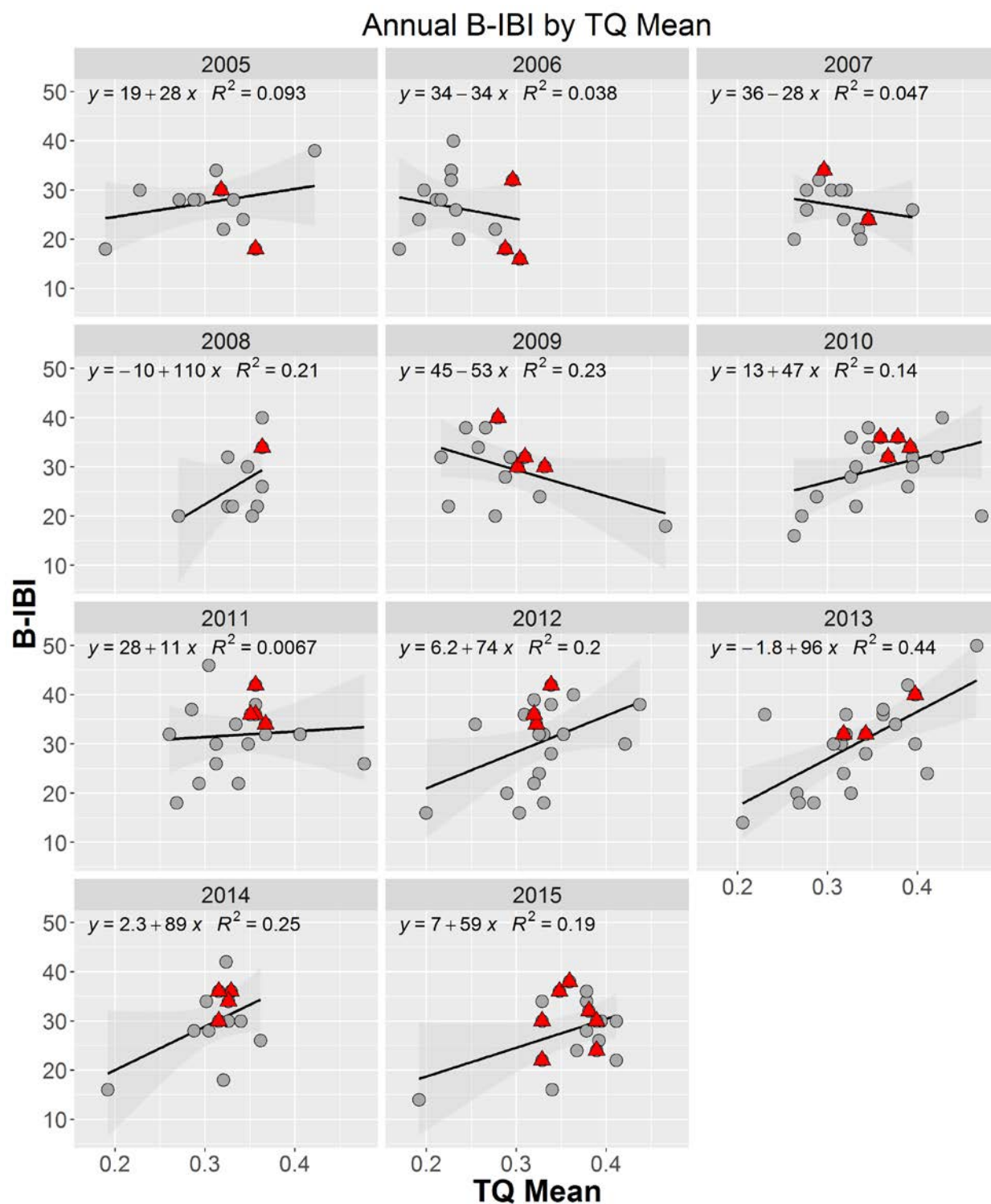


Figure F-6 B-IBI (10–50 scale) in relation to TQ Mean (TQM) for each year (2005–2015). Study area sites are indicated by red triangles; regional sites outside of the study area are indicated by grey circles. A linear regression is shown for each year, with parameter estimates printed on each panel.

## Appendix G: Tables of Sites and Gauges

**Table G-1 B-IBI sites in the study area. B-IBI scores are shown on both the 0-100 and 10-50 scales. B-IBI Trend is the regression coefficient describing the linear change in B-IBI score over time. Available covariate data associated with each site are also shown. These include flashiness metrics (HPC = high pulse count, HPR = high pulse range, HPD = high pulse duration, TQM = TQ mean. B-IBI standard errors (SE) are shown for both 0-100 and 10-50 scales.**

Site	Stream	B-IBI (0-100)	B-IBI (10-50)	B-IBI Trend	HPC	HPR	HPD	TQM	Proportion Urban Cover	Road Density	B-IBI (0-100) SE	B-IBI (10-50) SE
02O	Seidel Creek	45.45	33.00	-2.54					0.00	0.00	1.00	2.45
02P	Seidel Creek	56.85	34.00	3.51					0.00	0.00	0.00	2.55
08BEA3312	Monticello Creek	55.67	28.00	-0.79					0.16	6.90	2.00	3.70
08BEA3321	Cold Creek	55.20	31.33	-0.32					0.33	6.50	1.33	2.57
08BEA3474	Bear Creek (Sammamish River)	52.10	27.33	3.04					0.37	4.70	2.67	3.69
08BEA3478	Mackey Creek	60.23	29.33	-0.05					0.16	4.40	3.71	11.18
08BEA3571	Cottage Lake Creek	35.33	23.33	-1.07					0.28	4.60	0.67	4.08
08BEA3650	Bear Creek (Sammamish River)	69.90	34.67	0.66	10.67	147.33	4.43	0.34			1.33	3.20
08BEA3737	Seidel Creek	67.93	34.67	1.17							1.33	1.68
08BEA3747	Bear Creek (Sammamish River)	50.00	24.67	0.10					0.14	3.00	2.91	4.01
08BEA3826	Struve Creek	73.90	38.67	0.21					0.28	4.40	4.06	4.06
08BEA3914	Colin Creek	59.75	31.00	-0.36					0.35	4.70	1.00	2.65
BearHW	Bear Creek (Sammamish River)	25.70	14.00									

Site	Stream	B-IBI (0-100)	B-IBI (10-50)	B-IBI Trend	HPC	HPR	HPD	TQM	Proportion Urban Cover	Road Density	B-IBI (0-100) SE	B-IBI (10-50) SE
E1168	Cottage Lake Creek	53.50	29.00	0.79					0.31	4.70	1.00	2.80
E1261	Struve Creek	61.50	32.00	0.82					0.22	5.20	0.00	5.60
ESDAM234	Seidel Creek	18.20	20.00									
EssexRed105	Tylers Creek	19.95	19.00	-0.38					0.64	8.70	3.00	13.35
MackRed107	Mackey Creek	70.50	36.00	-1.06					0.16	4.60	2.31	8.92
MacRed212	Mackey Creek	38.05	26.00	-2.70					0.10	5.50	6.00	13.25
MontRed35	Monticello Creek	37.40	20.00	-4.48					0.16	6.90	2.00	5.33
MontRed94	Monticello Creek	62.75	32.00	-0.12					0.10	6.90	2.00	6.75
NPDESBP1	Cottage Lake Creek	54.60	27.00	-7.00	8.50	119.00	3.31	0.35			3.00	3.50
NPDESBP7	Seidel Creek	68.35	34.00	-8.30							0.00	4.15
NPDESBP8	Seidel Creek	66.30	32.00	5.60							0.00	2.80
PerrRed182	Perrigo Creek	31.90	21.33	-4.33					0.30	7.70	3.33	5.83
RSM06600- 165607	Bear Creek (Sammamish River)	40.80	24.00									
RSM06600- 193111	Bear Creek (Sammamish River)	52.40	30.00									
Stensland Lower	Stensland Creek	54.40	26.67	-15.61					0.17	4.30	5.81	16.46
Stensland Middle	Stensland Creek	53.60	26.00	-3.29					0.13	4.60	2.00	7.64
Stensland Ponds-Reach #1	Stensland Creek	10.27	14.67	0.40							2.40	3.77



Site	Stream	B-IBI (0-100)	B-IBI (10-50)	B-IBI Trend	HPC	HPR	HPD	TQM	Proportion Urban Cover	Road Density	B-IBI (0-100) SE	B-IBI (10-50) SE
Stensland Ponds-Reach #2	Stensland Creek	54.53	29.33	3.30							0.67	3.44
Stensland Upper	Stensland Creek	42.63	26.67	-4.87					0.15	4.80	2.40	9.39
WAM06600- 013031	Bear Creek (Sammamish River)	48.60	30.00	2.96					0.35	4.50		
WAM06600- 017111	Bear Creek (Sammamish River)	51.50	27.33	-2.02					0.40	4.50	3.53	7.96
WAM06600- 036971	Bear Creek (Sammamish River)	72.10	32.67	1.44	8.33	142.67	4.63	0.34	0.19	3.60	0.67	2.17
WAM06600- 057527	Bear Creek (Sammamish River)	79.60	38.00	6.50					0.45	4.50		
WAM06600- 076119	Cottage Lake Creek	74.97	35.33	-0.95	9.67	130.33	3.56	0.37	0.27	4.90	2.91	7.88
WAM06600- 111639	Bear Creek (Sammamish River)	81.40	36.00	4.07					0.17	4.50		
WAM06600- 122423	Mackey Creek	59.63	31.33	0.90					0.16	5.00	1.33	0.47

**Table G-2. Gauges used to calculate stream flashiness metrics. For each gauge, the years of stream flow data are shown along with corresponding average B-IBI score and average values for stream flashiness metrics (HPC = high pulse count, HPR = high pulse range, HPD = high pulse duration, TQM = TQ mean).**

Gauge	Years	B-IBI Site	Latitude	Longitude	B-IBI (0-100)	B-IBI (10-50)	HPC	HPR	HPD	TQM
21A	2010–2015	07GRN077319	47.62	-121.90	65.70	34.00	9.00	137.00	4.67	0.38
02e	2005–2014	08BEA3650	47.72	-122.08	68.64	34.18	8.91	165.00	4.24	0.33
02f	2005–2007	08BEA3747	47.76	-122.06	39.27	19.33	4.67	116.67	8.51	0.34
31p	2005–2008	08CED2433	47.47	-122.16	45.67	26.50	12.50	207.00	3.96	0.26
31L	2005–2006	08CED4192	47.37	-122.02	86.85	39.00	1.50	54.50	36.00	0.33
37a	2005–2015	08EAS1964	47.53	-122.20	50.83	28.00	7.73	174.00	6.00	0.31
35c	2005–2015	08WES0903	47.75	-122.28	31.76	21.64	6.64	166.91	4.55	0.33
02e	2005–2015	BearRed223	47.72	-122.08	70.90	36.00	10.00	158.00	4.20	0.36
21A	2010–2015	SEN06600-GRIF09	47.60	-121.89	78.02	37.67	8.33	163.00	7.41	0.32
21A	2010–2015	SEN06600-GRIF09	47.60	-121.89	79.20	37.33	8.67	179.33	6.07	0.35
31q	2010–2013	WAM06600-022259	47.42	-121.91	88.20	43.50	7.00	181.50	4.33	0.41
34a	2010–2013	WAM06600-035963	47.78	-122.29	15.10	18.50	15.75	255.75	2.75	0.28
02f2	2009–2015	WAM06600-036971	47.75	-122.06	70.40	33.14	7.29	138.71	4.99	0.34
38C	2013	WAM06600-038087	47.62	-122.15	11.90	18.00	21.00	346.00	2.00	0.27
37a	2005–2015	WAM06600-081267	47.52	-122.17	57.70	32.50	9.75	228.00	5.47	0.32
27a	2010–2013	WAM06600-083959	47.71	-122.21	13.18	19.50	18.00	278.25	1.94	0.29
31h	2009–2013	WAM06600-115443	47.41	-122.03	68.10	36.00	12.60	227.40	4.04	0.35
BC0119	2015	08BEA3312	47.70	-122.09	62.10	30.00	17.00	320.00	2.94	0.33

Gauge	Years	B-IBI Site	Latitude	Longitude	B-IBI (0-100)	B-IBI (10-50)	HPC	HPR	HPD	TQM
02M2	2015	08BEA3826	47.73	-122.06	71.60	38.00	13.00	153.00	3.85	0.36
18a	2005–2015	08EVA3555	47.67	-122.08	39.10	25.64	5.91	139.45	9.68	0.38
15b	2005–2010	08LAK3540	47.60	-122.08	29.35	20.67	7.83	151.33	5.65	0.25
15h	2015	08LAK3627	47.61	-122.07	34.50	24.00	3.00	109.00	3.67	0.37
15c	2005–2015	08LAK3879	47.57	-122.05	56.19	28.55	7.82	176.18	10.91	0.32
30A	2005–2007	08LIT2585	47.76	-122.16	43.47	26.67	7.67	219.00	5.01	0.29
13a	2012–2015	09DUW0225	47.50	-122.30	2.35	15.00	17.25	265.00	2.84	0.20
02c	2006	CLN_UPD	47.72	-122.04	26.00	18.00	8.00	126.00	8.75	0.29
BC0119	2015	MontRed35	47.70	-122.09	47.70	22.00	17.00	320.00	2.94	0.33
02g	2009–2015	NPDESBP1	47.72	-122.09	54.60	27.00	8.50	119.00	3.31	0.35
14b	2009–2013	WAM06600-039815	47.53	-121.99	73.96	36.80	11.00	215.60	4.65	0.34
51O	2013	WAM06600-050295	47.68	-122.14	18.30	18.00	14.00	333.00	2.14	0.28
67a	2012	WAM06600-062567	47.54	-122.06	64.50	31.00	10.00	240.00	5.54	0.32
02g	2009–2015	WAM06600-076119	47.73	-122.08	75.93	36.86	8.00	133.00	3.67	0.35
02N	2009–2010	WAM06600-111639	47.69	-122.08	63.45	33.00	10.00	168.50	3.64	0.35
41c	2005–2008, 2012–2015	09MIL0390	47.30	-122.26	52.62	29.00	7.50	156.50	6.96	0.30
54h	2006–2015	09SOO1022	47.33	-122.16	67.54	34.00	12.50	195.00	3.76	0.32
54i	2006–2015	09SOO1209	47.36	-122.13	45.16	26.20	6.90	139.90	4.12	0.37
DW_KC	2013	EPA06600-DEWA01	47.47	-123.03	67.00	36.00	7.00	334.00	3.86	0.23
28a	2005–2007, 2009–2012	VashJudd	47.41	-122.47	54.57	30.29	11.14	175.57	3.88	0.25