Macroinvertebrate-based Biomonitoring in Whychus Creek, 2005-2017

Whychus Creek side channel; C.A. Searles Mazzacano

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Table of Contents

Summary

Benthic macroinvertebrate sampling was done in August 2017 on 16 sites along Whychus Creek (RM26 to RM1.5). Thirteen sites were sampled by trained volunteers using the Oregon Department of Environmental Quality (ORDEQ) standardized protocol for targeted riffle habitat sampling in wadeable streams; duplicate samples were taken at two sites for quality control. Samples were also taken from three newly-created side channels around a restoration project at WC1100 that was implemented in late 2016. These sites were sampled by CASM Environmental and UDWC staff using a reachwide benthos protocol, which randomly samples multiple different microhabitats (riffle, pool, glide, run, woody debris). All samples were preserved in 80% ethanol and subsequently sub-sampled to a target count of 500 organisms and identified to the lowest practical level of taxonomic resolution.

Taxa data were analyzed via the ORDEQ PREDATOR predictive model and invertebrate-based index of biotic integrity (I-IBI). Multivariate analysis was done to assess changes in community composition and identify taxa contributing most to observed community dissimilarities, and multiple taxonomic and ecological traits were assessed. This is the ninth time of macroinvertebrate sampling in Whychus Creek since 2005, and the community in 2017 was analyzed independently and in the context of the entire monitoring period. Individual sites at which large restoration projects were implemented were also examined separately, including Whychus floodplain (WC2600), Camp Polk (WC1900-WC1825), and Whychus Canyon (WC1100).

The 2017 macroinvertebrate community had the highest number of taxa (104) since monitoring began, and the most taxa not seen in prior years (12), including three families collected for the first time. Many new taxa were found only in the side channels at WC1100, which had a greater variety of sampled microhabitat as well as more slow water habitats (from glides to pools); consequently, more of the new taxa were characteristic of lentic waters than in prior years. New restoration severely impacted the macroinvertebrate community at WC1100, which had the lowest diversity, abundance, and IBI score in any site or year, while the new side channels had a high abundance and diversity of lotic and lentic taxa.

Although IBI and PREDATOR scores have increased in recent years, assessment of individual community traits provides a clearer picture of community changes. Whychus Creek is now supporting a more diverse and balanced community, with more EPT and low sediment indicator taxa, and a lower sediment (%FSS) optima. PREDATOR scores vary and indicate poorer biological conditions, but sediment and temperature optima among the communities identified by the PREDATOR model as replacement taxa are lower than for missing taxa, and lower for increaser taxa compared to decreasers, with the most dramatic changes

occurring between 2005 and 2009. A recent increase in community temperature optima was not apparent in 2017 at downstream and upstream sites, but temperature optima continued to increase at mid-stream sites, and the relative abundance of tolerant taxa has been increasing in downstream and mid-stream sites in the last two years.

Some fluctuations in downstream, mid-stream, and upstream reaches are due to the immediate impacts of restoration activities. This has negatively affected taxa richness, dominance of the most abundant taxon, and numbers of sediment- and temperature-sensitive taxa at project sites, but some level of recovery is apparent by two years post-restoration.

Background

Whychus Creek watershed is a designated priority watershed for conservation and restoration in the upper Deschutes Basin. Restoration projects implemented from 1999-2016 restored perennial flows to the creek and increased instream flow volumes. The aquatic macroinvertebrate community has been monitored in Whychus Creek since 2005, with annual sampling in nine of the years during 2005-2017 (2005, 2009, 2011-20176) at 10-13 sites from RM 30.25 to RM 0.5, most consistently between RM 26 and 1.5. Multiple approaches are used to assess changes in the macroinvertebrate community and their ecological implications. Standard models developed by the Oregon Department of Environmental Quality (ORDEQ) are used to assign levels of biological impairment to sampling sites: general Invertebrate Index of Biotic Integrity (I-IBI), Grande Ronde IBI (GR-IBI), and PREDATOR predictive model (Hubler, 2008). Changes in individual IBI metrics, community tolerances for percent fine sediment and temperature, and diversity of ORDEQ temperature and sediment indicator taxa are examined. Univariate (ANOVA) and multivariate (CLUSTER, SIMPER) analysis is done to determine between-year macroinvertebrate community similarities and identify taxa contributing to community differences.

Methods

Sampling Sites

In 2017, benthic macroinvertebrate sampling was done in 13 reaches along Whychus Creek, with duplicate samples taken at two sites for quality control (Table 1). Samples were also taken in three new side channels at WC1100, where a floodplain re-connection project was implemented in late 2016. Sites are distributed into downstream (RM 1.6 - 11.5; DS), mid-stream (RM 18-19.5; MS), and upstream (RM 24.25-26; US) regions. Sites have been added, moved, or removed since sampling began in 2005 based on access, changes in land use, re-assessment of their importance, and/or implementation of new restoration projects, and some site names changed after improved GIS mapping in 2014. Not shown in Table 1 are two additional downstream sites sampled only in 2005 (RM 0.50 and 3.0), and three additional upstream sites not sampled after 2011 (RM 26.5, 27.0, and 30.25).

Table 1. Whychus Creek sampling sites

Site ID	Description	Coordinates	Year(s) sampled
WC0150	RM 1.5, d/s Alder Springs	44.446681, -121.34727	2009, 2011-2017
WC0600	RM 6, u/s Rd 6360	44.40412, -121.40259	2005, 2009, 2011-2017
WC0850	Rimrock Ranch d/s	44.391278, -121.406182	2011-2017
WC0900	RM 9, Rimrock Ranch	44.384198, -121.407892	2005, 2009, 2011-2017
WC1050[a]	RM 10.25, Rimrock Ranch u/s	44.371534, -121.415865	2011-2012, 2014-2017
WC1100	Whychus Canyon d/s	44.364587, -121.421706	2017
WC1150	Whychus Canyon u/s	44.361288, -121.427525	2014-2017
WC1825	Camp Polk d/s	44.32781, -121.495406	2009, 2011-2017
WC1850	Camp Polk lower channel	44.327182, -121.500152	2009, 2011-2017
WC1900	RM 19, DBLT property	44.321523, -121.507461	2005, 2009, 2011-2017
WC1950[b]	RM 19.5, d/s Camp Polk Bridge, DBLT property	44.318741, -121.514961	2009, 2011-2017
WC2425[b]	RM 24.25, City Park, d/s gauge	44.287806, -121.544229	2005, 2009, 2011-2017
WC2600	RM 26, 4606 Rd. footbridge	44.2730592, -121.555297	2005, 2009, 2011-2017
CH1 , CH2, CH3	new side channels, Whychus Canyon between WC1100 and WC1150	44.364468, -121.423702	2017

[a] prior to 2016, sampling site was at RM 10.25
[b] duplicate samples takan for QA/QC

Sampling Method

Whychus Creek mainstem

All mainstem reaches were sampled on 12 August 2017 by volunteers. On 13 August, UDWC and CASM Environmental staff sampled three side channels between WC1100 and WC1150 , along with a mainstem site that had been skipped by volunteers on 12 August (WC1850) and two sites where volunteers processed their samples incorrectly (WC1900 and WC1950; samples were elutriated but mineral material was not retained in final sample). Sampling was slightly earlier than the established index period of 17-20 August because in 2017 that weekend was too close to the much-anticipated solar eclipse, complicating travel and making it harder to find volunteers.

Benthic macroinvertebrates were collected from mainstem riffle habitats according to ORDEQ protocols for Oregon's wadeable streams (OWEB, 2003). Reach lengths are calculated as 40 times the average wetted stream width at the desired sampling point, within minimum/maximum lengths of 500 ft and

1000 ft. UDWC staff calculate reach lengths prior to sampling and flag the upstream and downstream extents so volunteers can find their sites. On the morning of 12 August, volunteers gathered at City Park in Sisters, OR to be trained by CASM Environmental, who demonstrated the sampling technique and explained each item on the data sheet. Teams received sampling kits and instructions for finding their sites and dispersed into the field. Each team returned samples, data sheets, and equipment to the park, and CASM Environmental staff inspected each sample to be sure it was properly labeled and preserved.

A site sample consists of eight individual net sets taken in riffle habitat in a designated reach. Each net set is collected from a 1 ft^2 area using a D-frame kick net with 500 µm mesh and a 1-ft opening. In reaches with eight or more riffles, a single net set is taken in each of eight randomly selected riffles; in reaches with fewer than eight riffles, two kick net samples are taken in each of four riffles. Large rocks and debris in the sampling area are rubbed and rinsed into the net to dislodge and collect any clinging organisms and set aside. The substrate is then disturbed thoroughly using a boot heel to a depth of 6-10 cm for 1-2 minutes. The eight net sets at each site are pooled in a bucket; large debris is rinsed and removed, and any vertebrates are noted on the data sheet and carefully replaced in the stream. Sample material is concentrated by pouring through a 500 µm sieve lined with a flexible square of 500 µm Nitex membrane; the membrane is lifted out and the concentrated sample carefully scooped and rinsed into a 1-liter Nalgene sample jar half-filled with 80% ethanol as a preservative.

Samples with excessive sand or gravel are elutriated, which allows soft-bodied invertebrates to be separated from heavier mineral material and placed in different sample jars to avoid crushing or grinding specimens. Elutriation is done by adding water to the composited sample in the bucket, swirling it thoroughly, then pouring the suspended organic material through the sieve. After two to three rinses, the organic material is placed in one sample jar and the mineral material in another; all sample material from each site is retained for subsequent examination in the lab so heavier-bodied organisms (i.e., snails, stonecase-making caddisflies) are not lost.

All jars are filled no more than halfway with sample to ensure good preservation, and the ethanol is replaced within 48 hours by CASM Environmental to maintain an 80% concentration, since water leaching from the sample dilutes the preservative. Each jar receives an interior and exterior label, written in pencil on waterproof paper. A simple physical habitat assessment is also done at each site to record human use and landscape alterations, substrate composition, water temperature and appearance, and wetted width and depth at each riffle sampled (see Appendix A for data sheet).

Whychus Creek side channels

A goal of the watershed council is to determine abundance and diversity of macroinvertebrate prey items for native fish in the new side channels. The channels have a variety of microhabitats with few riffles; therefore, to fully assess the macroinvertebrate community across all habitats, they were sampled using a reach-wide multi-habitat protocol (adapted from USEPA, 2009; Ode, 2016), which has been shown to be similar to and as robust as targeted single-habitat (riffle) sampling (Gerth & Herlihy, 2006). The channels ran more or less parallel within the canyon, with CH3 closest to the mainstem (southeastern-most channel) and CH1 furthest from the main channel.

Ten transects were set at 50 foot intervals in each channel. Each transect is perpendicular to the direction of flow, and the first is set at the downstream limit of the sampling reach. A D-frame kick net was used to take a single net set in each transect, alternating between the left (i.e., at 25% of the channel wetted width), center (at 50% of the wetted width), and right (at 75% of the wetted width) of the transect as the sampler moves upstream. Microhabitat type sampled in each transect was recorded; these included run, glide, pool, large woody debris, and small riffles. In water with sufficient flow (riffles, runs), samples were collected as described above for riffle habitat sampling. In transects where flow was insufficient to carry macroinvertebrates into the net (glides, pools), the substrate was continuously disturbed to a depth of several inches using hands or feet while the D-net was swept repeatedly through the suspended material to capture disturbed/dislodged invertebrates. If the sampling point was in vegetation, the net was jabbed and swept through the vegetation repeatedly during the 1 minute sampling time. Root wads, small wood tangles, and large woody debris were sampled similarly; invertebrates were picked off during a visual examination, then the net was held adjacent to and beneath the wood while the material was kicked vigorously to dislodge invertebrates. All 10 transect net sets were composited and processed as described above for riffle samples.

Macroinvertebrate Identification

Samples were identified by Cole Ecological, Inc. (http://www.coleecological.com). Each composite sample was randomly sub-sampled to a target count of 500 organisms. Sample containing fewer than 500 organisms were picked in their entirety. Organisms were identified to the level of taxonomic resolution currently recommended by ORDEQ and the Southwestern Association of Freshwater Invertebrate Taxonomists (SAFIT; Richards & Rogers, 2011), which is generally genus or species, although some groups are left at family or order. If a specimen was too immature for critical taxonomic characters to be fully developed or visible, identification was done only to family level.

Data Analysis

Biological condition of each sampling site was assessed using multimetric and probability-based models. Two multimetric indices developed by ORDEQ were used: a general macroinvertebrate-based Index of Biotic Integrity (I-IBI) and a more regional northeastern (Grande Ronde) GR-IBI (Table 2). A higher scaled score (5) is given to metric ranges considered typical of a healthy stream, while a lower scaled score (3 or 1) reflects values associated with more degraded conditions. Scaled scores for all metrics are summed to generate single value that reflects the level of site impairment.

The macroinvertebrate community in Whychus Creek was also analyzed using the probability-based PREDATOR model (Predictive Assessment Tool for Oregon; Hubler, 2008) developed for the Western Cordillera and Columbia Plateau (Klamath Mountain, Cascades, East Cascades, Blue Mountains, and Columbia Plateau ecoregions; WCCP). PREDATOR calculates the ratio of taxa observed at a sampling site to taxa expected if no impairment exists (O/E), based on community data collected previously at a large number of reference streams. The model uses site elevation, slope, and longitude to select the most appropriate reference streams. An O/E value <1 indicates taxa loss, while values >1.2 indicate enrichment, potentially in response to pollution or nutrient loading. Model outputs include a site test result, which indicates whether the habitat data falls within the model parameters; O/E score for each sample, which provides a measure of biological condition; a site probability matrix that identifies missing taxa (taxa expected to occur at each site but absent) and replacement taxa (taxa present at a site but not predicted by the model to occur there); and a sensitivity index that reveals "increaser" and "decreaser" taxa in the overall community (i.e., taxa collected at more or fewer sites than predicted by the model). O/E scores associated with a probability of capture (P_c) > 0.5 were used in the subsequent analyses to avoid rare taxa bias (i.e. the model considers only invertebrates with over 50% likelihood of being collected at reference sites). Site biological condition is assigned based on the following O/E scores: ≤0.78 = poor (most disturbed); 0.79 – 0.92 = fair (moderately disturbed); 0.93 – 1.23 = good (least disturbed); and >1.23 = enriched.

Table 2. ORDEQ genus-level general macroinvertebrate-based IBI and Grande Ronde IBI metrics and scoring. [a] for I-IBI, dominance (% abundance) of most abundant taxon is assessed; for GR-IBI, dominance of the three most abundant taxa is assessed. [b] Modified Hilsenhoff Biotic Index (Hilsenhoff, 1987), reflecting tolerance to organic pollution/ enrichment; values range from 1 (low tolerance) to 10 (high tolerance).

I-IBI				GR-IBI		
Scoring Criteria						
Metric	5	3	1	5	3	1
Taxa richness	>35	19-35	<19	>31	24-31	<24
Mayfly richness	>8	4-8	<4	>7	6-7	<6
Stonefly richness	>5	3-5	<3	>6	5-6	<5
Caddisfly richness	>8	4-8	<4	>4	2-4	<2
# sensitive taxa	>4	2-4	<2	>4	3-4	<3
# sediment-sensitive taxa	>2	1	0	>1	1	0
% dominance[a]	<20	20-40	>40	<39	39-42	>42
% tolerant taxa	<15	15-45	>45	<24	24-36	>36
% sediment-tolerant taxa	<10	10-25	>25	<10	10-15	>15
MHBI[b]	<4	4-5	>5	<3.9	3.9-4.3	>4.3
Summed score & condition						
Severely impaired		<20			<15	
Moderately impaired		20-29			15-25	
Slightly impaired		30-39			N/A	
Minimally/not impaired		>39			>26	

The Whychus Creek 2017 macroinvertebrate community was analyzed separately and in the context of the entire monitoring period. Additional characteristics examined included: temperature and percent fine sediment (%FSS) optima (based on an ORDEQ dataset of individual taxa optima values); presence of ORDEQ high/low temperature and sediment indicator taxa (see Hubler, 2008); and richness (number of taxa), relative abundance, and relative diversity of different macroinvertebrate groups. Because instream flow restoration is an important part of the work done on Whychus Creek in the past 10 years, macroinvertebrate streamflow indicator taxa were also assessed for the first time. These indicators were developed for a USEPA Rapid Assessment Protocol for streamflow duration in the West (Mazzacano &

Black, 2008; Nadeau et al., 2015). However, this assessment measure was uninformative and is therefore not discussed further in this report. Community changes at specific restoration sites were assessed, including Camp Polk (WC1900, WC1850, WC1800; 1.5 cfs diverted into constructed meadow channel beginning in 2009; creek diverted into constructed meadow channel in February 2012), Whychus floodplain (WC2600, live flow in 2014), and Whychus Canyon (WC1100 and side channels; 2016).

Analyses were done using the PAST 3.14 statistical software package (Hammer et al., 2001). CLUSTER, one-way ANOVA, and SIMPER analyses were done on Bray-Curtis similarity matrices of square root-transformed abundance data to investigate macroinvertebrate community similarity between sites and across years. CLUSTER analyses were also done on presence/absence datasets OF PREDATOR increaser/decreaser and missing/replacement taxa. SIMPER was used to find taxa that contributed most to differences between years and sampling reaches (DS, MS, US). One-way ANOVA was used to investigate differences in trait values across sampling years, and where ANOVA indicated a significant difference in mean values between years or sites ($p<0.05$), a Tukey's pairwise test was done to determine year and/or site pairs in which means of metric values were significantly different ($p<0.05$).

Results and Discussion

Macroinvertebrate Community 2017

The target of 500 organisms was attained for 7 of the 13 main channel samples, with anywhere from 15-100% of the total sample picked. The 500 organism target was not attained after picking 100% of the samples from WC0850, WC0900, WC1025, WC1100, WC1150, and WC1825, and counts ranged from 45 (WC1100) to 315 organisms (WC1025). A total of 104 unique taxa was collected across the entire sample set, which is the highest in all sampling years (76-83 unique taxa collected per year in 2005-2016). Twelve taxa were collected for the first time in the 2005-2017 monitoring period, including members of three new families (Dolichopodidae, long-legged flies; Stratiomyidae, soldier flies; and Siphlonuridae, primitive minnow mayflies). The number of new taxa also exceeds that in previous years (i.e, 3-10 new taxa in a year from 2011-2016), and they were also present in somewhat greater abundances (1-12 individuals) and at more sites (1-4 sites in 2017, while in past years new taxa were generally found at ≤ 2 sites). The majority of new taxa in 2017 were characteristic of slower waters, in contrast to the lotic types than comprised more new taxa in past years.

This larger number of new taxa and preponderance of lentic types is driven by the Whychus Canyon side channels, as these samples comprise more available microhabitats and flow types (reach-wide benthos sampling) than the targeted riffle samples in the main channel. Many new taxa were found only in side channel samples: *Oreodytes* and *Sanfilippodytes*, predaceous diving beetle (Dytiscidae) genera found in stream pools and slow-water habitats; two crane fly (Tipulidae) genera that inhabit wet soil in seeps and springs (*Pedicia*) and terrestrial as well as aquatic habitats (*Tipula*); long-legged flies (Dolichopodidae), found in slow waters and in stream margins; *Callibaetis*, a small minnow mayfly (Baetidae) that feeds on filamentous algae in slow waters; and larvae of Syrphidae (hover flies), whose telescoping breathing tube allows them to obtain oxygen in slower, warmer waters. The remaining new taxa were seen in both mainstem and side channel samples, including: *Erioptera*, a crane fly whose larvae inhabit muddy stream banks (WC0825, CH1); *Nemotelus*, a soldier fly (Stratiomyidae) found in the margins of lotic habitats and in lentic pools and marches (WC0150); *Baetis Rhodani Gr.* , a small minnow mayfly (Baetidae) found in riffle habitats (WC0600, WC1100, WC1850, WC1950, CH3); *Parameletus*, a primitive minnow mayfly (Siphlonuridae) more typical of lentic waters (WC1025); and aquatic Pyralidae (grass moths; WC0850, WC2400) sometimes taken in stream samples.

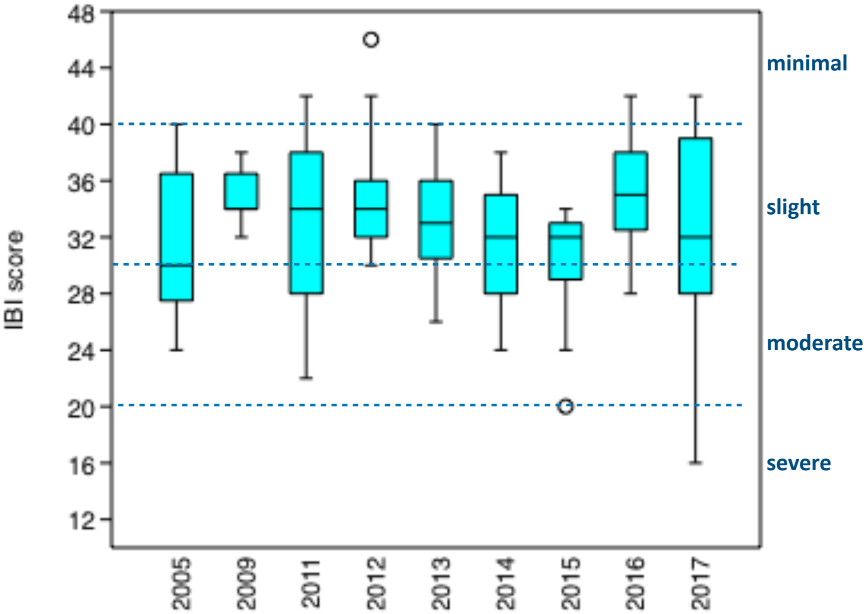
Indices of Biotic Integrity

Because the IBI was developed for riffle communities, it is not appropriate to apply it to the channel samples, although individual metrics were assessed for comparison to other downstream sites. Of the 13 mainstem sites sampled in 2017, one scored as severely impaired, two as moderately impaired, seven as slightly impaired, and three as minimally impaired (Table 3). This is the first year since sampling began that any site was severely impaired (Figure 1); however, this site (WC1100) was disrupted in late 2016 by a floodplain re-connection project. Overall, mean IBI scores changed the most from 2005 to 2009, a result of both a large gap in sampling years as well as the positive effects of restoring perennial flow to the creek. Restoration projects implemented in different years and reaches have impacted scores repeatedly throughout the monitoring period, but median IBI scores have increased in recent years (Figure 1), although means are not significantly different between years.

Table 3. ORDEQ I-IBI scores across time. Colors indicate biological conditions corresponding to I-IBI score (minimal impairment = green, slight impairment = blue, moderate impairment = orange, severe impairment = red).

Site	2005	2009	2011	2012	2013	2014	2015	2016	2017
WC0050	30	—	—	—	—	—	—	—	—
WC0150	—	38	44	34	36	34	28	38	32
WC0300	26	—	—	—	—	—	—	—	—
WC0600	24	32	38	32	32	28	30	34	38
WC0650	—	—	—	—	34	—	—	—	—
WC0875	—	—	40	30	26	30	30	36	32
WC0900	36	36	34	32	38	32	32	40	32
WC0950*	—	—	38	34	30	24	34	—	—
WC1025 (WC1100)	—	—	—	—	—	24	32	34	26
WC1100	—	—	—	—	—	—	—	—	16
WC1075 (WC1150)	—	—	—	—	—	30	34	32	20
WC1800	32	—	—	—	—	—	—	—	—
WC1825	—	36	34	34	32	32	20	34	30
WC1850	—	34	22	36	26	28	32	36	42
WC1900	40	34	28	34	36	24	32	32	40
WC1950	—	34	34	36	36	36	34	42	36
WC2325	28	—	—	—	—	—	—	—	—
WC2425	28	34	26	42	40	38	24	38	38
WC2600	30	38	28	46	32	36	30	28	40
WC2650	—	—	32	—	—	—	—	—	—
WC2700	—	—	36	—	—	—	—	—	—
WC3025	38	38	36	—	—	—	—	—	—

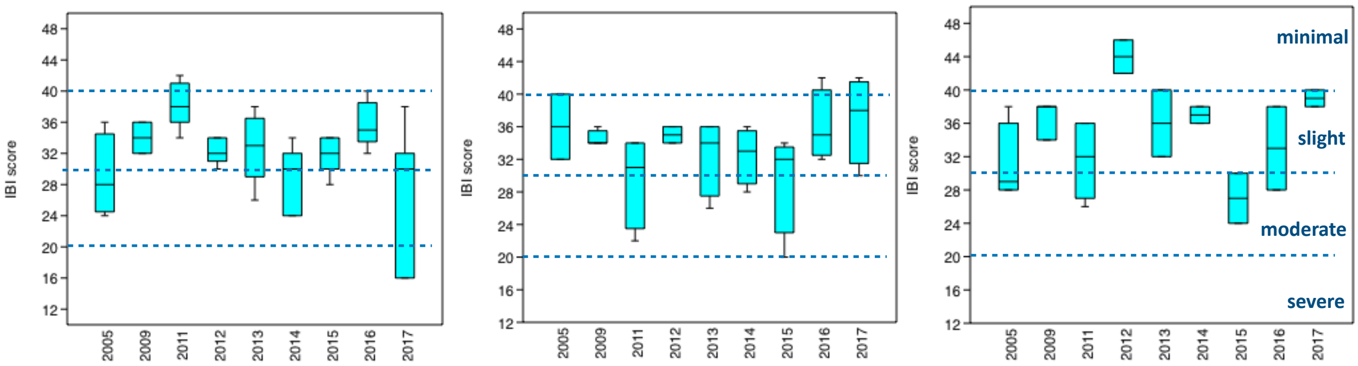
Figure 1. IBI scores across time among all sampling sites. Horizontal line in each box indicates median value; filled box shows interquartile range; whiskers depict data range; circles indicate outlier values. Dotted lines show cutoff points for impairment levels in I-IBI scoring.



Scores calculated using the Grande Ronde IBI (GRIBI) indicate better overall biological conditions than the standard IBI. However, in contrast to 2016, when all sites received a GRIBI score indicating minimal impairment, in 2017 only nine of the 13 mainstem sites were minimally impaired, while three showed moderate impairment and one (WC1100) was severely impaired. The difference in condition between the two IBIs is in part due to the fact that the GRIBI has only three biological condition categories while the I-IBI has four, and score that corresponds to minimal impairment is much lower in the GRIBI ($\geq$ 26) than the I-IBI (> 39). However, the GRIBI was developed specifically for streams in northeastern Oregon, with scoring ranges designed to reflect the biotic community conditions expected in those settings, and the I-IBI and GRIBI site scores continue to show a strong correlation (Pearson's r = 0.807).

IBI scores in different sampling reaches vary annually, often reflecting impacts of restoration and recovery (Figure 2). Median scores in most years fall into the slight impairment range, but have gone more into the moderately impaired range among downstream and mid-stream sites. IBI scores in downstream sites differ significantly between years (F=3.783, p=0.002109), with scores in 2011 significantly higher than in 2005 and 2014, and scores in 2017 significantly lower than in 2011 and 2016. Lower scores in 2017 are driven by the restoration-induced disturbance around RM 11. IBI scores were higher overall among mid-stream sites in 2016 and 2017, but between-year differences are not significant. IBI scores fluctuated the most among upstream sampling sites, with a sustained decrease from 2013 to 2015 that recovered in 2016-2017, and scores differed significantly among these sites (F=3.146, p=0.02665), with mean IBI scores for upstream sites in 2012 significantly greater than in 2015.

Figure 2. IBI scores across time among downstream, mid-stream, and upstream sampling reaches. Horizontal line in each box indicates the median value; filled box shows the interquartile range; whiskers depict data range; circles indicate outlier values. Dotted lines show cutoff points for impairment levels in I-IBI scoring.



A. Downstream sampling sites

B. Mid-stream sites

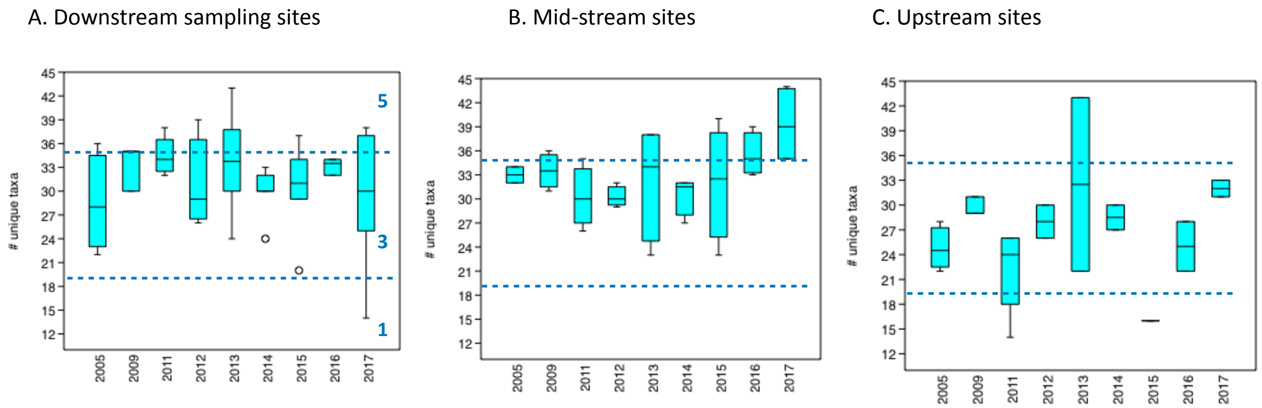
C. Upstream sites

Changes in Individual Community Metrics

Taxa richness

High-quality habitat is considered to contain a variety of microhabitats and niches that sustain a greater organismal diversity, so habitat improvement is expected to be accompanied by increased diversity in the macroinvertebrate community. A one-way ANOVA showed no significant between-year differences in the number of unique taxa among downstream, mid-stream, or upstream sites. However, taxa richness among mid-stream and upstream sites has increased in recent years, with the majority of mid-stream sites scoring on the high end of this metric in the past two years (Figure 3), and the difference in taxa richness among upstream sites in 2017 vs. 2015 is close to significant.

Figure 3. Taxa richness among downstream, mid-stream, and upstream sampling reaches. Horizontal line in each box indicates median value; filled box shows the interquartile range; whiskers depict data range; circles indicate outlier values. Dotted lines show cutoff points for IBI scoring; bold numbers show scaled scores for IBI.


A. Downstream sampling sites

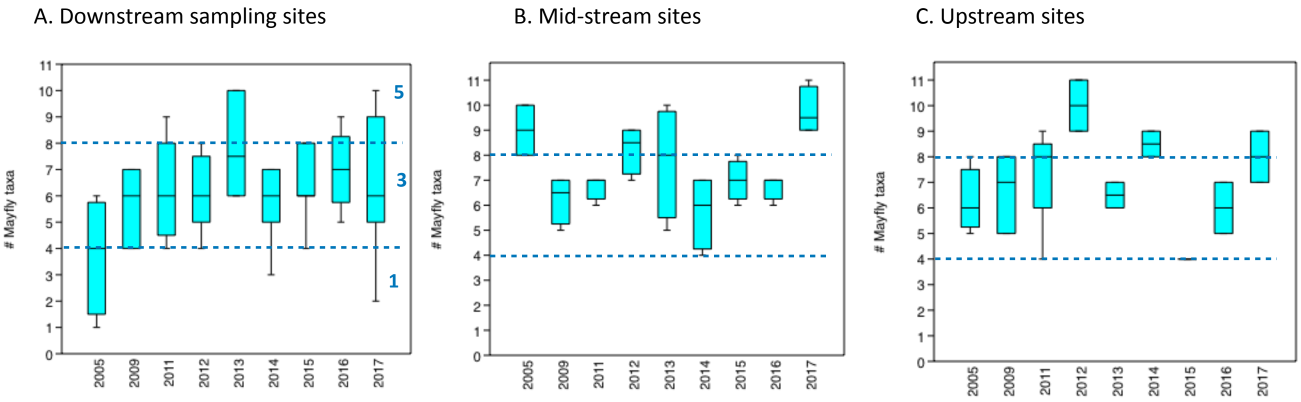
B. Mid-stream sites

C. Upstream sites

Ephemeroptera richness

The number of mayfly taxa among downstream sites stabilized in recent years after a significant increase from 2005-2013 (Figure 4). The wider range and lower median value in 2017 was due to the impacts of restoration at WC1100, which greatly reduced mayfly diversity. Mayfly richness fluctuated among mid-stream sites, but the median number in 2017 was the largest since sampling began, and 2017 mean was significantly greater than in 2009, 2011, 2014, and 2016. Similarly, mayfly diversity in upstream sites increased from 2005-2012 then fluctuated for several years, but the number of taxa has increased in recent years and between-year means are significantly different (F=2.834, p=0.03913), although the mean in 2017 was not significantly different from prior years.

Figure 4. Ephemeroptera richness across time. Horizontal line in each box indicates median value; filled box shows interquartile range; whiskers depict data range; circles indicate outlier values. Dotted lines show cutoff points for IBI scoring; bold numbers show scaled scores for IBI.


A. Downstream sampling sites

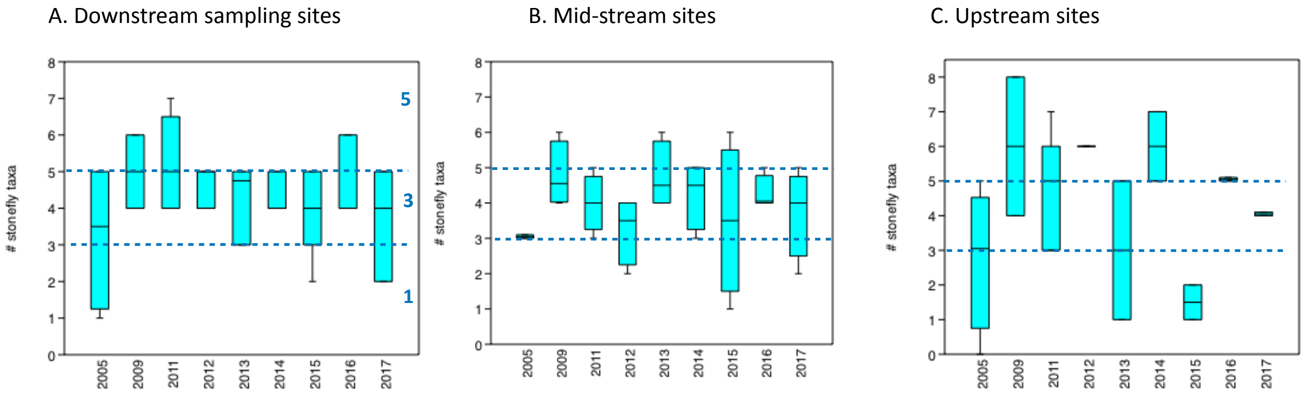
B. Mid-stream sites

C. Upstream sites

Plecoptera richness

The number of stonefly taxa in different years (Figure 5) has changed least among downstream sites. Downstream and mid-stream sites score mainly in the intermediate range of the IBI for this metric, while upstream sites score in the upper portion in more years. Plecoptera richness increased at upstream sites in the last two years after reaching an all-time low in 2015. One-way ANOVA showed no significant difference in between-year means for any sampling reaches, though the difference was close to significant in upstream sites (F=2.233, p=0.08564).

Figure 5. Plecoptera richness across time. Horizontal line in each box indicates the median value; filled box shows the interquartile range; whiskers depict data range; circles indicate outlier values. Dotted lines show cutoff points for IBI scoring; bold numbers show scaled scores for IBI.


A. Downstream sampling sites

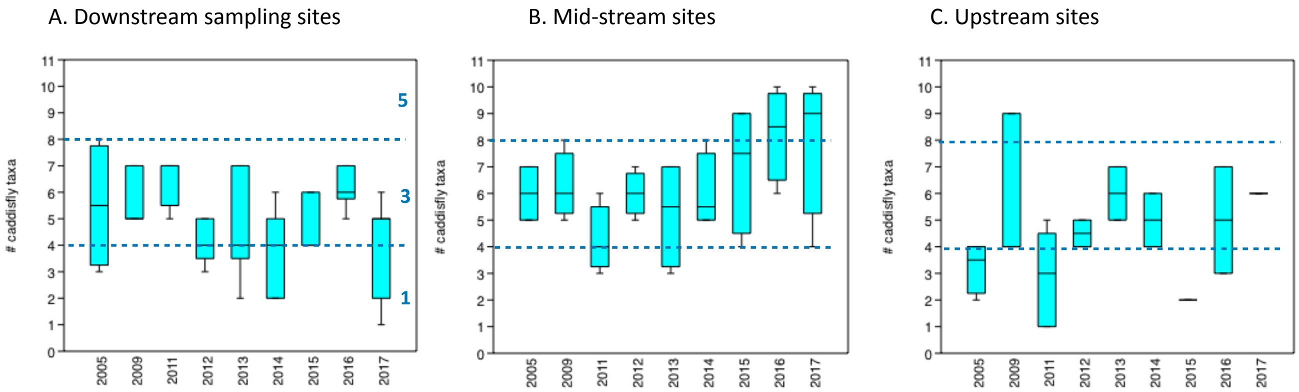
B. Mid-stream sites

C. Upstream sites

Trichoptera richness

The number of caddisfly taxa (Figure 6) increased steadily among mid-stream sites, with greater annual fluctuations in the other reaches. Downstream sites in most years scored in the intermediate range of the IBI for caddisfly diversity; 2017 saw a drop in richness driven by the low number of taxa at WC1100 and WC1150, and the mean was significantly lower in 2017 than in 2016. Means among all years for mid-stream sites were not quite significantly different (F=1.959, p=0.09513), but the median number of caddisfly taxa in 2017 was the highest since sampling began, and values have been in the upper portion of the IBI scoring range for last three years. Between-year means were not significantly different among upstream sites, but the recovery in the number of Trichoptera taxa that was seen in 2016 persisted into 2017, although in most years sites score in the intermediate range of the IBI for this metric.

Figure 6. Trichoptera richness. Horizontal line in each box indicates the median value; filled box shows the interquartile range; whiskers depict data range; circles indicate outlier values. Dotted lines show cutoff points for IBI scoring; bold numbers show scaled scores for IBI.


A. Downstream sampling sites

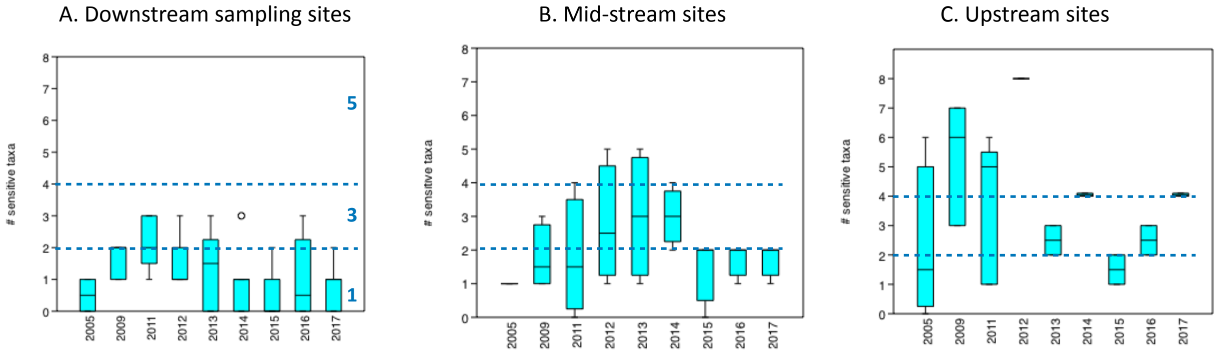
B. Mid-stream sites

C. Upstream sites

Number of sensitive taxa

The number of sensitive taxa has generally been low across all sampling reaches and does not show a consistent pattern of change (Figure 7). There are few sensitive taxa in downstream sites, usually falling within the lowest scaled score range for the IBI. The range of values for this metric narrowed among mid-stream sites in recent years, and more sites scored at the low end of the IBI scale. Upstream sites consistently have the greatest number of sensitive taxa, with more values that correspond to the highest scaled IBI scoring range, and since 2012 the range of this metric within each year has narrowed greatly. However, between-year means are not significant in any of the sampling reaches.

Figure 7. Number of sensitive taxa across time. Horizontal line in each box indicates median value; filled box shows interquartile range; whiskers depict data range; circles indicate outlier values. Dotted lines show cutoff points for IBI scoring; bold numbers show scaled scores for IBI.


A. Downstream sampling sites

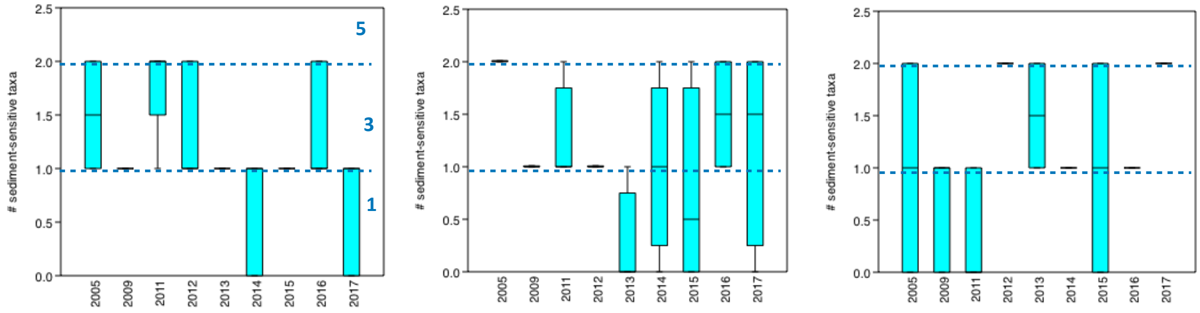
B. Mid-stream sites

C. Upstream sites

Number of sediment-sensitive taxa

The information content of this metric is limited, as sites generally have very few sediment-sensitive taxa, which is reflected by the fact that just two at a site corresponds to the highest scaled score in the IBI. The number of sediment-sensitive taxa has never exceeded two at any site (Figure 8), but while some sites lacked sediment-sensitive taxa in particular sampling years, there are no years in which at least one was not found within each sampling reach. Since 2015, no upstream site has lacked sediment-sensitive taxa, and both upstream sites scored in the highest IBI range for this metric in 2017.

Figure 8. Number of sediment-sensitive taxa across time. Horizontal line in each box indicates median value; filled box shows interquartile range; whiskers depict data range; circles indicate outlier values. Dotted lines show cutoff points for IBI scoring; bold numbers show scaled scores for IBI.



A. Downstream sampling sites

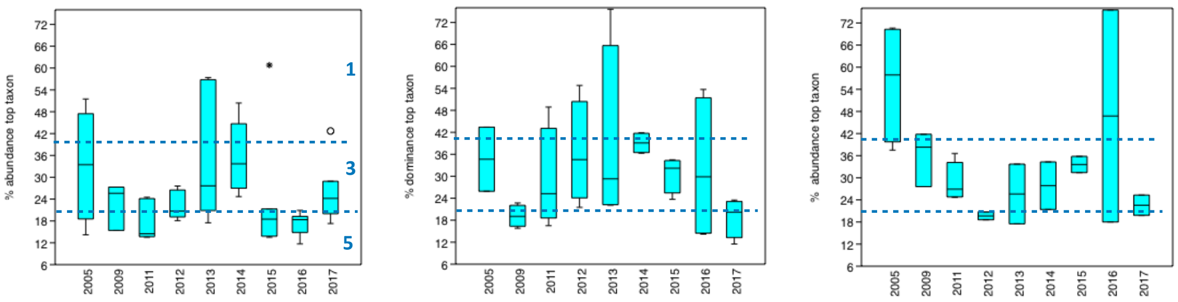
B. Mid-stream sites

C. Upstream sites

Dominance of the top taxon

A balanced biological community should not be numerically dominated by a single group; thus, a lower abundance of the top taxon at a site receives a higher scaled IBI score. Changes in this metric generally reflect improved conditions across time, with a few anomalous years that correspond to restoration activity (Figure 9). Mean abundance of the top taxon among downstream sites was significantly different between years (F=2.207, p=0.0468), with the mean in 2016 significantly lower than in 2012-2014 and 2017. The difference in 2017 was driven by an unbalanced community at WC1150, which consisted of 43% Oligochaeta (tolerant and sediment-tolerant aquatic earthworms; visible as an outlier in Figure 9A); this was likely due to restoration activity, as all other downstream sites had a top taxon abundance from 17-29% in 2017. Between-year means were not significant among mid-stream or upstream sites, although a downward trend in top taxon abundance continues at mid-stream sites. In 2016, the mean for upstream sampling sites was skewed because the community at WC2600 consisted mainly of black flies (*Simulium*). This is a common event post-restoration, as simuliids can be a pioneer species following stream disturbance (Hammock & Bogan, 2014), and in 2017 the community was more balanced, with the mayfly *Baetis tricaudatus* comprising the greatest abundance, at just 25%.

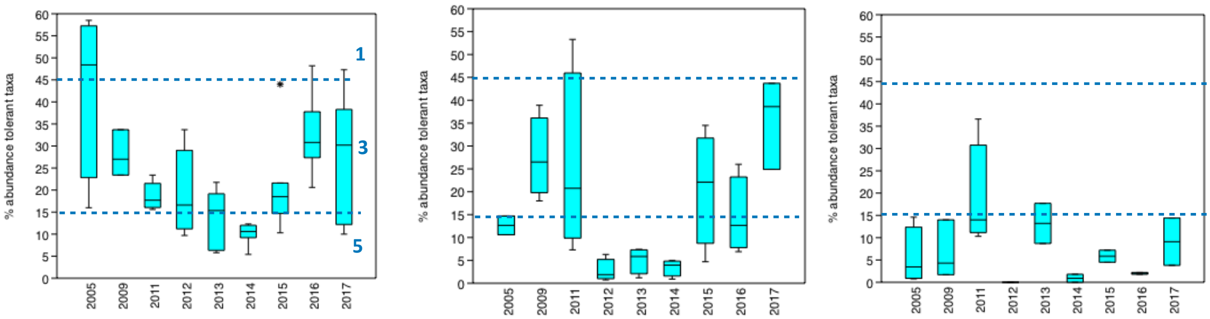
Figure 9. Relative abundance of top taxon across time. Horizontal line in each box indicates median value; filled box shows interquartile range; whiskers depict data range; circles indicate outlier values. Dotted lines show cutoff points for IBI scoring; bold numbers show scaled scores for IBI.


A. Downstream sampling sites B. Mid-stream sites C. Upstream sites

Percent tolerant taxa

The relative abundance of tolerant taxa is another negative IBI metric, with a lower raw value receiving a higher scaled score. This metric decreased for several years in both downstream and mid-stream sites, with scaled IBI scores correspondingly moving from the intermediate to highest range, but in the past two years the proportion of tolerant taxa has again increased in these reaches (Figure 10). The difference in mean values for this metric is significantly different between years among downstream sampling sites (F=5.444, p=0.0001) and among mid-stream sampling sites (F=5.205, p=0.0008). In downstream sites, the mean in 2005 was significantly greater than in 2011-2015 and the mean in 2016 was significantly higher than in 2014. Among mid-stream sites, the mean proportion of tolerant taxa was significantly greater in 2017 than in 2012-2014. Upstream sites consistently have the lowest relative abundances of tolerant taxa, scoring in the highest scaled range of the IBI, and the difference in the mean values of this metric between years is not quite significant (F=2.478, p=0.06179).

Figure 10. Relative abundance of tolerant taxa across time. Horizontal line in each box indicates median value; filled box shows interquartile range; whiskers depict data range; circles indicate outlier values. Dotted lines show cutoff points for IBI scoring; bold numbers show scaled scores for IBI.


A. Downstream sampling sites

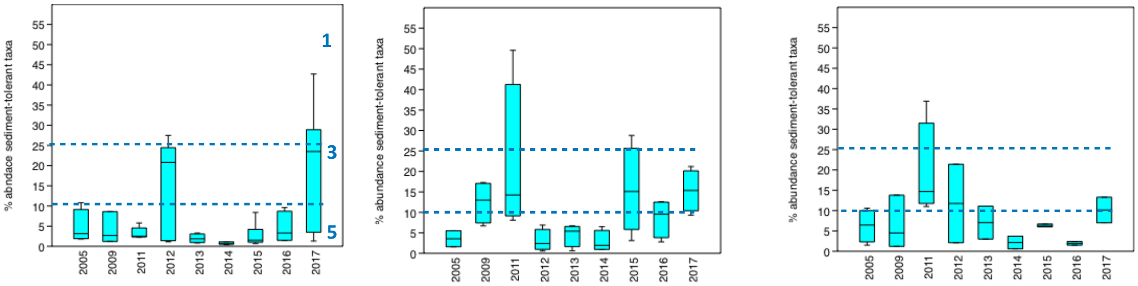
B. Mid-stream sites

C. Upstream sites

Relative abundance of sediment-tolerant taxa

The relative abundance of sediment-tolerant taxa is a negative metric, with a lower raw value receiving a higher scaled score. Sediment conditions have been a strong driver of the macroinvertebrate community in Whychus Creek, and in recent years the value for this metric among downstream and upstream sampling sites has been in the highest scoring range of the IBI (Figure 11). The increased mean for this metric in 2017, which was significantly higher than in 2011 and 2013-2016, was related to restoration activity at WC1100; the community downstream at WC1150 had a much higher proportion of sediment tolerant taxa (42%) compared to sites further from this disturbance (1.3-5.6% at sites WC600-WC0900). Among mid-stream sites, the mean relative abundance of sediment-tolerant taxa decreased after 2009 and remained low for several years, but increased in recent years. Between-year means in upstream sites are significantly different (F=2.562, p=0.0343), with 2017 mean significantly greater than in 2012-2014. Between-year differences in mean values for this metric are not significant among upstream sites, where relative abundances of sediment-tolerant taxa decreased after 2011 and have remained low since (i.e., at the highest end of the scaled IBI score).

Figure 11. Relative abundance of sediment-tolerant taxa across time. Horizontal line in each box indicates median value; filled box shows interquartile range; whiskers depict data range; circles indicate outlier values. Dotted lines show cutoff points for IBI scoring; bold numbers show scaled scores for IBI.


A. Downstream sampling sites

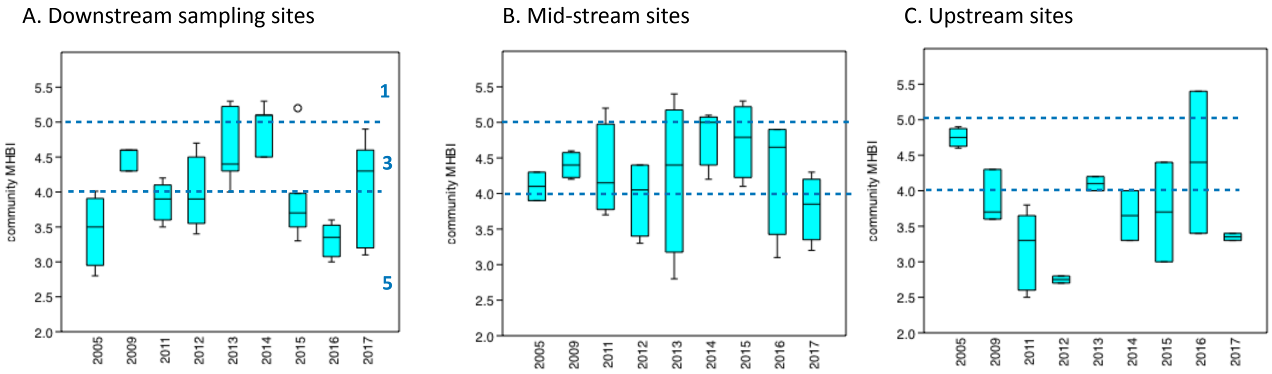
B. Mid-stream sites

C. Upstream sites

Modified Hilsenhoff Biotic Index (MHBI):

MHBI is a measure of tolerance to organic inputs and thus is often more revealing in urban streams. Values range from 0 to 10, with a lower value indicating greater sensitivity. Community MHBI is calculated for each sample as the weighted mean of individual taxon MHBI values. This metric shows substantial annual variation among all reaches (Figure 12). A sustained increase in community MHBI among downstream sites from 2005-2014 has decreased in recent years; means are significantly different between years (F=6.712, p=.00001), with the mean in 2015 significantly lower than in 2014 and the 2016 mean significantly lower than in 2009 and 2013-2014. In 2017 the community MHBI increased but the mean was not significantly different from other years, and the highest values again occurred around the new restoration site (WC1100 and WC1150). Community MHBI has a wider range among mid-stream sites and though it has decreased in recent years, differences in between-year means are not significant. Among upstream sites, a drop in community MHBI from 2009-2012 was followed by several years of increase, which may have been driven by impacts of the Whychus floodplain restoration project at WC2600. Between-year means differ significantly (F=3.611, p=0.01546), with the mean in 2012 significantly lower than in 2005; the mean value for sites in 2017 did not differ significantly from previous years, but the range was much narrower and closer to the values seen in 2012.

Figure 12. Community MHBI across time. Horizontal line in each box indicates median value; filled box shows interquartile range; whiskers depict data range; circles indicate outlier values. Dotted lines show cutoff points for IBI scoring; bold numbers show scaled scores for IBI.


A. Downstream sampling sites

B. Mid-stream sites

C. Upstream sites

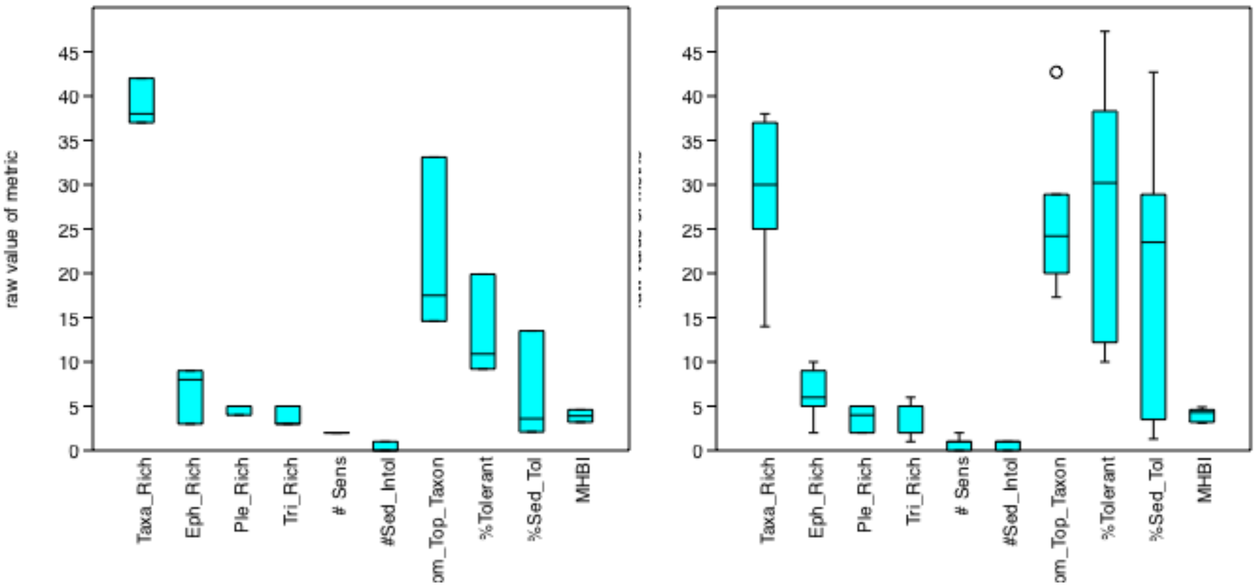
Side channels at Whychus Canyon

Because the IBI was developed as an assessment tool for riffle samples and the side channel samples were taken in a variety of microhabitats, direct comparison of IBI scores between channel and mainstem samples in not appropriate. However, to establish a baseline and provide comparison with stream samples in the same region of the creek, individual metric scores were examined (Figure 13).

Within the three side channels, CH1 and CH2 were most similar (Bray-Curtis similarity = 0.876). The major trait differences for CH3 compared to the other two channel samples were a much lower number of mayfly taxa, a more unbalanced community, a higher proportion of sediment-tolerant taxa, and a higher community MHBI. Taxa richness in each channel was similar, but CH3 had only one-third as many mayfly taxa as CH2 and was dominated by chironomid midges in the Orthocladiinae subfamily (33.1%). The other channels were dominated by more lotic taxa types at lower relative abundances (CH1 dominated at 17.5% total abundance by the stonefly *Zapada cinctipes*, and Ch2 dominated at 14.6% abundance by the mayfly *Attenella margarita)*.

The IBI metric values of the 2017 channel and mainstem downstream sampling sites had an average dissimilarity of 26.4% (SIMPER test on Bray-Curtis index), with the primary drivers of observed differences being % tolerant taxa (contributing 26.9% of difference) and % sediment-tolerant taxa (contributing 25% of difference), the mean values of which were both greater in downstream sites.

Figure 13. Raw values for individual IBI metrics among new side channels at the WC1100 restoration project and mainstem downstream sites (WC0150 - WC1150). Note that Y-axis values for the first six metrics shown are number of taxa, the next three are percent abundances, and the final metric is the community MHBI value. Horizontal line in each box indicates the median value; filled box shows the interquartile range; whiskers depict data range; circles indicate outlier values.



A. Channel sites, 2017

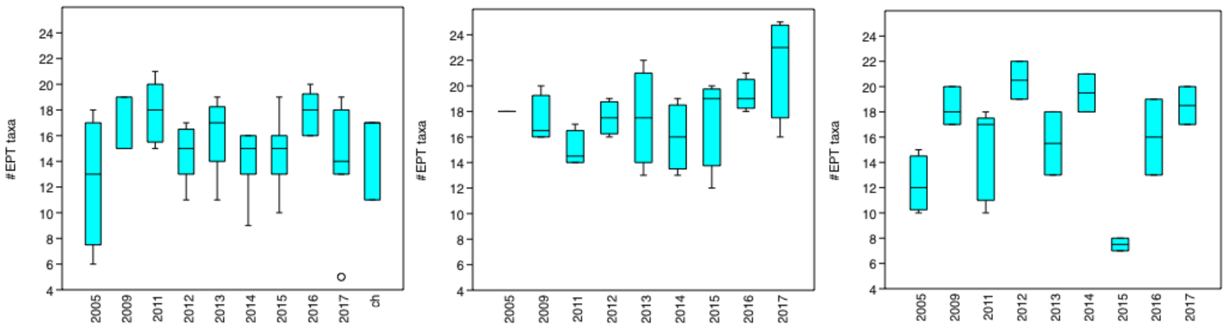
B. Downstream sites, 2017

Additional Community Metrics

EPT Richness

EPT are often examined as a group, as these orders contain some of the most sensitive stream taxa. EPT richness increased over time in all sampling reaches (Figure 14). In downstream sites, mean values are not significantly different between years, but EPT numbers were higher in 2016 and 2017 than in previous years, except for WC1100 in 2017. EPT richness in side channel samples was similar to other mainstem downstream sites in 2017. Number of EPT taxa has increased among mid-stream sampling sites, but between-year means are not quite significantly different (F=2.069, p=0.0787). EPT diversity in upstream sites has fluctuated more, but increased overall since 2005. An exception occurred in 2015, when WC2425 and WC2600 samples had much lower richness than in other years, but numbers recovered in 2016-2017. Between-year differences in mean EPT richness in upstream sites are significant (F=4.858, p=0.00417), with the 2015 mean significantly lower than in 2017, 2014, 2012, and 2009, and not quite significantly lower than in 2016 (p=0.0765).

Figure 14. Number of EPT taxa (Ephemeroptera, Plecoptera, Trichoptera) across time. Horizontal line in each box indicates median value; filled box shows interquartile range; whiskers depict data range; circles indicate outlier values. “Ch” indicates newly-created side channels around WC1100 sampled in 2017.



A. Downstream sampling sites

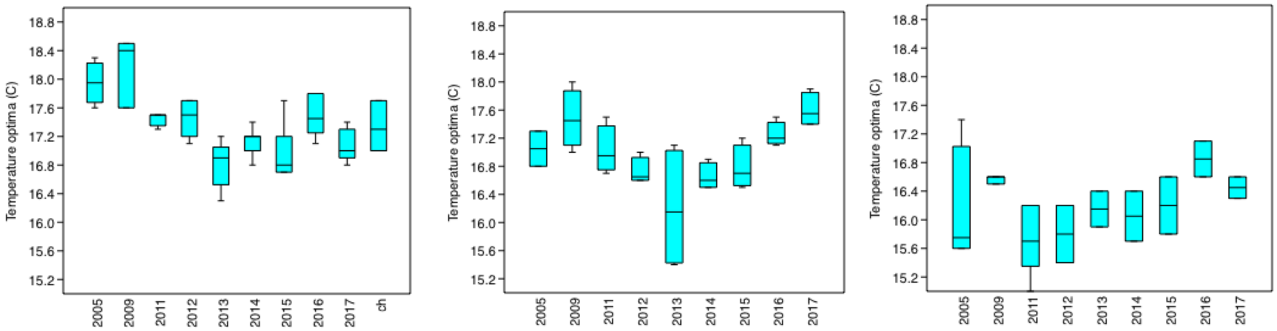
B. Mid-stream sites

C. Upstream sites

Community Temperature Optima

Community temperature optima are calculated as the weighted mean of optima for individual taxa in the sample. When monitoring began, downstream sites had the highest community temperature optima and upstream sites had the lowest, but mean temperature optima decreased overall through 2013 (Figure 15). In 2016 temperature optima rose in all reaches, suggesting that additional stressors such as climate change could be operating. In 2017, community temperature optima stabilized or decreased at downstream and upstream sites, but were higher at mid-stream sites. Between-year differences in temperature optima were significant among downstream sites (F=11.02, p=4 x 10^{-8}); the mean in 2013 was significantly lower than in all previous years, while means in 2017, 2015, and 2014 were significantly lower than in 2005 and 2009. In contrast, the community temperature optima of mid-stream sites has increased steadily since 2014, and between-year means are significantly different (F=4.716, p=0.0012), with the means in 2016 and 2017 significantly greater than in 2013. This sustained increase among mid-stream sampling sites suggests that while earlier projects such as restoration of instream flow allowed colonization and/or survival of taxa with lower temperature optima, either additional stressors are operating in this region of the stream in recent years, or the community is reflecting a sustained habitat condition such as lack of shading. Mean temperature optima among upstream sampling sites changed less than in other reaches and are not significantly different between years.

Figure 15. Mean community temperature across time. Horizontal line in each box indicates median value; filled box shows interquartile range; whiskers depict data range; circles indicate outlier values. “Ch” indicates new side channels.


A. Downstream sampling sites

B. Mid-stream sites

C. Upstream sites

ORDEQ Indicator Taxa for Temperature

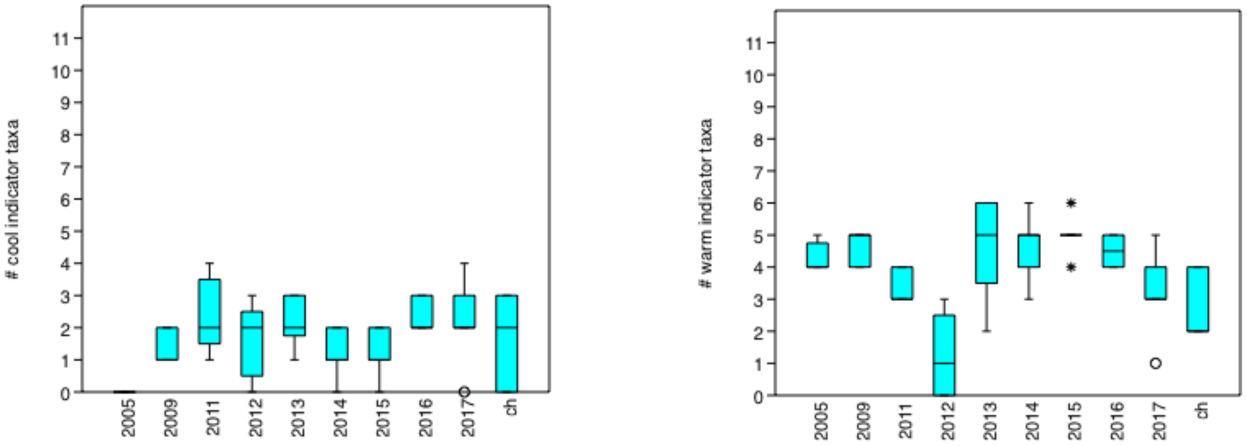
ORDEQ developed a dataset of taxa that indicate cool or warm water conditions (see Appendix B). Numbers of cool indicator taxa increased since 2005 in all sampling reaches (Figure 16), and means are significantly different between years in downstream (F=3.854, p=0.0018) and mid-stream sites (F=3.542, p=0.0071), and not quite significant in upstream sites (F=2.48, p=0.0616). There were no cool indicators in downstream sites in 2005, and the mean number was significantly higher in most later years (2011, 2013, 2016, and 2017). The number of cool indicator taxa was also lowest in mid-stream sites in 2005, and means increased through 2013. A decrease in cool indicators in 2014-2016 recovered in 2017, and the mean in 2017 is significantly greater than in 2005. Upstream sites have the most cool indicator taxa overall, with a three-fold increase by 2012. A decrease in cool indicator taxa from 2013-2015 is recovering in recent years, and the 2017 mean, while not significantly different from other years, is similar to 2009 and 2011.

The increase in cool indicators was accompanied by a decrease in warm indicator taxa in all reaches, and the means differ significantly between years in downstream (F=8.066, p=0.000002), mid-stream (F=9.363, p=0.000007), and upstream (F=6.563, p= 0.0009) sites. For the first few years the number of warm indicators at downstream sites decreased, and while they increased significantly in 2013-2016 compared to 2012, downstream sites had fewer warm indicator taxa in 2017. Similarly, the number of warm indicator taxa in mid-stream sites decreased in early sampling years (with significantly lower mean numbers in 2011, 2012, and 2014 than in 2005) then increased in 2015 and 2016 (means significantly higher than three of the four previous sampling years). However, the number of warm indicator taxa in 2017 was significantly lower than in 2005. Upstream sites have never had more than three warm indicator taxa, and the means 2011, 2012, 2015 are significantly lower than lower than in 2005.

Figure 16. Number of DEQ indicator taxa for cool and warm temperatures. Horizontal line in each box indicates median value; filled box shows interquartile range; whiskers depict data range; circles indicate outlier values. “Ch” indicates newly-created side channels around WC1100 sampled in 2017.

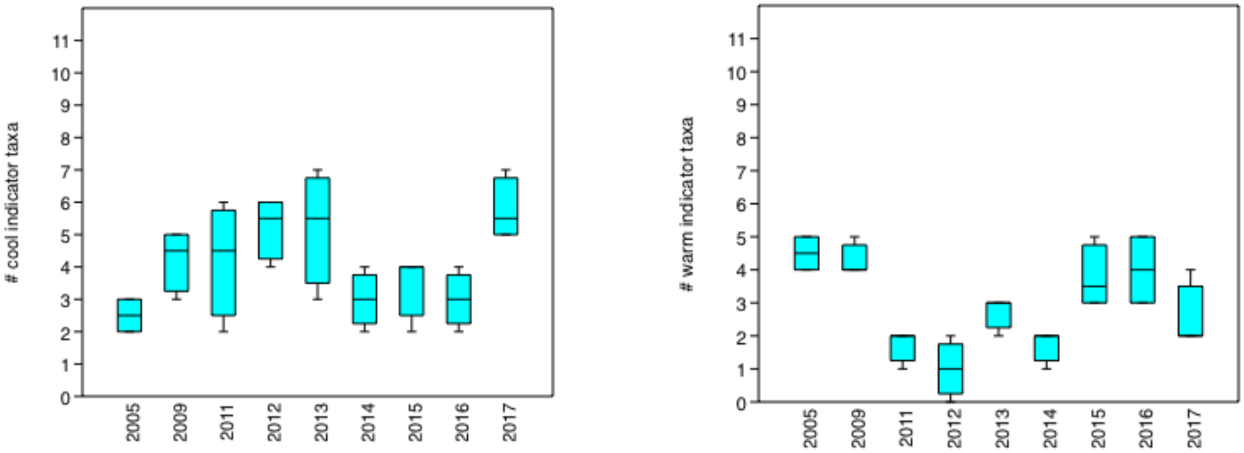
A. Downstream, cool indicator taxa

B. Downstream, warm indicator taxa

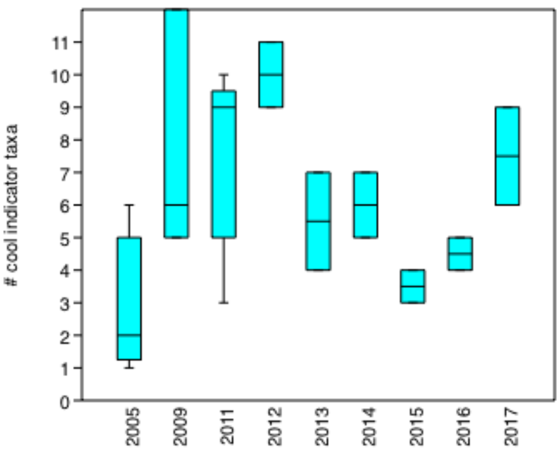


C. Mid-stream, cool indicator taxa

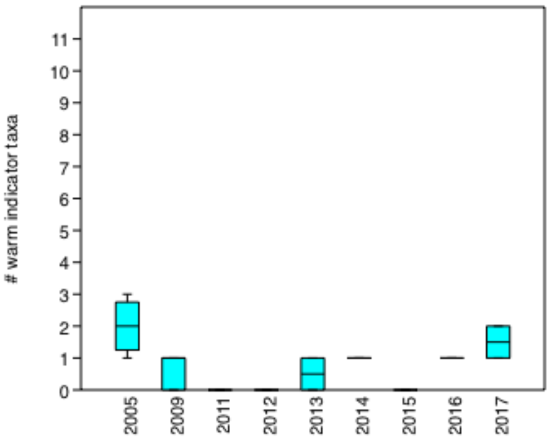
D. Mid-stream, warm indicator taxa



E. Upstream, cool indicator taxa



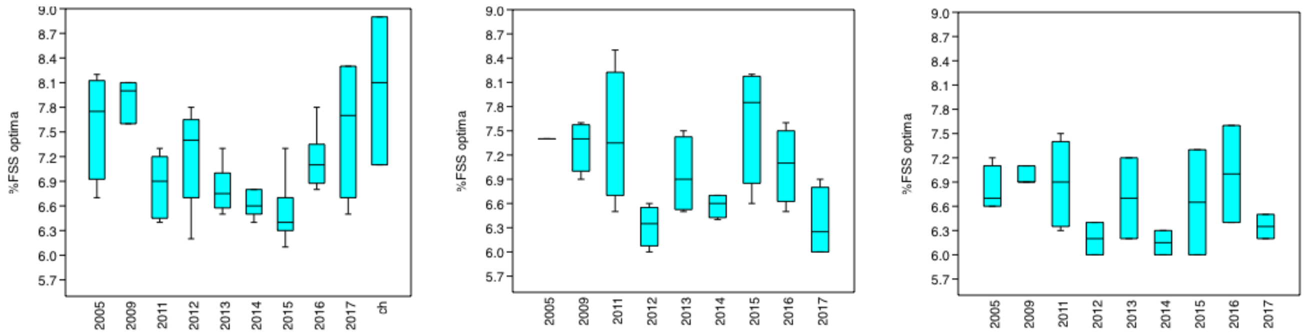
F. Upstream, warm indicator taxa



Community Sediment Optima

ORDEQ developed a dataset of individual taxa optima values for percent fine sediments (%FSS). Community sediment optima are calculated for each site as the weighted mean of optima for individual taxa in the sample. The %FSS optima decreased overall from 2005-2014 in all reaches (Figure 17). Among downstream sites, mean community %FSS were significantly lower (F=4.918, p=0.00026) in 2011, 2013, 2014, and 2015 compared to 2009. Although the 2017 mean did not differ significantly from other years, the highest community %FSS optima were at WC1100 and WC1150, where a new restoration project was implemented, and communities in the new side channels at WC1100 also had high %FSS optima. Community %FSS optima fluctuated greatly among mid-stream sites and was significantly different between years (F=3.753, p=0.0051), with means in 2012 and 2017 significantly lower than in 2015. Mean %FSS optima among upstream sites are lower overall than in other reaches, and while values fluctuate from year to year, the differences are not significant.

Figure 17. Mean community optima for percent fine suspended sediment (%FSS) across time. Horizontal line in each box indicates the median value; filled box shows the interquartile range; whiskers depict data range; circles indicate outlier values. "Ch" indicates newly-created side channels around WC1100 sampled in 2017.


A. Downstream sampling sites

B. Mid-stream sites

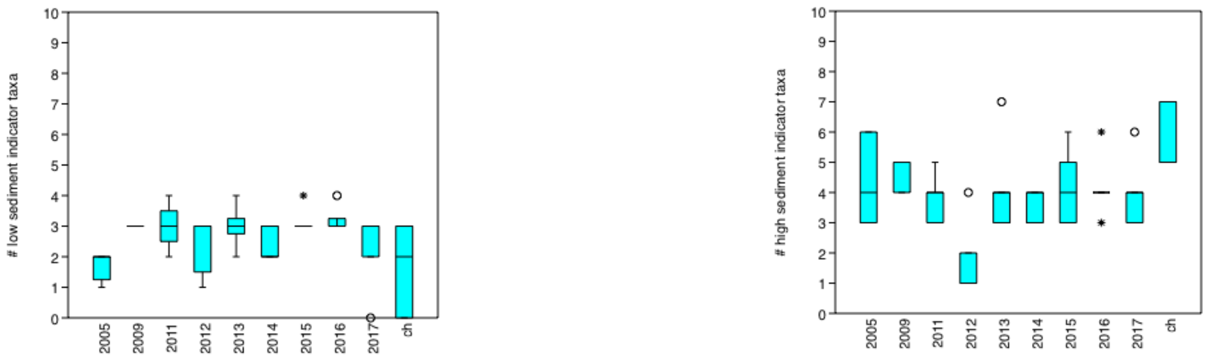
C. Upstream sites

ORDEQ Indicator Taxa for Sediment

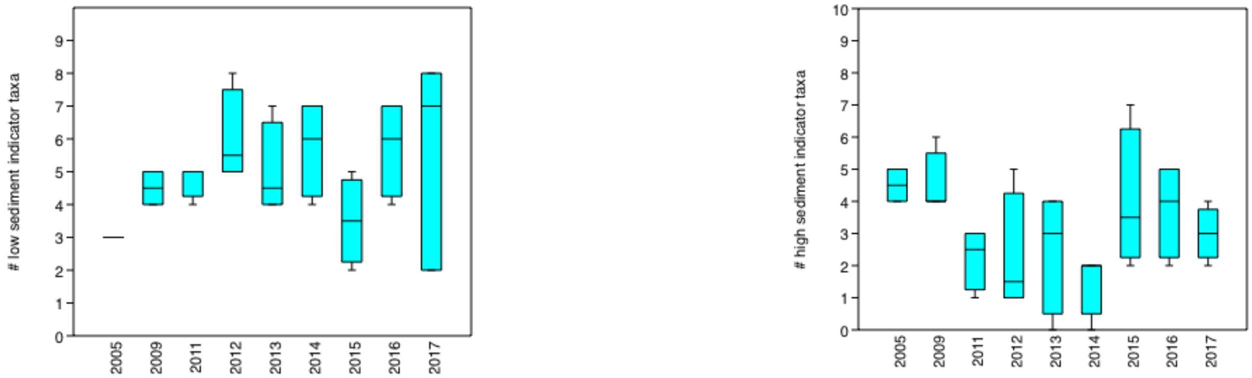
ORDEQ developed a dataset of taxa that are considered indicators of low or high sediment conditions (see Appendix B). The number of low sediment indicator taxa increased since 2005 in all sampling reaches, with mid- and upstream sites having consistently higher numbers compared to downstream reaches (Figure 18). Among downstream sites, the increased number of low sediment indicators after 2005 remained fairly stable; in 2017, not surprisingly, WC1100 was an outlier that lacked low sediment indicators, as did one of the new side channels. Between-year means are significantly different (F=2.491, p=0.0269), with 2016 greater than 2005, and the mean in 2015 not quite significantly greater than 2005 (p=0.0535). The increase in low sediment indicator taxa in mid-stream sites after 2005 also remained stable, apart from a drop in 2015, and between-year means are not significantly different. The number of low sediment indicator taxa is highest in upstream sites, and after a decrease in 2013-2015 that may have been related to restoration at Whychus floodplain, numbers recovered in 2017. Between-year means are significantly different (F=4.904, p=0.00399), with the means in 2017 and 2012 significantly greater than in 2015.

The increase in low sediment indicators in early sampling years was accompanied by a decrease in high sediment indicator taxa in all reaches. In downstream sites, the number of high sediment indicators reached a low in 2012 then increased slightly and stabilized. Between-year means differ significantly (F=2.804, p=0.01418), with the mean in 2012 significantly lower than in all sampling years except 2011. The new side channel communities sampled in 2017 had the most high sediment indicators. In mid-stream sites, the decrease in high sediment indicators was interrupted in 2015, but they have not increased in recent years, and between-year means are not significantly different. Upstream sites have fewer high sediment indicator taxa overall, and while numbers increased slightly since 2014, between-year means are not significantly different.

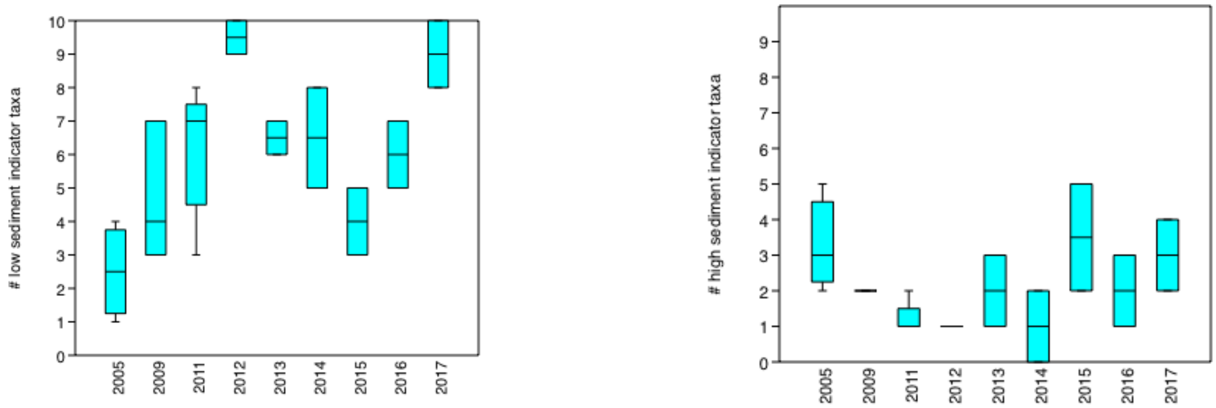
Figure 18. Number of DEQ indicator taxa for low and high sediment conditions. Horizontal line in each box indicates the median value; filled box shows the interquartile range; whiskers depict data range; circles indicate outlier values. “Ch” indicates newly-created side channels around WC1100 sampled in 2017.


A. Downstream, low sediment indicator taxa

B. Downstream, high sediment indicator taxa


C. Mid-stream, low sediment indicator taxa

D. Mid-stream, high sediment indicator taxa


E. Upstream, low sediment indicator taxa

F. Upstream, high sediment indicator taxa

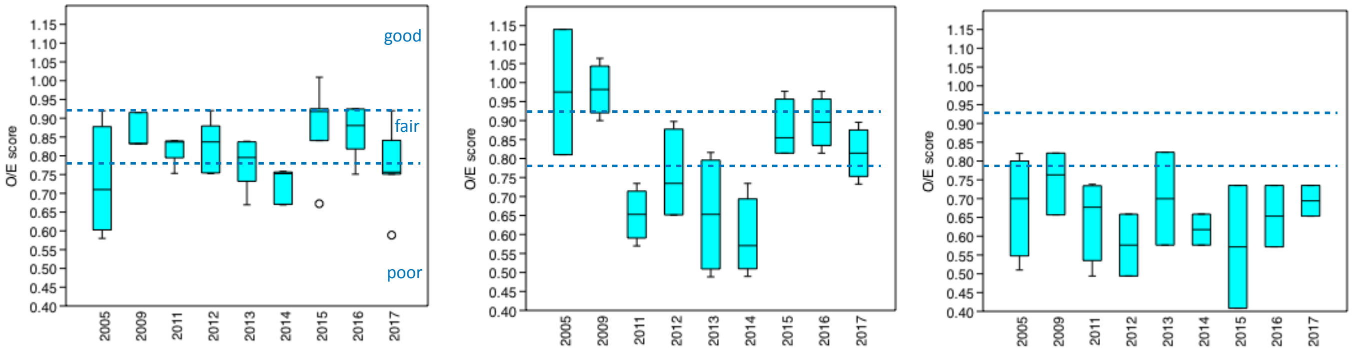
Predator Model

Of the 13 mainstem sites sampled in 2017, none had PREDATOR O/E scores indicating good/least disturbed conditions; five (38.5%) had scores indicating fair/moderately disturbed conditions; and eight (61.5%) had scores indicating poor/most disturbed conditions. The mean among downstream sites was 0.76 ± 0.10 (poor conditions), but restoration at WC1100 gave this site an anomalously low score; if WC1100 is excluded, the mean among downstream sites is 0.80 ± 0.07 (fair condition). The mean among mid-stream sites also corresponds to fair condition (0.81 ± 0.07), while the upstream site mean was lower (0.69+0.06; poor condition).

As always, biological conditions indicated by PREDATOR scores are worse than those indicated by the IBI (i.e., upstream site IBI scores in 2017 corresponded to slight and no disturbance), and correlation between IBI and O/E scores is poor (Pearson's r =0.203, p=0.033). The relationship is stronger among downstream (Pearson's r = 0.419, p=0.0025) and mid-stream sites (Pearson's r = 0.348, p=0.043), but is not significant for upstream sites (p=0.084).

Among downstream sites, O/E scores decreased overall through 2014 then rose again in recent years (Figure 19). Between-year differences are significant (F=2.647, p=0.019), with the mean in 2016 significantly higher than in 2014. Mid-stream sites show a similar pattern; between-year means are significantly different (F=7.005, p=.00008), and mean scores in 2016 and 2015 are significantly higher than 2014. Upstream sites have fluctuated less but remain in the lower scoring range, and mean values between years are not significantly different.

Figure 19. PREDATOR O/E scores. Horizontal line in each box indicates median value; filled box shows interquartile range; whiskers depict data range; circles indicate outlier values. Dotted lines indicate cutoff values for biological condition scoring ranges.


A. Downstream sampling sites

B. Mid-stream sites

C. Upstream sites

PREDATOR consistently indicates poorer biological condition than the IBI and downgrades upstream sampling sites. In contrast, many traits such as #EPT and community sediment and temperature optima show a community responding to improved habitat conditions. Although in each year the site test indicates that the model is suitable and that appropriate reference streams were identified for comparison, Whychus Creek has lower annual precipitation than any of the reference streams the model selects as most appropriate (Shannon Hubler, pers. comm.), making it an outlier. The PREDATOR model has not been re-calibrated since its creation using stream survey data from 1998-2004, and the WCCP model for the Cascades has lower precision than the MWCF model for the Willamette Valley (Hubler, 2008; Hubler, pers. comm.). Periodic sampling of reference streams is needed to detect shifts in reference conditions, so the sensitivity of this model may have changed over time, especially since despite substantial changes since 2005 in macroinvertebrate community composition, some taxa are identified by the model as missing or replacement in every year (see below).

Missing/Replacement Taxa

The PREDATOR model identifies taxa that are expected to occur at each sampling site but were not collected (missing), and taxa that were not expected but were collected (replacement), based on comparison to model reference sites. The missing/replacement taxa are investigated in each year to provide further details about community changes.

Community Composition

Downstream sites:

SIMPER analysis of presence/absence data on the missing/replacement taxa for the most consistently monitored downstream sites (WC0150, sampled 2009-2017; WC0600, sampled 2005-2017; WC0900, sampled 2005-2017) showed a high between-year similarity of missing taxa groups (63-80% similar). At the site with the lowest overall community similarity (WC0900), missing taxa identified in 2005 differed most from subsequent years, and missing taxa in later years were 78% similar. Several taxa were identified as missing in each site and sampling year, including *Malenka* (forest stonefly) and Pisidiidae (fingernail clam; high sediment indicator). At WC0150, no taxa were consistently identified as missing in early but not later sampling years, or vice versa; at WC0600, *Epeorus* (sensitive flat-headed mayfly; a low sediment/cool temperature indicator) and Tanypodinae (chironomid midge subfamily; high sediment indicator) were identified as missing in early years but not in the past three years; and at WC0900, the lotic *Baetis* (mayfly) and *Simulium* (black fly) were missing in 2005 but not in subsequent years.

Groups of replacement taxa differed more between years at each site (49-60% similar), and 2005 was not an outlier at any site. Replacement taxa were less consistent between sites, but those that occur most frequently across years and sites are *Acentrella* (baetid mayfly), *Ampumixis* (riffle beetle), *Atherix* (tolerant water snipe fly), and *Glossosoma* (sediment-intolerant saddlecase-maker caddisfly; requires perennial flow; low sediment indicator).

Mid-stream sites:

Similarity between years was low (25-74% similar) among missing taxa at the most consistently sampled mid-stream sites (WC1825 and WC1900, sampled 2005-2017; WC1850 and WC1950, sampled 2009-2017). At sites with the lowest overall similarity (WC1825 and WC1900), missing taxa identified in 2005 differed most from subsequent years, and taxa identified in later years were 64% and 62% similar, respectively. *Calineuria* (golden stonefly), *Malenka*, and Pisidiidae were identified as missing across almost all years and sites. In 2012-2014, years in which the creek was in its new channel at Camp Polk, Chironominae (tolerant non-biting midge subfamily) and *Hydropsyche* (tolerant net-spinning caddisfly; perennial flow indicator; warm temperature indicator) were identified as missing from WC1825, and Leptophlebiidae (prong-gill mayflies) and *Optioservus* (tolerant riffle beetle; perennial flow, warm temperature, and high sediment indicator) were identified as missing from WC1900.

Replacement taxa differed more between years at each site (41-55% similar); the 2005 community was an outlier at the site with the lowest between-year similarity (WC1900), and the community in subsequent years was 52% similar. *Antocha* (sediment-tolerant crane fly; warm temperature indicator), *Rhithrogena* (flat-headed mayfly; low temperature indicator), and *Acentrella* (small minnow mayfly) were seen as replacement taxa in almost every year. Some taxa were identified as replacements only in early years, including *Tricorythodes* (little stout crawler mayfly; sediment-tolerant and tolerant) and *Wormaldia* (sediment-intolerant finger-net caddisfly; perennial flow indicator); and some replacement taxa were seen only in later years, including *Brachycentrus* (humpless case-maker caddisfly), *Ochrotrichia* (tolerant micro-caddisfly), and *Agapetus* (saddlecase-maker caddisfly; perennial flow indicator).

Upstream sites:

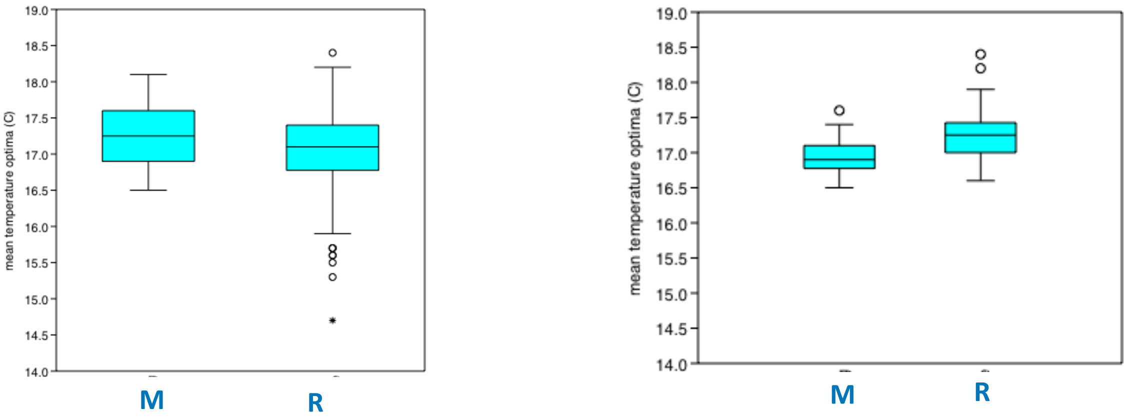
Overall similarity between years for missing taxa at sites WC2425 and WC2600 (sampled in all years) was low (48% at both sites); the 2005 community differed most from all other years, and taxa identified as missing from 2009-2017 were 72-80% similar. At both sites, *Calineuria* and *Zaitzevia* (tolerant riffle beetle; perennial flow indicator) were identified as missing in all years, and the tolerant *Hydropsyche* and Pisidiidae, along with *Malenka,* were missing in every year except 2005.

Replacement taxa in upstream sites had the lowest between-year similarity of all sampling reaches (35% overall similarity), and the 2005 replacement community was not an outlier. *Acentrella* was a replacement taxon in all years at both sites, and taxa identified as replacement among the sites after 2005 included *Suwallia* (green stonefly) and *Serratella* (spiny crawler mayfly).

Temperature Optima

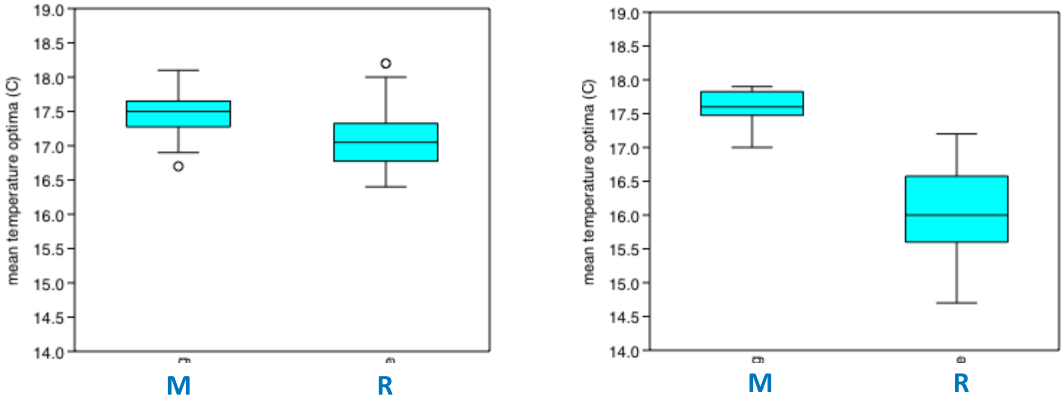
Mean temperature optima of replacement communities are significantly lower than for missing communities (F=11.88, p=0.0007) in all sampling sites and years (Figure 20). When considered by reach, the mean temperature optima for the replacement community at downstream sites is significantly higher than for the missing community (F=24.76, p=0.000004), but significantly lower at mid-stream (F=16.73, p=0.00011) and upstream sites (F=78.52, p,0.00001).

Figure 20. Mean temperature optima among missing and replacement communities for sites sampled in all sampling years between 2005-2017. Horizontal line in each box indicates the median value; filled box shows interquartile ranges; whiskers depict data range; points show outliers. M = missing community; R = replacement community.



A. All sites

B. Downstream sites



C. Midstream sites

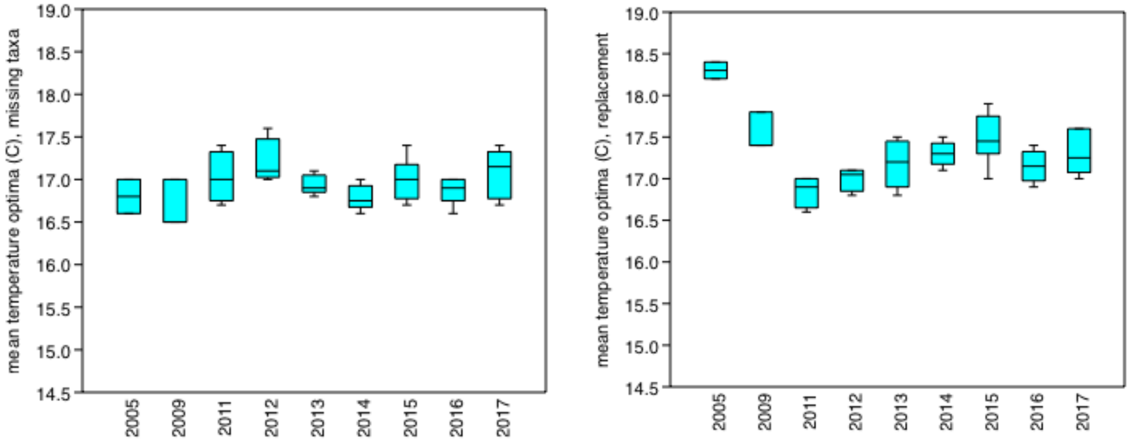
D. Upstream sites

Temperature optima also differ significantly between years in downstream and mid-stream sites (Figure 21). In downstream sites, between-year mean temperature optima of the missing community were not significantly different, but differences in means of replacement communities were significant (F=9.116, p=1.5x10-6), with mean temperature optima in 2009-2017 significantly lower than in 2015, means in 2011-2012 significantly lower than in 2009, and the 2015 mean significantly higher than 2011.

Among mid-stream sites, between-year mean temperature optima were significantly different for both the missing (F=7.544, p=.00004) and replacement community (F=4.633, p=0.0014). Mean temperature optima of missing taxa were significantly higher in 2011-2015 and 2017 than in 2005; significantly higher in 2012 and 2014 than in 2009; and significantly higher in 2016 than in 2012. Mean temperature optima among replacement taxa were significantly lower in 2011 and 2012 than in 2005, and significantly higher in 2013 and 2015 than in 2012.

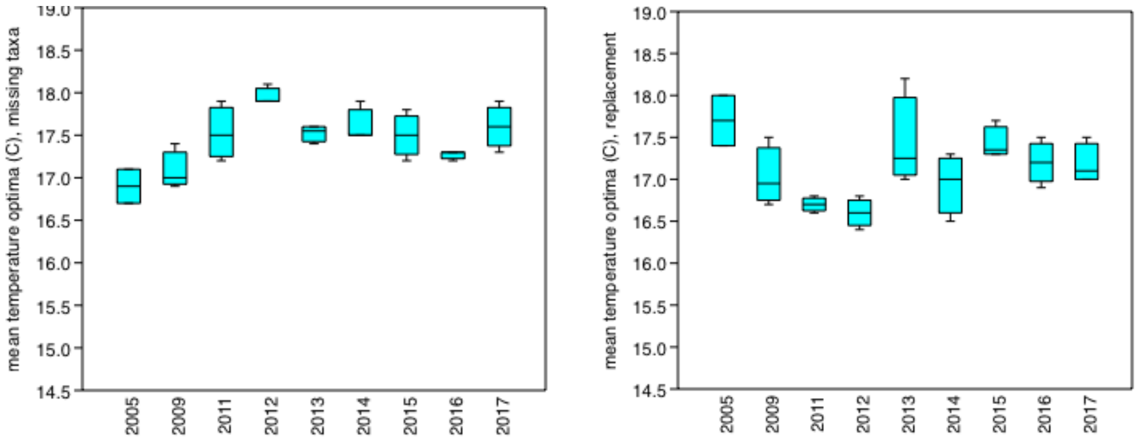
Among upstream sites, there was no significant difference between years for mean temperature optima of missing or replacement communities, although optima among the replacement taxa decreased steadily from 2005-2011, while temperature optima of the missing communities increased over time.

Figure 21. Mean temperature optima among missing and replacement communities between years. Horizontal line in each box indicates the median value; filled box shows interquartile ranges; whiskers depict data range; points show outliers.

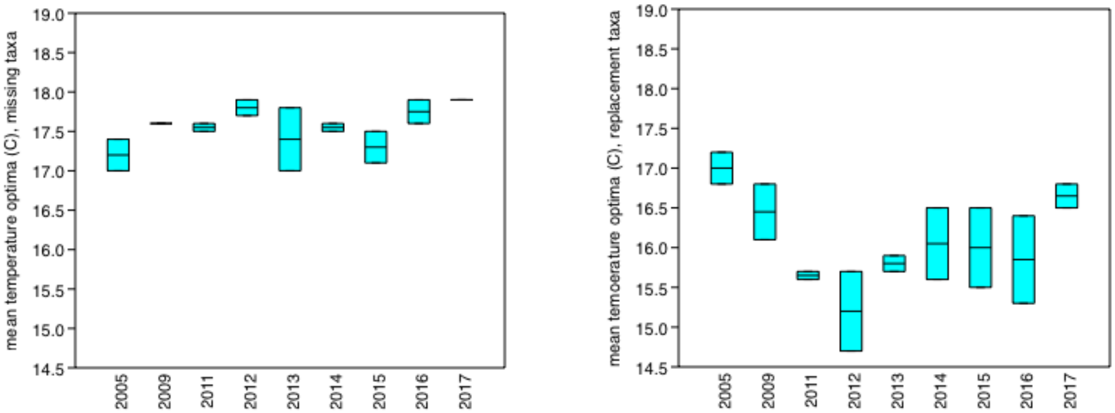


A. Downstream sites, taxa identified as missing

B. Downstream sites, taxa identified as replacement


C. Mid-stream, taxa identified as missing

D. Mid-stream, taxa identified as replacement


E. Upstream, taxa identified as missing

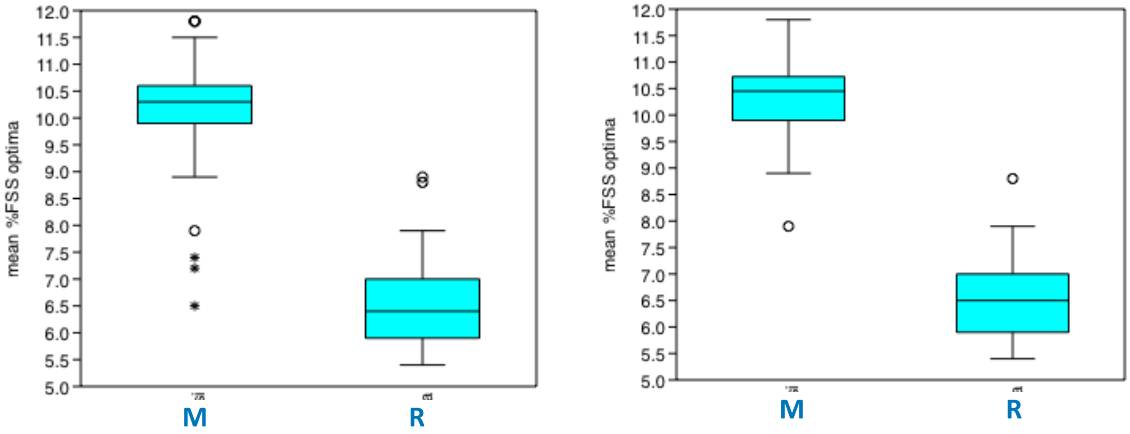
F. Upstream, taxa identified as replacement

Fine suspended sediment (%FSS) optima

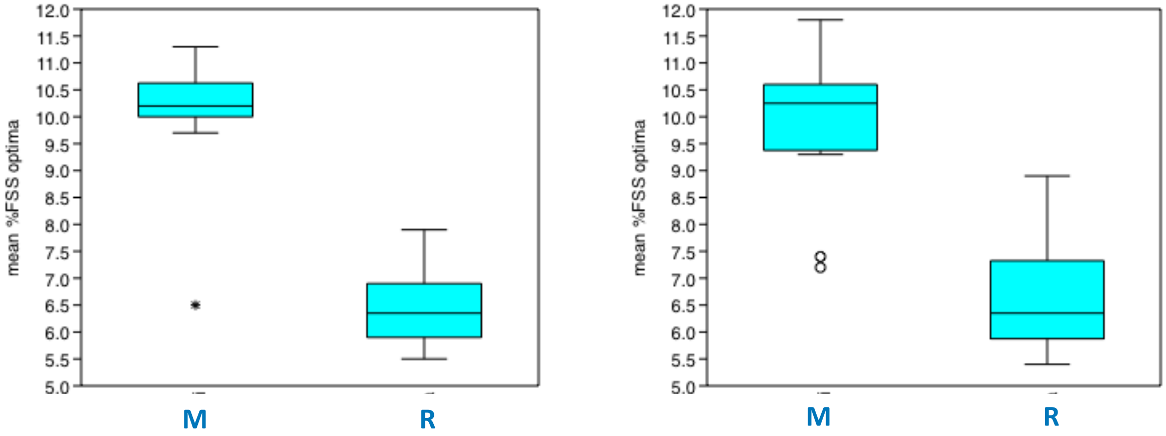
Mean %FSS optima in all sampling sites and years are significantly lower in replacement communities than missing communities (F=978.7, p<0.00001) as well as in each sampling reach (F>93 and p<0.00001; Figure 22).

The mean %FSS optima of missing communities also differed significantly between years in all sampling reaches (downstream, F=2.521, p=0.0292; mid-stream, F=4.097, p=0.0003; upstream, F=11.01, p=0.0008; Figure 23). Among downstream sites, the mean %FSS optima of missing taxa in 2015 was significantly greater than in 2005. Among both mid-stream and upstream sites, means in 2009-2017 were significantly greater than 2005. However, mean %FSS optima among replacement taxa did not differ significantly between years in any of the sampling reaches.

Figure 22. Mean %FSS optima among missing and replacement communities for sites sampled in all sampling years between 2005-2017. Horizontal line in each box indicates median value; filled box shows interquartile ranges; whiskers depict data range; points show outliers. M = missing taxa; R = replacement taxa.

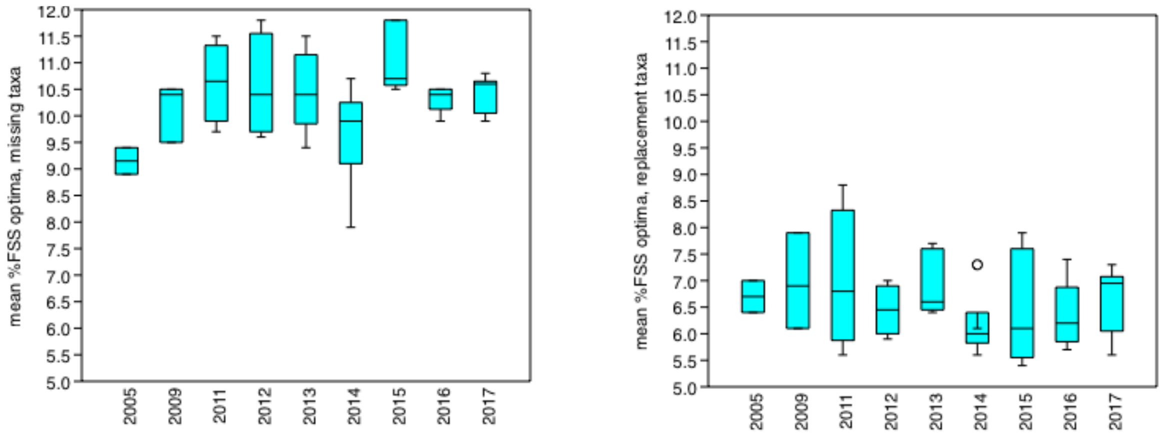

A. All sites, all years

B. Downstream sites, all years

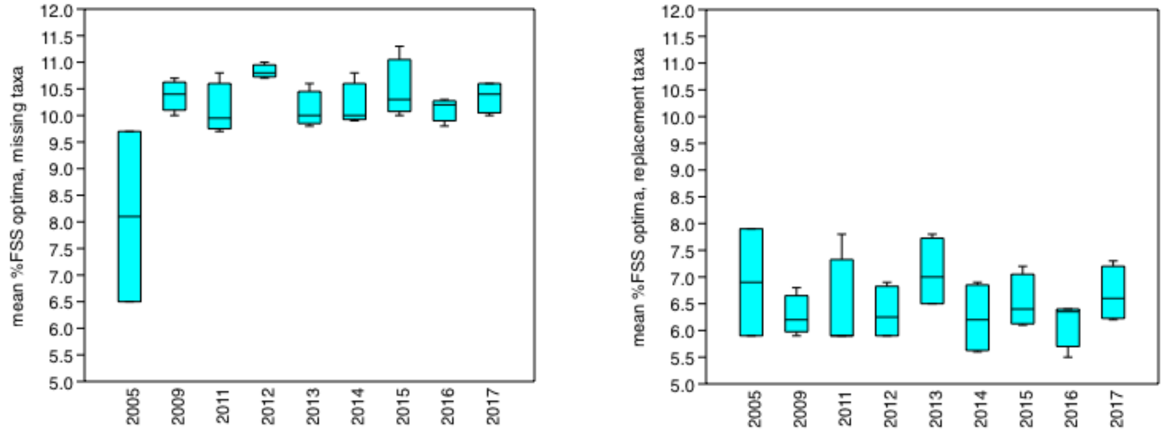

C. Midstream sites, all years

D. Upstream sites, all years

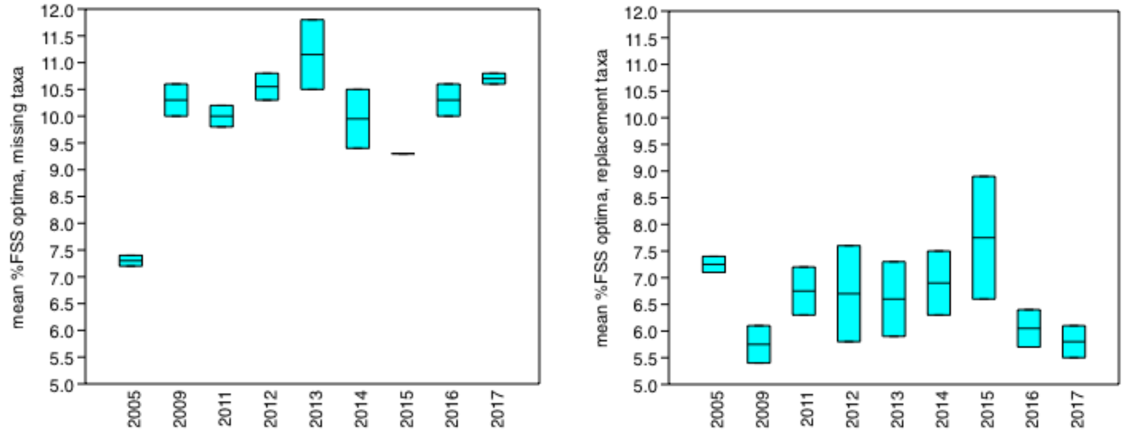
Figure 23. Mean %FSS optima among missing and replacement communities between years. Horizontal line in each box indicates median value; filled box shows interquartile ranges; whiskers depict data range; points show outliers.


A. Downstream sites, taxa identified as missing

B. Downstream sites, taxa identified as replacement


C. Mid-stream, taxa identified as missing

D. Mid-stream, taxa identified as replacement


E. Upstream, taxa identified as missing

F. Upstream, taxa identified as replacement

Increaser/Decreaser Taxa

The PREDATOR model calculates a sensitivity index based on the number of sites at which a taxon was collected divided by the number at which it was expected to be collected (So/Se). A single sensitivity score is thus generated for each taxon across the entire sampling set; taxa with So/Se >1 are increasers (collected more frequently than expected) and taxa with So/Se <1 are decreasers (collected less frequently than expected). Increaser and decreaser taxa in Whychus Creek were analyzed across all sampling years; to avoid a bias for rare taxa, increasers were identified using So/Se >1.3 and taxa with So/Se <0.8 were identified as decreasers.

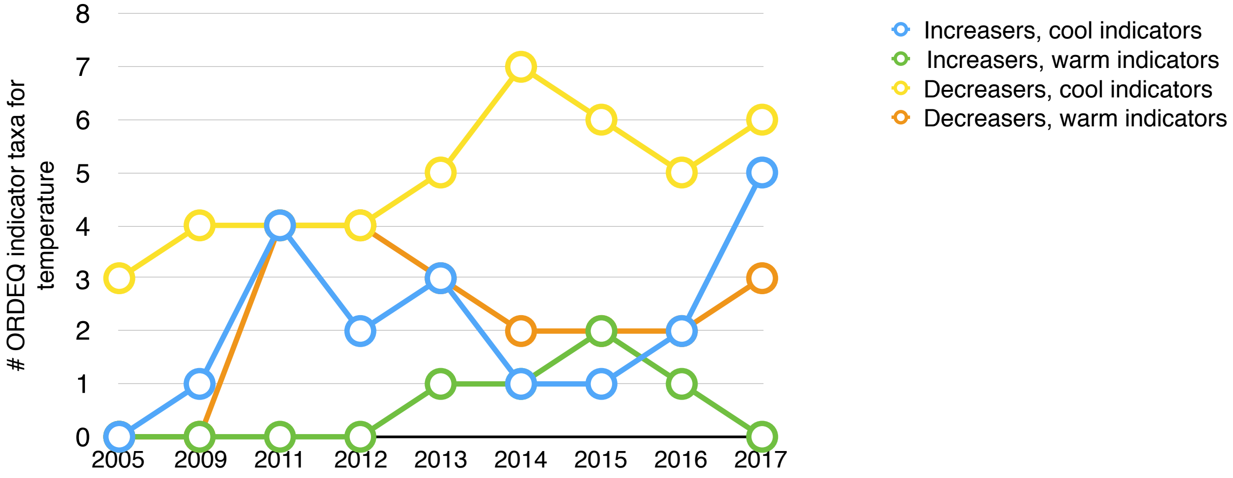
The decreaser community is more similar across all sampling years than the increaser community (60% vs. 42% overall similarity). The 2017 increaser community had three taxa not identified as increasers in any previous year: *Arctopsyche*, a sediment-intolerant net-spinning caddisfly (perennial flow and low sediment indicator) found at most mid-stream and upstream sites; *Petrophila*, an aquatic moth caterpillar, found at WC0850 and WC2400; and *Visoka*, a sensitive stonefly (cool temperature and intermittent flow indicator) found at upstream sites. The decreaser community contained two taxa not seen as decreasers in prior years: *Doroneuria*, a golden stonefly (cool temperature, low sediment, and perennial flow indicator) and *Cheumatopsyche*, a tolerant net-spinning caddisfly (high sediment indicator), both absent from the 2017 sample set.

The number of EPT taxa was lowest in both the increaser and decreaser community in 2005 and 2009 (11-16); in later years the numbers more than doubled in both communities (20-35 EPT taxa/year among increasers and 21-32 EPT/year among decreasers in 2011-2017). However, the number of EPT among increasers was equal to or less than that among decreasers in five of those seven years, so this increase in EPT in both communities in later years is more of a reflection of overall increased EPT richness after 2009.

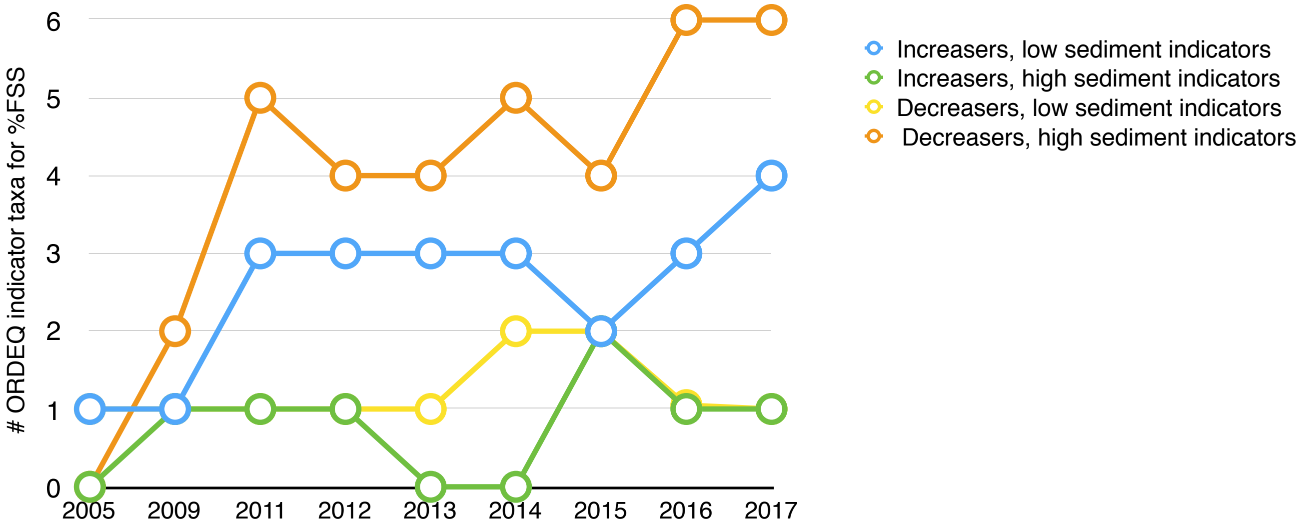
Changes in abundance of ORDEQ indicator taxa for sediment and temperature in the increaser/decreaser communities indicate a stronger response to improved sediment conditions (Figure 24). There were no cool indicator taxa among increasers in 2005, but their numbers rose through 2011, and although they decreased in 2012-2014 (years in which additional restoration projects were implemented), recent years have seen another increase. Warm indicator taxa first appeared in the increaser community in 2013 in low numbers and again dropped to zero in 2017.

Figure 24. ORDEQ indicator taxa for temperature and fine suspended sediment (%FSS) present in increaser and decreaser communities.

A. Temperature indicator taxa



B. Sediment indicator taxa



The number of warm indicator taxa in the decreaser community also rose from 2005 -2012, and while it dropped slightly in subsequent years, numbers were again higher in 2017. More unexpectedly, the number of cool indicator taxa in the decreaser community doubled since sampling began. These nine cool indicator taxa are mainly EPT with a variety of feeding modalities. One commonality is that most have a univoltine life cycle (one generation/year); aquatic insects with faster life cycles tend to be more abundant (i.e., better able to survive) in disturbed systems (Piliere et al., 2016), and so might be expected to decrease in abundance or diversity as stream conditions improve. However, all but one of the cool indicator taxa in the increaser community are also EPT with a variety of feeding guilds and a univoltine life cycle, so neither functional feeding group nor life history appears to be an explanation for the presence of numbers of cool indicator taxa in the decreaser community.

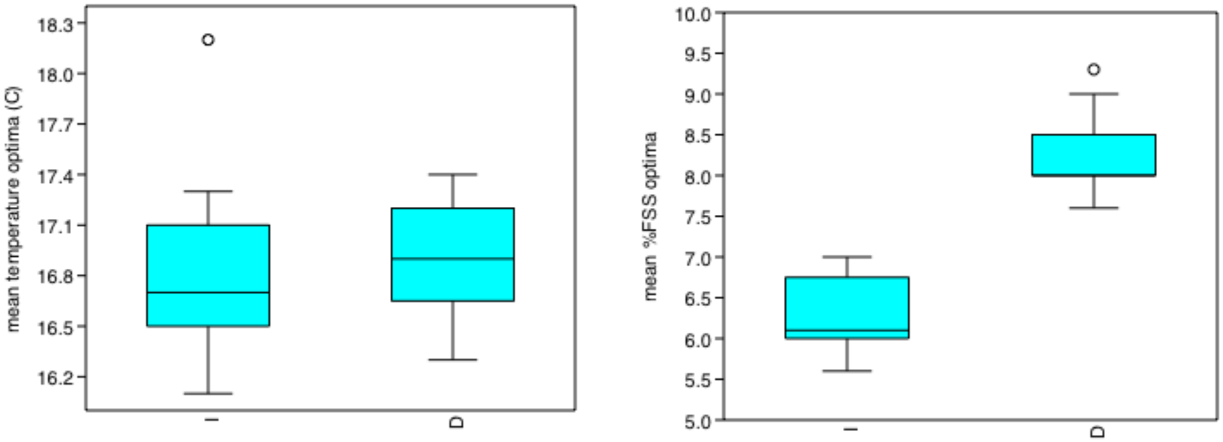
Response to changing sediment conditions is stronger and more consistent. The number of low sediment indicators in the increaser community tripled since sampling began, while the number of high sediment indicators among the increasers remains low. The number of high sediment indicators in the decreaser community rose steadily through 2011, then plateaued and increased again in the last two sampling years, while the number of low sediment indicators among the decreasers remains low.

Increaser and decreaser taxa also show greater separation between mean %FSS optima than between mean temperature optima (Figure 25). The mean temperature optima of the increaser community overall is lower than the decreaser community, but the difference is not significant. However, when examined by year, mean temperature optima of increaser taxa is significantly higher than that of decreasers in 2005 (p=0.0526), and in all other years except 2015, the mean temperature optima of the increaser community was equal to or less than that of the decreaser community, though the difference was significant only in 2011 (p=0.0449).

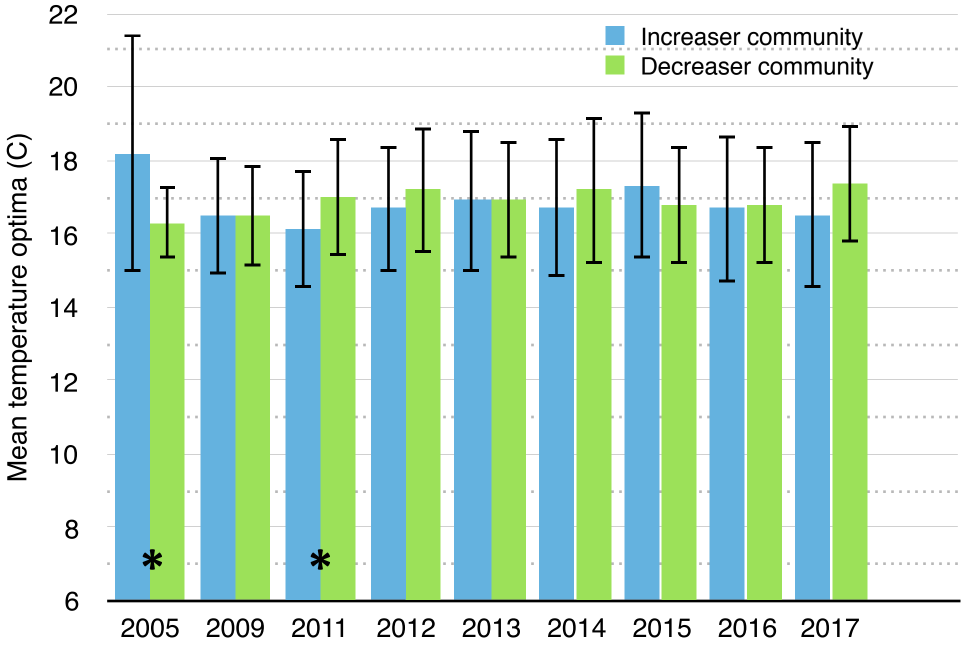
The overall mean %FSS optima of increasers is significantly lower than that of decreasers (F=63.11, p<0.00001), and mean %FSS optima of the increaser community is lower than that of the decreasers in every sampling year, though the difference is significant only after 2011 (significant in 2012, 2014, 2016-2017, and close to significant in 2011 [p=0.0641]).

Figure 25. Community temperature and sediment optima of taxa identified in each year as increasers and decreasers by the PREDATOR model. Asterisk indicates significant difference ($p < 0.05$) between increaser and decreaser community means in that year.

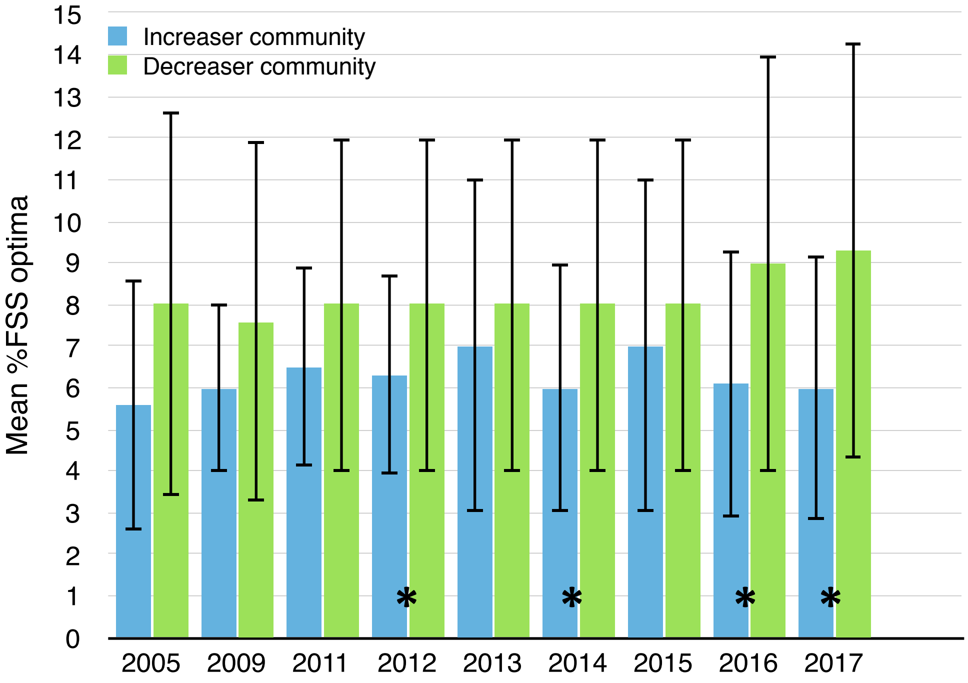
A. Community temperature optima (left) and %FSS optima (right) of increaser and decreaser taxa across all sampling years. Horizontal line in each box indicates the median value; filled box shows interquartile ranges; whiskers depict data range; points show outliers. I = Increasers, D = decreasers.



B. Comparison of community temperature optima of increaser and decreaser taxa by year. Asterisk indicates years where the difference between the means of the increaser and decreaser community is significant ($p<0.05$).



C. Comparison of community %FSS optima of increaser and decreaser taxa by year. Asterisk indicates years where the difference between the means of the increaser and decreaser community is significant (p<0.05).



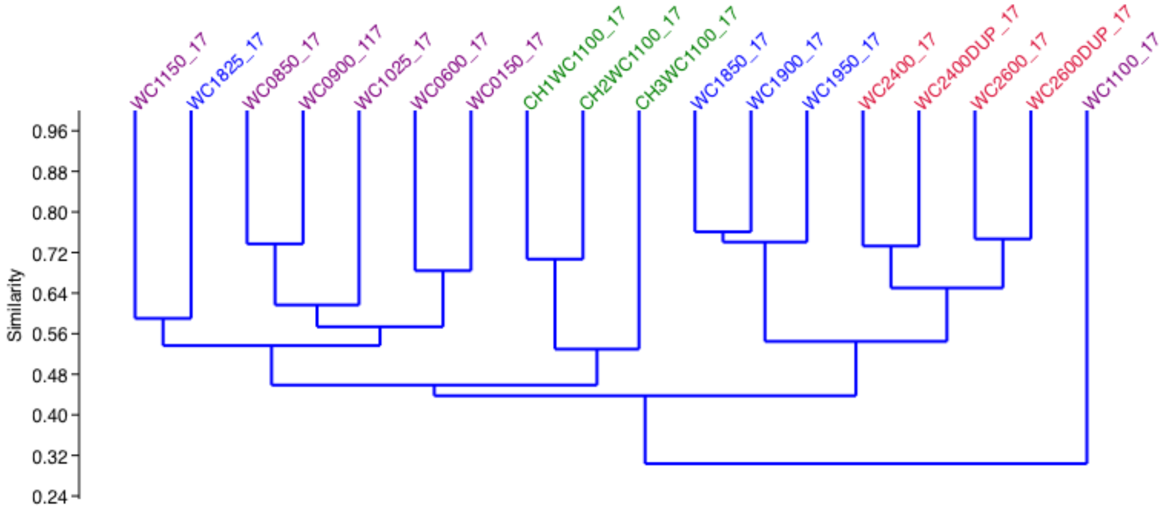
Community Composition

CLUSTER analysis of the 2017 macroinvertebrate data validated the sampling protocol, as the sample taken at each duplicate site was most similar to its control. As in past years, most samples clustered by reach, with upstream and mid-stream samples forming two separate clusters more closely related to each other than to either the downstream or side channel samples (Figure 26). The exception is WC1100, where severely reduced macroinvertebrate abundance and diversity resulting from recent restoration made this community the least similar to all other sites. The side channels, which formed a separate cluster at 52% overall similarity, were most closely related to the remaining downstream sites, suggesting they are providing habitat for taxa that moved from the disturbed reach at WC1100.

Within the side channels, CH1 and CH2 communities were most similar and had more lotic taxa than CH3. Ch3 had a higher overall abundance of non-biting midges (Chironomidae), especially less specialized, more tolerant types (Orthocladiinae and Chironomini, found in gravel and sand/silt, respectively), while CH1 and CH2 had greater abundance and diversity of mayflies and caddisflies, especially *Brachycentrus* (humpless case-making caddisfly; found on logs, branches and plants in riffles), and a much greater abundance of *Atherix* (water snipe fly; found in riffles and pools in lotic habitats).

Side channel communities overall differed most in comparison to mainstem downstream sites by having higher abundances of *Zapada cinctipes* (forest stonefly) and *Brachycentrus*, as well as more of the tolerant Orthocladiinae midges.

Figure 26. CLUSTER analysis of the 2017 Whychus Creek macroinvertebrate community. Analyses were done on a Bray-Curtis similarity matrix of square root-transformed abundance data. Downstream sites = purple, side channel sites = green, mid-stream sites = blue, upstream sites = red



A two-way ANOSIM of the macroinvertebrate community from 2005-2017 showed site separation by both year (R=0.6649, p=0.0001) and location (i.e. DS, MS, US; R=0.7929, p=0.0001). The macroinvertebrate community in Whychus Creek changed most in earlier sampling years. The 2017 macroinvertebrate community is least similar to the 2005 community across all reaches (31-37% similar), while the communities in 2009 are 42-54% similar to the 2017 communities, and the communities in 2016 are 53-59% similar to the 2017 communities. The years between 2009 and 2016 did not necessarily see a steady increase in average similarity to the 2017 community, however. Macroinvertebrate communities typically show high annual variation, but ongoing restoration projects along Whychus across the complete sampling period are driving shifts in macroinvertebrate community composition. To investigate this further, changes in macroinvertebrate community traits were examined at specific restoration sites.

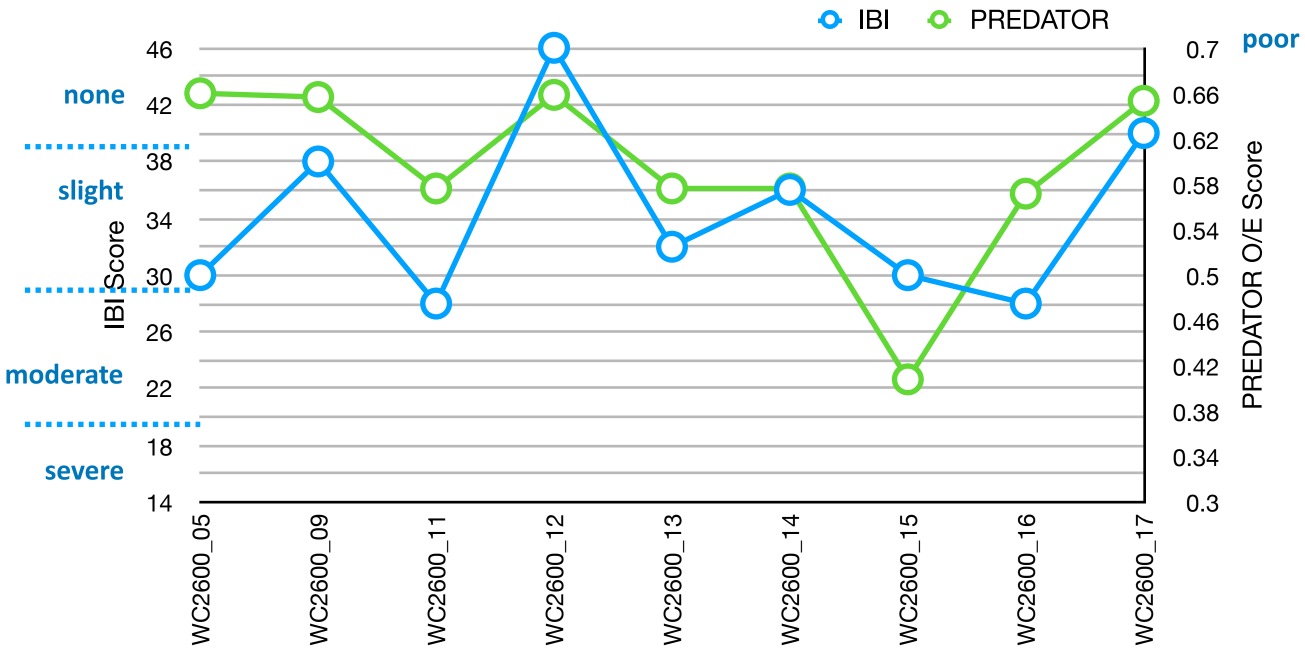
Individual analysis of restored sites

Projects implemented in the early years of Whychus Creek restoration (i.e., increased streamflow) are expected to have positive impacts on aquatic macroinvertebrate communities throughout the creek, while others, though improving habitat conditions in the future, will have short-term negative impacts due to disruptions such as dewatering and movement of the creek into a new channel. Some of the annual fluctuations in community composition and traits described above may be driven by restoration activities. For this reason, macroinvertebrate community composition and traits were examined at specific sites in different reaches where intense restoration activity occurred: Whychus Floodplain (WC2600); Camp Polk (WC1825-WC1950); and Whychus Canyon (WC1100-WC1150 and side channels).

Whychus Floodplain (WC2600)

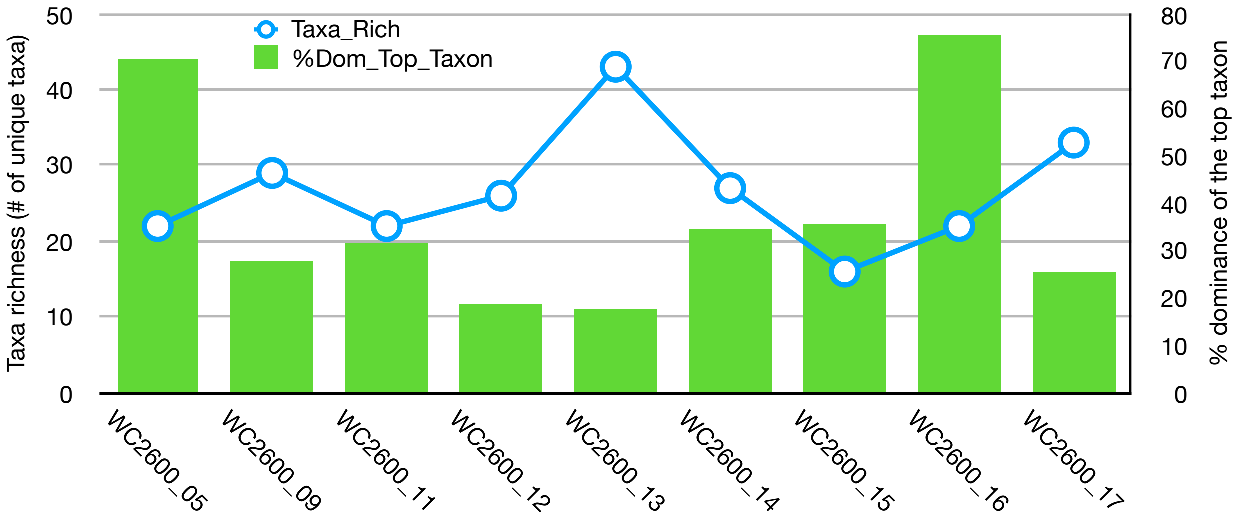
The creek was directed into a new meandering channel at this site in 2014. The PREDATOR score for this site has indicated poor biological conditions (<0.78) in every sampling year, while IBI scores indicate better biological conditions, from moderate to slight and no disturbance (Figure 27). The highest IBI and PREDATOR scores at this site occurred in 2012; both sets of scores dropped in 2013-2015 and increased in recent years.

Figure 27. IBI and PREDATOR O/E scores for WC2600.



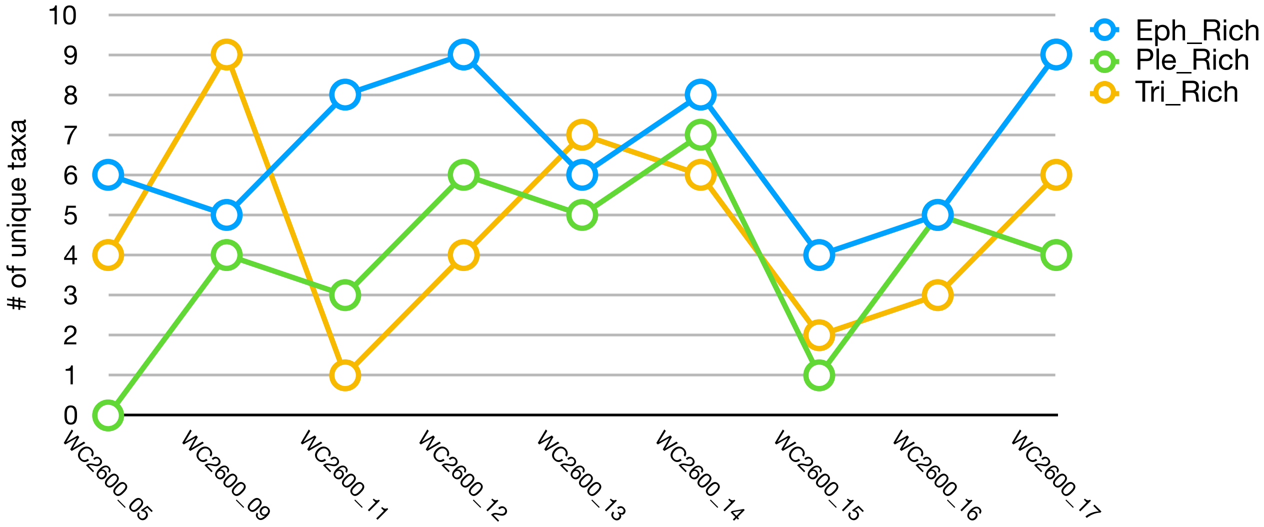
Several individual IBI metrics that improved in early sampling years were apparently impacted negatively by restoration activities but recovered subsequently. The site had only 22 unique taxa in 2005, but by 2013 diversity peaked at 43 taxa, and increasing diversity was accompanied by a decrease in relative abundance of the dominant taxon. In 2005, the community was dominated by chironomid midges (71% Orthocladiinae); in 2013, Orthocladiinae still dominated, but the relative abundance of the top taxon was at its lowest (18%). A drop in taxa richness in 2014-2015 was mirrored by a rise in % dominance of the top taxon, and in 2016, black fly larvae (*Simulium*) comprised 76% of the community. Black flies can be pioneer species and ecological engineers and may dominate in disturbed habitats, creating substrate and resources used by later colonists (Wotton et al., 1998; Hammock & Bogan, 2014). Indeed, in 2017, when taxa richness recovered again to near-peak numbers (33 taxa), *Simulium* comprised only 2% of the macroinvertebrate community, and the site was dominated by the mayfly *Baetis tricaudatus* (a low sediment indicator) at a relative abundance of 25%.

Figure 28. Changes in diversity (Taxa_Rich) and relative abundance of the top taxon (%Dom_Top_Taxon) at WC2600.



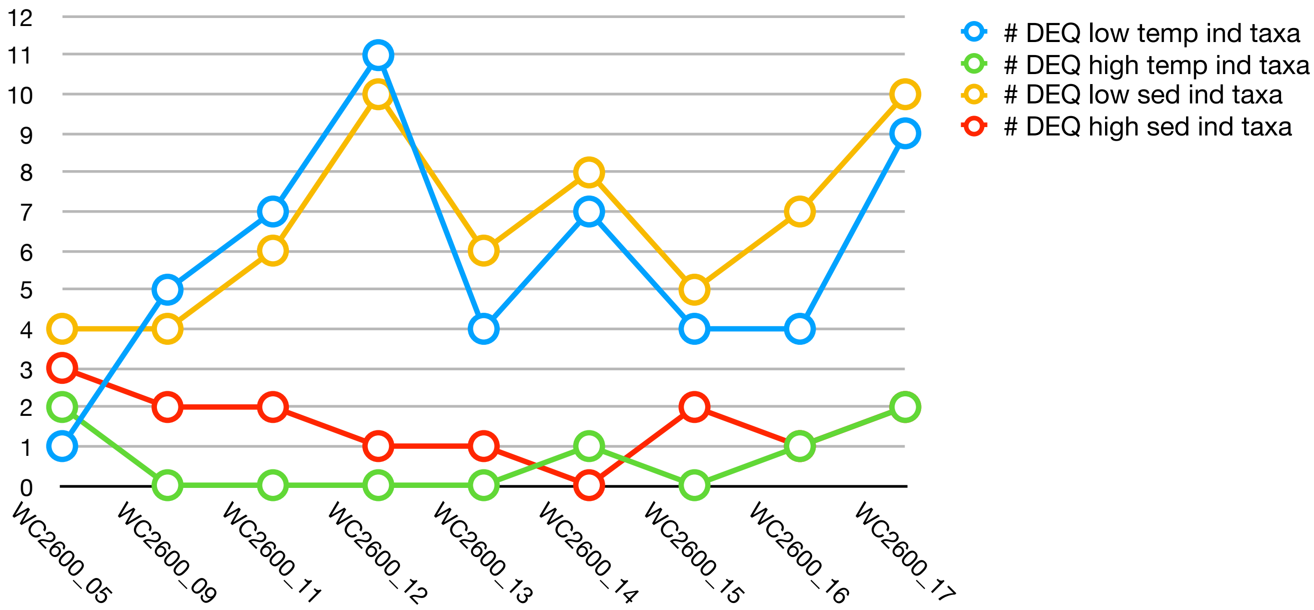
EPT richness at WC2600 was low in 2005, with few mayfly and caddisfly taxa and no stoneflies (Figure 29). Stonefly and mayfly diversity increased overall through 2014, then crashed in 2015. Caddisfly richness varied more, although Trichoptera diversity also increased from 2005 to 2009, but their numbers were lower in 2011 as well as in 2015. Diversity of all three orders increased in the last two sampling years, although Plecoptera recovery is slower.

Figure 29. Number of mayfly (Eph_Rich), stonefly (Ple_Rich), and caddisfly (Tri_Rich) taxa at WC2600



Diversity and abundance of taxa sensitive to pollution, sediment, and temperature varied as stream conditions changed. The number of sensitive taxa in the community rose from zero to eight in 2005-2012, but only two sensitive taxa were found in 2015. Sensitive taxa richness increased in each year after 2015, although it has not yet recovered to prior levels (four taxa in 2017). In 2005 the community had the fewest indicator taxa for both low temperature and low sediment (Figure 30); their numbers increased steadily through 2012, dropped in 2013, and recovered again in 2016-2017.

Figure 30. Changes in the number of DEQ temperature and sediment indicator taxa at WC2600.



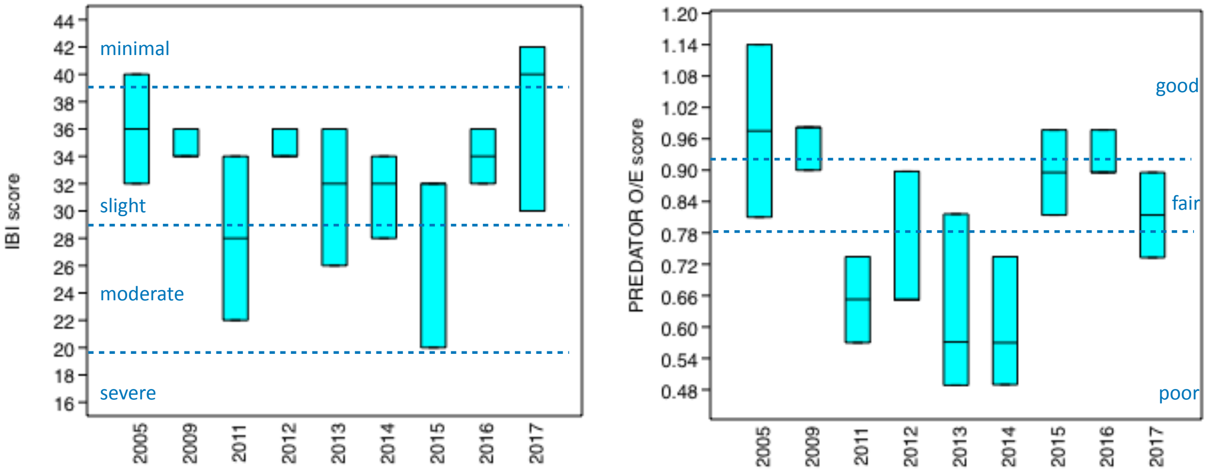
Other community attributes at WC2600 are not informative; the number of sediment-intolerant taxa is low across all sampling years (0-2), and relative abundances of tolerant and sediment-tolerant taxa, community MHBI, and temperature and sediment optima fluctuate from year to year with no consistent pattern.

Camp Polk (WC1825, WC1850, WC1900)

In 2009, a new channel was constructed in this reach, into which the channel was moved in 2012. IBI scores among these sites show a general decrease in 2011-2015 and recovery in 2016-2017 (Figure 31), but means are not significantly different between years. IBI scores indicate slightly disturbed conditions (average IBI = 31.3±4 to 37±6) in all years except 2011 and 2015, when scores were just under the slight/ moderate disturbance threshold of 30 (average IBI = 28±6 in both years). The mean in 2017 (37±6) is higher than in any other year and just under the slight/minimal disturbance threshold.

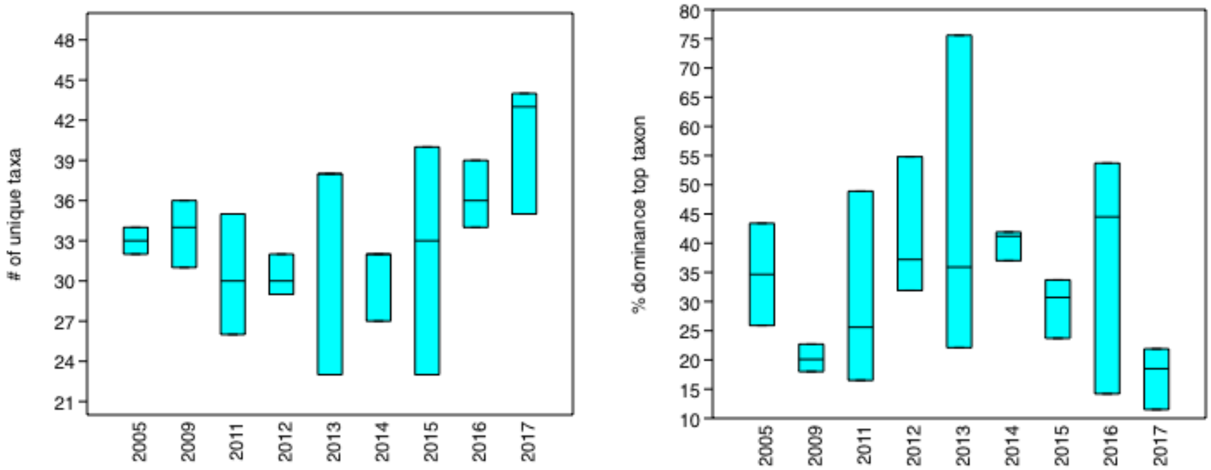
Mean PREDATOR scores were also lower in 2011-2014 (corresponding to poor biological conditions), and recovered in subsequent years to fair/good levels. Between-year means differ significantly (F=4.527, p=0.0043); the mean score in 2014 was significantly lower than in 2005 and 2009, and the mean score in 2013 was significantly lower 2005 and close to significantly lower than 2009 (p=0.0696).

Figure 31. IBI and PREDATOR scores at sites WC1825-WC1900. Horizontal line in each box indicates median value; filled box shows interquartile ranges; whiskers depict data range. Dotted lines show transitions points for biological condition scores.



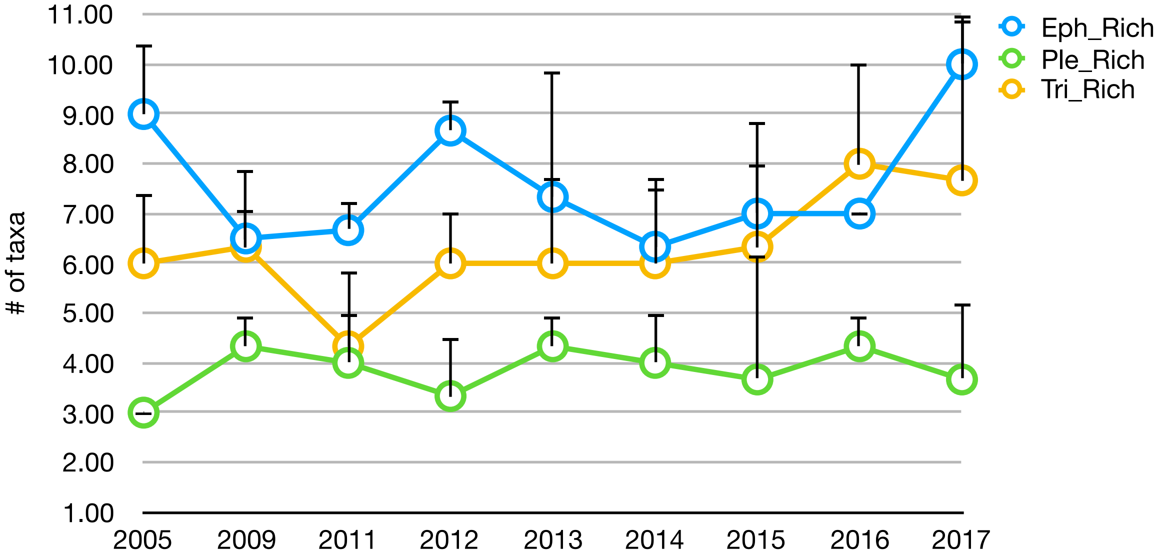
Mean richness decreased slightly overall from 2005 (33±1 unique taxa) to 2014 (30±3), then increased to a high in 2017 (41±5 unique taxa). The dominance of the most abundant taxon varied widely, but was highest in 2012-2014 (mean = 40-41% abundance) and lowest in 2009 and 2017 (mean = 20.3% and 17.3%, respectively). However, between-year means were not significantly different for either richness or dominance.

Figure 32. Diversity and % dominance of the most abundant taxon at sites WC1825-WC1900. Horizontal line in each box indicates the median value; filled box shows interquartile ranges; whiskers depict data range.



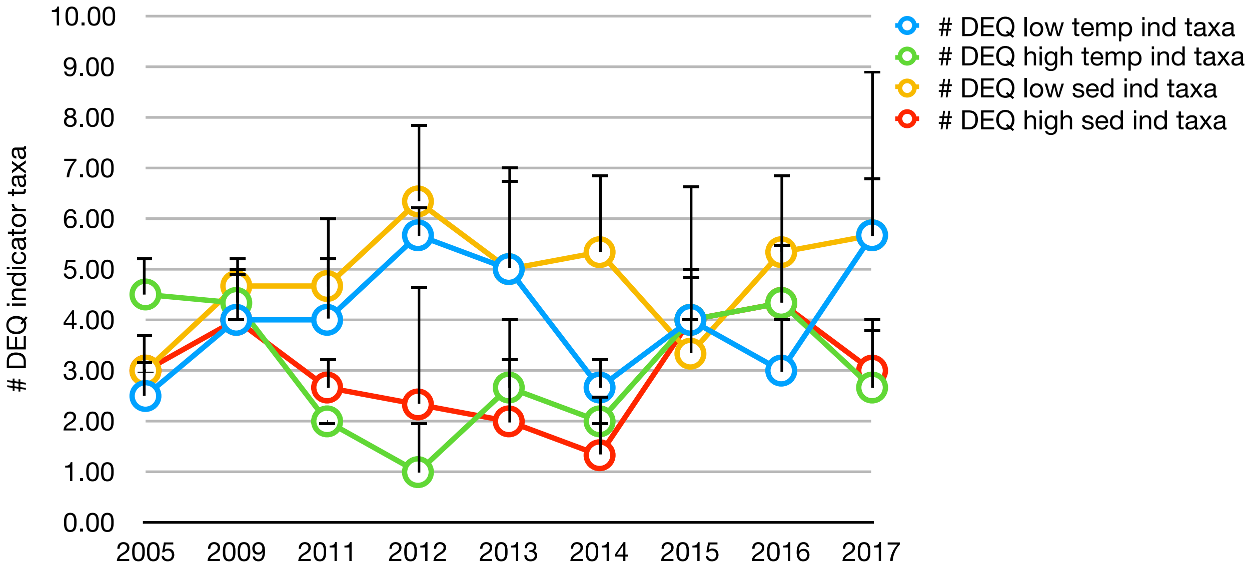
The number of stonefly and caddisfly taxa among these sites is consistent (Figure 33), and between-year differences between means are not significant, although the number of caddisfly taxa increased from 2005 (mean = 6.0+1.4) through 2017 (mean = 7.7+3.2). The mean number of mayfly taxa has fluctuated more, with decreases in both 2009-2011 and 2013-2016, but the mean was significantly higher in 2017 than in 2014 (F=3.371, p=0.0167)

Figure 33. Mean diversity of mayflies (Eph_Rich), stoneflies (Ple_Rich) and caddisflies (Tri_Rich) at sites WC1825-WC1900. Vertical bars show standard deviation.



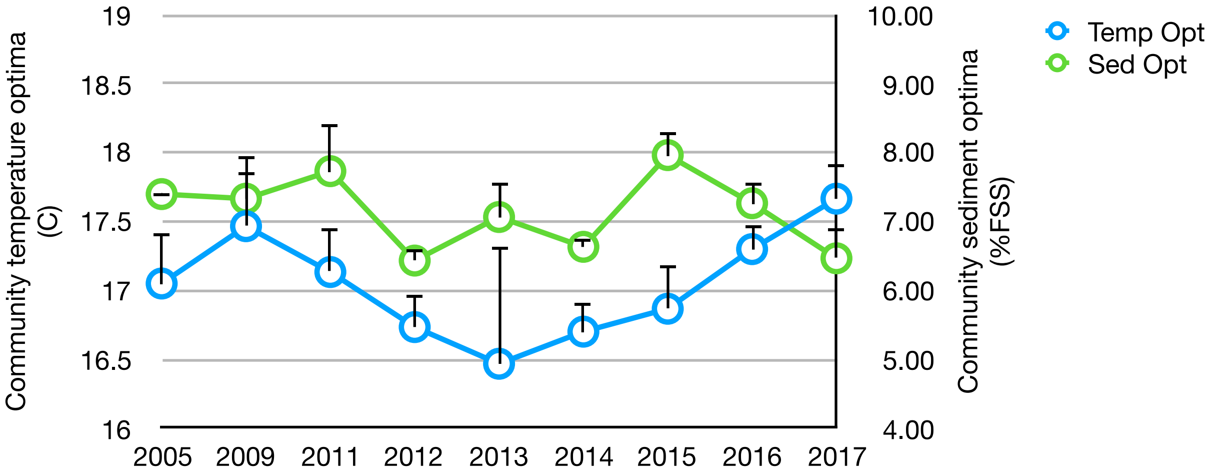
Changes in the numbers of DEQ indicator taxa for low temperature and fine sediment are mirrored by changes in high temperature and sediment indicators. Low sediment and temperature indicator taxa numbers increased from 2005 through 2012/2013, while the number of high temperature and sediment indicators dropped. High sediment and temperature indicators increased from 2014-2016 and decreased again in 2017, while low temperature and sediment indictors dropped during this period and increased again in 2017. The mean numbers of low and high temperature indicators are significantly different between years (F=2.789, p=0.059 and F=7.009, p=0.0004, respectively). The mean number of low temperature indicators in 2017 is significantly higher than in 2005 and 2014, while the mean number of high temperature indicator taxa is significantly lower in 2011, 2012, and 2014 than in 2005, and significantly higher in 2015-2016 than in 2012. The mean numbers of low and high sediment indicators are not significantly different between years.

Figure 33. Mean numbers of DEQ temperature and sediment indicator taxa at WC1825-WC1900. Vertical bars show standard deviation.



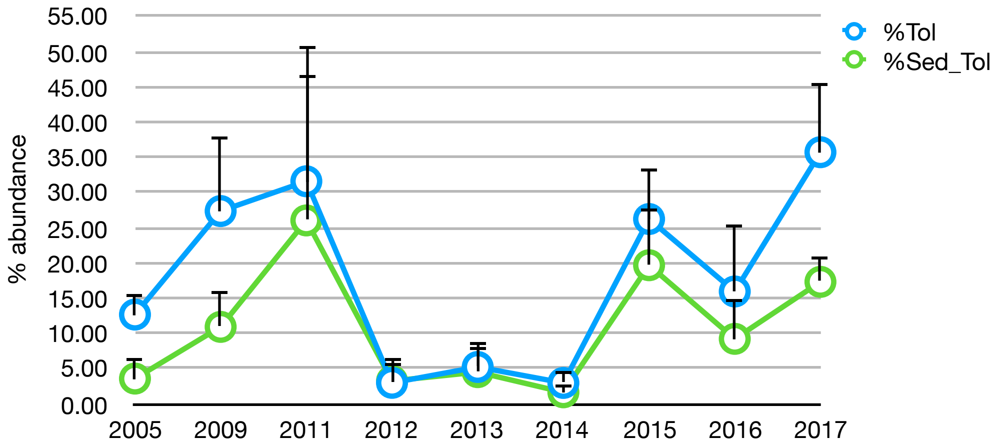
Mean community sediment and temperature optima also differ significantly between years (F= 5.818, p=0.0011 and F=2.733, p=0.0388, respectively). Community sediment optima changed little in early sampling years but decreased in 2012-2014, rose again in 2015, and have been decreasing since; the mean optima in 2012, 2014, and 2017 are significantly lower than in 2011 and 2015. Community temperature optima also decreased from 2011-2013 and but unlike sediment optima, temperature optima continued increasing in subsequent years, and the mean temperature optima in 2017 is significantly higher than in 2013.

Figure 34. Mean community temperature and sediment optima at WC1825-WC1900. Vertical bars show standard deviation.



Two other community attributes, % tolerant taxa and % sediment-tolerant taxa, also decreased to their lowest points in 2012-2014 (Figure 34); however, the increase that occurred in the years immediately after channel diversion has continued, and the mean % tolerant organisms in 2017 is significantly higher than in 2012-2014.

Figure 34. Mean relative abundances of tolerant taxa (% Tol) and sediment-tolerant taxa (% Sed_Tol) community temperature and sediment optima at WC1825-WC1900. Vertical bars show standard deviation.

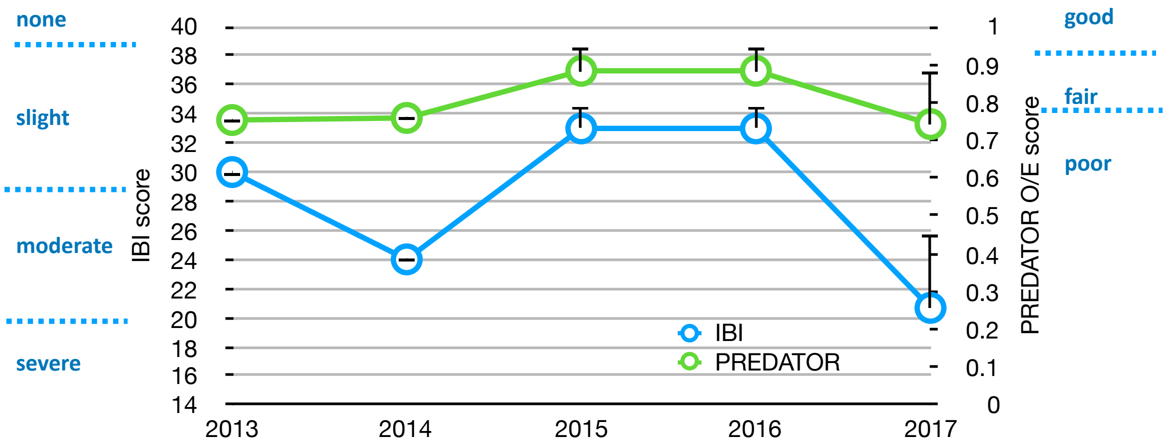


Whychus Canyon (WC1100 and side channels)

Whychus Creek was connected to new side channels at WC1100 in late 2016. Sites in this reach have varied; sampling was not done at some as early as 2005/2009, and WC1100 was a new site in 2017. Almost all community characteristics show effects of harsh environmental filters acting on the macroinvertebrates post-restoration. Prior to 2017, PREDATOR and IBI scores in the reach spanning WC1025-WC1150 increased, indicating fair conditions (O/E) and slight disturbance (IBI). In 2017, both sets of scores were slightly lower at WC1050 and 1150 (O/E still fair; IBI indicating moderate disturbance), but the IBI score at WC1100 was the lowest in the 2005-2017 data set (16; severe disturbance) and the PREDATOR score was the lowest for any downstream site since 2005 (0.58; poor).

Abundance and diversity were greatly reduced at WC1100 in 2017, with only 45 organisms representing 14 unique taxa in the entire sample. Prior to 2017, taxa richness in this reach was consistently in the mid-level IBI scoring range (29-33 taxa), and community richness at WC1050 and 1150 remained at those levels, although diversity was higher upstream of the project site (33 taxa at WC1050) than downstream (25 taxa at WC1150). EPT richness was also lower at WC1100 in 2017 than in any other site or year, and three-fold lower than the surrounding sites. Relative abundance of the dominant taxon was similar to previous years, but the community at WC1050-1150 was dominated by aquatic earthworms (Oligochaeta), a change from previous years when the dominant taxa at sites in this span were lotic types including riffle beetles, mayflies, and caddisflies.

Figure 35. IBI and PREDATOR scores at WC1025-WC1150. Vertical bars show standard deviation. Dotted lines show scoring ranges for disturbance/biological condition.

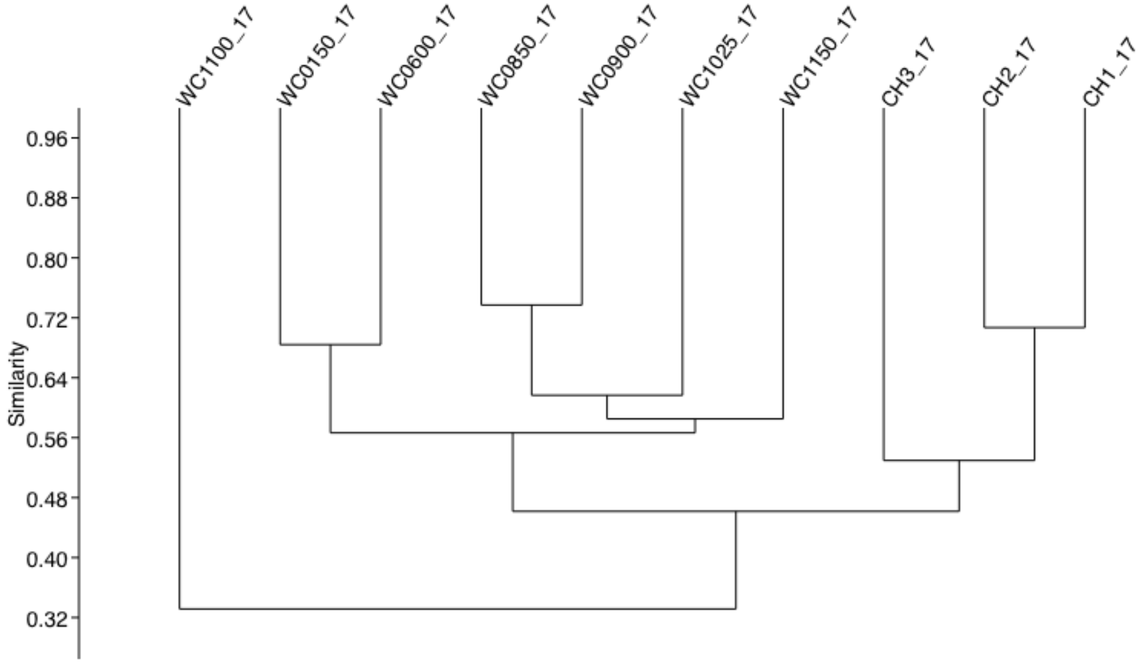


The 2017 community at WC1100 had no indicator taxa for low sediment or cool temperatures, unlike surrounding sites in the same year which had an average of three of each of these indicators. Community temperature and sediment optima in 2017 were higher at WC1100 and WC1150 than at WC1050, and mean community sediment optima at WC1050-1150 was significantly higher than in both preceding years (F=29.19, p=0.0041).

Because the side channels had little riffle habitat and macroinvertebrate sampling was done in a variety of microhabitats, IBI and PREDATOR models are not appropriate. CLUSTER analysis showed that channel communities were more similar to each other than to any other site sampled in any other year, and the community at these sites was 44% similar to other downstream sites sampled in 2017 (with the exception of WC11100, which had the least similarity to any other downstream community in 2017; Figure 36). Diversity in the side channels was significantly higher than at the mainstem downstream sites (p=0.0275), even when the outlier WC1100 was omitted. The mean number of EPT taxa in side channels and downstream sites was similar (15+3.5 vs. 14.9±1.6 respectively, with the outlier WC1100 omitted) indicating that substantial lotic habitat currently exists in these channels.

Macroinvertebrate abundance was also higher in the side channels than at surrounding mainstem sites; the target count of 500 organisms was met in channel samples with 20-40% of the sample picked, while samples from WC1025 and WC1150 were picked in their entirety to yield 315 and 220 individuals.

Figure 36. CLUSTER analysis of the macroinvertebrate community at mainstem downstream sites (WC) and new side channels (CH).



Conclusions

The macroinvertebrate community in Whychus Creek in 2017 shows continued improvement in several metrics. IBI and PREDATOR scores have increased in recent years, and communities are more diverse (increased richness) and better balanced (lower % dominance of the top taxon), and contain more EPT taxa. Community sediment optima were lower in 2017, and numbers of low sediment indicator taxa were higher. Community temperature optima, which decreased from 2005-2013 but have been increasing again recently, decreased again in 2017 among downstream and upstream sites but were higher in mid-stream sites. However, the number of cool indicator taxa was higher among all reaches in 2017 than in the most recent sampling years, and the number of warm indicator taxa has decreased overall since monitoring began. PREDATOR scores fluctuate annually and tend to indicate poorer biological conditions, but sediment and temperature optima among the communities identified by the

PREDATOR model as replacement taxa are lower than for missing taxa, and are lower for increaser taxa compared to decreasers, with the most dramatic changes occurring between 2005 and 2009.

Some of the annual fluctuations observed among downstream, mid-stream, and upstream reaches are due to the immediate negative impacts of restoration activities. Restoration-related impacts cause the greatest perturbations in taxa richness, dominance of the most abundant taxon, and numbers of sediment- and temperature-sensitive taxa, but some level of recovery is apparent by two years post-restoration. In 2017, downstream community composition and metrics were negatively impacted by restoration-related disturbances around WC1100; this site received the lowest IBI score of any year and had severely reduced abundance and taxa diversity. However, the side channels at WC1100 were colonized by a high abundance and diversity of macroinvertebrates with a variety of habitat and flow preferences from surrounding reaches. Macroinvertebrate communities should change for several years post-restoration as the main channel recovers and the hydrology of the side channels is established.

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Appendix A. Macroinvertebrate monitoring data sheet

Site ID ____ Date:

Sampled by: ____

Start time: End time: Air temp.: °C Water temp.: °C

Sample Information:

\# of riffles sampled: _____ # of kicks composited: 8 x 1 ft² # sample jars _______

Duplicate collected? ___ yes ___ no If yes, total # duplicate jars _____

Human use & influence (*right & left bank relative to observer facing downstream*)

A = absent **B** = on bank **C** = ≤ 30 ft from bank **D** = > 30 ft from bank

Disturbance	**Left bank**	**Right bank**		**Disturbance**	**Left bank**	**Right bank**
Riprap/wall/armored bank				Landfill/dump		
Buildings				Park/lawn		
Industrial				Row crops		
Rural residential				Pasture/range/hayfield		
Urban residential				Livestock access		
Pavement/cleared lot				Logging in last 5 years		
Road/railroad				Sand or gravel mining		
Pipes (inlet/outlet)				Forest/woodland		
Other:						

Qualitative observations (circle 1 choice for each):

Water odors: none **/** organic **/** rotten eggs **/** fishy **/** chlorine **/** petroleum **/** other (describe):

Water appearance: clear **/** turbid **/** milky **/** dark brown **/** foamy **/** oily sheen **/** other (describe):

Dominant land use: Forest **/** agriculture (crops / pasture) **/** urban (industrial / residential) **/** other:

Extent of algae covering submerged materials: none **/** 1-25% **/** 25-50% **/** 50-75% **/** 75-100%

Type of algae: none **/** close-growing **/** filamentous (i.e. strands >2”) **/** floating clumps

Physical characteristics: (*if fewer than 8 riffles, record <u>only for the riffles sampled</u>*)

Substrate (estimate % each type present; each column should add to 100%)

% composition of riffle	Riffle1	Riffle2	Riffle3	Riffle4	Riffle5	Riffle6	Riffle7	Riffle8
Bedrock (continuous rock)								
Boulder (> 12 in.; larger than basketball)								
Cobble (2.5-12 in.; tennis ball to basketball)								
Gravel (0.6-2.5 in.; marble to tennis ball)								
Sand (< 0.6 in.; smaller than marble)								
Silt/clay/muck (fine particles)								
Woody debris								
Other (describe)								

Water depth (in feet and inches)

Parameter	Riffle1	Riffle2	Riffle3	Riffle4	Riffle5	Riffle6	Riffle7	Riffle8
Wetted width								
Depth @ ¼ wetted width								
Depth @ ½ wetted width								
Depth @ ¾ wetted width								

Additional notes or observations (including other wildlife noted):

Appendix B. ORDEQ Indicator Taxa for Temperature and Sediment

Values in parentheses indicate temperature (^{o}C) or sediment (% fine sediment) optima for each taxon.

Taxon	Temperature indicator	Fine sediment indicator
Prosimulium	Cool (12.2)	---
Baetis bicaudatus	Cool (12.3)	---
Zapada columbiana	Cool (12.9)	---
Neothremma	Cool (12.9)	---
Parapsyche elsis	Cool (13.5)	Low (4)
Caudatella	Cool (13.6)	Low (4)
Megarcys	Cool (13.6)	Low (4)
Visoka	Cool (13.7)	---
Epeorus grandis	Cool (14.2)	Low (2)
Yoraperla	Cool (14.2)	---
Ephemerella	Cool (14.4)	---
Drunella coloradensis/flavilinea	Cool (14.5)	---
Doroneuria	Cool (14.5)	---
Despaxia	Cool (14.5)	---
Turbellaria	Cool (14.6)	---
Ironodes	Cool (14.9)	---
Drunella doddsi	Cool (15.2)	Low (3)
Ameletus	Cool (15.2)	---
Rhyacophila Brunnea Gr.	Cool (15.5)	Low (4)
Cinygmula	Cool (15.5)	Low (6)
Micrasema	Cool (15.6)	---
Diphetor hageni	Warm (17.9)	---
Antocha	Warm (18.3)	---
Hydropsyche	Warm (18.5)	---
Juga	Warm (18.6)	High (15)
Chironomini	Warm (18.8)	High (10)
Zaitzevia	Warm (19.0)	High (9)
Optioservus	Warm (19.6)	High (12)

Taxon	Temperature indicator	Fine sediment indicator
Dicosmoecus gilvipes	Warm (20.6)	---
Physa	Warm (21.1)	High (21)
Arctopsyche	---	Low (2)
Rhyacophila Hyalinata Gr.	---	Low (3)
Rhyacophila Angelita Gr.	---	Low (3)
Drunella grandis	---	Low (3)
Epeorus longimanus	---	Low (4)
Rhithrogena	---	Low (5)
Rhyacophila Betteni Gr.	---	Low (5)
Glossosoma	---	Low (5)
Baetis tricaudatus	---	Low (6)
Oligochaeta	---	High (10)
Paraleptophlebia	---	High (11)
Tanypodinae	---	High (12)
Ostracoda	---	High (17)
Hydroptila	---	High (17)
Lymnaeidae	---	High (18)
Cheumatopsyche	---	High (20)
Sphaeriidae	---	High (21)
Coenagrionidae	---	High (25)