
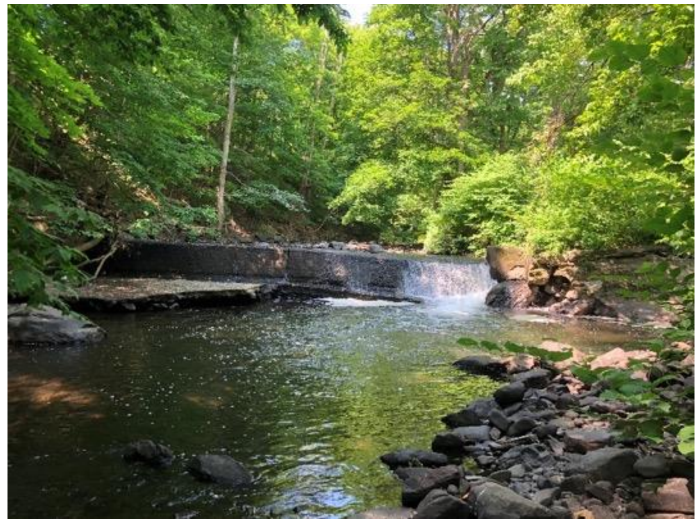


ANNUAL REPORT ON THE ECOLOGICAL MONITORING OF DAM REMOVAL PROJECTS IN THE HUDSON RIVER ESTUARY

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Title Page Images: Stony Point Dam on Cedar Pond Brook (Top Left), Strooks Felt Dam on Quassaick Creek (Top Right), and Lake Ida dam on The Poestenkill (Bottom Center).

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INTRODUCTION

The goal of this project is to monitor and evaluate the effectiveness of likely dam removals. Monitoring pre-removal stream conditions will allow project partners to understand the biological, habitat, and physical responses in the stream compared to post-monitoring conditions.

This document reports on the 2020 findings of barrier-removal monitoring efforts within the Hudson River Estuary watershed. Prior reports submitted to the New York State Water Resource Institute (WRI) and the Hudson River Estuary Program (HREP) between 2016-2019 have provided data, analyses, and conclusions regarding two prior barrier removal successes: Shapp Pond Dam on the East Branch Wappingers Creek (Dutchess County, NY) and 'Troy Gate' on the Wynantskill (Rensselear County, NY). Additionally, pre-removal monitoring data has been compiled at Browns Pond Dam on the Otterkill (Orange County, NY), Annandale Dam on the Sawkill (Dutchess County, NY), and Maiden Lane Dam on Furnace Brook (Westchester County, NY).

During the 2020 monitoring season, pre-removal data has continued for the second year at barriers on Cedar Pond Brook (Stony Point Dam, Stony Point, NY) and Quassaick Creek (Strooks Felt Dam, Newburg, NY). Barrier removal at Lake Ida dam on the Poestenkill (Troy, NY) in November 2019 has provided a post-removal monitoring opportunity during the 2020 season. Geographic location information for each site monitored in 2020 can be found in Table 1 below.

Table 1: Location information for dam-removal study sites in 2020.

Site Name	County	Township	Tributary Name	Location	Northing[1]	Easting[1]
Lake Ida Dam	Rensselear	Troy	Poestenkill	Upstream	4730763	608804
				Downstream	4730781	608607
Stony Point Dam	Rockland	Stony Point	Cedar Pond Brook	Upstream	4565062	583811
				Downstream	4565021	583914
Strooks Felt Dam	Orange	Newburg	Quassaick Creek	Upstream	4593693	581969
				Downstream	4593695	582061

[1]: UTM Zone 18N, Datum: WGS 1894

METHODS

Sample Locations

Each of the 2020 sampling locations contain, or formerly contained, a historic impoundment of ponded water. At each location, paired upstream and downstream locations were monitored for aquatic macroinvertebrates, substrate and habitat composition, stream channel morphology delineations, and general site characteristics. Site accessibility was contained by permissible property boundaries. A detailed list of methodologies, habitat parameter conditions, and monitoring design attributes can be referenced in the projects Quality Assurance Project Plan, which is available on request to the project manager, Jeremy

Dietrich, at JAD65@cornell.edu. A QAPP was prepared to ensure that data collected will be useful to a broad group of practitioners and resource managers.

<u>Habitat Recording</u>

At each sample point general habitat parameters were measured and recorded. Physical measurements included air and water temperature, water depth, substrate composition, overhead canopy cover, and presence of woody debris. Additionally, biological observations of periphyton cover, aquatic macrophyte abundance, algal bloom presence, as well as any human impacts (trash, point sources, angling remnants) were also documented.

<u>Substrate Composition and Stream Channel Elevation Survey</u>

To accurately track changes in substrate composition post-removal a comprehensive cross-stream transect was established at each lotic transect. Beginning and end-points of each transect were monumented with permanent pins spanning bank-full width. At interval points of 1-foot along each transect, stream-bottom elevation and substrate composition were measured. Substrate composition was conducted by recording the first substrate class encountered when blind-touching a point on the stream bottom, as described in the Wolman Pebble Count method (Bevenger and King, 1995). Stream-bottom elevation was surveyed using standard rod and transit-level techniques. A local benchmark was established for each transect, allowing future surveying measurements to be indexed to the same relative elevation. Due to the lentic nature of upstream habitats, detailed transect measurements were infeasible.

At each upstream sample point, water depth and sediment composition were recorded. Sediment composition was visually estimated by separating sieved sediment types from total sediment volume captured in the Ponar grab.

<u>Aquatic Macroinvertebrate Sampling</u>

Specific methodological techniques related to macroinvertebrate sampling, collection, and biometric calculations can be in the 2014 Standard Operating Procedure: Biological Monitoring of Surface Waters in New York State (Smith, 2014). The Poestenkill was kick-sampled at three riffle-run locations at increasing distances, ~30-50 meters apart, upstream and downstream of the barrier. At Quassaick Creek, the upstream impoundment zone was nearly filled in with substrate, possessing habitat attributes similar to a lotic segment versus a lentic one. Consequently, kick-samples were performed at consecutive riffles away from the barrier at both upstream and downstream locations. At Cedar Brook kick-samples were performed at three consecutive downstream riffle locations. Upstream of Stony Point Dam, the impoundment was substantially filled, yet too shallow to confidently deploy multiplate samplers. Three replicate Ponar grabs were collected upstream of Stony Point dam.

Invertebrate Collection Techniques

At each lotic habitat type, a travelling kick sample was performed across the width of the stream angled in an upstream direction. Downstream replicates were collected in a downstream-to-upstream direction as to avoid drift/dislodge bias within subsequent samples. Following sample collection, large debris (rocks, woody debris, and leaves) were rinsed, picked of invertebrates, and removed from the netted sample. Remaining sample volume was preserved on-site with 70% Ethanol. Within lentic habitats, Ponar grab sediments were rinsed through 500um sieves to remove silt and fine detritus, and the remaining sample was preserved on site in 90% ethanol.

Collected invertebrate samples were returned to the lab and identified to the lowest practicable taxonomic level using a 40x dissecting microscope. Chironomidae taxa keyed to family only, as time constraints prevented slide-mount preparation and IDs of this Dipteran family. All taxa were stored in 70% ethanol and archived. For identification of kick and Ponar samples, a ~100-count individual subsample was randomly removed from respective sample collections.

Biological Assessment of Water Quality

Following enumeration and identification of aquatic macroinvertebrates, calculations of water quality impairment were made. Metrics used for the calculation of water quality impairment designations associated with kick, Ponar, and multiplate samples include (1) Species Richness (SPP), (2) Ephemeroptera-Plecoptera-Trichoptera Richness (EPT), (3) Hilsenhoff's Biotic Index (HBI), (4) Percent Model Affinity (PMA), (5) Species Diversity (DIV), and (6) Dominance-3 (DOM). Once individual metric scores are determined, they are converted to a common 0-10 scale, with 0 being poor water quality and 10 being excellent water quality.

The assignment of a Biological Assessment Profile (B.A.P) per sampling location is made by averaging the water quality scores across each metric. Water quality impairment designations are assigned by the B.A.P and include four categories: non-impact, slight impact, moderate impact, and severe impact.

Data and Statistical Analyses

Data recorded on field observation sheets was compiled into a summary master data base in Microsoft Excel. For statistical analyses, summary data were defined by Site (i.e. Poestenkill, Cedar Pond Brook), Location (i.e. 'Upstream' or 'Downstream'), and Replicate Transect (i.e. '1','2',or '3'). Some replicate variables in the summary data sheet may represent a single observation or measurement associated with a transect, such as 'Water Temperature' – taken once during sampling at each transect. For other variables recorded at each transect, such as depth and substrate composition, the summary value represents the mean of multiple measurements across the transect. Depth is measured at 10 points across the transect, so the Depth summary value is the mean of those 10 points, for instance.

Data associated with the Poestenkill was analyzed using multiple linear regression and a one-way analysis of variance to test differences between 'before and after' removal data. To further explore changes across years, we used multiple linear regression and a two-way analysis of variance with year and site as covariates to test differences in biometric responses between pre-removal baseline data and post removal recovery data. Comparative year-to-year pre-removal data observed on Quassaick Creek and Cedar Pond Brook were analyzed using standardized T-tests. All analyses were performed with R software version 3.5.1 (R Development Core Team 2018).

RESULTS

POESTENKILL

Pre-removal habitat conditions surrounding the barrier were sub-optimal [Figure 5, left panel]. Substrate composition within the impoundment largely comprised of sand and small gravel, with increasing proportions of sand closer to the barrier. Downstream, the in-stream habitat was dominated by bedrock, as high as 90% at transect 2, with sand often lingering in the bedrock crevices. This wide disparity of pre-removal habitat conditions is further demonstrated quantitatively with the mean upstream particle size at 3.71cm, representing gravel, while the mean downstream particle size was 384cm, representing bedrock.

The barrier breach resulted in upstream habitat which remained similar to 2019, although gravel was more dispersed along the reach [Figure 5, right panel]. Mean sand and gravel composition of the wetted-width substrate in 2019 accounted for 56.7 and 43.3 percent, respectively, and in 2020 the proportions were 53.8 and 42.9 percent, respectively. The mean upstream particle size decreased from 3.71cm, representing large gravel, to 0.355cm, representing small gravel [Figure 6]. One reason the upstream particle size may not have increased more substantially is due to the nature of the barrier removal process. This barrier was a wooden dam, and at the time of the 2020 field monitoring a couple of the lowest flash-boards were still intact, which would hinder a full emigration of upstream sediment to the level of the lowest flash-board. Despite this idiosyncrasy however, the upstream channel is cutting into its bed and beginning to meander back into a historic channel path. New riffles and runs are developing in an area which was previously, entirely, inundated.

Dam removal in November 2019 on the Poestenkill caused substantial changes to the local reaches upstream and downstream of the barrier. Overall, one season post-removal showed conflicting invertebrate community responses. The upstream reach experienced improvements with respect to the macroinvertebrate community composition and water quality designations, while the downstream reach demonstrated mixed results as a consequence of barrier removal.

The initial upstream pre-removal invertebrate assemblage in 2019 was dominated by Chironomid midges which composed 55% of the community composition [Figure 7, left panel]. Mayflies were the next abundant taxa at 22.6% abundance; however, their presence was disproportionately represented in drift. Mayflies composed 29.6% of the drift organisms, as captured by the multiplate samples, versus only 3.5% of the benthic habitat sampled by the

Ponar grab samples. Oligochaete aquatic worms and caddisflies made up 9.8% and 6.3% of the upstream population, and the remaining minority taxa comprised of Ostracods (1.3%), Copepods (1.1%), Snails (0.8%), and others. Stoneflies were represented by a single individual (*Agnetina*, Family: Perlidae) captured within one of the multiplate samplers, and contributed ~0.1% of the total upstream relative abundance.

The pre-removal community downstream contained a taxa assemblage more typical of lotic habitats [Figure 8, left panel]. Mayflies dominated the community with 44% abundance, followed by caddisflies (16.2%), Chironomid midges (13.9%), Oligochaete aquatic worms (10.7%), beetles (5.2%), and amphipods (3.2%). Remaining minority taxa included Copepods (1.6%), Isopods (1.3%), water mites (1.0%), and others. Stoneflies only represented 0.6% of abundance with two *Agnetina* individuals captured in the kick samples.

The categorical upstream change from pre-removal lentic habitat to post-removal lotic habit caused significant shifts in the aquatic macroinvertebrate community [Figure 8, right panel]. Mayflies increased significantly from 16.9% to 47.9% (P=0.0198) and while stoneflies significantly increased from 0.1% to 3.4% (P=0.0026). These positive gains manifested over the significant decline of Chironomid midges, falling 56.6% to 30.3% (P=0.0137). Beetles and caddisflies increased by 0.8% and 1.6%, respectively, while Oligochaete aquatic worms decreased by 5.6%.

These shifts in the aquatic invertebrate community imposed similar changes to the biometric values and water quality designations [Figure 9]. The Hilsenhoff Biotic Index (HBI) decreased significantly (a benefit) from 6.05 to 4.23 (P=0.0027). Species Diversity increased significantly from 1.97 to 2.90 (P=0.0353) and Species Dominance decreased significantly from 84.9% to 66.9% (P=0.0384). The remaining biometrics moved in beneficial directions. Species Richness increased from 13.8 to 14.7, EPT Richness increased from 6.3 to 10.6, and Percent-Model-Affinity increased from 51.4 to 76.8. Overall, the Biological Assessment Profile Score (BAP) increased from 4.19 to 6.83, a borderline significant increase (P=0.0505) [Figure 10]. Consequently, the water quality designation within the upstream reach improved from Moderately Impacted to Slightly Impacted [Figure 11].

Barrier removal caused historically deposited sediment trapped behind the dam to migrate throughout the reach downstream of the dam. The wetted-width habitat conditions changed dramatically as a result [Figure 5, right panel]. Bedrock prevalence declined significantly from 76.7% to 31.5% (P=0.0136), while sand increased significantly from 13% to 51.4% (P=0.0058). Gravel prevalence remained similar at ~4.5%, while cobble and boulder remained at near 1%.

This change caused the wetted-width mean particle size to decline significantly from 384cm to 155cm [Figure 6]. This sand deposition also raised the elevation of the channel bed, on average, 0.214ft across the immediate downstream reach. The amount of this deposition increased for each individual transect as distance from the dam increased. Mean bed elevation at Downstream #1 was raised 0.018ft and Downstream #2 was raised 0.264ft. The channel bed at Downstream #3 raised highest at 0.324ft [Figure 12], and sand uniformly blanketed the former bedrock sheet, and filled in many of the crevices [Figure 13].

This dramatic change in post-removal downstream habitat conditions had overall negative effects on the aquatic macroinvertebrate community [Figure 8, right panel]. Most notably, caddisflies declined significantly from 14.4% to 1.9% (P=0.0284), while Chironomid midges increased significantly from 14.1% to 53.8% (P=0.0120). Mayflies declined from 44.6% to 35.7%, beetles declined 5.2% to 1.6%, and Oligochaete aquatic worms declined 10.2% to 3.6%. Stonefly representation remained consistently low at 0.7% in 2019 and 0.9% in 2020.

Similarly, in concert with changes in the aquatic invertebrate community, downstream biometric values declined following dam removal, a number of them significantly [Figure 9]. Percent-Model-Affinity significantly declined from 80.0% to 62.1% (P=0.0446). Species Diversity significantly declined from 3.54 to 2.06 (P=0.0138) and Species Dominance significantly increased (a detriment) from 48.9% to 84.8% (P=0.0057). Species Richness declined from 19.3 to 13.0 and EPT Richness declined from 10.6 to 7.3. The HBI Index value declined slightly from 4.75 to 4.53, representing a minor benefit. These post-removal biometric changes caused the overall Biological Assessment Profile (BAP) score to decline significantly from 7.42 to 5.25 (P=0.0295) [Figure 10]. While both of these values remain within Slightly Impacted water quality designation, the post-removal value now hovers at the threshold of Moderately Impacted [Figure 11].

<u>QUASSAICK CREEK</u>

Continuing pre-removal monitoring efforts on Quassaick Creek found consistent habitat conditions above and below Strooks Felt dam [Table 5, Figure 14]. Two years of pre-removal observation data found substrate conditions above the dam were dominated by boulder (44.3%) and cobble (38.3%). Gravel, sand, and silts/clays represent only 13.0%, 4.2%, and 0.3%, respectively. The mean particle size above the dam during 2019 was 40.2cm and during 2020 it was 36.8, maintaining an overall boulder description [Figure 15]. Downstream of Strooks Felt dam, pre-removal observations showed a highly coarse overall substrate composition averaged 19.7% bedrock, 19.4% boulder, 30.7% cobble, and 25.9% gravel. Sand and fines represented only 3.8% and 0.4%, respectively. The mean particle size downstream of the barrier during 2019 and 2020 was 129.2cm and 102.4cm, respectively, also indicating overall boulder composition [Figure 15]. No significantly different substrate conditions were found during the first two years of pre-removal data on Quassaick Creek.

Across both pre-removal years, similar aquatic macroinvertebrate community assemblages were observed both upstream and downstream of the dam [Table 5, Figures 16 and 17]. These similarities can be attributed to the common substrate compositions between the two sampling locations. Upstream benthic communities, were dominated by Chironomid midges (28.8%), oligochaetes (15.1%), caddisflies (10.6%), and amphipods (22%). Downstream invertebrate communities were comprised of comparable proportions of Chironomid midges (28.8%), oligochaetes (15.7%), caddisflies (16.4%), and amphipods (17.5%). No significant changes in macroinvertebrate composition were observed between 2019 and 2020, although upstream oligochaete populations dropped from 24.9% to 5.1%, while upstream amphipod populations increased from 10.9% to 33.1%. A non-significant increase in amphipods was also observed downstream, changing from 13.1% in 2019 to 21.9% during 2020. Overall increases in the amphipod populations are likely attributed to broader site-level demographic influences versus a barrier effect.

Quantitatively, we found the consistent biometric values over the prior two years of pre-removal observations between the upstream and downstream kick samples [Table 7, Figure 18]. The upstream Biological Assessment Profile significantly increased from 4.72 in 2019 to 5.19 during 2020 (P=0.0403). This is likely due to the drop in Oligochaete populations between the two years and how Oligochaete population data is factored into the BAP score. This change incrementally improves the water quality designation from just under the 5.00 threshold of slightly/moderately impacted to just over it, and garnering a slightly impacted designation for 2020 [Figure 19]. Downstream water quality designation also improved from 4.88 to 5.47, also rising from moderately impacted to slightly impacted. The downstream change was not deemed significant, and both locations remain near the threshold of moderate impact.

CEDAR BROOK

During two seasons of pre-removal monitoring on Cedar Brook contrasting habitat types were observed above and below Stony Point dam [Table 8, Figure 21]. Overall, sand and fine-sediments (silt/clay) were most prevalent upstream of the dam, with 48.9% and 20.8%, respectively, and combined, attributed nearly 70% of the substrate composition at each replicate location. The remaining substrate composed of gravel (17.2%) and cobble (13.2%). The mean particle size upstream of Stony Point dam was 1.845cm, representing medium gravel [Figure 22]. Downstream of Stony Point dam, the substrate composition was more varied, with 34.2% bedrock, 7.4% boulder, 11.6% cobble, 15.5% gravel, 25.4% sand, and 1.1% fines. The mean particle size downstream of the barrier was 177.1cm, representing large boulder [Figure 23]. The high particle size downstream is attributable to the prevalence of bedrock, which contributed to a third of the wetted-width substrate composition at the two lower downstream transect locations. Overall, substrate composition at Cedar Pond Brook did not change significantly during the past two years of observation, upstream or downstream of the dam.

Differing aquatic macroinvertebrate community assemblages were observed within each of the disparate habitat types above and below Stony Point dam, however each respective community assemblage remained similar over the prior two years of observation [Table 9, Figures 23 & 24]. Upstream benthic communities, as represented in the Ponar grabs, were dominated by Chironomid midges (71.6%) and oligochaetes (18.2%), while mayflies only represented 2.5% and beetles represented 1.9% of the community. A significant increase in Chironomid midge populations occurred during 2020, increasing from 57.3% in 2019 to 85.9% in 2020 (P=0.0368). This was offset by a significant drop in Oligochaete aquatic worm populations from 31.9% in 2019 to 4.5% in 2020 (P=0.0091).

Contrastingly, downstream invertebrate communities were dominated by mayflies (35.6%), midges (31.3%), aquatic worms (13.4%), caddisflies (7.6%), stoneflies (4.6%), and beetles (1.9%). The relatively high contribution of stoneflies downstream (nearing 5%), suggests good ambient water quality, sourced from upstream of the dam, exists at the site.

Similar to the annual trend upstream, significantly higher Chironomid midge populations were observed during 2020, increasing from 20.7% in 2019 to 41.8% in 2020 (P=0.0039). It is unclear if this increase is due to localized factors downstream or a result of a sourcing effect from the upstream impoundment

The upstream-downstream contrast is also visible with the quantitative biometric data [Table 10, Figure 25]. The upstream Ponar grabs were found to possess deficient values across each individual biometric parameter compared to the downstream kick samples. A significant decline in Species Diversity was observed during 2020, dropping from 1.48 in 2019 to 0.9 in 2020. Contrastingly, a significant decline (but a benefit) in the Hilsenhoff Biotic Index was also observed, dropping from 6.48 in 2019 to 5.95 in 2020. These changes are likely the paradoxical result of the increase in Chironomid midge larvae which decreases the overall species diversity, and the decrease in Oligochaete aquatic worm populations, which decreases the HBI value (by reducing a high index value component). Despite the changes in these two biometrics, the overall Biological Assessment Profile water quality score for the upstream impoundment was not significantly different between 2019 and 2020, and averaged 2.40 [Figure 26]. The upstream impoundment has remained severely impacted during our monitoring observation period to date [Figure 27].

Downstream, where each mean biometric value was more favorable than upstream, we observed consistent, but non-significant improvements to most biometric values [Figure 25]. Taxa Richness increased by 4.6, EPT Richness increased by 5, HBI decreased by 0.07, Taxa Diversity increased by 0.42, and Taxa Dominance decreased by 9.9. Collectively, however, these improvements significantly raised the overall Biological Assessment Profile water quality score from 5.91 to 7.12 (P=0.0039) [Figure 26]. While still considered slightly impacted both years, the increase in 2020 positions the downstream reach near the threshold of non-impacted [Figure 27].

DISCUSSION

The process of post-barrier removal lotic recovery has begun within the upstream reach of the Poestenkill site. Significant improvements were observed across substrate/habitat composition, invertebrate community composition, quantitative biometric indicators, and water quality designations. Observations on the Poestenkill reinforce the notion that dam removal efforts translate into tangible ecological improvements and benefits. Upstream changes on the Poestenkill display similar trends to those observed during the post-removal recovery period on the East Branch Wappingers Creek, presenting a rapid, annual increase in water quality designation and macroinvertebrate community improvement.

One-year post removal data on within the former impoundment on the Poestenkill showed an 85% increase in mayfly nymphs and a 30-fold increase in stonefly nymphs, the two taxa most sensitive to system disturbance and degradation. Additionally, Oligochaete aquatic worm populations declined 80% and habitat conditions shifted to favor traditionally lotic aquatic invertebrates. All of the upstream biometric parameters moved in beneficial directions. Taxa Richness increased 6.5%, EPT Richness of sensitive taxa increased 68%, HBI Indices decreased 30%, Percent-Model-Affinity increased 50%, Taxa Diversity increased 6.1%, and Taxa Dominance decreased 22%. These improvements contributed to a 63% increase in the BAP water quality score from a moderately impacted value of 4.19 to a slightly impacted value of 6.83. Casual field observations during the field monitoring recorded a riparian zone recolonizing with other animals commonly found along stream courses, including beavers, turtles, and herons. Additionally, riparian vegetation is regrowing and stabilizing the shorelines.

The rapid mobilization of impounded sediment was documented on the Poestenkill after a period of approximately nine months post-removal. Stream channel morphology surveys conducted during summer 2020 showed a drop in channel thalweg elevation of ~5.044ft by June 2020 at our upstream most replicate location [Figure 28], while the channel thalweg elevation at the replicate location closest to the dam dropped by ~2.675ft [Figure 29] during June 2020. The surveying data also shows that the channel itself is still meandering, as at both locations, the June 2020 thalweg filled in and migrated towards river-right. Using rough calculations – the average maximum channel incision (3.86ft), average wetted channel width (18ft), and an impoundment channel length of ~740ft, a conservative estimate of 951 cubic yards of sediment has emigrated from the impoundment zone during the first season post-removal. Had the lowest wooden flashboard been removed to allow incision to the full natural stream bed, the volume of sediment emigrated would presumably be larger still.

The emigration of upstream sediment, particularly sand and silt/clay, imposed negative consequences within the immediate downstream reach below the barrier. A decline in biometrics, habitat quality, and key macroinvertebrate taxa was observed. An idiosyncratic characteristic of the downstream Poestenkill reach, which is influencing the sediment emigration behavior, is the presence of a low-head dam approximately 1,150ft downstream of Lake Ida dam, positioned immediately upstream of a waterfall and gorge [Figure 30]. This dam would block the complete emigration of sediment originating from the Lake Ida impoundment, and cause it to back-up and be retained within the downstream reach monitoring locations.

This sediment retention caused a swing in habitat conditions from one unfavorable particle size extreme –bedrock dominated – to another – sand dominated. A nearly 300% increase in both sand and fine sediments blanketed the former rigid bedrock channel. This decline in habitat conditions caused a 20% decline in mayfly nymphs, a remarkable 87% decline in caddisfly larvae, and a 70% decline in beetles. Chironomid midge larvae benefited from the habitat shift, increasing 280% over pre-removal levels. Oligochaete aquatic worms decreased 65%, which, while an ordinarily favorable outcome, does not off-set the broad declines in insect taxa. Similarly, nearly all of the downstream biometric values declined from 2019. Taxa Richness declined 33%, EPT Richness of sensitive taxa declined 32%, Percent-Model-Affinity declined 23%, Taxa Diversity declined 42%, and Taxa Dominance increased 72%. Overall, this caused a 30% decline in the Biological Profile Score, barely retaining the prior 2019 designation of slightly impacted water quality.

It is unclear, yet, how mobile the emigrated sediment will be over time with a limiting barrier downstream. A high flood event and/or any dredging activity by the downstream barrier owner may remove some of the existing sediment, particularly sand and fine particle sizes, and improve conditions below the former Lake Ida barrier. Future monitoring efforts will provide insight as to how complete instream recovery attains when multiple barriers exist in close proximity and disrupt the natural hydraulic continuity of the system. But for now, the upstream reach chalks up for a 'win', and likely acts to portend downstream improvement potential if the otherwise artificial constraints are lifted.

Observations over two years of barrier pre-removal data on Quassaick Creek and Cedar Pond Brook further support the static-state conditions dams impose on localized reaches of stream ecosystems. These data support pre-removal data trends collected previously on the Otterkill, the Sawkill, and Furnace Brook between 2016 and 2018. Observations on intact systems continue to demonstrate that barriers depress taxa richness and diversity, decrease affinity towards ideal communities, and increase dominance of tolerant taxa.

Strooks Felt dam on Quassaick Creek is the final dam in a series of closely spaced dams. Six barriers exist within 2 miles upstream of Strooks Felt [Figure 31]. The fact that continuous sub-optimal conditions exist with such similarity both upstream and downstream of Strooks Felt dam suggests a cumulative barrier impact on biota, habitat, and water quality potential. A condition perhaps also beginning to manifest itself below the Poestenkill's Lake Ida dam. Nonetheless, biological and physical conditions on Quassaick Creek surrounding Strooks Felt dam remain in a compromised state. The high average particle sizes and classes allow less-preferred organisms to dominate, as is evident by Chironomid midge, Oligochaete aquatic worms, and amphipods collectively contributing between one-half and two-thirds of the aquatic macroinvertebrate communities upstream and downstream. The static nature of the system also illustrates itself with nearly unchanged year-after-year biometric values and water quality designations surrounding the barrier.

Static conditions were also documented surrounding the intact Stony Point dam on Cedar Pond Brook. Substrate composition, particle size, aquatic macroinvertebrate community structure, biometric values, and water quality designations were all similar during the 2019 - 2020 period, despite mid-to-late season drought conditions during 2020. This 'barrier over hydrology' effect was also documented at prior study sites within the Hudson Estuary during 2016-2017 on the Otterkill, Furnace Brook, and Sawkill Creek, albeit with the hydraulic conditions reversed (drought in 2016 preceded a wet 2017). Cedar Pond Brook recovery potential remains high, as despite the late-season drought conditions, an increase in Taxa Richness and, particularly, an increase in sensitive-taxa EPT Richness was observed. This demonstrates the watershed as a whole can supply a drift source of preferred lotic taxa to re-colonize a restored post-barrier reach if provided an opportunity.

In summary, the ecological and biological behavior of stream reaches imposed by, or relieved from, a historic barrier demonstrate remarkably consistency across the Hudson Estuary watershed. Monitoring data collected during 2020 support prior year observations that rapid in-stream recovery is possible after barrier mitigation. While on the other hand, static barriers continue to hamper water quality and habitat potential within the stream segments they exist on.

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Table 2: Before and after substrate composition and particle sizes for the wetted-width transect segment in vicinity of Lake Ida dam on the Poestenkill.

Year	Removal Status	Location	Rep.	% Bedrock	% Boulder	% Cobble	% Gravel	% Sand	% Silt/Clay	Particle Size [mean(cm)]	Particle Size (Log-10)
2019	Pre-Removal: Year -1	Upstream	1	0	0	0	85	15	0	3.361	0.526
			2	0	0	0	40	60	0	7.564	0.879
			3	0	0	0	5	95	0	0.205	-0.688
		Downstream	1	63.5	3.2	1.6	4.8	25.4	1.6	319.5	2.505
			2	90.2	1.6	0	1.6	4.9	1.6	452.1	2.655
			3	76.3	0	1.3	7.5	8.8	6.3	381.5	2.582
2020	Post-Removal: Year +1	Upstream	1	0	0	0	30	65	5	0.288	-0.541
			2	0	0	0	73.7	26.3	0	0.550	-0.260
			3	0	0	0	25	70	5	0.226	-0.645
		Downstream	1	42.6	0	1.6	3.3	45.9	6.6	213.5	2.329
			2	33.9	0	0	0	50.8	15.3	169.5	2.229
			3	16.7	0	0	10.3	57.7	15.4	83.5	1.921

Table 3: Aquatic macroinvertebrate community data for key taxa on The Poestenkill before and after the dam removal effort.

Year	Removal Status	Location	Sample Type	Rep.	% Mayflies	% Caddisflies	% Stoneflies	% Beetles	% Oligochaetes	% Midges
2019	Pre - Removal Year: -1	Upstream	Ponar	1	7.3	1.2	0	0	24.4	61.0
				2	1.2	1.2	0	0	29.3	63.4
				3	2.1	1.0	0	2.1	30.9	56.7
		Upstream	Multiplate	1	36.8	9.3	0	1.1	0.5	48.9
				2	38.9	8.0	0.4	0.8	1.5	37.8
				3	15.2	7.6	0	0	2.7	71.9
		Downstream	Kick	1	40.2	14.7	1.0	12.7	12.7	14.7
				2	39.4	22.1	1.0	1.9	4.8	9.6
				3	53.5	11.9	0	1.0	12.9	17.8
2020	Post - Removal Year: +1	Upstream	Kick	1	44.7	9.8	5.7	0.8	8.1	28.5
				2	53.4	5.2	2.6	1.7	15.5	21.6
				3	45.1	3.9	2.0	1.0	3.9	41.2
		Downstream	Kick	1	51.4	1.0	1.0	1.9	3.8	39.0
				2	35.0	3.0	0	1.0	6.0	53.0
				3	20.7	1.8	1.8	1.8	0.9	69.4

Table 4: Aquatic macroinvertebrate biometric data before and after dam removal on the Poestenkill.

Year	Removal Status	Location	Sample Type	Rep.	Taxa Richness	EPT Richness	%-Model Affinity	HBI Index	% Dominance	Taxa Diversity	BAP Water Quality Score
2019	Pre – Removal: Year: -1	Upstream	Ponar	1	9	4	39.6	6.43	89.0	1.73	3.30
				2	6	2	32.3	6.63	96.3	1.34	2.05
				3	10	3	37.4	6.74	92.8	1.68	2.92
			Multi-plate	1	22	12	71.0	5.37	69.8	2.75	6.37
				2	22	9	80.0	5.29	76.7	2.62	5.89
				3	14	8	48.1	5.84	85.2	1.70	4.40
		Downstream	Kick	1	17	9	84.7	4.78	50.0	3.39	7.00
				2	26	14	77.7	4.66	37.3	4.12	7.62
				3	15	9	78.6	4.80	59.4	3.13	6.70
2020	Post – Removal: Year: +1	Upstream	Kick	1	16	12	82.4	4.60	62.1	3.12	6.98
				2	14	11	74.5	4.17	60.3	2.98	7.15
				3	15	9	73.7	3.94	78.4	2.60	6.37
		Downstream	Kick	1	12	6	69.9	3.88	81.0	2.42	5.79
				2	12	8	66.0	4.67	87.0	2.02	5.41
				3	15	8	50.6	5.06	86.5	1.75	4.56

Table 5: Pre-Removal wetted-width substrate composition and particle size data on Quassaick Creek surrounding Strooks Felt dam during 2019 and 2020.

Year	Removal Status	Location	Rep.	% Bedrock	% Boulder	% Cobble	% Gravel	% Sand	% Silt/Clay	Particle Size [mean(cm)]	Particle Size (Log-10)
2019	Pre-Removal	Upstream	1	0	45	40	13	2	0	39.5	1.597
			2	0	60	25	10	5	0	49.0	1.690
			3	0	35	40	15	10	0	31.9	1.505
		Downstream	1	0	21.9	53.1	25	0	0	24.3	1.386
			2	2.9	35.3	38.2	17.6	5.9	0	47.4	1.676
			3	61.5	12.8	2.6	17.9	2.6	2.6	317.4	2.502
2020	Pre-Removal	Upstream	1	0	55	35	10	0	0	46.3	1.665
			2	0	35	45	15	5	0	32.1	1.506
			3	0	35	45	15	3	2	32.1	1.506
		Downstream	1	0	0	42.9	57.1	0	0	7.024	0.847
			2	0	31	24.1	34.5	10.3	0	20.85	1.319
			3	53.8	15.4	23.1	3.8	3.8	0	279.3	2.446

Table 6: Pre-Removal aquatic macroinvertebrate community data for key taxa on Quassaick Creek surrounding Strooks Felt dam during 2019 and 2020.

Year	Location	Sample Type	Rep.	% Mayflies	% Caddisflies	% Stoneflies	% Beetles	% Oligochaetes	% Midges
2019	Upstream	Kick	1	6.5	9.3	0	7.4	27.8	31.5
			2	6.4	8.5	0	3.2	26.6	31.9
			3	1.9	17.8	0	0.9	20.6	37.4
	Downstream	Kick	1	3.8	21.9	0	8.6	22.9	24.8
			2	8.9	7.9	0	8.9	17.8	23.8
			3	8.3	4.6	0	3.7	8.3	56.9
2020	Upstream	Kick	1	20.2	14.1	0	1.0	3.0	38.4
			2	17.3	8.7	0	7.7	1.0	16.3
			3	2.9	4.8	0	2.9	11.4	17.1
	Downstream	Kick	1	1.7	30.0	0	2.5	25.0	25.0
			2	3.6	10.9	0	8.2	8.2	16.4
			3	10.3	23.1	0	3.4	12.0	25.6

Table 2: Pre-Removal biometric data for Quassaick Creek surrounding Strooks Felt dam during 2019 and 2020.

Year	Location	Sample Type	Rep.	Taxa Richness	EPT Richness	%-Model Affinity	HBI Index	% Dominance	Taxa Diversity	BAP Water Quality Score
2019	Upstream	Kick	1	8	3	58.2	6.17	73.1	2.55	4.37
			2	14	5	53.2	6.05	67.0	2.89	5.12
			3	12	4	47.8	5.96	68.2	2.72	4.68
	Downstream	Kick	1	10	3	57.4	5.80	66.7	2.78	4.83
			2	14	3	60.7	5.63	56.4	3.16	5.63
			3	10	3	51.5	5.75	76.1	2.21	4.18
2020	Upstream	Kick	1	9	4	64.2	5.42	80.8	2.43	5.01
			2	13	2	60.6	5.64	67.0	2.75	5.43
			3	16	5	42.8	6.09	72.4	2.74	5.12
	Downstream	Kick	1	11	4	49.2	5.94	64.2	2.82	5.26
			2	17	5	53.1	5.99	60.0	3.22	5.60
			3	11	3	58.7	5.64	61.5	2.83	5.56

Table 8: Pre-Removal wetted-width substrate composition data on Cedar Pond Brook surrounding Stony Point dam during 2019 and 2020.

Year	**Removal Status**	**Location**	**Rep.**	**% Bedrock**	**% Boulder**	**% Cobble**	**% Gravel**	**% Sand**	**% Silt/Clay**	**Particle Size [mean(cm)]**	**Particle Size (Log-10)**
2019	Pre-Removal	Upstream	1	0	0	15	15	65	5	2.273	0.357
			2	0	0	15	5	50	30	2.060	0.314
			3	0	0	2	5	43	50	0.402	-0.396
		Downstream	1	44	0	0	14	42	0	220.2	2.343
			2	41.9	20.9	16.3	4.7	16.3	0	223.9	2.350
			3	34	8.5	8.5	21.3	21.3	6.4	177.6	2.250
2020	Pre-Removal	Upstream	1	0	0	25	25	45	5	3.126	0.495
			2	0	0	20	40	30	10	2.754	0.440
			3	0	0	2	13	60	25	0.457	-0.340
		Downstream	1	19	0	2.4	26.2	52.4	0	95.7	1.981
			2	35.9	10.3	25.6	10.3	17.9	0	187.6	2.273
			3	30.2	4.7	16.3	16.3	32.6	0	157.3	2.197

Table 9: Pre-Removal aquatic macroinvertebrate community data for key taxa at Cedar Pond Brook surrounding Stony Point dam during 2019 and 2020.

Year	Location	Sample Type	Rep.	% Mayflies	% Caddisflies	% Stoneflies	% Beetles	% Oligochaetes	% Midges
2019	Upstream	Ponar	1	2.4	0	0	0	36.1	50.6
			2	2.9	0	0	1.9	33.0	56.3
			3	1.2	2.4	0	1.2	26.5	65.1
	Downstream	Kick	1	41.7	0	1.9	0	17.5	32.0
			2	61.3	15.1	2.8	1.9	9.4	6.6
			3	39.1	7.0	7.0	2.6	17.4	23.5
2020	Upstream	Ponar	1	1.9	1.9	0	2.9	8.7	82.7
			2	3.3	0	1.1	1.1	1.1	92.3
			3	1.8	0	0.9	3.7	3.7	82.6
	Downstream	Kick	1	22.8	11.9	1.0	2.0	5.9	51.5
			2	22.9	6.1	7.6	3.1	20.6	28.2
			3	24.0	5.0	8.0	2.0	8.0	43.0

Table 10: Pre-Removal biometric data for Cedar Pond Brook surrounding Stony Point dam during 2019 and 2020.

Year	Location	Sample Type	Rep.	Taxa Richness	EPT Richness	%-Model Affinity	HBI Index	% Dominance	Taxa Diversity	BAP Water Quality Score
2019	Upstream	Ponar	1	6	1	37.4	6.64	92.8	1.65	2.19
			2	9	2	35.7	6.53	92.2	1.62	2.70
			3	7	3	33.7	6.28	95.2	1.39	2.43
	Downstream	Kick	1	18	4	73.8	5.59	72.8	2.58	5.49
			2	17	10	69.2	4.52	76.4	2.43	5.94
			3	15	9	84.1	4.97	70.4	2.93	6.29
2020	Upstream	Ponar	1	8	3	33.6	6.00	94.2	1.05	2.45
			2	7	3	27.7	5.84	65.6	0.59	2.17
			3	7	2	37.4	6.00	92.7	1.06	2.48
	Downstream	Kick	1	19	12	65.2	4.85	69.9	2.70	6.85
			2	22	13	71.1	5.20	63.1	3.24	7.09
			3	23	13	71.0	4.83	57.0	3.28	7.41

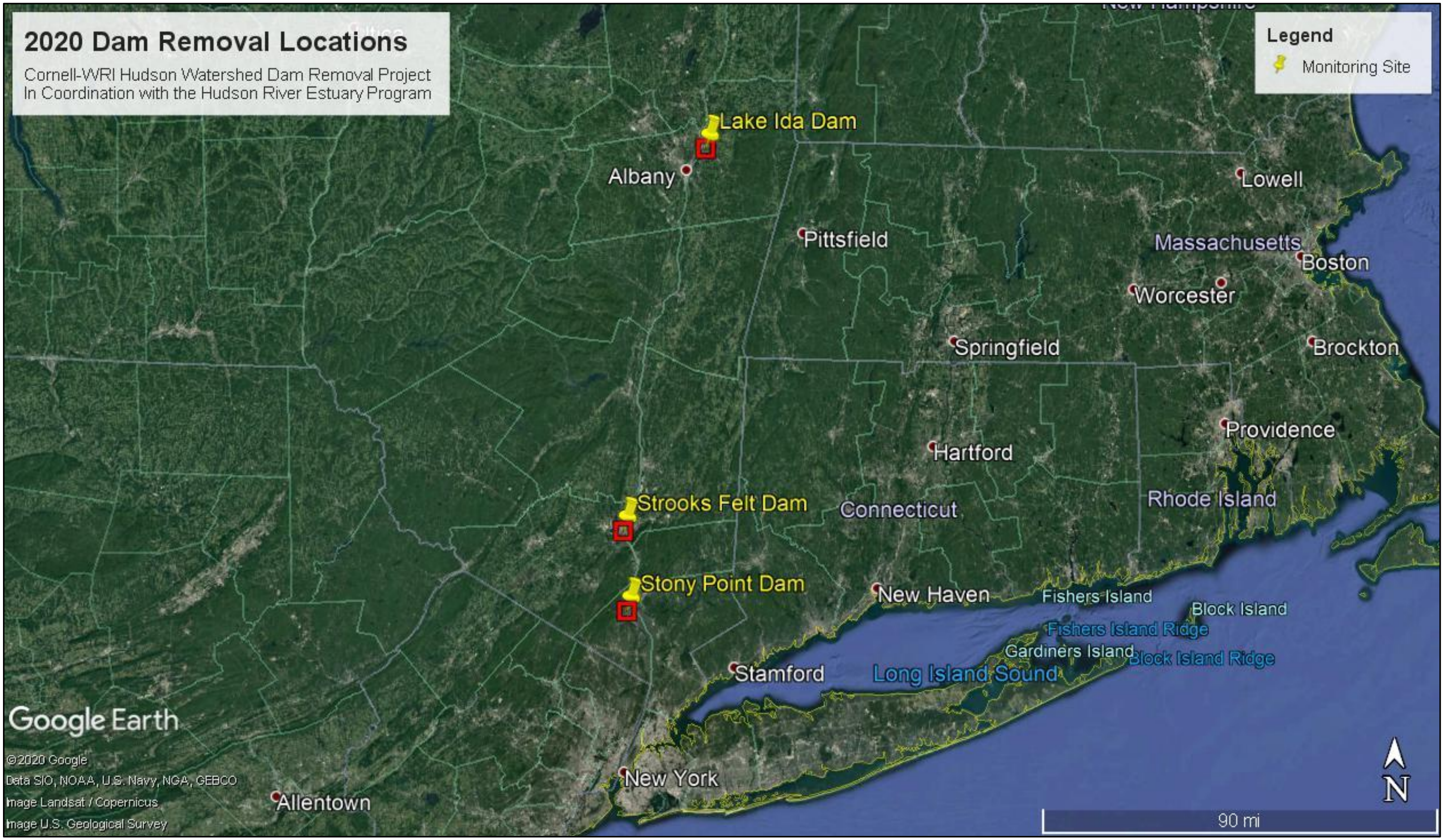


Figure 1: Study locations for dam removal monitoring efforts during 2020 within the Hudson River Estuary.

Figure 2: Upstream and downstream transect monitoring locations at Lake Ida dam on the Poestenkill during 2019 and 2020.

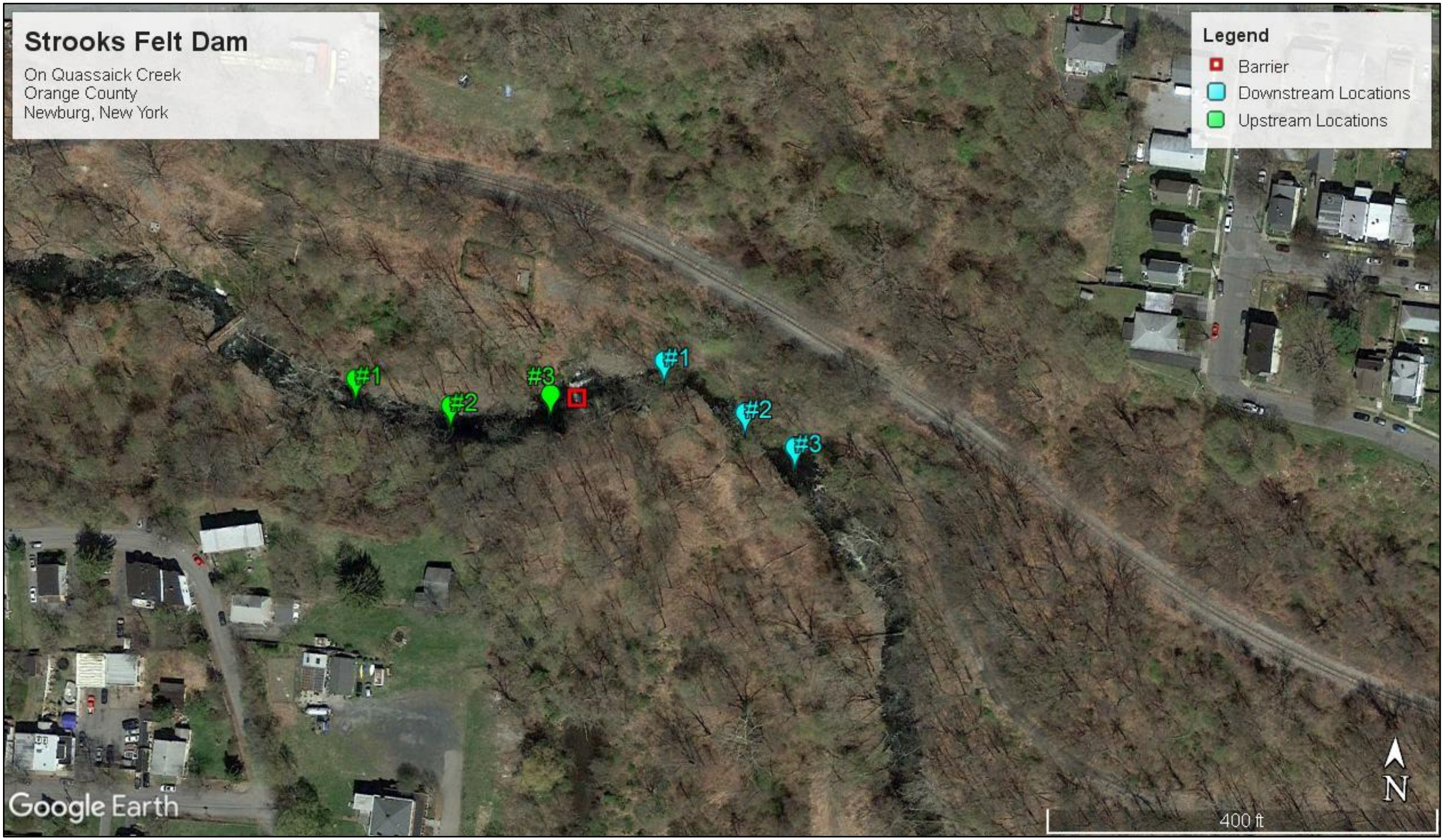


Figure 3: Upstream and downstream transect monitoring locations at Strooks Felt dam on Quassaick Creek during 2019 and 2020.

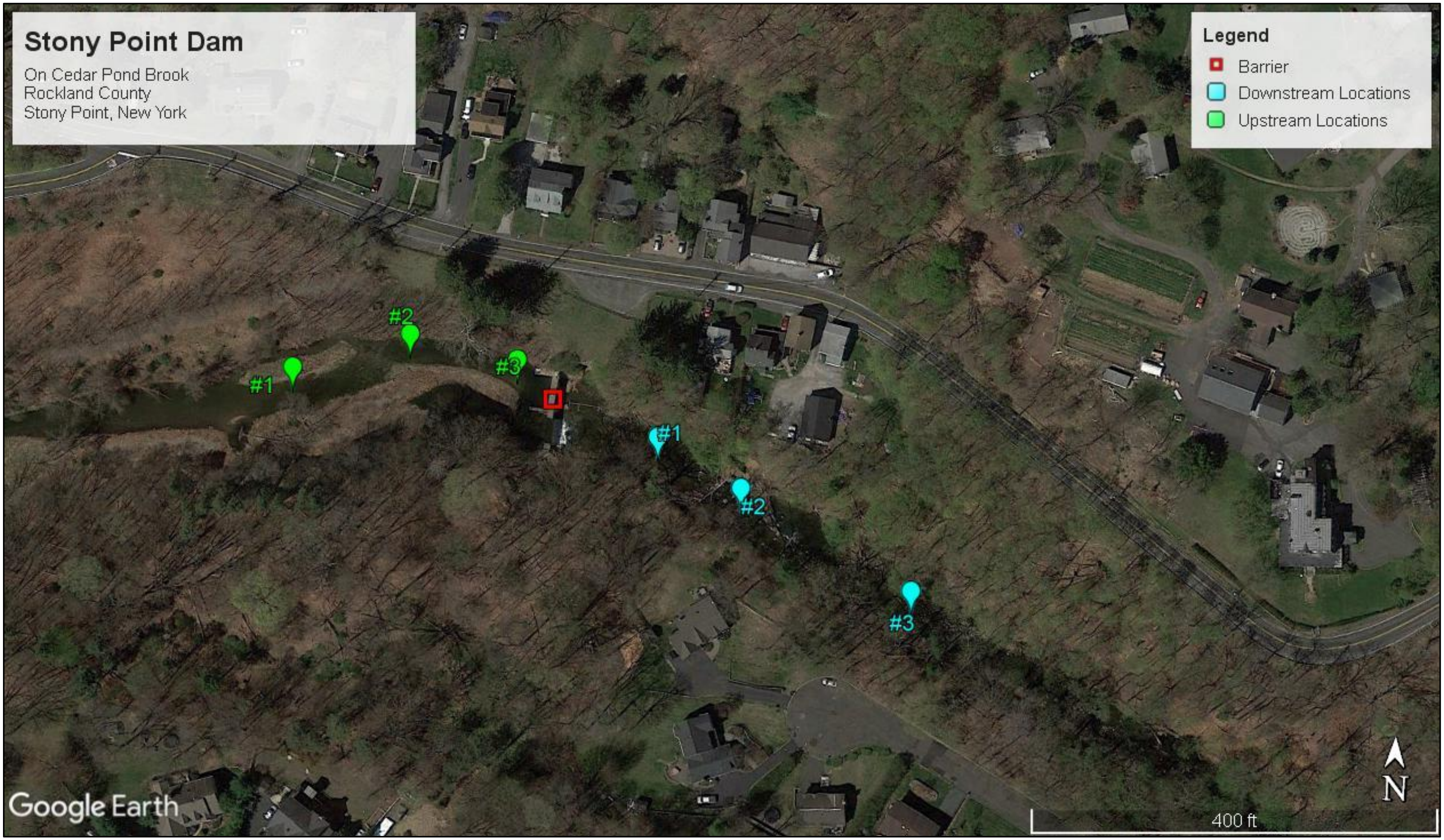


Figure 4: Upstream and downstream monitoring transect locations at Stony Point dam on Cedar Pond Brook during 2019 and 2020.

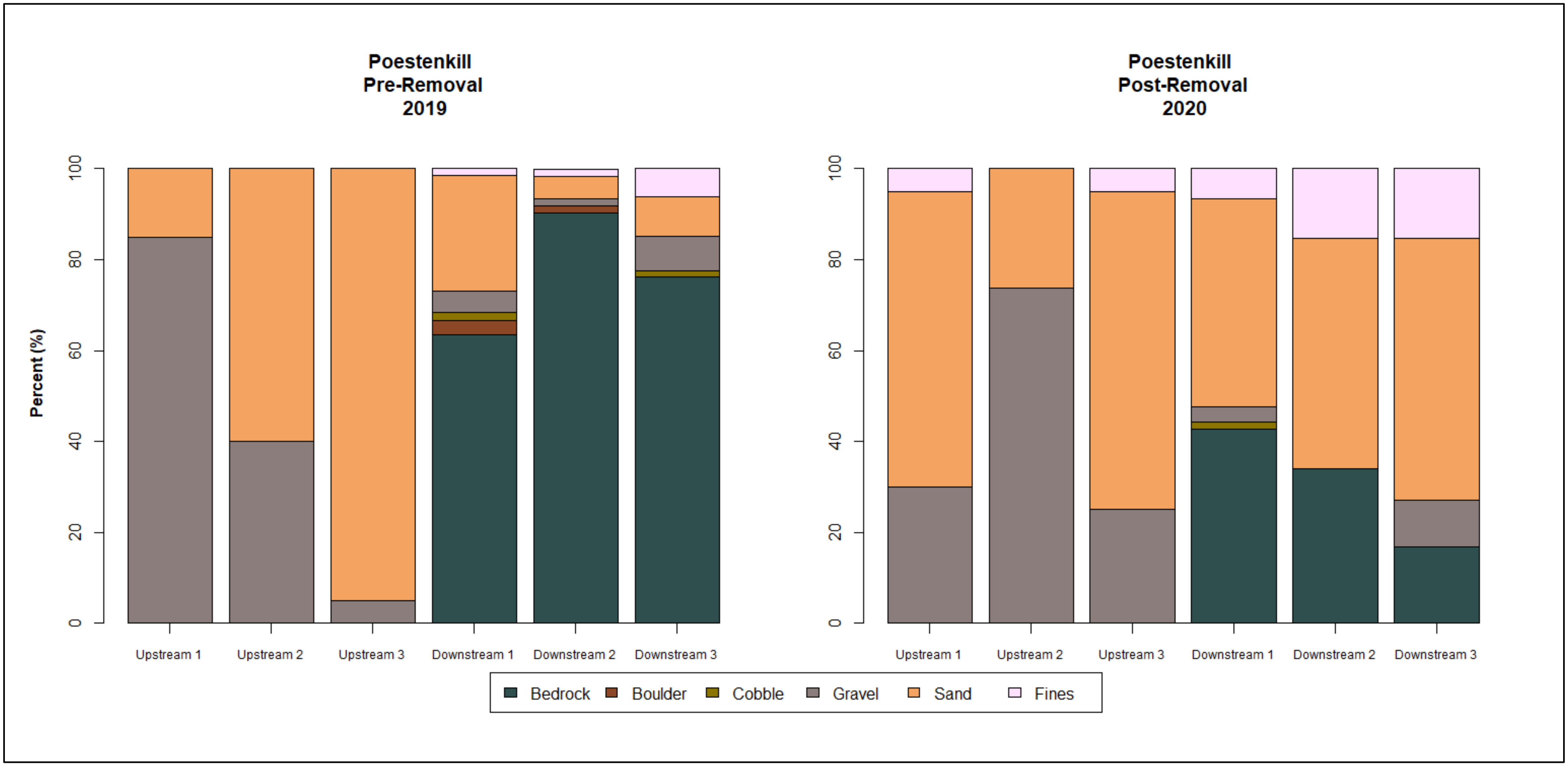


Figure 5: Wetted-width substrate composition at each of three upstream and downstream monitoring transects surrounding Lake Ida dam on the Poestenkill under 2019 pre-removal and 2020 post-removal conditions.

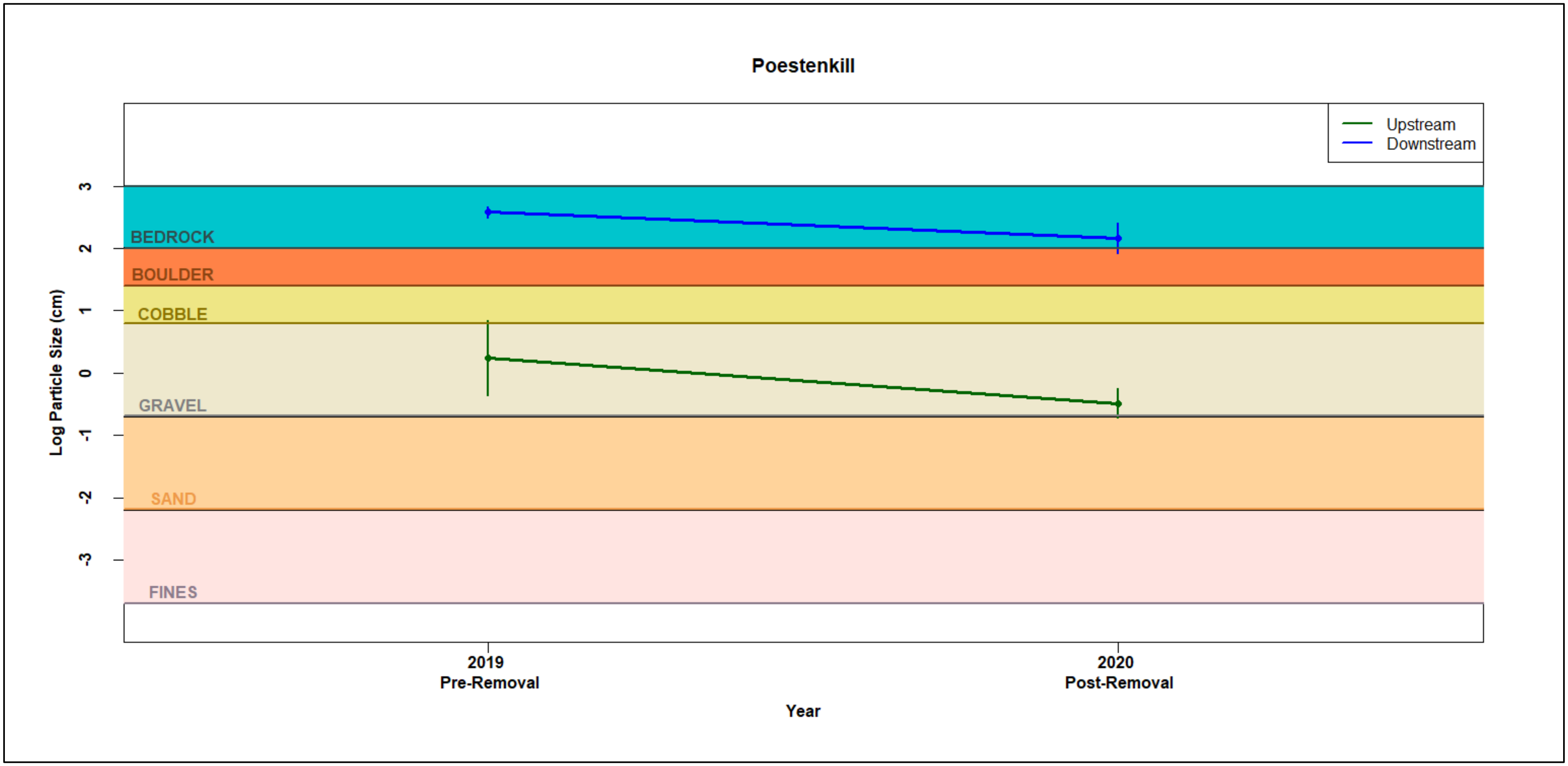
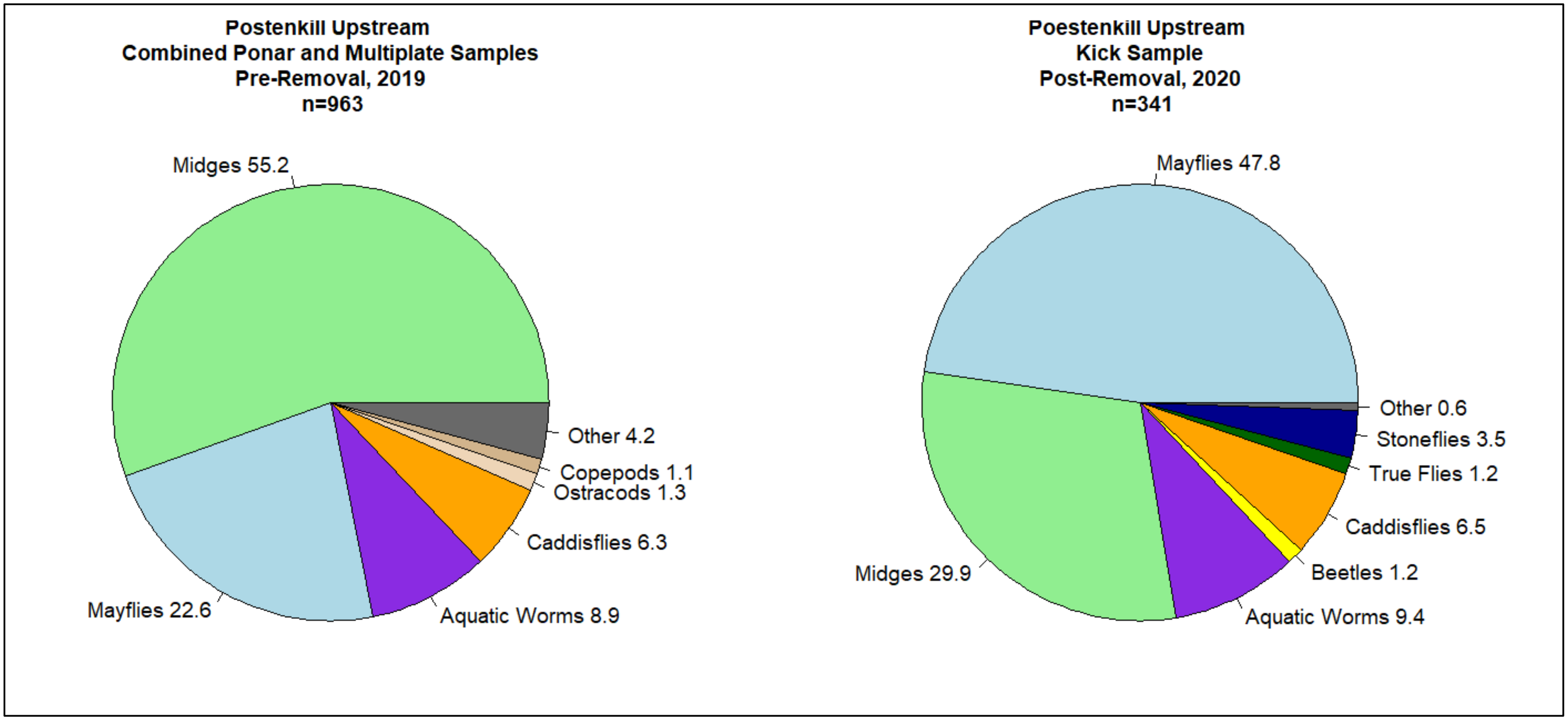


Figure 6: Change in substrate particle size at monitoring locations upstream and downstream of Lake Ida dam on the Poestenkill under 2019 pre-removal and 2020 post-removal conditions.



<u>Figure 7: Aquatic Macroinvertebrate community assemblages on the Poestenkill within the lentic pre-removal upstream impoundment during 2019 and the restored lotic stream segment post-removal in 2020.</u>

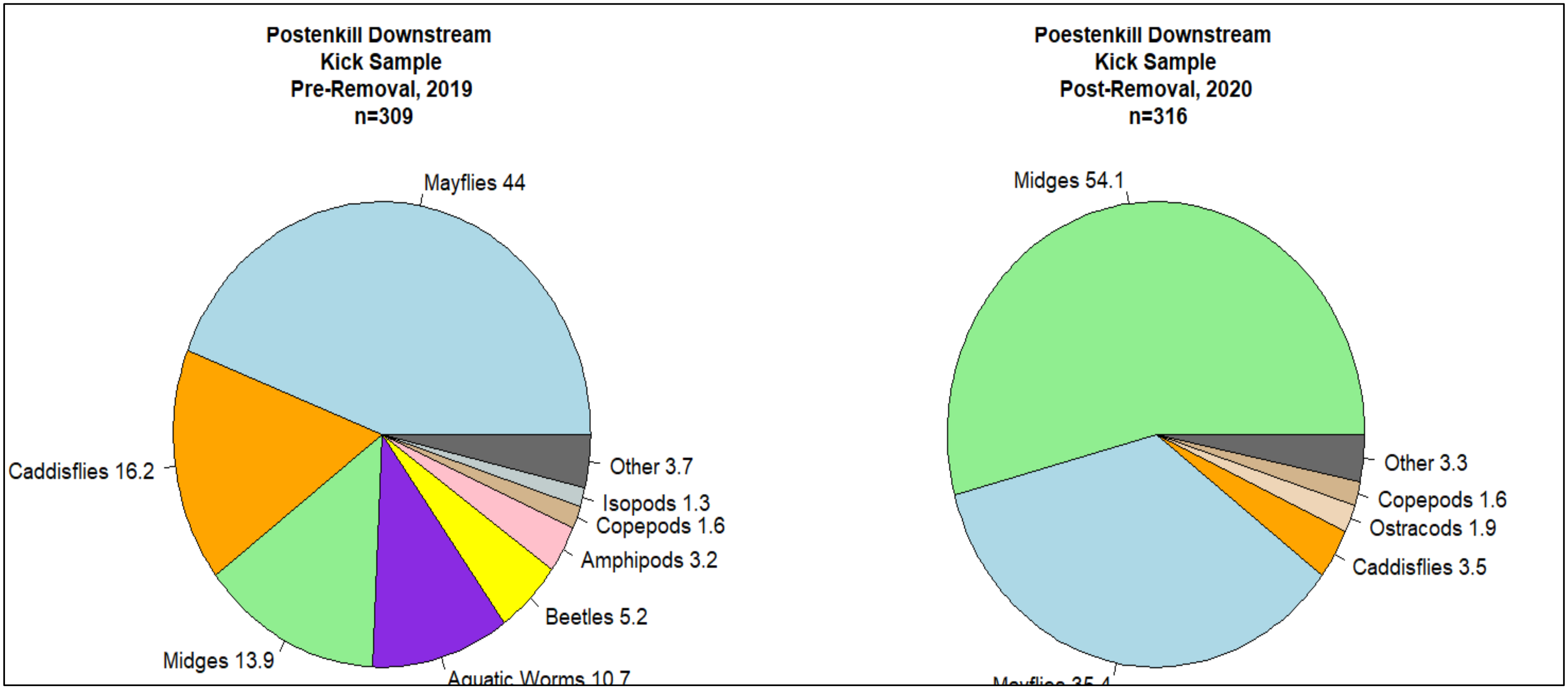


Figure 8: Aquatic Macroinvertebrate community assemblages on the Poestenkill within the lotic downstream reach under 2019 pre-removal and 2020 post-removal conditions.

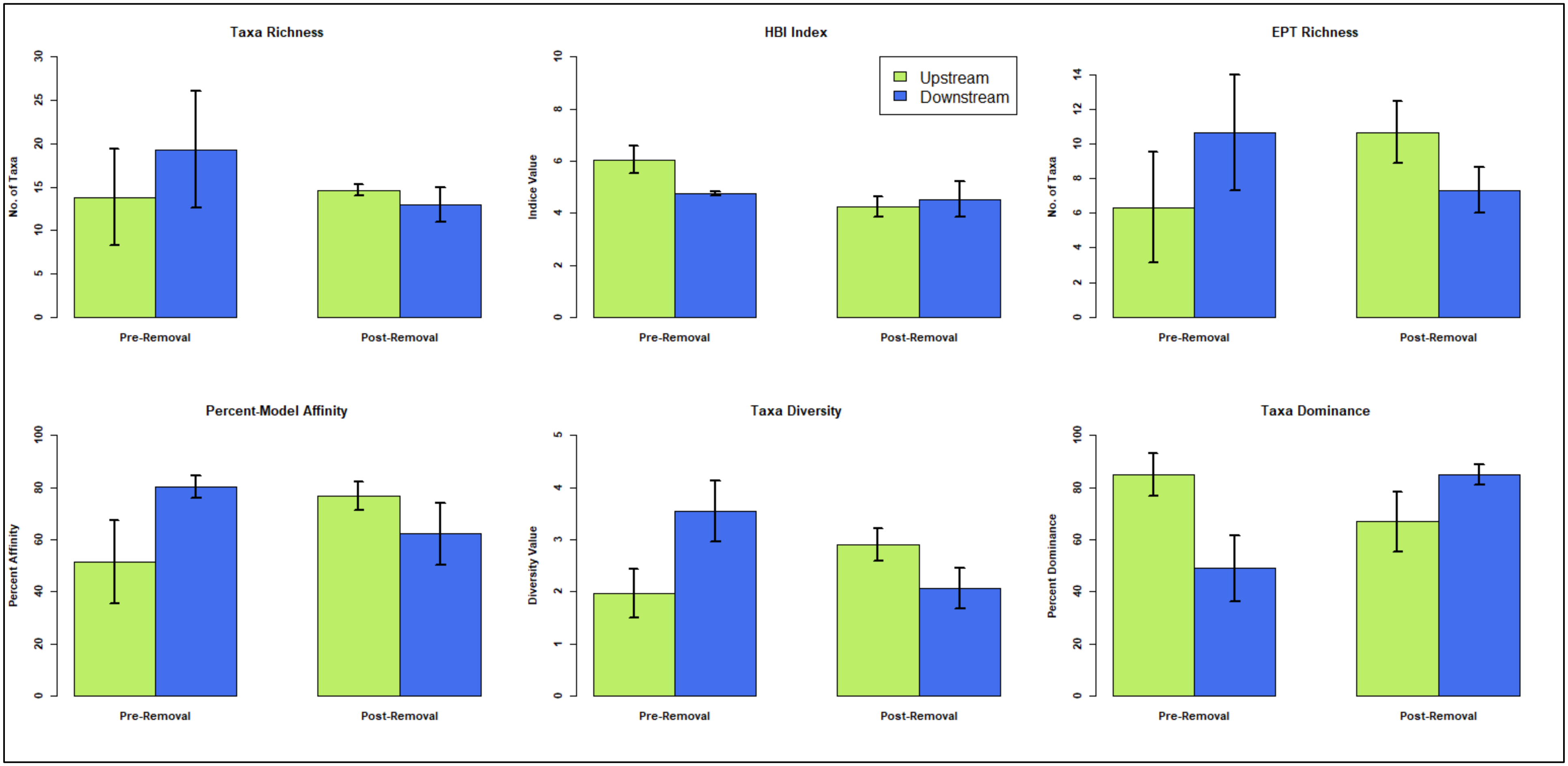


Figure 9: Comparative mean biometric values observed at upstream and downstream monitoring locations between 2019 pre-removal and 2020 post-removal contexts at Lake Ida dam on the Poestenkill.

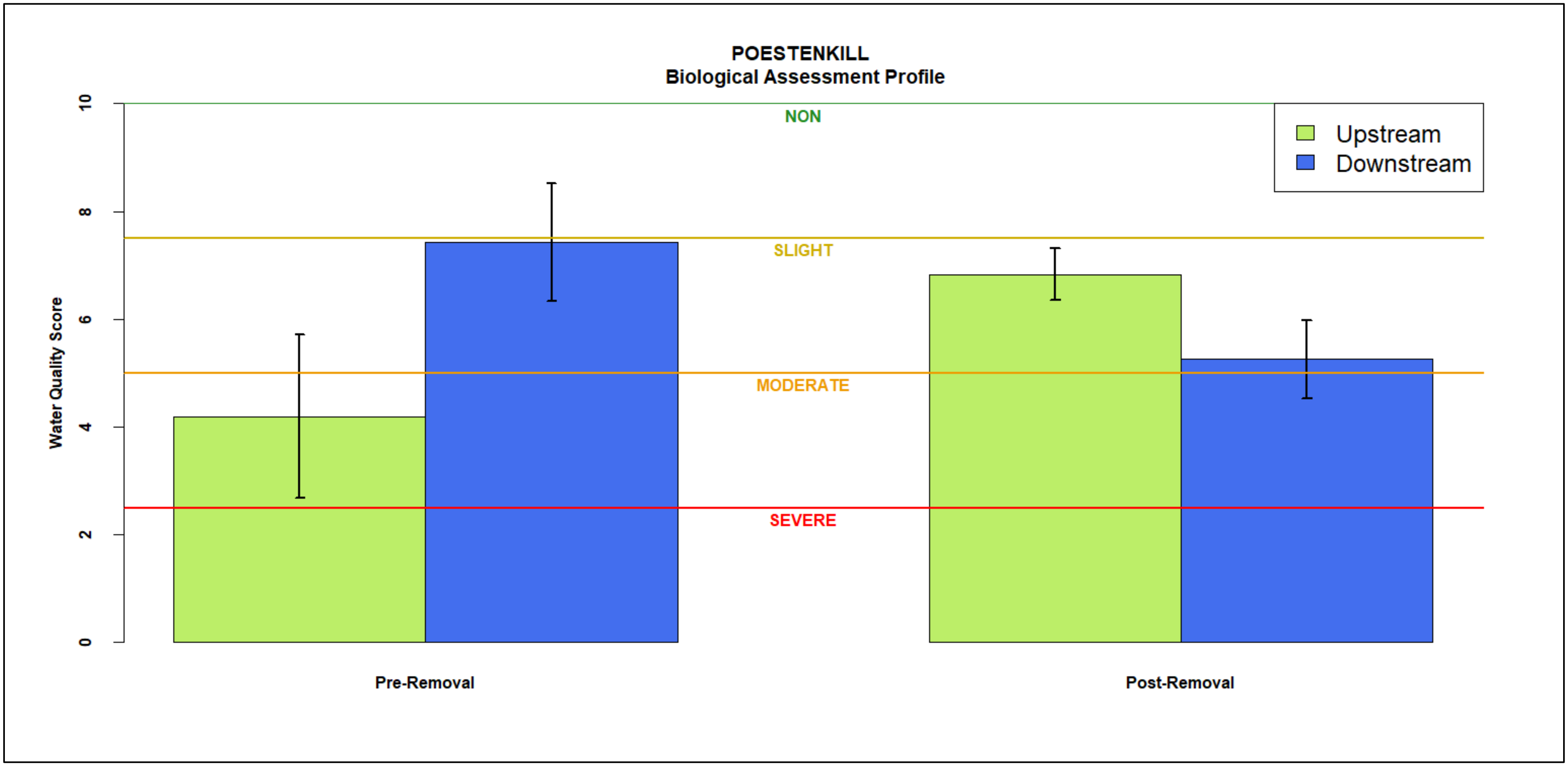


Figure 10: Differences in the Biological Assessment Profile score at monitoring locations upstream and downstream of Lake Ida dam on the Poestenkill under 2019 pre-removal and 2020 post-removal conditions.

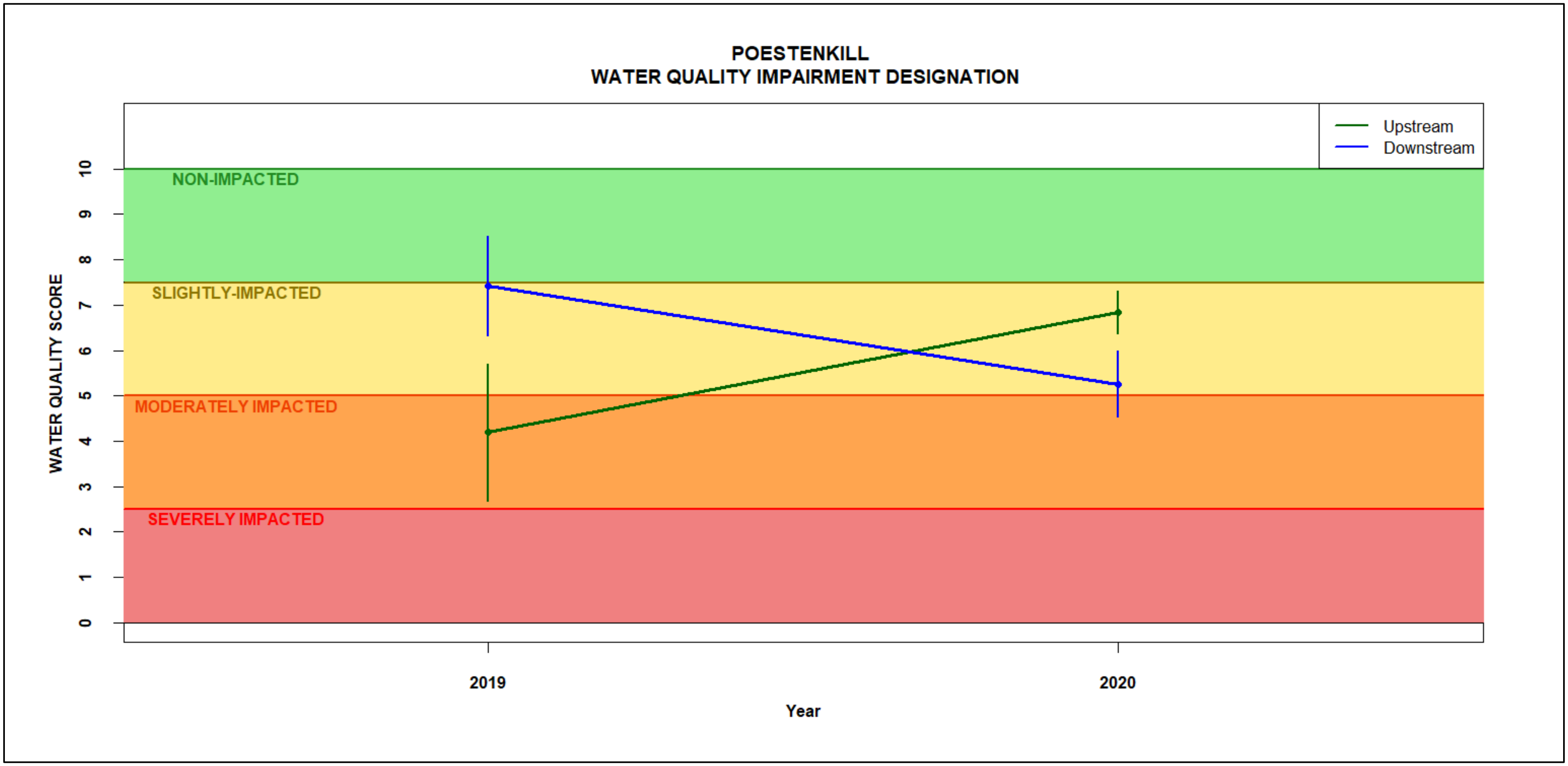


Figure 11: Changes in water quality impairment designation at upstream and downstream monitoring locations surrounding Lake Ida dam on the Poestenkill under 2019 pre-removal and 2020 post-removal conditions.

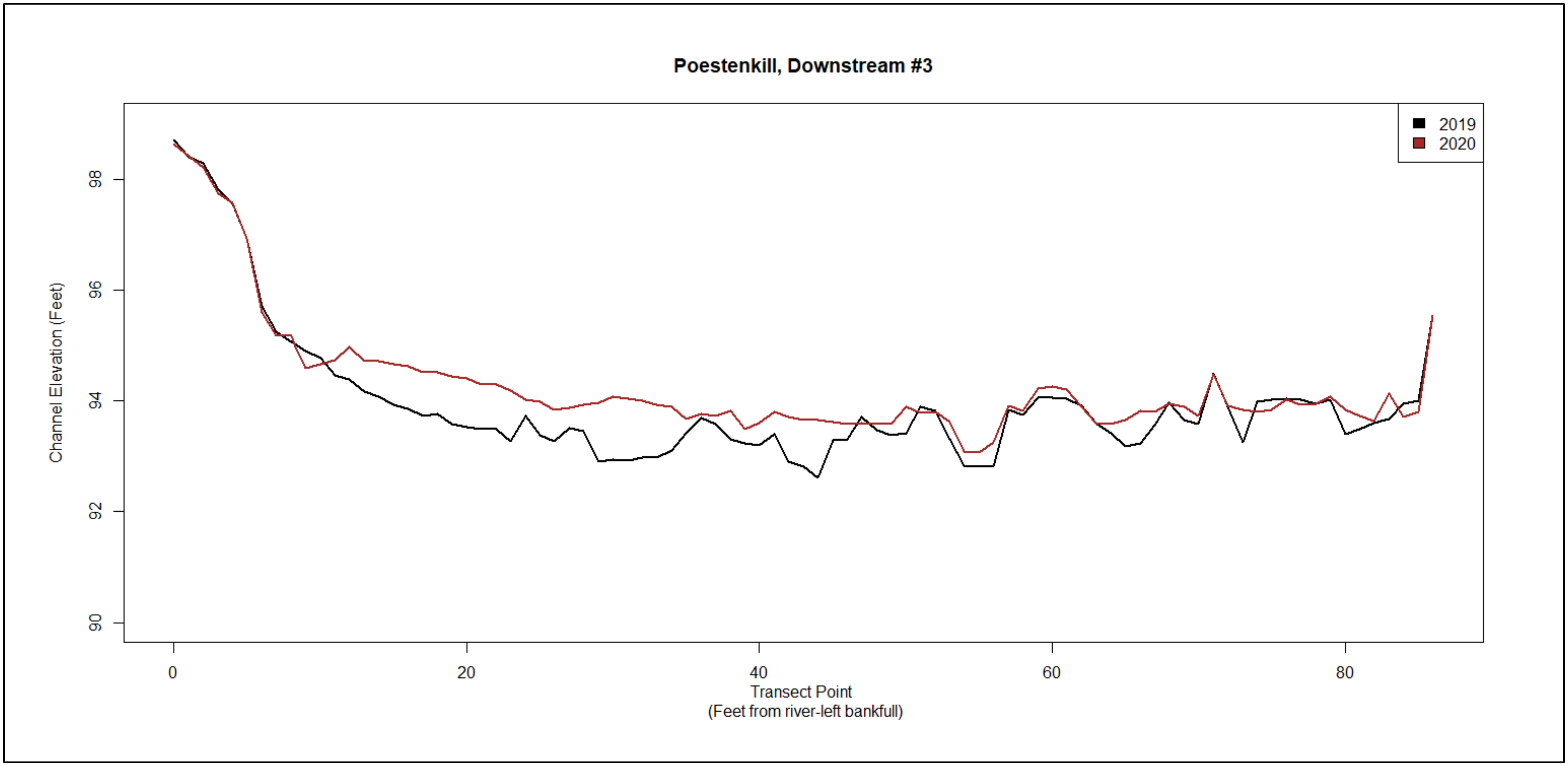
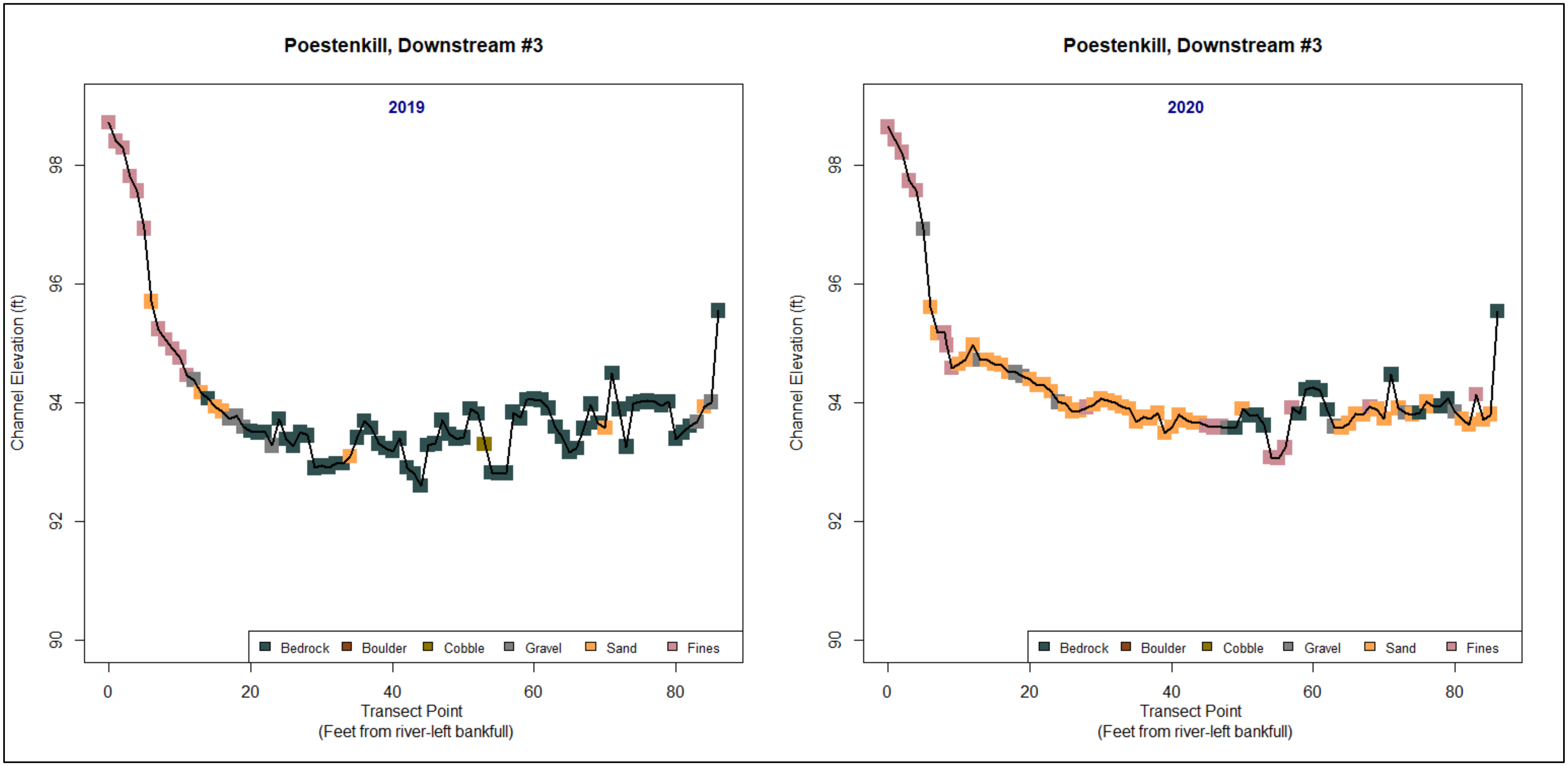


Figure 12: Stream channel morphology and elevation transects measured during pre-removal conditions in 2019 and post-removal conditions in 2020 at the #3 monitoring transect downstream of Lake Ida dam on the Poestenkill.



<u>Figure 13: Substrate composition along the #3 monitoring transect downstream of Lake Ida dam on the Poestenkill during pre-removal in 2019 and post-removal during 2020.</u>

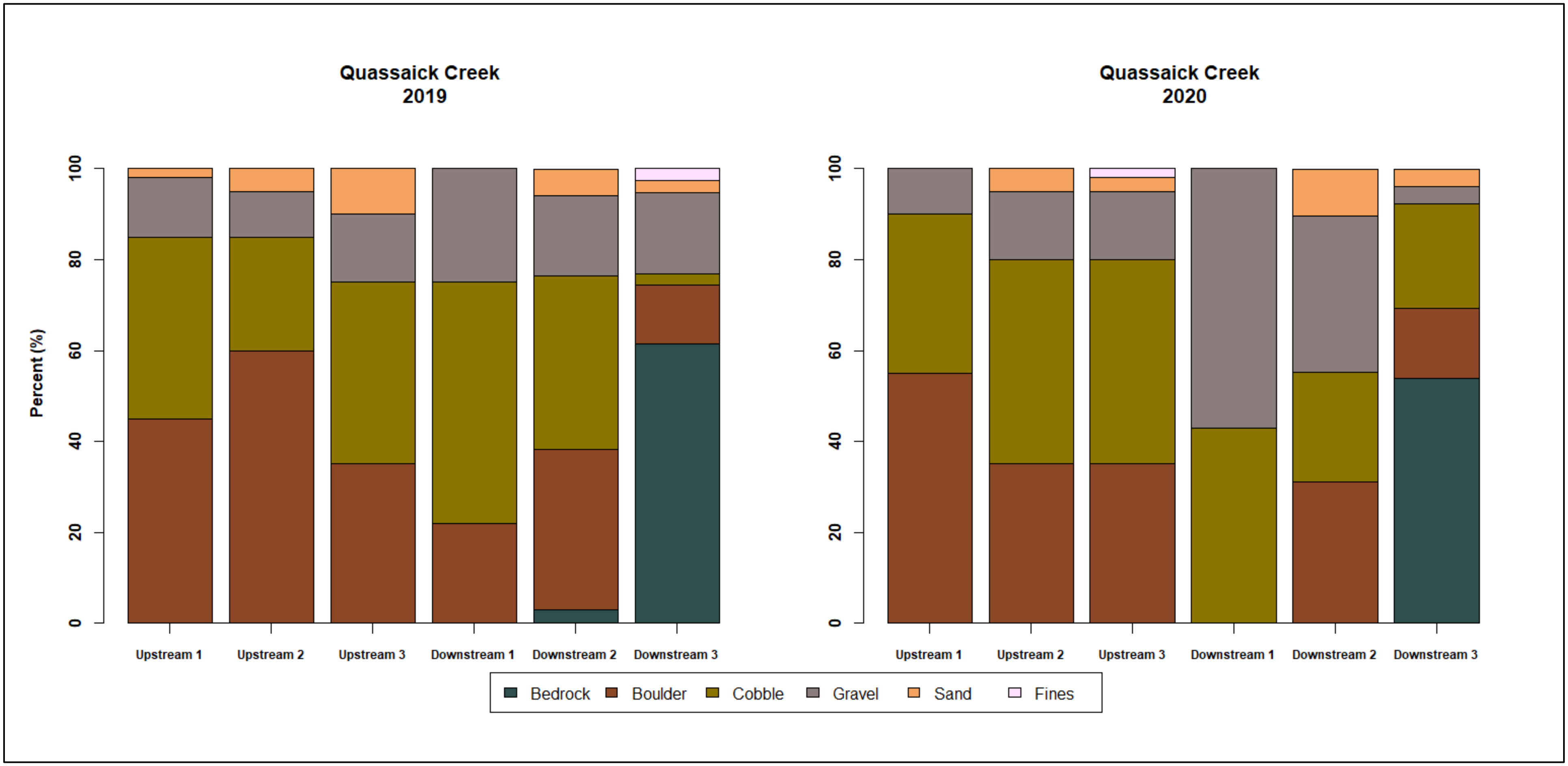


Figure 14: Pre-removal wetted-width substrate composition along each upstream and downstream monitoring transect surrounding Strooks Felt dam on Quassaick Creek during 2019 and 2020.

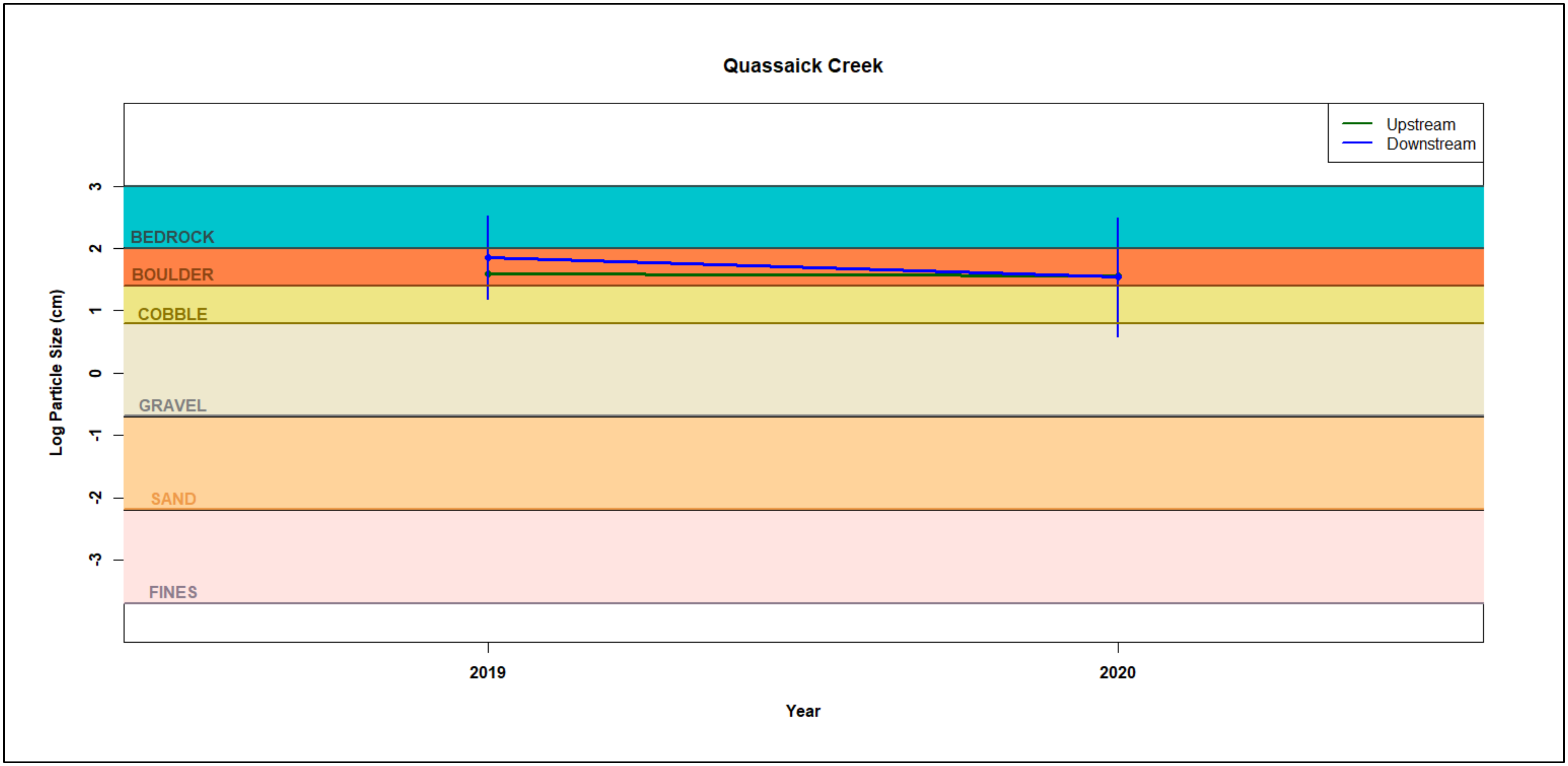


Figure 15: Pre-removal wetted-width particle size along upstream and downstream transects surrounding Strooks Felt dam on Quassaick Creek during 2019 and 2020.

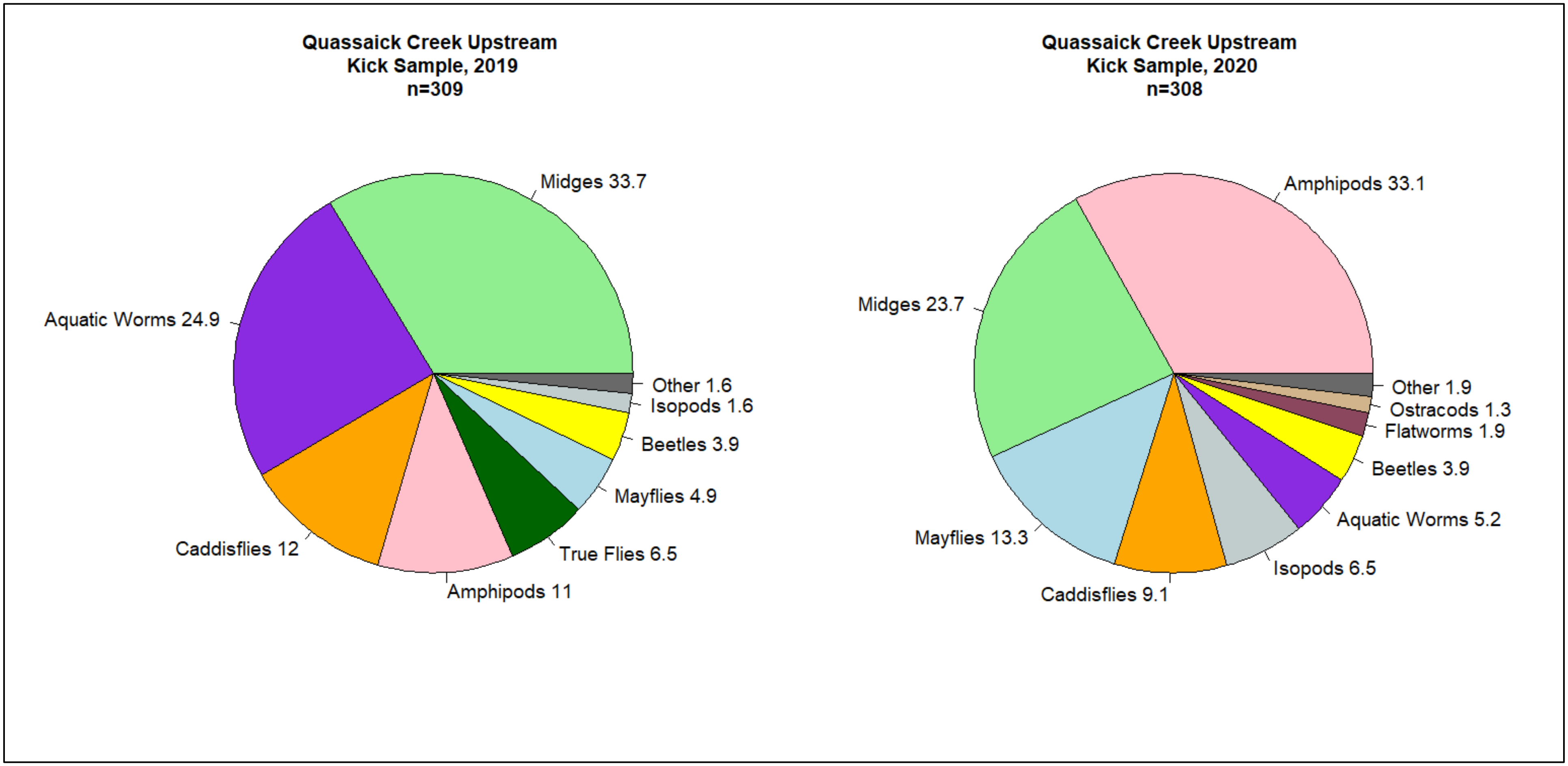


Figure 16: Pre-removal aquatic macroinvertebrate community assemblages collected by kick-samples within the upstream reach of Strooks Felt dam on Quassaick Creek during 2019 and 2020.

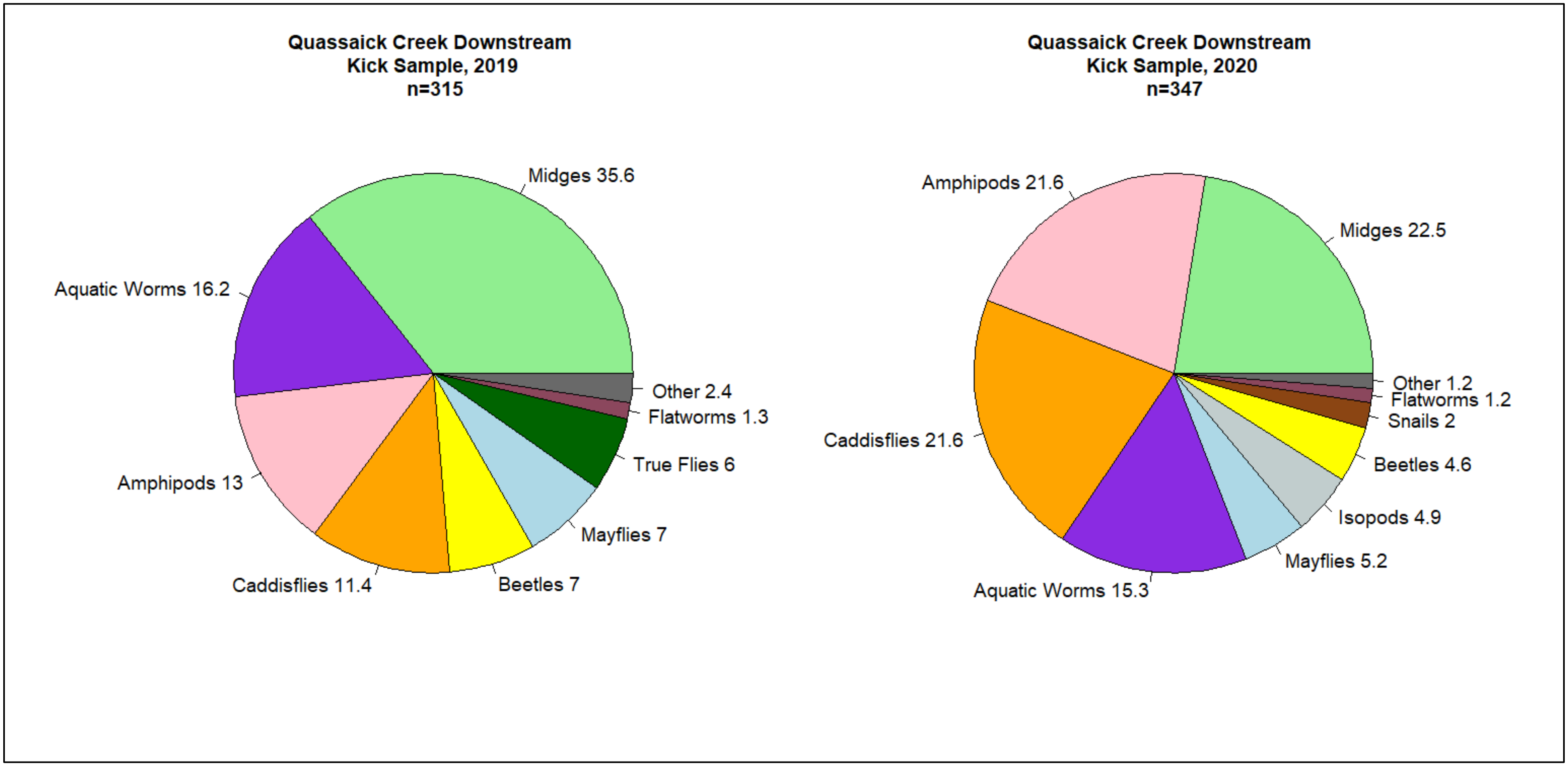


Figure 17: Pre-removal aquatic macroinvertebrate community assemblages collected by kick samples within the reach downstream of Strooks Felt dam on Quassaick Creek during 2019 and 2020.

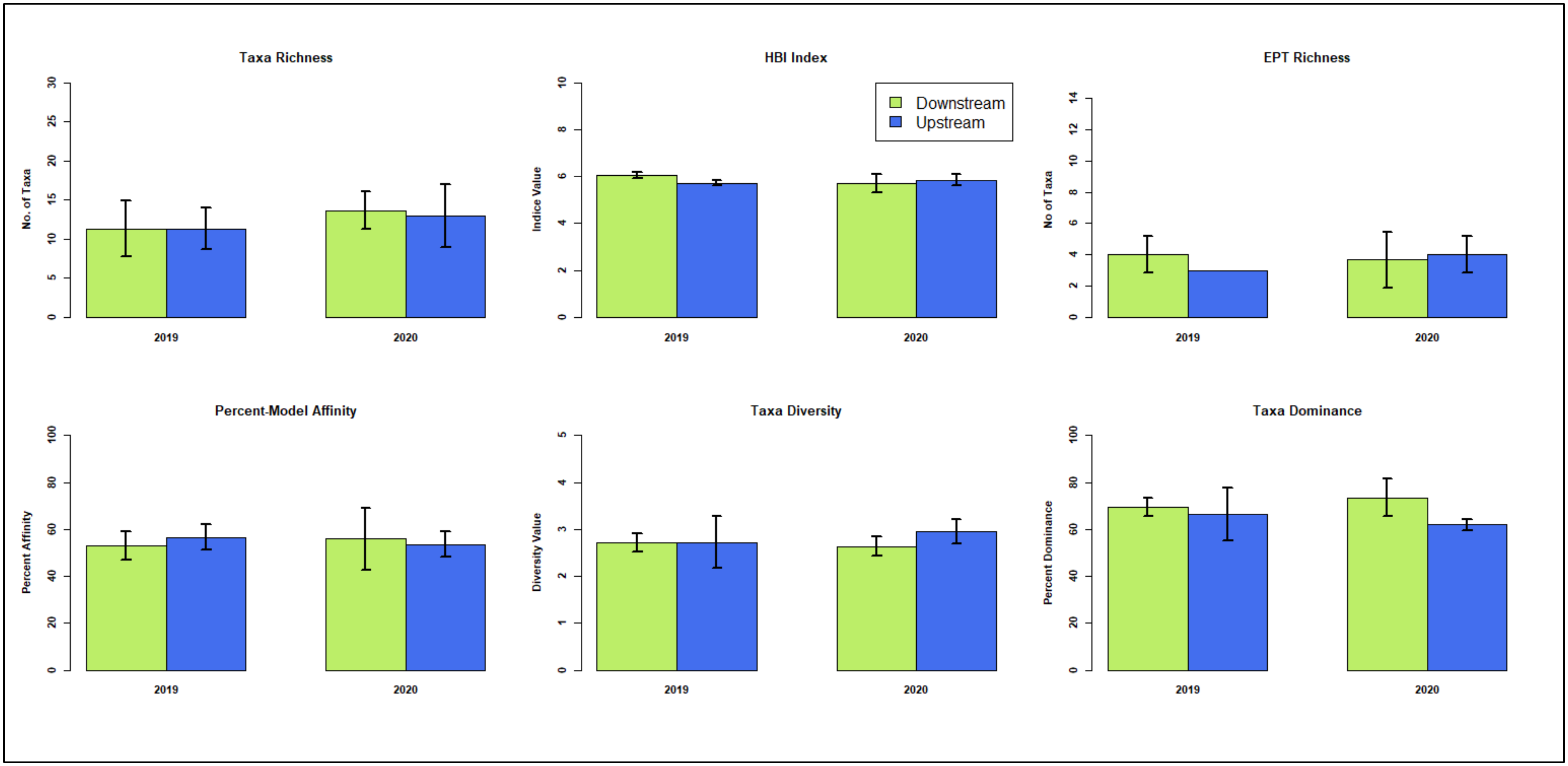


Figure 18: Pre-removal biometric values from within the upstream and downstream reaches surrounding Strooks Felt dam on Quassaick Creek during 2019 and 2020.

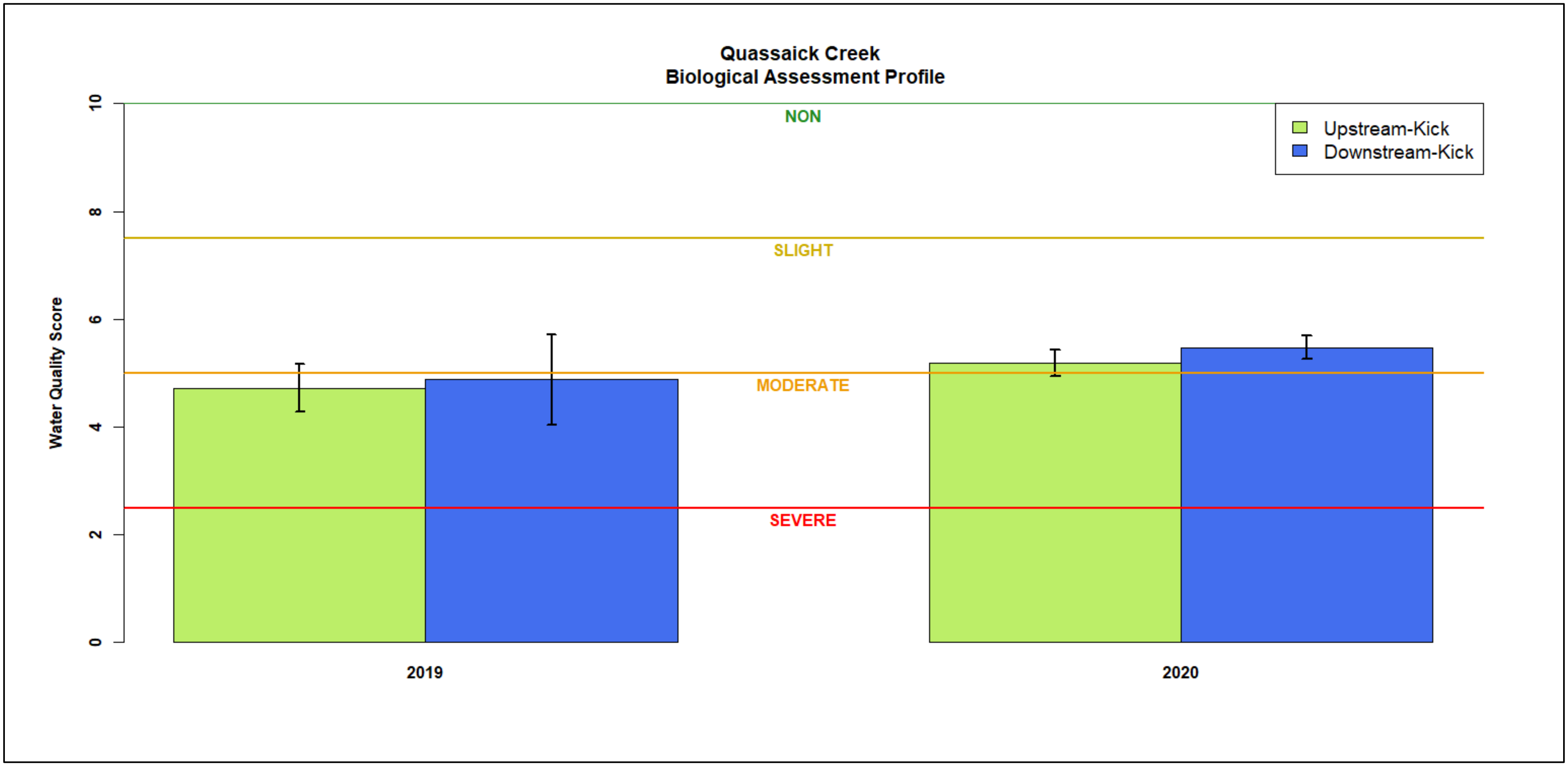


Figure 19: Pre-removal Biological Assessment Profile scores within the upstream and downstream reaches surrounding Strooks Felt dam on Quassaick Creek during 2019 and 2020.

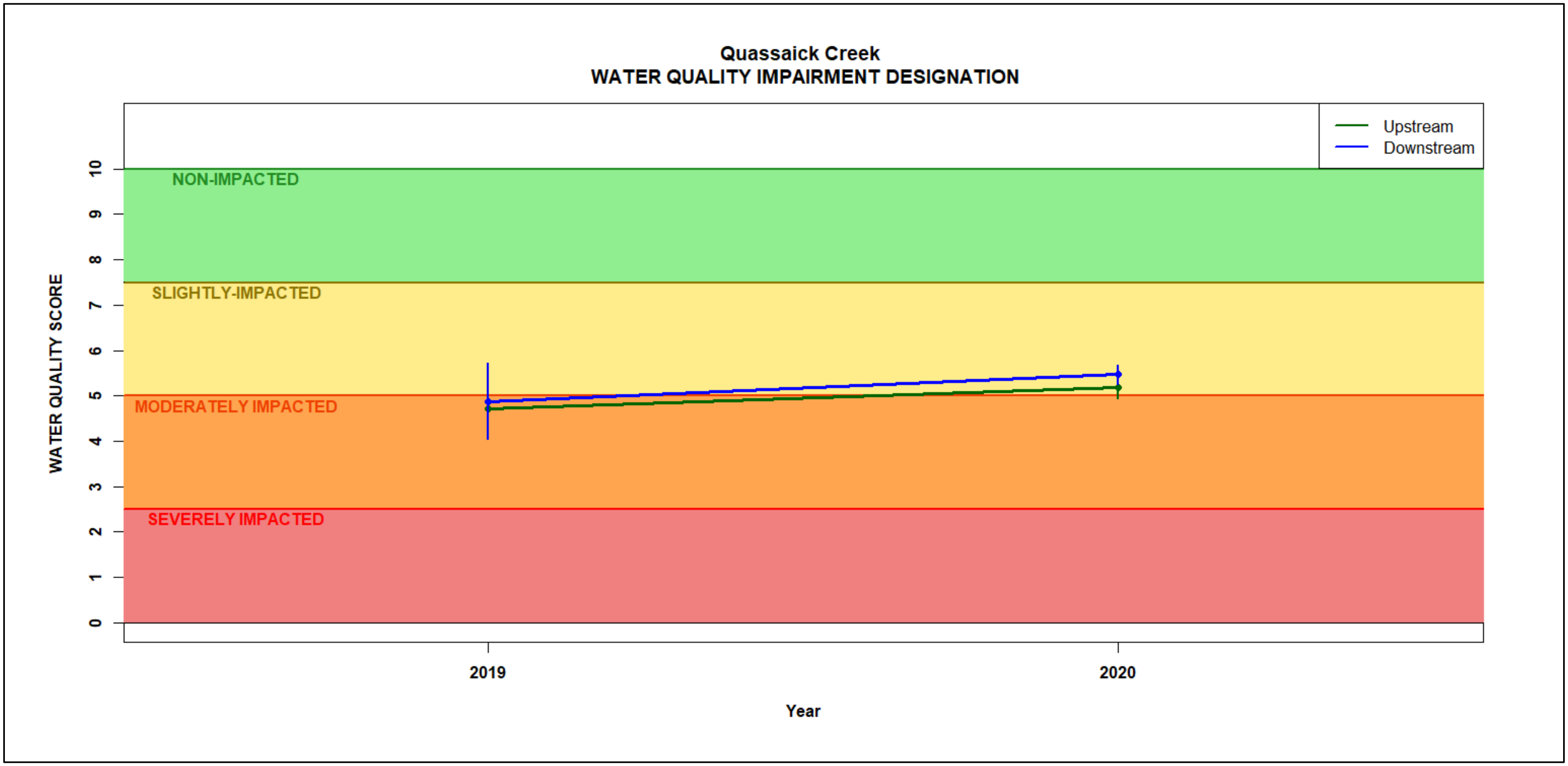


Figure 20: Pre-removal water quality designation trend upstream and downstream of Strooks Felt dam on Quassaick Creek over 2019 and 2020.

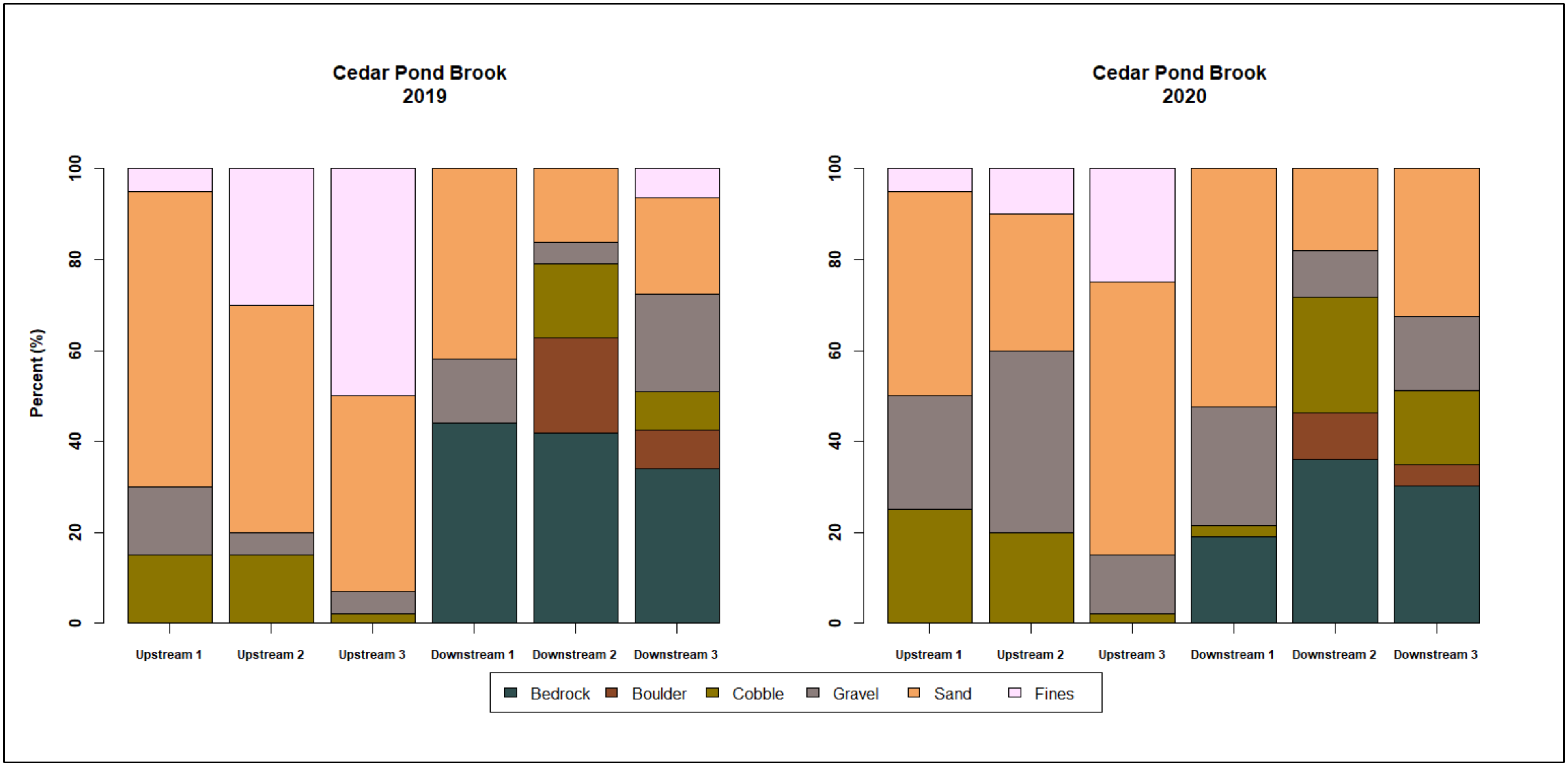


Figure 21: Pre-removal wetted-width substrate composition along each upstream and downstream monitoring transect surrounding Stony Point dam on Cedar Pond Brook during 2019 and 2020.

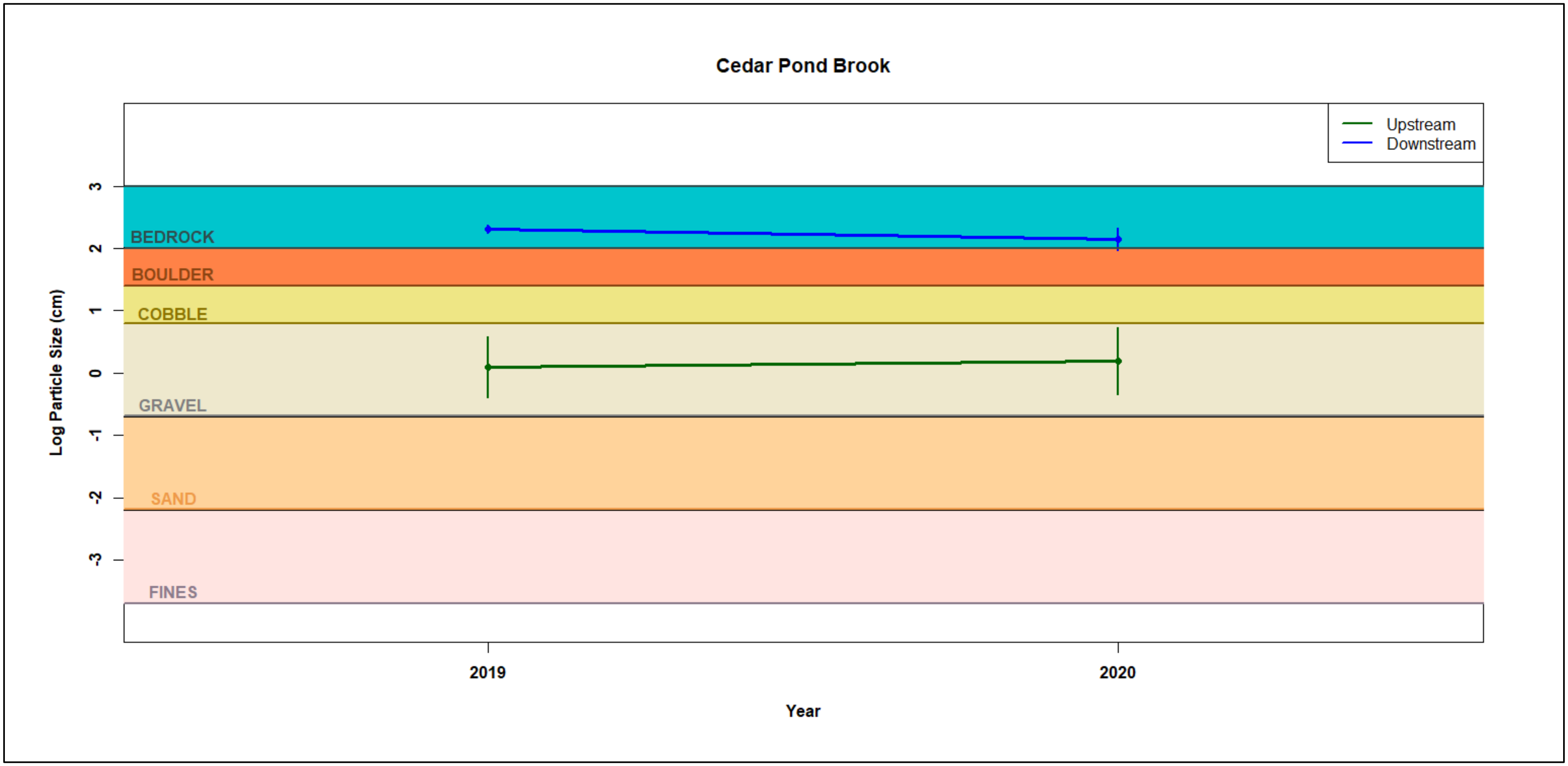


Figure 22: Pre-removal wetted-width particle size along upstream and downstream transects surrounding Stony Point dam on Cedar Pond Brook during 2019 and 2020.

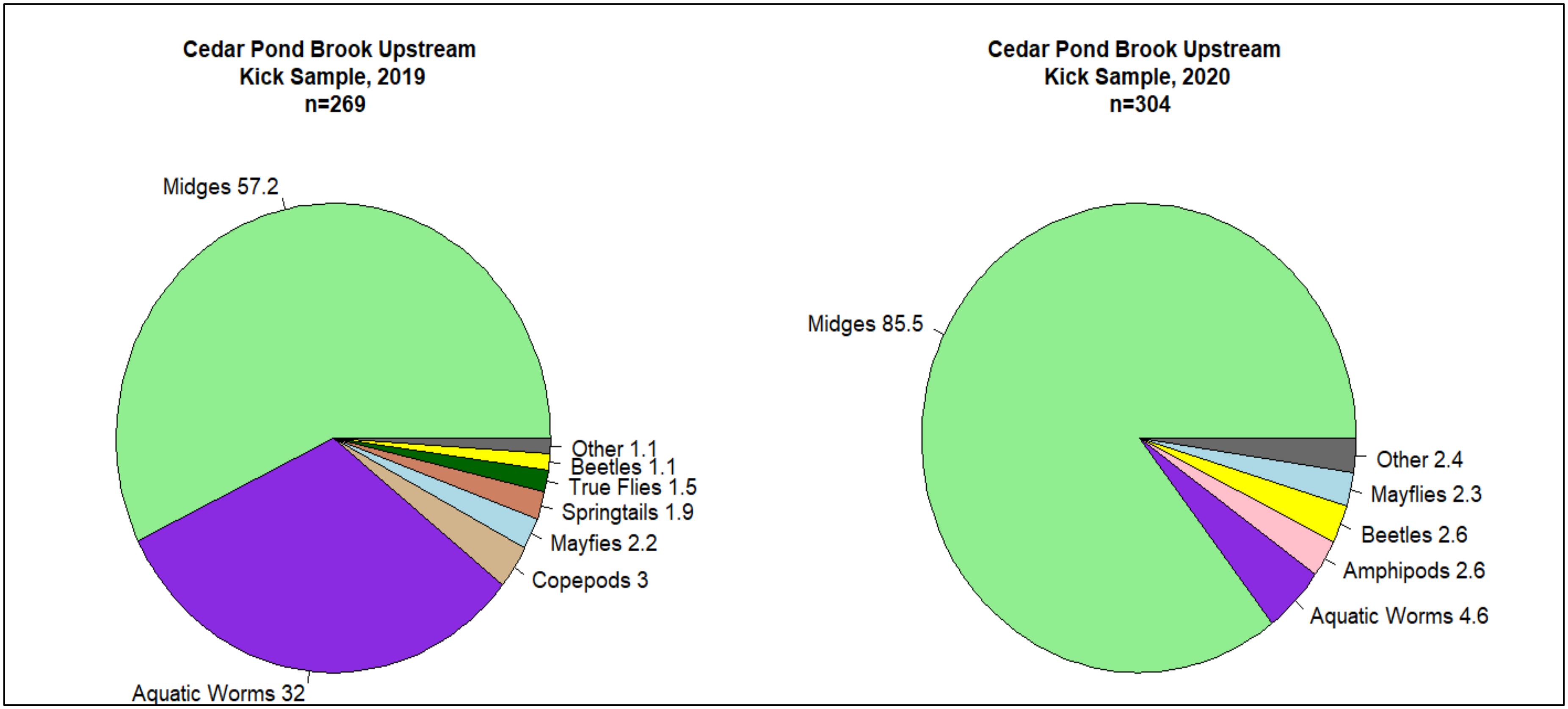
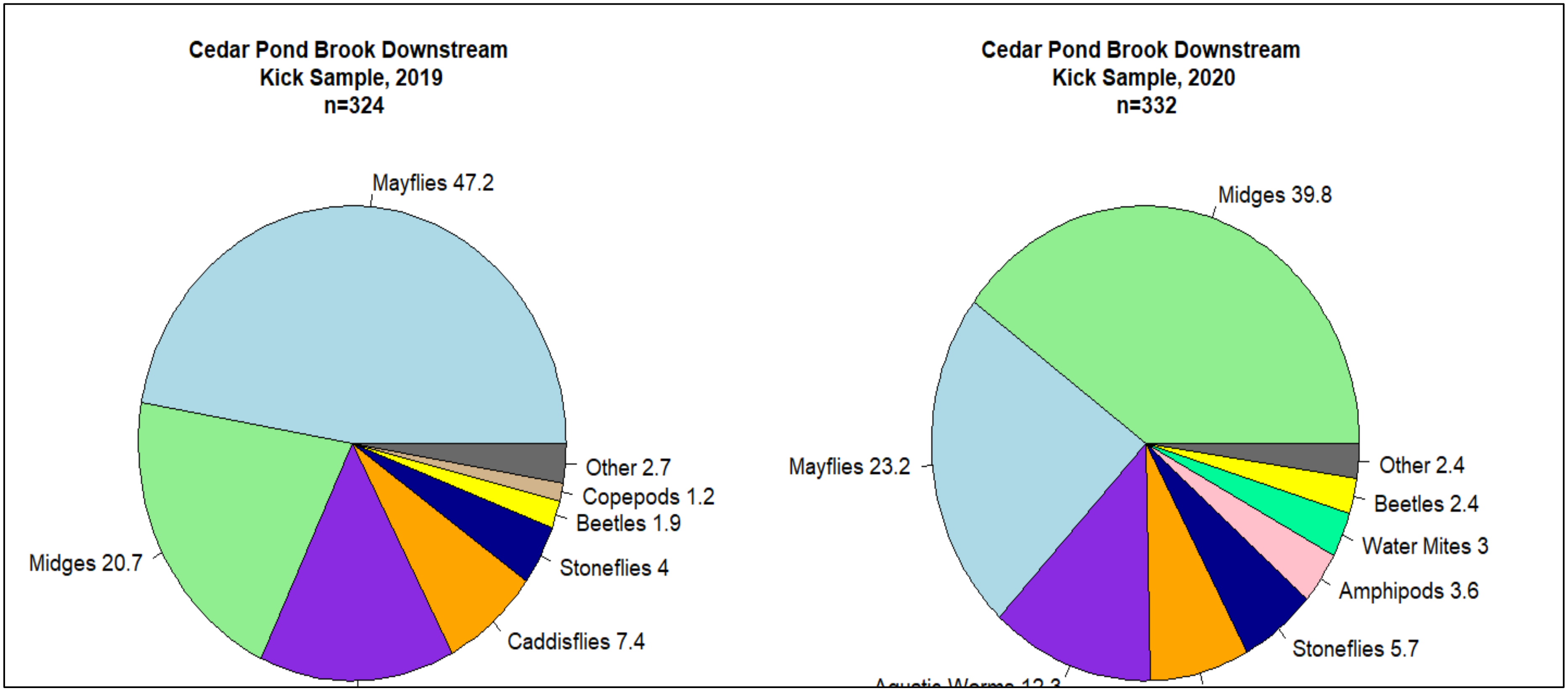


Figure 23: Pre-removal aquatic macroinvertebrate community assemblages collected by kick-samples within the upstream reach of Stony Point dam on Cedar Pond Brook during 2019 and 2020.



<u>Figure 24: Pre-removal aquatic macroinvertebrate community assemblages collected by kick samples within the reach downstream of Stony Point dam on Cedar Pond Brook during 2019 and 2020.</u>

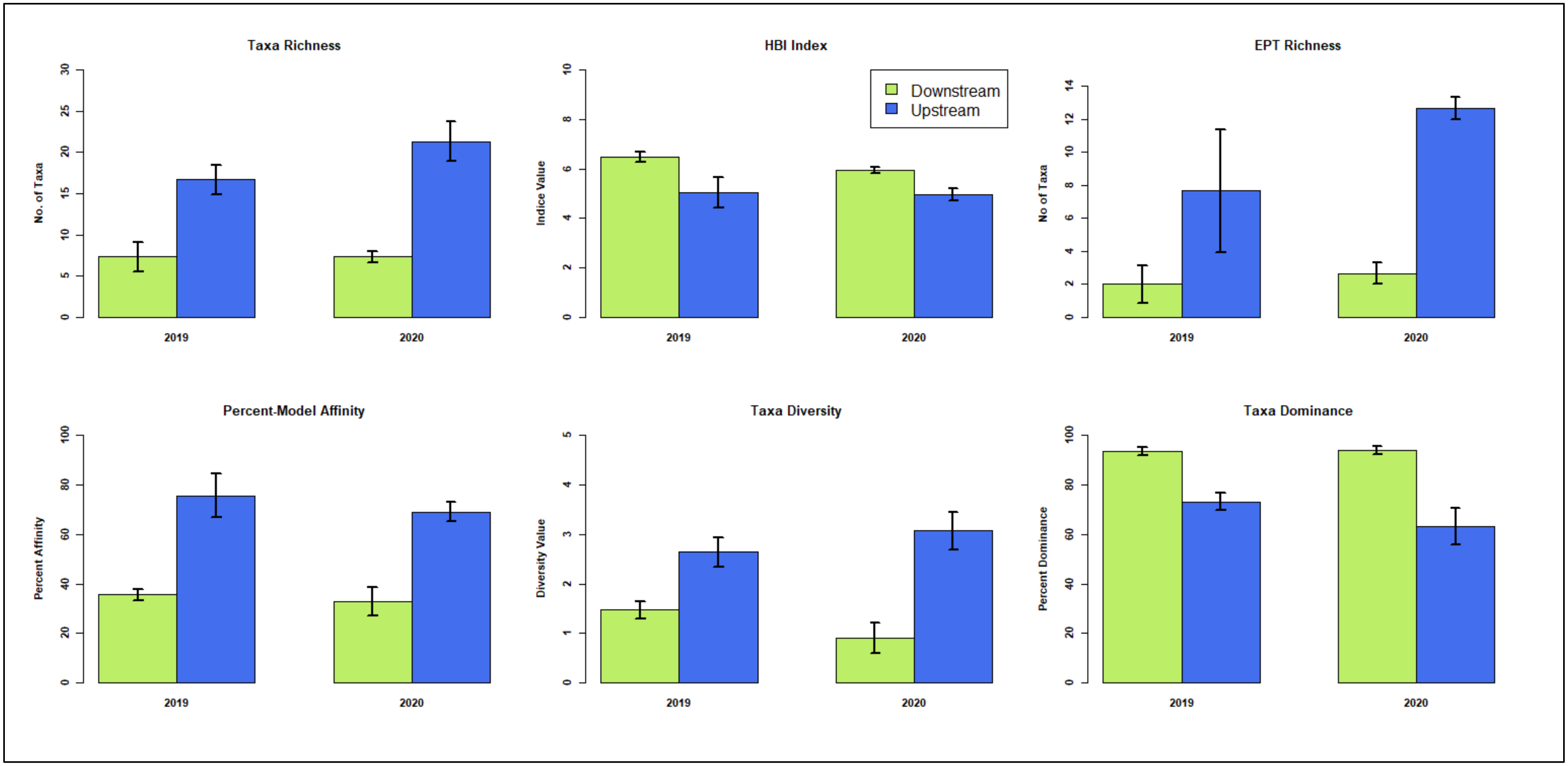
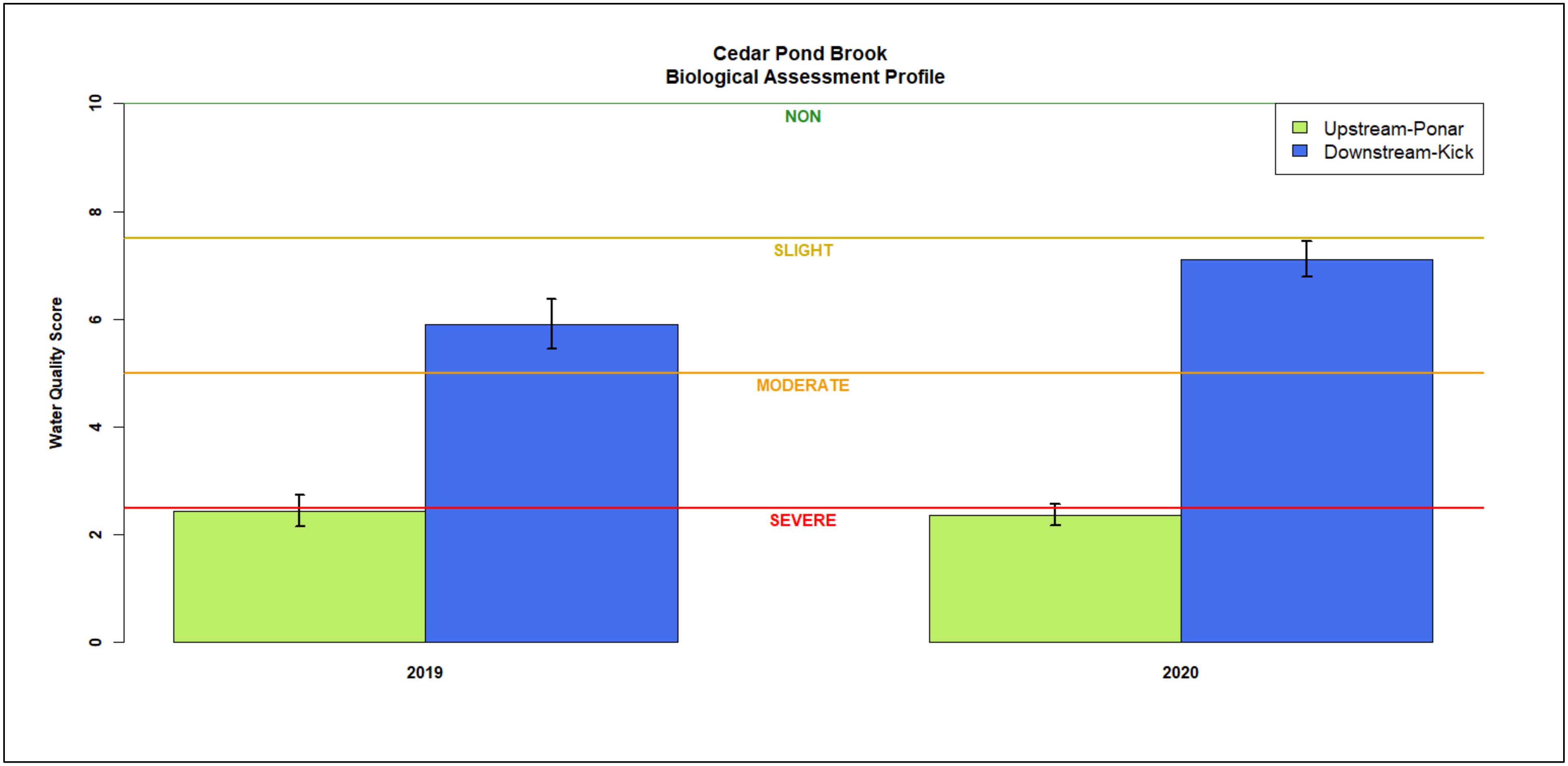


Figure 25: Pre-removal biometric values from within the upstream and downstream reaches surrounding Stony Point dam on Cedar Pond Brook during 2019 and 2020.



<u>Figure 26: Pre-removal Biological Assessment Profile scores within the upstream and downstream reaches surrounding Stony Point dam on Cedar Pond Brook during 2019 and 2020.</u>

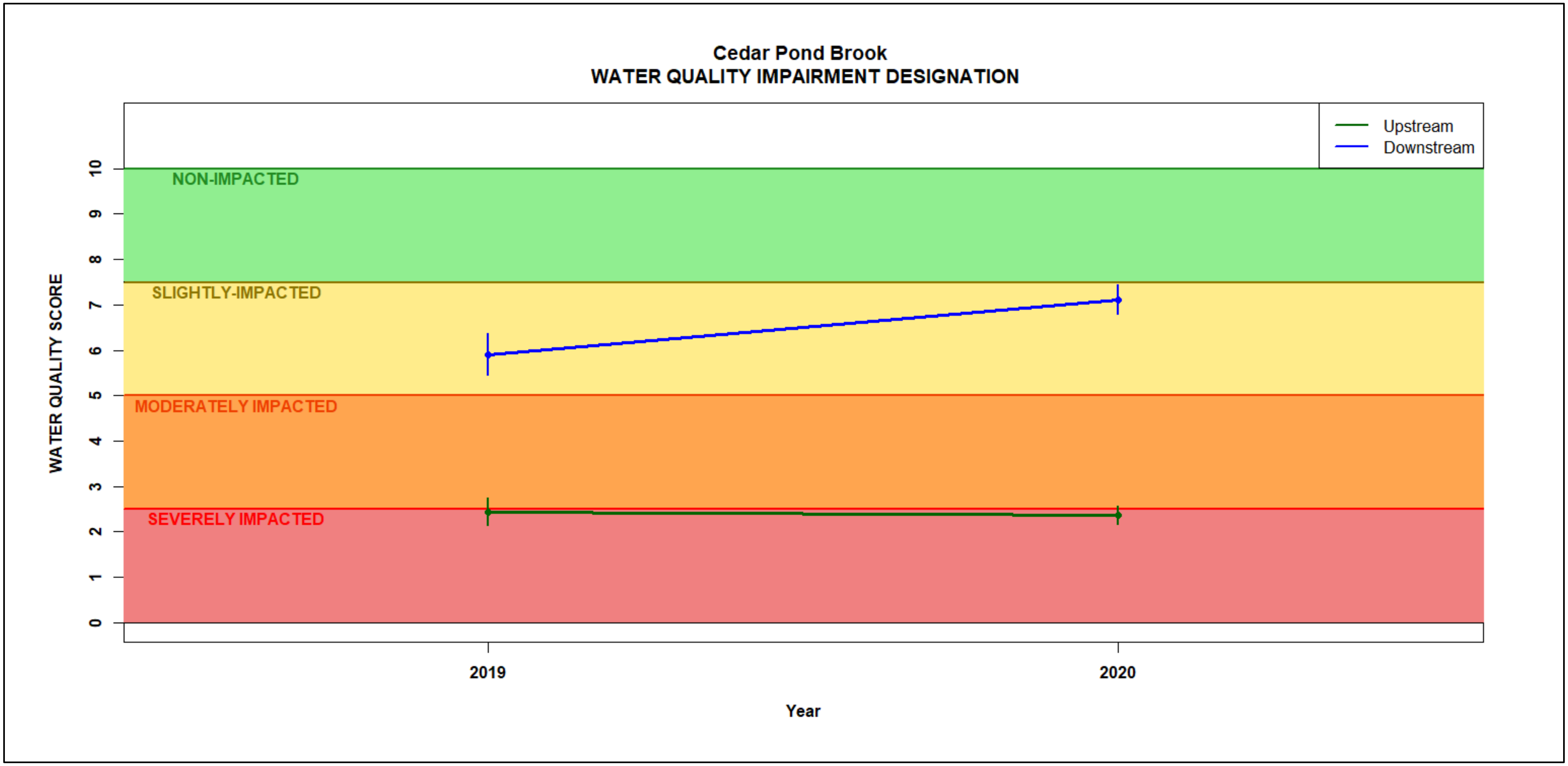


Figure 27: Pre-removal water quality designation trend upstream and downstream of Stony Point dam on Cedar Pond Brook over 2019 and 2020.

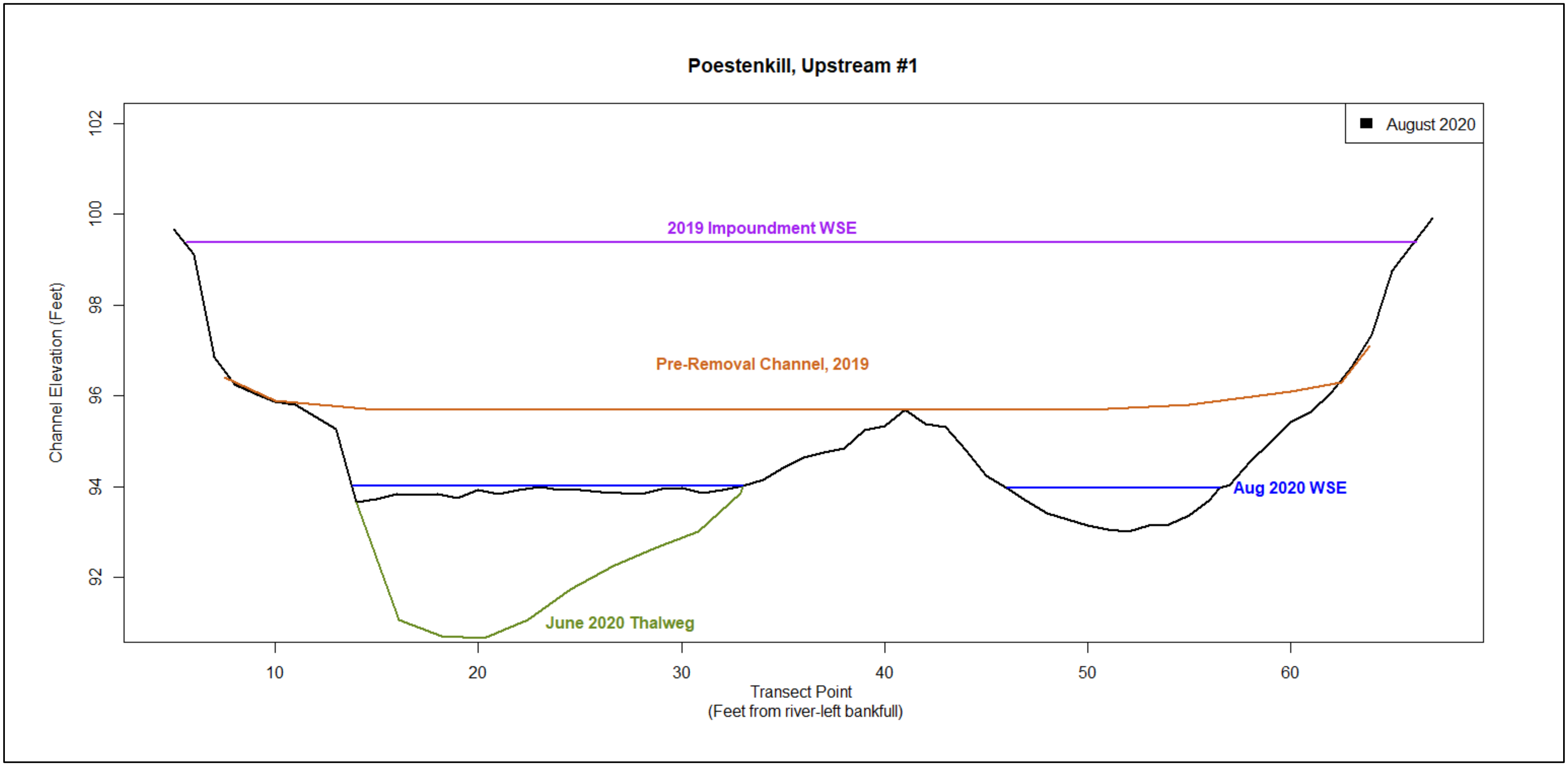
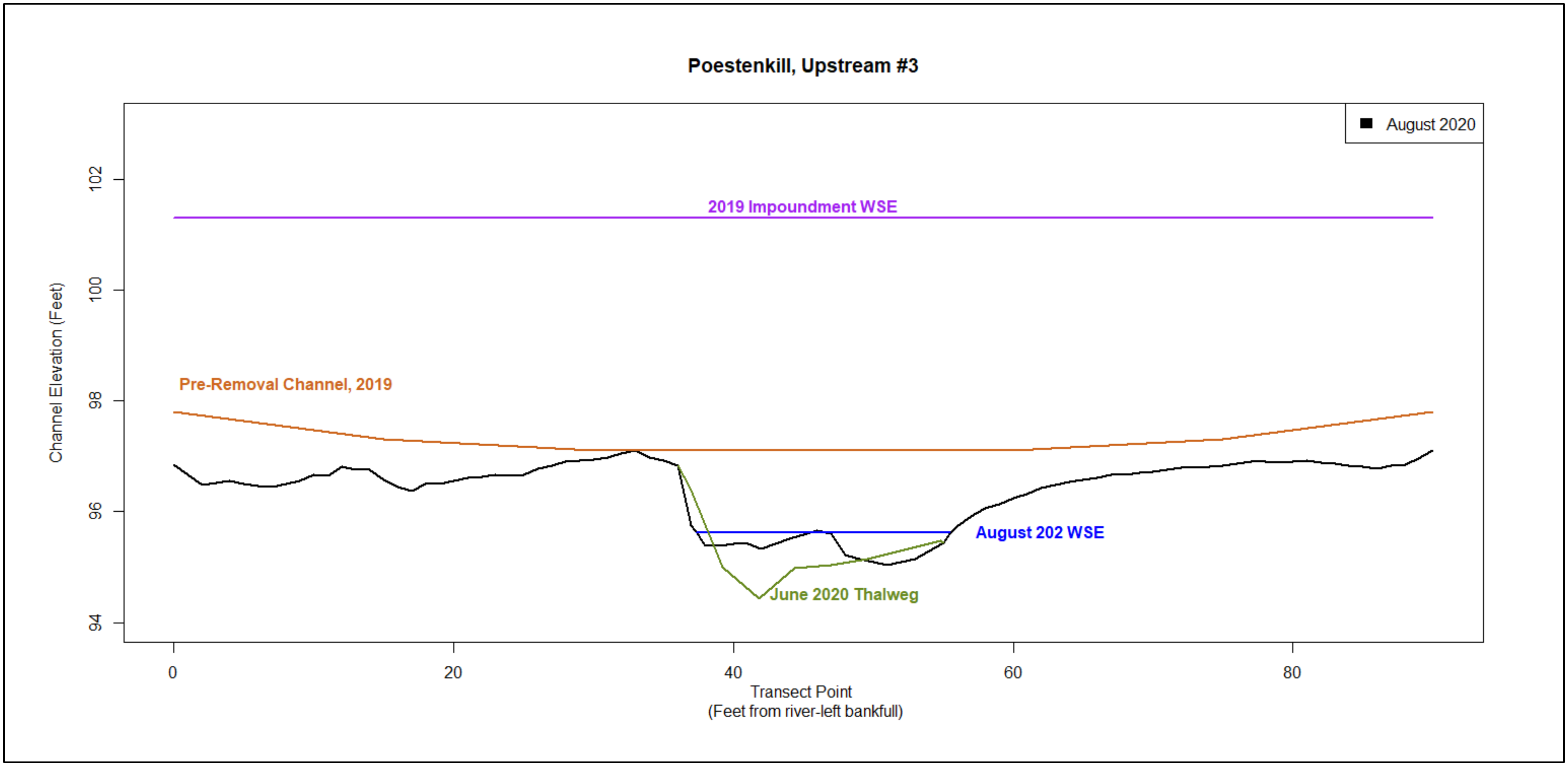


Figure 28: Changes in stream channel morphology prior to and following barrier removal of Lake Ida dam on the Poestenkill, reflected at the upstream monitoring transect #1 location, which is furthest upstream of the barrier. The 2019 impoundment water-surface-elevation (WSE) is based on the elevation of the top of the spillway.



<u>Figure 29: Changes in stream channel morphology prior to and following barrier removal of Lake Ida dam on the Poestenkill, reflected at the upstream monitoring transect #3 location, which is closes to the barrier.</u>

<u>Figure 30: A map depicting the proximity of the next low-head dam downstream of the former Lake Ida dam on the Poestenkill, followed by a natural waterfall. The distance run-of-river distance between the former Lake Ida dam and the next downstream barrier is ~384 yards.</u>

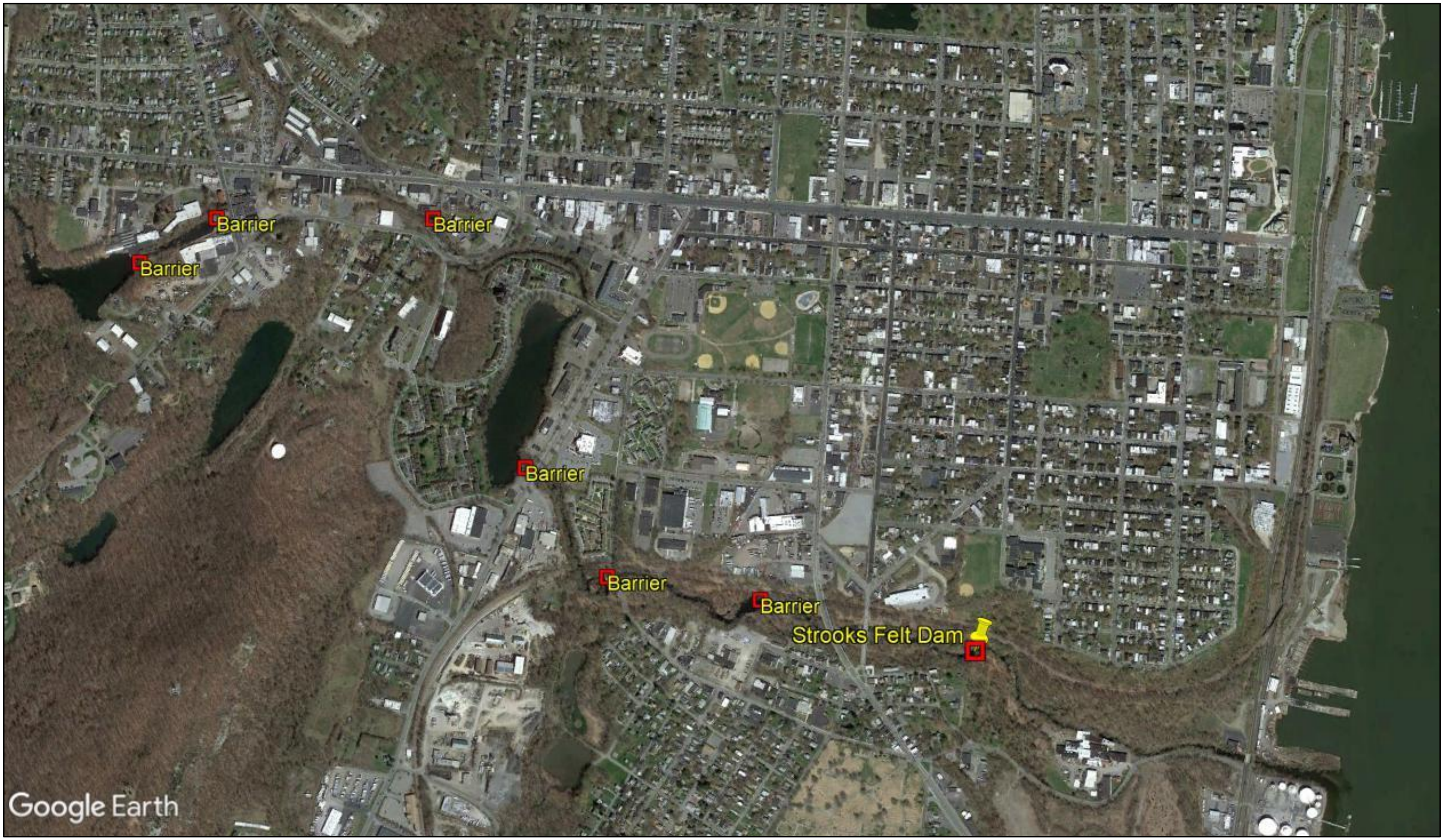


Figure 31: A map depicting the series of barriers built up along Quassaick Creek in the City of Newberg, New York, in relation to the Strooks Felt dam monitoring site.