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Central Coast Watershed Studies

CCoWS

2019 Post-San Clemente Dam Removal Morphological Monitoring of the Carmel River Channel in Monterey County, California

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Executive Summary

The San Clemente Dam was removed from the Carmel River in 2015. Cross section and pebble count surveys were performed before dam removal (2013 and 2015) and after dam removal (2016, 2017, 2018 and 2019) to document dam removal impacts. This report presents surveys from fall 2019, the fourth year after dam removal. Post dam-removal data collection sequentially preceded by the 2016 Soberanes Fire, several flooding events during winter 2017, and relatively average conditions of the 2018 and 2019 water years. 2019 Precipitation was 30.91 inches, and flow at the Robles del Rio gage reached 5010 cfs. Therefore, the water year 2019 rainfall well above average (8-yr event), and the peak flow was slightly lower than the estimated 5-yr event.

We found geomorphic changes at every reach in the study area, ranging from sand aggradation in the channel and floodplain to minor vertical erosion and several meters of lateral erosion. The most common geomorphic changes observed this year were the erosion and incision of fine sediment from the center of the channel, and deposition of new sediment on the channel banks.

Grain size fined and pools aggraded in most cross sections located downstream of the dam in 2017 and 2018—an impact of sand transported from an eroding reach of the river located 1.5 km upstream of the former dam site. During water year 2019, grain size fined at only half of the sites downstream of the dam, with large amounts of variation between cross sections at any given site. The reduced rate of fining in 2019 may indicate that the pulse of sand and find gravel that swept the entire lower river in 2017 is gradually winnowing. None of the sites have rebounded to pre dam-removal grain size coarseness (graphic mean). Given that the sand source upstream of the former dam site is still actively eroding, a new pulse of fine sand is likely when strong winter flows return.

Acknowledgements

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Table of Contents

1 Introduction

San Clemente Dam was removed from the Carmel River in 2015 due to seismic hazard, low storage capacity, and ecological impacts (Boughton et al. 2016; CCOWS 2012). The dam removal project was designed to minimize downstream impacts to fish habitat and flood frequency by sequestering all the stored sediment on site (SCDRP 2015). The specific concerns included the introduction of fine sediment that would impair steelhead spawning opportunities and in-channel sediment deposition that would reduce the channel capacity to contain high discharge events. Sediment transport modeling of the dam removal project indicated that the river would not be significantly altered by the project (Mussetter 2005).

In collaboration with the U.S. Geological Survey and NOAA Fisheries Service, we established several study reaches in 2013 to monitor downstream impacts of the dam removal project (Fig. 1; Leiker et al. 2014). Monitoring includes cross sectional surveys to detect changes in channel morphology and pebble counts to detect changes in particle size of the river substrate. The study reaches include six "impact" reaches located downstream, and one "control" reach located upstream of the former dam. The "control" reach is located directly downstream from the currently operating Los Padres Dam, approximately 11 km upstream from the former San Clemente Dam.

The 2013 and 2015 surveys assessed the natural geomorphic variability in the Carmel River prior to dam removal (Leiker et al. 2014 and Chow et al. 2016). Those surveys were conducted during severe drought years, so they likely do not represent the full range of geomorphic change in the Carmel River during wet years. The first survey following the dam removal was conducted after the average 2016 water-year. That study found minimal changes to geomorphology or grain size at the study reaches (Chow et al. 2017). A separate 2016 study focusing on near-dam sediment transport noted that a significant sand wave, likely sourced from an unstable reach of river passing through old reservoir sediment, had extended 3.5 km downstream from the dam site (Chow et al. 2016).

The second survey after the dam removal was conducted after the 2017 water-year. This survey showed large changes to both the morphology and grain size composition at the survey reaches (Steinmetz and Smith 2018), with mean grain size decreasing at all sites downstream of the dam removal site. In contrast to previous years, the 2017 water-year included flows reaching the 10-year flood on two occasions, and one storm peaking near the 25 to 30-year flood (Harrison et al. 2018). High flows of 2017 were preceded by the late summer 2016 Soberanes Fire which extended into the southern Carmel Watershed above the former San Clemente Dam, but suspended sediment studies indicate that the fire did not significantly impact the Carmel River channel (Harrison et al. 2018).

The significant changes in the Carmel River reported in 2017 resulted from the rapid growth and extension of the sediment wave first noted in 2016. Harrison et al. (2018) interpret the source to that sediment to be a combination of base level fall, knickpoint migration, and channel avulsion through the unstable river channel located in old reservoir sediments above the old dam site, triggered by the high flows of Water Year 2017.

The third survey after the dam removal took place after water year 2018. 2018 was a relatively dry water year, and geomorphic changes were minimal. Some cross sections that were not surveyed in 2017 showed large changes, but the changes were likely the result of the larger 2017 flows. The trend of particle size fining downstream from the dam continued in 2018, with all downstream sites lowering in mean particle size.

This report presents results from surveys conducted after the 2019 water-year. Flows in 2019 were higher than those in 2018, but much lower than 2017. Precipitation at the San Clemente Dam gage reached 30.91 inches, which is above the long term (1922 - 2019) average of 21.29 inches. The 2019 precipitation reflects the 8 year exceedance event. Runoff generated a peak flow near 5010 cfs at the Robles del Rio gage, which is a peak flow with a 5-yr exceedance recurrence interval.

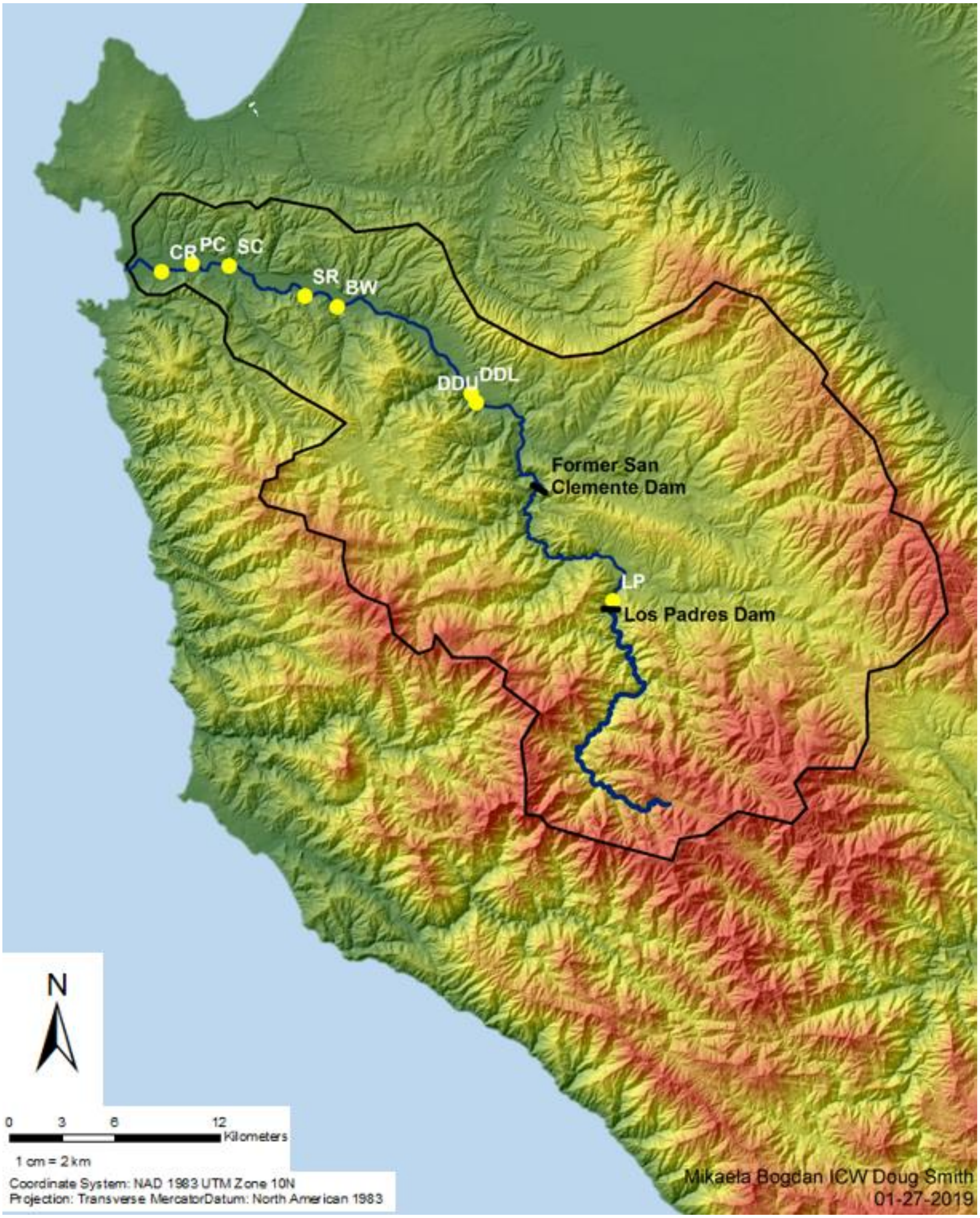

Figure 1. Location of study reaches relative to Los Padres Dam and the former San Clemente Dam on the Carmel River.

2 Methods

Following the methods of the initial 2013 study (Leiker et al. 2014), we conducted geomorphic measurements of the Carmel River before the San Clemente Dam removal at eight diverse and representative reaches of the river that could change character following dam removal (Fig. 1). Cross sections were surveyed and pebble counts were performed at each site in fall and winter 2019, when low flows provided easy access to the channel. Each study reach is described below:

- **Los Padres (LP)**: Located directly downstream from the Los Padres Dam, this reach is the most upstream reach established in 2015. This site spans a spawning gravel injection operation run by the Monterey Peninsula Water management District.
- **DeDampierre Upper (DDU)**: Located in the upper portion of DeDampierre Park, the reach extends from the footbridge past the baseball fields. This reach contains several pieces of large wood installed for a restoration project by the Monterey Peninsula Water Management district.
- **DeDampierre Lower (DDL)**: This reach begins at the lower end of DeDampierre park and extends to the Carmel Valley Trail and Saddle Club downstream of the park.
- **Berwick (BW)**: Established in 2015, this reach is located on California American Water property.
- **Schulte Road (SR)**: Located upstream of the Schulte Road Bridge. This reach begins in land owned by the Big Sur Land Trust and extends to 100m upstream of the Schulte Bridge.

- **San Carlos (SC)**: Located just downstream of the San Carlos Road Bridge. The reach extends from the bridge to the California American Water San Carlos production well.
- **Crossroads (CR)**: Located adjacent to the Crossroads Shopping Center at the mouth of Carmel Valley. This is the most downstream reach included in this study.

Each reach was approximately 300 m in length and contained four to six benchmarked cross sections, approximately spaced at 60 m intervals. Cross sections were set in a variety of hydraulic settings, but mainly in riffles and pools. Using the previous benchmarks established in 2013 or 2015, we resurveyed each cross section using an autolevel, leveling rod, and 50-meter transect tape (Harrelson et al. 1994). At each cross section, a taut tape was set between the left and right benchmarks. Points along each transect were shot according to locations along the transect tape in prior years with additional shots to record new breaks in slope. Surveys were opened and closed on the left benchmark, and closing errors were typically near 0.01 m. Cross sections were plotted with downstream view and with the left benchmark (LBM) set at a reference distance of zero. In several locations we were unable to locate the LBM, right benchmark (RBM), or both benchmarks of the cross section due to burial from sediment, vegetation, or removal from high flows. We re-established these benchmarks as close as possible to their original locations using a total station, often lengthening the cross-section if previous benchmarks were removed. Cross section data were plotted and visually compared with previous surveys to assess the changes that occurred in water year 2019.

At the end of water year 2019, several benchmarks lost through the year were re-established. Where benchmarks were lost to bank erosion, new benchmarks were established along the same cross section bearing, but farther up the bank, away from the channel. Where benchmarks were inaccessible because of large tree falls or large amounts of bank deposition, new benchmarks were established as near to the previous cross section as possible. These relocated cross sections are within 5 m along the river from the original locations, so they are still comparable to previous surveys, given the low rate of longitudinal geomorphic change on the Carmel River. Further, the new cross section benchmarks were vertically registered to the old cross sections (NAVD88) through total station survey relative to known elevations.

Pebble counts were performed along each cross section to determine average particle size distribution. Pebble counts included particles within the bankfull channel, but excluded eroding banks where old floodplain deposits were exposed instead of recently transported material. We employed the sampling technique from Bunte and Abt (2001) that uses a 60 x 60 cm sampling quadrat. This method reduces serial correlation by adjusting the spacing between intersections on the frame to equal the dominant large particle size (≈D95). The 60 x 60 cm square sampling frame was constructed from 1" PVC pipe with notches every 5 cm. Elastic bands were then attached to notches to create 20 equal areas within the quadrat. At locations where cross-sectional data could not be collected due to missing benchmarks, pebble counts were obtained near the general UTM coordinates of the missing cross section. The sampling grid was placed repeatedly across the estimated low flow channel at fived fixed intervals to achieve a sample size of ≥ 100. A gravelometer was used to measure particle sizes for pebble counts. Particle size histograms and cumulative frequency graphs were generated for each cross section, and averaged for each reach. Particle size percentiles were interpolated in R (R Core Team, 2018). The 2019 data were then compared to the previous data sets.

3 Results

The results are reported in spatial order from upstream to downstream.

3.1 Los Padres Reach

The Los Padres reach is located directly downstream of the Los Padres Dam (Fig. 1). This reach is upstream of the San Clemente Dam reroute site and serves as a control reach to be compared with the downstream reaches (Fig. 2). This reach also serves as the location for sporadic spawning gravel augmentation. The most recent augmentations occurred in 2014and 2019. The 2014 augmentation took place approximately 10 months before the first surveys, depositing a total of 1500 tons of 32 mm to 128 mm gravels. The 2019 augmentation deposited a further 1000 tons of similarly sized gravels throughout the reach, primarily in the plunge pool of the Los Padres Dam (B. Chaney, Personal Communication, March 2, 2020.) We collected cross section and pebble count data for all sites.

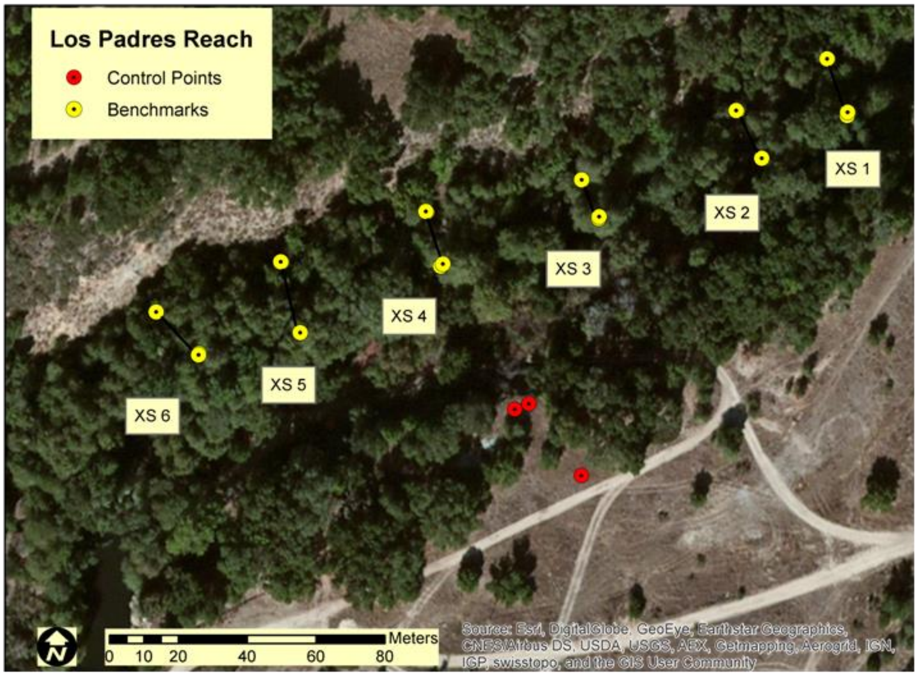

Figure 2. Location of georeferenced control points and cross sections within the Los Padres Reach.

Essentially no geomorphic change occurred between 2018 and 2019 cross sections at all locations (Appendix A).

Despite the latest gravel augmentation, the pattern of substrate coarsening observed in previous years continued in 2019. The graphic mean particle size increased from 122.0 mm in 2018 to 140.7 mm in 2019 (Table 1). This coarsening may be the result of augmented gravel being transported further downstream, leaving only the larger material. With the Los Padres Dam directly upstream, there is no source for sediment inputs other than adjacent banks. Given the combined lack of geomorphic change and general coarsening, the gravel-sized particles are mainly being transported from interstitial positions between the larger framework boulders, indicating that the gravel supply is waning. It is also possible that the recent gravel augmentation filled interstitial space between boulders, falling below the surface level that is counted for grain size analysis.

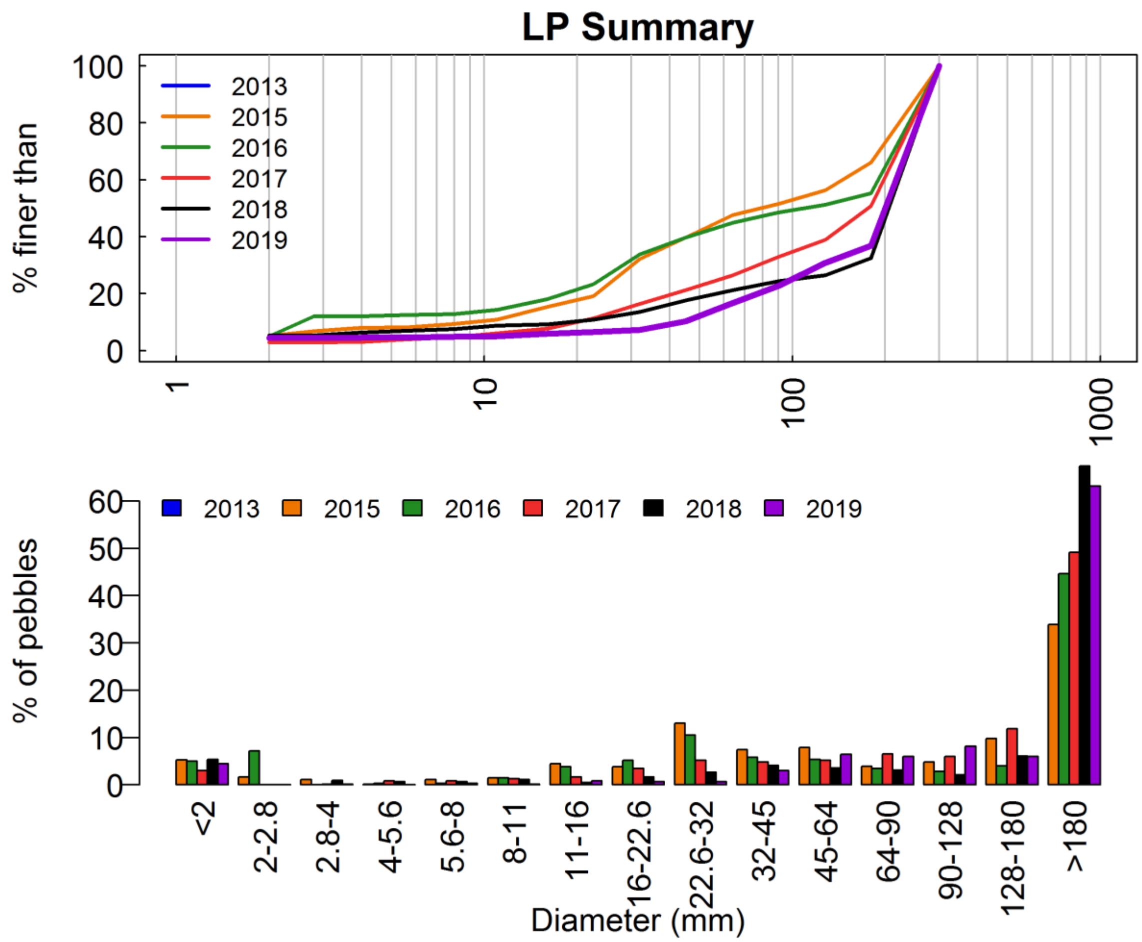

Figure 3. Summary pebble count distribution (LP 1 – LP 6) for the Los Padres reach displayed as cumulative percentiles (top) and individual bins (bottom) for 2015 to 2019.

Table 1. Summary grain size distribution among cross-sectional transects within the Los Padres Reach from 2015 to 2019.

Reach	Quantile	2015	2016	2017	2018	2019
LP	D5	2.0	2.0	8.3	2.0	8.4
	D16	16.9	12.9	30.9	39.1	61.4
	D50	78.6	108.4	175.7	197.2	193.7
	D84	216.8	225.7	228.3	235.5	234.2
	D95	243.0	246.1	247.0	249.4	249.0
	Graphic mean	66.1	68.2	107.5	122.0	140.7

3.2 DeDampierre Upper Reach

The DeDampierre Upper Reach (Fig. 4) is the most upstream reach monitored by CSUMB that will see impacts of the San Clemente Dam removal. We obtained cross section and pebble count data for DDU1through DDU6.

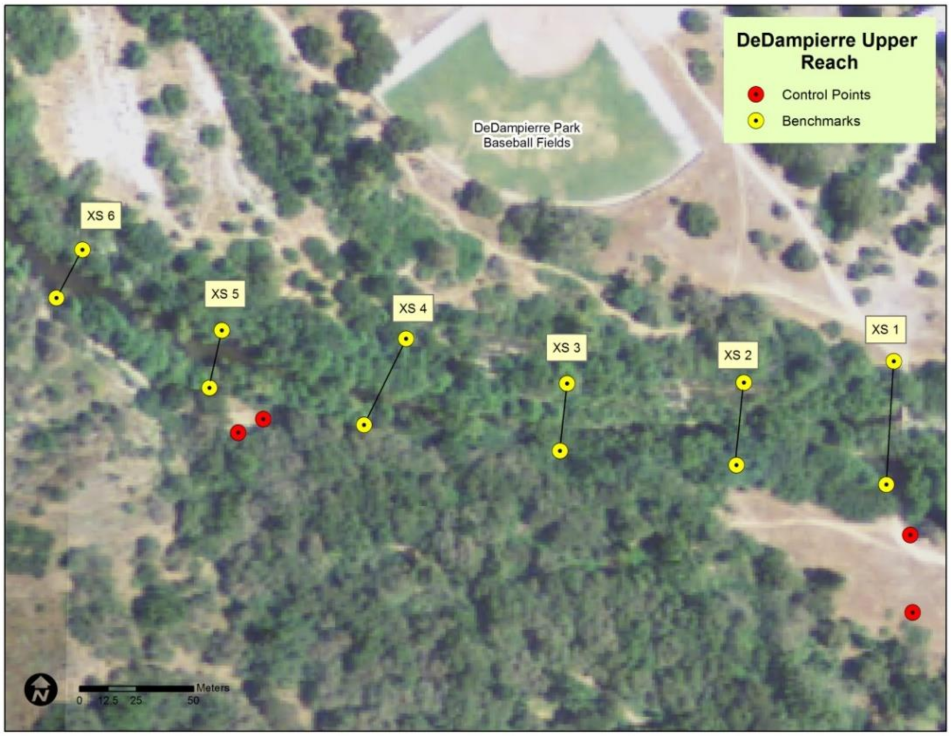

Figure 4. Location of georeferenced control points and cross sections within the DeDampierre Upper Reach.

Both erosional and depositional geomorphic changes took place on different cross sections at DDU (Appendix A). Sites one, four, and five show practically no change in channel morphology between 2018 and 2019. DDU 2 shows a small area of approximately 0.5 m of erosion, while DDU6 shows between 0.7 m and 0.2 m of erosion in the channel between 2018 and 2019 (Appendix A). DDU3 was the only site in the reach to experience significant deposition, with a maximum of approximately 0.7 m occurring on the right bank.

The graphic mean of grain size of this reach decreased from 7.5 mm in 2018 to 6.1 mm in 2019 (Table 2). This fining was not consistent across all cross sections, with DDU2 and DDU6 showing increases in sand (<2mm), DDU 4 showing a decrease, and the remaining cross sections showing little change (Appendix B; Fig. 5).

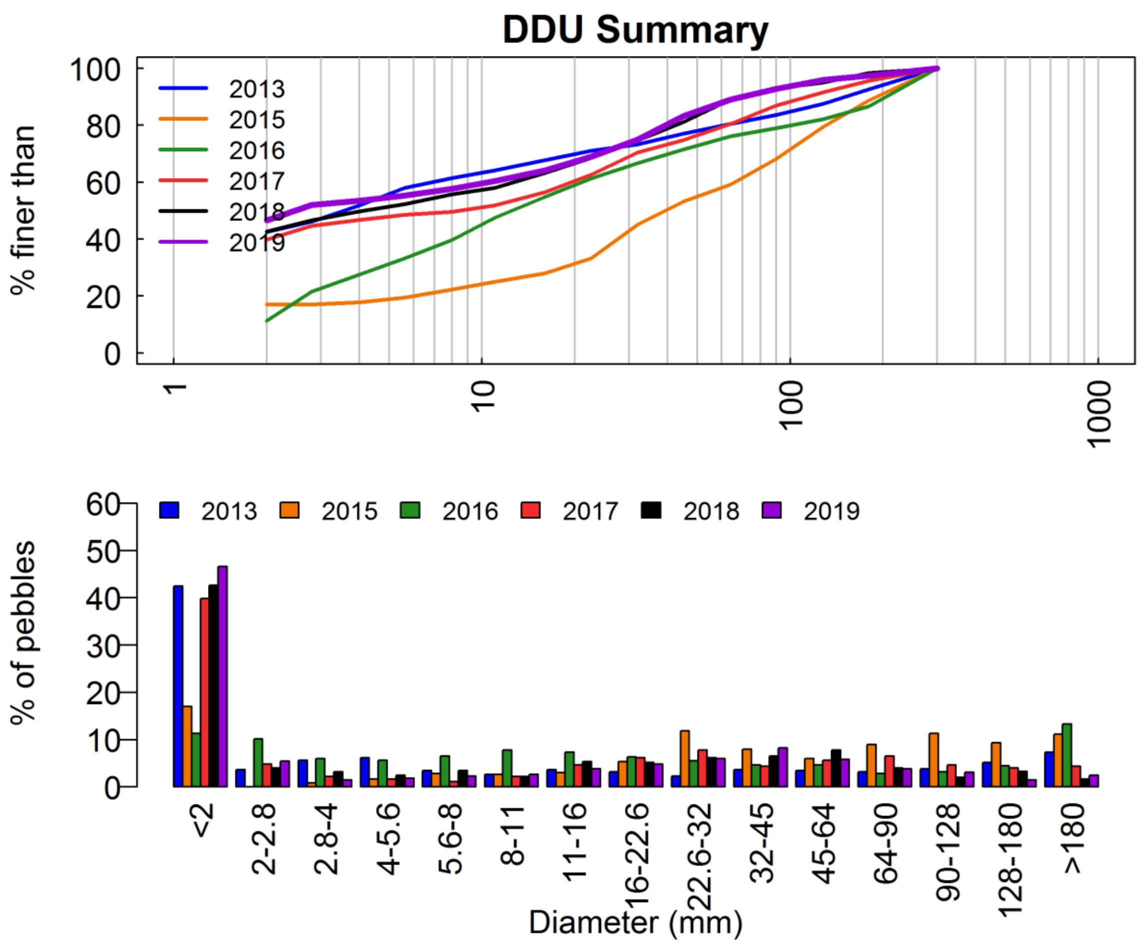

Figure 5. Summary pebble count distribution (DDU 1 – DDU 6) for the DeDampierre Upper reach displayed as cumulative percentiles (top) and individual bins (bottom) for 2013 to 2019.

Table 2. Summary grain size percentiles among cross-sectional transects within the DeDampierre Upper Reach from 2013 to 2019

Reach	Quantile	2013	2015	2016	2017	2018	2019
DDU	D5	2.0	2.0	2.0	2.0	2.0	2.0
	D16	2.0	2.0	2.3	2.0	2.0	2.0
	D50	3.6	39.5	12.4	8.4	4.1	2.5
	D84	92.8	151.6	147.4	76.9	51.1	47.1
	D95	201.3	219.1	224.4	170.1	128.0	114.2
	Graphic mean	8.7	22.9	16.2	10.9	7.5	6.1

3.3 DeDampierre Lower Reach

The DeDampierre Lower reach is located directly downstream of the DeDampierre Upper Reach near the northern extent of DeDampierre Park (Fig. 6). The upstream portion of the reach is a wide and open channel with a pool and long run. The reach narrows downstream from cross section 3 and has a steeper gradient than Upper DeDampierre. We obtained cross section and pebble counts at all cross section locations.

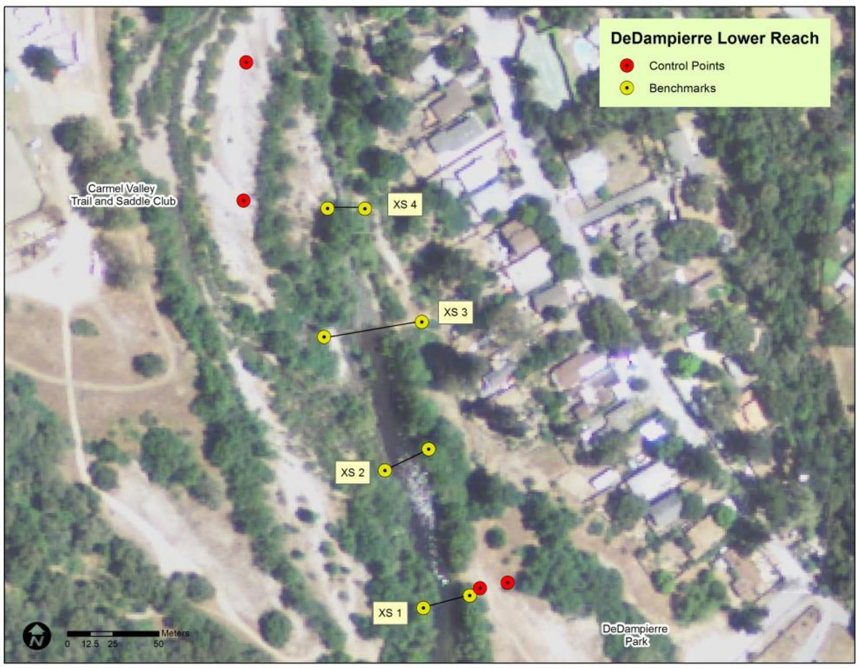

Figure 6. Location of georeferenced control points and cross sections within the DeDampierre Lower Reach.

Geomorphic changes occurring in the DDL reach during water year 2019 were generally erosional, and greater than those seen in water year 2018. DDL1 and DDL2 show approximately 0.5 m of erosion across their entire bed, while DDL3 experienced up to 1.0 m of erosion in a smaller area. DDL4 shows a slight adjustment, with both erosion and deposition taking place across the cross section (Appendix A).

The graphic mean particle size for DDL increased significantly, from 8.7mm in 2018 to 17.2 mm in 2019. This change was mostly due to a decrease in particles between 2 mm and 11 mm, and an increase in particles >180mm (Table 3). Similarly to DDU, the change was not consistent between cross sections. DDL1 showed a large increase in particles <2mm while DDL3 and DDL4 showed decreases (Appendix B).

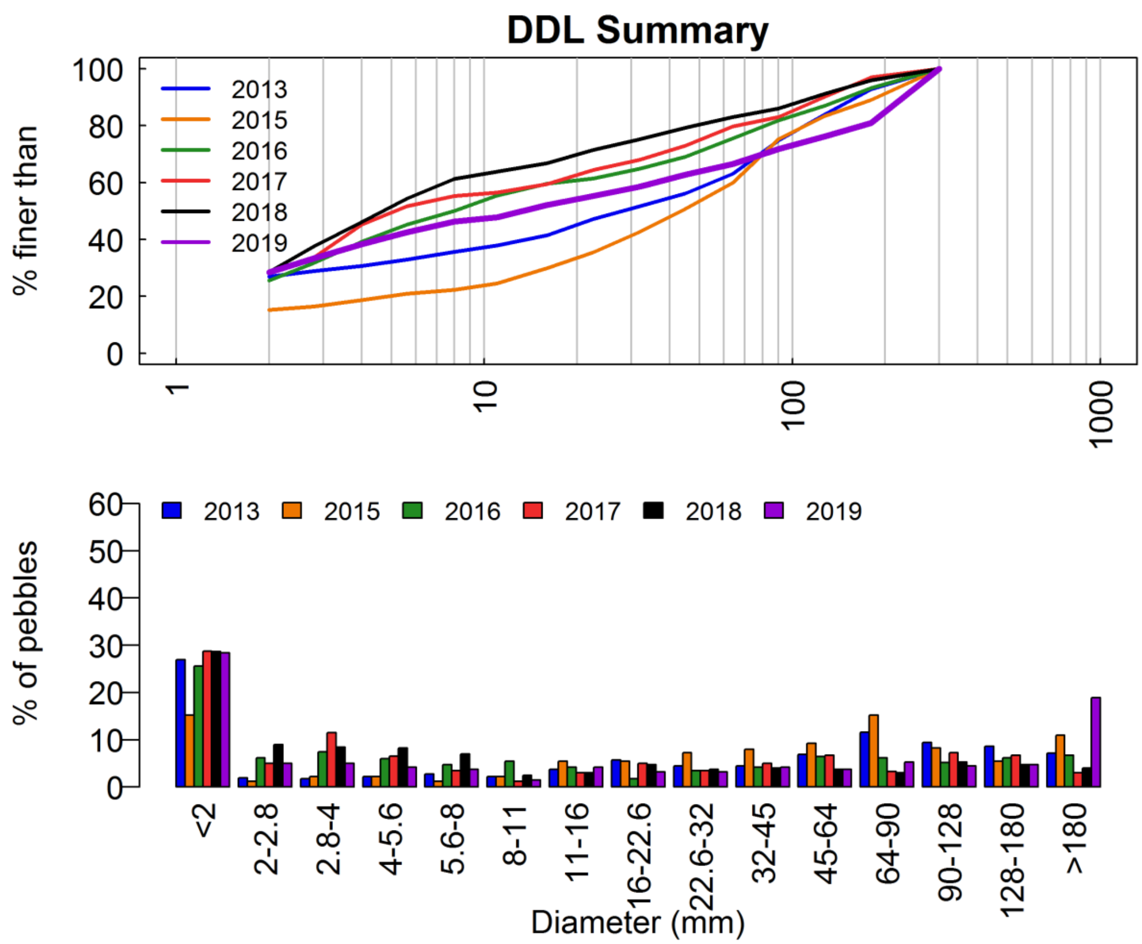

Figure 7. Summary pebble count distribution (DDL 1 – DDL 4) for the DeDampierre Lower reach displayed as cumulative percentiles (top) and individual bins (bottom) for 2013 to 2019.

Table 3. Summary grain size distribution among cross-sectional transects within the DeDampierre Lower Reach from 2013 to 2019.

Reach	Quantile	2013	2015	2016	2017	2018	2019
DDL	D5	2.0	2.0	2.0	2.0	2.0	2.0
	D16	2.0	2.4	2.0	2.0	2.0	2.0
	D50	28.0	43.6	8.0	5.1	4.7	13.3
	D84	127.2	132.0	104.1	94.5	71.4	190.2
	D95	200.3	218.1	197.0	162.7	167.4	233.3
	Graphic mean	19.2	24.1	11.9	9.9	8.7	17.2

3.4 Berwick Reach

The Berwick reach was established in 2015 (Fig. 8). Cross sections were generally shorter in this reach (11-17m), as they included less of the flood plain than other reaches in this survey. We obtained cross sectional and pebble count data at all cross-section locations.

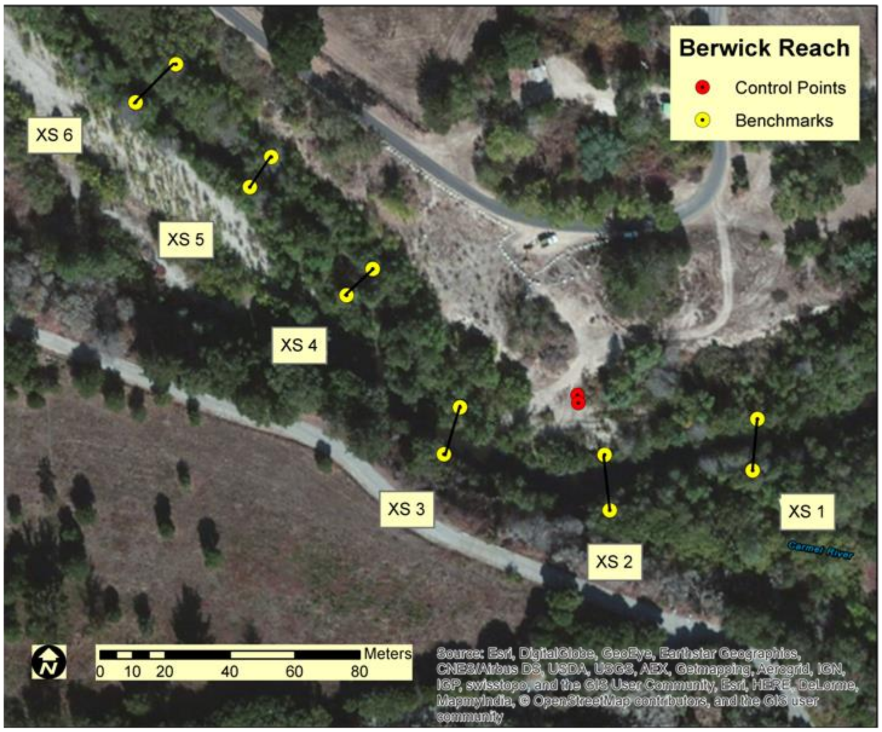

Figure 8. Location of georeferenced control points and cross sections within the Berwick Reach.

Geomorphic changes in the BW reach were primarily erosional. BW3, BW4 and BW5 experienced general erosion to different degrees, with approximately 0.2 m of erosion at BW3, and approximately 0.5 m of erosion at BW4 and BW5. Erosion was less consistent at BW1 and BW6, and there was a small amount of bank deposition at BW1 (Appendix A). BW2 was not surveyed due to lost benchmarks.

The trend of fining at BW did not continue in 2019. The graphic mean particle size increased from 5.7 mm in 2018 to 9.1 mm in 2019 (Table 4). Percent of particles

<2 mm in diameter decreased slightly in the reach, along with particles between 2 mm and 11mm (Figure 9).

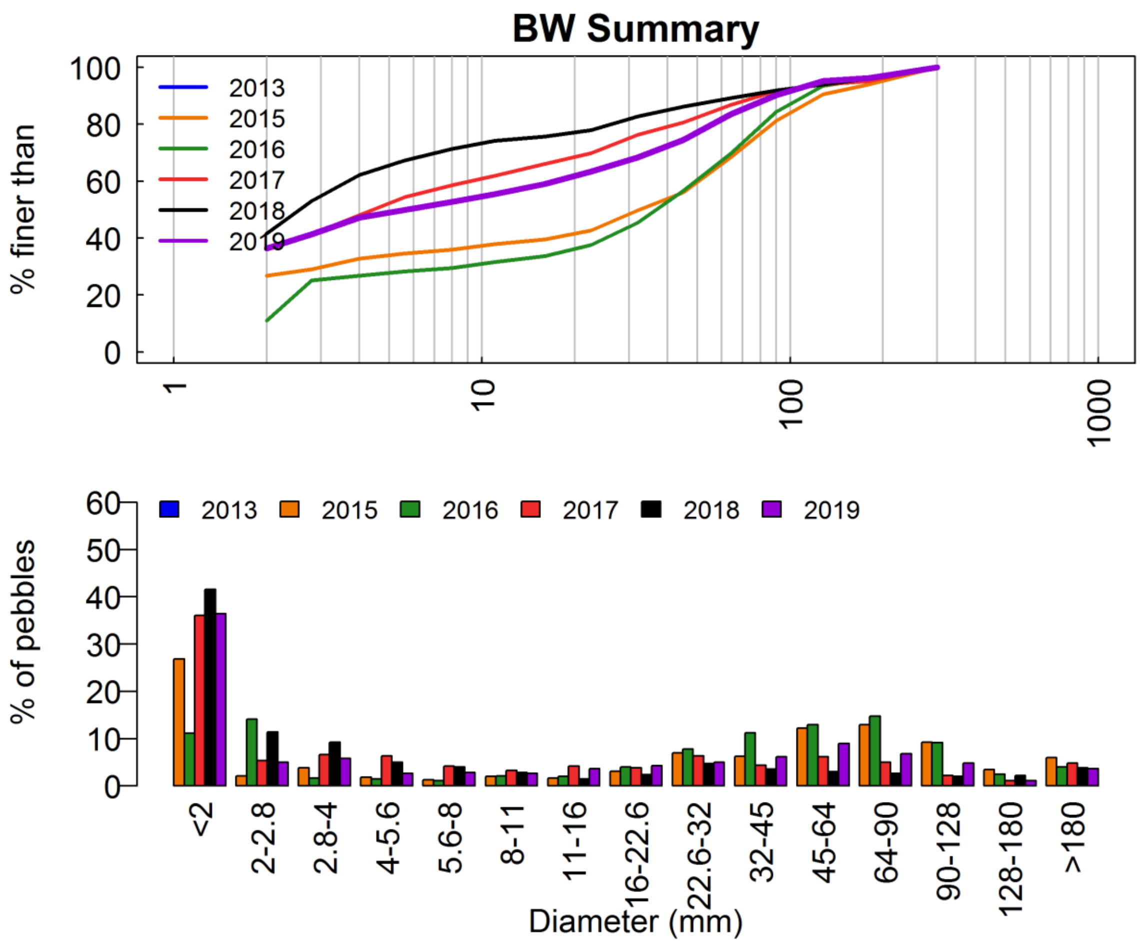

Figure 9. Summary pebble count distribution (BW 1 – BW 6) for the Berwick reach displayed as cumulative percentiles (top) and individual bins (bottom) for 2015 to 2019.

Table 4. Summary grain size distribution among cross sectional transects within the Berwick Reach from 2015 to 2019.

Reach	Quantile	2015	2016	2017	2018	2019
BW	D5	2.0	2.0	2.0	2.0	2.0
	D16	2.0	2.2	2.0	2.0	2.0
	D50	32.4	36.7	4.4	2.6	5.7
	D84	99.9	89.1	54.5	36.2	65.5
	D95	190.6	156.5	171.9	150.6	126.4
	Graphic mean	18.6	19.5	7.8	5.7	9.1

3.5 Schulte Road Reach

The Schulte Road reach is located approximately 200 m upstream of the Schulte Bridge and extends above the 'Steinbeck Pool' which is located between cross sections 2 and 3 (Fig. 10). The reach spans a 90-degree northern bend in the river. We obtained cross sectional and pebble count data at every cross-section location.

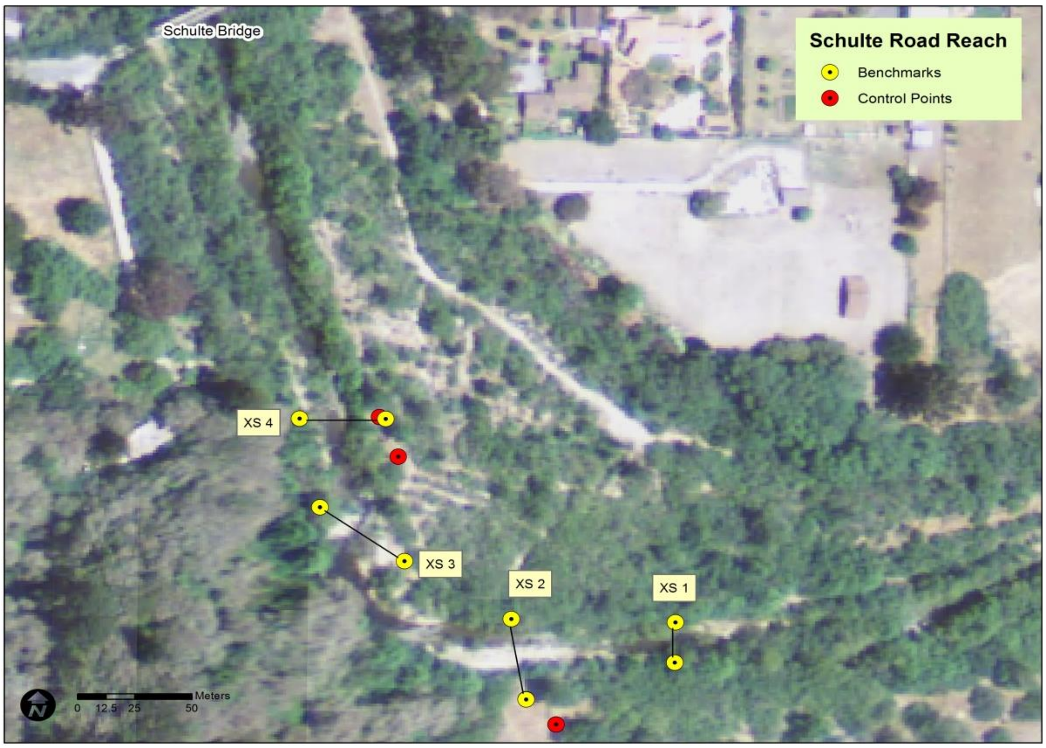

Figure 10. Locations of georeferenced control points and cross sections within the Schulte Road Reach.

While Schulte Road reach experienced significant bank erosion and local deposition in 2017, there was little change in 2019. The largest change was deposition of approximately 0.3 m on the right bank of SR2 (Appendix A).

The SR reach fined slightly in 2019. The graphic mean particle size decreased from 6.9 mm in 2018 to 6.4 mm in 2019 (Table 5). Previous fining at the SR reach had been the result of deposition of particles between 2mm and 4 mm, but in 2019 there was an increase in particles <2 mm (Figure 11). The increase in particles <2 mm was mostly seen at SR1 and SR4 (Appendix B).

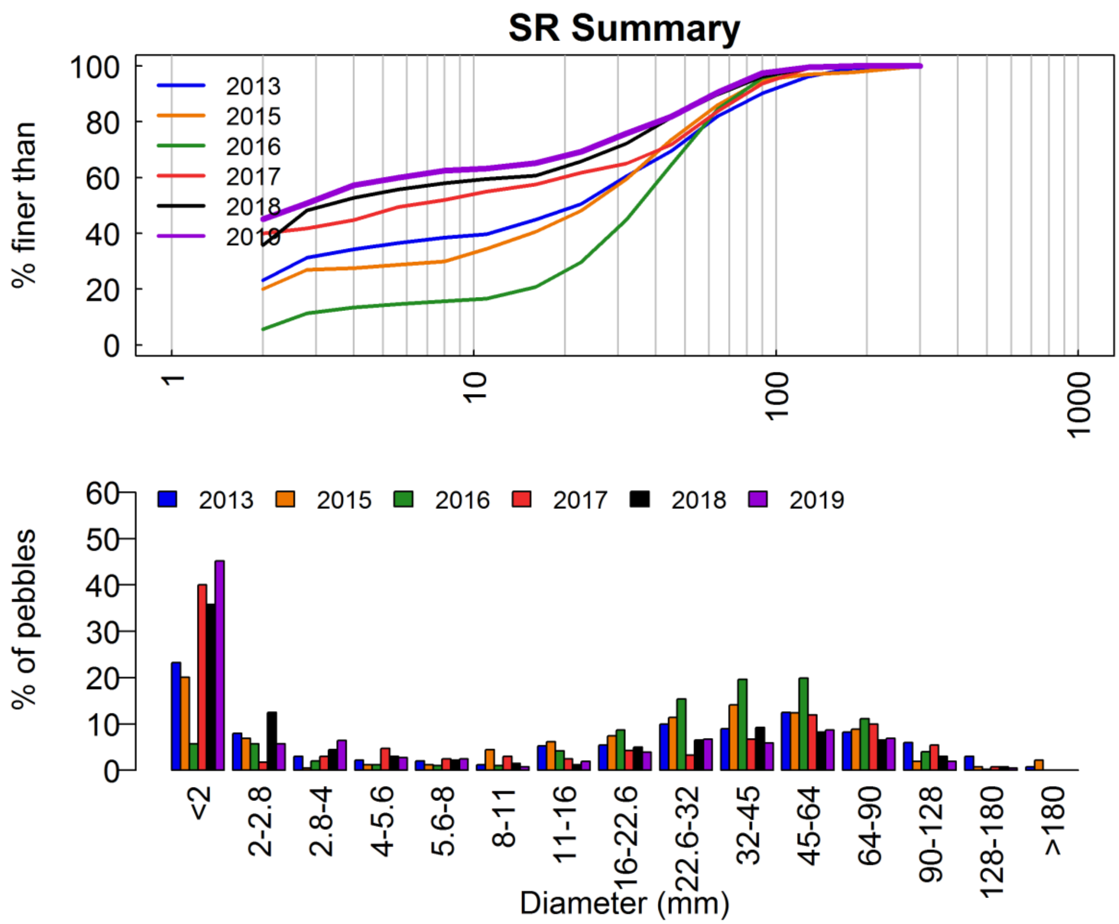

Figure 11. Summary pebble count distribution (SR 1 – SR 4) for the Schulte Road reach displayed as cumulative percentiles (top) and individual bins (bottom) for 2013 to 2019.

Table 5. Summary grain size distribution among cross-sectional transects within the Schulte Road Reach from 2013 to 2019.

Reach	Quantile	2013	2015	2016	2017	2018	2019
SR	D5	2.0	2.0	2.0	2.0	2.0	2.0
	D16	2.0	2.0	8.9	2.0	2.0	2.0
	D50	21.9	23.9	34.9	6.0	3.2	2.7
	D84	69.5	60.3	63.3	64.5	50.1	49.0
	D95	118.9	89.9	87.9	97.5	84.3	79.5
	Graphic mean	14.5	14.2	27.0	9.2	6.9	6.4

3.6 San Carlos Reach

The San Carlos Reach is located downstream of the Rancho San Carlos Bridge (Fig. 12). We obtained cross sectional data from all transects except SC3, and we collected pebble count data at all locations.

Figure 12. Locations of georeferenced control points and cross sections within the San Carlos Reach.

There was no notable change in cross section morphology between 2018 and 2019 except at SC2 and SC4. At SC2, there was significant erosion on the left bank that had been restored in 2018, as well as the right bank that had been constructed from small particles. SC4 experienced general deposition of approximately 0.7 m (Appendix A). SC3 was not surveyed due to lost benchmarks.

Particle size at the SC reach stayed relatively consistent during 2019 (Fig. 13). The graphic mean particle size at SC did not change from the previous year (Table 6). There was however, a decrease in the amount of particles <2 mm. This decrease can be attributed to SC1, SC4, SC5, and SC6, which saw decreases in sand (<2 mm). SC2 did not see this decrease, and instead saw a large increase in particles less than 4 mm. (Appendix B).

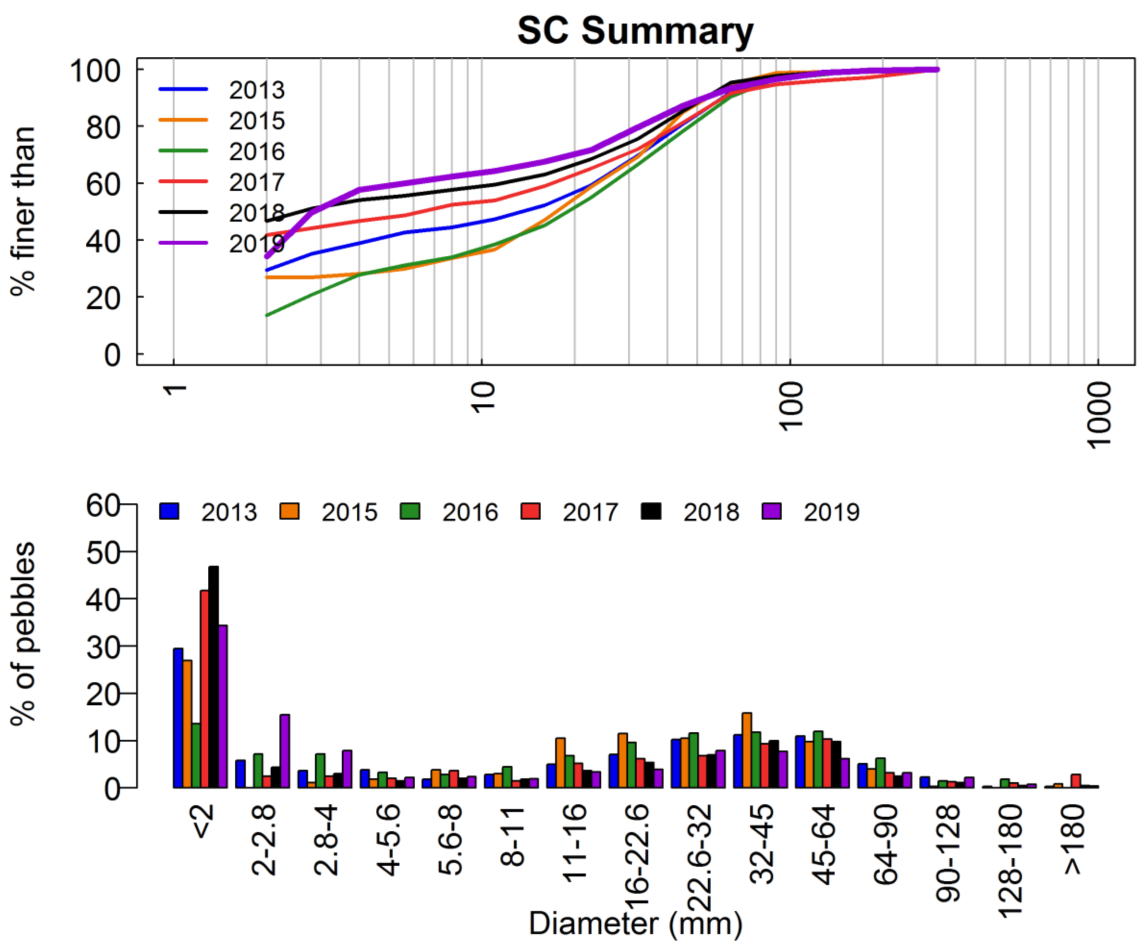

Figure 13. Summary pebble count distribution (SC 1 – SC 6) for the San Carlos reach displayed as cumulative percentiles (top) and individual bins (bottom) for 2013 to 2019.

Table 6. Summary grain size distribution among cross-sectional transects within the San Carlos Reach from 2013 to 2019.

Reach	Quantile	2013	2015	2016	2017	2018	2019
SC	D5	2.0	2.0	2.0	2.0	2.0	2.0
	D16	2.0	2.0	2.2	2.0	2.0	2.0
	D50	13.4	17.4	18.9	6.3	2.6	2.8
	D84	49.6	44.0	53.1	49.2	42.8	38.9
	D95	78.7	64.9	82.2	93.8	63.2	75.6
	Graphic mean	11.0	11.5	13.1	8.5	6.0	6.0

3.7 Crossroads Reach

Crossroads was the downstream end of the study, located adjacent to the Crossroads shopping center near the mouth of Carmel Valley (Fig. 14). We obtained cross sectional and pebble count date at all cross-section locations.

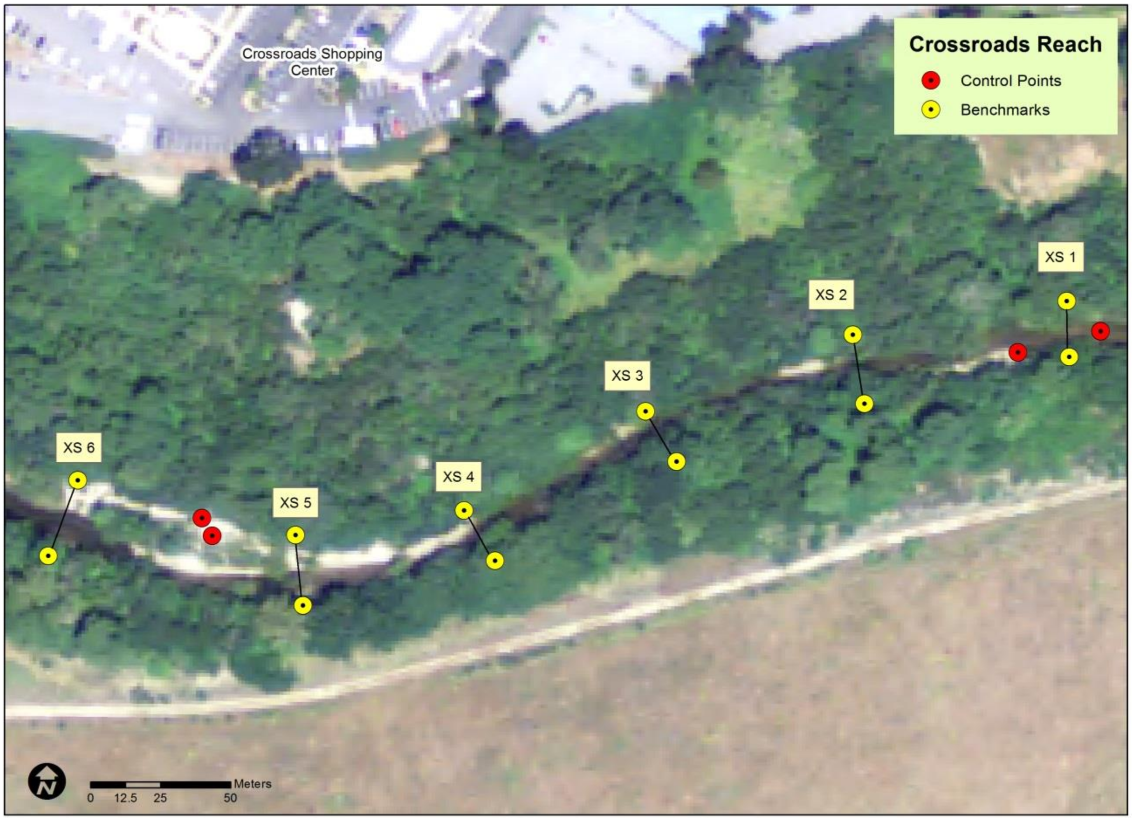

Figure 14. Locations of georeferenced control points and cross sections within the Crossroads Reach.

There was little geomorphic change in the CRO reach during 2019. CRO1 was the only site with notable changes, experiencing approximately 0.5m of erosion on the left bank (Appendix A).

On average, the CRO reach continued to fine. The graphic mean particle size decreased slightly from 4.2mm in 2018 to 3.6 mm in 2019 (Table 8). This fining however, was not the result of higher amounts of particles <2 mm, and instead was due mainly to an increase in particles between 2.8 mm and 8.0 mm (Figure 16). The large spike in particles <2mm seen at CRO2 in 2018 lessened slightly, but there is still a high concentration of fines.

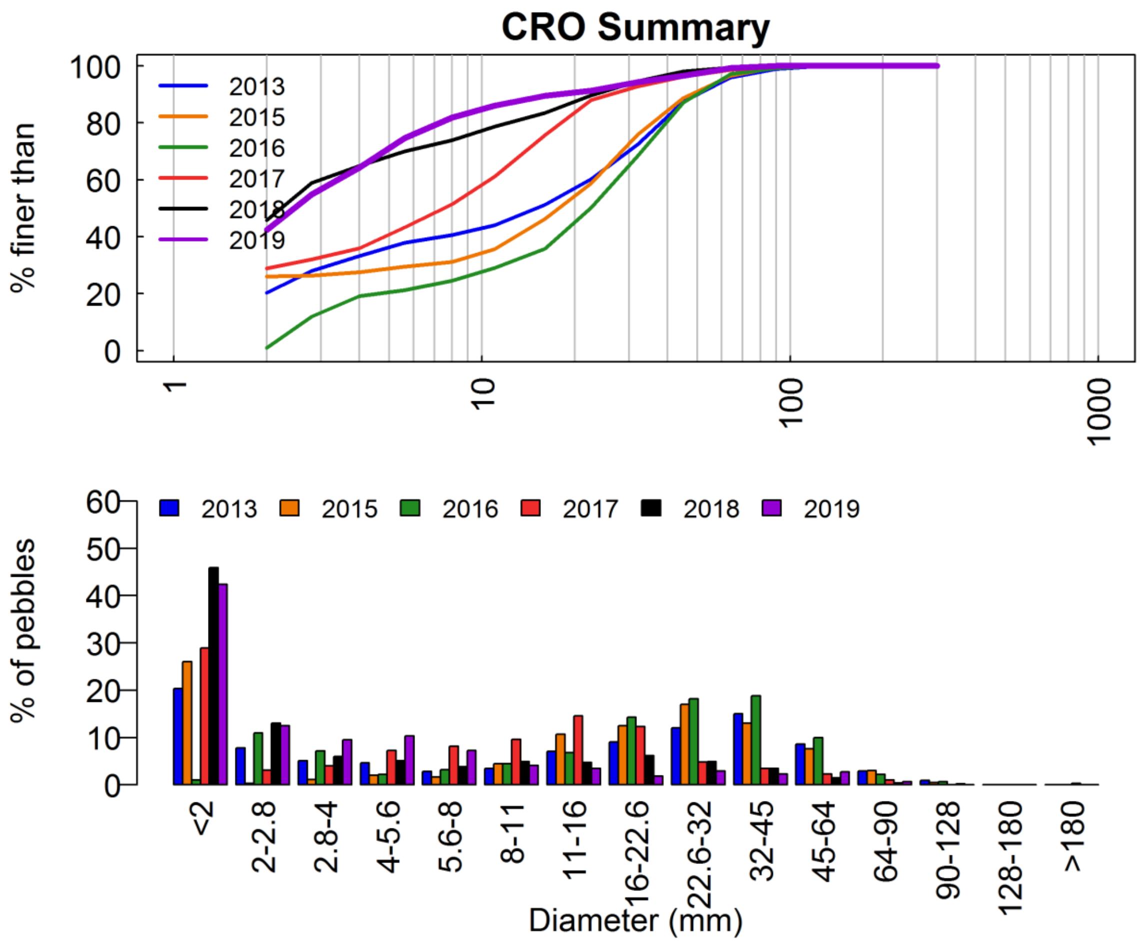

Figure 15. Summary pebble count distribution (CRO 1 – CRO 6) for the Crossroads reach displayed as cumulative percentiles (top) and individual bins (bottom) for 2013 to 2019.

Table 8. Summary grain size distribution among cross-sectional transects within the Crossroads Reach from 2013 to 2019. This reach is dominated by sand. It is the furthest downstream and has the smallest average grain size.

Reach	Quantile	2013	2015	2016	2017	2018	2019
CR	D5	2.0	2.0	2.3	2.0	2.0	2.0
	D16	2.0	2.0	3.4	2.0	2.0	2.0
	D50	15.0	17.7	22.5	7.5	2.2	2.5
	D84	41.6	39.6	42.5	20.2	16.5	9.4
	D95	61.3	59.7	59.3	39.5	33.4	35.7
	Graphic mean	10.8	11.2	14.8	6.7	4.2	3.6

4 Discussion

This report is part of a multi-year effort to describe channel substrate conditions and geomorphic change in the Carmel River following the removal of the San Clemente dam in 2015. The 2019 survey found minimal changes in channel morphology and substrate size

The fining trend seen in 2017 and 2018 was not as consistent in 2019. While in 2018, every site below the former San Clemente Dam had a lower graphic mean particle size, in 2019 this was only true for three of the six surveyed sites. However, pools that filled in 2017 generally remained full of sediment through 2019, indicating that there is likely a supply of sediment preventing them from emptying.

The large influx of fines deposited below the dam in 2017 largely stayed in place during 2019, with percentages varying at each site, but without a clear trend. No site has coarsened to pre-dam removal values, as measured by the graphic mean parameter. The Los Padres reach did not lose fines, possibly indicating that a slightly higher proportion of gravels were transported than fines (Figure 16).

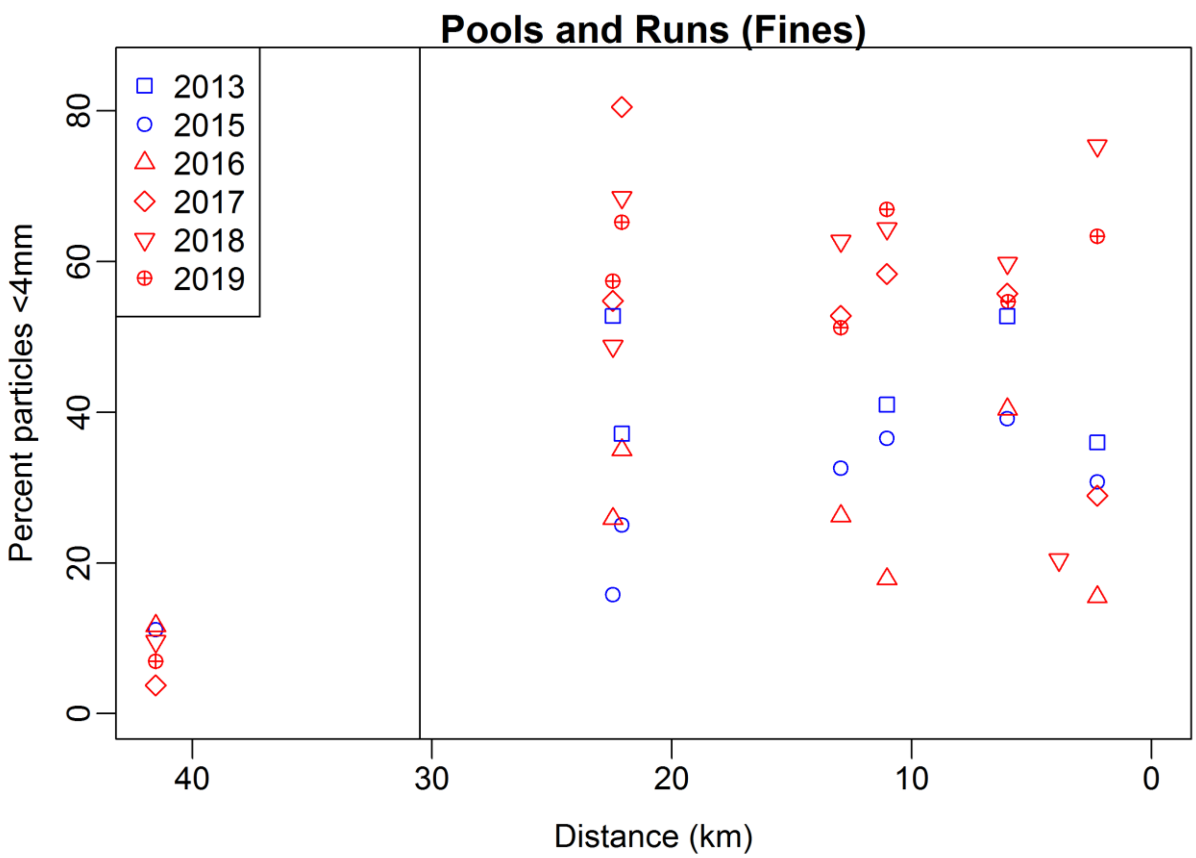

Figure 16. Percent of particles with diameter <4mm in morphological units of pools and runs as a function of year and distance upstream of the Carmel River mouth. Data points in blue show surveys conducted before dam removal, and those in red show surveys conducted after dam removal. A line shows the location of the former San Clemente Dam (30.5 km).

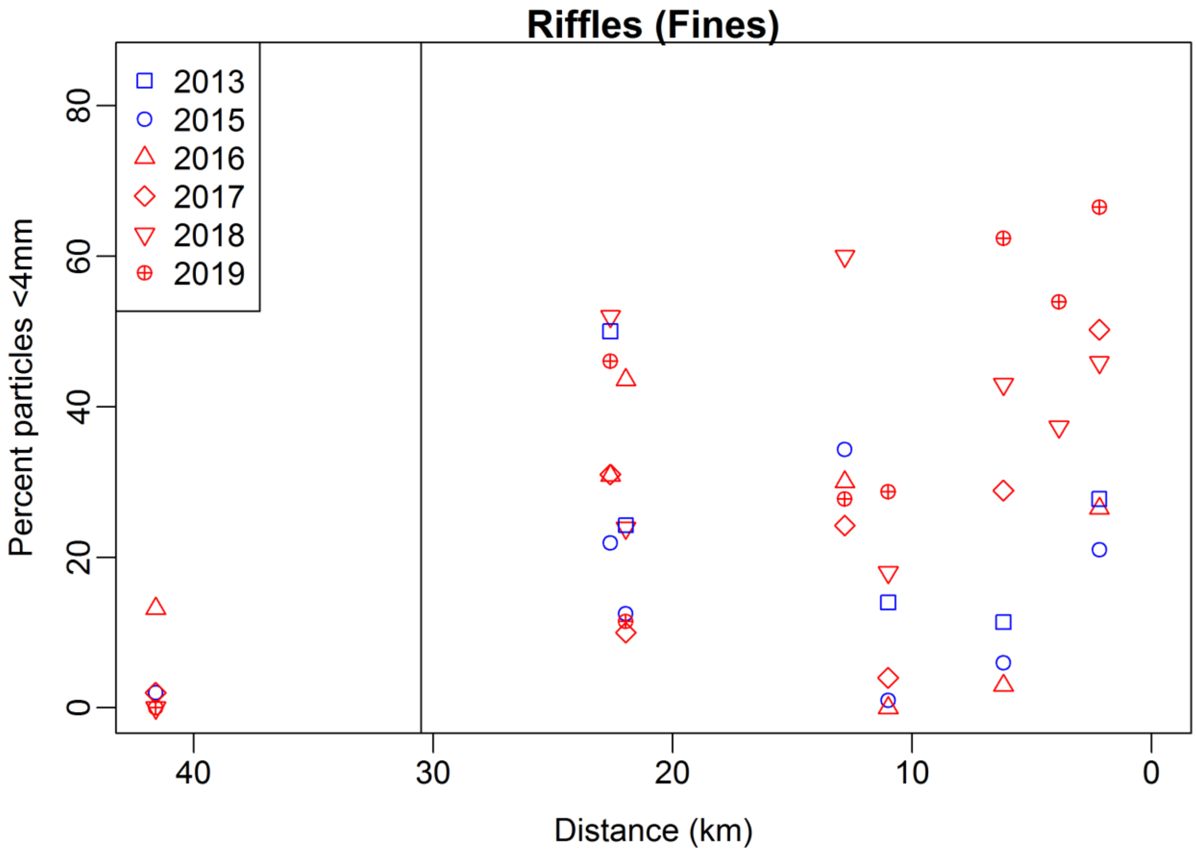

Figure 17. Percent of particles with diameter <4 mm in riffle morphological units as a function of year and distance upstream of the Carmel River mouth. Data points in blue show surveys conducted before dam removal, and those in red show surveys conducted after dam removal. A line shows the location of the former San Clemente Dam (30.5 km).

The percentage of fines was slightly lower in riffles than in pools and runs. Visually, riffles appeared to have a coarser grain size, and showed less change in relief. The pattern of downstream sites gaining fines while more upstream sites lost them continued in 2019, with DDU, DDL, and BW losing fines while the three downstream sites gained them (Fig. 17).

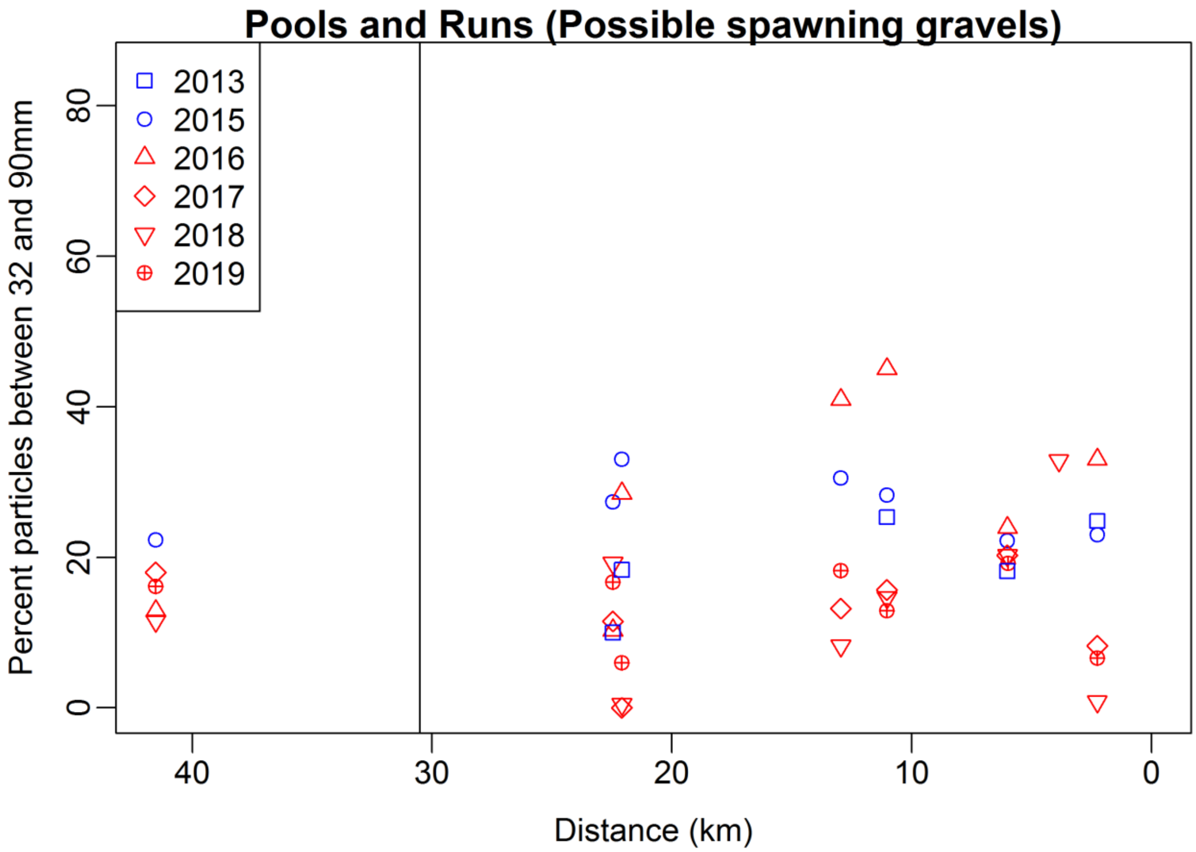

Figure 18. Percent of particles with diameter between 32 and 90 mm in morphological units of pools and runs as a function of year and distance upstream of the Carmel River mouth. Data points in blue show surveys conducted before dam removal, and those in red show surveys conducted after dam removal. A line shows the location of the former San Clemente Dam (30.5 km).

We defined possible steelhead spawning gravels as particles between 32 mm and 90 mm in diameter. The pattern of finer particle sizes at more downstream sites did not seem to influence spawning gravels in pools and runs. There was an increase in spawning gravels at DDL, BW, and CRO, and a decrease at DDU, and SR. SC stayed virtually the same in this category, as it has for the entire study. The 2019 augmentation of gravel at LP was mostly within this size range, and can be seen as a relatively small increase since 2018 (Fig. 18).

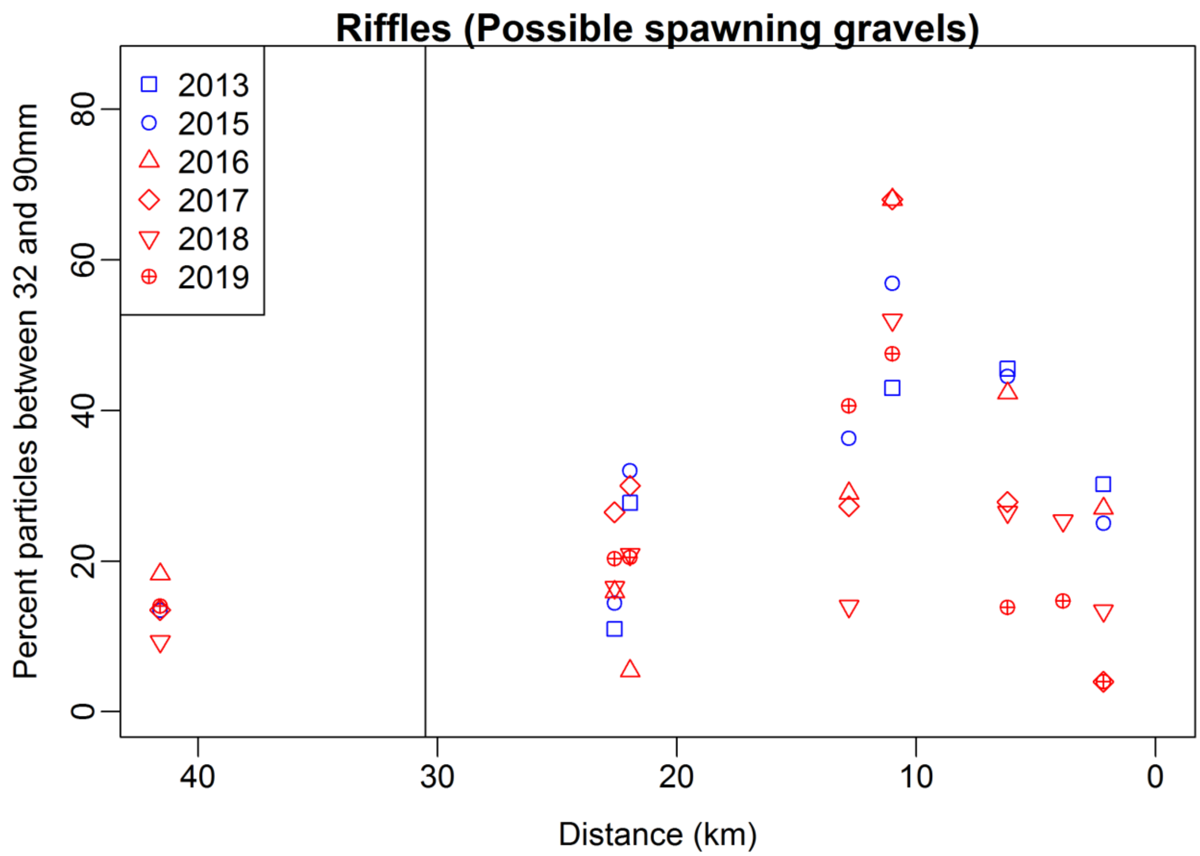

Figure 19. Percent of particles with diameter between 32 and 90 mm in riffle morphological units as a function of year and distance upstream of the Carmel River mouth. Data points in blue show surveys conducted before dam removal, and those in red show surveys conducted after dam removal. A line shows the location of the former San Clemente Dam (30.5km).

Changes were more consistent in spawning gravels in riffles. The downstream sites of CRO, SC, and SR all lost spawning gravels, while DDU and BW gained them and DDL remained virtually the same. The increase at DDU is consistent with the decrease in fines seen at riffles at that site. The gravel placement at LP can also be seen in riffles.

The overall temporal and spatial patterns emerging in the grain size analysis is consistent with a large pulse of fine sediment generated in high 2017 flows, now slowly moving downstream toward the mouth of the Carmel River. The change was less consistent in 2019 than in previous years, so there is still not enough evidence to say with certainty that the sediment pulse has begun to clear.

An unstable reach of river channel located approximately 1.5 km upstream of the former dam site generated a pulse of sand and fine gravel that spread down the entire lower Carmel River in 2017 (Harrison et al. 2018). The fine sediment persists in 2019. The unstable river reach is beginning to stabilize through natural colonization of willows and other riparian species. A recent site inspection indicates that tall unstable river banks exist that could renew the supply of fines to the lower river when another strong winter occurs.

5 References

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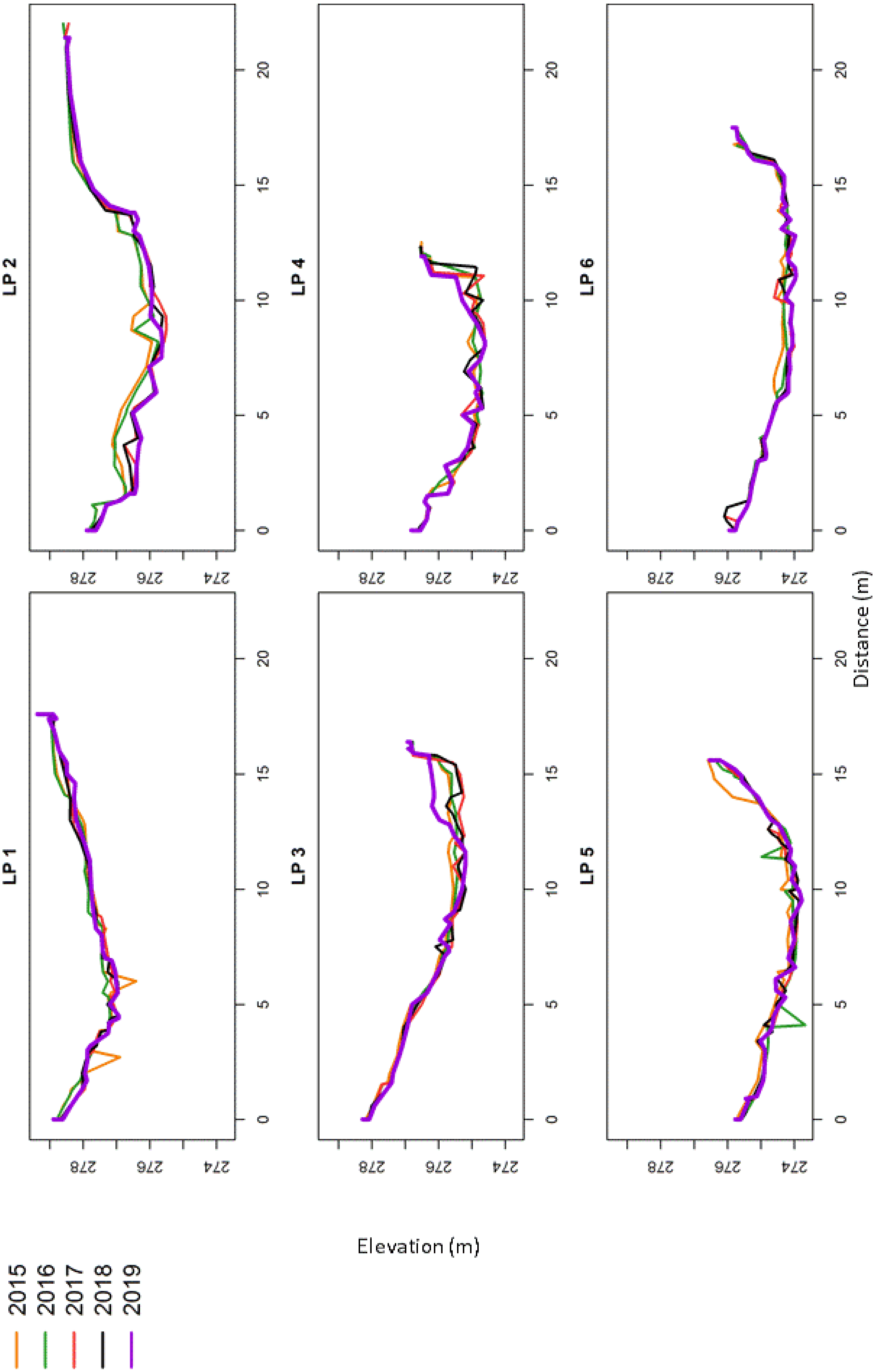
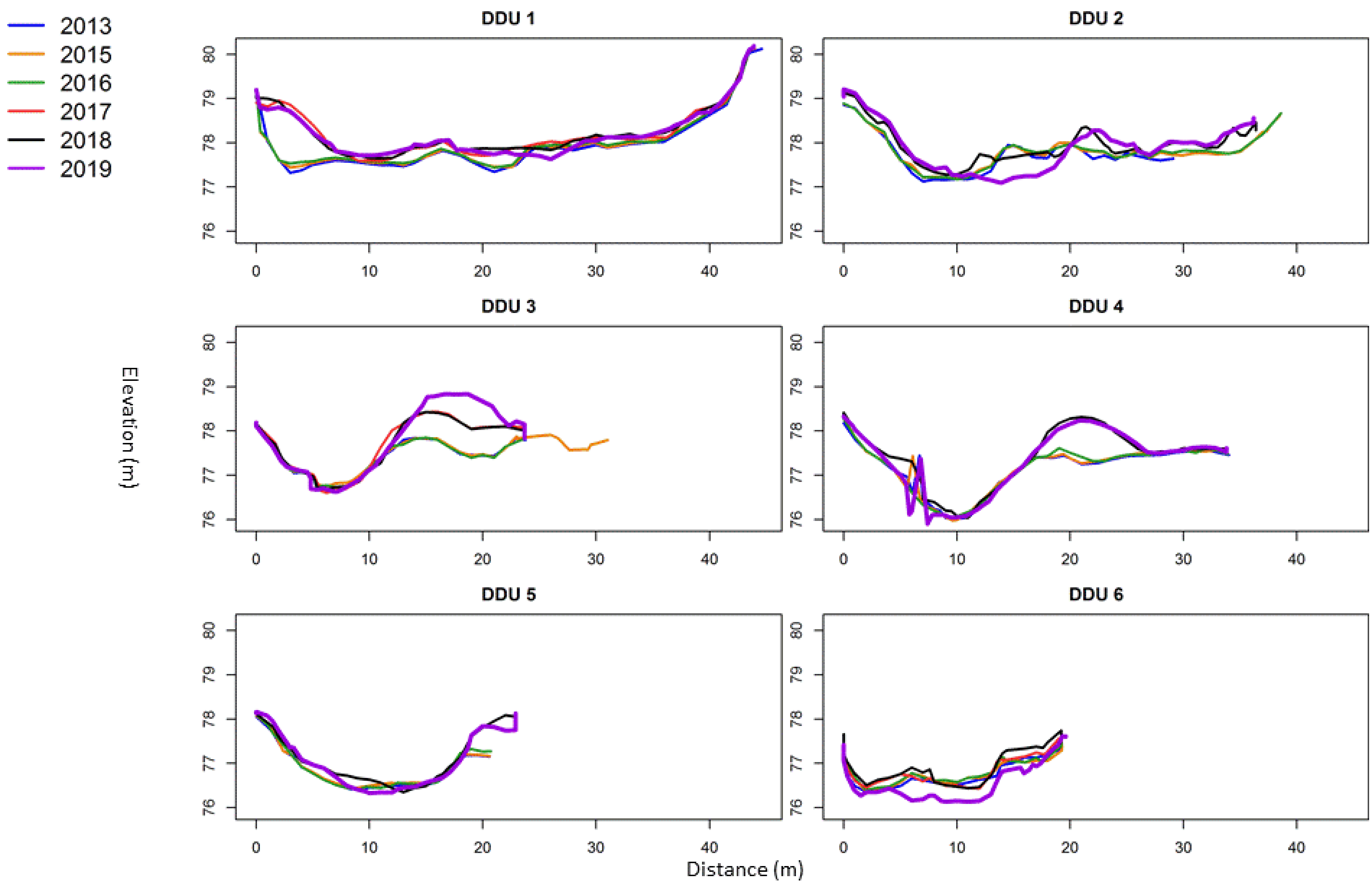
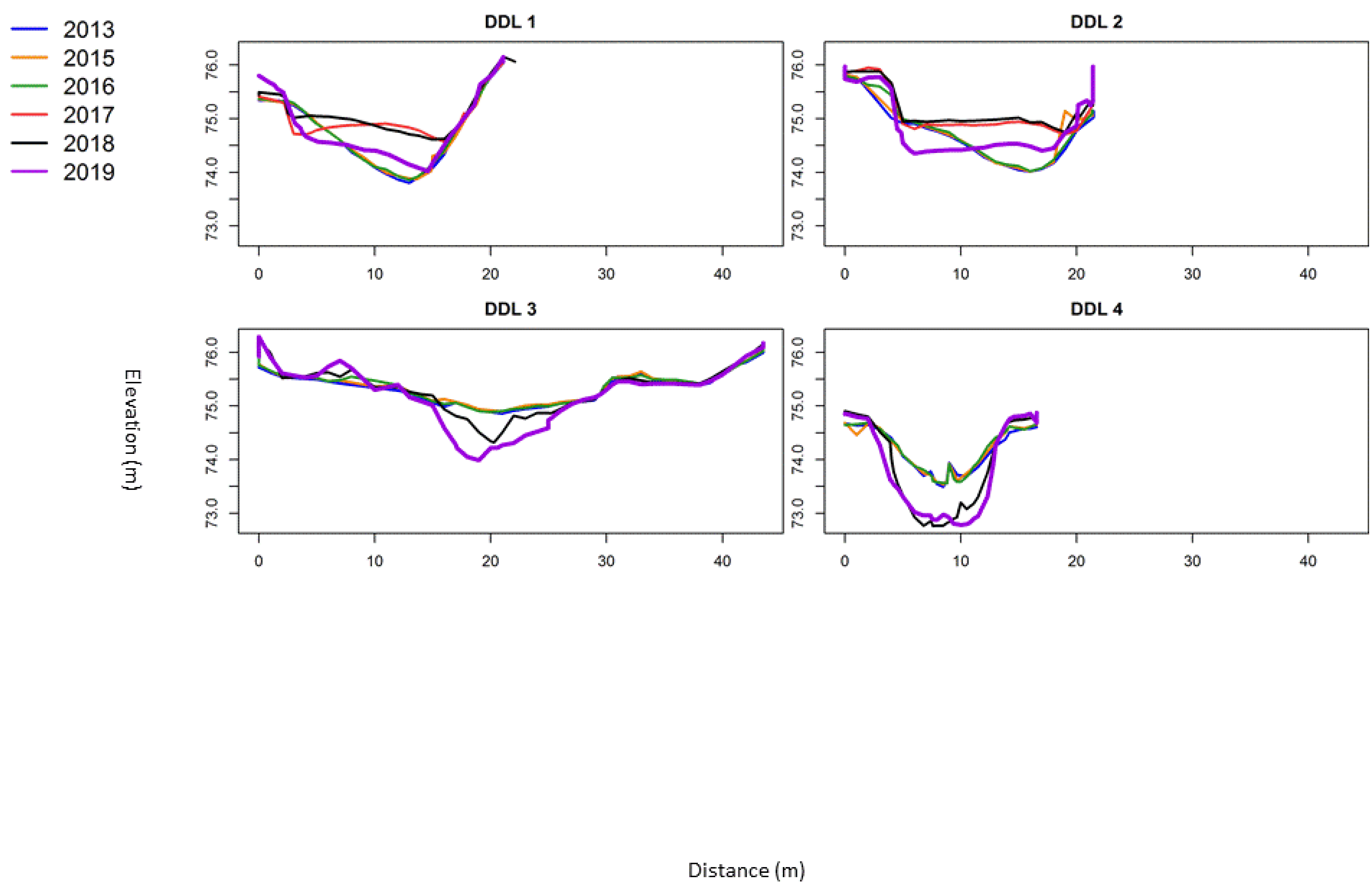
6 Appendix A: Cross Sections

Channel geometry for each cross section surveyed within each reach. Cross sections are denoted by their reach abbreviation (LP, DDU, DDL, BW, SR, SC, PC, and CR) and transect number descending from upstream to downstream (1 to 4 or 6).

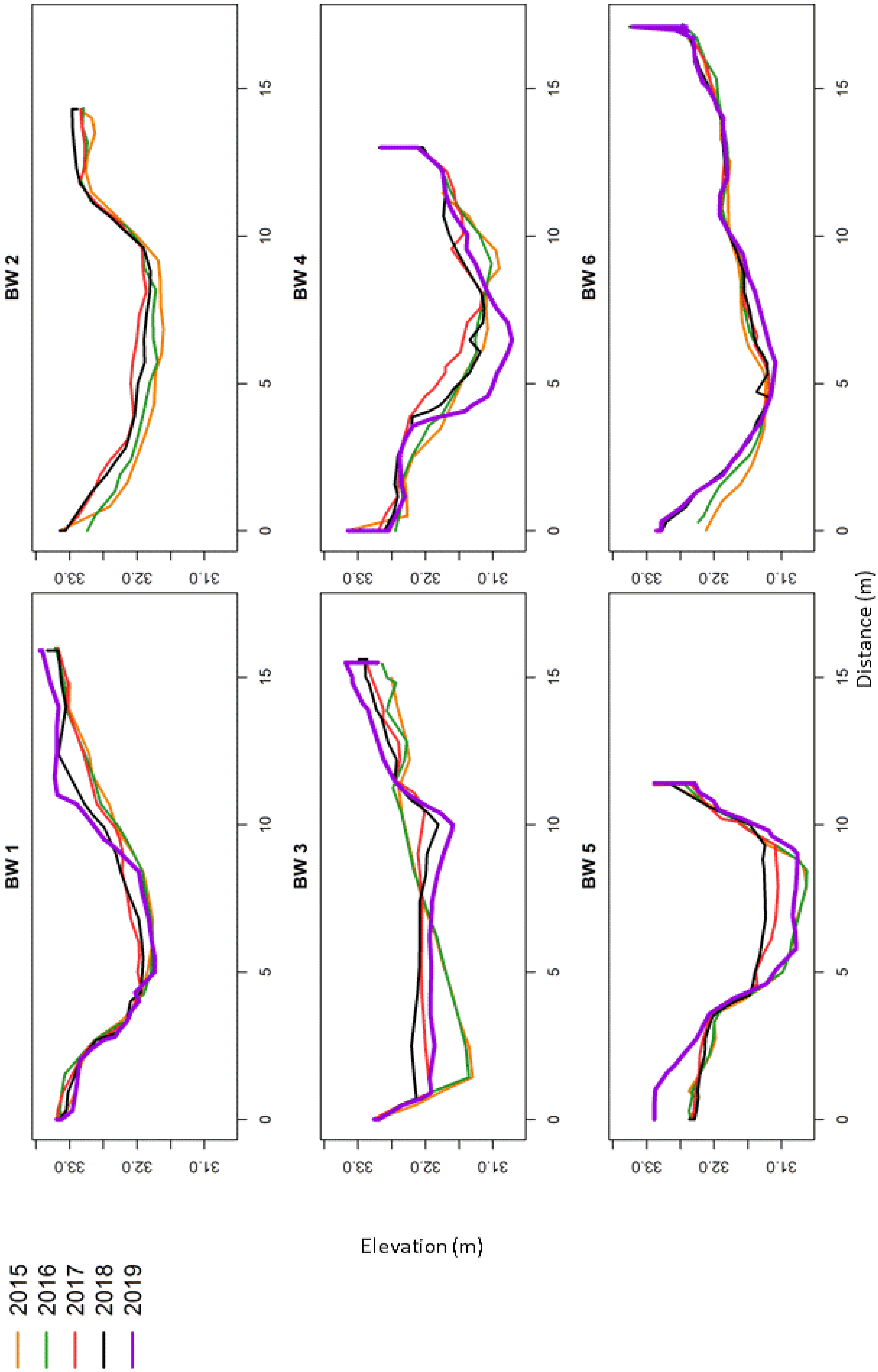

LP 1
LP 2
LP 3
LP 4
LP 5
LP 6
Distance (m)
Elevation (m)
2015
2016
2017
2018
2019



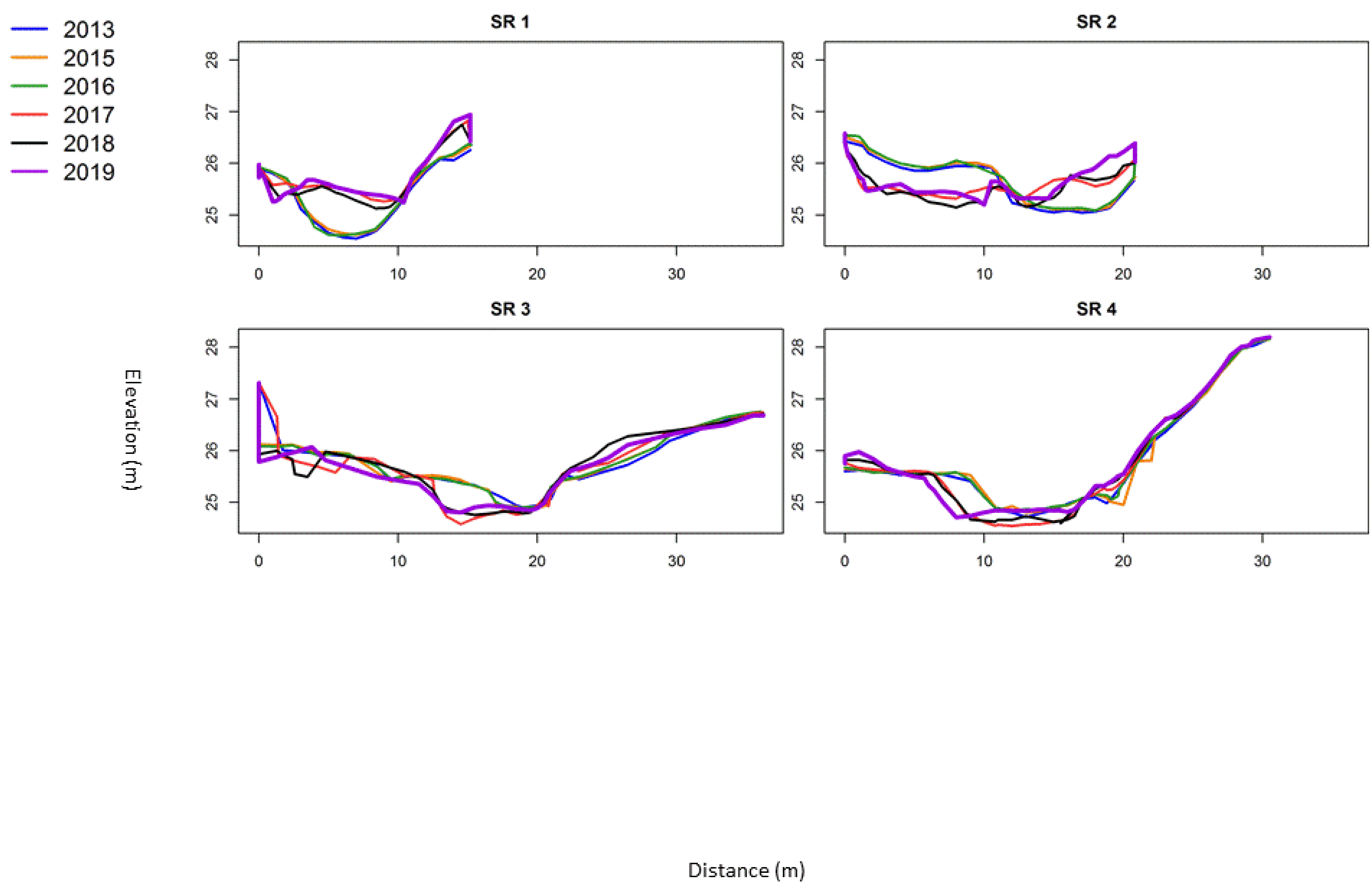
2013
2015
2016
2017
2018
2019
DDU 1
DDU 2
DDU 3
DDU 4
DDU 5
DDU 6
Elevation (m)
Distance (m)
76
77
78
79
80
0
10
20
30
40

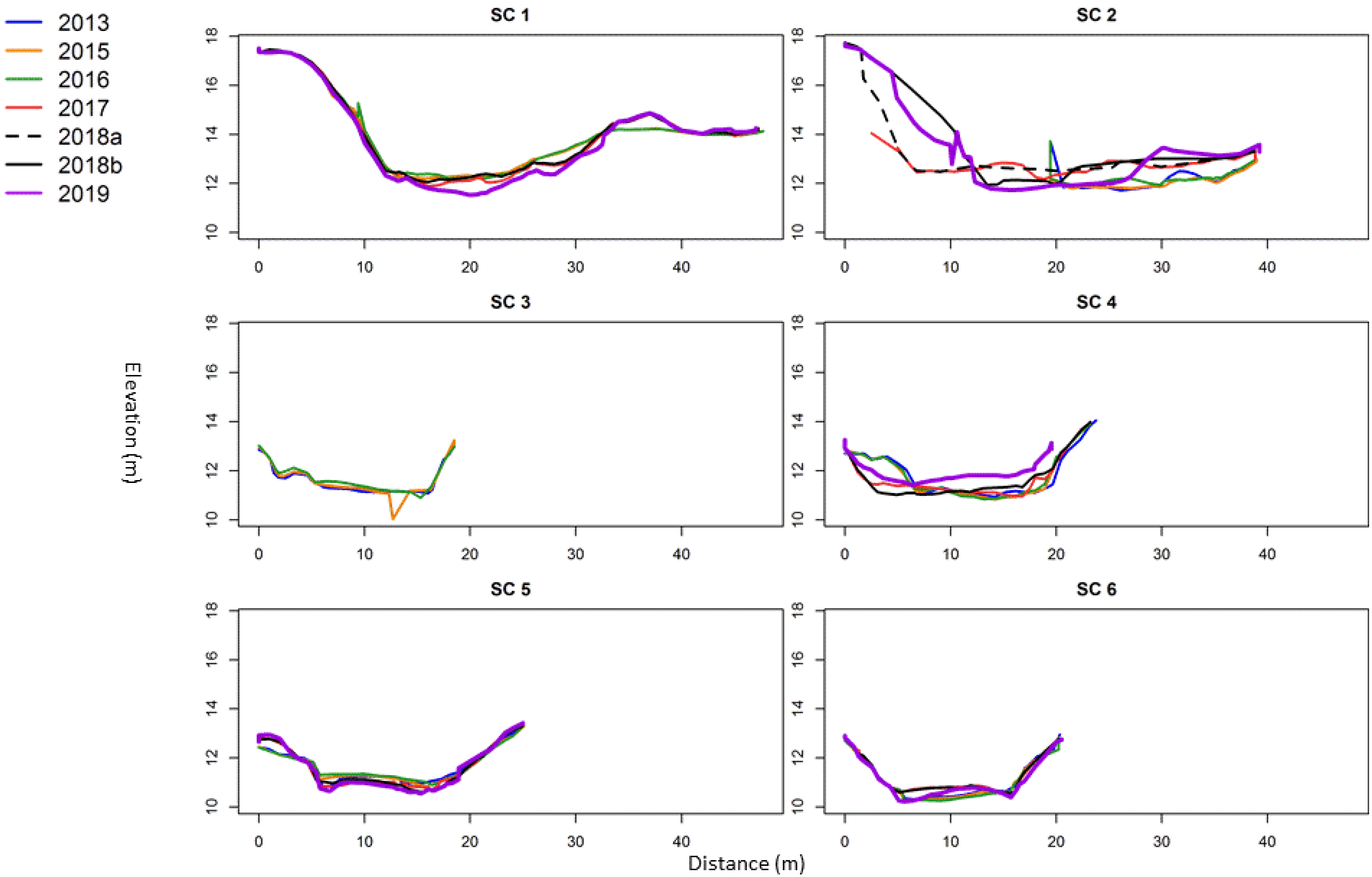


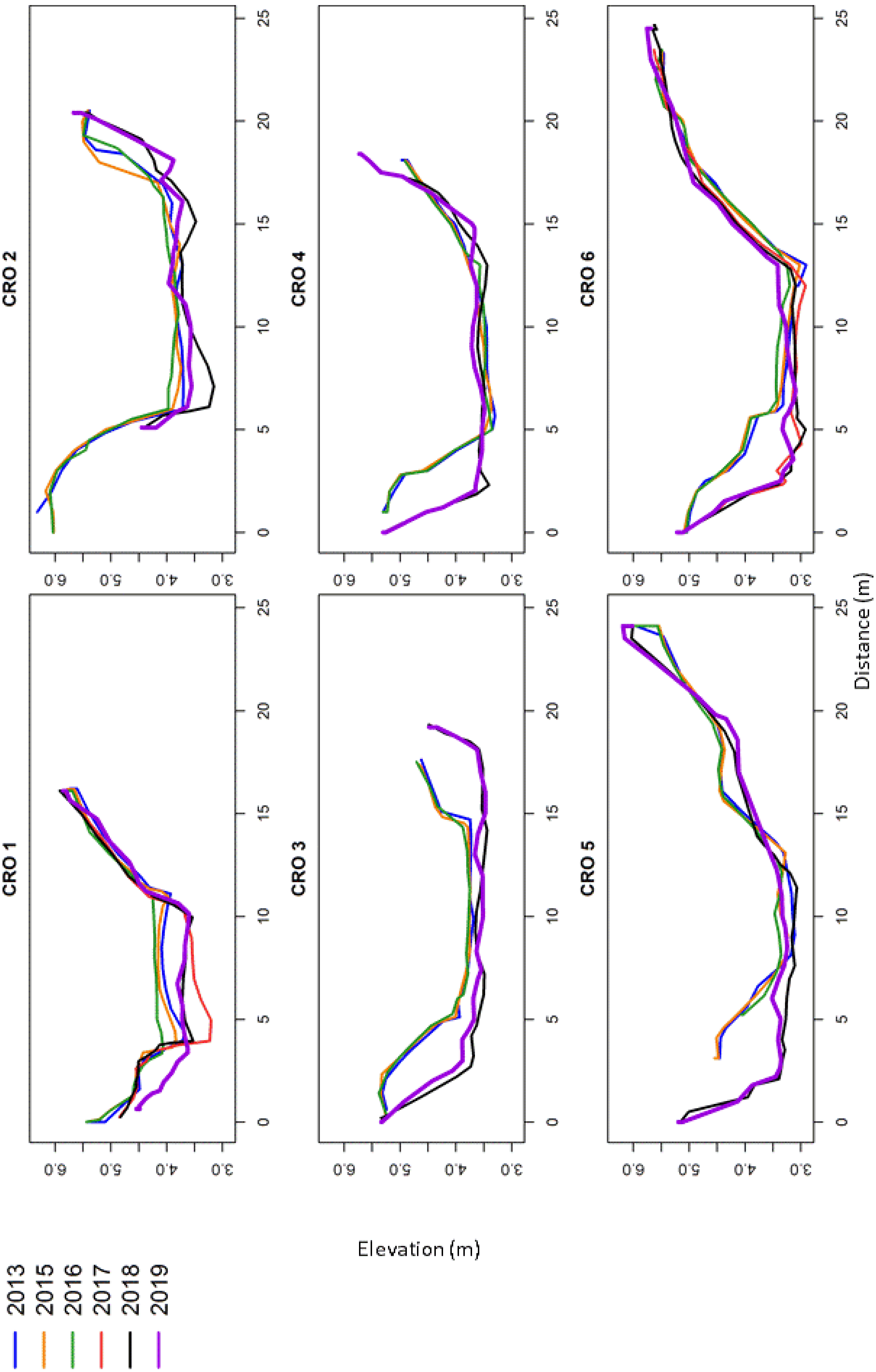
2013
2015
2016
2017
2018
2019
DDL 1
DDL 2
DDL 3
DDL 4
76.0
75.0
74.0
73.0
0
10
20
30
40
Elevation (m)
Distance (m)



BW 1
BW 2
BW 3
BW 4
BW 5
BW 6
Elevation (m)
Distance (m)
2015
2016
2017
2018
2019

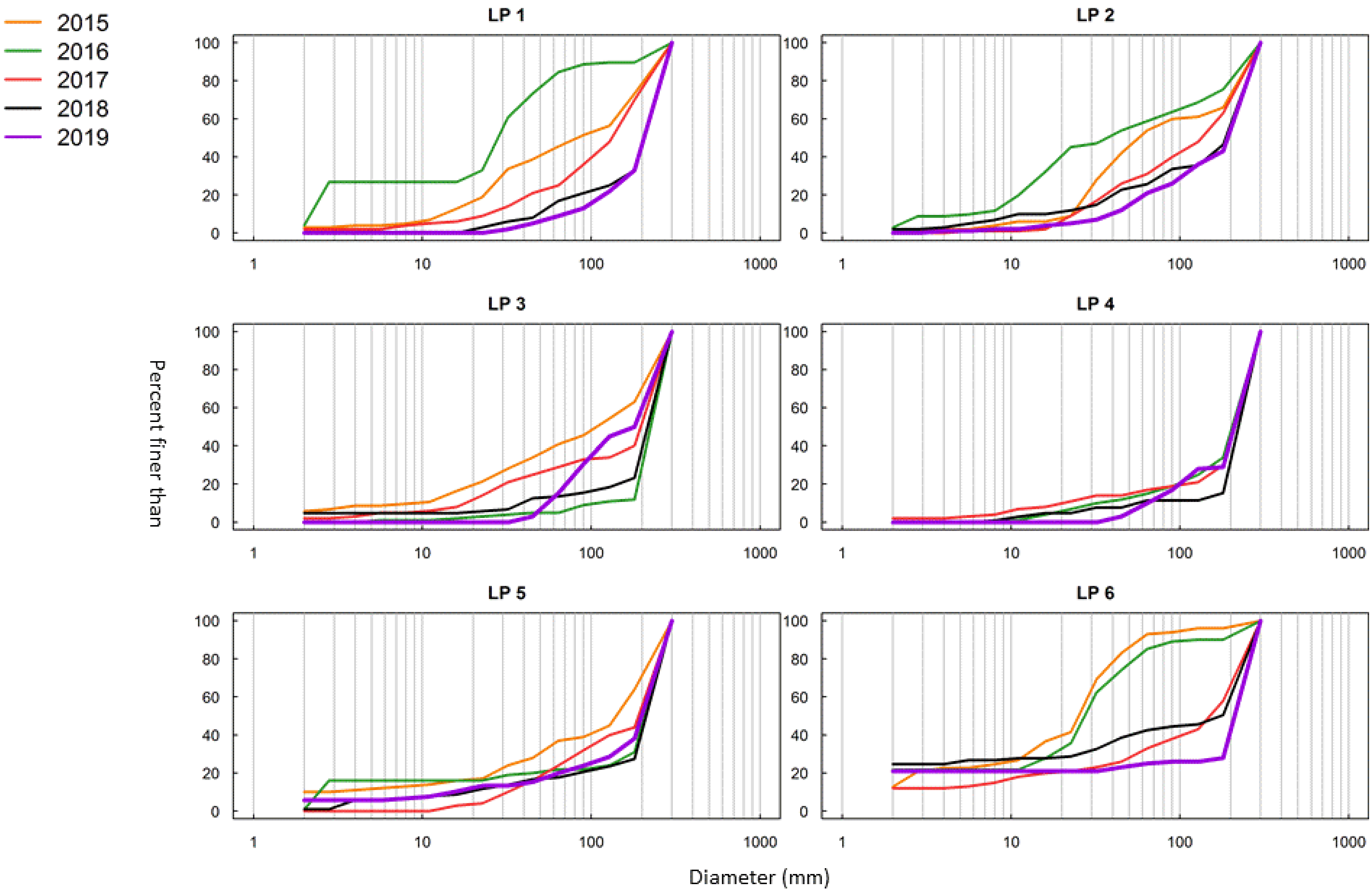

2013
2015
2016
2017
2018
2019
SR 1
SR 2
SR 3
SR 4
Elevation (m)
Distance (m)
25
26
27
28
0
10
20
30

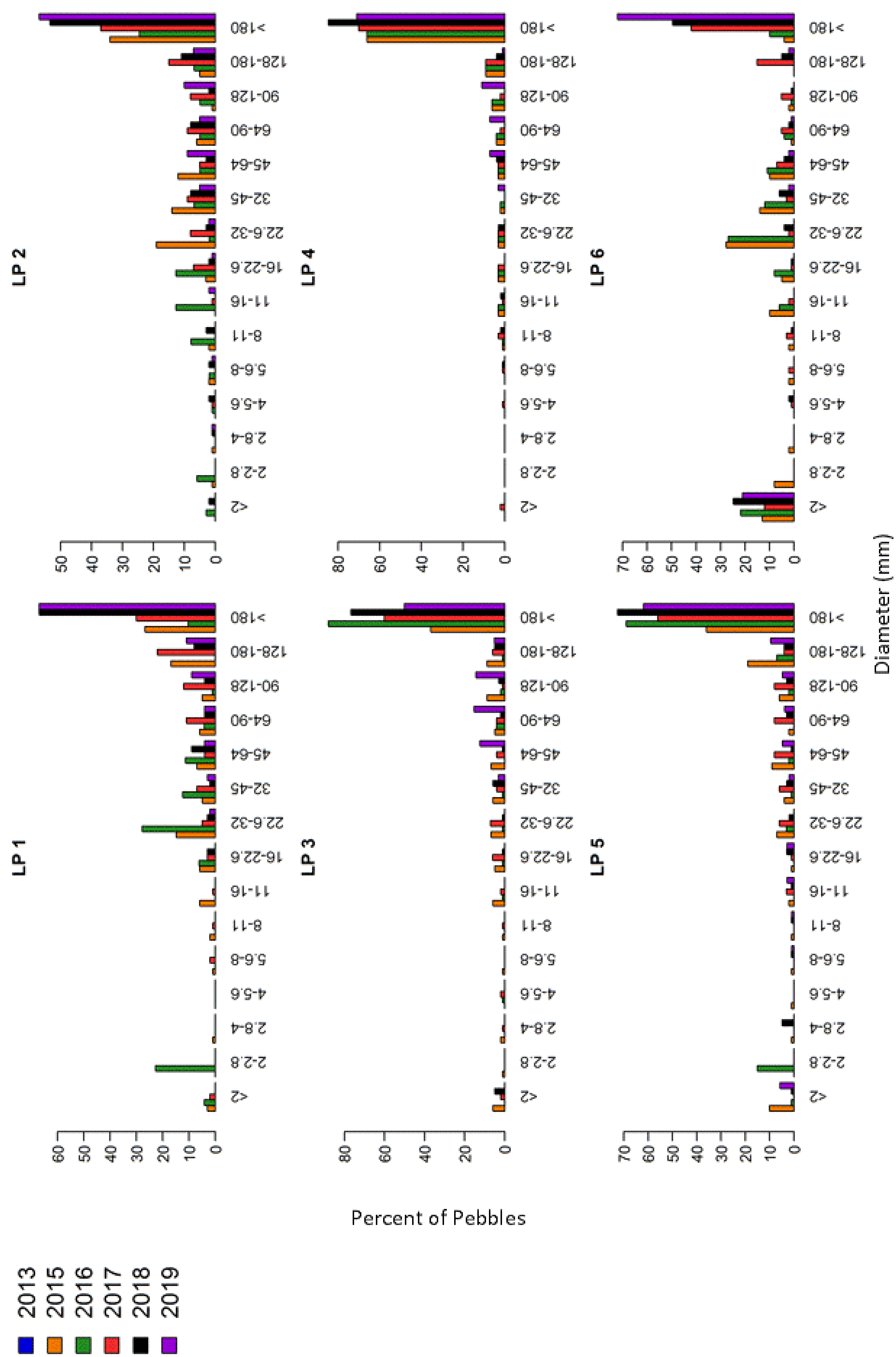

2013
2015
2016
2017
2018a
2018b
2019
SC 1
SC 2
SC 3
SC 4
SC 5
SC 6
Elevation (m)
Distance (m)
10
12
14
16
18
0
10
20
30
40


CRO 1
CRO 2
CRO 3
CRO 4
CRO 5
CRO 6
Elevation (m)
Distance (m)
2013
2015
2016
2017
2018
2019

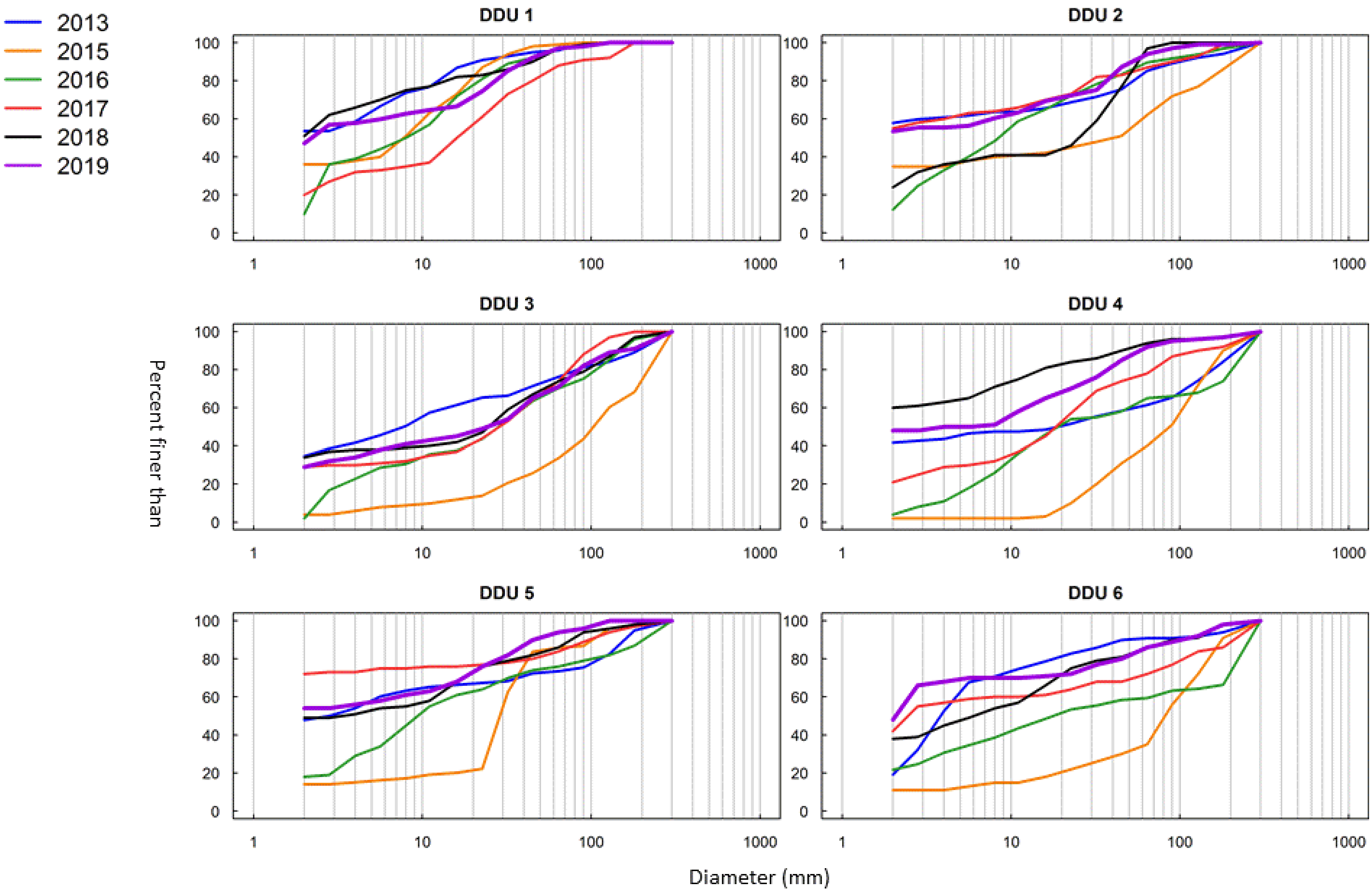
7 Appendix B: Pebble Count Plots

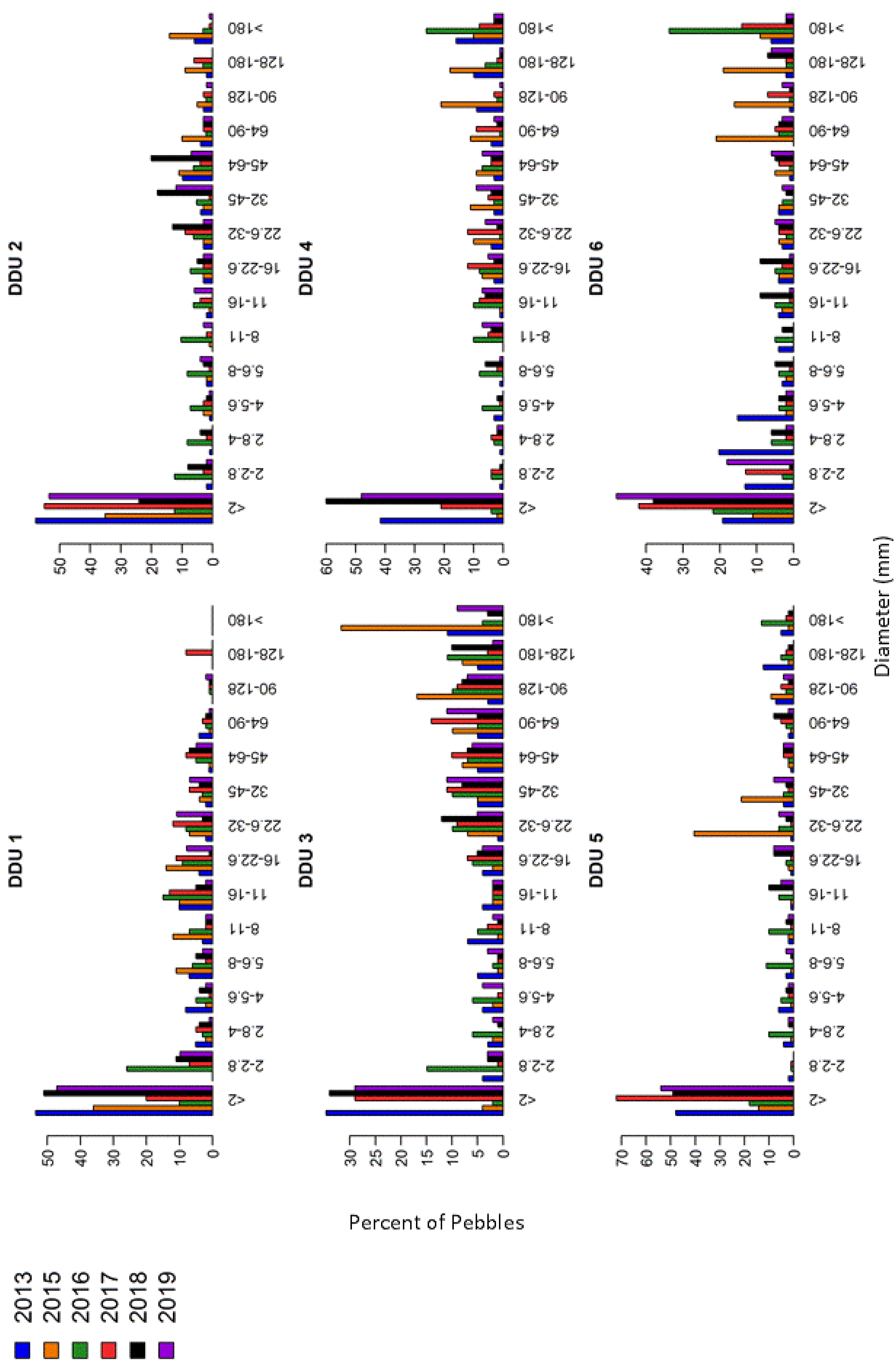
Channel pebble counts for each cross section within each reach. Reaches are denoted by their reach abbreviation (LP, DDU, DDL, BW, SR, SC, PC, and CR) and transect number descending from upstream to downstream (1 to 4 or 6).

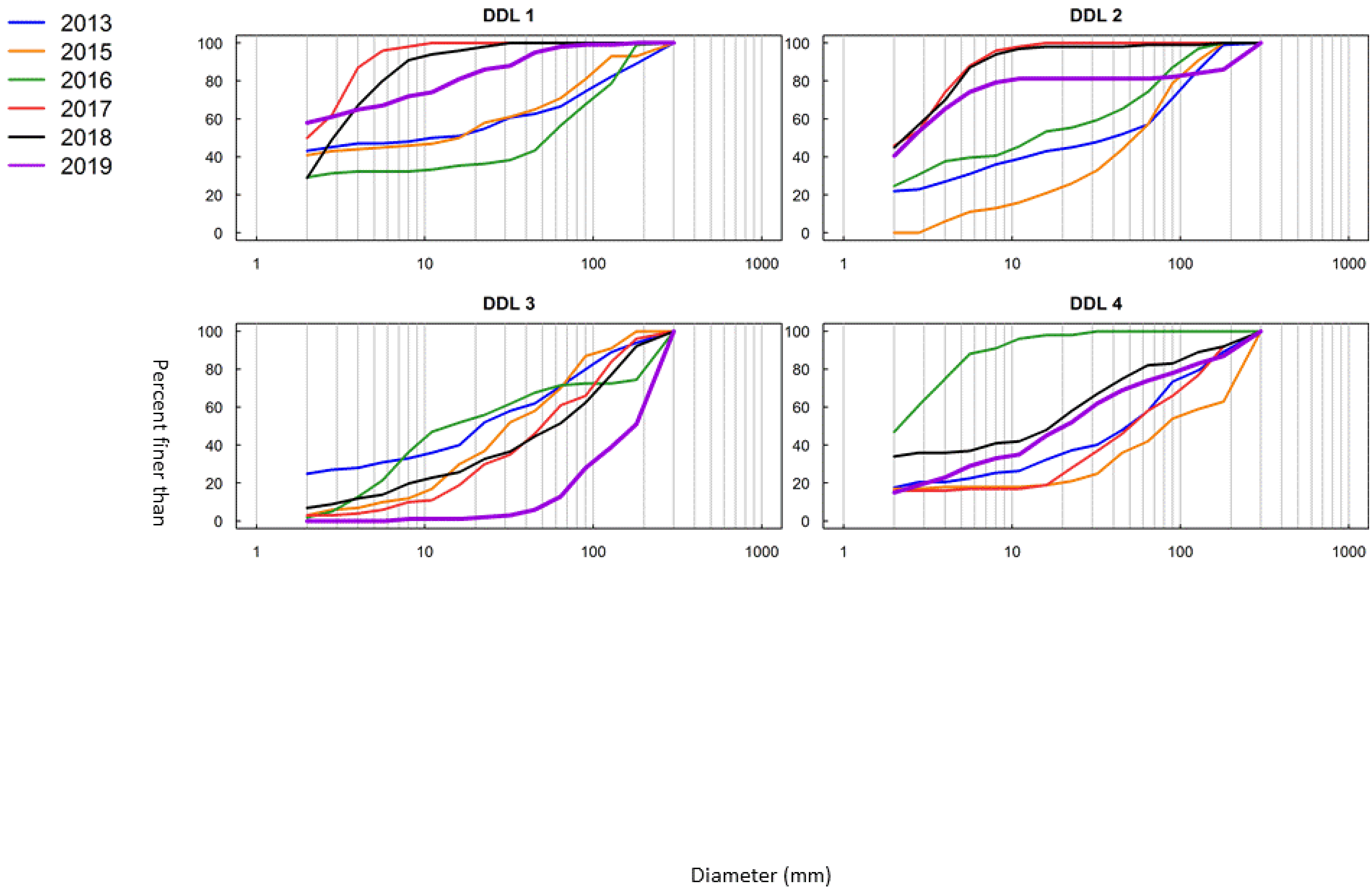

2015
2016
2017
2018
2019
LP 1
LP 2
LP 3
LP 4
LP 5
LP 6
100
80
60
40
20
0
1
10
100
1000
Percent finer than
Diameter (mm)

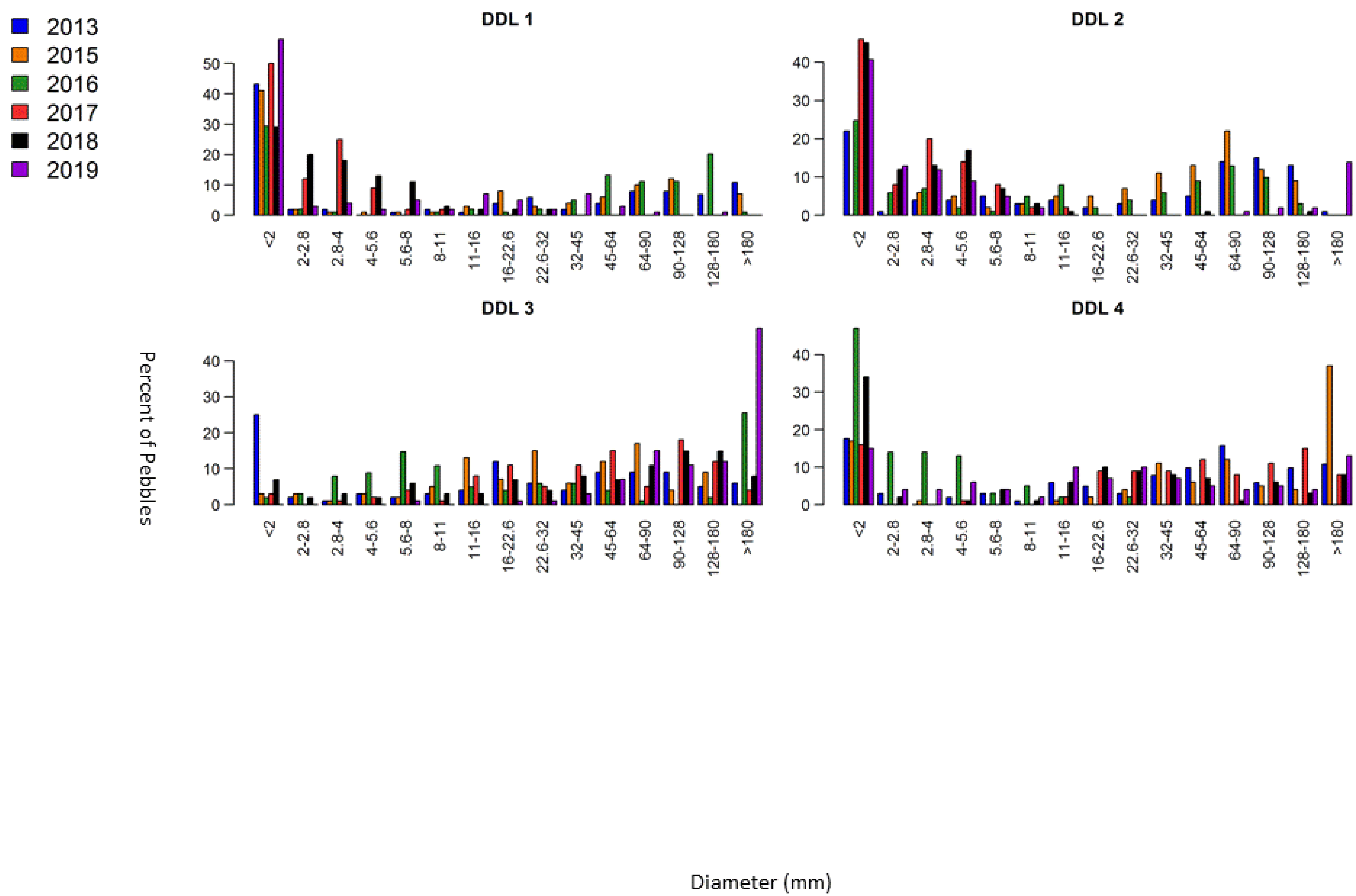


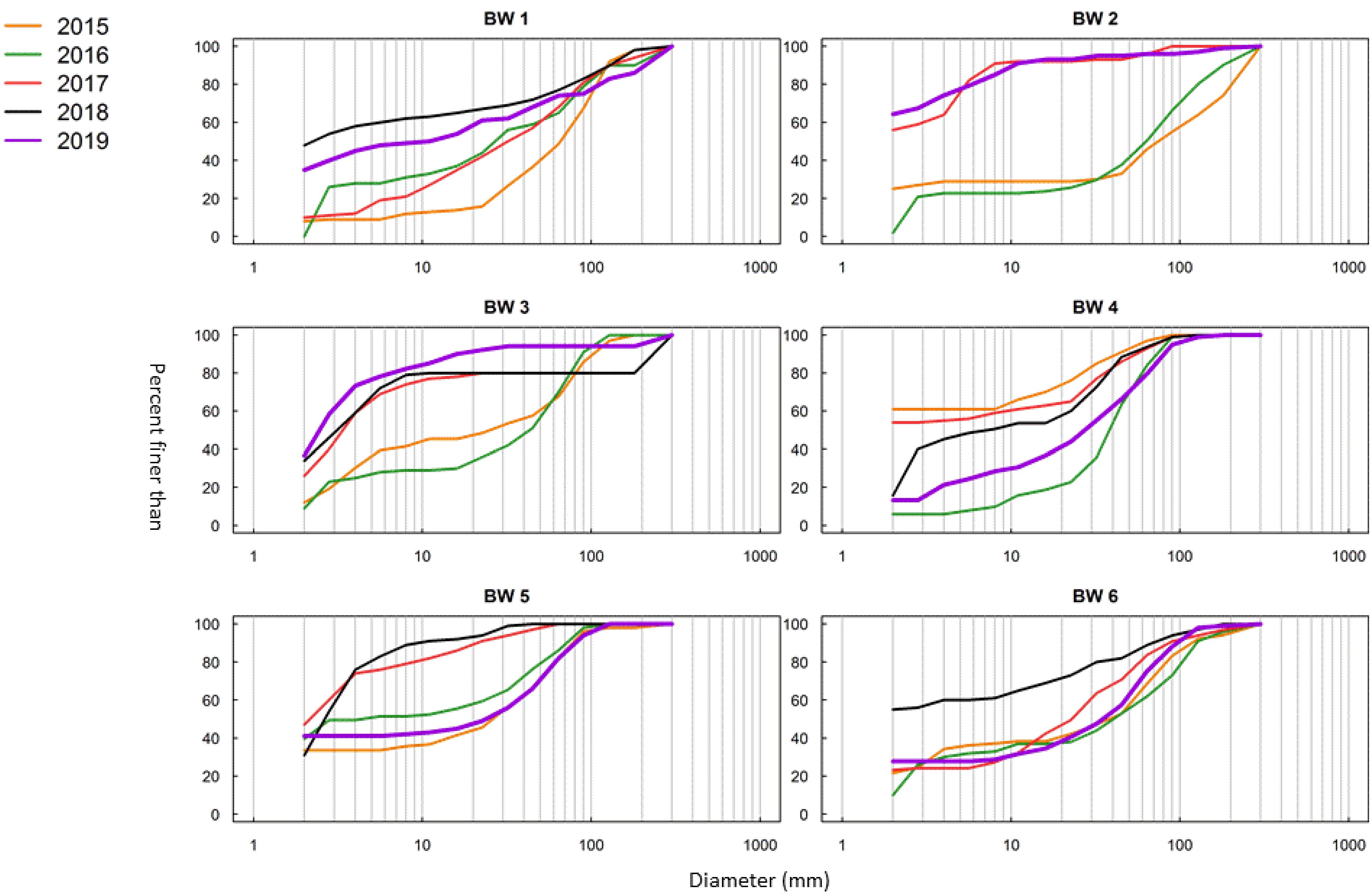
LP 1
LP 2
LP 3
LP 4
LP 5
LP 6
<2
2-2.8
2.8-4
4-5.6
5.6-8
8-11
11-16
16-22.6
22.6-32
32-45
45-64
64-90
90-128
128-180
>180
Percent of Pebbles
Diameter (mm)
2013
2015
2016
2017
2018
2019

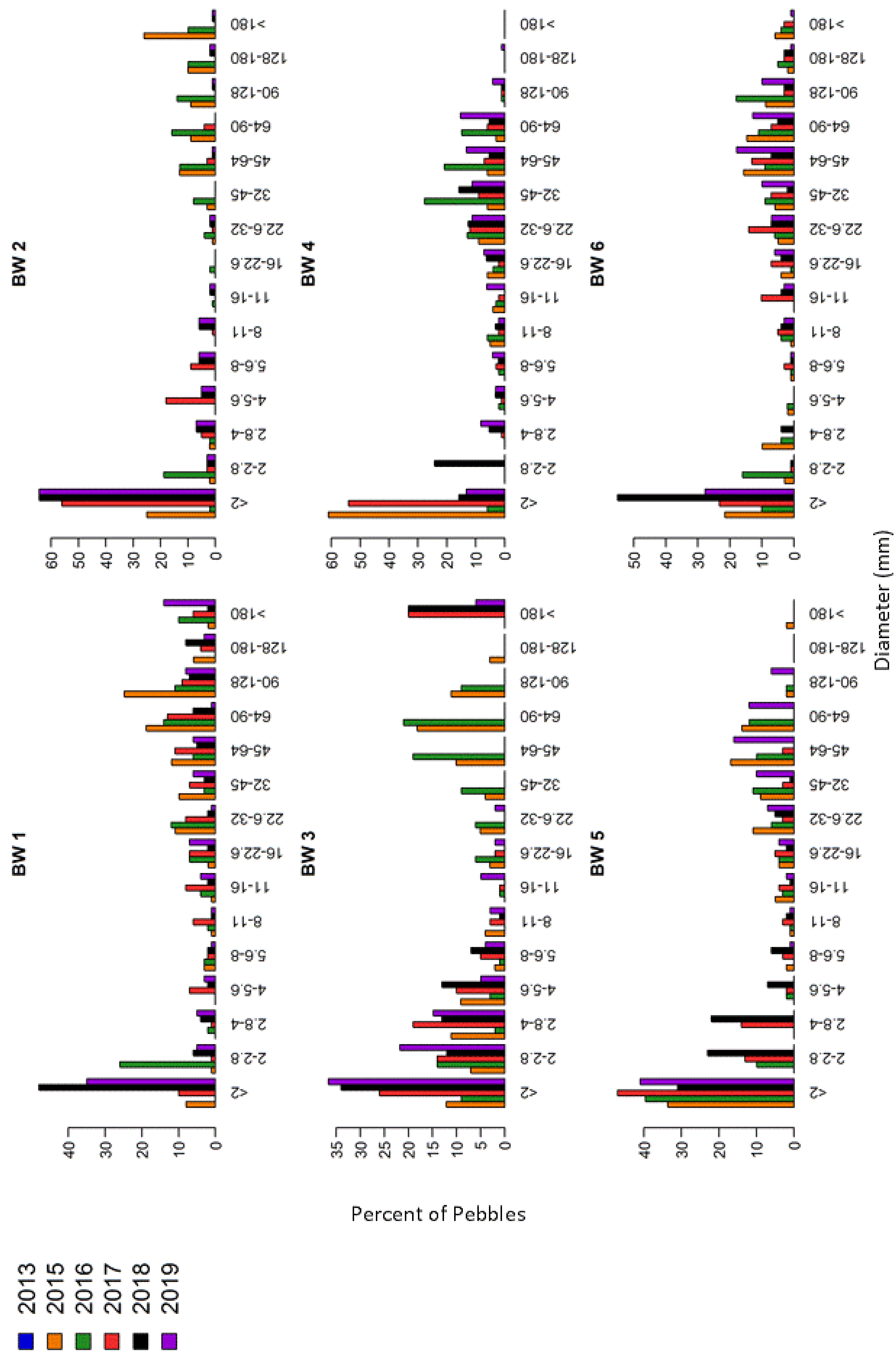

2013
2015
2016
2017
2018
2019
DDU 1
DDU 2
DDU 3
DDU 4
DDU 5
DDU 6
Percent finer than
Diameter (mm)
0
20
40
60
80
100
1
10
100
1000


DDU 1
DDU 2
DDU 3
DDU 4
DDU 5
DDU 6
<2
2-2.8
2.8-4
4-5.6
5.6-8
8-11
11-16
16-22.6
22.6-32
32-45
45-64
64-90
90-128
128-180
>180
Percent of Pebbles
Diameter (mm)
2013
2015
2016
2017
2018
2019

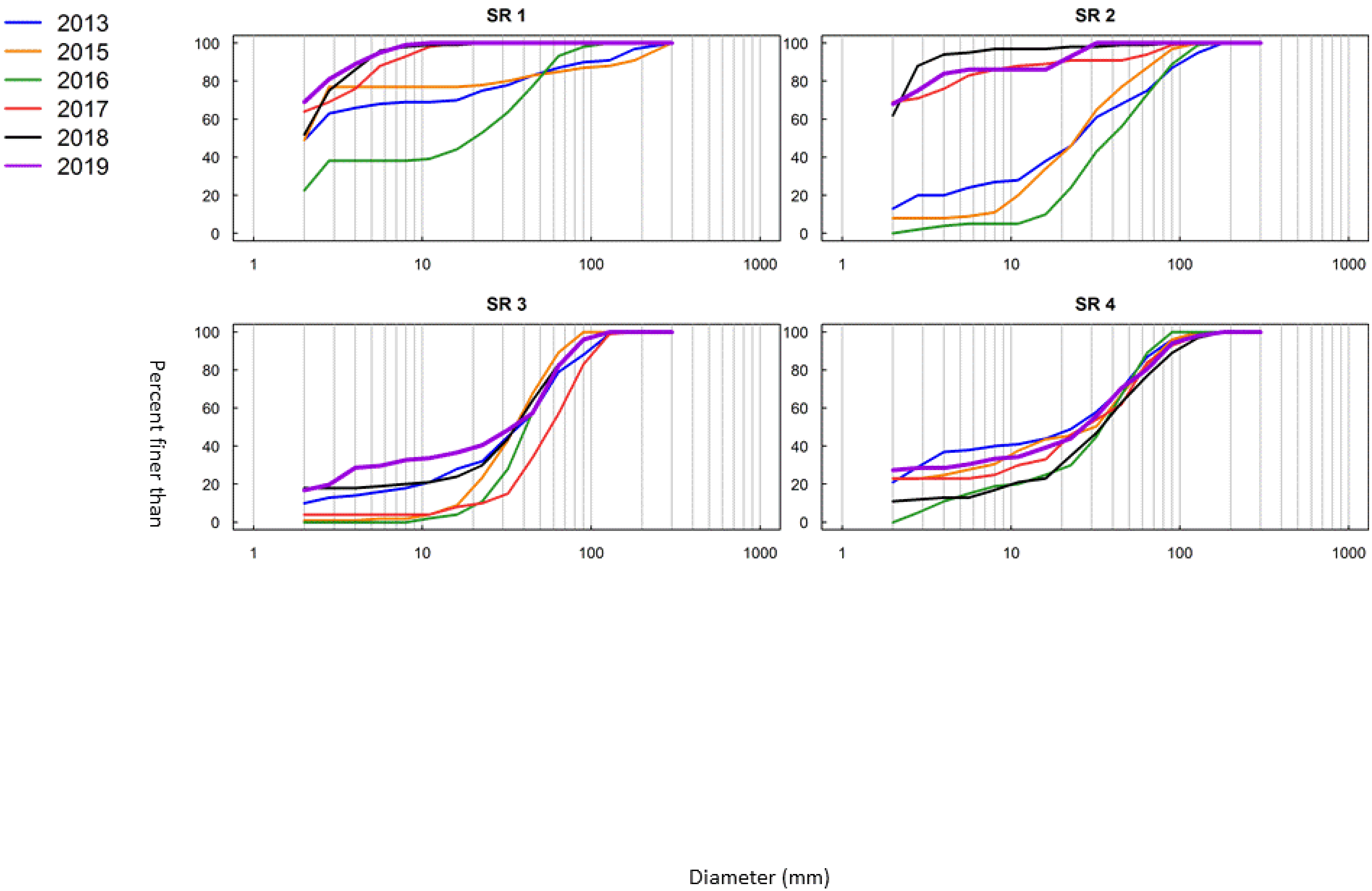

2013
2015
2016
2017
2018
2019
DDL 1
DDL 2
DDL 3
DDL 4
100
80
60
40
20
0
1
10
100
1000
Percent finer than
Diameter (mm)

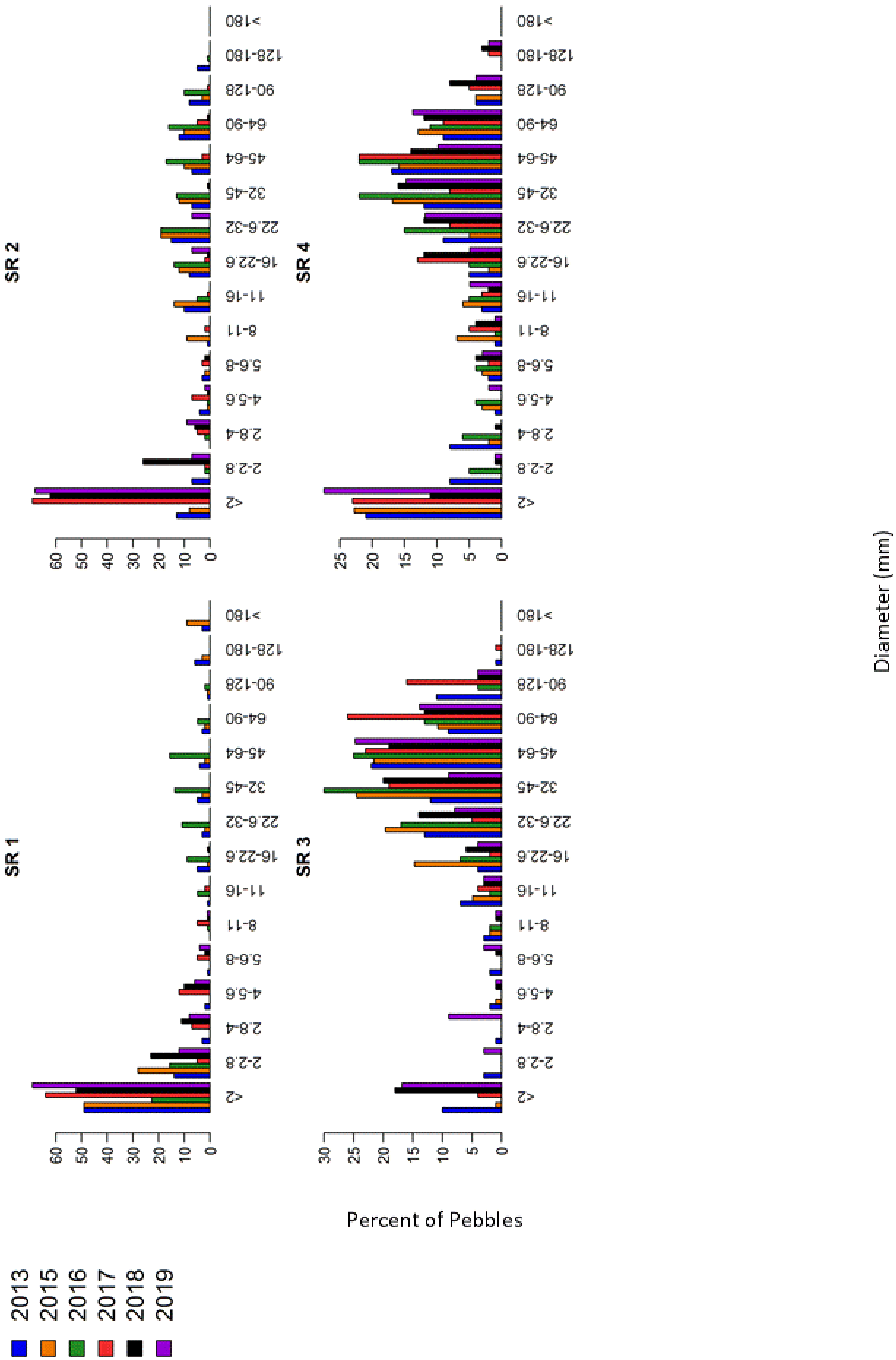

2013
2015
2016
2017
2018
2019
DDL 1
DDL 2
DDL 3
DDL 4
<2
2-2.8
2.8-4
4-5.6
5.6-8
8-11
11-16
16-22.6
22.6-32
32-45
45-64
64-90
90-128
128-180
>180
Percent of Pebbles
Diameter (mm)

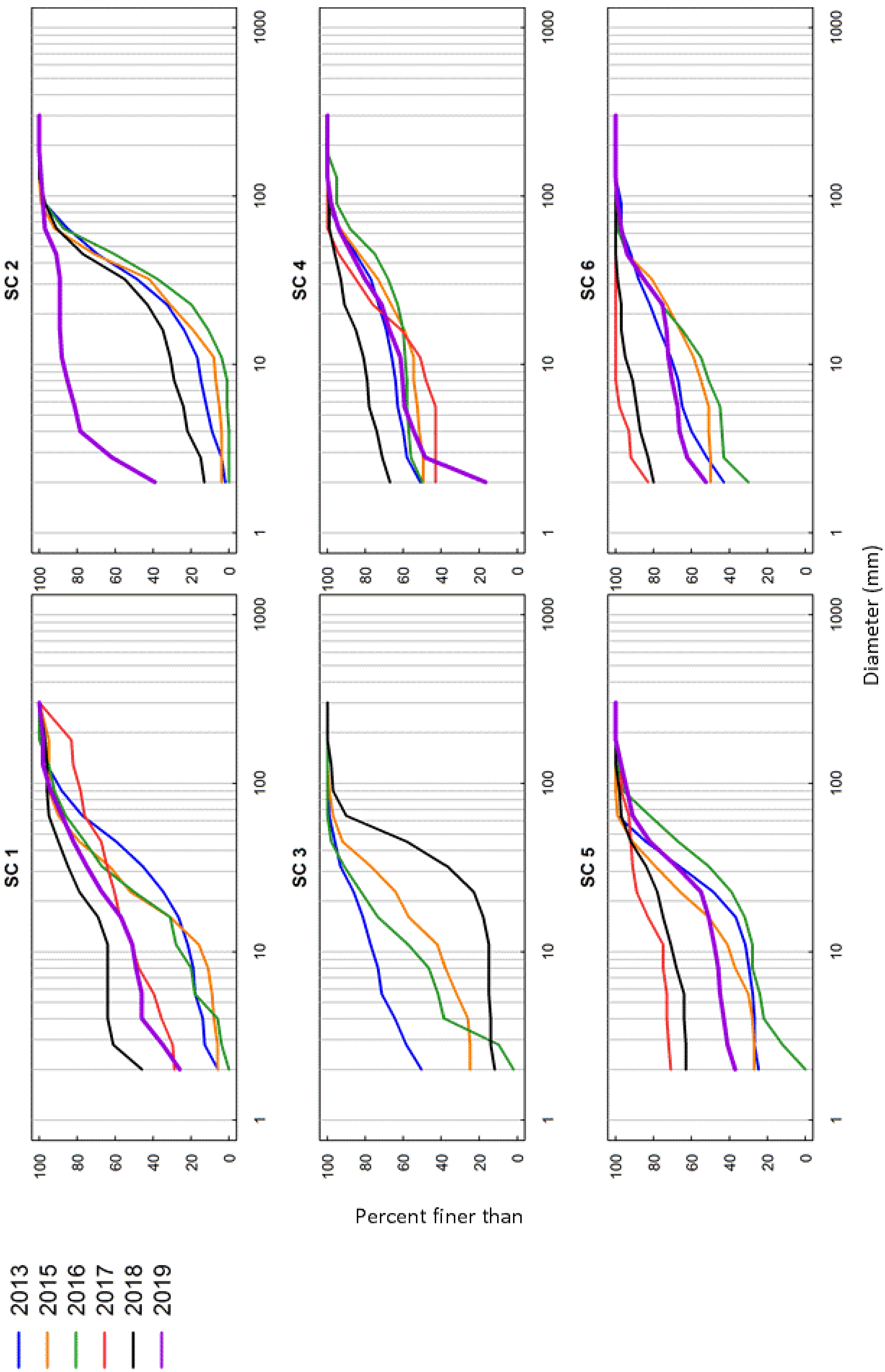

2015
2016
2017
2018
2019
BW 1
BW 2
BW 3
BW 4
BW 5
BW 6
Percent finer than
Diameter (mm)
0
20
40
60
80
100
1
10
100
1000



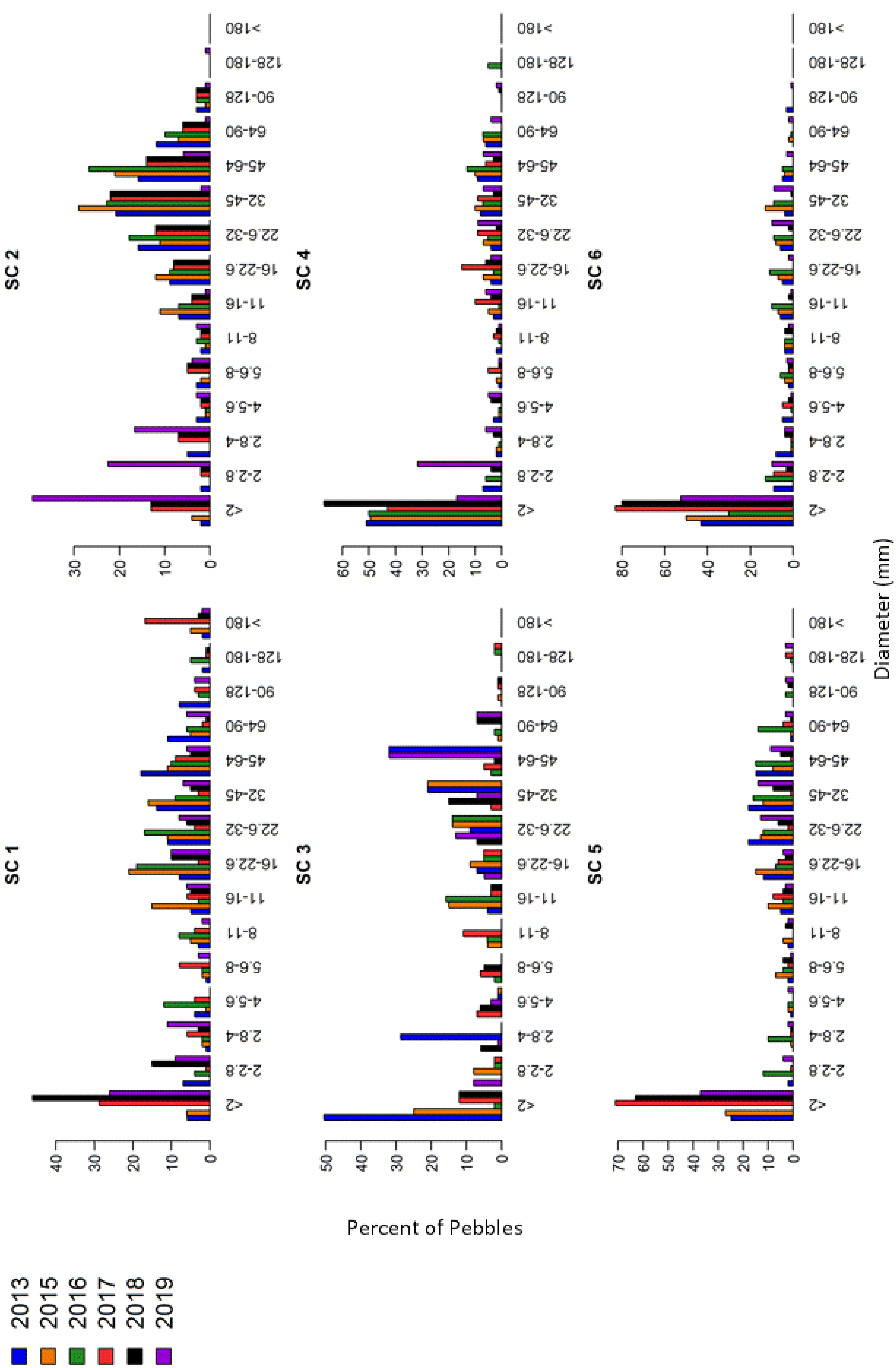
BW 1
BW 2
BW 3
BW 4
BW 5
BW 6
Percent of Pebbles
Diameter (mm)
<2
2-2.8
2.8-4
4-5.6
5.6-8
8-11
11-16
16-22.6
22.6-32
32-45
45-64
64-90
90-128
128-180
>180
2013
2015
2016
2017
2018
2019

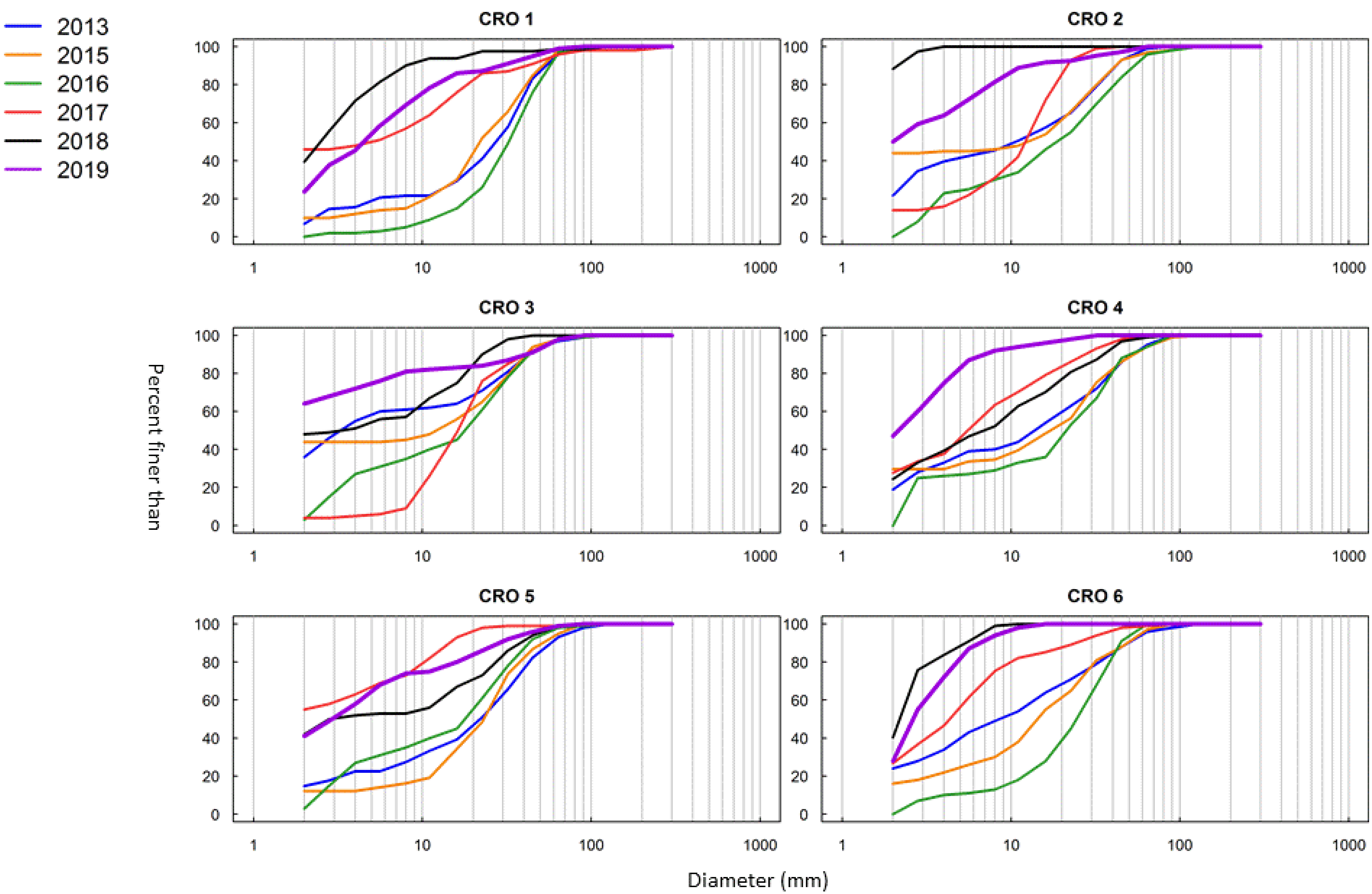

2013
2015
2016
2017
2018
2019
SR 1
SR 2
SR 3
SR 4
100
80
60
40
20
0
1
10
100
1000
Percent finer than
Diameter (mm)

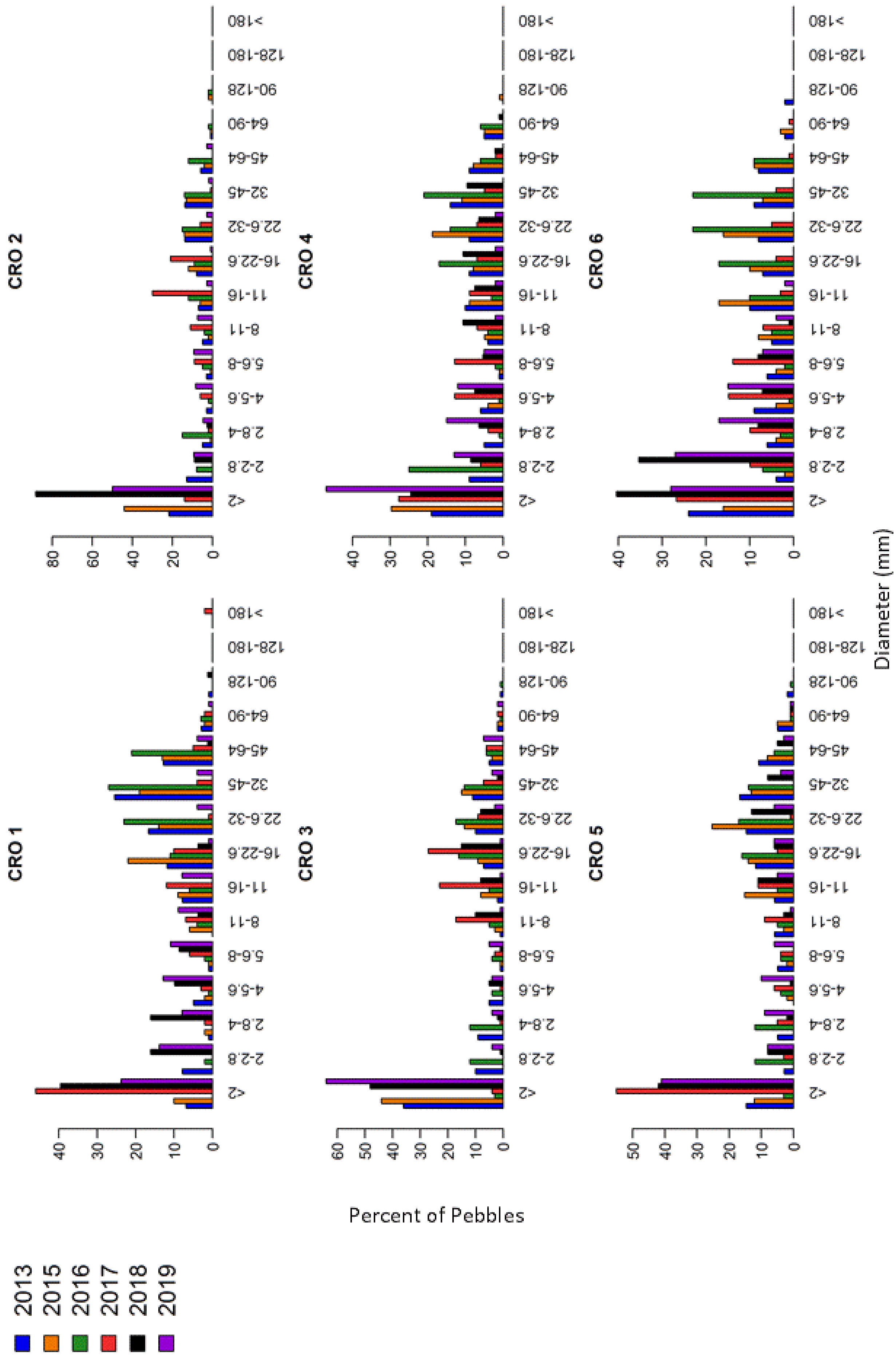

SR 1
SR 2
SR 3
SR 4
<2
2-2.8
2.8-4
4-5.6
5.6-8
8-11
11-16
16-22.6
22.6-32
32-45
45-64
64-90
90-128
128-180
>180
Percent of Pebbles
Diameter (mm)
2013
2015
2016
2017
2018
2019



SC 1
SC 2
SC 3
SC 4
SC 5
SC 6
Percent finer than
Diameter (mm)
2013
2015
2016
2017
2018
2019


SC 1
SC 2
SC 3
SC 4
SC 5
SC 6
<2
2-2.8
2.8-4
4-5.6
5.6-8
8-11
11-16
16-22.6
22.6-32
32-45
45-64
64-90
90-128
128-180
>180
Percent of Pebbles
Diameter (mm)
2013
2015
2016
2017
2018
2019


2013
2015
2016
2017
2018
2019
CRO 1
CRO 2
CRO 3
CRO 4
CRO 5
CRO 6
Percent finer than
Diameter (mm)


CRO 1
CRO 2
CRO 3
CRO 4
CRO 5
CRO 6
Percent of Pebbles
Diameter (mm)
<2
2-2.8
2.8-4
4-5.6
5.6-8
8-11
11-16
16-22.6
22.6-32
32-45
45-64
64-90
90-128
128-180
>180
2013
2015
2016
2017
2018
2019