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2018 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 (2013 and 2015) and after (2016, 2017, and 2018) dam removal to document dam removal impacts. This report presents surveys from fall 2018, the third year after dam removal. Data collection was preceded by the 2016 Soberanes Fire, several flooding events during winter 2017, and relatively average conditions of the 2018 water year. 2018 Precipitation was 13.52 inches, and flow at the Robles del Rio gage reached 3000 cfs. Therefore, the 2018 water year rainfall was below average, but the peak flow was slightly higher than the estimated 2-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 more significant geomorphic changes occurred in cross sections that had not been surveyed in 2017 because of benchmark losses. Those benchmarks were recovered or re-established and resurveyed in 2018. The more significant geomorphic changes in the study are expressed in the re-established transects, and the geomorphic changes are defensibly ascribed to the high flows of 2017. The transects that were surveyed both in 2017 and 2018 showed minimal additional adjustments to the very significant changes observed in 2017.

Grain size fined and pools aggraded in most cross sections located downstream of the dam in 2017—an impact of sand transported from an eroding reach of the river located 1.5 km upstream of the former dam site. Grain size analysis in 2018 indicates that the most sites are continuing to fine. More detailed analysis indicates that sites closest to the former dam site are starting to coarsen. That

observation is consistent with the down-valley migration of the sediment pulse introduced in 2017.

Acknowledgements

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1 Introduction

In 2015, the San Clemente Dam was removed from the Carmel River in the northern Santa Lucia Range due to its 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.

This report presents results from surveys conducted after the 2018 water-year. Flows in 2018 were relatively light compared to water-year 2017, and similar to water-year 2016. Precipitation at the San Clemente Dam gage reached 13.52 inches, which is below the long term (1922 -2018) average of 21.19 inches. The 2018 precipitation reflects the 8-yr drought (non-exceedance) event. Runoff generated a peak flow near 3000 cfs at the Robles del Rio gage, which is a peak flow with a 2-yr exceedance recurrence interval. Although that peak flow is capable of geomorphic change, there were only two significant runoff events during the year, so the total duration of geomorphically significant events was very short.

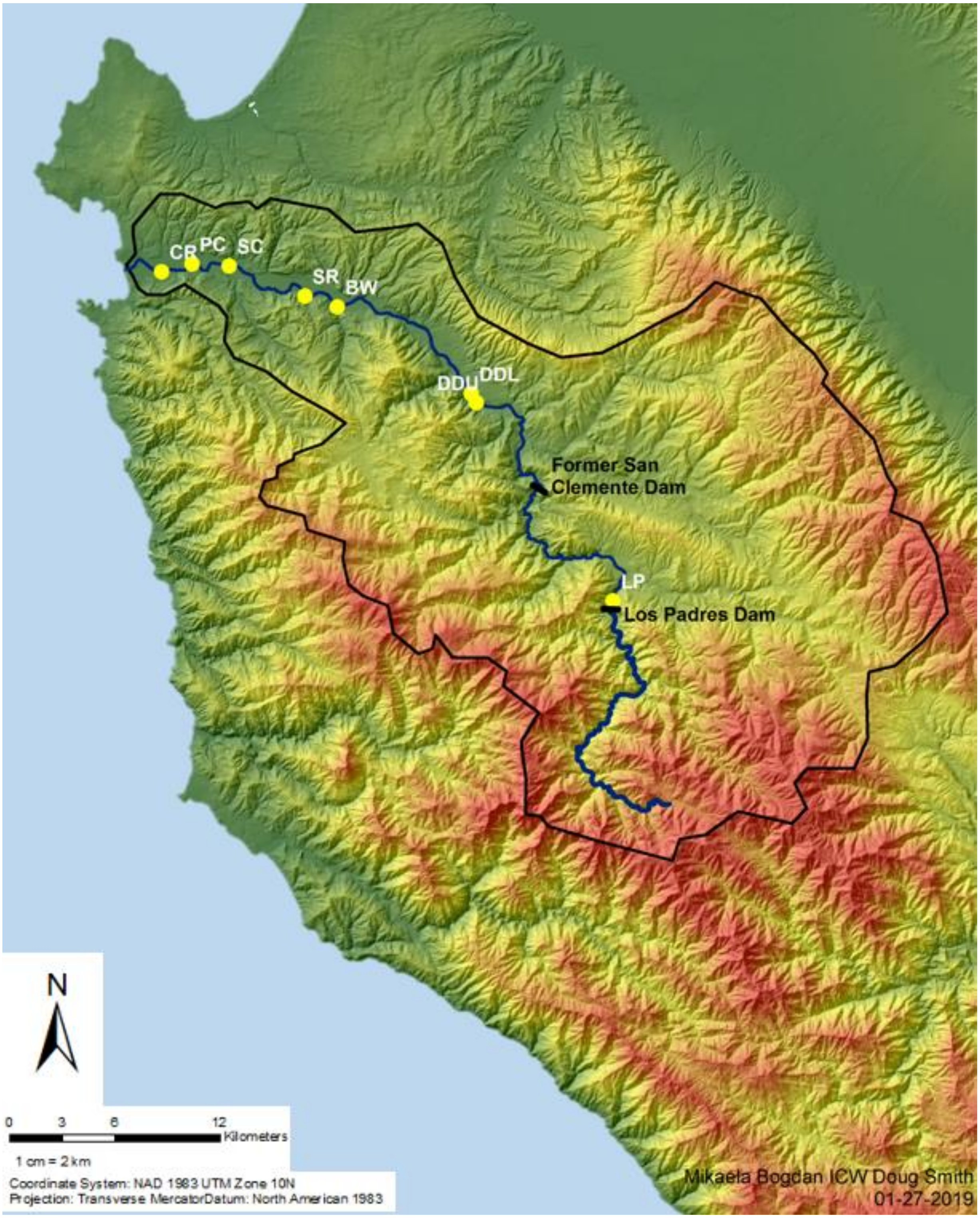

Figure 1. Location of study reaches relative to Los Padres Dam and the former San Clemente Dam on the Carmel River.

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 2018, 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.

- **Palo Corona (PC)**: Established in 2018, this reach is located at the recently established Palo Corona Regional Park (former Rancho Canada golf course), just upstream of Crossroads Shopping Center.
- **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 the 2017 surveys to assess the changes that occurred in water year 2018.

In water year 2018, several benchmarks lost during the high flows of 2017 were re-established and a new site was benchmarked and surveyed. Where benchmarks were lost to severe 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, 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. Four new cross sections were benchmarked and surveyed at a new site called "Palo Corona." Since there were no prior surveys to reference, shots were taken every two meters and to record major breaks in slope.

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 $\geq$ 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 2018 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 augmentation occurred in late calendar year 2014, approximately 10 months before the first surveys. We collected cross section and pebble count data for all sites.

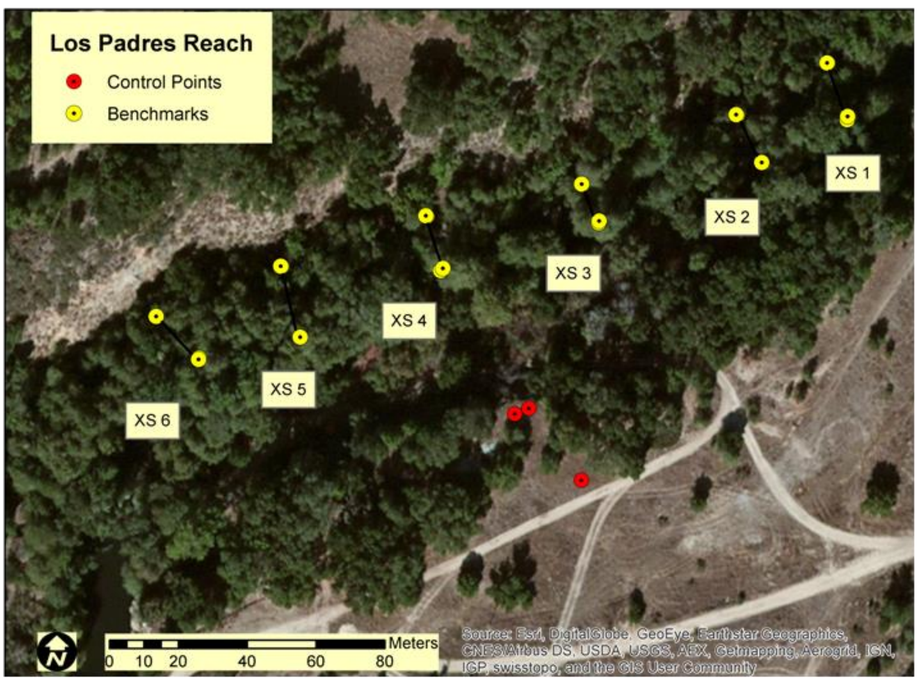

Figure 2. Location of georeferenced control points and cross sections within the Los Padres Reach.

Essentially no geomorphic change occurred between 2017 and 2018 cross sections at all locations (Appendix A).

The pattern of substrate coarsening observed in previous years continued in 2018. The graphic mean particle size increased from 107.5mm in 2017 to 122.0 mm in 2018 (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 rapidly waning.

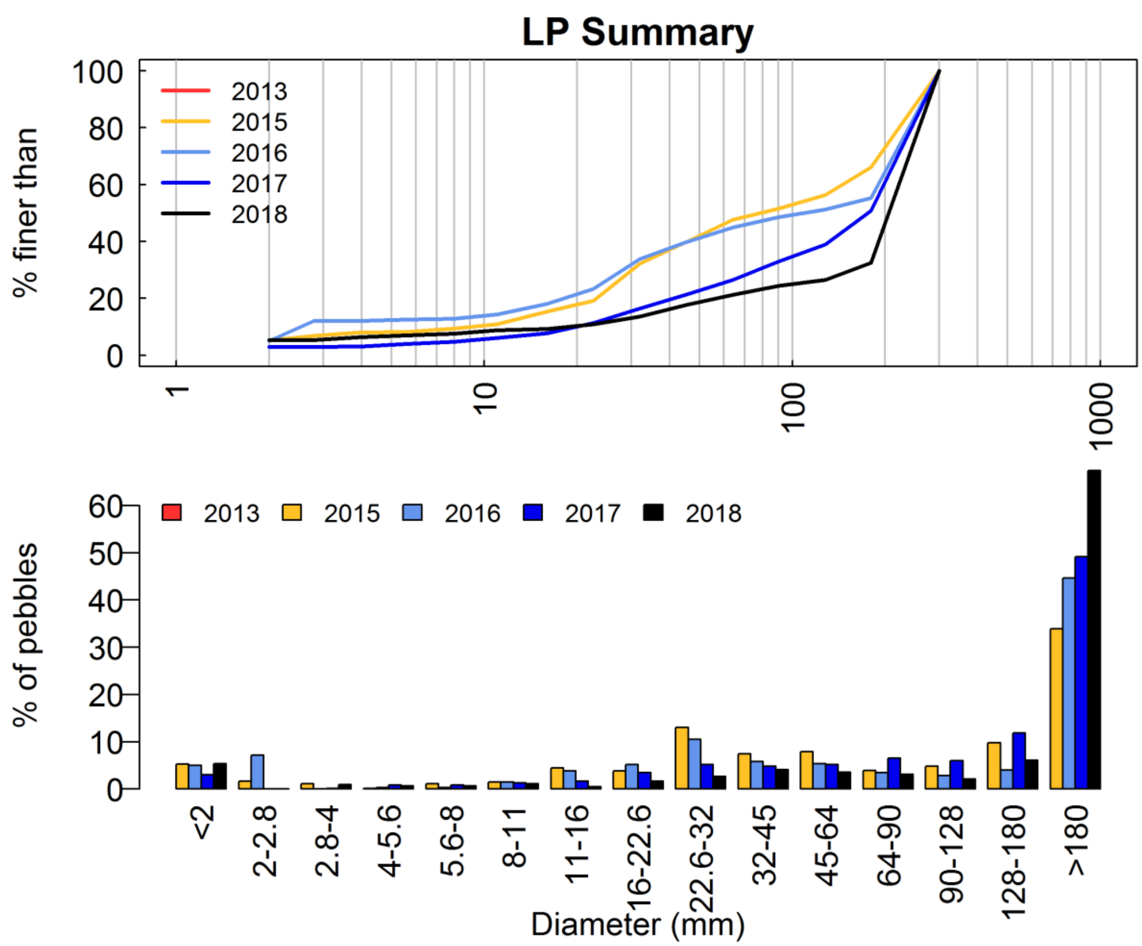

Figure 3. Summary pebble count distribution (LP 1 – LP 6) for the Los Padres reach displayed as cumulative percentiles (top) and individual bins (bottom) for 2015 to 2018.

Table 1. Summary grain size distribution among cross-sectional transects within the Los Padres Reach from 2015 to 2018.

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

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.

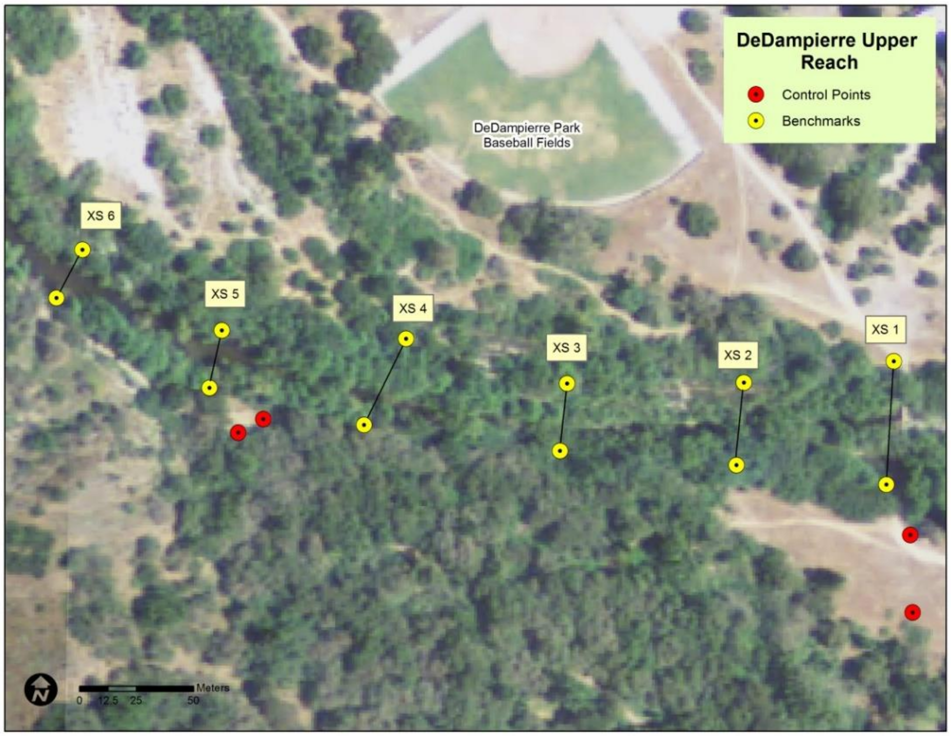

Figure 4. Location of georeferenced control points and cross sections within the DeDampierre Upper Reach.

Most of the geomorphic changes recorded at DDU cross sections were depositional (Appendix A). Sites one and three show practically no change in channel morphology between 2017 and 2018. DDU6 shows between 0.2 m and 0.3 m of aggradation in the channel between 2017 and 2018 (Appendix A). Cross sectional data were not collected in 2017 for DDU2, DDU4, and DDU5 because the benchmarks had been eroded away or deeply buried. The aggradation shown between 2016 and re-established 2018 cross sections likely occurred in water year 2017 (Appendix A), given the 2017 behavior of nearby cross sections and the observation that the highest flows of WY 2018 would not have reached the locations where much aggradation was recorded in the 2018 surveys.

The graphic mean of grain size of this reach decreased from 10.9 mm in 2017 to 7.5mm in 2018 (Table 2). This fining was not consistent across all cross sections, with DDU1, DDU3, and DDU4 showing increases in sand (<2mm), and the remaining cross sections showing a decrease (Appendix B; Fig. 5).

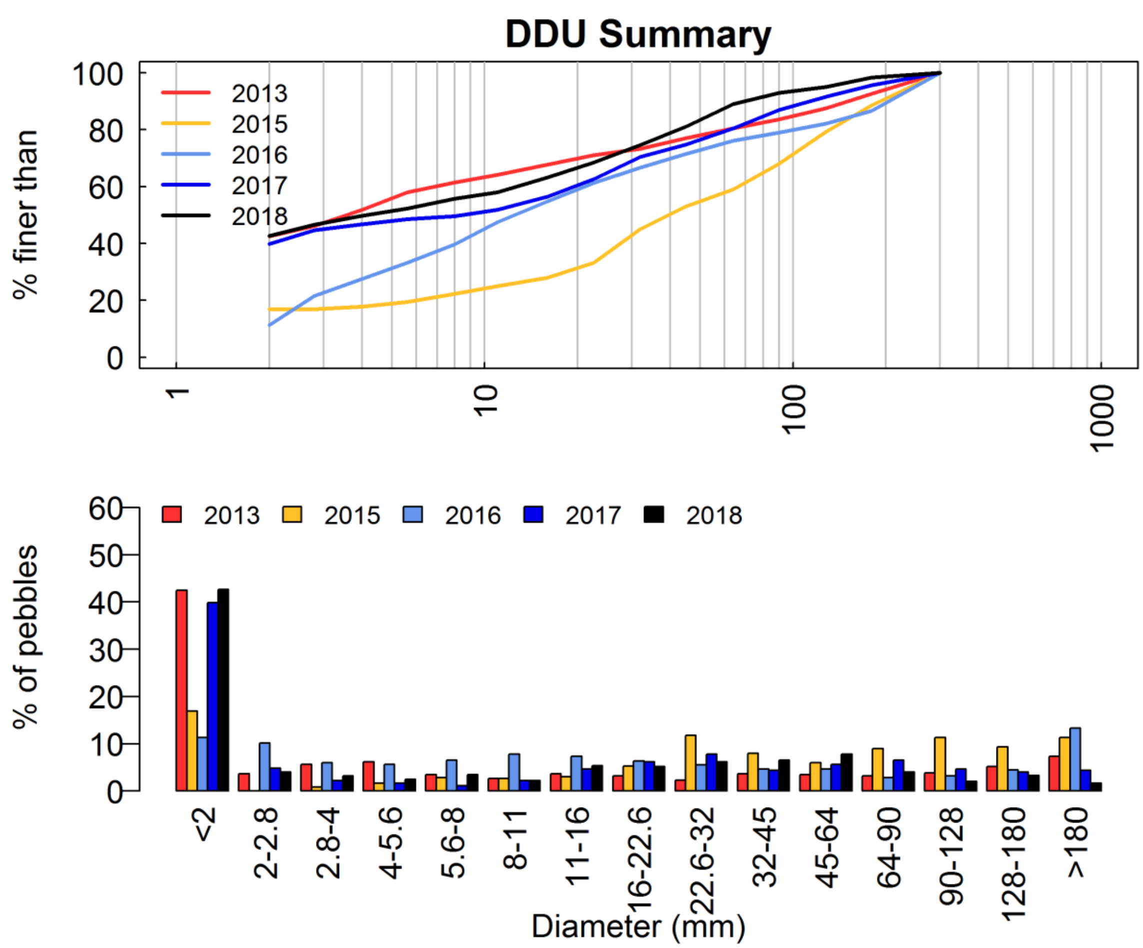

Figure 5. Summary pebble count distribution (DDU 1 – DDU 6) for the DeDampierre Upper reach displayed as cumulative percentiles (top) and individual bins (bottom) for 2013 to 2018.

Table 2. Summary grain size percentiles among cross-sectional transects within the DeDampierre Upper Reach from 2013 to 2018

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

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. 3). 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.

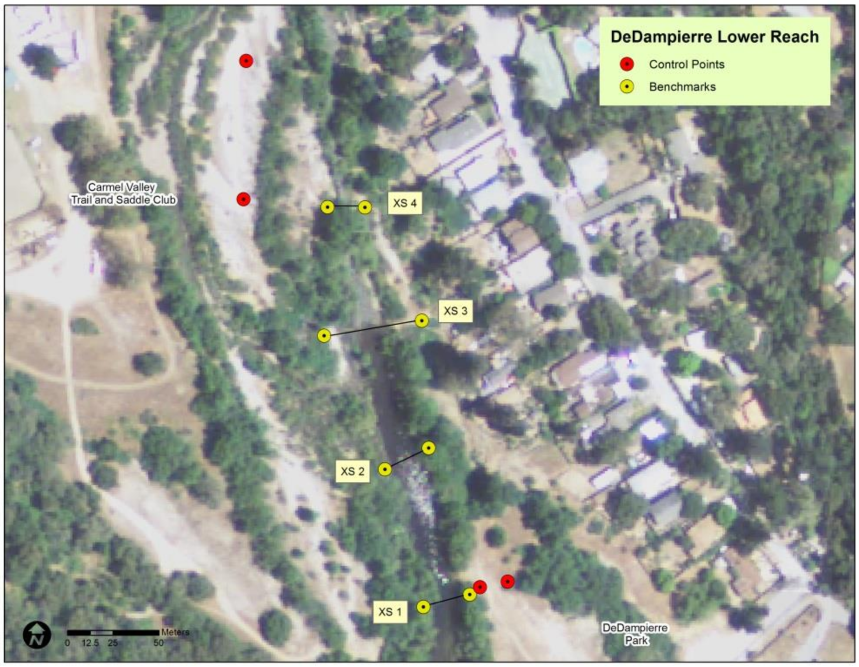

Figure 6. Location of georeferenced control points and cross sections within the DeDampierre Lower Reach.

Geomorphic changes occurred in DDL1 and DDL2 after the 2017 water year, in which the main channel at each cross section filled with up to 1.0 m of sand (Appendix A). Data collected in 2018 shows minimal change from 2017, with at most, only approximately 0.3 m of deposition at DDL1 (Appendix A). In contrast to the deposition at DDL1 and DDL2, DDL3 shows incision between 2016 and 2018 of up to 0.6 m at a distance of 20 m along the cross section. DDL4 shows incision of up to approximately 1.4 m over a cross sectional distance of nine meters. No cross-sectional data were collected in 2017 for DDL3 and DDL4, although based on similarities between 2017 and 2018 cross sections at DDL1 and DDL2 geomorphic changes between 2016 and 2018 at DDL3 and DDL4 likely occurred during water year 2017 (Appendix A). Further, the water year 2018 flows were not forceful enough to cause such significant geomorphic change anywhere else we visited in the entire Carmel River.

The graphic mean particle size for DDL decreased slightly, from 9.9mm in 2017 to 8.7 mm in 2018 (Table 3). Similarly to DDU, the fining was not consistent between cross sections. DDL3 and DDL4 showed increases in particles <2mm while DDL1 and DDL2 showed decreases (Appendix B).

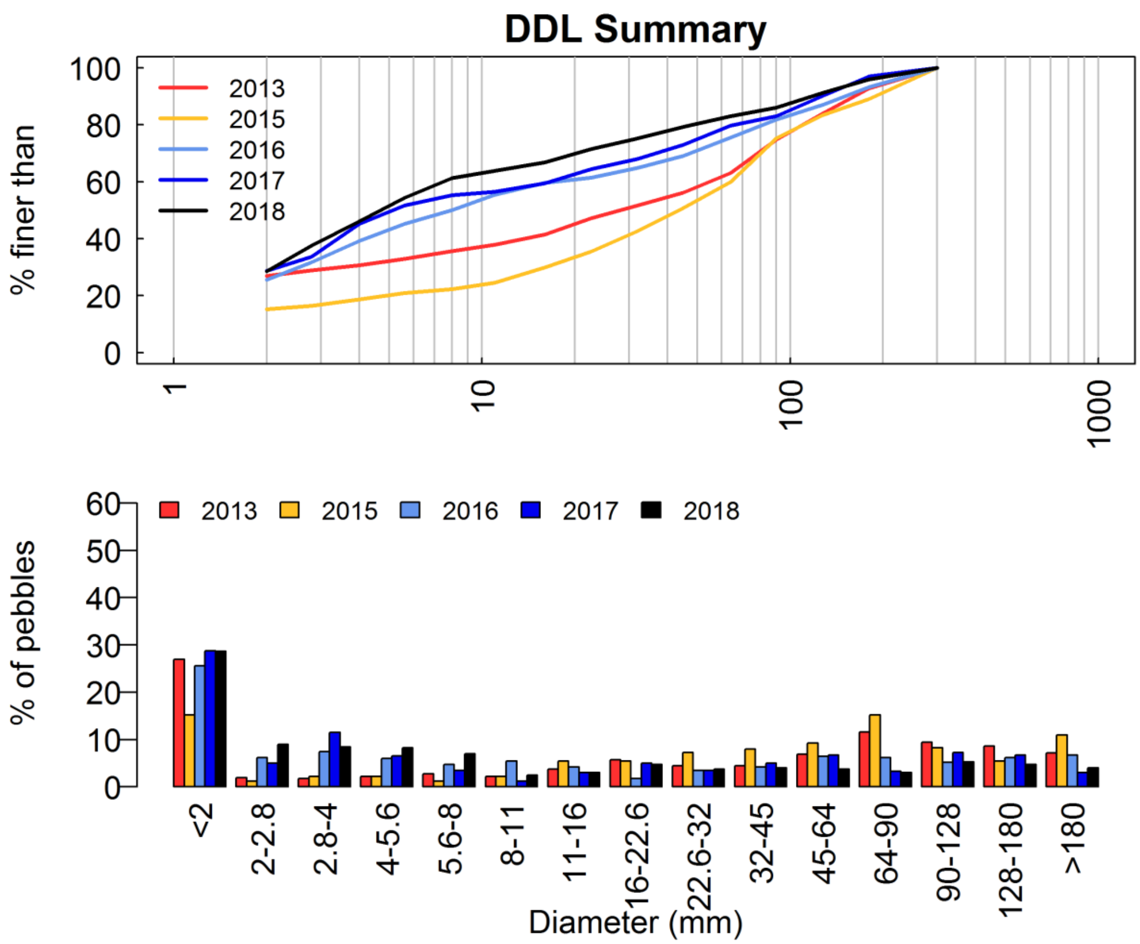

Figure 7. Summary pebble count distribution (DDL 1 – DDL 4) for the DeDampierre Lower reach displayed as cumulative percentiles (top) and individual bins (bottom) for 2013 to 2018.

Table 3. Summary grain size distribution among cross-sectional transects within the DeDampierre Lower Reach from 2013 to 2018.

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

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.

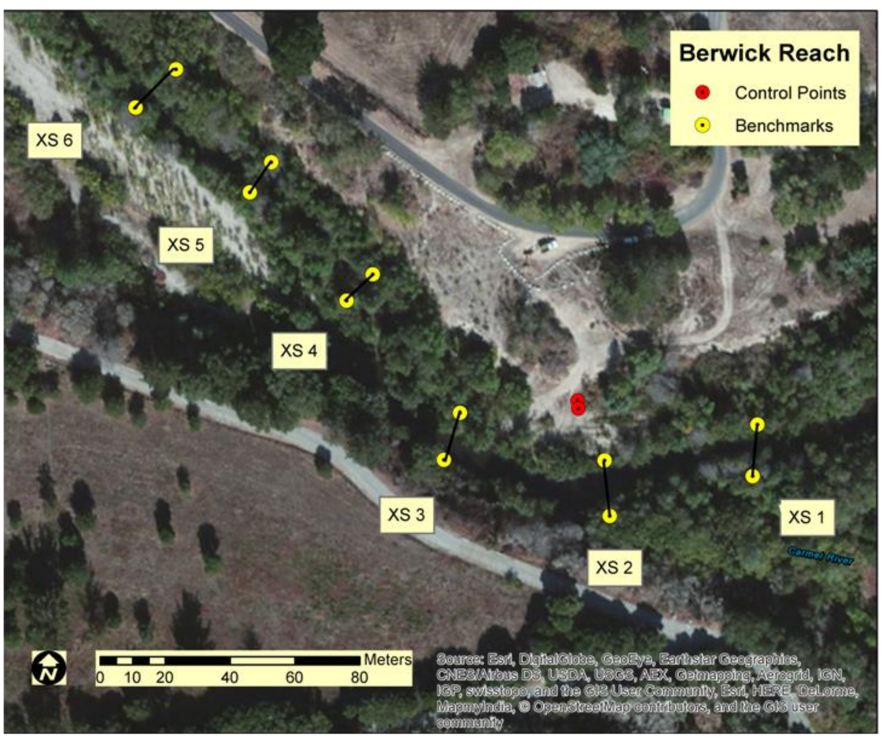

Figure 8. Location of georeferenced control points and cross sections within the Berwick Reach.

BW1 experienced deposition between 2017 and 2018 of up to 0.6 m at a cross sectional distance of 13 m, and BW5 experienced minor deposition between approximate distances of 5.8 m and 9.8 m (Appendix A). BW2 and BW4 show minor incision between 2017 and 2018 and BW3 experienced minor aggradation of up to 0.3 m at a distance of 3 m from the left benchmark and 0.3 m of incision at a distance of 10 m. Practically no change occurred at BW6 (Appendix A).

The BW reach continued to fine during 2018 (Figure 9). The graphic mean particle size decreased from 7.8mm in 2017 to 5.7mm in 2018 (Table 4). Percent of particles <2mm in diameter increased at BW1, BW2, BW3, and BW6. At the two cross sections that percentage of sand did not increase, the percentage of particles between 2 mm and 4 mm in diameter increased (Appendix B).

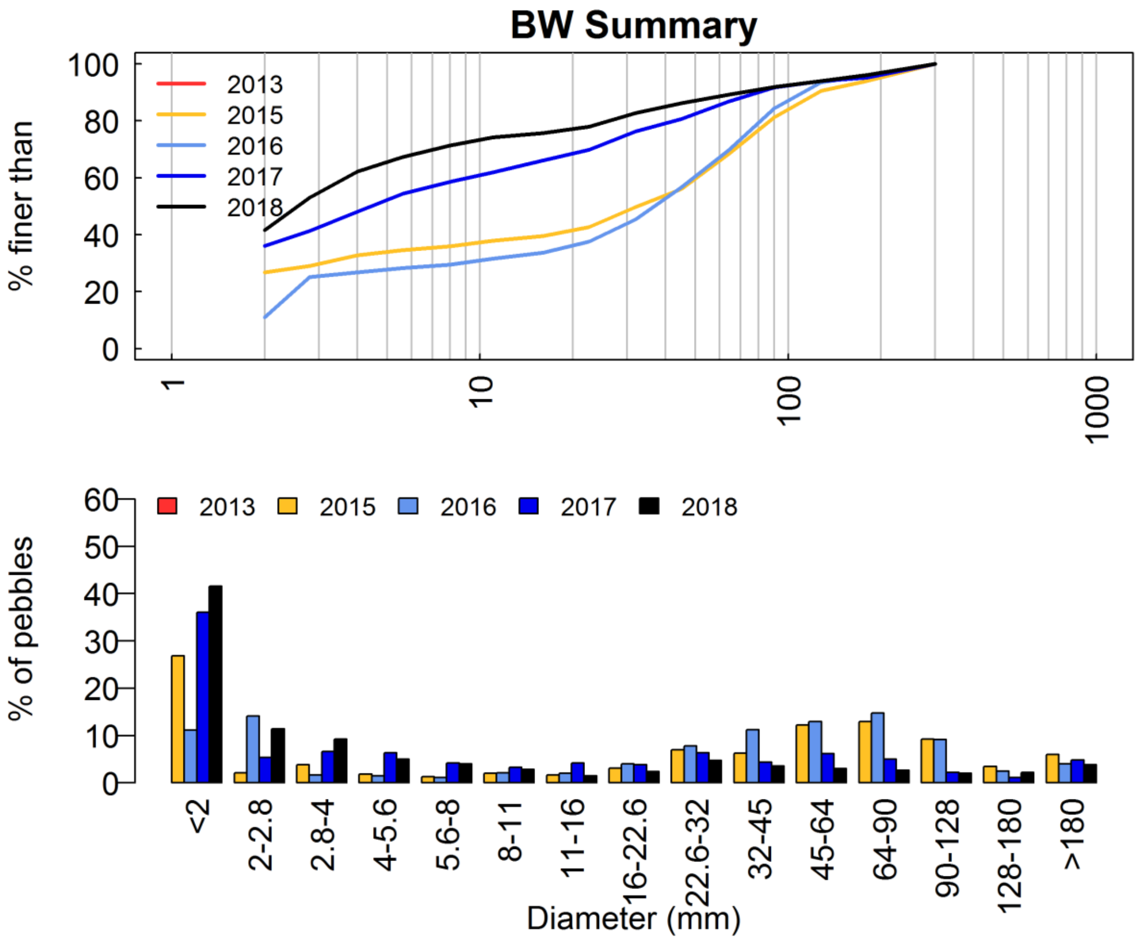

Figure 9. Summary pebble count distribution (BW 1 – BW 6) for the Berwick reach displayed as cumulative percentiles (top) and individual bins (bottom) for 2015 to 2018.

Table 4. Summary grain size distribution among cross sectional transects within the Berwick Reach from 2015 to 2018.

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

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.

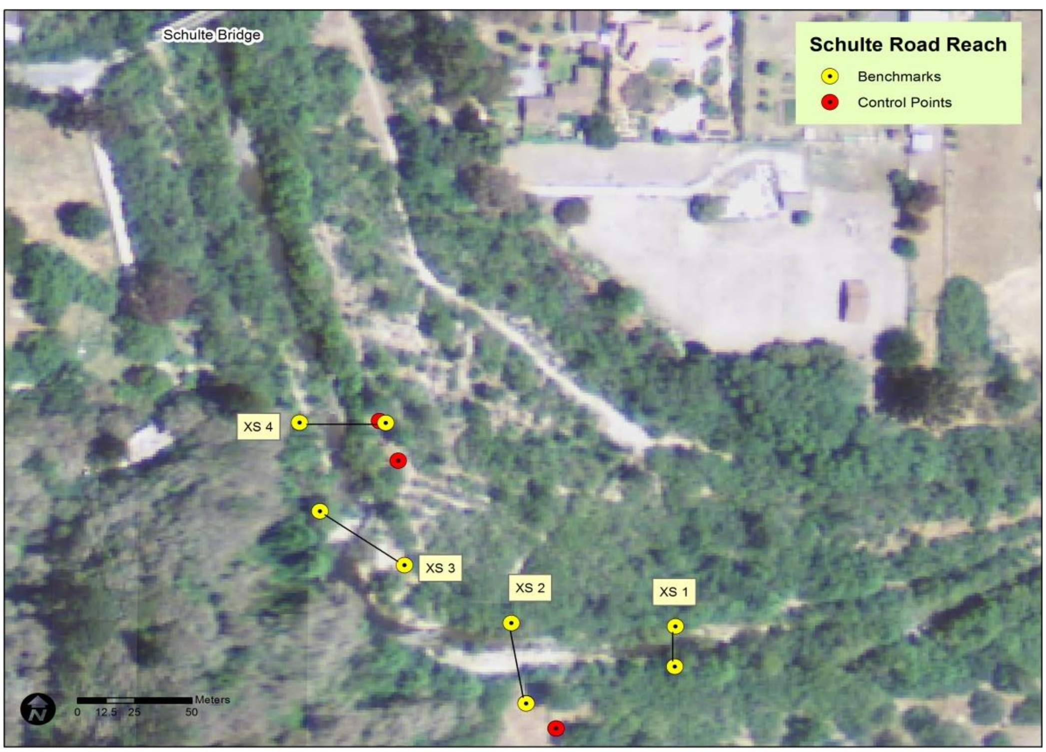

Figure 10. Locations of georeferenced control points and cross sections within the Schulte Road Reach.

While Schulte Road reach experienced significant bank erosion and local deposition in 2017, the 2018 surveys show little subsequent geomorphic change between 2017 and 2018; the largest change was incision of only 0.3 m at a distance of 10 m along cross section SR2 (Appendix A).

The SR reach fined in 2018. The graphic mean particle size decreased from 9.2 mm in 2017 to 6.9 mm in 2018 (Table 5). This fining was not the result of deposition of sand (<2mm), but instead was seen more in the ranges of 2mm to 4mm (Figure 11). SR3 was the only cross section that saw an increase in sand, while the other three cross sections saw either increases or no changes in percentages of particles 2mm to 4mm (Appendix B).

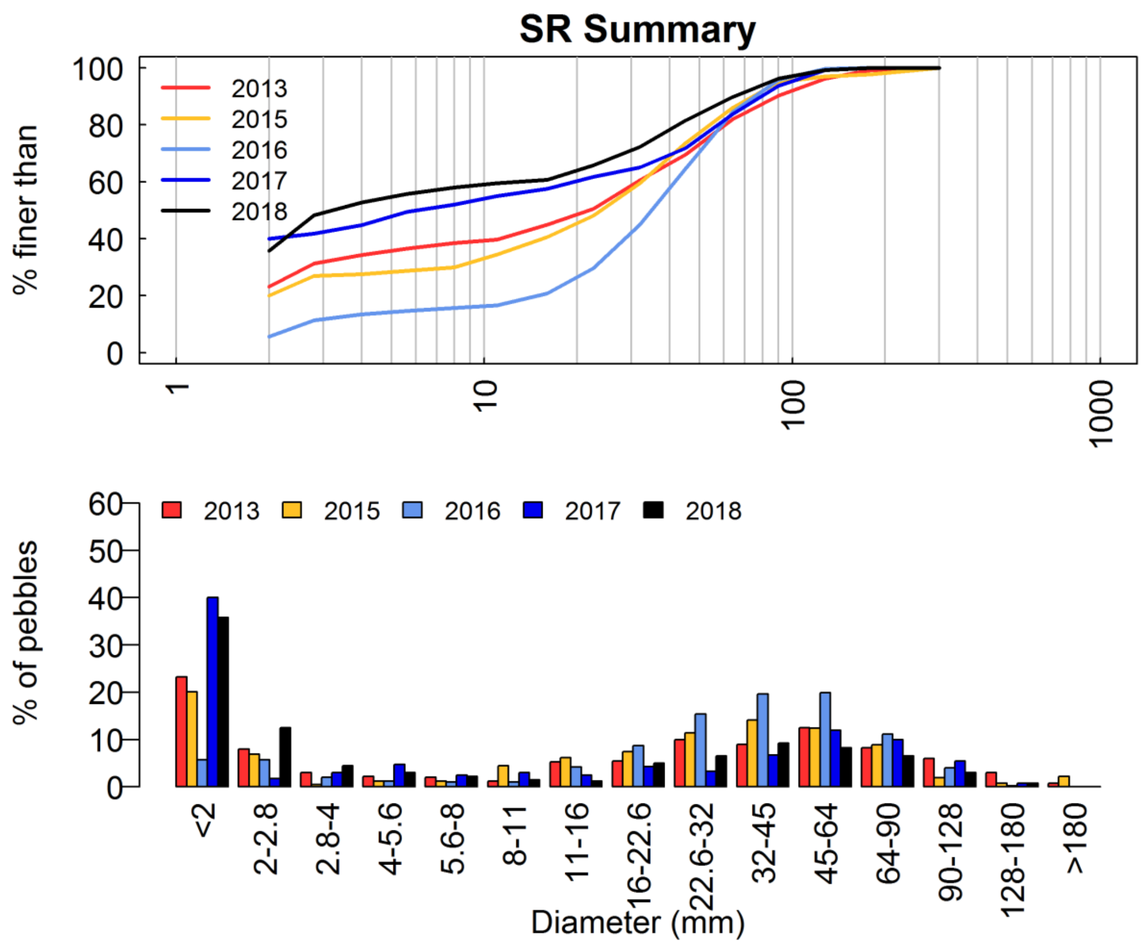

Figure 11. Summary pebble count distribution (SR 1 – SR 4) for the Schulte Road reach displayed as cumulative percentiles (top) and individual bins (bottom) for 2013 to 2018.

Table 5. Summary grain size distribution among cross-sectional transects within the Schulte Road Reach from 2013 to 2018.

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

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 2017 and 2018 except at SC2, where 20 meters of the 5-meter-tall left terrace that had been eroded in 2017 was partially rebuilt and protected by a planted crib wall treatment in 2018 (Appendix A). A 2018 survey of the terrace before restoration shows minimal deviation from data collected in 2017, whereas the 2018 survey conducted after restoration shows the newly restored bank has narrowed the channel by approximately 6 m (Appendix A).

The SC reach saw a small amount of fining in 2018 (Fig. 13). The graphic mean particle size at SC decreased from 8.5 mm in 2017 to 6.0mm in 2018 (Table 6). This fining can be mostly attributed to SC1, which saw increases in sand (<2 mm) and fine gravel between 2 and 2.8mm, as well as an increase in sand at SC4 (Appendix B).

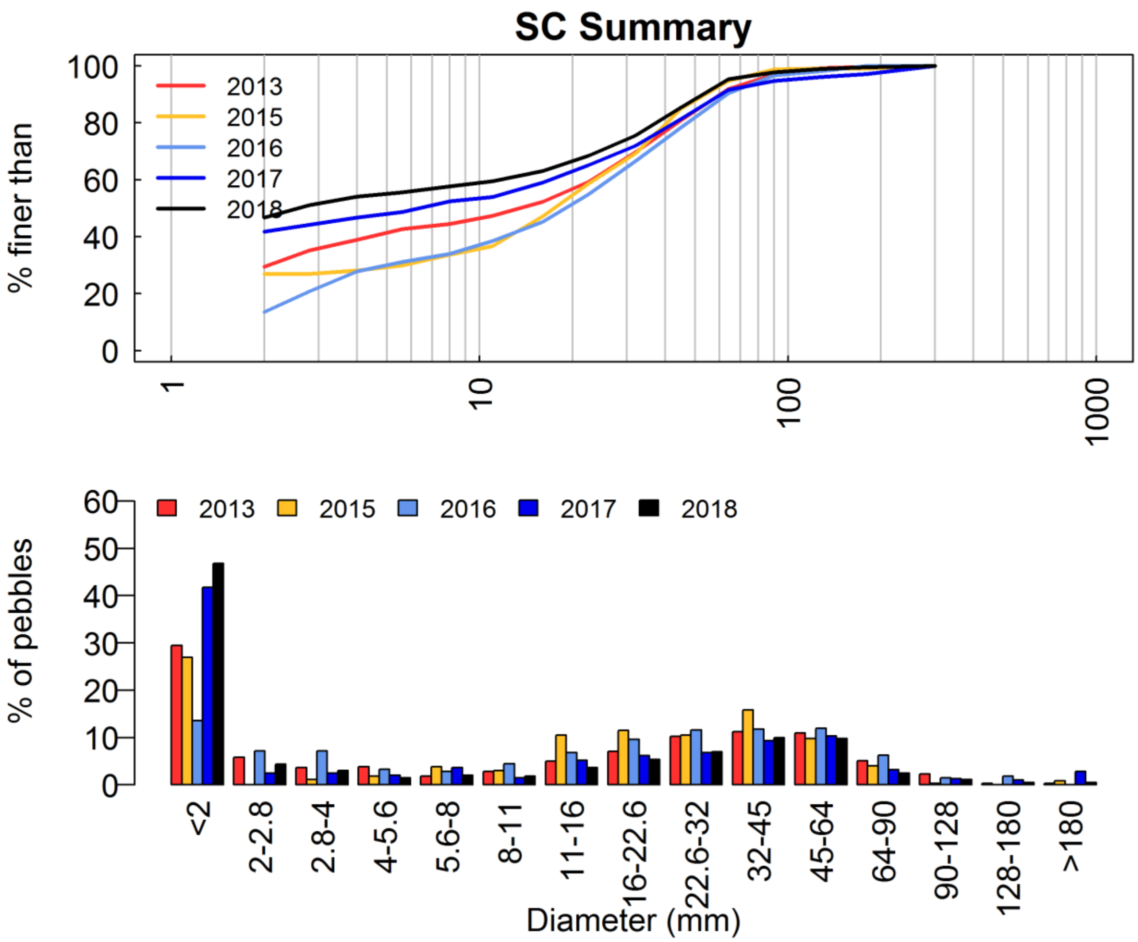

Figure 13. Summary pebble count distribution (SC 1 – SC 6) for the San Carlos reach displayed as cumulative percentiles (top) and individual bins (bottom) for 2013 to 2018.

Table 6. Summary grain size distribution among cross-sectional transects within the San Carlos Reach from 2013 to 2018.

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

3.7 Palo Corona Reach

The Palo Corona Reach is located at the former Rancho Canada golf course, just upstream of Crossroads Shopping Center (Fig. 13). We established four cross sections along the site and collected pebble count data at all four locations.

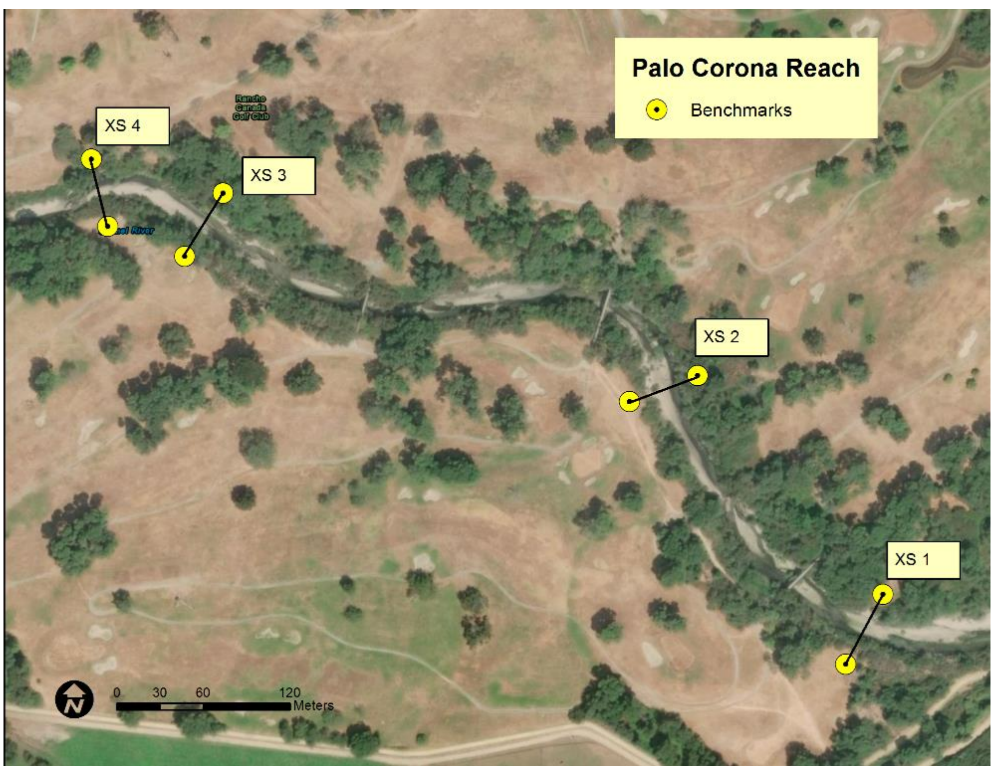

Figure 13. Locations of georeferenced control points and cross sections within the Palo Corona Reach.

The PC reach contains coarser particles than those around it (Figs. 13, 15, 17). It has a graphic mean particle size of 12.9 mm (Table 7), while SC, not far upstream of it has 6.0 mm (Table 6) and CRO, not far downstream of it has 4.2mm (Table 8). PC4 shows the highest percentage of sand in the reach, while PC2 shows the highest percentage of cobbles (Appendix B).

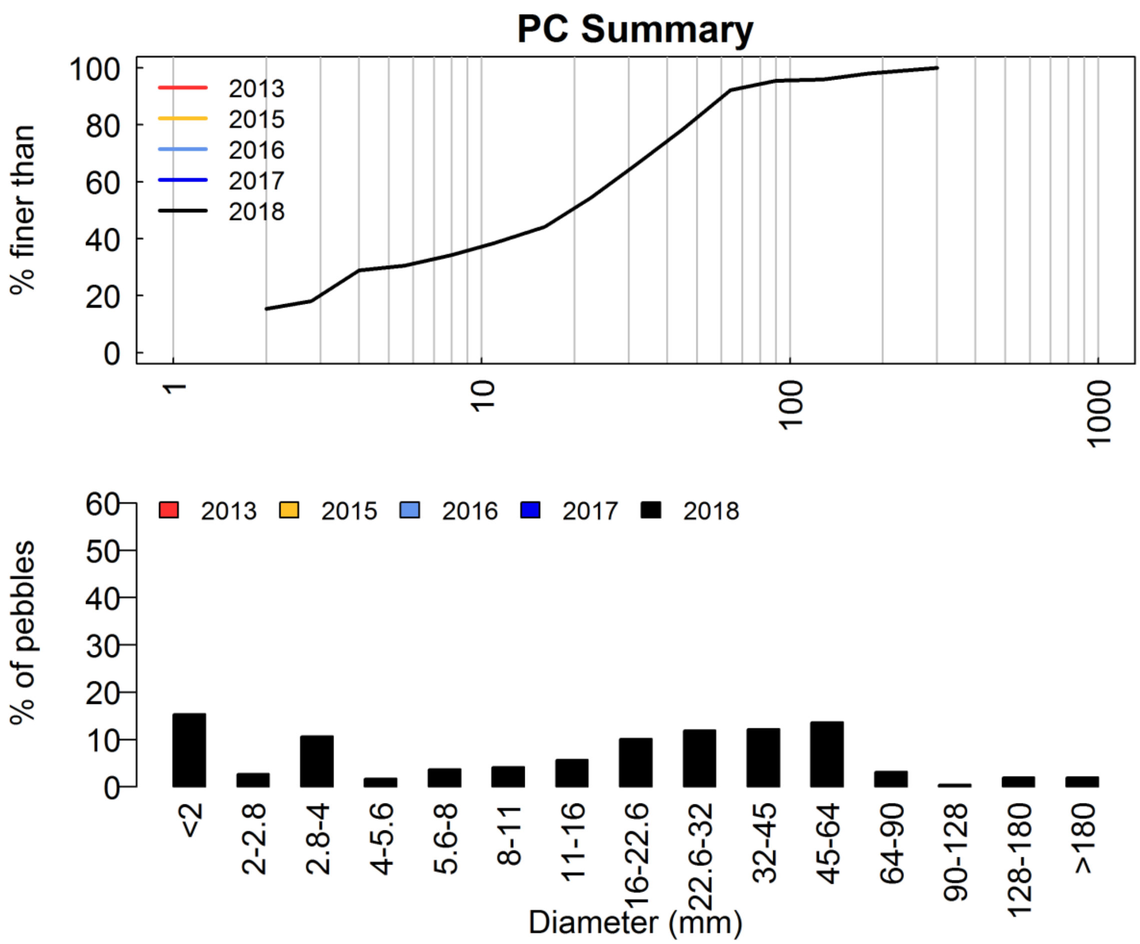

Figure 14. Summary pebble count distribution (PC 1 – PC 6) for the Palo Corona reach displayed as cumulative percentiles (top) and individual bins (bottom) for 2013 to 2018.

Table 7. Summary grain size distribution among cross-sectional transects within the Palo Corona Reach from 2013 to 2018.

Reach	Quantile	2018
PC	D5	2.0
	D16	2.1
	D50	19.4
	D84	51.7
	D95	85.2
	Graphic mean	12.9

3.8 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.

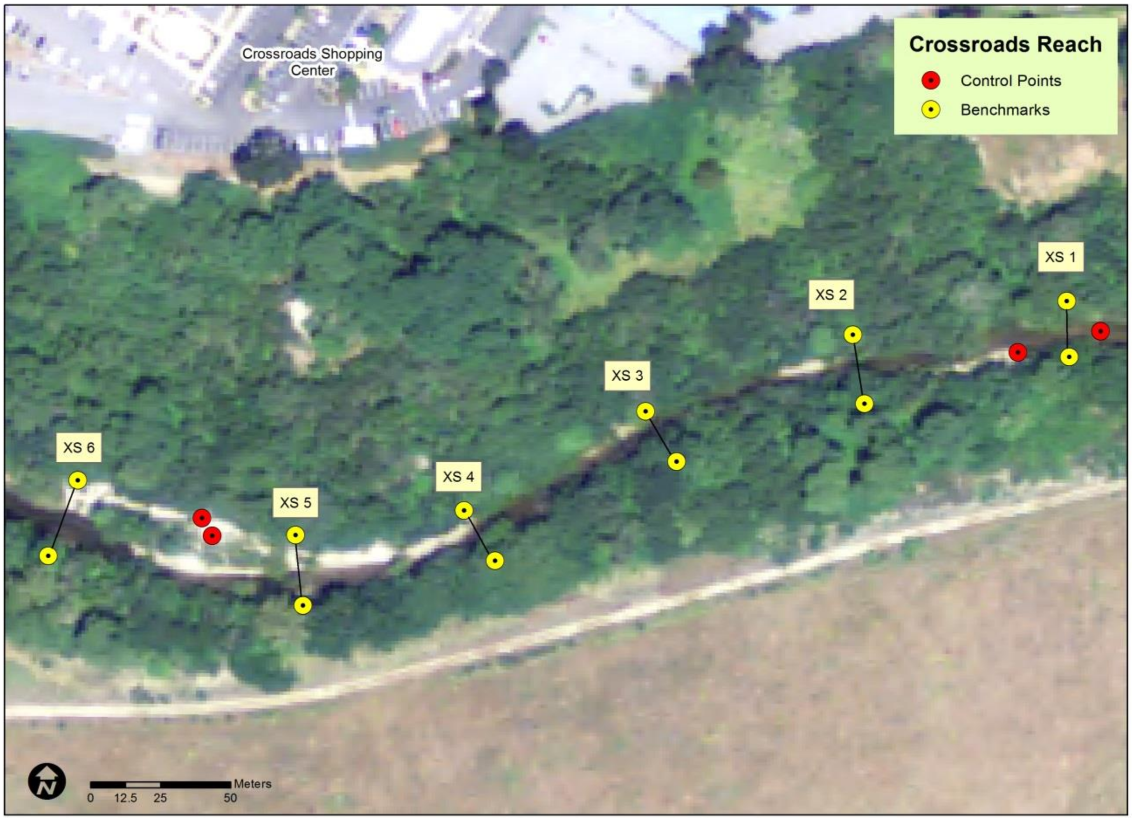

Figure 15. Locations of georeferenced control points and cross sections within the Crossroads Reach.

Minor deposition occurred at CRO1 since 2017 and CRO6 experienced nearly no changes between 2017 and 2018 surveys (Appendix A). Significant erosional changes between 2016 and 2018 at sites CRO2 through CRO5 likely occurred in water year 2017, although cross sectional data were not collected for these sites in 2017 because the benchmarks were either buried by large wood accumulations or lost through bank erosion. New benchmarks were established for those sites in 2018.

The CRO reach experienced an increase in fines less than 4mm (Figure 16). The graphic mean particle size decreased from 6.7mm in 2017 to 4.2mm in 2018 (Table 8). A very large increase in sand (<2 mm) was seen at CRO2, with 2018 pebble count measuring over 80% sand (Appendix B).

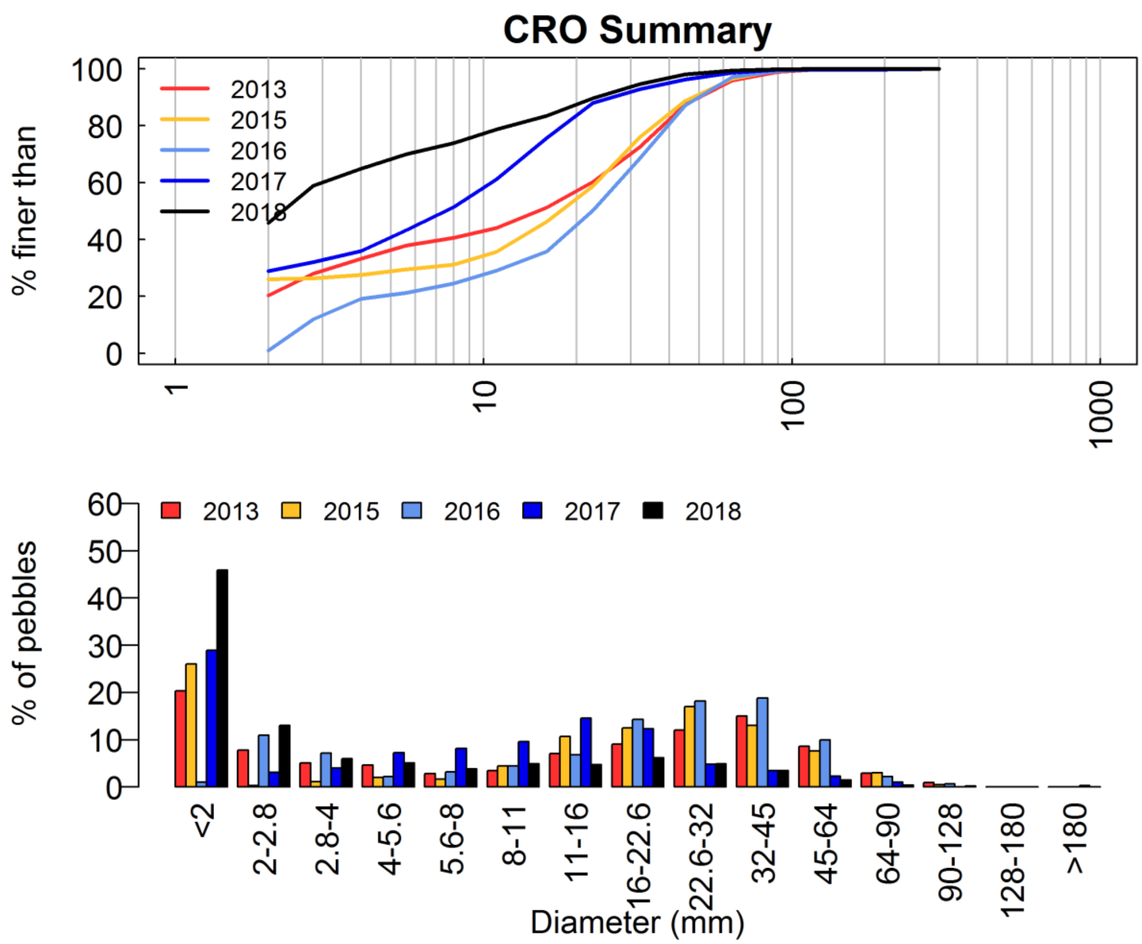

Figure 16. Summary pebble count distribution (CRO 1 – CRO 6) for the Crossroads reach displayed as cumulative percentiles (top) and individual bins (bottom) for 2013 to 2018.

Table 8. Summary grain size distribution among cross-sectional transects within the Crossroads Reach from 2013 to 2018 . 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
CR	D5	2.0	2.0	2.3	2.0	2.0
	D16	2.0	2.0	3.4	2.0	2.0
	D50	15.0	17.7	22.5	7.5	2.2
	D84	41.6	39.6	42.5	20.2	16.5
	D95	61.3	59.7	59.3	39.5	33.4
	Graphic mean	10.8	11.2	14.8	6.7	4.2

4 Discussion

This report is part of a multi-year effort to describe sediment transport and geomorphic changes in the Carmel River following the removal of the San Clemente dam in 2015. The 2018 survey found minimal changes in channel morphology but more noticeable changes in substrate size. Cross sections that were not surveyed in 2017 and were re-established in 2018 showed changes similar to those experienced by other cross sections in their reaches in 2017. These changes likely took place in 2017 but were not captured until 2018 surveys.

In general, the below-dam channel of the Carmel River continued to receive fine particles from the upper reaches of the river (overall fining trend), and retained sediment delivered in 2017 (pools remained full). The graphic mean grain size fell at all sites below the dam removal site. The fining trend began in the post-dam era, following the high flows of 2017 and continued through the current year, so it can likely be ascribed to dam removal (Figs. 16 and 17).

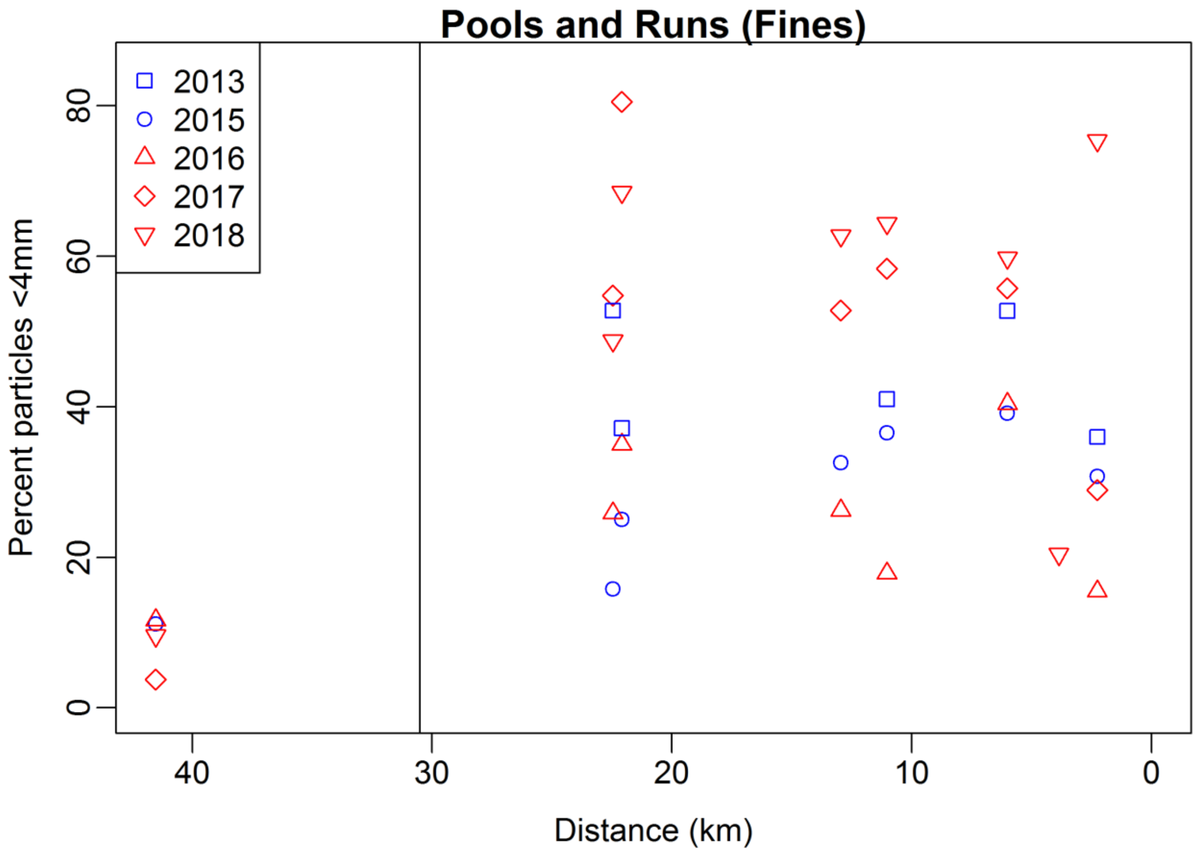

Figure 16. Percent of particles with diameter <4mm in morphological units of pools and runs as a function of year and distance upstream of the Carmel River mouth. Data points in blue show surveys conducted before dam removal, and those in red show surveys conducted after dam removal. A line shows the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

The large influx of fines deposited below the dam in 2017 moved further downstream, with percentages increasing at the four downstream sites with records from previous years (CRO, SC, SR, BW,) and decreasing at the two sites closer to the dam (DDU, DDL.) The new Palo Corona reach stands out as having a significantly lower percentage of fines than the sites around it, possibly explained by its lack of flood accommodation space, which would tend to amplify the shear-stress achieved by high magnitude flows. The Los Padres reach continued to lose fines.

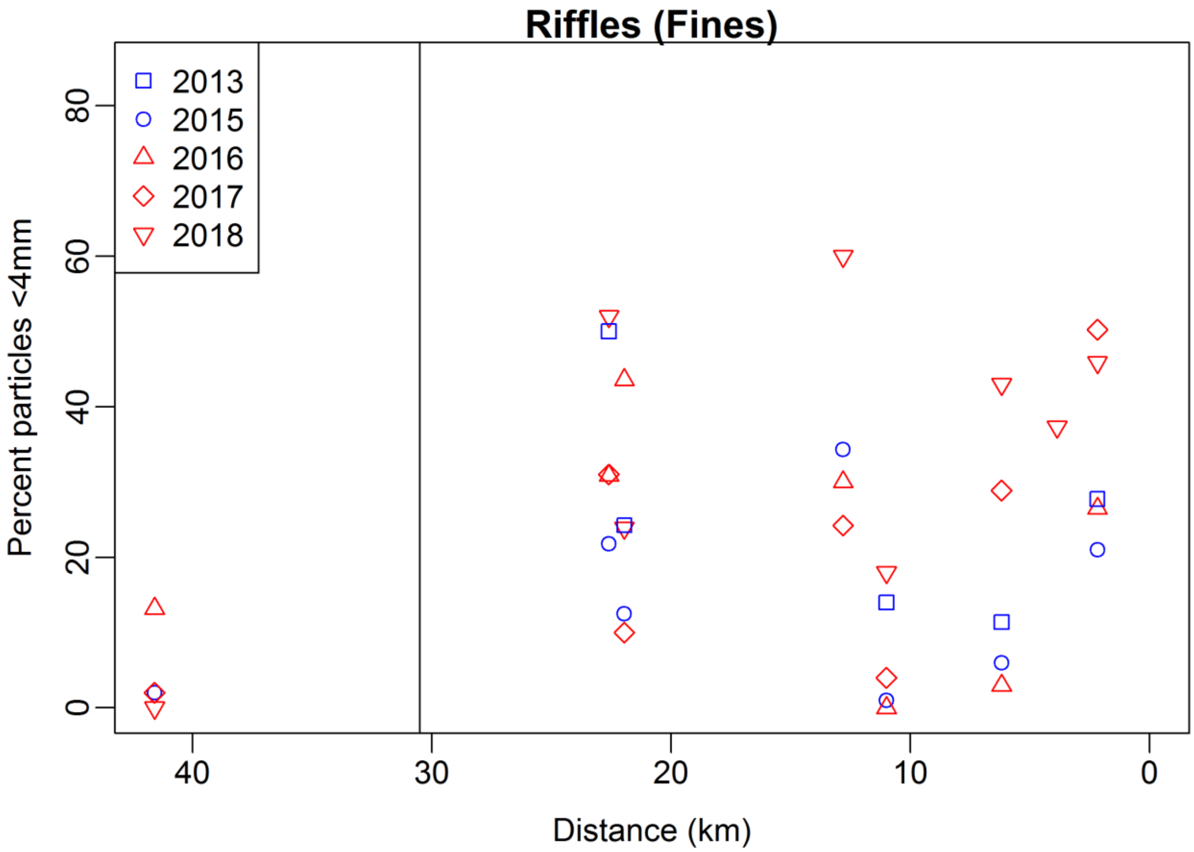

Figure 17. Percent of particles with diameter <4 mm in riffle morphological units as a function of year and distance upstream of the Carmel River mouth. Data points in blue show surveys conducted before dam removal, and those in red show surveys conducted after dam removal. A line shows the location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

The percentage of fines was 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 was less visible in riffles than in pools and runs, but could still be seen at BW, SR, and SC (Fig. 17).

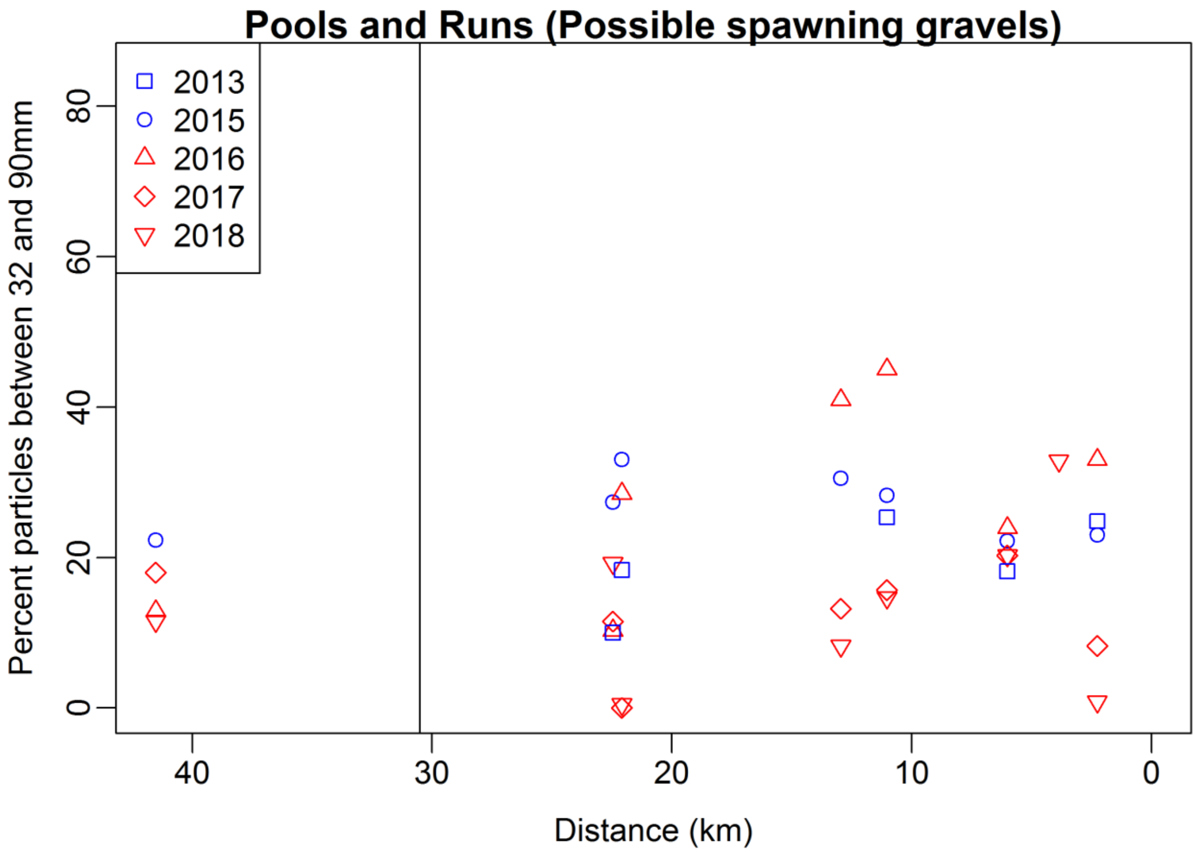

Figure 18. Percent of particles with diameter between 32 and 90 mm in morphological units of pools and runs as a function of year and distance upstream of the Carmel River mouth. Data points in blue show surveys conducted before dam removal, and those in red show surveys conducted after dam removal. 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 also manifested itself in a decrease in possible spawning gravels in pools and runs (Fig. 18). This pattern was seen at BW, SR, and CRO. There was an increase in these particles at DDU, as fines washed out of the pools and runs.

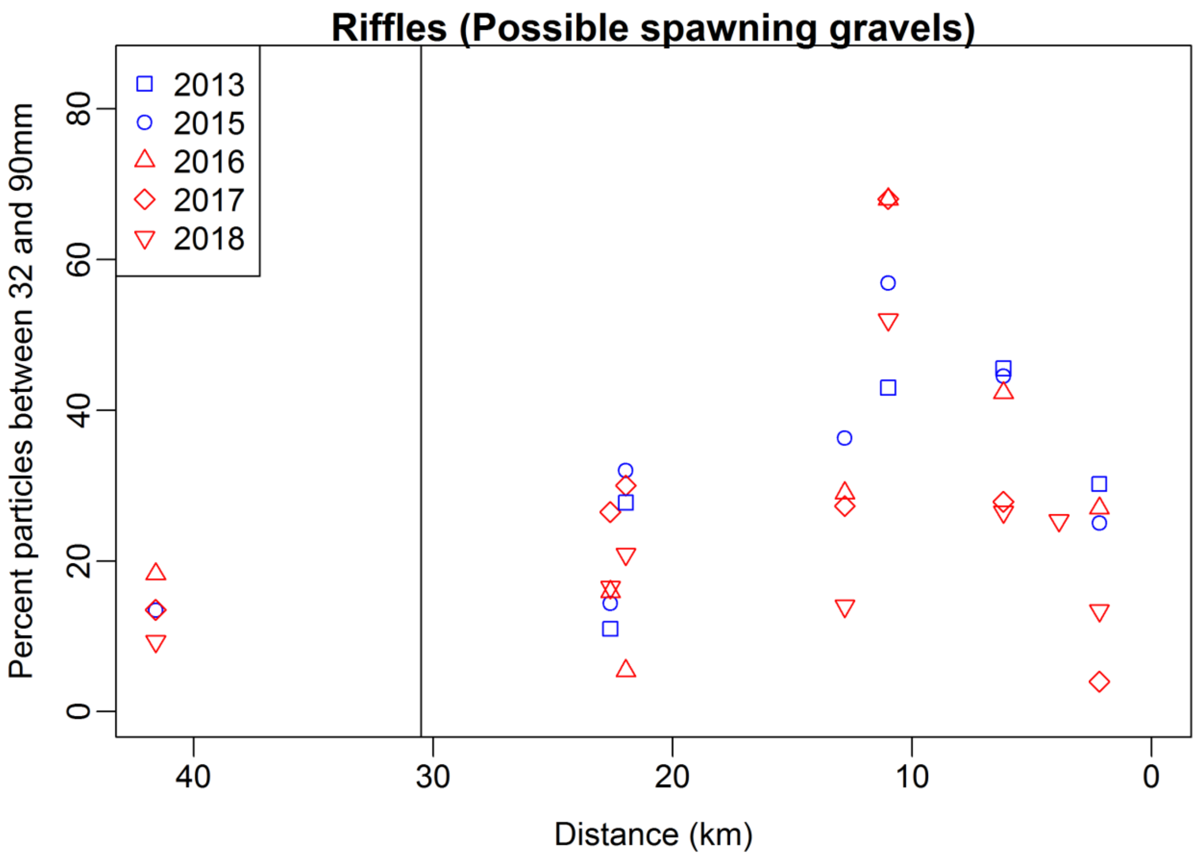

Figure 19. Percent of particles with diameter between 32 and 90mm in riffle morphological units as a function of year and distance upstream of the Carmel River mouth. Data points in blue show surveys conducted before dam removal, and those in red show surveys conducted after dam removal. A line shows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

Changes were less consistent in spawning gravels in riffles. BW and SR showed decreases, likely due to an influx in fines. The decrease at DDL is consistent with the increase in fines seen at riffles at that site. CRO showed an increase and SC experienced very little change.

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.

5 References

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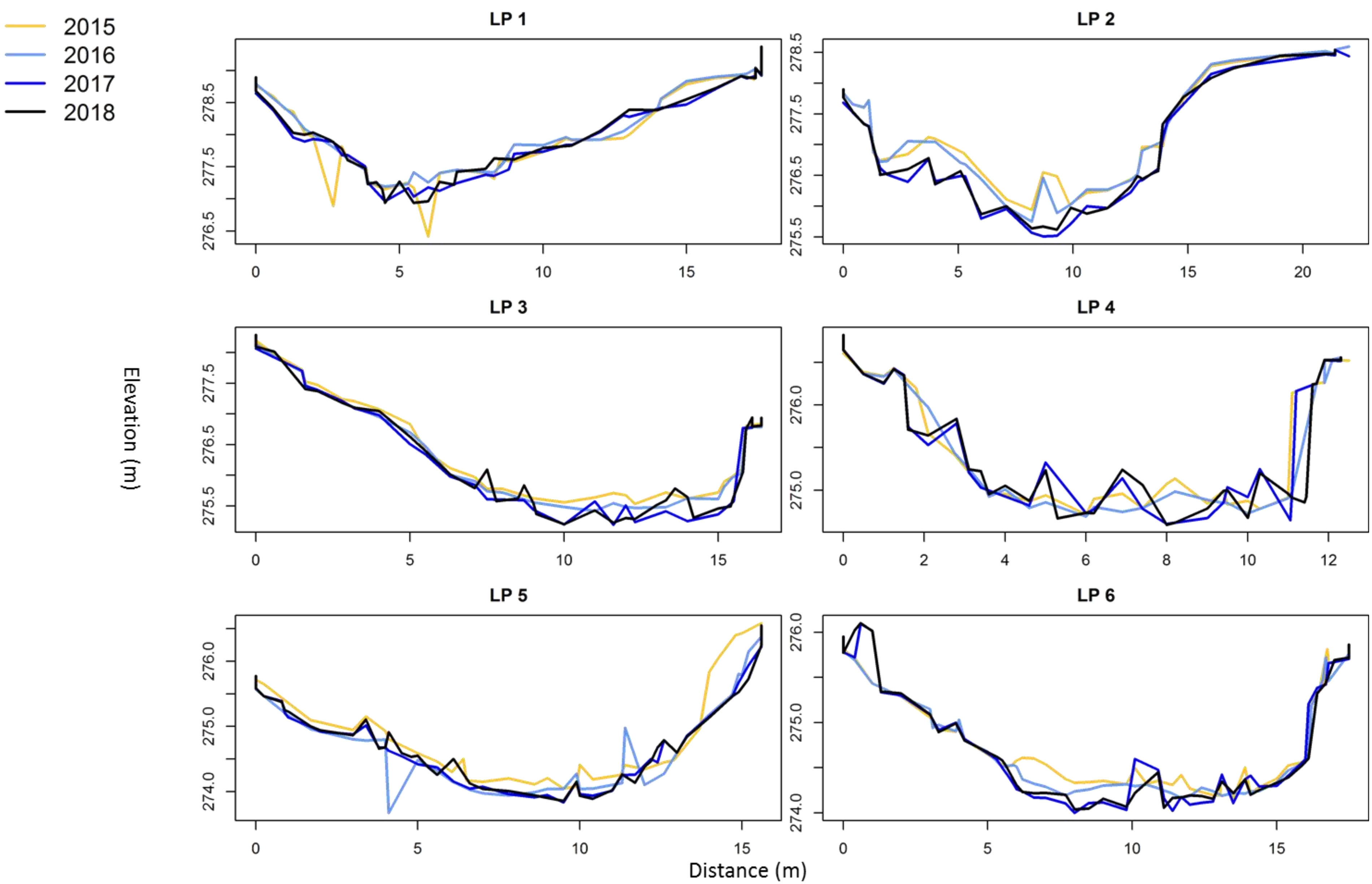
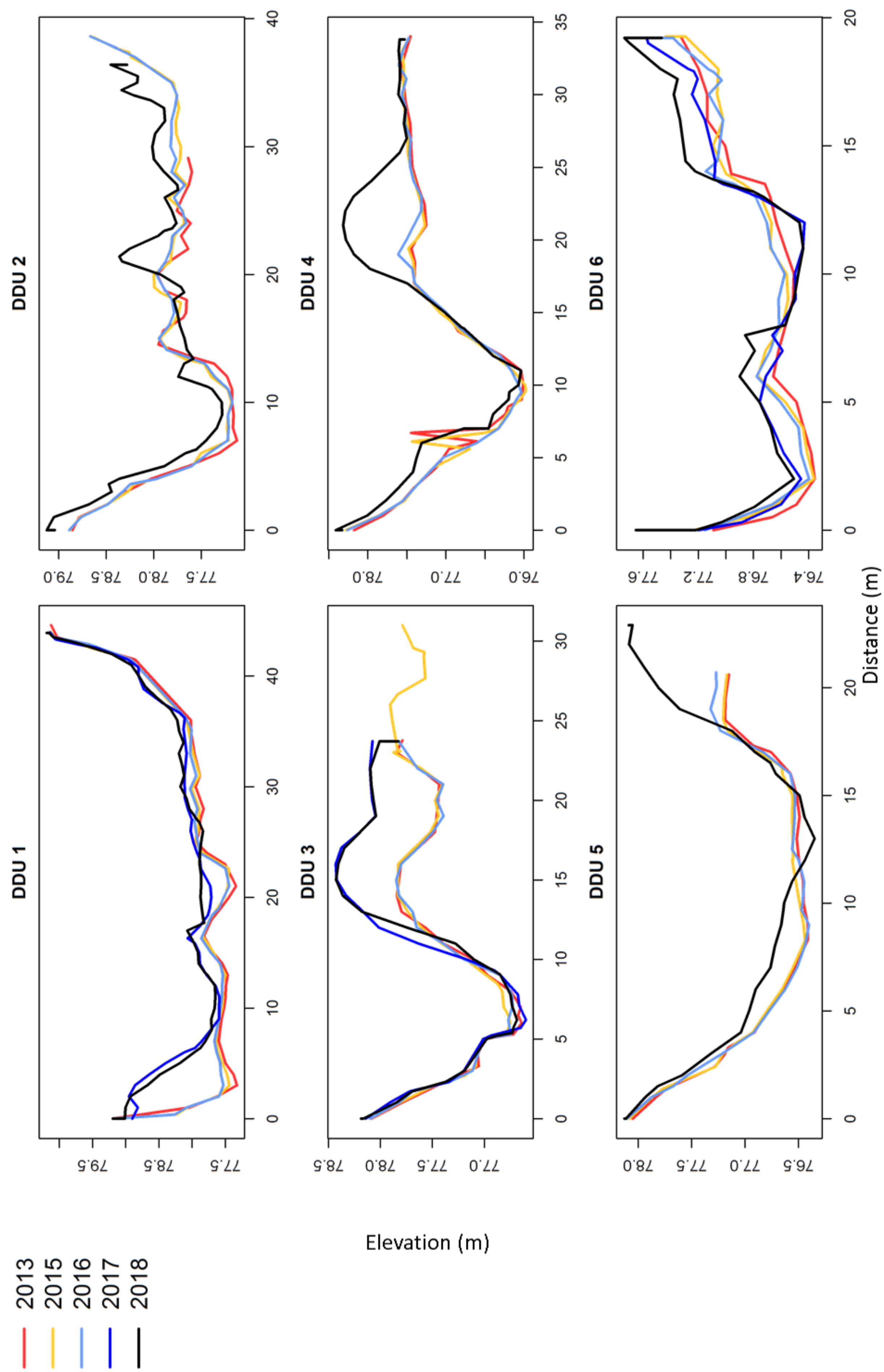
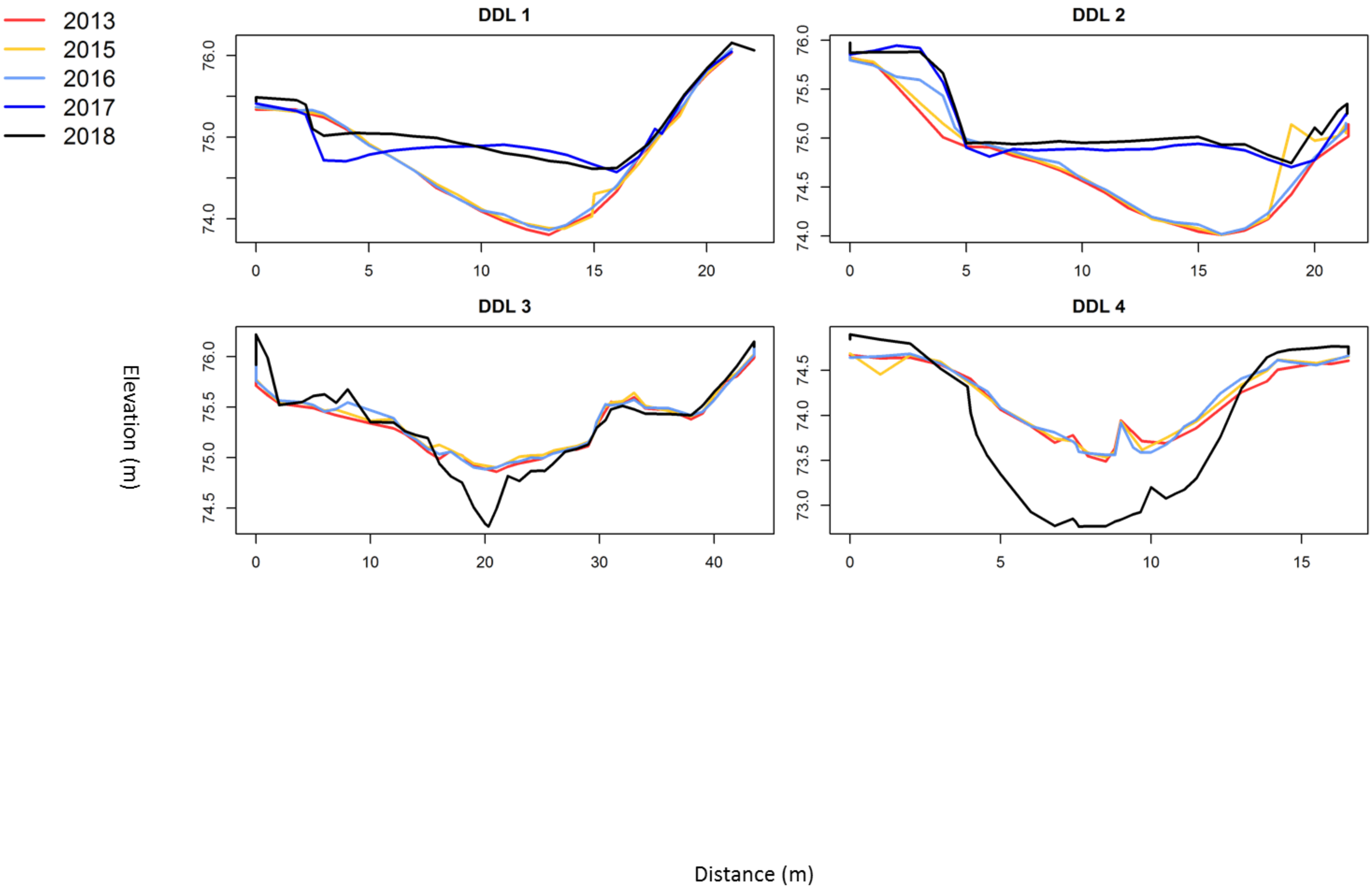
6 Appendix A: Cross Sections

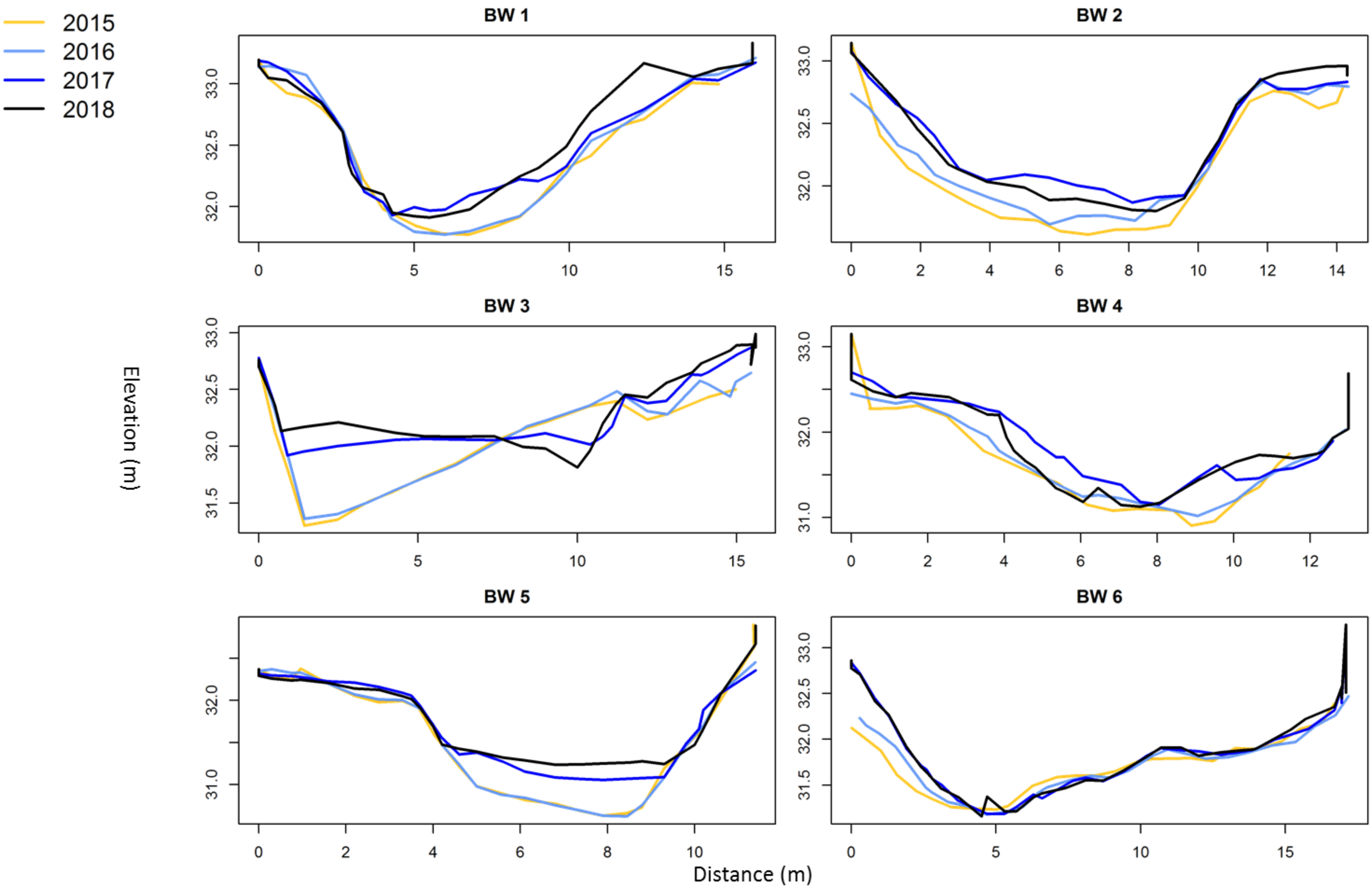
Channel geometry for each cross section surveyed within each reach. Cross sections are denoted by their reach abbreviation (LP, DDU, DDL, BW, SR, SC, PC, and CR) and transect number descending from upstream to downstream (1 to 4 or 6).

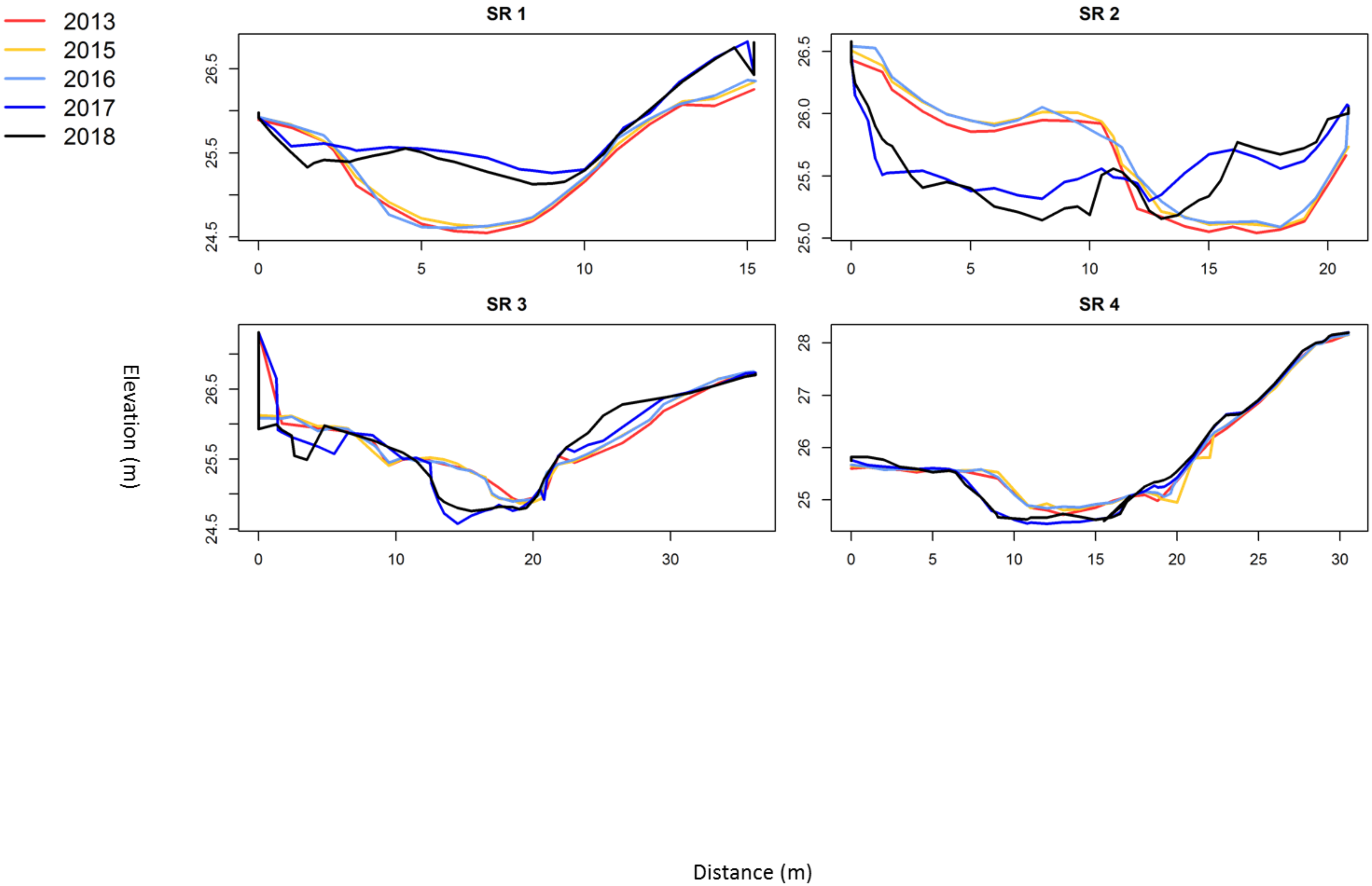

2015
2016
2017
2018
LP 1
LP 2
LP 3
LP 4
LP 5
LP 6
Elevation (m)
Distance (m)

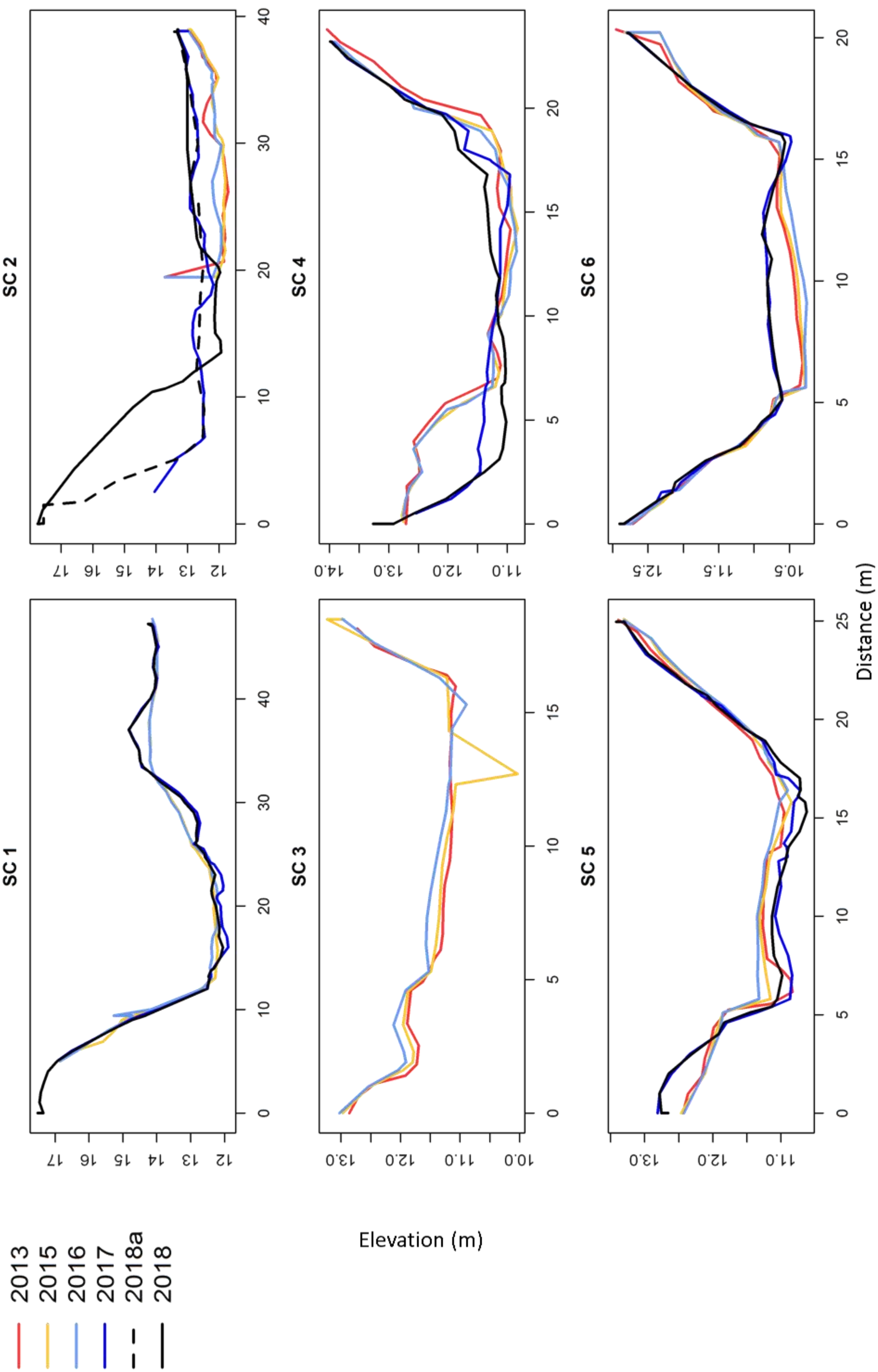


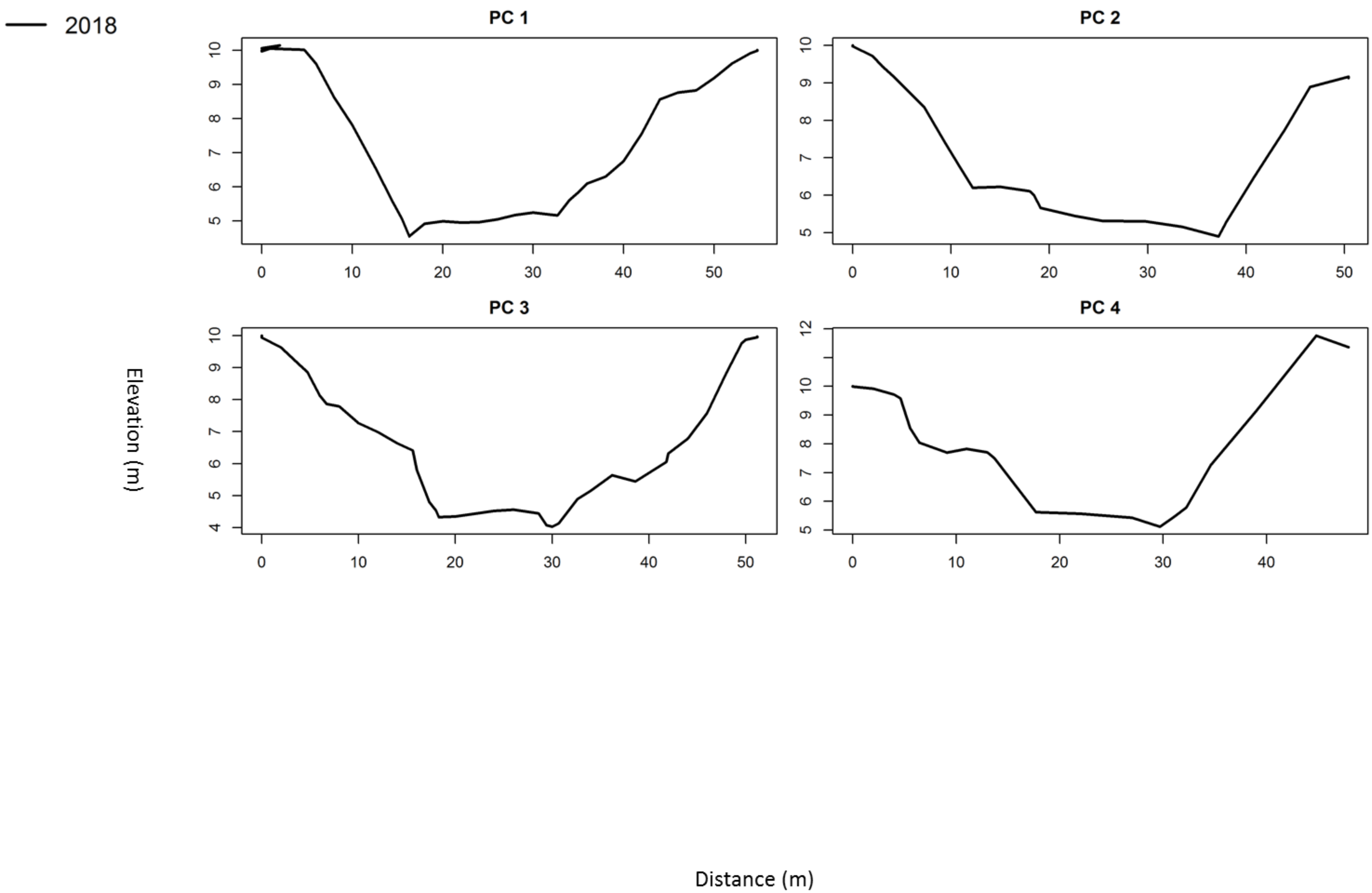
DDU 1
DDU 2
DDU 3
DDU 4
DDU 5
DDU 6
Elevation (m)
Distance (m)
2013
2015
2016
2017
2018

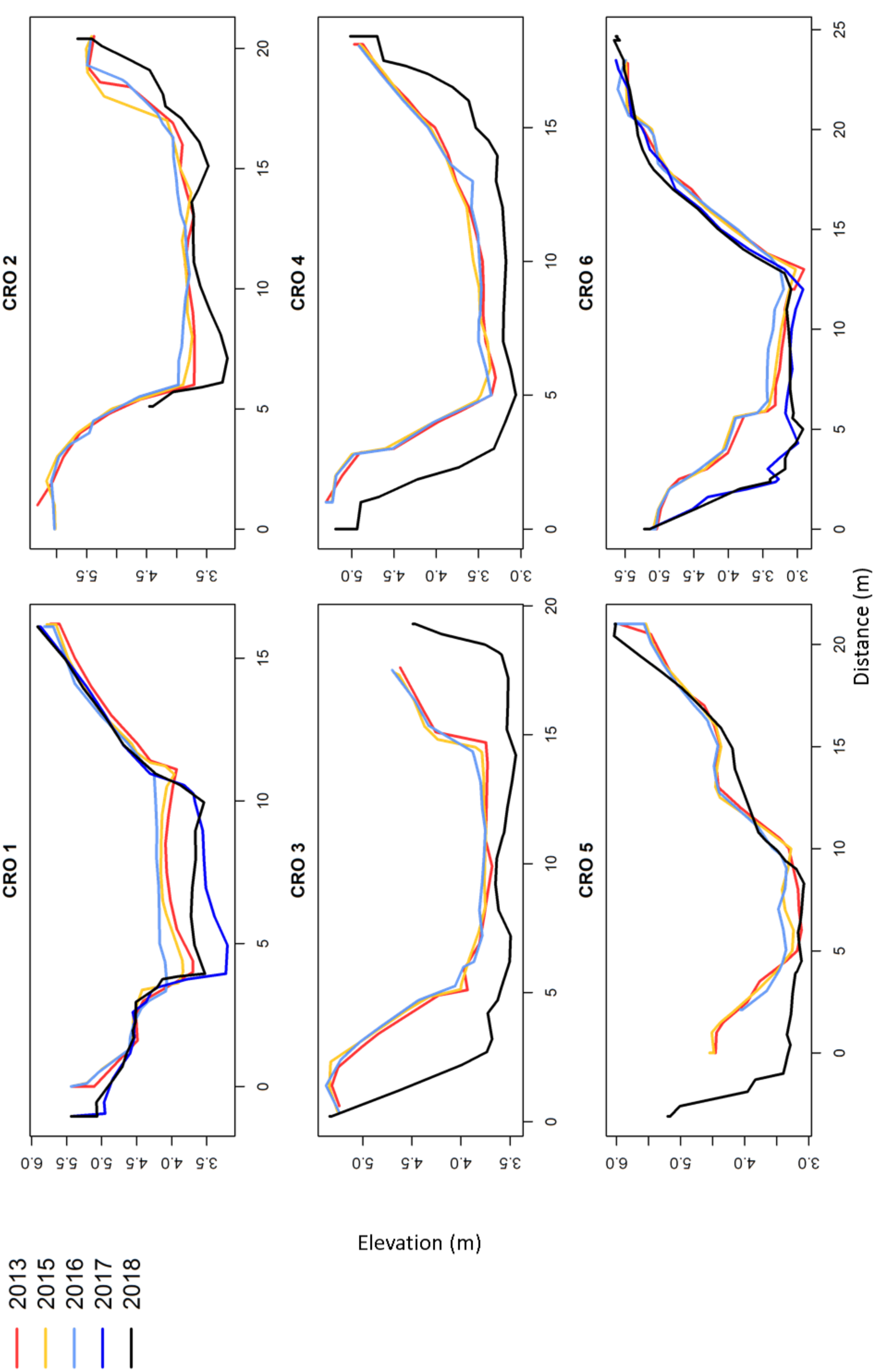

2013
2015
2016
2017
2018
DDL 1
DDL 2
DDL 3
DDL 4
Elevation (m)
Distance (m)


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


2013
2015
2016
2017
2018
SR 1
SR 2
SR 3
SR 4
Elevation (m)
Distance (m)

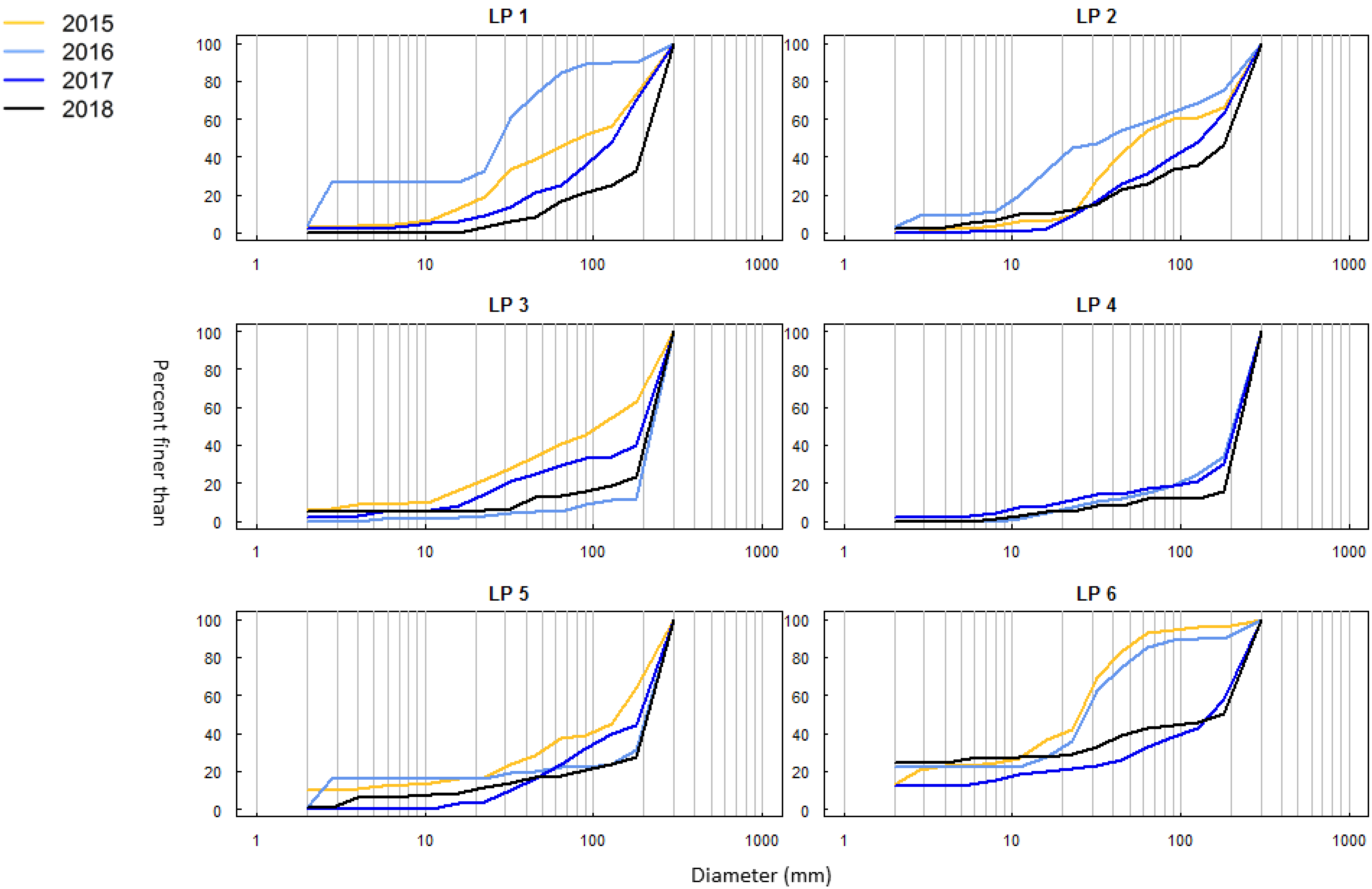

SC 1
SC 2
SC 3
SC 4
SC 5
SC 6
Elevation (m)
Distance (m)
2013
2015
2016
2017
2018a
2018


2018
PC 1
PC 2
PC 3
PC 4
Elevation (m)
Distance (m)

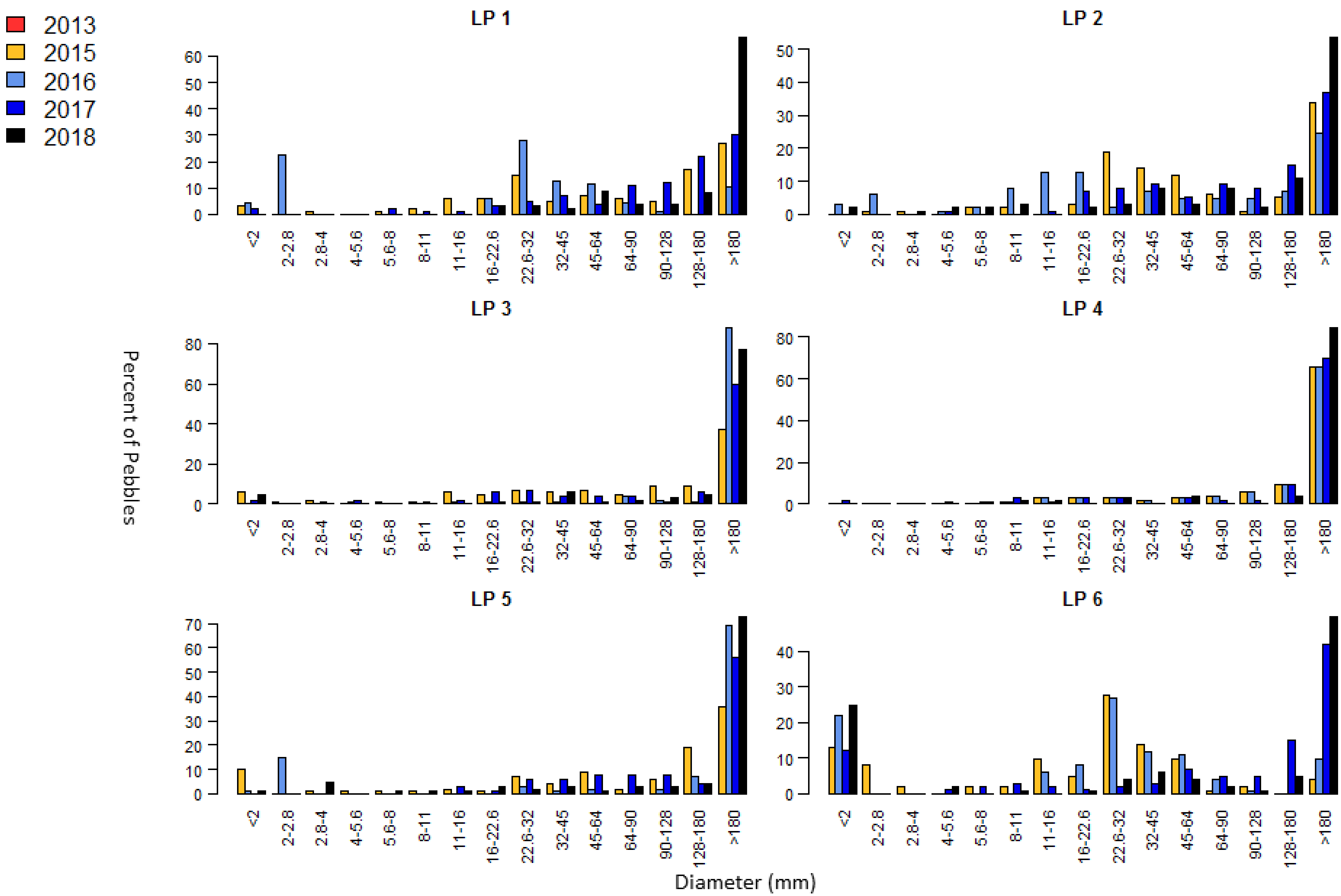

CRO 1
CRO 2
CRO 3
CRO 4
CRO 5
CRO 6
Elevation (m)
Distance (m)
2013
2015
2016
2017
2018

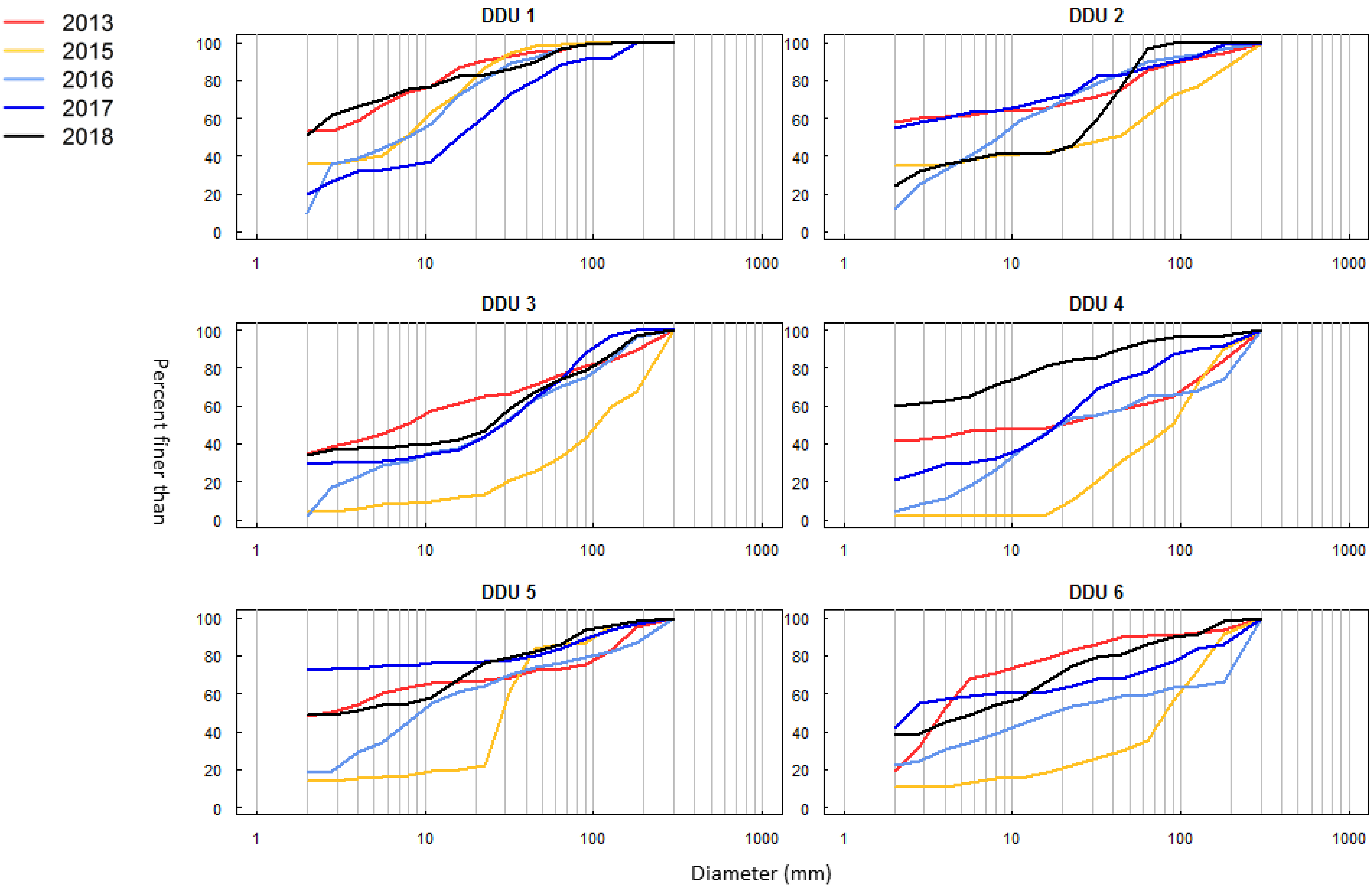
7 Appendix B: Pebble Count Plots

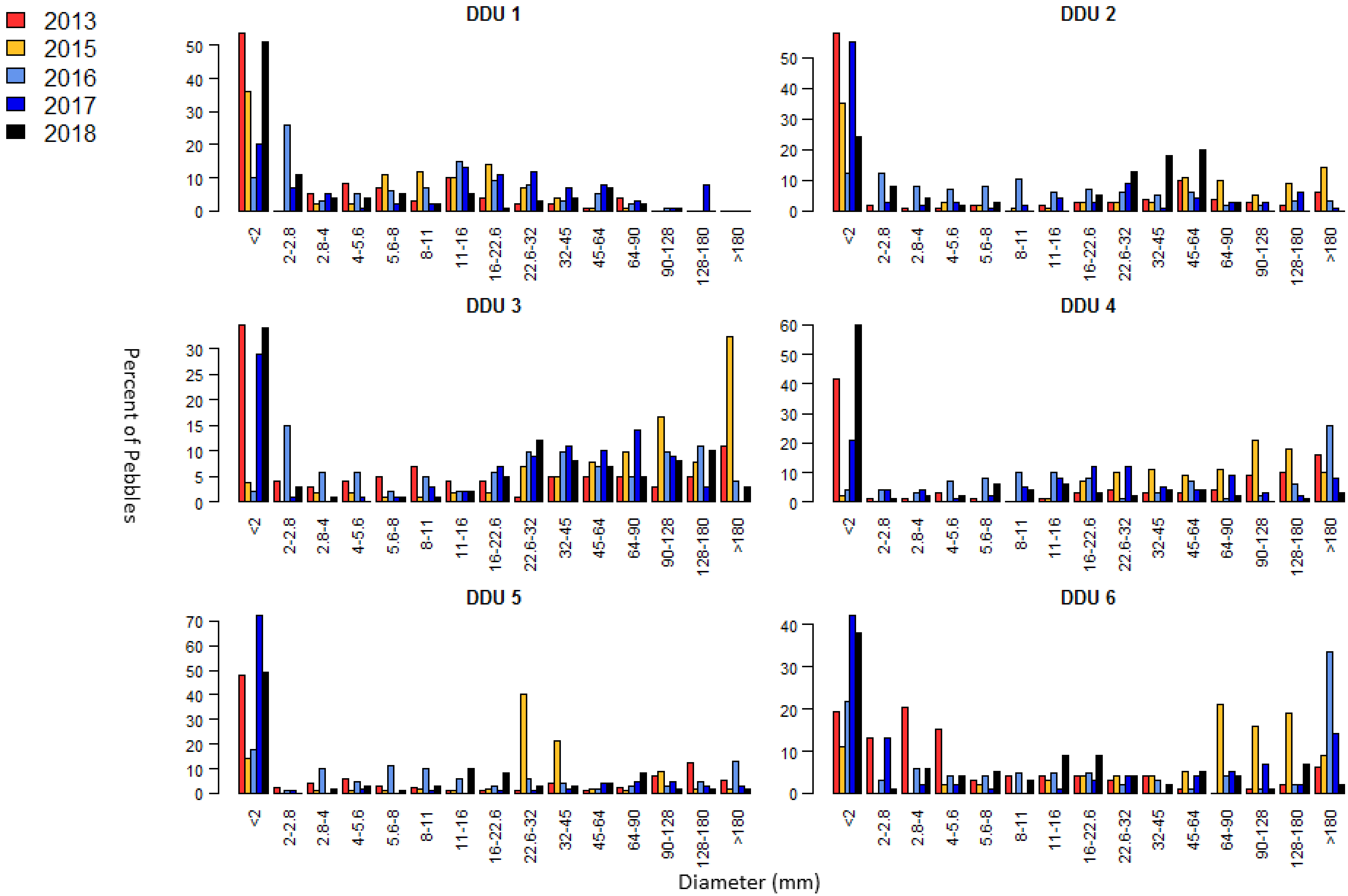
Channel pebble counts for each cross section within each reach. Reaches are denoted by their reach abbreviation (LP, DDU, DDL, BW, SR, SC, PC, and CR) and transect number descending from upstream to downstream (1 to 4 or 6).

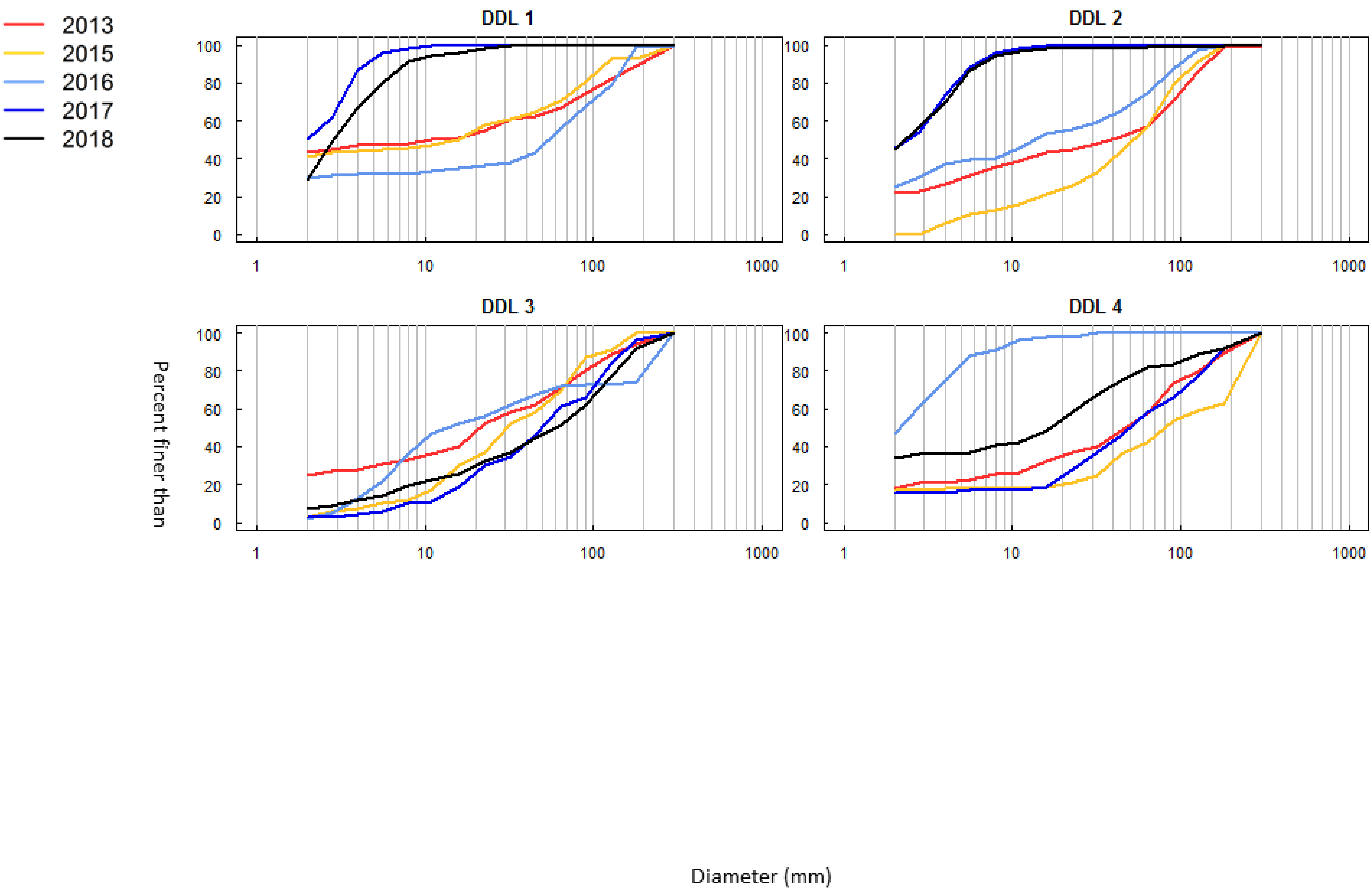


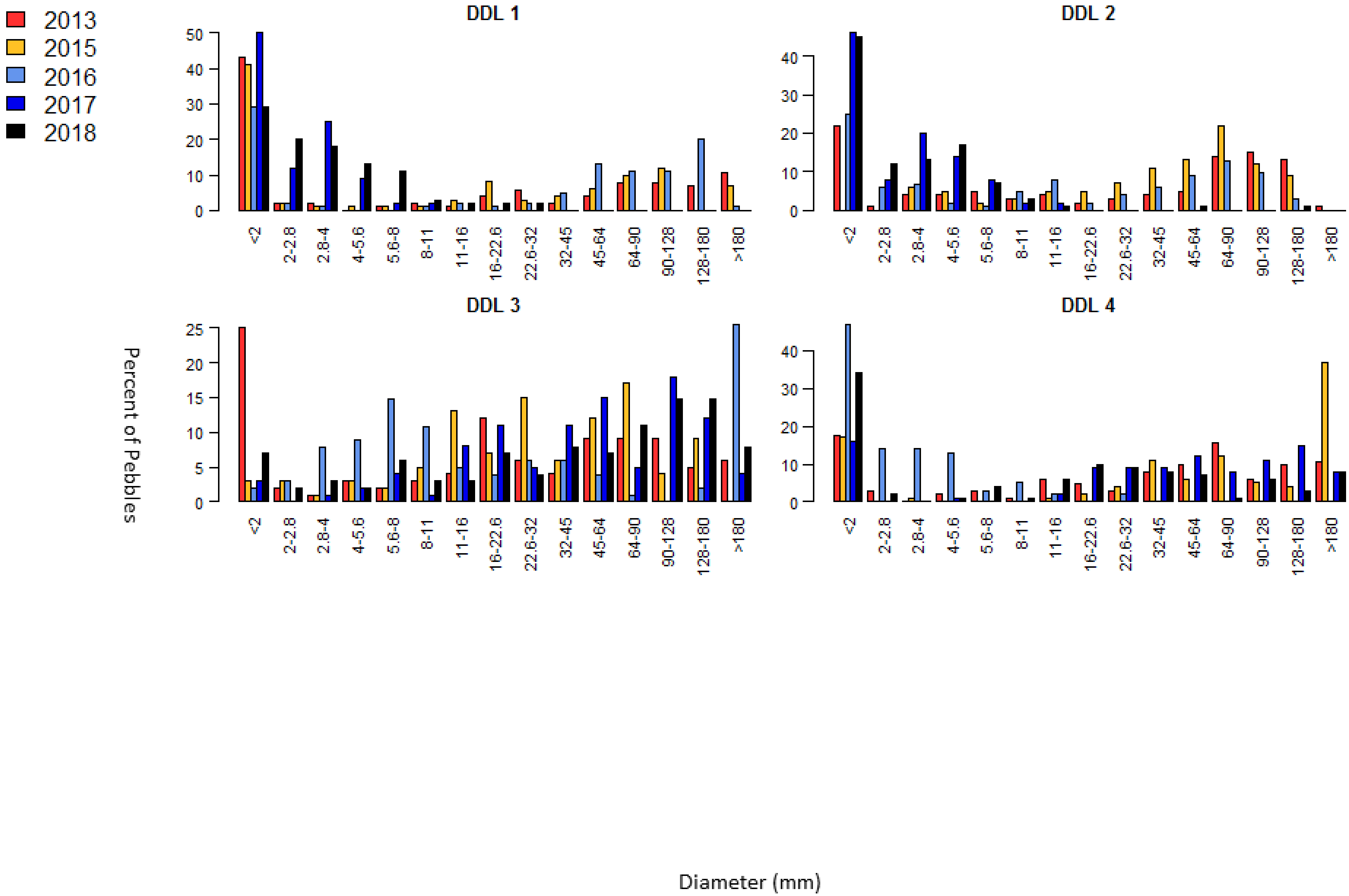
2015
2016
2017
2018
LP 1
LP 2
LP 3
LP 4
LP 5
LP 6
Percent finer than
Diameter (mm)

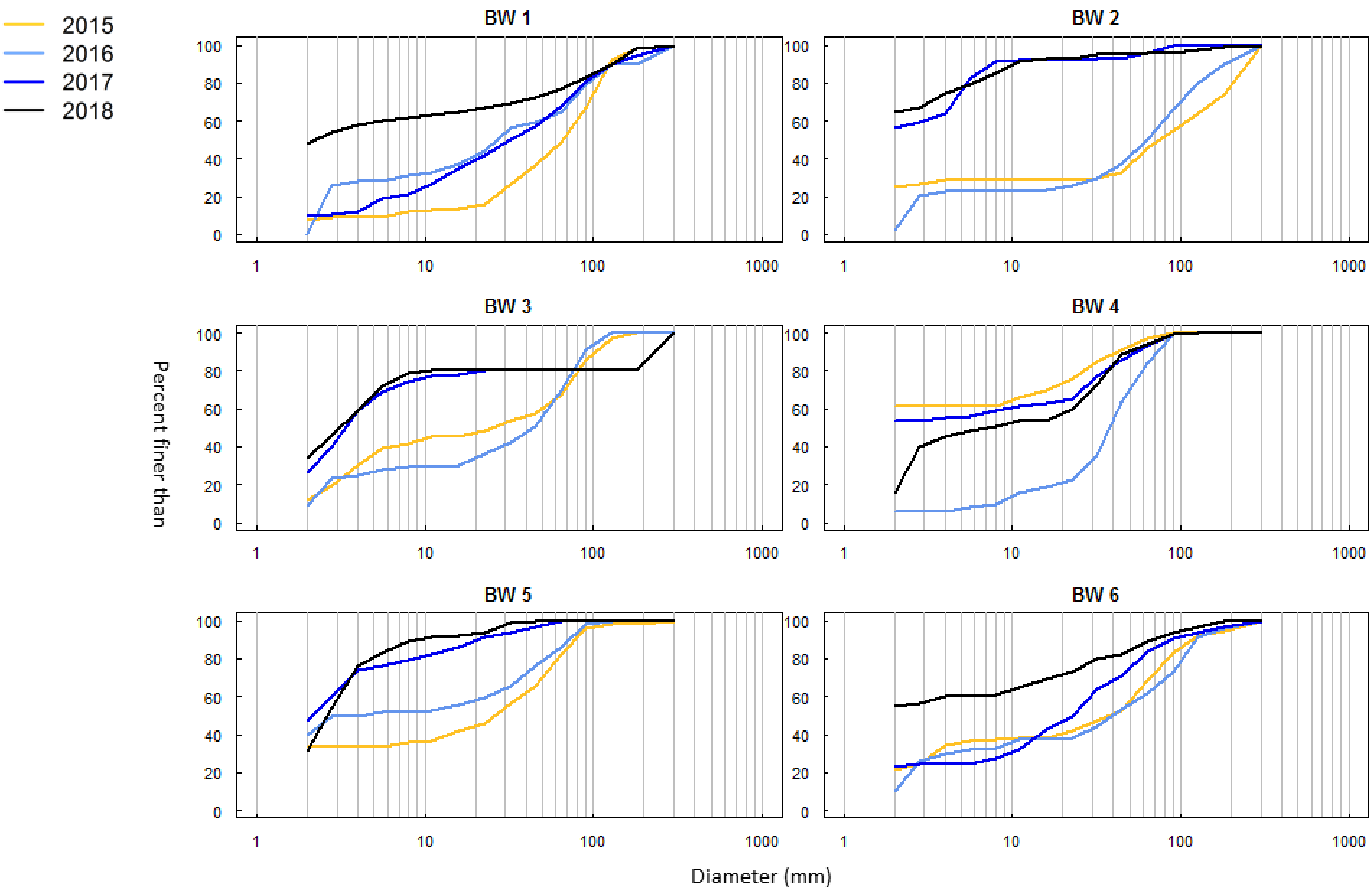

2013
2015
2016
2017
2018
LP 1
LP 2
LP 3
LP 4
LP 5
LP 6
Percent of Pebbles
Diameter (mm)
<2
2-2.8
2.8-4
4-5.6
5.6-8
8-11
11-16
16-22.6
22.6-32
32-45
45-64
64-90
90-128
128-180
>180

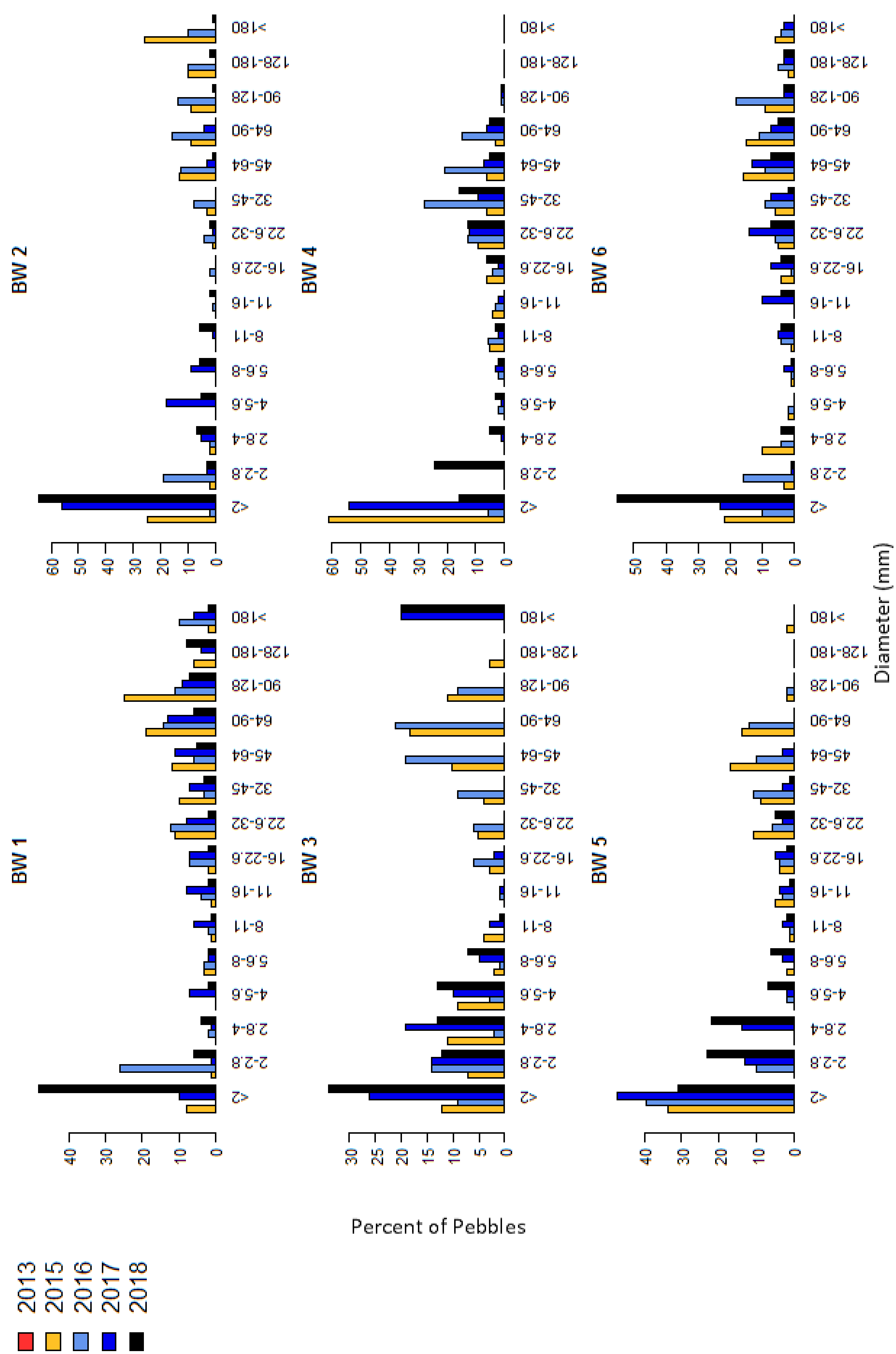

2013
2015
2016
2017
2018
DDU 1
DDU 2
DDU 3
DDU 4
DDU 5
DDU 6
Percent finer than
Diameter (mm)
0
20
40
60
80
100
1
10
100
1000

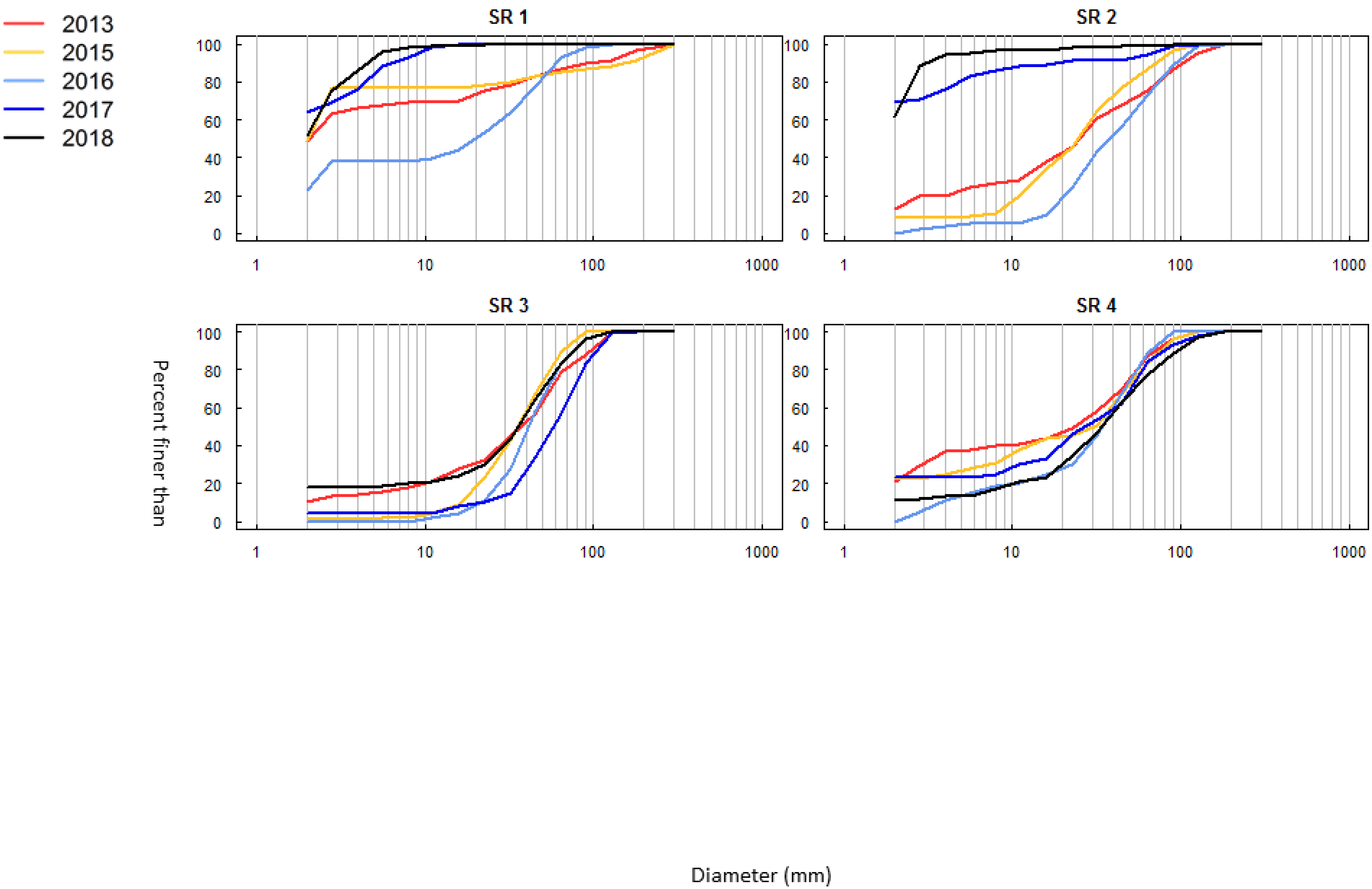

2013
2015
2016
2017
2018
DDU 1
DDU 2
DDU 3
DDU 4
DDU 5
DDU 6
Percent of Pebbles
Diameter (mm)
<2
2-2.8
2.8-4
4-5.6
5.6-8
8-11
11-16
16-22.6
22.6-32
32-45
45-64
64-90
90-128
128-180
>180

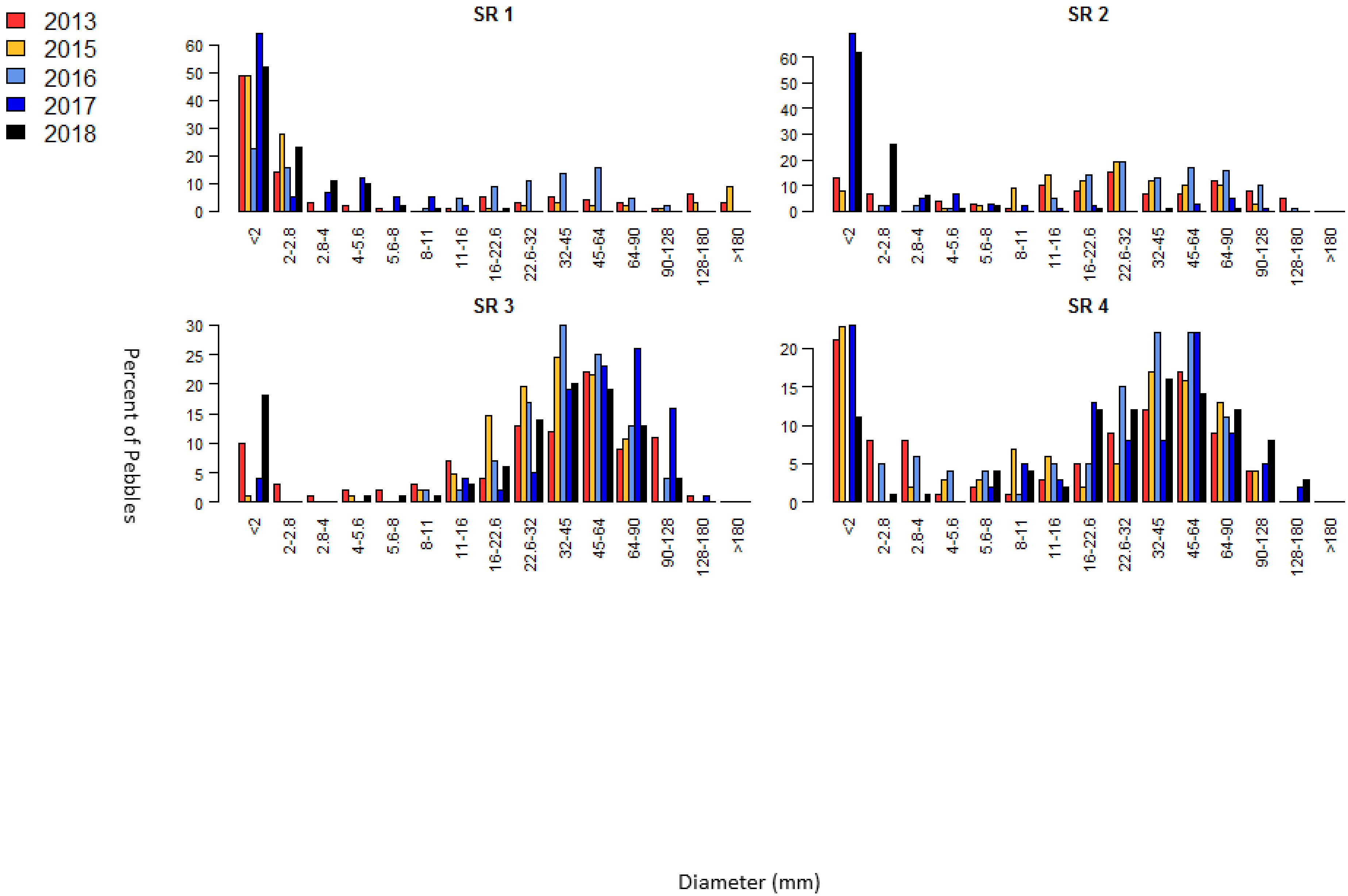

2013
2015
2016
2017
2018
DDL 1
DDL 2
DDL 3
DDL 4
Percent finer than
Diameter (mm)

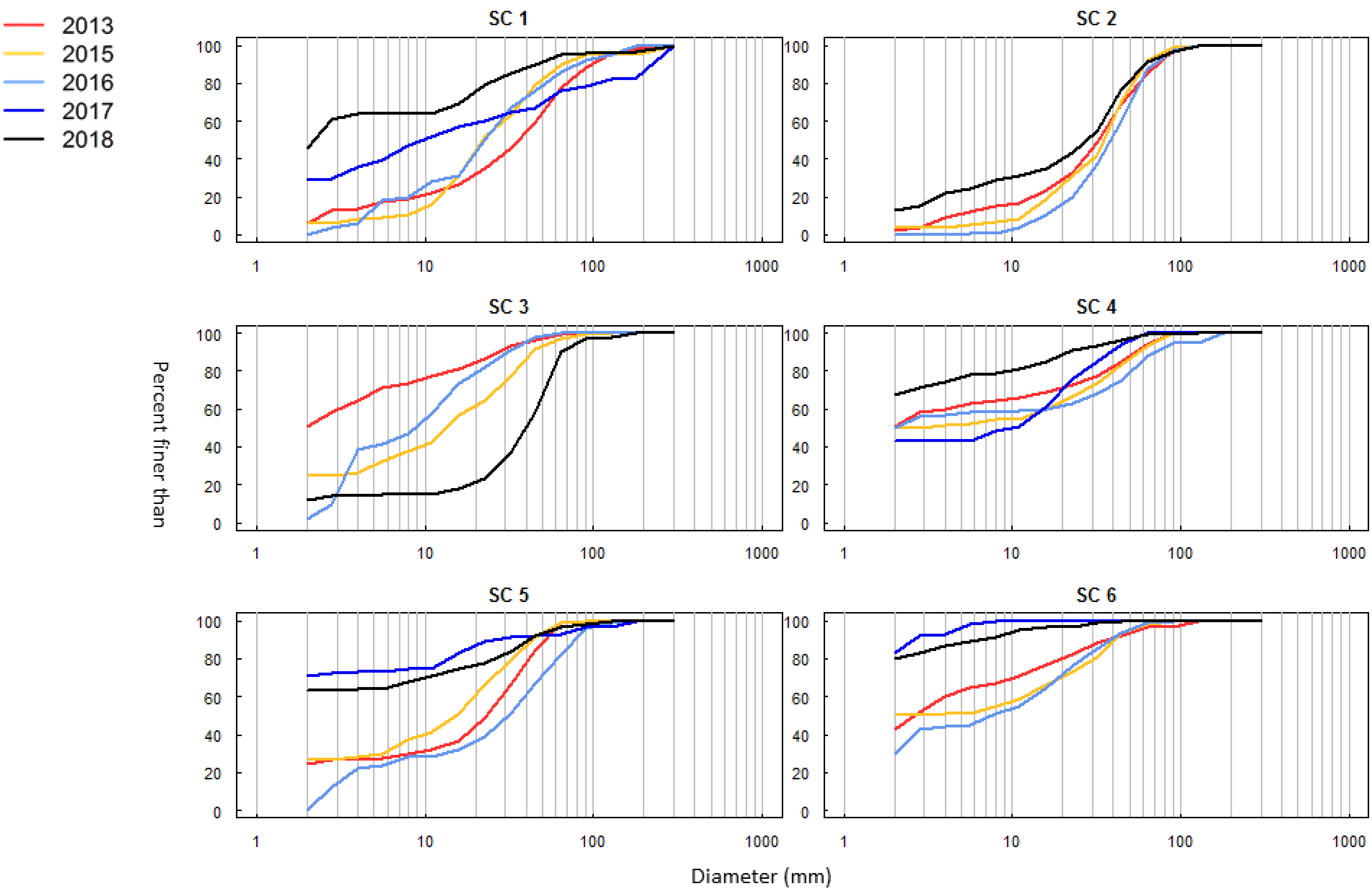

2013
2015
2016
2017
2018
DDL 1
DDL 2
DDL 3
DDL 4
Percent of Pebbles
Diameter (mm)
<2
2-2.8
2.8-4
4-5.6
5.6-8
8-11
11-16
16-22.6
22.6-32
32-45
45-64
64-90
90-128
128-180
>180


2015
2016
2017
2018
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

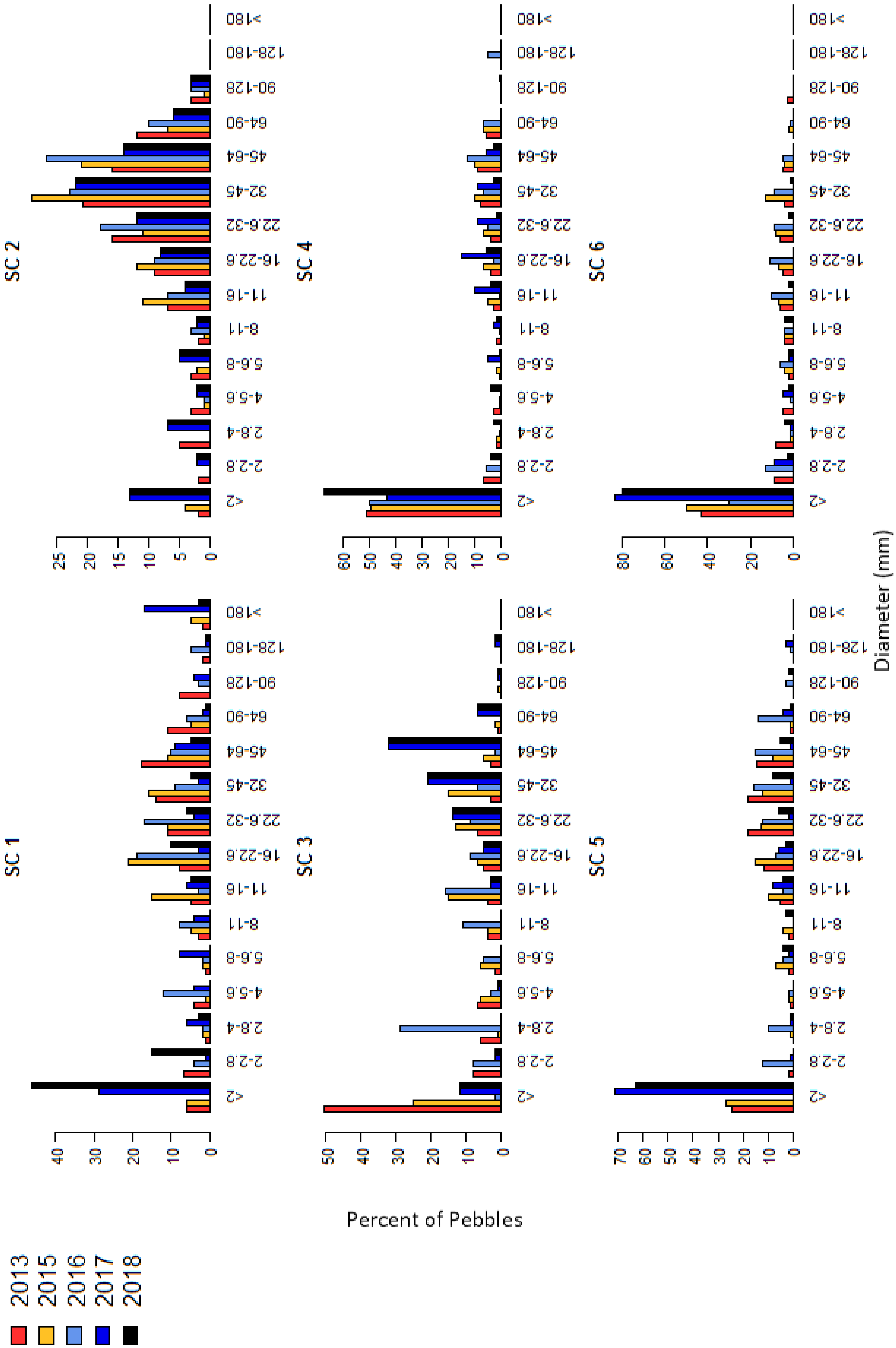

BW 1
BW 2
BW 3
BW 4
BW 5
BW 6
<2
2-2.8
2.8-4
4-5.6
5.6-8
8-11
11-16
16-22.6
22.6-32
32-45
45-64
64-90
90-128
128-180
>180
Percent of Pebbles
Diameter (mm)
2013
2015
2016
2017
2018

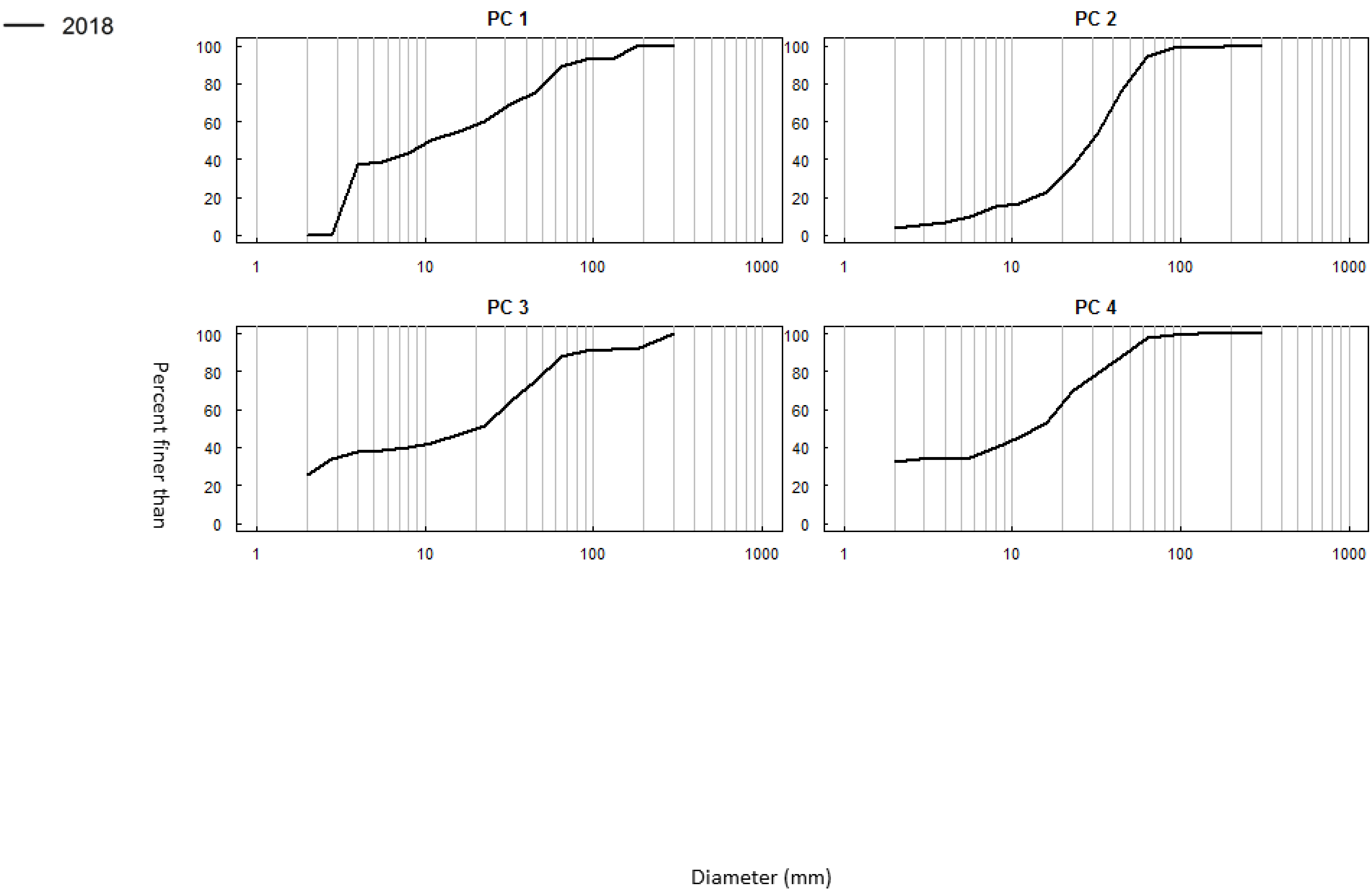

2013
2015
2016
2017
2018
SR 1
SR 2
SR 3
SR 4
100
80
60
40
20
0
1
10
100
1000
Percent finer than
Diameter (mm)

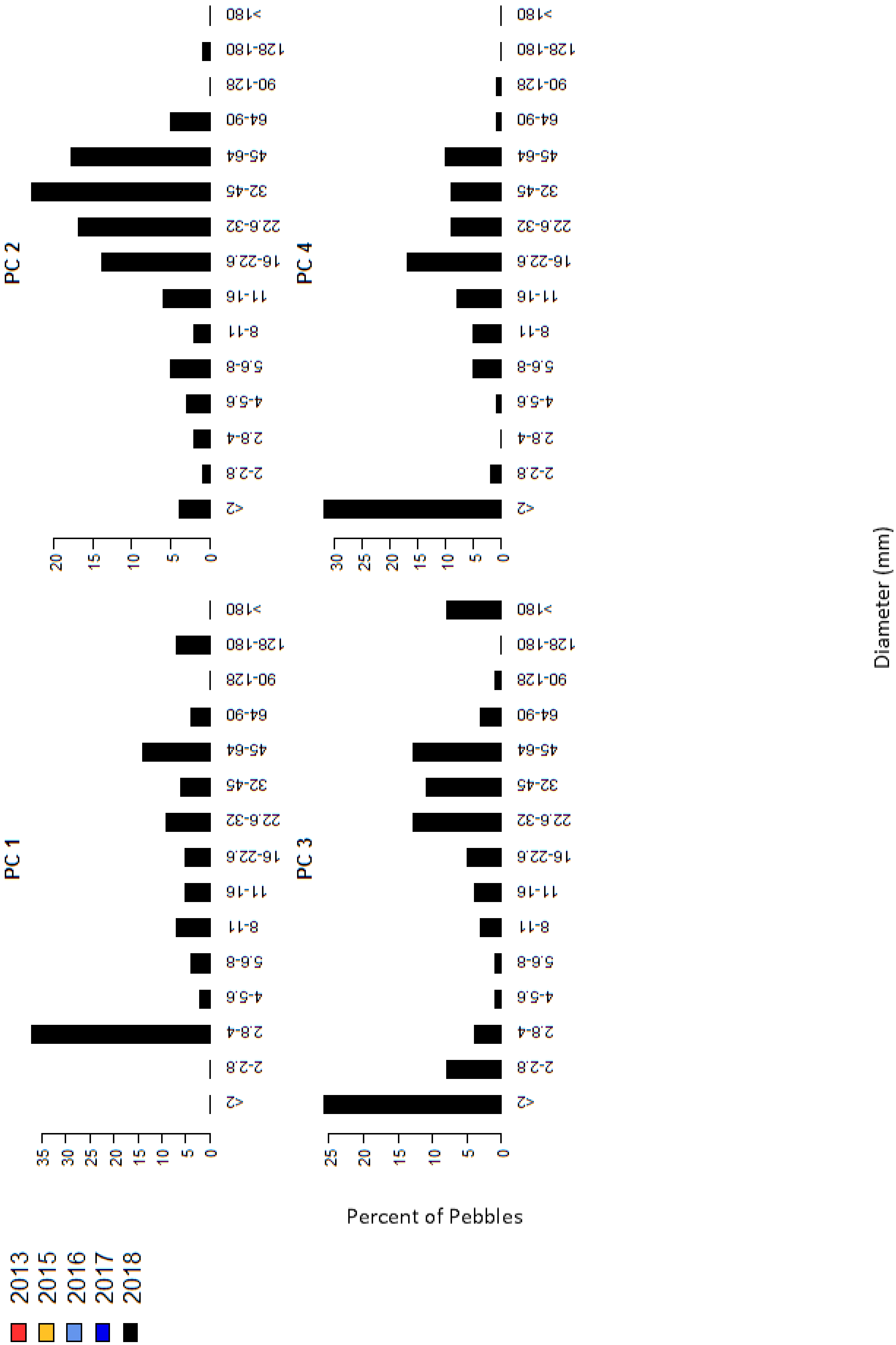

2013
2015
2016
2017
2018
SR 1
SR 2
SR 3
SR 4
<2
2-2.8
2.8-4
4-5.6
5.6-8
8-11
11-16
16-22.6
22.6-32
32-45
45-64
64-90
90-128
128-180
>180
Percent of Pebbles
Diameter (mm)

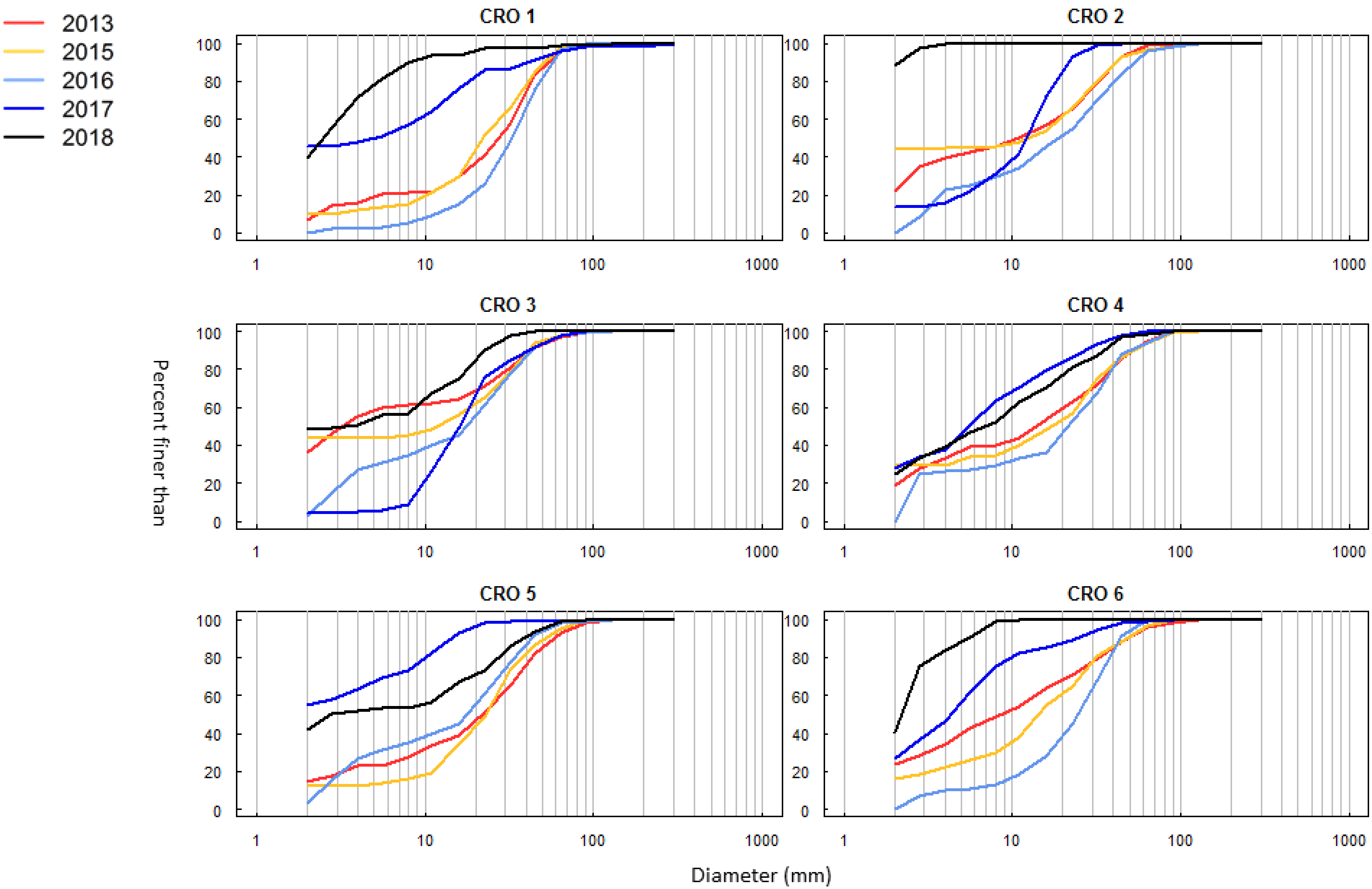


2013
2015
2016
2017
2018
SC 1
SC 2
SC 3
SC 4
SC 5
SC 6
Percent finer than
Diameter (mm)

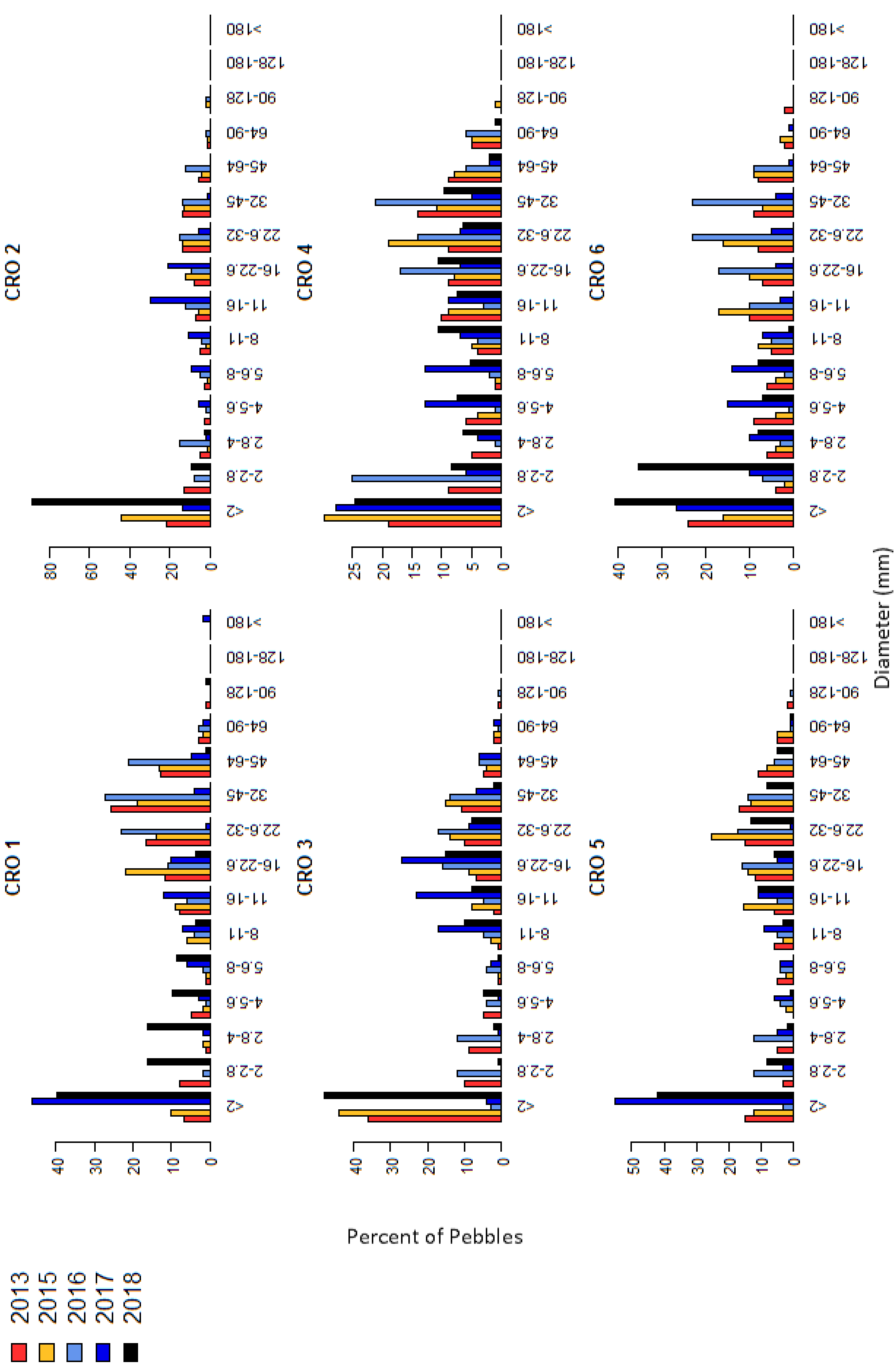

SC 1
SC 2
SC 3
SC 4
SC 5
SC 6
<2
2-2.8
2.8-4
4-5.6
5.6-8
8-11
11-16
16-22.6
22.6-32
32-45
45-64
64-90
90-128
128-180
>180
Percent of Pebbles
Diameter (mm)
2013
2015
2016
2017
2018


2018
PC 1
PC 2
PC 3
PC 4
100
80
60
40
20
0
1
10
100
1000
Percent finer than
Diameter (mm)


PC 1
PC 2
PC 3
PC 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
Diameter (mm)
Percent of Pebbles
2013
2015
2016
2017
2018



2013
2015
2016
2017
2018
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)
2013
2015
2016
2017
2018