

The Effects of Large Wood on Stream Channel Morphology on Three Low-Gradient Stream Reaches in the Coastal Redwood Region¹

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Abstract

Several studies have shown that large wood has a prominent role in habitat quality, however there is little research on the role of wood on pool characteristics and other habitat components in low gradient streams (channel slopes less than one percent). Longitudinal profiles are used to analyze general residual pool characteristics of three approximately 1000-meter stream reaches with similar stream and watershed characteristics and vastly different large wood loadings (759 vs. 329 vs. 39 m³/ha). This study devises a new classification methodology to subdivide long pools, due to different formation mechanisms and physical barriers within pools. Shallow long runs at the start or end of pools are also removed because they do not represent pool habitat. Higher large wood loading is associated with decreased individual pool lengths, maximum depths, and longitudinal residual pool areas. Greater wood loads however increase reach percent channel in pools and pool frequency. Cumulative reach longitudinal residual pool area per 100 meters and mean thalweg depths did not vary between the study reaches. Bedrock pools had greater pool lengths, maximum depths, and longitudinal residual pool areas than pools formed by large wood. Bedrock pools also had more complex bed topography than large wood pools, but had no difference in pool edge rugosity.

Key words: large wood, salmonid habitat, stream channel morphology

Introduction

The twentieth century has seen a dramatic increase in the extraction of natural resources in the western United States. Today, the impacts of these disturbances can be seen in changing habitats and decreases in species diversity and populations. The Pacific Northwest has received much attention due to two valuable resources, timber and salmonids. The role of large, downed, instream wood has been determined to play a key role in the success of salmonids (Fausch and Northcote 1992, McMahon and Hartman 1989, Quinn and Peterson 1996). Large wood (LW) is critical in

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creating habitat complexity, and its reduction has caused stream simplification and a decrease in habitat quality (Fausch and Northcote 1992, Quinn and Peterson 1996).

Low gradient streams (less than one percent channel slope) are an essential part of salmonid habitat, yet the effect of large wood has not been studied as extensively for this particular channel type. The percent of streams in pools and the character of pools is an important component of salmonid habitat (McMahon and Hartman 1989, Moore and Gregory 1988). Yet in low gradient streams of small to moderate size (in other words, less than one percent gradient and less than approximately 20 m in bankfull width) the channel is largely made up of pools and slack water habitat and the pools can extend for dozens of meters (Robison 1988). This channel type is distinct from a classic riffle/pool sequence or step/pool systems (Leopold and others 1964, Montgomery and Buffington 1997) that have received the bulk of large wood and channel morphological study. These pool features often have multiple influences creating them over their long distances as well as distinct breaks in character that are not accounted for with traditional channel unit systems because the unit is simply called a “pool.” A study that focuses on the nuances of these types of systems is long overdue. This study represents a case study of these types of low gradient reaches for three long stream reaches that have nearly identical channel and watershed characteristics (in other words, drainage area, bankfull width, gradient, levels of confinement, climate, forest type, sediment input rates, and geology). The one thing that separates them is the degree of large wood loading in these reaches. This difference in wood loading allows for some observations to be made between these reaches in terms of stream morphology forming processes and the role wood does and does not play in forming and modifying pools. The research investigates habitat at the reach scale and the habitat unit scale, specifically pools, in order to determine complexity at various scales.

This study uses clear, repeatable, non-subjective methods in measuring physical stream parameters in order to quantify complexity. Pools are precisely defined from detailed survey data using residual depths (Bathurst 1981, Lisle 1987, Robison 1998, Robison and Kaufmann 1994) and by scaling to channel size.

Longitudinal profiles in conjunction with three-dimensional surface surveys were used to measure pool parameters to isolate the effect of LW at both the reach and pool scale. The hypothesis at the reach scale is that LW increases the density of pools, percent channel in pools, longitudinal residual pool area (LRPA) per 100 meters, mean thalweg depth, thalweg depth variation, and percent pools formed by LW. The hypothesis at the individual pool scale is that pool parameters such as length, maximum depth, and longitudinal residual pool area decrease with higher LW loading. Additionally, at the individual pool scale, bedrock created pools tend to be longer, deeper, and larger pools than LW, but LW pools have more complex bed topography and pool edge rugosity, due to the relationship between LW and complexity.

Methods

The Mill and Prairie Creek watersheds are located on the coast in northwest California near the northern limit of coastal redwoods. Both watersheds are redwood and Douglas-fir forests with Prairie Creek almost all old growth and Mill Creek almost completely harvested at least once. Two study reaches are located in the Mill

Creek watershed. The East Fork and West Branch study reaches have drainage areas of 37 km² and 24 km². A study reach in Prairie Creek has a drainage area of 31 km². Bankfull widths average between 17 and 21 m on all study reaches. All three study reaches have low gradients of approximately 0.6 percent. All study reaches have unconfined channels with prominent floodplains. Valley widths on average are at least four times bankfull width. All study reaches contain bedrock in the channel. The Prairie Creek bedrock consists mostly of competent conglomerated fluvial deposits and East Fork and West Branch are mostly sandstone. Despite the difference in bedrock type, both bedrock pool types were classified the same because they create similar pools.

Data collection consisted of LW surveys, longitudinal profiles, and topographic mapping of pools. LW was defined as any piece of wood larger than 0.1 meters in diameter and two meters long. In some cases LW jams prevented the counting of individual pieces, and a total volume was obtained by measuring jam dimensions. For this study LW data is based only on pieces within the bankfull channel, as they were determined to be most important in affecting channel morphology.

Longitudinal profiles were surveyed with points taken an average of every four meters. Residual characteristics of the stream channel (Bathurst 1981, Lisle 1987) were determined for each of the long profiles. The reaches were divided into pools and riffles based on the elevation of the downstream riffle crests (Bathurst 1981, Lisle 1987). Residual depth removes the effect of discharge, but in low gradient streams, pools with separate formation factors and habitat features often combine to form one large pool. Simple, repeatable, guidelines were created to better characterize pools in low gradient streams. Pools were defined by the channel size (Buffington and others 2002, Montgomery and others 1995). Using Montgomery and others (1995) a minimum residual depth for a pool was determined to be 25 percent of mean bankfull depth of the reach. The minimum pool length was defined as half bankfull width. These pool dimensions represented significant habitat features and removed small, insignificant, localized scour and steps in riffles. Minimum pool depth was determined to be 0.25 m (mean bankfull depth from cross sections was approximately one meter on all reaches) and minimum pool length varied from 8.5 to 10.5 m depending on the reach.

Once pools were defined there were two factors that led to additional manipulations to pool dimensions. First, due to the low gradient of the study reaches there were often long areas of flatwater that encompassed multiple pools. These compound pools were subdivided because there were different formation factors for different areas of the pool and physical barriers within the larger pool that yielded separate smaller pools. A compound pool was divided if the depth at a high point between two pools was less than 25 percent of the maximum depth of the deeper pool and at least half the depth of the shallower pool. Secondly, shallow water at the tail or start of a pool was removed from pool dimensions if they were at least the minimum pool length and depth for that reach. These pool definitions were needed to accurately quantify pool habitat in these low gradient reaches.

The final data collection phase involved detailed mapping of pool beds using a Total Station. Eleven pools were mapped in detail by measuring point data in three dimensions and using a Geographic Information System (GIS) to create surfaces using triangulated irregular networks (TIN). Six of the pools were LW formed pools and five were bedrock pools. Pools were chosen based on formation type and ability to survey. Cross sections were placed every ~1/15 channel width and points were

spaced every $\sim 1/50$ channel widths (Kail 2002). The mapping was done to compare complexity of bed topography and pool edge rugosity in LW and bedrock pools.

Results

Reach characteristics for each of the sites can be seen in *table 1*. LW loadings clearly show the old growth Prairie Creek with the most, the managed West Branch with half the old growth amount, and the managed East Fork with almost none. Although piece dimensions were similar, due to a few very large pieces on Prairie Creek the mean volume per piece is greater than twice that of the managed streams.

Table 1—*Reach, large wood, and pool characteristics of Prairie Creek, West Branch Mill Creek, and East Fork Mill Creek, 2003.*

Variable	Prairie Creek	West Branch Mill Creek	East Fork Mill Creek
Reach length (m)	1098	1051	1408
Large Wood loading (m ³ /ha)	759	329	39
Number of pieces	263	244	66
Pieces/100m	24	23	5
Mean piece diameter (m)	0.6	0.4	0.4
Mean piece length (m)	7.3	6.3	7.3
Mean piece volume (m ³)	5.2	1.9	1.5
Percent channel in pools (%)	64	64	50
Number of pools	32	27	24
Pool spacing (bankfull widths)	2.0	1.8	3.2
Longitudinal residual pool area / 100 meters (m ² /100m)	27.1	30.8	28.6
Mean reach thalweg depth every 2 meters (m)	0.28	0.33	0.28
Reach depth coefficient of variation	1.07	0.97	1.37
Mean pool length (m)	22	25	29
Mean pool longitudinal residual pool area (m ²)	9.2	12.0	16.7
Mean maximum pool depth (m)	0.8	0.8	0.9
Maximum pool depth (m)	1.3	1.4	2.1
Mean pool depth (m)	0.4	0.5	0.5

Higher LW loadings led to closer pools, greater percent channel in pools, but had little effect on mean thalweg depth and LRPA per 100 m. Pool spacing, measured in bankfull widths (BFW), was almost the same on Prairie Creek (2.0 BFW) and West Branch (1.8 BFW) while greater on East Fork (3.2 BFW). Higher LW loadings increased the percent channel in pools (East Fork had just under 50 percent while West Branch and Prairie Creek had 64 percent). LW did not affect the LRPA per 100 m, as all reaches were almost the same. If LRPA is an indicator of pool size, then East Fork has longer, deeper, and larger pools than the wooded reaches. This results in East Fork having an equal amount of LRPA per 100 m despite the fact there are fewer pools. Mean thalweg depths from measurements taken every two meters showed little difference. West Branch (0.33 m) was the deepest followed closely by Prairie Creek (0.28 m) and East Fork (0.28 m). Standard deviations and coefficient of variations indicate that East Fork has greater variation in thalweg depths than Prairie Creek and West Branch.

When reaches were analyzed by pool forming mechanism, a clear separation between wooded and non-wooded reaches was determined (*fig. 1*). Prairie Creek (62 percent) and West Branch (59 percent) had a similar percentage of LW pools, while East Fork had 79 percent bedrock and only 13 percent LW. The results that West Branch and Prairie Creek are very similar in percent pool type and different from East Fork led analysis in two directions. Individual pool parameters were first compared between the three study reaches and then between formation types, bedrock and LW.

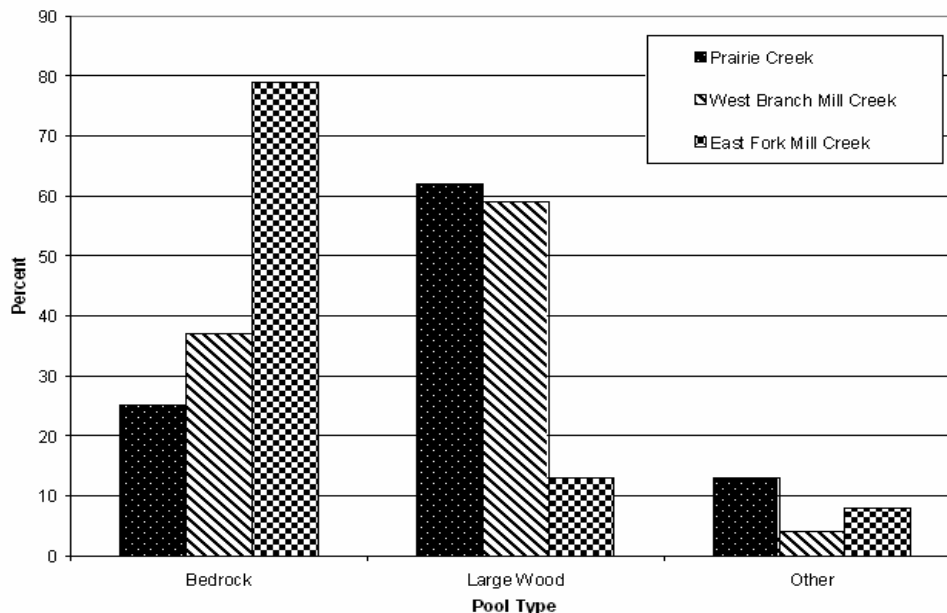


Figure 1—Distribution of pool types in Prairie Creek, West Branch Mill Creek, and East Fork Mill Creek, 2003.

All individual pool characteristics followed a similar pattern with East Fork generally having longer, deeper, and larger (based on LRPA) pools with West Branch in the middle and Prairie Creek with the shortest, shallowest, and smallest pools (*table 1*). Frequency plots were created to show differences in pool dimensions between the reaches (*fig. 2, 3, and 4*). East Fork has a few pools at the smallest level in each category but as the percent increases East Fork has longer, deeper, and larger pools than the two reaches with LW. West Branch and Prairie Creek had similar pool dimension frequencies in all cases. When the smaller pools in East Fork were investigated it was observed that they were all from LW origin and that all the larger pools were bedrock. This led to analysis on the difference between bedrock and LW pools.

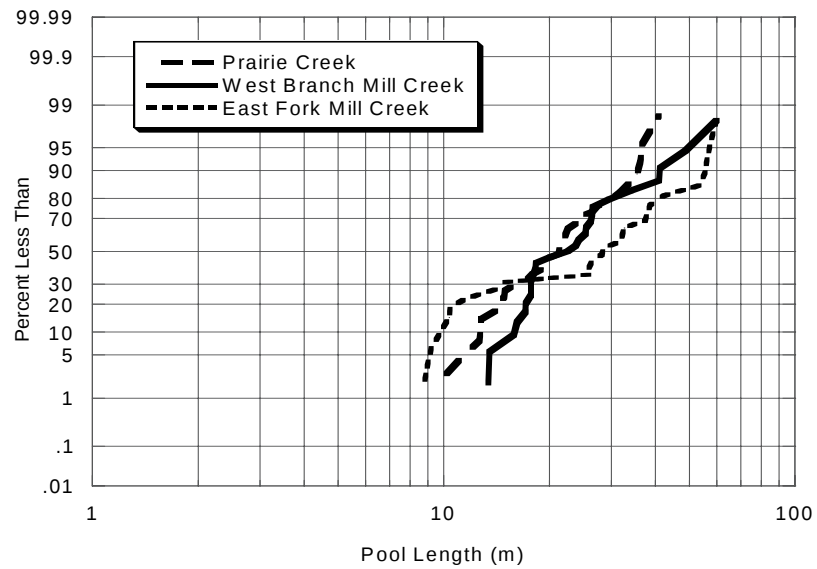


Figure 2—Frequency distribution of individual pool lengths in each study reach, 2003.

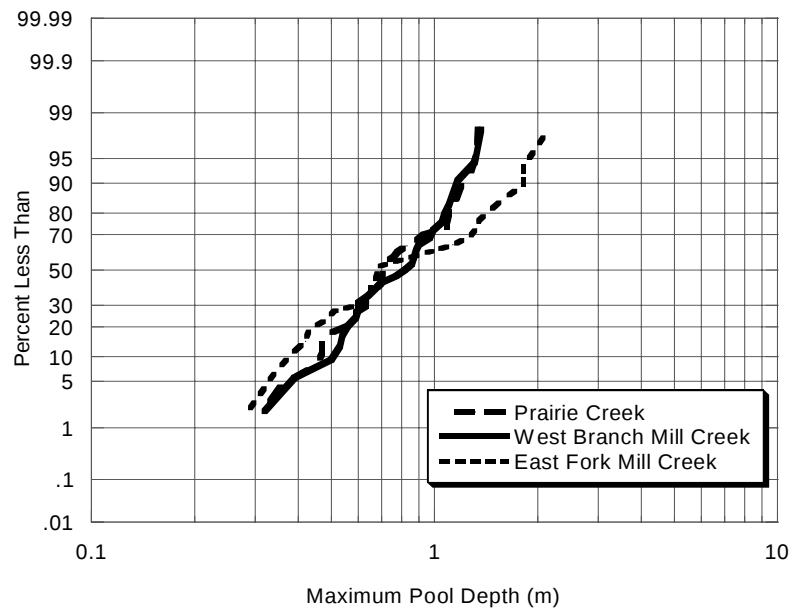


Figure 3—Frequency distribution plot of individual pool maximum depths in each study reach, 2003.

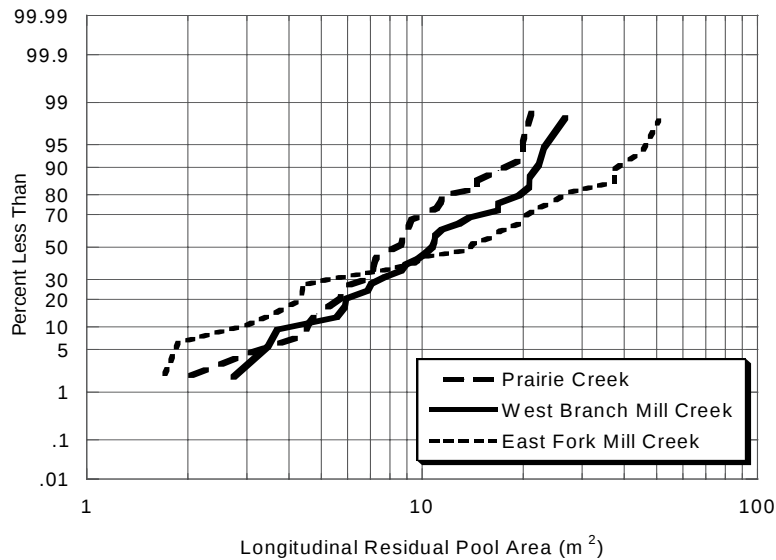


Figure 4—Frequency distribution plot of individual pool LRPA in each study reach, 2003.

Despite having different LW loadings Prairie Creek and West Branch have a similar distribution of pool types. A comparison of bedrock vs. LW pools was done to determine the differences between the pool types. Bedrock pools averaged approximately seven meters longer, almost twice the LRPA, and 0.25 deeper at its maximum depth than LW pools. These results led further into the topographic differences between the pool types. Complexity of both the bed and the edges of bedrock and LW pools were determined by mapping a subset of pools in each of the study reaches. Edge rugosity (Actual edge length / straight line edge length) was used to determine complexity of pool margins. There was no difference in mean edge rugosity (1.10) between bedrock and large wood pools. The second feature investigated was the effect of pool formation type on the bed topography. First, three-dimensional rugosity (bed surface area / pool planimetric surface area) was calculated on each of the pools. There was a difference between pool types as bedrock pools had consistently greater rugosity than large wood pools. Bedrock pools had at least a 10 percent increase in bed surface area compared to planimetric area. All large wood pools had less than a 10 percent increase in bed surface area except one. The second comparison to determine pool bed complexity was to compare the individual depths of each pool. The coefficient of variation of all individual depth values was used to remove the effect of different sized pools. Individual depths were used as a comparison because points were taken at a consistent spacing throughout the pool. A separation again occurred, with LW pools having lower coefficients of variation than bedrock pools. Both results indicate that bedrock pools have more complex bed topography than LW pools.

Discussion

Large wood affects stream channel morphology in low gradient coastal redwood streams at both the reach and individual pool scale. The results indicate that despite Prairie Creek and West Branch having different LW loadings they form a similar physical environment (pool spacing and percent channel in pools). A potential reason why there is not much difference between the reaches is that much of the large wood volume in Prairie Creek consists of a few very large pieces that only utilize a small percentage of their volume to form a pool or effect habitat. The LW character was different in West Branch, where pieces were smaller, part of jams, and typically within the low flow channel. This distribution of LW volume in these two streams may explain the similarities.

Although some reach parameters were different with various LW loadings, some characteristics were the same. LRPA per 100 meters of stream for the three reaches was not significantly different, indicating that despite East Fork having almost no LW it has a similar amount of pool area as the other reaches. Pool area was assumed to be a critical role of LW, it was assumed that increases in LW would create more scour. These results indicate LW does not affect reach pool area in these low gradient streams, rather LW affects the distribution of pool area. These results concur with Beechie and Sibley (1997) and Robison (1998) who determined that large wood in low gradient streams had less effect on pool area than in moderate and high gradient streams. In moderate and higher gradient streams (in other words, streams with gradients greater than one percent) or in larger streams with low gradients, large wood has a more active role in pool formation (Montgomery and others 1995, Robison 1998). It was also expected LW would increase mean thalweg depth, but it was almost the same for all reaches and East Fork actually had a higher thalweg depth variation. Two important results came from the reach investigation; first, LW created a clear difference between wooded (Prairie Creek and West Branch) and non-wooded reaches (East Fork) in terms of characteristics such as pool length and spacing and pool creating mechanism. Secondly, the Prairie Creek and West Branch study reaches had almost the same physical conditions, despite Prairie Creek having twice the LW loading. The similarities can be attributed to the fact West Branch had enough LW to create a similar distribution of pool types by formation mechanism to Prairie Creek. Bedrock was prominent in all the channels but when LW loading was minimal (East Fork) pool types dramatically shifted from favoring large wood to bedrock pools. The reach level results led to further investigation of individual pool parameters by reach and formation mechanism.

The hypothesis, at the individual pool scale, that higher LW loads yield shorter, shallower, and smaller pools in low gradient streams was confirmed as the pools in East Fork were significantly longer, deeper, and larger than the wooded Prairie Creek and West Branch. The difference in pool sizes is attributed to the type of pools in East Fork. The larger bedrock pools dominate in East Fork and smaller LW pools dominate in Prairie Creek and West Branch. The similar percentages of pool types found on West Branch and Prairie Creek may explain why their channel morphologies are similar. The final hypothesis was that LW pools should be more complex than bedrock pools due to the fact LW is associated with habitat complexity. When pool edge rugosity was compared there was no clear difference between the pool types. This lack of difference in pool edge rugosity may not express the margin complexity LW provides. Wooded reaches (Prairie Creek and West Branch) had more off-channel habitat than East Fork. The presence of back channels is critical in

providing velocity refugia for fish during high winter flows (Bell 2001, Moore and Gregory 1988). A measure of bank rugosity rather than pool rugosity may have better shown the effect LW has on creating complex margin habitat. When pool bed surfaces were compared, bedrock pools had greater three-dimensional rugosity. Bedrock pools also had greater coefficients of variation of evenly spaced individual depths. This analysis indicates that in low gradient streams LW does not provide more complex bed topography, although it may create quality, complex habitat in other ways. LW can provide cover for fish in pools by creating shadows, covering the surface, velocity refugia, and three-dimensional partitions within the water column (Harmon and others 1986). LW creates habitat partitions at the reach scale by increasing pool distribution and increasing habitat unit diversity, while at the pool scale LW partitions habitat by creating physical dividers within the water column.

Conclusion

Management has typically revolved around setting target values of certain stream features such as LW amounts, pool dimensions, and fish populations. The problem is that quality habitat is described as complex, which cannot always be fully determined with simple measurements or surveys. This research suggests that the dimension of pools or the amount of LW in a stream may not reflect habitat quality in low gradient streams, rather the distribution and organization of LW, the cover complexity, and the distribution of pools may be most critical. This research indicates that the stream (East Fork) with the least LW has deeper, longer, and larger pools and greater thalweg depth variation. Additionally, the majority of the pools in East Fork are of bedrock origin, which has been determined to have more complex bed topography. Complexity is more than simply measured channel characteristics. LW does not create a complex environment in low gradient streams by simply creating pools and space for fish but rather it performs a number of roles throughout the length of streams.

This research has quantified stream reaches with easy to measure, non-subjective, repeatable procedures. Pools have been defined clearly, with a specific new methodology to deal with the low gradient of the study reaches. Watershed and stream characteristics were limited by choosing study sites with similar drainage area, bankfull width, gradient, levels of confinement, climate, forest type, sediment input rates, and geology. Long reaches were utilized to capture all variability in LW loading. To further this research, additional studies such as the role of LW and off channel habitat quality, the relationship between substrate and LW, velocity and LW interactions, and investigations into fish production and LW need to be done. Research also needs to be expanded from a case study to include more samples to develop statistically based results. With respect to management, this research shows that single target values might not be the best method to determine habitat quality in low gradient streams. It may not be possible to predict habitat quality by using single results such as individual pool parameters, reach characteristics, or LW loadings, rather all factors must be considered when quantifying stream habitat. The complexity that LW provides in low gradient streams is varied and diverse, and many aspects are difficult to measure and quantify. The best method involves utilizing multiple scales and taking a non-subjective, repeatable approach that encompasses the many different roles LW plays in creating complex salmonid habitat.

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