Central Coast Watershed Studies

CCoWS

Publication No. WI-2017-03

07 March 2017

The Watershed Institute

Division of Science and Environmental Policy
California State University Monterey Bay
http://watershed.csumb.edu

100 Campus Center, Seaside, CA, 93955-8001
831 582 4696 / 4431

Large Woody Debris on the Carmel River From the Dam Keeper's House to Carmel Lagoon Fall 2016

Leah MacCarter
Julia Fields
Douglas Smith (Ph.D.)

Contact:
dosmith@csumb.edu

Preface

The following report documents the Fall 2016 locations and characteristics of large woody debris (LWD) along the lower reach of the Carmel River in California, from the former Dam Keepers House to the Carmel Lagoon. The report includes an ArcMap GIS project and electronic spreadsheets containing the data.

This report may be cited as:
MacCarter L, Fields J, Smith DP. 2017. Large Woody Debris on the Carmel River from the Dam Keeper's House to Carmel Lagoon, Fall 2016: Watershed Institute, California State University Monterey Bay, Publication No. WI-2017-03, 27 pp.

Previous LWD survey reports:
2015:
MacCarter L, Fields J, Smith DP. 2016. Large Woody Debris on the Carmel River from Camp Steffani to the Carmel Lagoon, Fall 2015: Watershed Institute, California State University Monterey Bay, Publication No. WI-2016-05, 25 pp.

2013:
ENVS 660, CSUMB Class. Beck E, Geisler E, Gehrke M, Goodmansen A, Leiker S, Phillips S, Rhodes J, Schat A, Snyder A, Teaby A, Urness J, Wright D. 2013. A Survey of Large Wood on the Carmel River: Implications for Bridge Safety Following San Clemente Dam Removal: The Watershed Institute, California State Monterey Bay, Publication No. WI-2013-04, 46 pp.

2003:
Smith DP, Huntington P. 2004. Carmel River large woody debris inventory from Stonepine to Carmel Lagoon, Fall 2003: Watershed Institute, California State University Monterey Bay, Publication No. WI-2004-01, 72 pp.

2002 pilot study:
Smith DP, Huntington P, Harter K. 2003. Carmel River Large Woody Debris Inventory from San Clemente Dam to the Lagoon Fall 2002: Watershed Institute, California State University Monterey Bay, Publication No. WI-2003-13, 38 pp.

Acknowledgements

Funding and support for this project was provided by U.C. Santa Cruz and NOAA Fisheries Service's Southwest Fisheries Science Center. We thank the following individuals for their assistance in completing the project.

- Larry Hampson and Thomas Christensen (MPWMD)

Table of Contents

Table of Figures

Table of Tables

Executive Summary

Large woody debris (LWD) serves multiple functions in stream channel morphology and ecology. It provides services and habitat for several life stages of steelhead trout, improves riparian habitat, connects aquatic and terrestrial habitats, fosters hydraulic habitat complexity, and influences streambank stability. LWD also poses potential risks to infrastructure; surges in the accumulation and abundance of LWD in a channel can increase flood frequency and threaten bridge safety.

Flow of LWD to the lower Carmel River (Monterey County, California) was restricted by the San Clemente Dam (SCD), built in 1922. The dam was removed in fall of 2015 before the 2016 water-year runoff. We conducted a before-and-after dam removal study to assess changes in LWD that occurred as a result of dam removal. This report documents the position and general description of all LWD in the lower Carmel River after the 2016 water-year runoff. These data provide a clear picture of the "after" dam removal state of LWD that can be compared to the 2015 inventory performed "before" dam removal.

The average density of LWD in 2016 between the Carmel Lagoon and Camp Steffani Road was 29.3 LWD occurrences/km (719 pieces). This decreased from 33.3 LWD/km (785 pieces) recorded in 2015 in the same 15 reaches. The average density increased in 2015 and 2016 from 20.5 LWD/km (471 pieces) recorded in 2003. The increase between 2003 and 2015 was likely due to MPWMD management activities that promoted native riparian tree growth along the lower Carmel River. The increase between 2015 and 2016 may have resulted from reconnection of the upper and lower Carmel river when the dam was removed. Also, drought conditions from 2003-2015 may have accelerated LWD recruitment as willows and cottonwoods died back.

In 2016 we surveyed two additional reaches above Camp Steffani Road that were not surveyed in 2003 or 2015. Including these new reaches, there were approximately 824 instances of single or multiple LWD in the entire 2016 study reach (26.39 km) with an average density of 31.2 LWD/km. Density was generally less in reaches that were close to the lagoon. Nine out of the 15 reaches increased in density from 2015 to 2016, mostly in the upstream half of the channel surveyed, supporting the idea that the increase was related to dam removal. Most LWD were single, partially-decomposed pieces that were not embedded and measured between 15-30 cm in diameter and 1.5-3.0 m in length.

The increase in LWD in the upper study reaches was likely the result of removing the dam that separated the highly productive upper watershed from the lower watershed. LWD entering the system above the former dam could move freely to the lower watershed during the 2016 water year. We should be able to see this "wood wave" move through the lower Carmel River in subsequent surveys. The decrease in LWD in the lower reaches was due to relatively high flows

that mobilized LWD and transported it through the Carmel River and Lagoon and out into the open ocean.

Introduction

Large woody debris (LWD) has a significant impact on ecological and geomorphic processes in river systems (Daniels 2006). LWD provides hydraulic roughness, improves river connectivity to the floodplain, and facilitates bed scour and pool formation necessary for successful steelhead spawning and anadromous fish habitat (Collins *et al.* 2012; Montgomery *et al.* 2003). Accumulation of LWD creates organic debris dams which are the foundation for trophic stability in the river (Bilby and Likens 1980); many riparian plant and animal species depend on LWD to provide protection and retain moisture in intermittent pools (Tabacchi 1998). Large woody debris can also damage bridges and riverside properties and increase flood frequency when it is transported downstream during large discharge events (Swanson *et al.* 1975; Wohl *et al.* 2016; Lyn *et al.* 2003).

Dams inhibit the transport of LWD downstream and impact the natural hydrology and ecology of reaches below impoundments by minimizing large discharge events (Graf 2006). Reduced flow of LWD can result in a loss of habitat for aquatic and riparian species (Beechie *et al.* 2010; Boughton *et al.* 2016). The San Clemente Dam (SCD) was constructed in 1922, 18.5 miles up the Carmel River in the Santa Lucia Mountains on California's Central Coast, and was removed in 2015. In 1992, the SCD was deemed unsafe due to its location in a seismically active area and potential for structural failure. The SCD retained large quantities of sediment and LWD over its 93-year lifespan and the reservoir was reduced to 150-feet of storage by 2005 (MEI 2005).

The Carmel River Re-route and San Clemente Dam Removal (CRRDR) project began July 2013 to restore flow dynamics in the Carmel River (Boughton *et al.* 2016). The CRRDR reconnected the upper and lower Carmel Watershed, allowed movement of LWD and sediment to lower reaches, and removed two barriers that inhibited federally listed steelhead migration and mobility.

A 2013 LWD survey found higher abundances of LWD above the former SCD that could be mobilized in high flow events (CSUMB 2013). Wood that migrates beyond the former SCD has the potential to increase channel roughness and slow discharge in the lower Carmel River. This supports the expectation that the lower Carmel River would experience an increase in channel complexity and pool habitat formation following dam removal due to the geomorphic effects of LWD (Boughton *et al.* 2016).

Prolonged drought may have affected the transport of LWD through the lower Carmel River. From 2002-2011, flows in the lower Carmel River peaked above 1,000 cfs each year. However, no discharge events above 1,000 cfs were observed at the USGS Carmel Near Carmel gage between water-years 2011 and 2015. The lack of high peaks likely affected LWD accumulation and

transport through the lower Carmel River. Severe drought conditions subsided with the 2016 water-year; two discharge events peaked at 1,150 and 1,080 cfs, respectively.

We surveyed the density and distribution of LWD in the Carmel River below the former SCD after the 2016 water-year runoff using the methods described in California State Monterey Bay (CSUMB) 2003 and 2015 LWD inventories (Smith and Huntington 2004, MacCarter *et al.* 2016). We surveyed the same reaches that were inventoried in 2015 from Camp Steffani Road to the Carmel Lagoon and two additional reaches from the former dam keepers house to the Carmel Lagoon for a total of 26.39 km (Fig. 1). This report compares LWD surveyed fall 2016 following dam removal with the 2015 pre-removal baseline.

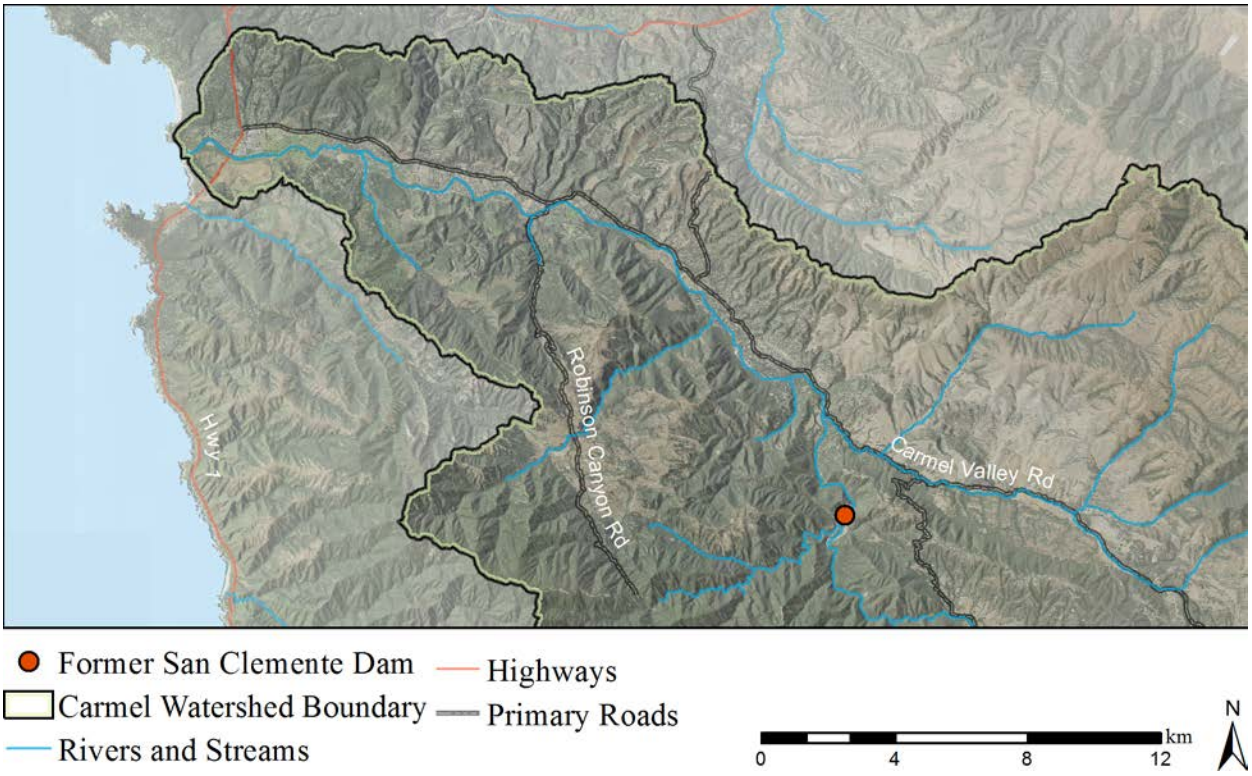


Figure 1. Survey area overview below former San Clemente Dam, Carmel Watershed, CA.

Methods

Following the Smith and Huntington (2004) survey protocol, we inventoried all single pieces of wood with a diameter and length of at least 15 cm and 1.5 m, respectively. LWD was included if it occurred in the active channel of the Carmel River. The active channel was defined as the approximate bankfull channel. We identified bankfull when at least two of the following indicator criteria were met:

1. A consistent break in slope to a lower angle indicating the presence of a floodplain.
2. ≥ 50% vegetated cover, including woody and herbaceous species.
3. A fining in surface sediment particle size.

We recorded LWD that had the greatest potential to move within the channel and documented whether they were positioned in the active channel or in the area connecting the active channel to the floodplain (Table 1, Appendix A, B). Pieces found in the intermediate area were recorded as <50% within the active channel. Several instances of LWD occurred on the floodplain and were recorded when they had the potential to be recruited at high flow conditions. The study did not include all floodplain areas because they were not usually accessible; the inclusion or exclusion of perichannel wood has the potential to vary between inventories.

When two or more qualifying pieces of LWD were touching, we considered them a "multiple" piece accumulation. In 2016, we also considered multiple pieces an accumulation when two or more pieces of LWD were not touching but were grouped together with smaller wood. We documented the approximate length and width of the accumulation, the average length and width of the pieces within the accumulation by size categories, and the number of LWD in the accumulation (Appendix A, B). We noted the presence of rootballs for both single and multiple LWD occurrences. We recorded rootballs separately if they had a diameter and length of at least 15 cm and 1.5 m respectively and were detached from the trunk.

We visually approximated the dominant substrate directly below LWD as sandy, pebbles, cobble, or boulders.

LWD embedment was documented by how well it was anchored in the vegetative bank or the streambed. Pieces of LWD that rested above the sediment were considered not embedded. LWD that were incompletely embedded in either the streambed or vegetative bank were marked as partially embedded and pieces that were entrenched along their entire length were recorded as fully embedded.

Table 1. Data fields for Carmel large woody debris survey. See Appendix A for category descriptions and Appendix B for a sample data sheet.

Category	Description
Date, reach, surveyors	General reach name assigned
Location	Eastings and northings in feet (NAD 1983 California State Plane Zone IV)
Log type	Single, multiple, +/- rootball
Width (cm)	LWD diameter in centimeters (15 cm minimum, measured in size classes)
Length (m)	LWD length in meters (1.5 m minimum, measured in size classes)
# Pieces	Estimated number of LWD pieces in a multiple
Condition	Degree of wood decay
Embedment	How well anchored the wood is in the bed or vegetative bank
Part of channel	Main channel, <50% in active channel, not in active channel
Bank Location	Location of the wood on river right, river left, or main channel.
Type of Substrate	Visual approximation of median grain size beneath LWD
Estimated Length	Approximate length of LWD accumulations and jams (m)
Estimated Width	Approximate width of LWD accumulations and jams (cm)
Comments	

We recorded the condition of LWD as less than 5% decomposed, partially decomposed, or greater than 75% decomposed (Appendix A, B). Pieces that still had most their bark and smaller branches intact were marked as less than 5% decomposed. Pieces were considered greater than 75% decomposed if they easily broke apart. See Appendix A for descriptions of the data collected.

In the fall of 2016 (September 30 – November 11), 17 reaches of the Carmel River were surveyed for LWD (Fig. 2). From upstream to downstream, these reaches were:

1. Dam Keeper's House to Sleepy Hollow (not surveyed in 2003 or 2015)
2. Sleepy Hollow to Camp Steffani Road (not surveyed in 2003 or 2015)
3. Camp Steffani Road to Lower Circle
4. Lower Circle to Rosie's Bridge (not surveyed in 2003)
5. Rosie's Bridge to de Dampierre
6. De Dampierre to the Carmel Valley Trail and Saddle Club at Borronda Road
7. Borronda Road to Garland Park Stables
8. Garland Park Stables to Garland Park
9. Garland Park to the Narrows
10. Narrows to Scarlett Road
11. Scarlett Road to Robinson Canyon Road
12. Robinson Canyon Road to Upstream Schulte Road
13. Upstream Schulte to Downstream Schulte Road
14. Downstream Schulte Road to Quail Lodge Golf course
15. Quail Lodge Golf Course to Via Mallorca Road
16. Via Mallorca Road to Rancho Cañada Golf Course
17. Rancho Cañada Golf Course to the head of the Carmel Lagoon.

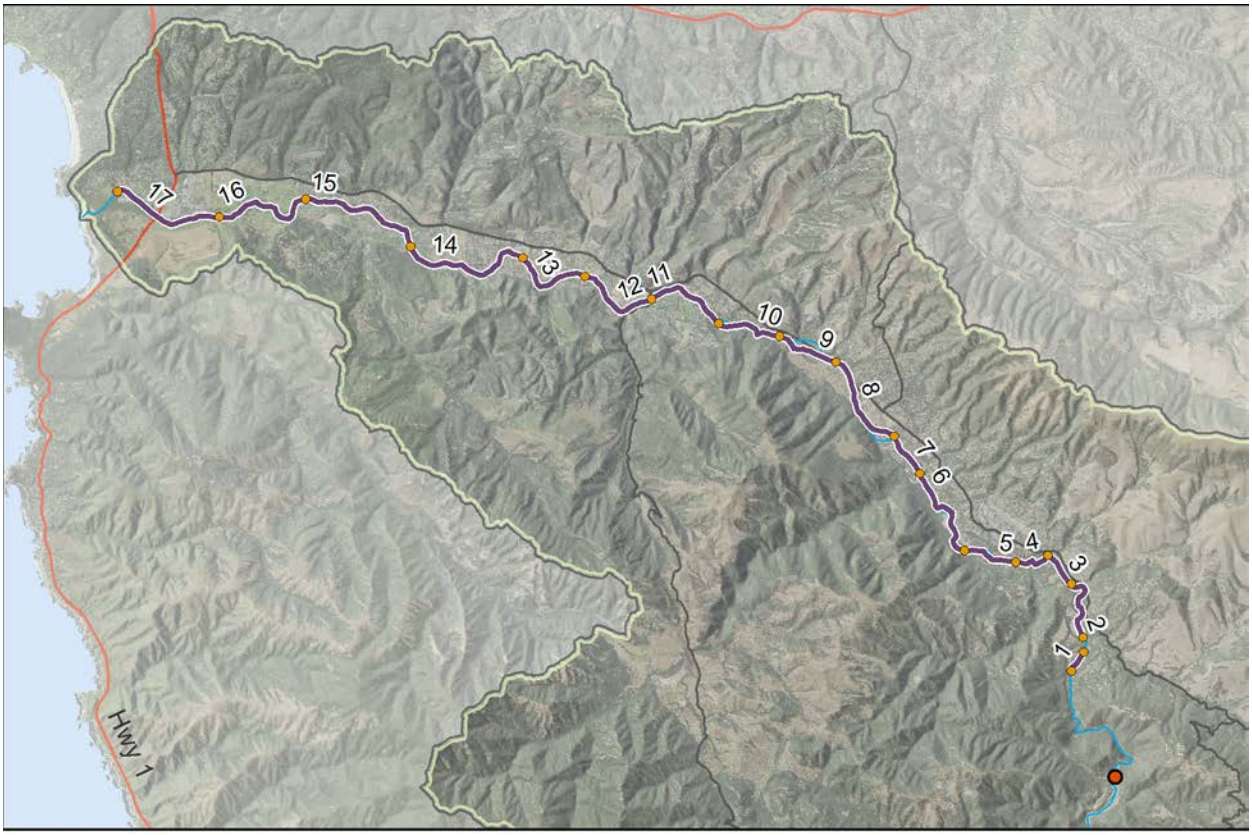
The 2016 census re-inventoried reaches from the 2015 survey and were based on the 2003 survey by Smith and Huntington (2004, Table 2). The 2015 and 2016 surveys included an additional river segment from Lower Circle to Rosie's Bridge that was not inventoried in 2003. In 2016 we surveyed two additional reaches from the Dam Keeper's House to Camp Steffani Road. In each of our descriptive and quantitative comparisons, we only use the reaches that the studies had in common.

The former Dam Keeper's House marked the upper limit of the 2016 study. The structure was razed in 2016, following our survey. The upper end of the reach is UTM NAD83 615028E 4035151N. We did not survey a 0.33 km section between the Dam Keeper's House and Sleepy Hollow because the channel was braided and identification of the main channel and bankfull was not possible. We ended the survey in the Carmel Lagoon when the water became too deep to wade during low-flow conditions. This point was approximately in-line with the Carmel Valley Mission.

We recorded LWD locations with a handheld Trimble GeoExplorer-III receiver set to SBAS real-time processing. We differentially corrected the GPS coordinates in Pathfinder Office.

We created maps using ArcMap (v.10.4) GIS that displayed each single and multiple LWD occurrence over a high resolution NAIP digital orthophoto.

We compared the 2016 results to LWD censuses completed in 2003 and 2015 to identify trends in the distribution and density of wood and to assess how the amount and composition of LWD below the SCD changed over time.



** 2016 survey only * Not surveyed in 2003

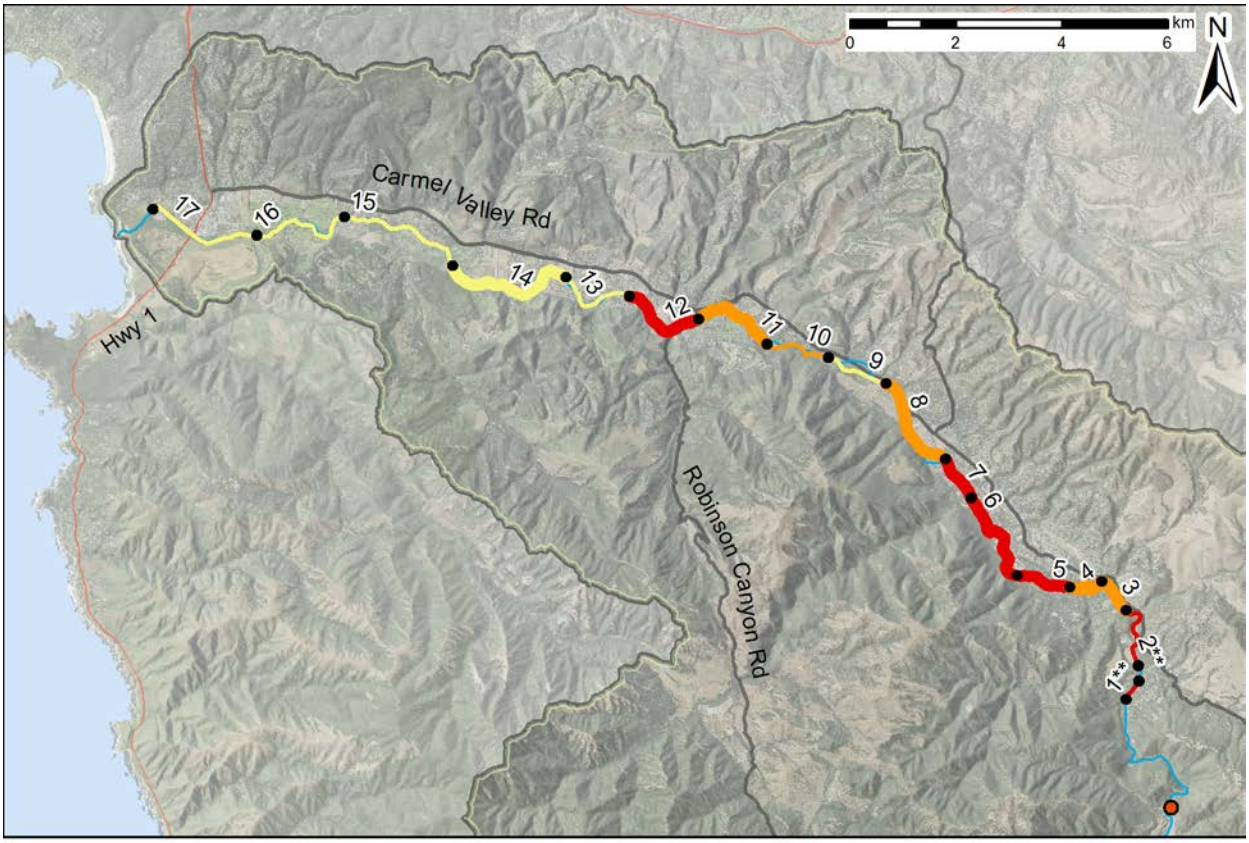
Figure 2. Lower Carmel River survey reaches based on the 2003 Smith and Huntington survey.

Results

We recorded 824 instances of single or multiple LWD occurrences within 26.39 km (16.36 mi; Fig. 3, Table 2). Most of the wood surveyed was between 15 cm and 30 cm in diameter (81.5%) and 1.5 to 3.0 meters long (37.2%, Fig. 4, 5). The dominant substrates were cobble (40%) and sand (31.8%; Table 4); Figure 6 compares the percent of each substrate type by reach for 2015 and 2016. Tables 2 through 7 summarize LWD for the fifteen reaches.

The average density of LWD for the entire 2016 study area was 31.2 occurrences per kilometer (Table 2). Density was low (13-29 LWD/km) in reaches that were close to the lagoon and highest (46-63 LWD/km) in the two additional reaches surveyed below the former SCD (Fig. 3, 7).

The average density of LWD in 2016 between the Carmel Lagoon and Camp Steffani Road was 29.3 LWD occurrences/km (719 pieces). This decreased from 33.3 LWD/km (785 pieces) recorded in 2015 in the same 15 reaches (Fig. 7). The average density increased in 2015 and 2016 from 20.5 LWD/km (471 pieces) recorded in 2003. While overall density decreased in 15 reaches from 2015 to 2016, nine out of the 15 reaches increased in density from 2015 to 2016 (mostly in the upstream section of the channel surveyed, Fig. 3).



LWD Denisty (Occurences/ km)
Low (13- 29)
No increase from 2015
Increase from 2015
Medium (30- 45)
No increase from 2015
Increase from 2015
High (46- 63)
No increase from 2015
Increase from 2015

1. Dam Keeper to Sleepy Hollow **
2. Sleepy Hollow to Camp Steffani Road **
3. Camp Steffani Road to Lower Circle
4. Lower Circle to Rosies Bridge *
5. Rosies Bridge to Dedampierre
6. DeDampierre to Borronda
7. Borronda to Garland Stables
8. Garland Stables to Garland Park
9. Garland Park to Narrows
10. Narrows to Scarlett
11. Scarlett to Robinson Canyon Road
12. Robinson Canyon Road to Upstream Schulte
13. Upstream to Downstream Schulte
14. Downstream Schulte to Quail Lodge
15. Quail Lodge to Via Mallorca
16. Via Mallorca to RanchoCanada
17. Rancho Canada to Lagoon

Former San Clemente Dam

** 2016 survey only * Not surveyed in 2003

Figure 3. Single and multiple LWD occurrences per km for each survey reach. Thicker lines indicate an increase in LWD from 2015 to 2016. The greatest wood density in Fall 2016 was present closest to the SCD site (reaches one and two).

Table 2. Positions of fifteen sample reaches in 2016 large woody debris (LWD) survey of the Carmel River, California including the number of LWD occurrences per kilometer.

#	Reach	Reach length (km)	Cumulative Distance (km)	Cumulative Distance (mi)	Occurrences of LWD	LWD/ km
1	Dam Keeper- Sleepy Hollow	0.44	26.4	16.4	27	62
2	Sleepy Hollow- Camp Steffani	1.40	26.0	16.1	78	56
3	Camp Steffani-Lower Circle	0.74	24.6	15.2	23	31
4	Lower Circle-Rosie's Bridge	0.75	23.8	14.8	26	35
5	Rosie's Bridge-De Dampierre	1.07	23.1	14.3	52	49
6	De Dampierre-Borronda	2.01	22.0	13.6	85	42
7	Borronda-Garland Stable	0.89	20.0	12.4	39	44
8	Garland Stable-Garland Park	2.01	19.1	11.8	68	34
9	Garland Park-Narrows	1.25	17.1	10.6	29	23
10	Narrows-Scarlett	1.33	15.8	9.8	42	32
11	Scarlett-Robinson	1.67	14.5	9.0	64	38
12	Robinson-Upstream Schulte	1.69	12.8	8.0	86	51
13	Upstream-Downstream Schulte	1.61	11.2	6.9	21	13
14	Downstream Schulte-Quail Lodge	2.66	9.5	5.9	62	23
15	Quail Lodge-Via Mallorca	2.50	6.9	4.3	41	16
16	Via Mallorca-Racnho Canada	2.14	4.4	2.7	38	18
17	Rancho Canada-Lagoon	2.24	2.2	1.4	43	19
	Total and Weighted Mean[1]		**26.4**	**16.4**	**824**	**31.2**

1. Average is weighted by the length of each reach.

Table 3. Summary statistics for 2016 LWD survey of the Carmel River showing LWD occurrence type and whether a rootball was present. See data descriptions in Appendix A.

		LWD Occurrence Type (% of total reach)			
Reach #	Occurrences of LWD	Single	Multiple	Rootball Only	Rootball Present
1	27	74%	26%	0%	11%
2	78	79%	17%	4%	10%
3	23	78%	13%	9%	4%
4	26	88%	12%	0%	19%
5	52	83%	13%	4%	6%
6	85	88%	11%	1%	8%
7	39	85%	10%	5%	8%
8	68	84%	16%	0%	4%
9	29	76%	24%	0%	3%
10	42	90%	10%	0%	0%
11	64	84%	14%	2%	14%
12	86	81%	16%	2%	9%
13	21	71%	29%	0%	5%
14	62	90%	10%	0%	10%
15	41	88%	10%	2%	5%
16	38	92%	8%	0%	8%
17	43	88%	12%	0%	7%
Wt. mean[1]	**824**	**84%**	**14%**	**2%**	**12%**

1. Averages are weighted by the number of occurrences of LWD in each reach.

Table 4. Summary statistics for 2016 LWD survey of the Carmel River showing LWD bank location and underlying substrate for each reach. See data descriptions in Appendix A.

	Bank Location (% of total reach)			Substrate (% of total reach)			
Reach #	Main Channel	River Left	River Right	Sandy	Pebbles	Cobble	Boulders
1	15%	30%	56%	15%	26%	30%	26%
2	32%	31%	32%	14%	9%	72%	4%
3	13%	13%	74%	13%	39%	43%	4%
4	12%	27%	46%	35%	27%	38%	0%
5	8%	40%	31%	23%	37%	40%	0%
6	20%	32%	40%	27%	22%	49%	1%
7	31%	41%	26%	41%	8%	51%	0%
8	10%	46%	44%	25%	31%	44%	0%
9	14%	52%	34%	28%	31%	34%	7%
10	21%	24%	55%	57%	17%	26%	0%
11	9%	36%	50%	38%	27%	36%	0%
12	7%	33%	44%	45%	23%	24%	7%
13	5%	38%	48%	33%	19%	48%	0%
14	15%	26%	58%	24%	31%	42%	3%
15	5%	59%	27%	44%	17%	29%	10%
16	16%	34%	37%	50%	18%	29%	3%
17	9%	53%	28%	30%	49%	21%	0%
Wt. mean[1]	**15%**	**36%**	**42%**	**32%**	**25%**	**40%**	**3%**

1. Averages are weighted by the number of occurrences of LWD in each reach.

Table 5. Summary statistics for 2016 LWD survey of the Carmel River showing the condition of LWD for each reach. See data descriptions in Appendix A.

	Condition (% of total reach)		
Reach #	<5% Decomposed	Partially Decomposed	>75% Decomposed
1	7%	78%	15%
2	1%	67%	35%
3	57%	43%	4%
4	38%	50%	12%
5	27%	65%	8%
6	21%	72%	7%
7	38%	56%	8%
8	22%	71%	7%
9	34%	52%	14%
10	52%	36%	12%
11	30%	53%	19%
12	38%	51%	12%
13	24%	62%	14%
14	47%	45%	8%
15	27%	51%	22%
16	32%	63%	5%
17	63%	37%	0%
Wt. mean[1]	**31%**	**57%**	**13%**

1. Averages are weighted by the number of occurrences of LWD in each reach.

Table 6. Summary statistics for 2016 LWD survey of the Carmel River showing LWD embedment for each reach. See data descriptions in Appendix A.

	Embedment (% of total reach)				
Reach #	No embedment	Partially in bed	Partially in veg bank	Fully in bed	Fully in veg bank
1	30%	11%	59%	0%	0%
2	55%	13%	28%	1%	3%
3	65%	0%	26%	0%	9%
4	65%	8%	27%	0%	0%
5	73%	8%	19%	0%	0%
6	62%	16%	19%	0%	2%
7	64%	13%	23%	0%	0%
8	66%	9%	19%	0%	6%
9	66%	7%	28%	0%	0%
10	71%	5%	21%	2%	0%
11	59%	13%	27%	2%	0%
12	65%	7%	22%	0%	6%
13	52%	10%	38%	0%	0%
14	58%	10%	29%	3%	0%
15	39%	20%	27%	5%	10%
16	32%	24%	39%	0%	5%
17	56%	19%	26%	0%	0%
Wt. mean[1]	**59%**	**12%**	**26%**	**1%**	**2%**

1. Averages are weighted by the number of occurrences of LWD in each reach.

Table 7. Summary statistics for 2016 LWD survey of the Carmel River showing whether LWD was part of the active channel for each reach. See data descriptions in Appendix A.

	Part of Channel (% of total reach)		
Reach #	In Active Channel	<50% in Active Channel	Not in Active Channel
1	63%	37%	0%
2	62%	37%	1%
3	52%	48%	0%
4	46%	38%	15%
5	27%	52%	21%
6	62%	27%	11%
7	64%	33%	3%
8	60%	38%	1%
9	59%	41%	0%
10	50%	48%	2%
11	56%	41%	2%
12	45%	37%	17%
13	57%	33%	10%
14	47%	52%	2%
15	51%	37%	12%
16	50%	34%	16%
17	51%	40%	9%
Wt. mean[1]	**49%**	**36%**	**7%**

1. Averages are weighted by the number of occurrences of LWD in each reach.

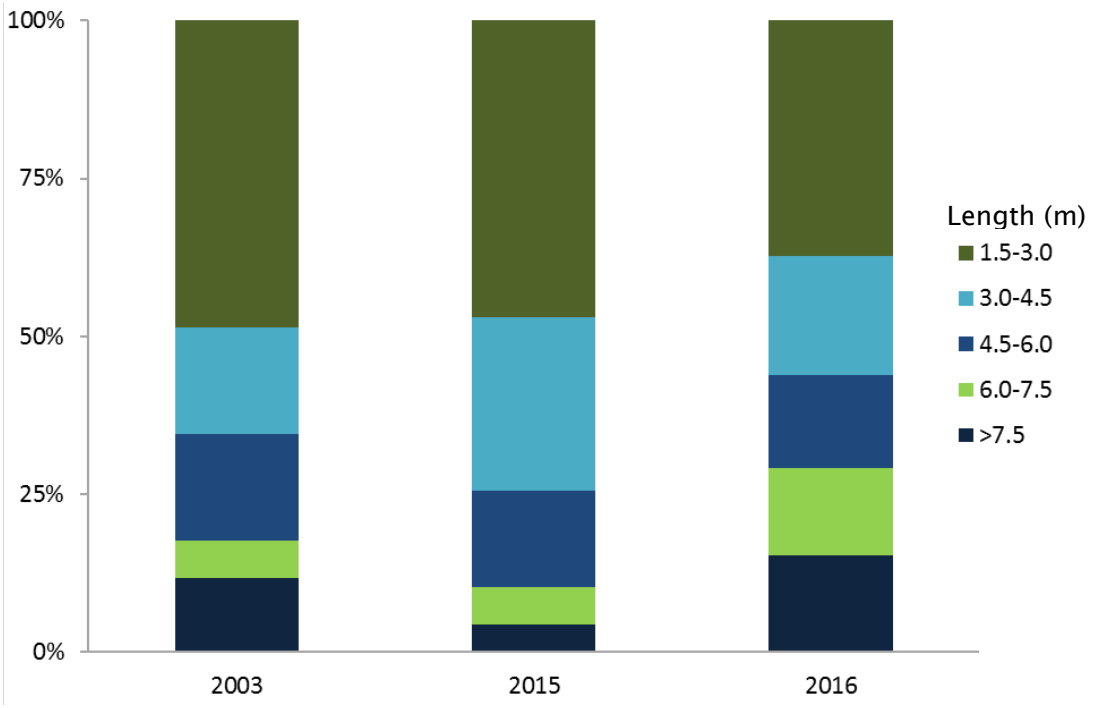
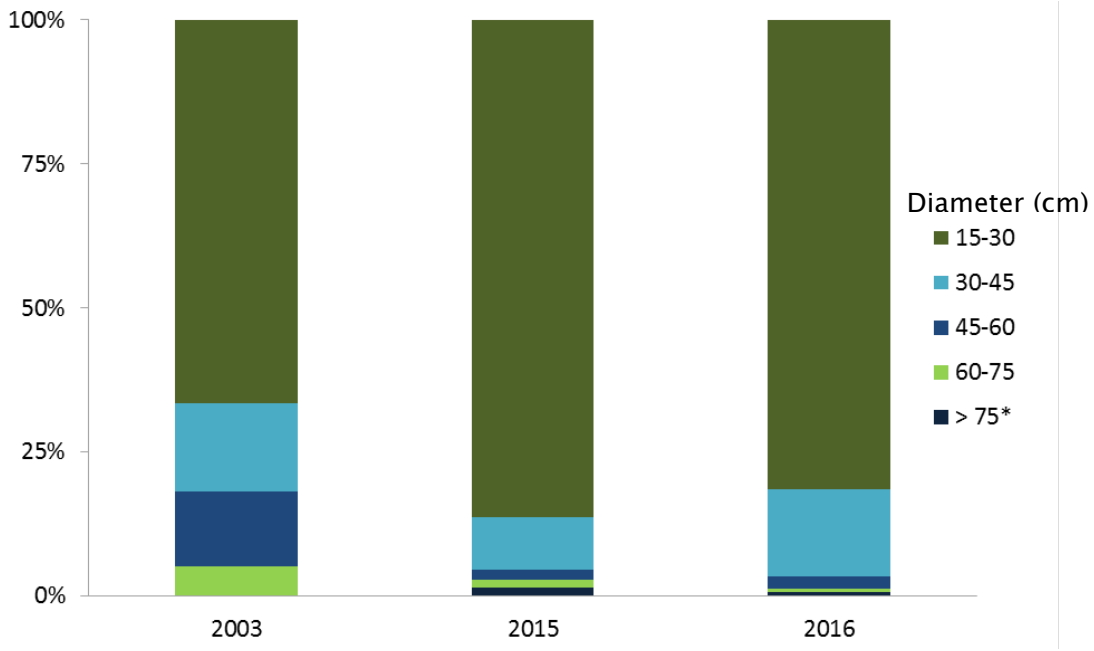
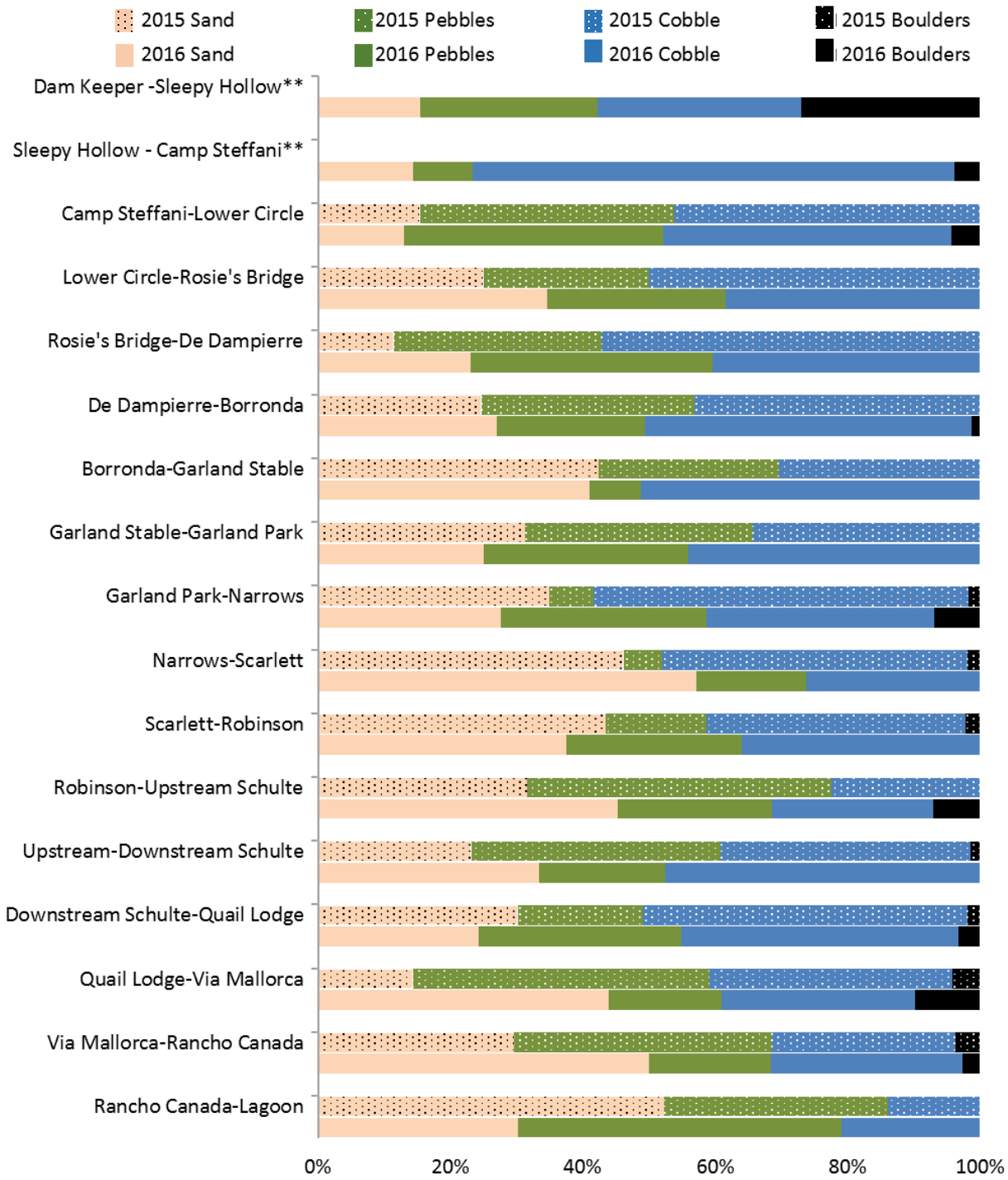


Figure 4. Percent of LWD in each length class by year. The 2003 and 2015 surveys were ~24 km while the 2016 study surveyed 26 km. We compared the 2016 survey reach to the shorter 2015 reach and found minimal difference in percentages in each category. A small increase was found in the 1.5 – 3.0 (m) range.



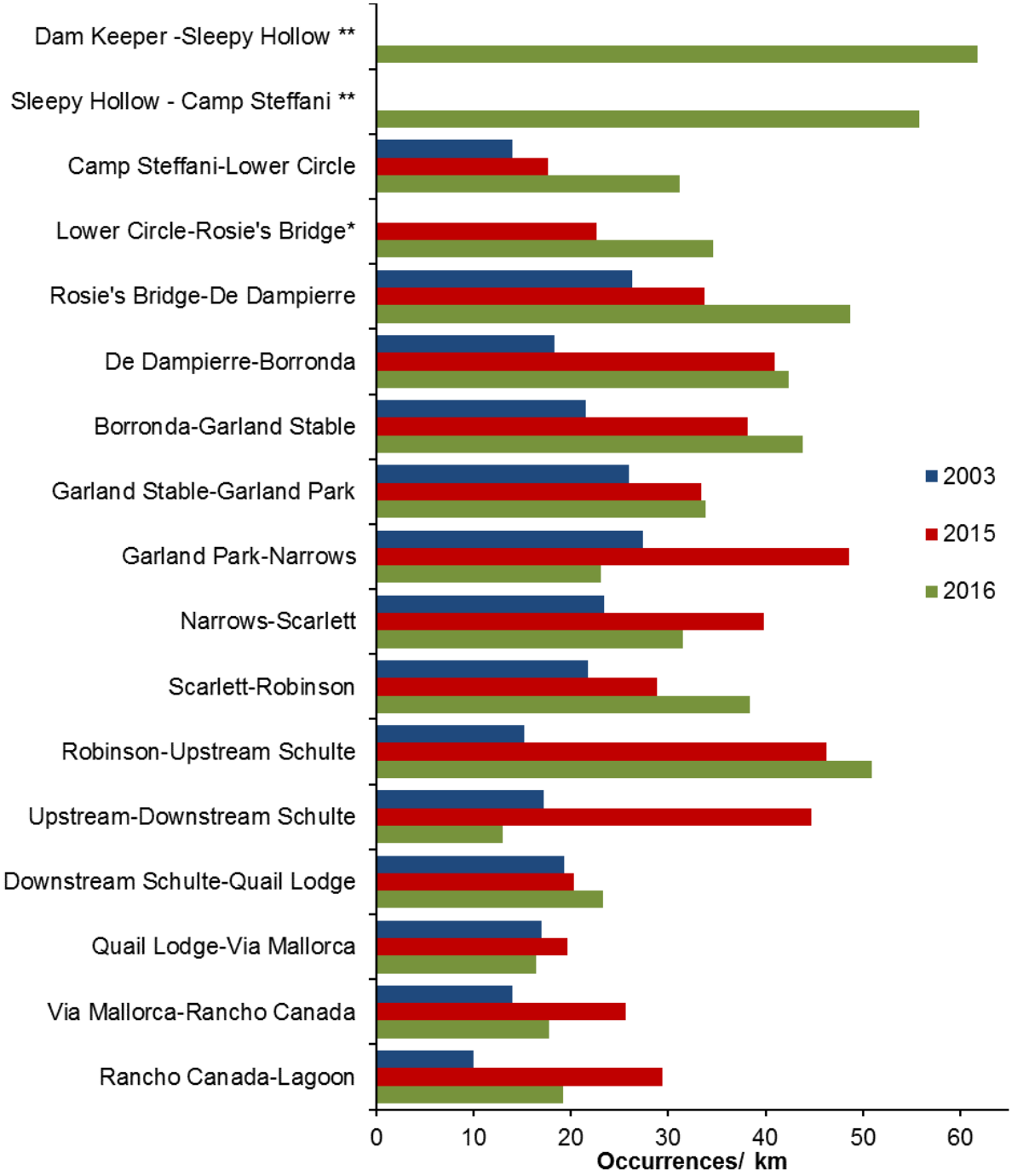
* 2003 did not use the > 75 cm size category, the largest measurement was > 60 cm.

Figure 5. Percent of LWD in each diameter class by year. The 2003 and 2015 surveys were ~24 km while the 2016 study surveyed 26 km. We compared the 2016 survey reach to the shorter 2015 reach and found minimal difference in percentages in each category. A small increase was found in the 15–30 cm range.



** Dam Keeper to Camp Steffani was not surveyed in 2015.

Figure 6. Percent of dominant substrate underlying each LWD occurrence for 2015 and 2016. Substrates were estimated visually. Textured and solid bars represent 2015 and 2016 surveys, respectively.



* Lower Circle to Rosie's Bridge was not surveyed in 2003.

** Dam Keeper to Camp Steffani was not surveyed in 2003 or 2015.

Figure 7. Occurrences of large woody debris (LWD) per kilometer by reach for 2003, 2015, and 2016. Accumulations were considered a single occurrence for this figure.

Hydrographs of the Carmel River from gages at Robles del Rio (Esquiline Rd.) and Carmel (near Via Mallorca) depict discharge from 2002 to 2016 with arrows indicating when LWD surveys occurred (Fig. 8).

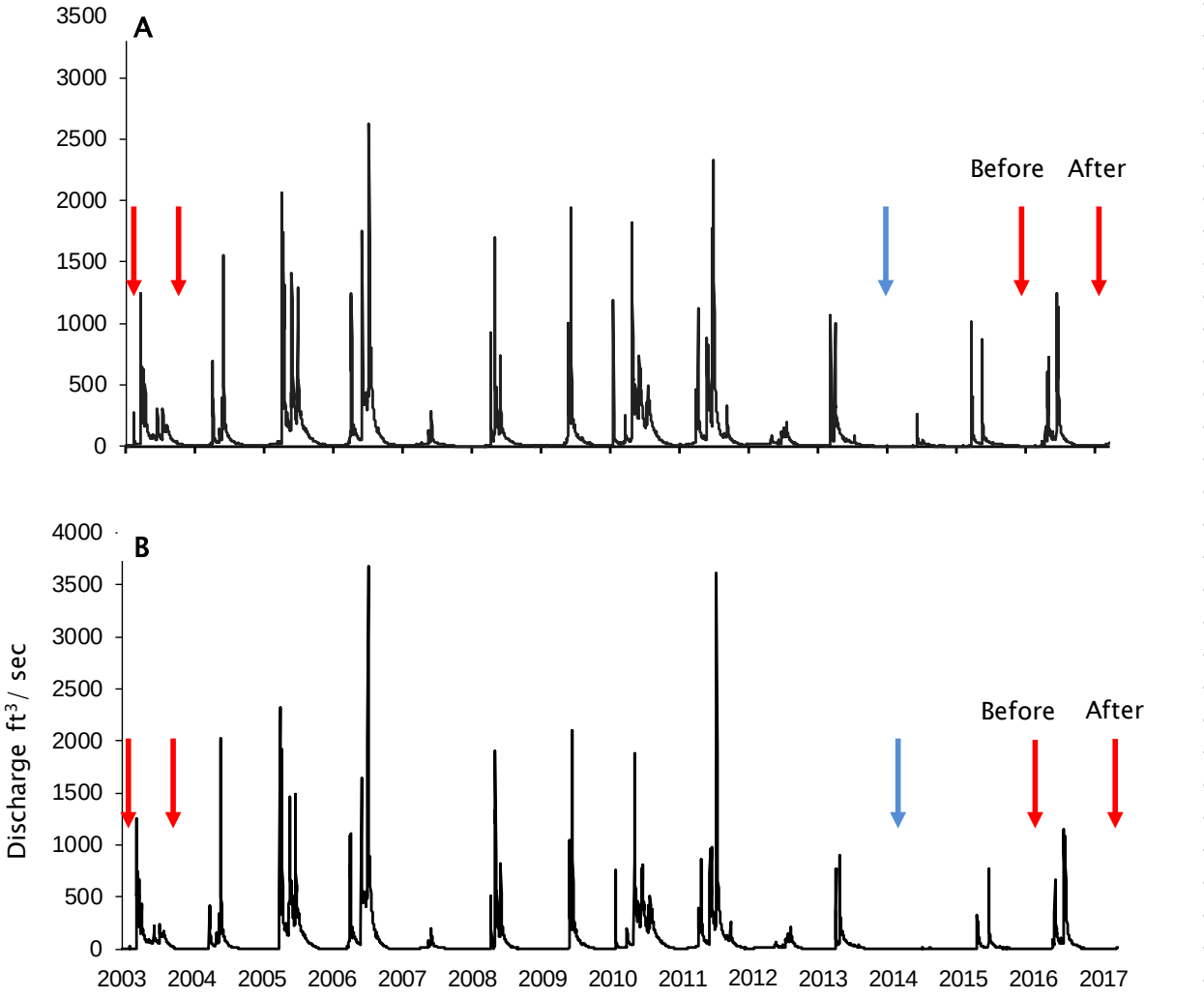


Figure 8. Hydrograph of mean daily stream flow for the (A) Carmel Robles del Rio and (B) Carmel Near Carmel gages on the Carmel River. Time axis indicates "water year." Red arrows indicate when LWD surveys using Smith and Huntington (2004) methods took place. The blue arrow indicates when a sub-sample of LWD was inventoried (CSUMB 2013). "Before" (MacCarter et al. 2016) and "After" (this study) indicate the surveys performed immediately before and after San Clemente Dam removal.

Discussion

San Clemente Dam removal was predicted to have several impacts on stream ecology including unimpaired flow of LWD to the lower Carmel River (Boughton et al. 2016). The influx of wood in reaches directly below the SCD provided evidence that LWD entering the system above the dam could now flow to the lower Carmel River (Fig. 7). These observations were consistent with a 2013 CSUMB survey that reported elevated occurrences of LWD upstream of the San Clemente Dam and predicted that LWD density would increase in the lower Carmel River when the dam was removed. Density of LWD in reaches near the lagoon was less in 2016 than 2015 (Fig. 3). The reduction in the far downstream reaches was probably due to high flows that mobilized and transported the ambient LWD through the Carmel River and Lagoon, but without the benefit of new wood to take its place. There was apparently a time lag between the dam removal and the movement of LWD through the entire system. The magnitude of the time lag is likely related to the amount of wood passing the dam site and the duration of flows that are high enough to mobilize large wood. The major runoff events of water year 2016 were not long in duration (Fig. 8). The notable difference between high and low LWD densities in the upper and lower reaches of the 2016 survey marks the downstream front of the "wood wave" released from behind the former SCD. In particular, we note that the highest abundance of wood was found closest to the dam site (Fig. 7). Future surveys should be able to observe the wood wave as it traverses the lower river.

We recognize the potential for variation between the 2003 and 2015/2016 surveys such as observer bias and differences in active channel delineation. The 2003 survey was conducted by a single individual that did not participate in the 2015/2016 surveys. The 2015/2016 surveys maintained continuity between observers and study methods. Defining the active stream channel and upper limits of high flow proved difficult in braided reaches such as de Dampierre to Rosie's Bridge. This reach was more complex than other sections of the survey area with the presences of long side channels and dense willow growth that could disguise LWD occurrences.

The abundance of LWD was impacted by the expansion and maturation of the riparian forest along the lower river corridor. The MPWMD Riparian Habitat Program has managed LWD and riparian vegetation in the lower Carmel channel since 1988 (MPWMD 2012). Since then, the riparian corridor developed more robust vegetation which can be recruited into the stream system over time. In 2016, we found more occurrences of long (6.0 m to >7.5 m) wood in the lower Carmel River but the diameter of LWD remained mostly in the 15-30 cm size range; we attribute this to the abundance of fast growing red and arroyo willows (*Salix laevigata* and *S. lasiolepis*). Increased observances of LWD in the active channel since 2003 are likely the result of the improved riparian vegetation conditions along the river corridor.

We observed the greatest increase in LWD occurrence between Rosie's Bridge and de Dampierre between the 2015 and 2016 water-years; rising from 34 to 49 LWD/km, respectively. The complexity of the reach likely accumulated more wood as it was transported downstream. During

a high flow event that peaked at 6,560 cfs at the Robles del Rio gage (gage height 8.68 ft) in the 2017 water-year, ten residences near de Dampierre Park flooded (USGS 2017; Coury 2017). These same residences were not flooded during the 1995 flow event that peaked at 16,000 cfs at the same gage, located 1.55 km upstream of the impacted neighborhood (gage height 12.9 ft; CNRFC 2017; MCRMA 2016). High densities of LWD may be responsible for increased channel roughness and slowing movement of water downstream. Studying the LWD influx after dam removal helps land managers better understand how density of LWD affects channel morphology, flood frequency, and stream ecology.

References

Beechie T, Sear DA, Olden JD, Pess GR, Buffington JM, Moir H, Roni P, Pollock MM. 2010. Process-based principles for restoring river ecosystems. American Institute of Biological Sciences. 60(3):209-222.

Bilby RE, Likens GE. 1980. Importance of organic debris dames in structure and function of stream ecosystems. Ecological Society of America. 61(5):1107-1113.

Boughton DA, East A, Hampston L, Kiernan J, Leiker, S, Mantua N, Nicol C, Smith D, Urquhart K, Williams T, Harrison L. 2016. Removing a dam and re-routing a river: Will expected benefits for Steelhead materalize in Carmel River, California? NOAA Technical Memorandum, NOAA-TM-NMFS-SWFSC-553. US Department of Commerce. Southwest Fisheries Science Center, Santa Cruz, CA. 89 pp.

[CNRFC] California Nevada River Forecast Center. 2017. Carmel River-Robles Del Rio. National Oceanic and Atmospheric Administration [Internet]. [cited 2017 Feb 26]. Available from: http://www.cnrfc.noaa.gov/graphicalRVF.php?id=RDRC1

Collins BD, Montgomery DR, Fetherston KL, Abbe TB. 2012. The floodplain large-wood cycle hypothesis: A mechanism for the physical and biotic structuring of temperate forested alluvial valleys in the north pacific coastal ecoregion. Geomorphology. 139:460-470.

[CSUMB] ENVS 660, CSUMB. Beck E, Geisler E, Gehrke M, Goodmansen A, Leiker S, Phillips S, Rhodes J, Schat A, Snyder A, Teaby A, Urness J, Wright D. 2013. A Survey of Large Wood on the Carmel River: Implications for Bridge Safety Following San Clemente Dam Removal: The Watershed Institute, California State Monterey Bay, Publication No. WI-2013-04, 46 pp.

Coury N. 2017. Carmel Valley homes flood after heavy rains. Monterey County Weekly. [Internet]. [Cited February 22, 2017]. Available from: http://www.montereycountyweekly.com/blogs/news_blog/photos-carmel-valley-homes-flood-after-heavy-rains/article_00325498-d6c2-11e6-977c-0bdf487e240b.html

Daniels, MD. 2006. Distribution and dynamics of large woody debris and organic matter in low-energy meandering streams. Geomorphology. 77(3-4):286-298.

Graf W. 2006. Downstream hydrologic and geomorphic effects of large dams on American rivers. August 2006. Geomorphology. 79(1):336-360.

Lyn DA, Cooper TJ, Yi YK, Sinha RH, Rao AR. 2003. Debris accumulation at bridge crossings: laboratory and field studies. FHWA/IN/JTRP-2003/10. Joint Transportation Research Program. Indiana Department of Transportation and Purdue University. West Lafayette, IN. 59 pp.

MacCarter L, Fields J, Smith DP. 2016. Large woody debris on the Carmel River from Camp Steffani to the Carmel Lagoon, Fall 2015: Watershed Institute, California State University Monterey Bay, Publication No. WI-2016-05. 25 pp.

[MEI] Mussetter Engineering Inc. April 2005. Hydraulic and sediment-transport analysis of the Carmel River bypass option, California. 74 pp.

[MCRMA] Monterey County Resource Management Agency. 2016. Flood management- historical flooding. [Internet]. [cited 2017 Feb 22]. Available from: http://www.mcwra.co.monterey.ca.us/floodplain_management/historical_flooding.php

Montgomery DR, Collins BD, Buffington JM, Abbe TB. 2003. Geomorphic effect of wood in rivers. *In:* The Ecology and Management of Wood in World Rivers. American Fisheries Society, Bethesda, Maryland. 21-47 pp.

[MPWMD] Monterey Peninsula Water Management District. April 2012. White paper: The MPWMD Mitigation Program.

Smith DP, Huntington P. 2004. Carmel River large woody debris inventory from Stonepine to Carmel Lagoon, Fall 2003: Watershed Institute, California State University Monterey Bay, Publication No. WI-2004-01, 72 pp.

Swanson FJ, Leinkaemper GW, Sedell JR. 1976. History, physical effects and management implication of large organic debris in western Oregon streams. USDA Forest Service General Technical Report PNW-56. 21 pp.

Tabacchi E. 1998. Development, maintenance and role of riparian vegetation in the river landscape. Freshwater Biology. 40(3):497-516.

[USGS] United States Geological Survey. 2017. USGS 11143200 Carmel Robles del Rio gage. National Water Information System [Internet]. [cited 2017 Feb 26]. Available from: https://waterdata.usgs.gov/ca/nwis/uv?cb_00060=on&cb_00065=on&format=html&site_no=11143200&period=&begin_date=2017-01-06&end_date=2017-02-26

Wohl E, Bldsoe BP, Fausch KD, Kramer N, Bestgen KR, Gooseff MN. 2016. Management of large wood in streams: an overview and proposed framework for hazard evaluation. Journal of the American Water Resources Association. 52(2):315- 335.

Appendix A: Data Category Descriptions

Category	Characteristic	Description
Reach		Name of the stretch of Carmel River surveyed
		LWD locations recorded using easting and northing in feet (NAD 1983 California State Plane Zone IV)
Piece #		LWD were assigned a unique ID as they were recorded
LWD Occurrence Type	Single	A single piece of LWD at least 15 cm by 1.5 m
	Multiple	2 or more touching pieces of LWD
	Rootball	Rootball only, tree no longer attached
Type of Substrate	Sandy	Sediment <2 mm, assessed qualitatively without gravelometer
	Pebbles	Golf ball sized, assessed qualitatively without gravelometer
	Cobble	Fist-sized, assessed qualitatively without gravelometer
	Boulders	Cinderblock size or larger, assessed qualitatively
Rootball present	Yes/ No	Rootball attached to LWD or not
Part of Channel	Yes	LWD >50% in active channel
	<50% active channel	LWD partially in active channel, but >50% was in the floodplain
	No	LWD just outside the active channel that had the potential to be recruited into the river at high flow conditions
Length (m)	1.5 m size classes	LWD length in meters (1.5 m minimum)
		1.5-3.0, 3.0-4.5, 4.5-6.0, 6.0-7.5, >7.5
		For multiple pieces, this was the average log length
Width (cm)	15 cm size classes	LWD diameter in centimeters (15 cm minimum)
		15-30, 30-45, 45-60, 60-75, >75
		For multiple pieces, this was the average log diameter
Length of Accumulation		Multiple pieces only, approx. length of entire accumulation (m)
Width of Accumulation		Multiple pieces only, approx. width of entire accumulation (cm)
# Pieces in Accumulation		Multiple pieces only, # pieces LWD present
Condition	<5% decomposed	Bark intact, smaller branches present
	Partially decomposed	Bark missing, branches deteriorating
	>75% decomposed	Would break apart if stepped on
Embedment	No embedment	LWD not buried in sediment at all
	Partially in river bed	LWD embedded in the streambed along part of its length
	Partially in vegetative bank	LWD embedded in the vegetative bank along part of its length
	Fully embedded in river bed	LWD embedded in the streambed along its entire length
	Fully embedded in bank	LWD embedded in the vegetative bank along its entire length
Bank location	River Left	Left bank looking down river
	Main Channel	LWD in the main channel, not associated with either bank
	River Right	Right bank looking down river
NA		Data was either not applicable or missing

Appendix B: 2015 Survey Data Sheet

Data sheet: **Single Piece**
Date:
Surveyors:
Reach:
Piece #:

Type of Substrate:
Sandy
Pebbles
Cobble
Boulders

Rootball present:
Yes/ No

Part of Channel:
Yes/ No
<50% active channel

Length (m):
1.5-3.0
3.0-4.5
4.5-6.0
6.0-7.5
>7.5

Width (cm):
15-30
30-45
45-60
60-75
>75

Condition:
<5% decomposed
Partially decomposed
>75% decomposed

Embedment:
No embedment
Partially in bed
Partially in veg bank
Fully embedded in bed
Fully embedded in veg bank

Bank location:
River left
Main Channel
River Right

Data sheet: **Multiple Pieces**
Date:
Surveyors:
Reach:
Piece #:

Type of Substrate:
Sandy
Pebbles
Cobble
Boulders

Rootball present:
Yes/ No

Part of Channel:
Yes/ No
<50% active channel

Average Length of LWD (m):
1.5-3.0
3.0-4.5
4.5-6.0
6.0-7.5
>7.5

Average Width of LWD (cm):
15-30
30-45
45-60
60-75
>75

Length of Accumulation (m):
Width of Accumulation (cm):
 # LWD in Accumulation:

Condition:
<5% decomposed
Partially decomposed
>75% decomposed

Embedment:
No embedment
Partially in bed
Partially in veg bank
Fully embedded in bed
Fully embedded in veg bank

Bank location:
River left/ Main Channel/ River right

Data sheet: **Rootball Only**
Date:
Surveyors:
Reach:
Piece #:

Type of Substrate:
Sandy
Pebbles
Cobble
Boulders

Part of Channel:
Yes/ No
<50% active channel

Length (m):
1.5-3.0
3.0-4.5
4.5-6.0
6.0-7.5
>7.5

Width (cm):
15-30
30-45
45-60
60-75
>75

Condition:
<5% decomposed
Partially decomposed
>75% decomposed

Embedment:
No embedment
Partially in bed
Partially in veg bank
Fully embedded in bed
Fully embedded in veg bank

Bank location:
River left
Main Channel
River Right

Appendix C: Photo Documentation

Figure 9. LWD Rootball located in the Sleepy Hollow to Camp Steffani reach.

Figure 10. Multiple piece accumulation composed of nine pieces with an average length of 3.0–4.5. Dominant substrate type: cobble.

Figure 11. Single piece observance in the main channel reach between Garland Park stables and Garland Park, substrate beneath the occurrence was estimated as cobble.

Figure 12. Single piece with rootball located in the main channel in Garland Park.

Figure 13. LWD located between the former Dam Keeper's House and Sleepy Hollow community. Wood surveyed in this reach was generally longer and wider than wood found in lower reaches.

Figure 14. Irrigation pipeline installed by the MPWMD as part of the RHP in the Quail to Via Mallorca survey area. The LWD on the right was outside the active channel, but recorded due to recruitment potential during a high flow event.