CONTRIBUTION OF ORGANIC MATTER TO SUSPENDED SEDIMENT
AND TURBIDITY IN STREAMS WITH DIFFERING FOREST COVER

By

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ABSTRACT

CONTRIBUTION OF ORGANIC MATTER TO SUSPENDED SEDIMENT AND TURBIDITY IN STREAMS WITH DIFFERING FOREST COVER

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In this study, I quantified particulate organic matter and total suspended sediment (TSS) discharged during four storms from six tributaries of the Mattole River in northern California during the 2012 hydrological year. The six catchments ranged in size from 1.42 to 5.41 km². The percentage of forest cover ranged from 30 to 97%. Sampling was conducted to evaluate hypotheses that more organic matter is discharged from catchments with more forested area, the percentage of organic matter discharged is greater with more forest cover, and the percentage of organic matter is negatively related with turbidity. Coarse particulate organic matter in the streams comprised less than 1% of the organic matter discharged. Fine particulate organic matter (FPOM) in suspension did not differ significantly between more forested and less forested catchments (p=1, n₁=3, n₂=3, W=10). The percentage of organic matter discharged is not greater with more forest cover because R² values of the relationship between the percentage of organic matter and TSS ranged from 0.082 to 0.371. Also, I cannot conclude that FPOM is negatively related with turbidity because the R² values ranged from 0.081 to 0.262. Low sample sizes and high variability in organic matter contributed to the rejection of my hypotheses.
ACKNOWLEDGEMENTS

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INTRODUCTION

An estimated 170,590 kilometers of stream are threatened or impaired by sediment in the United States, second only to pathogens in total length of stream affected (Environmental Protection Agency, 2011). In California, 135 water bodies are listed as sediment-impaired (California State Water Resources Control Board, 2006a). Many northern California coastal streams experienced heavy disturbance from grazing (Keter, 1995), logging (Napolitano, 1998), and other land use activities upon the arrival of European immigrants (National Marine Fisheries Service, 2012). Most northern California rivers are currently listed as sedimentation/siltation impaired (California State Water Resources Control Board, 2006b).

Settled fine sediment can suffocate salmonid eggs and prevent alevin escapement (Harvey and Railsback, 2009; Lisle, 1989; Kondolf et al., 2008). Furthermore, fining of the stream bed reduces macroinvertebrate food availability and any reduction in settled fine sediment is beneficial for most salmonids (Suttle et al., 2004). Settling of sand on redds may be beneficial, however, when it allows enough through flow of water and prevents predation by oligochaete worms (Meyer et al., 2005).

Mass wasting, sediments from overland flow and gully erosion, and erosion of channel banks supply a stream with sediments, many of which are transported downstream in suspension. Suspended load is composed of inorganic and organic particles. Inorganic suspended sediments are composed of sands, silts, and clays that
may remain suspended in the water column for an extended period of time. Although different agencies use slightly different particle size classifications, most are based on the Wentworth scale, with clays ranging from 0.0002-0.01mm, silts 0.002-0.10mm, fine sand 0.02-0.65mm, and coarse sand 0.2-2.0mm (Ward and Trimble, 2004). Stream ecologists commonly divide organic sediments into three size classes (e.g., Gurtz et al., 1980; Cushing et al., 1995; Ock, 2010). Coarse particulate organic matter (CPOM) is greater than 1mm and consist of leaves, algae, and wood particles. Fine particulate organic matter (FPOM) ranges from 0.5 microns to 1mm and consists of fractionated CPOM, aquatic invertebrate waste products, flocculated dissolved organic matter, and dead plant cells. Dissolved organic matter (DOM) is less than 0.5 microns and consists of soluble acids from nearby soils, leachate from fallen leaves, and other detrital material.

Particulate Organic Matter (POM) represents a mixture of organic material of varying sizes and information on POM composition can indicate natural and anthropogenic activity within a basin (Hedges et al., 1986). POM in a stream plays an important role in supporting heterotrophic food webs by providing energy resources to primary consumers and by conditioning microhabitats of stream organisms (Vannote et al., 1980). Particulate organic matter dynamics are affected by complex interactions among the source of the organic matter, its size fractionation, and the physical, chemical, and biological retention potential for a given reach of stream or river (Cummins and Wilzbach, 2008). In-stream, or autochthonous, organic matter is primary production and all byproducts of this initial sequestration of carbon. Out-of-stream, or allochthonous, organic matter comes from surrounding vegetation and eroding soils (Leopold, 1964;
Lewis et al., 2007), lakes feeding into streams (Angradi, 1993), and discharges from human activities (agricultural and urban).

Organic matter has the potential to disproportionately contribute to turbidity readings because it is less dense than inorganic sediment (Madej, 2005). Calow and Petts (1992) reported that depending on land use and stream order, organic matter percentages ranged from 1.5 to 30.6%. The organic fraction of suspended sediment samples is overlooked or discarded by physical scientists (Madej, 2005). Madej et al. (2007) and Bilotta and Brazier (2008), found that organic matter can be a large portion of sediment loads and should be included in turbidity analyses.

Historically, measurements of flow have been used to estimate suspended sediment loads. More recently, suspended sediment has been found to be more accurately estimated with turbidity, and turbidity is now routinely measured as a surrogate for suspended sediment (Lewis, 1996). Turbidity measures the inhibition of light transmission through a sample of streamflow from absorption and scattering from suspended and dissolved materials, such as clay, silt, finely divided organic matter, plankton, microscopic organisms, organic acids, and dyes (ASTM International, 2003). Color of water, whether resulting from dissolved compounds or suspended particles, can affect turbidity measurements (Gippel, 1995). Turbidity is not an inherent property of water, as is temperature or pH (Davies-Colley and Smith, 2001). Turbidity data are used for regulating and maintaining drinking water standards, determining water quality for aquatic organisms, and determining transport of contaminants associated with suspended materials (Gray and Glysson, 2003). Recognition of the utility and ubiquitous measuring
of turbidity has resulted in a growing demand for high-quality and objective turbidity measurements (Anderson, 2005).

The impact of turbidity on aquatic life specifically has been studied in great detail (e.g., Newcombe and Jensen, 1996; Harvey et al., 2009). For example, relative reactive distance of brook trout was shown to decline exponentially from approximately 8 NTU to 44 NTU (Harvey and Railsback, 2009). However, trout may select turbid habitat for feeding to avoid predation risk. Also, Steelhead and Coho Salmon have slower growth in artificial channels characterized by chronic elevated turbidity levels (Sigler et al., 1984 in Harvey and Railsback, 2009).

Suspended sediment, organic matter, and turbidity have been shown to be important to aquatic life in northern California. It is also apparent that uncertainties exist pertaining to how organic matter may affect the quantification of suspended sediment and turbidity. In light of these uncertainties my hypotheses are the following:

**H₁:** The amount of organic seston is greater in catchments with a higher percentage of forest cover.

**H₂:** The percentage of the organic component of the suspended sediment load is higher in catchments with a higher percentage of forest cover.

**H₃:** As turbidity increases, the percentage of organic matter decreases regardless of the percentage of forest cover.

If the hypotheses are supported by my data, this study would add weight to arguments that organic sediments may be an important component of the suspended sediment load,
differentially affect turbidity, and that the contribution of organic sediments is likely to vary with the percentage of forest cover in a catchment.
MATERIALS AND METHODS

Site Description

All data were collected from the Mattole River watershed in coastal northern California. The river flows from northern Mendocino County through southern Humboldt County through the Coast Range. Seven hundred and eighty seven square kilometers of land contributes to over 100 kilometers of free flowing river with over 74 tributary streams (MRC, 2013). The river and its tributaries are home to three salmonid fish species: Steelhead (*Oncorhynchus mykiss*), Coho Salmon (*Oncorhynchus kisutch*), and Chinook Salmon (*Oncorhynchus tshawytscha*). Six tributaries were sampled in this study (Figure 1): Lower Bear Creek, Lower Mill Creek, West Branch of East Mill Creek, East Branch of East Mill Creek, Granny Creek, and Cook Gulch.

All map files used were provided by the United States Department of Agriculture (USDA) geospatial data gateway (datagateway.nrcs.usda.gov/, 2013). National Agricultural Imagery Program (NAIP) files were used as the base layer of vegetation and compared to personal observations. Polygons of drainage area were created from the NAIP imagery and the 10m National Elevation Dataset. Vegetation polygons were created from the NAIP image to quantify differences in vegetation between the study catchments. ArcGIS was used to compute the areas of the polygons.
Figure 1. The six study tributaries in the lower Mattole River watershed in northern California are outlined in gold. In order from upstream to downstream (right to left) the tributaries are Cook Gulch, Granny Creek, East Branch of East Mill Creek, West Branch of East Mill Creek, Lower Mill Creek, and Lower Bear Creek.
I assessed catchment characteristics of the six study streams (Table 1). I did this to understand how comparable the catchments were and reasons why differences in the data might exist. Geology of the catchments was determined from maps (Davenport et al., 2002) (Table 2). Cumulative perennial stream length was measured in ArcGIS with the National Hydrography dataset. Drainage density was calculated by dividing cumulative blue line stream length by drainage area. Basin length is the length of the line parallel to the main drainage line from the headwater divide to the stream monitoring site. Drainage shape is drainage area divided by basin length squared. Basin relief is the highest elevation minus the elevation at the stream monitoring site determined from the 10 m National Elevation Dataset. The basin relief ratio is the basin relief divided by basin length. The entire stream gradient is the elevation at 85% minus the elevation at 10% of the stream length divided by the stream length between these two points. Cutting off the stream at the top and the bottom takes out the rapid rise in the headwaters and flattening out at the mouth. The average watershed slope is the total contour length times the contour interval times 100 divided by the drainage area (United States Department of Agriculture, 1997). To determine the average slope I used ArcGIS to sum the total contour length, with the given contour interval.
Table 1. Catchment characteristics of the six study streams.

<table>
<thead>
<tr>
<th>Name</th>
<th>Drainage Area (km²)</th>
<th>Cumulative Perennial Stream Length (km)*</th>
<th>Drainage Density (km/km²)</th>
<th>Basin Length (km)</th>
<th>Drainage Shape</th>
<th>Basin Relief (m)</th>
<th>Basin Relief Ratio</th>
<th>Entire Stream Gradient</th>
<th>Average Watershed Slope (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Mill Creek</td>
<td>5.41</td>
<td>8.4</td>
<td>1.5</td>
<td>4.072</td>
<td>0.326</td>
<td>659</td>
<td>0.162</td>
<td>0.12</td>
<td>13.5</td>
</tr>
<tr>
<td>Lower Bear Creek</td>
<td>1.42</td>
<td>2.3</td>
<td>1.6</td>
<td>2.024</td>
<td>0.347</td>
<td>473</td>
<td>0.234</td>
<td>0.23</td>
<td>43.6</td>
</tr>
<tr>
<td>East Branch</td>
<td>2.47</td>
<td>3.6</td>
<td>1.5</td>
<td>2.889</td>
<td>0.296</td>
<td>551</td>
<td>0.191</td>
<td>0.10</td>
<td>43.8</td>
</tr>
<tr>
<td>East Mill Creek</td>
<td>2.16</td>
<td>2.8</td>
<td>1.3</td>
<td>2.658</td>
<td>0.306</td>
<td>469</td>
<td>0.176</td>
<td>0.12</td>
<td>41.2</td>
</tr>
<tr>
<td>West Branch</td>
<td>1.53</td>
<td>1.6</td>
<td>1.1</td>
<td>2.079</td>
<td>0.354</td>
<td>442</td>
<td>0.213</td>
<td>0.11</td>
<td>37.4</td>
</tr>
<tr>
<td>Granny Creek</td>
<td>2.39</td>
<td>3.0</td>
<td>1.3</td>
<td>2.816</td>
<td>0.301</td>
<td>466</td>
<td>0.165</td>
<td>0.08</td>
<td>30.3</td>
</tr>
</tbody>
</table>

*From the bluelines in the national hydrography dataset.
Table 2. Geology underlying the six study streams (Davenport et al., 2002). Cook Gulch and Granny Creek are co1. East Branch of East Mill Creek and West Branch of East Mill Creek are co1, co2, co3, and co4. Lower Mill Creek and Lower Bear Creek are co2 and co3.

<table>
<thead>
<tr>
<th>Map Unit*</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>co1</td>
<td>Melange</td>
<td>Dominantly highly folded argillite and highly clayey, penetratively sheared rock that exhibits rounded, lumpy, and irregular, poorly incised topography.</td>
</tr>
<tr>
<td>co2</td>
<td>Melange</td>
<td>Subequal amounts of shattered sandstone and argillite with much clayey, penetratively sheared rock that exhibits generally irregular topography lacking well-incised sidehill drainages.</td>
</tr>
<tr>
<td>co3</td>
<td>Broken sandstone</td>
<td>Exhibits sharp-crested topography with a well-incised system of sidehill drainage.</td>
</tr>
<tr>
<td></td>
<td>and argillite</td>
<td></td>
</tr>
<tr>
<td>co4</td>
<td>Intact sandstone</td>
<td>Exhibits sharp-crested topography with a regular, well-incised system of sidehill drainage.</td>
</tr>
<tr>
<td></td>
<td>and argillite</td>
<td></td>
</tr>
</tbody>
</table>

*All map units are part of the Coastal Terrane (Pliocene to Late Cretaceous) Coastal Belt Franciscan Complex.
Catchments of the six streams differed in percentage of forest cover. Lower Mill Creek, Lower Bear Creek, and East Branch of East Mill Creek were 97%, 92%, and 80% forested, respectively. West Branch of East Mill Creek, Cook Gulch and Granny Creek were 60%, 55% and 30% forested, respectively. Much of the forest in the study catchments were dominated by Douglas fir (*Pseudotsuga menziesii*). Lower Mill Creek and Lower Bear Creek had a dense understory of ferns, such as sword fern (*Polystichum munitum*), and shrubs, such as salmon berry (*Rubus spectabilis*). Forested areas of East Mill Creek appeared to have more hardwoods present, such as tan oak (*Lithocarpus densiflorus*), and the non-forested areas were actively grazed by cattle. Mature alders (*Alnus rubra*) lined the banks of East Mill Creek (Figure 2). The forested headwaters of Cook Gulch and Granny Creek were homogenous patches of roughly 40 year old Douglas fir. Much of the remaining area of Cook Gulch and Granny Creek were undergoing ecological succession from annual grasslands to shrubs, such as poison oak (*Toxicodendron diversilobum*), and scotch broom (*Cytisus scoparius*), with a scattering of large oak trees (*Quercus* spp). Red alder (*Alnus rubra*) was common alongside all of the stream channels, with the exception of denuded portions of lower Granny Creek and Cook Gulch (Figure 3). Many pepperwood trees (*Umbellularia californica*) populated slopes near the riparian zone in the East Mill, Granny Creek, and Cook Gulch catchments.

Cook Gulch, Granny Creek, East Branch of East Mill Creek, West Branch of East Mill Creek, and Lower Bear Creek are ephemeral to second order basins, depending upon the wetness of each water year. Lower Mill Creek is a second to third order basin, again
depending on whether more or less rain falls in a given water year. Drainage areas range from 1.42 km$^2$ to 2.47 km$^2$, with the exception of Lower Mill Creek which is 5.41 km$^2$. Drainage densities range from 1.1 km/km$^2$ to 1.6 km/km$^2$. Low drainage densities are an indication of high infiltration and more delayed flood peaks than areas with higher drainage density because more streams per area will drain water faster. Basin lengths range from 2.0 km to 2.9 km, again with the exception of Lower Mill Creek at 4.0 km. Drainage shapes range from 0.3 to 0.35 for the six streams, reflecting similarly rounded, not elongate, catchments. More elongate catchments have lower drainage shape values. Basin reliefs range from 442 m to 659 m. The entire stream gradient ranges from 0.08 to 0.12, with the exception of Lower Bear Creek at 0.23. Average catchment slopes range from 30% to 44%, with the exception of Lower Mill Creek at 13.5%.
Figure 2. Representative view of lower East Mill Creek in the Mattole River watershed in northern California. Photograph taken 10/08/2012 during a period of storm sampling.
Figure 3. Riparian landslide in Cook Gulch in the Mattole River watershed in northern California. Photograph taken 11/03/2012 during a period of storm sampling.
Sample Collection

Sampling occurred during hydrologic year 2013. Hydrologic year 2013 started on October 1, 2012 and ended on September 30, 2013. Four storms were analyzed. A storm was generally considered to be greater than an inch of precipitation in a twelve hour period. Storm events are referred to in Appendix A. Data were collected from two winter storms (storms one and two) and two spring storms (storms three and four). Sampling for storm one occurred from November 27th to December 13th. Sampling for storm two occurred from December 23rd to the 29th. Sampling for storm three occurred from March 6th to 9th. Sampling for storm four occurred from April 4th to 5th.

Field samples were collected by employees of the Mattole Restoration Council (MRC). All samples were collected on the recessional limb of the storm hydrographs. Sampling began near the peak flow of the storm and continued until turbidity values were less than 10 NTRU in all streams. Sampling was distributed evenly among storm dates. Grab samples were taken from the water surface in the same location of each stream using hard, transparent, 500 mL plastic bottles. Stream flows were turbulent and well mixed throughout the cross-sectional width and depth. Mattole Restoration Council personnel collected discharge measurements along cross-sections next to stage gages at high, medium, and low stages. With these data, they developed rating curves for each stream.
Sample Processing

Water samples were placed in a cooler after collection and transported to the MRC laboratory. Samples were refrigerated or stored in a cool, dark place and were processed for turbidity within 48 hours of sample collection. Mattole Restoration Council personnel measured turbidity by stirring the bottle, pouring a portion of the sample into a cuvette, and inserting the cuvette into a tabletop turbidimeter (Hach, 2100P). Five drops of 10% hydrochloric acid was added to each water sample to lower the pH to 2-3 to deter bacterial growth. Sample water volume was marked with a line on each sample bottle. Samples were then stored in a cooler with an ice pack. Samples were transported for refrigeration at Humboldt State University (HSU) where they were stored for no longer than two weeks before being processed for suspended sediment and organic matter as described below.

One hundred and ninety four bottles were processed from the six streams. I processed samples throughout the range of discharges in each stream for each storm to get data throughout the range of suspended sediment concentrations. Twelve to sixteen bottles were processed per stream from storm one. Seven to nine bottles were processed per stream from storm two. Five to eight bottles were processed per stream from storm three. Four bottles were processed per stream from storm four. My first hypothesis needed absolute values of suspended sediment discharged to answer. If a stream had greater quantities of suspended sediment longer, i.e. the turbidity remained above 10 NTRU, it was sampled more at the tail end of the storm. During storm one, two samples
from Cook Gulch and one from East Branch of East Mill Creek exceeded the turbidity range of the turbidometer (1000 Nephelometric Turbidity Ratio Units (NTRU)). Dilutions were not prepared when these samples were measured for turbidity. Therefore, these data points were considered unreliable and were not included in the analyses involving turbidity.

I processed samples in the HSU watershed laboratory. One micron particle sized glass fiber filters (Fisherbrand, G4) were used. Filters were prepared by first being placed in aluminum dishes and heated in a furnace (Thermolyne, Type 48000) for 30 minutes between 450°C-500°C. Filters were rinsed with distilled water and dried in an oven (VWR, 1370G) at 103°C-105°C for one hour. Sample bottles were weighed to the hundredth gram with a scale (Ohaus, Adventurer Pro). Filters were weighed to the ten thousandth gram with an analytical balance (Scientech, ZSA 80). Sample water was filtered through ASTM standard sieve numbers 18 and 230 to remove coarse sand, fine sand, and silt/clay sized sediments. Particles in the size range of 63 microns to one millimeter were washed out of the number 18 sieve into pre-weighed aluminum dishes. Dishes with filters were dehydrated in the oven for 20-24 hours at 103°C-105°C. Filters and dishes were cooled to room temperature in a desiccator (Sanplatec Corporation, Dry Keeper). Total suspended sediment was weighed to the ten thousandth gram. Aluminum strips were then wrapped around the dishes so they could be stacked and inserted into the furnace. Filters and dishes were heated to between 475°C-500°C for two hours to burn off the organic matter (Madej, 2005). Two hours is less than the four to twelve recommended by Lee (2011) and Wang et al. (2011), respectively, but this length of time
did burn off organic matter from samples. Filters were cooled in a desiccator and reweighed to the ten thousandth gram. Water loss from the interstitial spaces of clays was measured by re-wetting the sediment, re-drying for 20-24 hours at 103°C-105°C, re-cooling in a desiccator and re-weighing to the ten thousandth gram.

Analysis

I calculated the masses, volumes, concentrations, and percentages of sediment to answer the hypotheses. Data were input into Microsoft Excel. Results were calculated and recorded using the formulas shown in Figure 4. For some samples with high sediment volumes, multiple filters were summed to generate the mass of silts and clays. Sediment density was assumed to be 2.65 g/mL (Lewis and Eads, 2008). Following ashing, organic matter masses were calculated the same way as total sediment masses, after the burn. Negligible coarse particulate organic matter was present in samples except for a small number of particles over one millimeter at the highest discharges. In samples in which interstitial water mass was measured (n = 135), interstitial water mass was subtracted from the organic matter mass. Not all samples had the interstitial water mass measured (n = 59). For samples without interstitial water mass measured, a linear function was used to estimate the interstitial water lost. The linear functions were creek and storm specific and were generated from the samples that did have the interstitial water mass measured.
Formulas:

1. \( M_{\text{fine sediment}} = M_{\text{fine sediment+filter}} - M_{\text{filter(s)}} \)

2. \( M_{\text{sand(s)}} = M_{\text{sand(s)+dish}} - M_{\text{dish}} \)

3. \( M_{\text{total suspended sediment}} = M_{\text{fine sediment}} + M_{\text{sand(s)}} \)

4. \( V_{\text{water}} = M_{\text{water+bottle}} - M_{\text{bottle}} - M_{\text{sediment}} \)

5. \( V_{\text{total suspended sediment}} = M_{\text{total suspended sediment}} / D_{\text{sediment}} \)

6. \( V_{\text{sample}} = V_{\text{total suspended sediment}} + V_{\text{water}} \)

7. \( C_{\text{total suspended sediment}} = M_{\text{total suspended sediment}} / V_{\text{sample}} \times 1,000,000 \)

8. \( C_{\text{fine particulate organic matter}} = M_{\text{fine sediment}} / V_{\text{sample}} \times 1,000,000 \)

9. \( %_{\text{fine particulate organic matter}} = M_{\text{fine particulate organic matter}} / M_{\text{total suspended sediment}} \times 100 \)

10. \( M_{\text{water lost}} = M_{\text{dish or filter after rehydration and dessication}} - M_{\text{inorganic suspended sediment}} \)

Where:

\( M = \text{Mass (g)} \)

\( V = \text{Volume (mL)} \)

\( D = \text{Density (g/mL)} \)

\( C = \text{Concentration (mg/L)} \)

\( % = \text{Percentage} \)

Figure 4. The formulas used to calculate the concentrations and percentages of organic and inorganic sediment of various size classes (Lewis and Eads, 2008).
Total mass of sediment yield from each stream for each storm was generated by using the concentration of total suspended sediment averaged by day, or between days, to obtain one value of total suspended sediment per day. Discharges measured during collection of each sample were also averaged by day, or between days, to obtain the total discharge per day. For example, if two samples were processed from the same site on the same day, total suspended sediment concentration and discharge values for these two samples were averaged to obtain one value for each parameter for the day. For unsampled days, total suspended sediment concentration and discharge values for the next closest day before and after were averaged to interpolate a value for the missing day of data. Sediment yield per day were summed for each day of a storm to obtain a value for the total mass of total suspended sediment discharged during a storm.

I estimated the measurement error by averaging the difference in mass of blank filters and dishes processed with the samples at each step of the process: Total suspended sediment (n = 17), FPOM (n = 18), water loss (n = 13). This absolute value and the volume of each sample were used to generate an error estimate for each sample. Error for each sample was averaged to obtain one error value per stream per storm. This error value and the liters discharged per day during each storm were used to obtain the error in sediment yield / d. Values were summed to obtain the error estimate in sediment yield for an entire storm.

I used the Wilcoxon Rank Sum Test to evaluate my first hypothesis that more forested catchments discharge more organic matter. I divided the catchments into less forested and more forested categories. The less forested group had from 30-60% forest
cover. The more forested group had from 80-97% forest cover. There were three tributaries in each group. The organic matter discharged from the four storms were summed to get a total amount of organic matter discharged for each tributary. I used linear regressions to evaluate my second and third hypotheses that more forested catchments discharge higher percentages of organic matter and that the percentage of organic matter is negatively related to turbidity. I transformed the values of total suspended sediment and turbidity by taking the logarithm of both parameters to be able to describe these relationships with a line.
RESULTS

The first two storms of the hydrologic year occurred in October and November, the three largest storms occurred in December and January, two storms occurred in March and April, and two storms occurred in July and September. Peak river flow reached 40,000 cfs (1,133 cms) in early December at United States Geological Survey gauge #11469000 in the Mattole River near Petrolia, CA (Appendix A). Flows from each of the six study streams were approximately 1/1000th the flow of the Mattole River during the four storms analyzed. The greatest discharge came from Lower Mill Creek, the largest of the six tributaries. Unit discharge of each stream for each storm is shown in Appendix B. Granny Creek received much less precipitation than the other catchments during storm one. Granny Creek and Cook Gulch received less precipitation during storm four.

Data obtained from every sample are displayed in their component turbidigraphs (Figures 5-16). In the first two storms, the highest turbidity values set a scale, which makes it difficult to see the actual values of the lowest turbidity values. In the third and fourth storms the lower flows and turbidities makes it possible to see all of the values, and the relationships between the components, more clearly.
Figure 5. Cook Gulch sample values from storms one (n=14) and two (n=9).
Figure 6. Granny Creek sample values from storms one (n=16) and storm two (n=9).
Figure 7. East Branch of East Mill Creek sample values from storm one (n=11) and storm two (n=8).
Figure 8. West Branch of East Branch Creek sample values from storm one (n=12) and storm two (n=7).
Figure 9. Lower Bear Creek sample values from storm one (n=15) and storm two (n=8).
Figure 10. Lower Mill Creek sample values from storm one (n=13) and storm two (n=9).
Figure 11. Cook Gulch sample values from storms three (n=8) and four (n=4).
Figure 12. Granny Creek sample values from storm three (n=7) and storm four (n=4).
Figure 13. East Branch of East Mill Creek sample values from storm three (n=7) and storm four (n=4).
Figure 14. West Branch of West Mill Creek sample values from storm three (n=6) and storm four (n=4).
Figure 15. Lower Bear Creek sample values from storm three (n=6) and storm four (n=4).
Figure 16. Lower Mill Creek sample values from storm three (n=5) and storm four (n=4).
Cook Gulch discharged an estimated 198,806 kg of sediment during storm one. This is more than the estimated 161,254 kg of sediment discharged from all of the other catchments combined during storm one (Figure 17). The East Branch of East Mill Creek, Cook Gulch, and Lower Bear Creek discharged the most FPOM during storm one, an estimated 22,902 kg, 19,862 kg, and 19,431 kg, respectively (Figure 18). Catchments with 80-97% forest had on average 29% FPOM in the suspended load and catchments with 30-60% had on average 19% FPOM in the suspended load. Averaged over all four storms, the estimated FPOM discharged by the 80-97% and 30-60% forested catchments was 9,166 kg/km² and 6,227 kg/km², respectively (Figure 19). However, because of overlapping standard deviations and small sample sizes I do not have enough evidence to conclude that more forested catchments discharge more organic matter than less forested watersheds (p=1, n₁=3, n₂=3, W=10). If Cook Gulch had been excluded from the analysis, the less forested catchments would have averaged 4,236 kg/km² discharged over four storms, but I still would not reject the null hypothesis (p=0.8, n₁=2, n₂=5, W=5).
Figure 17. Total suspended sediment loads during four storm events from Lower Bear Creek (LBC), Lower Mill Creek (LMC), West Branch of East Mill Creek (WEM), East Branch of East Mill Creek (EEM), Granny Creek (GRC), and Cook Gulch (COG). Estimated measurement error is shown by the bars above and below each column value.
Figure 18. Fine Particulate Organic Matter Loads from Lower Bear Creek (LBC), Lower Mill Creek (LMC), West Branch of East Mill Creek (WEM), East Branch of East Mill Creek (EEM), Granny Creek (GRC), and Cook Gulch (COG). Estimated measurement error is shown by the bars above and below each column value.
Figure 19. Fine particulate organic matter loads from three streams with differing forest cover. The 80-97% forested streams are Lower Bear Creek, Lower Mill Creek, and East Branch of East Mill Creek. The 30-60% forested streams are West Branch of East Mill Creek, Granny Creek, and Cook Gulch. Each column value is the average of the total FPOM discharged from each stream after all four storms divided by the size of the catchment. The error bars represent the standard deviation of the FPOM loads of the three streams in each category.
The relationships between the percentage of FPOM and TSS concentrations are shown in Figure 20. The slopes are all negative, showing how the percentage of FPOM tends to decrease as TSS concentrations increase. The slopes are -3.0 for Cook Gulch, -6.5 for Granny Creek, -10 for West Branch of East Mill Creek, -11.9 for Lower Mill Creek, -14.1 for East Branch of East Mill Creek, and -19.2 for Lower Bear Creek. The intercepts are 12.4 for Cook Gulch, 19.7 for Granny Creek, 31.6 for West Branch of East Mill Creek, 33.5 for Lower Mill Creek, 36.3 for East Branch of East Mill Creek, and 45.7 for Lower Bear Creek. The three less forested catchments have the three lowest intercepts, suggesting that they have less FPOM in the lower ranges of TSS concentrations. However, the $R^2$ values are not high enough for me to accept my hypothesis. The $R^2$ values range from 0.082 to 0.3705. Therefore, at worst 8.2% and at best 37.1% of the variability among the observed values of the percentage of FPOM and TSS concentrations is explained by the linear relationship between the two.
Figure 20. Linear regressions of the percentage of fine particulate organic matter (FPOM) versus the logarithm of total suspended sediment concentration. Cook Gulch (COG, n=37), Granny Creek (GRC, n=36), West Branch of East Mill Creek (WEM, n=31), East Branch of East Mill Creek (EEM, n=31), Lower Bear Creek (LBC, n=33), Lower Mill Creek (LMC, n=31). The logarithm of 10 mg/L total suspended sediment is 1, 100 mg/L is 2, and 1,000 mg/L is 3.
The relationships between the percentage of FPOM and turbidity are shown in Figure 21. The slopes are all negative, showing how the percentage of FPOM tends to decrease as turbidity increases. The slopes are -4.1 for Cook Gulch, -7.6 for Granny Creek, -8.8 for West Branch of East Mill Creek, -12.3 for Lower Mill Creek, -17.0 for Lower Bear Creek, and -20.9 for East Branch of East Mill Creek. The intercepts are 13.5 for Cook Gulch, 19.7 for Granny Creek, 27.2 for West Branch of East Mill Creek, 31.8 for Lower Mill Creek, 37.1 for East Branch of East Mill Creek, and 39.8 for Lower Bear Creek. The three less forested catchments have the three lowest intercepts, suggesting that they have less FPOM in the lower ranges of TSS concentrations. However, the $R^2$ values are not high enough for me to accept my hypothesis. The $R^2$ values range from 0.081 to 0.262. Therefore, at worst 8.1% and at best 26.2% of the variability among the observed values of the percentage of FPOM and turbidity is explained by the linear relationship between the two.
Figure 21. Linear regressions of the percentage of fine particulate organic matter (FPOM) versus the logarithm of turbidity. Cook Gulch (COG, n=35), Granny Creek (GRC, n=36), West Branch of East Mill Creek (WEM, n=29), East Branch of East Mill Creek (EEM, n=30), Lower Bear Creek (LBC, n=33), Lower Mill Creek (LMC, n=31). The logarithm of 10 NTRU is 1, ~32 NTRU is 1.5, and 100 NTRU is 2.
The components of turbidity generally less than 75 NTRU and persisting over a period of days, a.k.a. chronic turbidity, are shown in Appendix C. In storm one five of the six streams dropped below 20 NTRU by Dec. 6th. Cook Gulch, however, remained above 40 NTRU for an additional five days, from Dec. 7th to Dec. 12th. During storm two five of the six streams remained below 30 NTRU from Dec. 24th to Dec. 29th. Cook Gulch, however, was greater than 40 NTRU from Dec. 24th to Dec. 29th.
DISCUSSION

The River Continuum Concept (Vannote et al., 1980) predicts headwater streams (Orders 1-3) to be contributors of coarse particulate organic matter (CPOM). I expected that decreased forest cover would result in a decreased input of CPOM in headwater systems. In contrast to my expectations, I found that negligible amounts of CPOM was transported by these streams during the four storm events that were sampled. My sampling, however, did not include the first two storms of the season, when much of the CPOM could have been flushed, or had not been broken down into FPOM. Also, saturated organic matter that is passed through the middle or the bottom of the water column was not captured by the sampling protocol in this study.

To my knowledge, components of a turbidigraph (Figures 5-16) have not been previously published. Cook Gulch in the winter storms was filled with mostly clay and silt and this dominance of one size class created turbid conditions that increased linearly with concentration (Figure 5). Granny Creek contained sand at the highest turbidity value, pushing the turbidity up. The relationship between concentration and turbidity best fit a power function (Figure 6). The East Branch of East Mill Creek, Lower Bear Creek, and Lower Mill Creek contained samples in the lower range of turbidity with variable amounts of sand, introducing error into the turbidity function (Figures 7, 9, and 10). The East and West Branches of East Mill Creek had roughly equal amounts of sand and clay/silt at the higher turbidities. The relationships between concentration and turbidity best fit a power function (Figures 7 and 8). Lower Mill Creek contained low
amounts of sand at higher turbidities, and the steadily increasing clay and silt content increased turbidity linearly (Figure 10). Increase in turbidity at the highest discharges was from higher content of clays and silts entrained, in agreement with a study by Lewis (2003), but increased sand entrained in the study creeks also added turbidity. When equal amounts of clay/silt and sand are mobilized at the higher discharges, the additive properties of the two size classes creates a turbidigraph displaying a power function (Figures 7 and 8). In smaller storms, i.e. less than 100 NTRU, variable sand at similar turbidities introduces error (Figures 13, 15, and 16). Again, where sand is low, turbidity increased in a linear function with the clay and silt content (Figure 14). If the proportion of size classes of sediment in a stream change during a storm, or from storm to storm, altering the mathematical functions used to estimate suspended sediment loads would increase accuracy. For the six streams in this study, most of the sand captured from the surface of the streams was between 0.063 mm to 1 mm. Only during the highest flows from storm one was sand greater than 1 mm observed.

Golladay (1997) maintained that the contribution of organic matter should be less from grassland than forestland due to less above ground primary production and less lateral movement of this material, i.e. less allochthonous stream input. The dense network of stems in grassland is hypothesized to trap the outflow of organic material; in forested area, more space between trees allows for the outflow of material. The results of this study did not to support this expectation. One of the catchments in this study with less forest cover experienced far greater erosion than the other catchments (Figure 17). The bulk of the FPOM discharged was during the largest storm sampled and during this
storm the less forested catchment with more erosion had similar amounts of FPOM in suspension as the more forested catchments (Figure 18). Organic matter in the eroding soil probably contributed to this effect. Therefore, it is evident that effects of the percentage of forest cover on the organic matter in a stream can be masked by more or less total erosion. If the catchments in the study had more similar total erosion, for example by excluding Cook Gulch, then the results would have been more significant. However, if Cook Gulch was not included in the study, effects of greater erosion on the differences between organic matter and water quality of catchments in the Mattole River watershed would not have been discovered. It would be interesting to learn whether in-stream retention of organic matter affects outflow of organic matter throughout the storm season. Relatively lower discharge of organic matter from Lower Mill Creek may be because the slopes are more than twice as gradual as the other catchments in the study and the larger stream may have more floodplain area for trapping organic matter.

Percentage of organic matter has been found to decrease with an increase in flow and suspended matter (Beschta et al., 1981; Martilla and Klove, 2010). My data did support this assertion. In winter storms the percentage of FPOM at the lowest turbidities was significantly higher than at the highest turbidities for both groupings of catchments. This is because at higher turbidities, regardless of the amount of forest cover, greater quantities of inorganic sediments are discharged. Potential differences in the components of turbidity from catchments with high and medium forest cover could have implications for natural resource managers. For example, if there is greater POM in streams draining more forested land, equivalent turbidity readings may not indicate equivalent aquatic
conditions as in the streams draining less forested land. However, only at mid ranges of TSS during spring storms did the standard deviations of these data indicate a significant difference between the percentage of FPOM between the more forested and less forested catchments.

Elevated levels of turbidity (>40 NTRU) persisting over a period of days after a storm was evident only in Cook Gulch (Appendix C). A greater supply of streamside and in-channel silts and clays in Cook Gulch could be the reason for this. Figure 3 shows one such landslide. Changes in sand concentrations did not change the turbidity levels on the falling limb of the hydrograph. This can be seen in Lower Mill Creek in storm one and Lower Bear Creek and the West and East Branches of East Mill Creek in storm two. Furthermore, changes in FPOM concentration did not change the turbidity levels. In storm three this was apparent in Lower Bear Creek, Lower Mill Creek, and East Branch of East Mill Creek. The falling turbidity of all streams exhibited a linear, positive relationship with clays and silts, which agreed with a study by Foster, et al. (1992).

The results of this thesis could have been more robust and accurate. The estimates of sediment discharge likely would have been more accurate if I had interpolated the suspended sediment concentrations and discharge and then integrated the product of suspended sediment concentrations and discharge. I also could have determined the discharge between each pair of samples and then multiplied this by the average concentration of the pair. If the study was conducted over a period of many years, there would have been a larger sample size both between storms of similar size and the total amount of different types of sediment discharged per year. With a larger sample
size, normality of the data can be assessed. Also, regardless of the normality of the data, a larger sample size will give more conclusive answers to hypotheses. However, with the great variability in the amount of organic matter in the samples, no amount of sampling may have garnered a relationship that was statistically defensible. My method of determining the weight of the organic matter was not as precise as it could have been. If the mass of water loss from the burning of organic matter is going to be measured and shorter combustion times are going to be applied, it would be better to heat the sediment to 550° C. Pieces of organic material turned to ash and lost weight with the method. There would be no difference in organic matter masses from the six streams if it had not. However, the organic matter may be slightly underestimated. More recalcitrant organic matter takes longer to burn. If sediment samples would have been heated for between four and twelve hours, more organic matter may have burned off (Wang et al., 2011). Nonetheless, this would only influence the comparisons between the streams if they had variable amounts of more recalcitrant organic matter. Furthermore, using aluminum dishes for the sand size classes introduces more error in weighing than filters. I can only speculate that uneven bottom surfaces, additional mass, and/or accumulated dirtiness and/or scratches may add error to their measurement. Sand size classes should be washed out of the sieves onto prepared filters to get the most accurate and reliable masses.
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APPENDIX A

Appendix A: Water year 2013 Mattole River hydrograph.

![Discharge Graph](image-url)
APPENDIX B

Appendix B: Hydrographs per square mile (unit or normalized discharge) for the six study streams for the four storms sampled, starting with the first storm and ending with the fourth.
APPENDIX C

Appendix C: Storm tail out sediment components and turbidity.

Lower Bear Creek during storm one.
Lower Mill Creek during storm one.

West Branch of East Mill Creek during storm one.
East Branch of East Mill Creek during storm one.

Granny Creek during storm one.
Cook Gulch during storm one.

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<th>Sand</th>
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Lower Bear Creek during storm two.
Lower Mill Creek during storm two.

West Branch of East Mill Creek during storm two.
East Branch of East Mill Creek during storm two.

Granny Creek during storm two.
Cook Gulch during storm two.

Lower Bear Creek during storm three.
Lower Mill Creek during storm three.

West Branch of East Mill Creek during storm three.
East Branch of East Mill Creek during storm three.

Granny Creek during storm three.
Cook Gulch during storm three.