THE INFLUENCE OF LARGE ORGANIC DEBRIS ON CHANNEL MORPHOLOGY IN QUEEN CHARLOTTE ISLAND STREAMS

Daniel Hogan
The University of British Columbia
Department of Geography
Vancouver, B.C. V6T 1W5

INTRODUCTION

A commonly held opinion in fish habitat rehabilitation is that "...management plans dealing with large organic debris should strive to duplicate natural processes found in undisturbed basins" (Keller et al, 1981, p. 175). Previous studies have provided inventories of large organic debris quantities and noted the influence of specific debris pieces on channel morphology (Heede, 1981; Swanson et al, 1976; Swanson and Lienkaemper, 1978; Keller and Tally, 1978; Keller and Swanson, 1979; Keller et al, 1981; Toews and Moore, 1982). However, relatively little work has been done on the actual placement, or arrangement, of the material within the channel zone. When faced with the task of placing large organic debris in a channel with the objective of duplicating natural conditions, it remains unclear where, and in what orientation, the material should be located.

The purpose of this paper is to report findings from large organic debris studies conducted in the Queen Charlotte Islands. The objective of the study is to compare large organic debris characteristics in logged and unlogged watersheds. This objective encompasses two central questions; first, how is the large organic debris organized in the channel? and second, how does the woody material act to influence channel morphology? The work was carried out as part of the federally and provincially funded Fish-Forestry Interaction Program (FFIP).

STUDY DESIGN, AREA AND METHODS

Within the overall FFIP design (Poulin, 1983), four stream basins were selected for the study of large organic debris. A total of four unlogged and three logged stream reaches were considered in detail. Their locations are shown in Figure 1. Basin characteristics are given in Table 1. Mosquito and Government Creeks constitute one pair; both basins have thick Quaternary deposits (fluvio-glacial gravels and cobbles) in the valley bottoms. Bonanza and Hangover, the second pair, have marine muds in the reaches studied.

The Queen Charlotte Islands exhibit considerable climatic variability. Mean annual total precipitation amounts range from approximately 1300 mm/yr in the north central and northeastern areas to over 4000 mm/yr along the west coast. All study basins lie within a zone characterized by between 3660 and 3780 mm of precipitation per year.

The study areas are within the Coastal Western Hemlock biogeoclimatic zone (Toews and Wilford, 1978). The commercial stands at lower elevations are composed of western hemlock, Sitka spruce, western red cedar and yellow cedar (Carr, 1983). Bonanza Creek was logged during the early 1980s by high
Figure 1: Location map showing study watersheds

Figure 2: Frequency distribution of large organic debris by volume
Table 1: Watershed and Stream Reach Characteristics

<table>
<thead>
<tr>
<th>WATERSHEDS</th>
<th>Pair</th>
<th>Government Creek</th>
<th>Mosquito Creek</th>
<th>Hangover Creek</th>
<th>Bonanza Creek</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Area (km²)</td>
<td>16.2</td>
<td>17.3</td>
<td>20.2</td>
<td>68.3</td>
<td></td>
</tr>
<tr>
<td>Absolute Relief (m)</td>
<td>520</td>
<td>1,110</td>
<td>730</td>
<td>730</td>
<td></td>
</tr>
<tr>
<td>Stream Length (mainstem, km)</td>
<td>5.1</td>
<td>6.4</td>
<td>8.5</td>
<td>16.0</td>
<td></td>
</tr>
<tr>
<td>Geology</td>
<td>Triassic Basalt</td>
<td>Recent Alluvium</td>
<td>Triassic Basalt</td>
<td>Paleocene Basalt</td>
<td></td>
</tr>
<tr>
<td>Land Use</td>
<td>Unlogged</td>
<td>Logged</td>
<td>Unlogged</td>
<td>Logged</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>STREAM REACHES</th>
<th>Government Creek</th>
<th>Mosquito Creek</th>
<th>Hangover Creek</th>
<th>Bonanza Creek⁴</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reach</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
</tr>
<tr>
<td>Contributing Area (km²)</td>
<td>16.2</td>
<td>6.91</td>
<td>6.77</td>
<td>3.93</td>
</tr>
<tr>
<td>Stream Order</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Average Gradient</td>
<td>0.0090</td>
<td>0.0125</td>
<td>0.0199</td>
<td>0.0207</td>
</tr>
<tr>
<td>Total Length of Survey (m)</td>
<td>476</td>
<td>581</td>
<td>696</td>
<td>875</td>
</tr>
<tr>
<td>Mean Bankfull Width (m)</td>
<td>22.5</td>
<td>16</td>
<td>18</td>
<td>11</td>
</tr>
<tr>
<td>Pool/Riffle Ratio</td>
<td>1.35</td>
<td>1.63</td>
<td>1.83</td>
<td>1.50</td>
</tr>
<tr>
<td>No. of Widths per Pool-Riffle Sequence</td>
<td>1.9</td>
<td>2.8</td>
<td>2.5</td>
<td>2.9</td>
</tr>
<tr>
<td>No. of LOS Steps</td>
<td>3</td>
<td>4</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>% Change in Bed Elevation Due to LOS Steps</td>
<td>6.7</td>
<td>7.7</td>
<td>13.4</td>
<td>8.7</td>
</tr>
</tbody>
</table>

²From Sutherland-Brown (1983) - prominent rock type
³Strahler ordering based on 1:15,000-1:20,000 topographic maps and air photographs
⁴Bonanza A is below Bonanza-Hangover confluence
B is above Bonanza-Hangover confluence
line methods with haul road access. Logging was restricted to the south side of the channel and a leave strip was provided. Mosquito Creek was logged during the 1960s by similar techniques except logging extended to the channel edge and any timber felled into the channel was removed. Mosquito Tributary has experienced extensive channel widening and sediment accumulation since logging (Roberts, 1984).

The main large organic debris input mechanisms are mass-wastage from adjacent hillslopes, tree blow down, near channel debris input by bank erosion and flotation of woody material from upstream (Keller and Swanson, 1979). All are important in the streams studied, although direct mass-wastage was evident in Government Reach D only.

Because the position of the reach within the watershed is important, all paired basins had similar stream orders, channel gradients, contributing drainage basin areas, and geology. It is important to stress the similar biophysical conditions of each pair particularly in light of the large variability in woody debris quantities between streams studied by Keller and Swanson (1979) and Toews and Moore (1982). In those cases, differing vegetation type and logging techniques were important factors contributing to between reach variability.

Standard survey methods were used to map the study reaches. Maps were drafted and debris pieces were located on the maps in the field. Diameters at each end and length of each piece were measured and volumes estimated by assuming a cylindrical log shape. The amount of bark, branches and moss on each piece was recorded as an indication of length of time each piece had been in the channel. Pieces were also described according to their influence in forming steps, banks and directing stream flow.

RESULTS AND DISCUSSION

Large Organic Debris Quantities

The total number of organic pieces in each reach is presented in Table 2. The paired reaches reveal no consistent pattern. There are fewer pieces in Government Reach D than in Mosquito Tributary (more in logged, less in unlogged), yet the opposite pattern occurs between Mosquito Main and the other Government reaches. Combined, the number of pieces per unit area is slightly less for logged basins having a mean of 0.0271 pieces per area compared to the unlogged basin mean of 0.0384 pieces per unit area of channel.

The range of large organic debris volumes per unit area of channel is given in Table 2. The mean debris loading for unlogged systems is 0.0528 m³/m² compared to a mean of 0.0352 m³/m² for logged basins. In all cases there are lower volumes in the logged streams. The mean volume of debris pieces for each reach is presented in Table 2. The large standard deviations indicate that the woody material consists of a wide range of sizes. If logging alters the character of woody material, through both removal of large material and break-up of material into smaller pieces (Toews and Moore, 1982), there should be a difference in the size distribution between stream type. The distributions of woody material volumes are summarized in Figure 2. Frequency curves for individual reaches (not presented here) show that
### Table 2: Number of Pieces and Volume of Large Organic Debris and Channel widths associated with Debris.

<table>
<thead>
<tr>
<th>Stream</th>
<th>Number of Pieces</th>
<th>Volume (m$^3$)</th>
<th>Reach Area (m$^2$)</th>
<th>No./Unit Area</th>
<th>Vol/Unit Area</th>
<th>Mean LOD Vol. (m$^3$)</th>
<th>Standard Deviation LOD Vol. (m$^3$)</th>
<th>Stability Index</th>
<th>Characteristic width (m)</th>
<th>Mean width (m)</th>
<th>Low debris vol.</th>
<th>Mean width High debris vol.</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Government:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reach B</td>
<td>236</td>
<td>280.04</td>
<td>4,377.5</td>
<td>0.0478</td>
<td>0.0567</td>
<td>1.19</td>
<td>2.83</td>
<td>high</td>
<td>20.2</td>
<td>16.1</td>
<td>12.1-29.0, n=29</td>
<td>22.2</td>
<td>10.0-32.8, n=30</td>
</tr>
<tr>
<td>Reach C</td>
<td>204</td>
<td>306.83</td>
<td>5,266.2</td>
<td>0.0367</td>
<td>0.0573</td>
<td>1.50</td>
<td>4.82</td>
<td>high</td>
<td>21.1</td>
<td>22.0</td>
<td>16.0-29.2, n=31</td>
<td>19.3</td>
<td>15.4-26.1, n=20</td>
</tr>
<tr>
<td>Reach D</td>
<td>186</td>
<td>192.90</td>
<td>4,320.3</td>
<td>0.0431</td>
<td>0.0446</td>
<td>1.04</td>
<td>2.98</td>
<td>high</td>
<td>18.8</td>
<td>17.9</td>
<td>10.9-30.4, n=38</td>
<td>21.6</td>
<td>9.5-32.0, n=17</td>
</tr>
<tr>
<td>Mosquito:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Main*</td>
<td>209</td>
<td>286.46</td>
<td>10,153.7</td>
<td>0.0206</td>
<td>0.0282</td>
<td>1.37</td>
<td>4.52</td>
<td>low</td>
<td>37.6</td>
<td>38.9</td>
<td>32.0-43.2, n=18</td>
<td>41.3</td>
<td>34.0-49.5, n=16</td>
</tr>
<tr>
<td>Tributary*</td>
<td>290+</td>
<td>234.05</td>
<td>6,169.3</td>
<td>0.0470+0.0379</td>
<td>0.69</td>
<td>2.33</td>
<td>low</td>
<td>low</td>
<td>27.7</td>
<td>25.5</td>
<td>14.7-33.5, n=34</td>
<td>35.8</td>
<td>22.8-37.5, n=6</td>
</tr>
<tr>
<td>Hangover</td>
<td>182</td>
<td>393.36</td>
<td>7,653.7</td>
<td>0.0238</td>
<td>0.0517</td>
<td>2.17</td>
<td>5.22</td>
<td>high</td>
<td>29.3</td>
<td>26.4</td>
<td>18.1-47.4, n=31</td>
<td>36.8</td>
<td>22.6-70.0, n=23</td>
</tr>
<tr>
<td>Bonanza*</td>
<td>186</td>
<td>537.85</td>
<td>13,653.7</td>
<td>0.0136</td>
<td>0.0294</td>
<td>3.09</td>
<td>7.08</td>
<td>medium</td>
<td>45.4</td>
<td>44.1</td>
<td>27.6-63.0, n=16</td>
<td>42.2</td>
<td>29.0-59.5, n=18</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 Stability Index: high >50% LOD covered by moss; medium 20-50%; low <30%

*Logged basins
small material is more frequent (significant at $\alpha = 0.05$) in Mosquito than Government. The same trend is evident in Hangover and Bonanza but the difference is not significant at $\alpha = 0.05$. The summary plot (Figure 2) shows a significantly higher frequency of very small material in logged channels and more intermediate size material (0.13 to 3.0 m$^3$) in unlogged streams. There are few very large pieces in either stream type. The degree of moss coverage indicates that the material in unlogged channels is more stable than material in logged streams (Table 2).

Large Organic Debris Arrangement within the Channel Zone

Very little work has been conducted on orientation of large organic debris within the channel zone. Orientation is an important consideration because specific channel features, such as pools, riffles and gravel bars will depend partially on the way in which woody material influences stream flow direction. Specific orientations may produce particular features; some may be preferred fish habitat.

Initially, arrangement will depend on the mechanism of input from the overbank zone to the stream channel. Woody material derived from landslides, wind-blown trees and bank erosion should be approximately random (due to interference en-route) in orientation. However, once the material is moved during high flow events there may be a preferred arrangement along the channel. Field investigations indicate that much of the stable material, which influences pool and riffle configuration and stored clastic sediment, crosses the channel diagonally with the logs pointing either up or down stream. Cross-channel debris appears more prevalent in unlogged basins. This is thought to be due to the generally smaller nature and greater mobility of debris in logged streams.

The orientation of each debris piece was measured on the maps of woody material placement. All measurements were made with respect to a center line drawn parallel to the trend of the channel banks (Figure 3). Log direction (pointing up or down stream) was based on log diameter or position of the rootwad. The long axes of debris clusters were used if it was not possible to account for individual pieces.

The distribution of number of pieces per orientation sector is similar to that of the mean volume except that disproportionately few pieces comprise a large volume in some sectors, particularly $340^\circ$ to $360^\circ$ in the logged stream type. The volume of large organic debris contained within 20° interval sectors for each reach is presented in Figure 3. It is evident (Figure 3a) that no simple or strongly consistent pattern emerges when considering only unlogged channels. In general, the distribution is multi-modal with maximum volumes occurring in sectors between $80^\circ$ to $160^\circ$ and $200^\circ$ to $280^\circ$. The preferred orientation is debris placed diagonally across the channel, from either right or left bank, with the large end of the tree on the downstream end and close to the bank.

In the logged and unlogged pairs (Figure 3b and 3c), there appears to be a shift in preferred orientation from diagonal in the unlogged towards parallel in the logged streams. The relatively high volumes (approximately 40% of the total material) arranged between $320^\circ$ and $20^\circ$ in Mosquito Main indicates that much of the material is oriented with the large end upstream.
Figure 3: Large organic debris orientation by volume

DEFINITION SKETCH

KEY:
- Low flow channel-edge
- Flow direction
- Bank bottom
- Rootwad and LOD
- Orientation reference line
- Sub-reach division
- Sub-reach 3: LOD no.1

21 = 0°  31 = 0°/360°
22 = 140°  32 = 90°
23 = 227°  33 = 180°
24 = 270°  34

a) Government
   - Reach B
   - Reach C
   - Reach D

b) Gov't Reach C
   - Mesquite Main

c) Gov't Reach D
   - Maq. Tributary

d) Hangover
   - Bonanza

Orientation of LOD (°)
The large value (22.6%) for the 80° to 100° sector in Mosquito Tributary is associated with one major log jam.

The debris distributions by orientation sector for Hangover and Bonanza are similar (Figure 3d). The main departure is an increased amount lying upstream parallel in Bonanza. Generally, however, both streams have a similar pattern to Government. The similarity of the logged Bonanza reach is probably due to abundant large material remaining in the system.

Another feature of large organic debris arrangement is the tendency for material to accumulate into large clusters. To investigate this clustering, the study reaches were partitioned into zones with length equal to one bankfull width. The volume of material within each zone was calculated and the differences between these values and the mean volume for the entire reach were plotted (Figure 4). Caution must be exercised when interpreting these results because the stream lengths are relatively short (less than twelve bankfull widths).

The cluster spacing for the three Government reaches (Figure 4a and 4b) are similar; spacings of 3.0 to 3.7 widths are longer than pool and riffle spacings of 2.5 to 2.9 widths (Table 2). The width of each cluster is less than 1.5 widths for all reaches. The cluster and pool to riffle spacing for Mosquito Main (Figure 4b and Table 2) are similar and both are less than their unlogged pairs. Mosquito Tributary (Figure 4c) is characterized by only 1 cluster in 8 widths compared to a spacing of 3.7 widths for Government Reach D. Although the Tributary reach is relatively short, the large cluster spacing value is similar to that found during long profile surveys over greater distances.

Although the study reaches are relatively short it is possible to consider the implications of the orientation and clustering studies. In unlogged stream reaches the large organic debris is commonly oriented diagonally across the channel with the large end of the log against the downstream bank. Debris in this position tends to be stable and increases variability in channel depth and width, hence influencing habitat conditions. Large woody debris appears to accumulate into clusters which range between 3 and 4 widths apart in unlogged channels. Pool and riffle spacing appear to be slightly less than the cluster spacing. These patterns could be duplicated in attempts to rehabilitate disturbed stream channels. 

The Influence of Large Organic Debris on Channel Morphology

Large organic debris influences several channel features; its effect on channel gradient, depth and width will be considered here. Debris steps account for between 6.7% and 13.4% of the total drop in bed elevation (Table 1) in Government Creek but do not contribute to bed elevation change in Mosquito Creek. Large quantities of stored sediment occur immediately upstream of the debris steps. In Mosquito Main and Tributary, very large amounts of sediment are stored upstream of major, but less frequently occurring log jams. Therefore, in both stream types large organic debris exerts considerable control over the long profile. In unlogged streams, slope is adjusted to a combination of log jams and discrete debris steps while in logged channels, slope is influenced primarily by log jams. The stability of the unlogged channel is increased because sediment is stored
Figure 4: Clustering of large organic debris

Figure 5: Longitudinal profile of Hangover Creek
more evenly along the channel and the many log steps and minor jams buffer the effects of large flood flows and failure of individual barriers. Large floods in logged channels may displace infrequent debris obstructions resulting in major redistribution of sediment. This argument is in agreement with the generally high stability index ratings for unlogged channels and low ratings for logged channels (Table 2). The debris steps within the study sections always consist of large pieces, greater than 2 m³ in volume and are oriented predominantly between 80° to 130° and 230° to 280°.

Streams flowing in alluvial channels form relatively regular alternating deep and shallow areas. Pools and riffles form regardless of the influence of woody material. The role of large organic material is to increase the variability in channel depths (Keller and Tally, 1978).

An example of the influence on depth variability is presented in Figure 5. Hangover Creek has two distinct sections; the lower half has well below normal debris loading and the upper half has above average quantities (Figure 4c). The long profile shows the downstream section as one long deep pool (2.5 widths in length), whereas the upstream section alternates between short pools and riffles (combined total less than 1 width). Large organic debris increases depth variability by producing scour pools parallel and downstream of the debris.

The Mosquito Tributary long profile shows several relatively deep but short pools and long riffles (pool-riffle ratio = 0.63, Table 2). In all cases the pools are associated with very large (trunk diameters greater than 1 m), usually upright, stumps, or logs oriented parallel to the channel. During summer low flow conditions, channels in the sediment stored behind log jams can become de-watered with the only surface water found in pools associated with the stumps.

Large organic material also influences channel width. Table 2 includes a summary of channel widths in zones with above and below normal debris volumes. With the exception of Government Reach C, the mean channel width is greater in zones of above normal debris amounts. Hangover Creek, for example, has a relatively constant width on its downstream section (low debris loading, Figure 4c) and the mean width increases by almost 30% in the upstream zones with abundant debris. The width doubles in certain areas with large amounts of material. Other systems display similar patterns but there is some indication that width variability is reduced in logged basins (e.g. Mosquito Main and Bonanza, Table 2).

SUMMARY

This study indicates that although there is no difference in the number of large organic debris pieces between logged and unlogged basins, there is a shift towards smaller material in the former type. In third and fourth order streams, woody material has a tendency to be oriented diagonally across the stream with their large ends located against the downstream banks. Material tends to cluster at intervals of approximately 3 to 4 widths and the clusters tend not to exceed 2 widths in length. It has been shown that woody material influences channel gradient and stability, increases depth variability and causes local channel widening.
REFERENCES


Sutherland Brown, A., 1968, Geology of the Queen Charlotte Islands, British Columbia, B.C. Dept. of Mines and Petroleum Resources.


