EVALUATING THE IMPACT OF RESTORATION USING LARGE WOOD ON THE BEVERLEY BROOK, WIMBLEDON COMMON, LONDON

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INTRODUCTION

This report evaluates the early impact of restoration interventions along a 2 km length of the Beverley Brook within Wimbledon Common, Surrey, England. The restoration involved three actions: removal of wooden toe reinforcement of the banks; felling of some riparian trees; introduction of the felled wood into the river channel.

The restoration was implemented early in 2019. Figure 1a shows a typical view of the river prior to restoration. While the banks are well vegetated and support mature trees, they have relatively smooth profiles and are very high. This coupled with the wide river bed suggests historical 'channelisation' of the river many decades ago with subsequent slow morphological recovery under vegetation colonisation to produce the current semi-natural woodland cover. Although the river has a gravel bed, much of the gravel is buried below layers of fine sand and silt, and much of silt has a high organic content.

The MoRPh survey (<u>www.modularriversurvey.org</u>, Gurnell et al., 2019, Shuker et al., 2017) was used at six month intervals to monitor the early impact of the restoration actions using a Before-After-Control-Impact (BACI) monitoring design. The pre-restoration (baseline) condition of the river was observed in December 2018, thereafter the post-restoration condition and subsequent early responses to restoration were monitored in June 2019, December 2019 and June 2020. Graphical presentations of the MoRPh survey data are used to illustrate the restoration actions, the direct physical effects of those actions, and the short-term sedimentary and morphological consequences of the actions.



Figure 1: (a). the river prior to restoration. The three types of wood introduced during restoration: trees (b), large logs, trunks or stumps (c), brash, branches, small logs (d).

METHODS

The study site and monitoring design

Figure 2 illustrates the study reach and the layout of the field survey. Monitoring was conducted within 8 subreaches (A1, A2, B1, B2, C1, C2, D1, D2), each comprised of 5 contiguous MoRPh survey modules. Because the river was typically between 5 and 10 m wide, each MoRPh survey module was 20m long and thus each subreach was 100 m long.

Subreaches A1 and A2 were located in a section of the river that was not restored, providing two upstream control subreaches for comparison with six downstream treatment subreaches. The treatment subreaches (B1, B2, C1, C2, D1, D2) were located to capture variability in application of the restoration measures. The restoration was envisaged to proceed from downstream to upstream but the upstream extent of the restoration depended on time and resources so was unknown when the pre-project MoRPh surveys were carried out.

Because the restoration was to be implemented early in 2019, the pre-project MoRPh surveys were conducted in early December 2018. Thereafter, surveys were conducted at sixmonthly intervals to include a survey soon after project completion (early June 2019), one year after the pre-project survey (early December 2019), and one full year after project completion (early June 2020).

In addition to conducting MoRPh surveys on these four occasion, the quantity and types of wood features placed in the river were also recorded. Three types of emplaced wood feature were observed (Figure 1 b, c, d): trees (i.e. trunks with branches still attached); large logs, entire trunks, or tree stumps; brash, branches, small logs.

In some cases large branches may have been recorded as trees, but in all cases there was a distinct stem (trunk) supporting a canopy of branches. Large logs were identified as those that were at least 10 cm in diameter and 1 m long, although in practise they were much larger since they were usually parts of tree trunks or the main stems of large branches, but they had the common property of being single unbranched wood pieces. Wood classified as either trees or large logs, trunks or stumps was recorded as a count. Wood classified as brash, branches, small logs was recorded as an areal extent across the river bed (i.e. it was scored from 0 to 10 to represent units of 10% of the bed area being surveyed).

The 8 subreaches and 4 surveys supported a BACI design, whereby observations from subreaches A1 and A2 provided controls against which observations from subreaches B1, B2, C1, C2, D1, D2 could be compared. Such comparisons allow responses to the restoration actions in the treatment subreaches to be separated from responses across all subreaches to other factors, such as the occurrence of particular flow events. Interestingly, subreach A2 experienced natural tree fall and wood input during the survey period. This allowed A1 to act as a true control (no change in in-channel wood) while A2 provided evidence of changes in response to natural wood additions. The difference between 'natural' wood and 'introduced' wood is that the latter was attached to chestnut stakes driven into the river bed or, in the case of whole trees and larger logs, trunks were secured with a single Platypus© ground anchor. As a result, the untethered 'natural' wood could be moved freely by river flows whereas the 'introduced' wood could only move locally around the stakes or ground anchor to which it was tethered.



Figure 2: Location and layout of monitoring subreaches within the study reach on the Beverley Brook

Survey data analysis

The MoRPh survey data were used to investigate and summarise: (i) the restoration actions; (ii) the direct physical effects of the restoration actions; and (iii) the early sedimentary and morphological consequences of the restoration actions

All of these aspects were investigated by plotting graphs representing the aggregated observations of surveyed properties across groups of 5 MoRPh modules (also referred to as MoRPh5 subreaches). MoRPh surveys either record the number or count (e.g. pools) or the abundance (areal or linear extent, e.g. silt bed material, side bars) of a particular property / feature of the river bed, bank faces and bank tops. For the number / count fields, the aggregate over the five MoRPh modules was the sum of these numbers / counts. For the abundance fields, an APTE (absent, trace, present, extensive) scale is used, so the observed abundances were translated into approximate mid-point percentages (0, 2, 19, 67%, respectively, for A, P, T, E) and then summed to give a total over the 5 MoRPh modules.

Therefore, for APTE fields, the maximum possible aggregated value is 335 (i.e. 5x67) for bed features and 670 (i.e. $5 \times 2 \times 67$) for features recorded on both banks. However, many bank features tend to alternate from one bank to the other along the length of a river (e.g. side bars), giving a likely achievable maximum of 335.

To quantify the restoration actions, information recorded for the following properties were graphed. The quantity and type of introduced wood and the linear extent of toe reinforcement were plotted to represent these two direct restoration actions. The areal extent of trees on each river bank top and face were plotted to identify the main locations and extent of tree felling that supplied the introduced wood.

To quantify the direct physical effects of the restoration actions the following survey fields were graphed:

- the areal extent of channel shade (before and after tree felling);
- the areal extent of large wood in the channel (including 'introduced' wood and any 'natural' fallen wood); and
- the areal extent of 'discrete' accumulations of smaller organic material in the channel.

'Discrete' accumulations of organic material are substantial, compact, dense accumulations of twigs and leaves that are built by river flows from dispersed twigs and leaves delivered to the river naturally (e.g. autumn leaf fall) or during tree felling and wood introduction operations.

To represent the sedimentary and morphological consequences of the restoration actions, survey observations were selected that showed 'consistent' and/or 'notable' changes. As a result of inevitable observer (surveyor) variance in identifying and quantifying features during the field surveys, apparent variations between surveys at the same site may be recorded even when no change has occurred. Therefore, 'notable' changes were identified as those where differences in the aggregated values between surveys exceeded at least 20% of the potential range. For example, for data fields based on the APTE scale, a 20% change is equivalent to a numerical change of 67 when the potential range is 0 to 335. This is equivalent to an observation in at least one of the five MoRPh surveys moving from A (absent) to E (extensive). This represents an enormous change within 6 months, which is highly unlikely to be the result of observer error. Alternatively, it is equivalent to at least 4 MoRPh surveys showing an increase from A (absent) to P (present), which is a sizeable change across almost all of the five MoRPh surveys that is again unlikely to be the result of observer error. 'Consistent' changes are those where several subreaches show changes in the same (positive or negative) direction between surveys, even if these are smaller than 20% of the possible range, since it is unlikely that such consistent changes would occur simply through observer error.

RESULTS

Restoration Actions

The magnitudes of the restoration actions across the 8 subreaches are illustrated in Figure 3, either by quantifying the introduced wood (Figure 3a) or by comparing observations before (December 2018) and shortly after (June 2019) the restoration (Figure 3 b, c, d, e, f).

Introduction of wood to the river channel bed, varied in both its type and also its number or areal extent across the 6 treatment subreaches (Figure 3a). No wood was deliberately introduced into the control subreaches (A1, A2). The greatest variety in both the types and quantity of introduced wood was observed in subreaches B1 and B2. Subreaches C1 and D2 received less wood than B1 and B2, and whereas C1 received all three types of wood, no trees were added to subreach D2. Only quite small amounts and a restricted range of types of wood were introduced into subreaches C2 and D1. Note that in Figure 3a, trees and large logs/trunks/stumps are recorded as a count across the 5 MoRPh surveys, whereas brash/branches/small logs are recorded in units of 10% areal extent across the river bed (i.e. a potential range of 0 to 10).

The second restoration action was the removal of toe reinforcement from both banks within a potential numerical range of 0 to 335 on each bank and thus 670 for both banks (Figure 3b). The linear extent of toe reinforcement in the control subreaches (A1, A2) is very high and remains unchanged, whereas there are major reductions in the linear extent of reinforcement in all the treatment subreaches (all observed reductions exceed 134 and thus show > 20% change within the potential 0 to 670 range), with almost complete removal of toe reinforcement along subreaches B1, C1 and D2.

The third restoration action was tree felling, which provided the wood for introduction into the river. Figures 3 c, d, e, f compare the areal extent of trees on each river bank top and bank face before and after the restoration The only notable reduction in tree cover on the exceeding 67) changes were observed. However, the right bank shows notable reductions in tree cover on the bank top (Figure 3d, subreaches B2, C1 and D2) and bank face (Figure 3f, subreaches B1, B2, D2) and no other notable changes whether positive or negative.

These restoration actions at each subreach are summarised in Table 1.

Table 1 Summary of presence	/ absence of restoratior	n actions at each subreach
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Restoration action		Subreach								
	A1*	A2*	B1	B2	C1	C2	D1	D2		
Introduced trees			\checkmark	\checkmark	\checkmark		\checkmark			
Introduced large logs			\checkmark	\checkmark	\checkmark	\checkmark		\checkmark		
Introduced small logs, branches, brash			\checkmark	\checkmark	\checkmark	\checkmark	\checkmark	\checkmark		
Toe board removal			\checkmark		\checkmark			\checkmark		
Tree felling			\checkmark	\checkmark	\checkmark	\checkmark		\checkmark		

* No restoration actions in the control subreaches (A1, A2), although there was some natural wood input (tree fall) to subreach A2.



Figure 3: A summary of river restoration actions (observed changes between the preproject survey in December 2018 and the first post-project survey in June 2019):

a. the amount and types (whole trees, large logs-trunks-stumps, brash-branches-small logs) of wood added to the subreaches (note that where the vertical axis refers to brash-branches-small logs, it is expressed in units of approximately 10% cover of the river bed)

b. change in the linear extent of toe reinforcement (maximum possible value 670 across both bank faces).

c. to f. change in the areal extent of tree cover (maximum possible value 335) on the left and right bank tops (c, d) and left and right bank faces (e, f).

Direct Physical Effects of the Restoration Actions

Direct effects of the restoration actions are illustrated in Figure 4. Changes in shading of the channel are illustrated by comparing winter pre-project (December 2018) and post project (December 2019) conditions (Figure 4a). There were notable reductions in shade within subreaches B2, C1, C2 and D2, reflecting tree felling. Notable increases in the areal extent of wood are observed as wood is introduced between the first two surveys (December 2018, June 2019), particularly in subreaches B1, B2, C1 and D2, with further consistent but small increases in all the treatment subreaches as additional (mobile) wood pieces are trapped in the following two surveys (December 2019, June 2020) (Figure 4b). There is also close to a 20% increase in the areal extent of wood retained in control subreach A2 over the observation period as a result of natural wood input processes. In addition to these larger wood pieces, discrete organic accumulations comprised largely of leaves and twigs increase consistently in all treatment subreaches and one control subreach (A2) through the two year observation period, with notable increases in subreaches B1, B2, C1, D1 and D2 (Figure 4c). The introduced wood slows local water flow velocities, leading to consistent increases in the areal extent of no perceptible flow immediately post restoration (Figure 4d, June 2019) followed by either no change or a slight reduction as the wood settles and becomes more streamlined over the last two observation periods (December 2019, June 2020). These reductions in the area of no perceptible flow are notable (> 67) in treatment subreaches B1, B2, C1 and D2. In addition there is a smaller but still sizeable increase in the area of no perceptible flow in control subreach A2. These changes are summarised in Table 2

Sedimentary and Morphological Consequences of the Restoration Actions

Sedimentary consequences of the restoration actions are expressed mainly by the silt cover on the river bed (Figure 5 a, b, c). To remove seasonal variations in bed condition, these changes are illustrated by comparing the pre-project (December 2018) and post project (December 2019) winter observations. The data shows consistent but modest increases in the area of the bed covered by substantial thicknesses of silt in five of the treatment subreaches (B2, C1, C2, D1, D2, Figure 5a), and the area of the bed covered by a continuous superficial layer of silt in four of the treatment subreaches (C1, C2, D1, D2, Figure 5c). At the same time, there are notable decreases in the area of the bed covered by a discontinuous, superficial layer of silt in both control subreaches and three of the treatment subreaches (A1, A2, B1, B2, D1, Figure 5e).

Three main morphological changes were observed. First, a consistent increase was observed in the number of pools in 5 of the treatment subreaches (Figure 5b, 0 to 3 pools in subreach B1, 0 to 6 in B2, 1 to 4 in C1, 0 to 1 in C2, 1 to 3 in D1) but there was also an increase from 3 to 7 in control subreach A2. Second, the linear extent of marginal backwaters (embayments at the bank toe) showed a notable increase in treatment subreaches B2, C1 and D2 (Figure 5d). This takes account of the fact that although such backwaters could occur on opposing banks (theoretical maximum range 0 to 670), in practise they tend to occur on only one bank (realistic maximum range of 0 to 335). Lastly, four of the treatment subreaches (B1, B2, C1, D2, Figure 5f) showed a notable appearance (B1, B2, C1) or increase (D2) in the

linear extent of unvegetated side bars between the third and fourth surveys. These changes are summarised in Table 3



Figure 4: Direct consequences of restoration actions:

a. change in the areal extent (maximum possible value 335) of channel shading in winter between the first survey (pre-project - December 2018) and the third survey (post-project - December 2019)

b to d. changes in the areal extent (maximum possible value 335) of large wood (b), discrete accumulations of organic material (c), and no perceptible flow (d) across the channel bed through the four surveys

Table 2:	Summary	of notable	immediate	changes	following	restoration
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Notable changes	Subreaches							
	A1*	A2*	B1	B2	C1	C2	D1	D2
Reductions in shade				\checkmark	\checkmark	\checkmark		\checkmark
Increase in areal extent of wood		\checkmark	\checkmark	\checkmark	\checkmark			\checkmark
Increase in areal extent of discrete organic			\checkmark	\checkmark	\checkmark		\checkmark	\checkmark
accumulations								
Increase in areal extent of no perceptible flow		\checkmark	\checkmark	\checkmark	\checkmark			\checkmark

* Changes observed in the control subreaches (A1, A2) cannot be attributed to restoration actions.



Figure 5: Secondary consequences of restoration actions:

a, c, e. changes in the areal extent (maximum possible value 335) of thick silt bed material (a), continuous silt (c) patchy silt (e) overlying coarser material from the first survey (preproject - December 2018) to the third survey (post-project - December 2019)

b, d, f. changes in the number of pools (count, b), the extent of marginal backwaters (maximum possible value 670, d) and the extent of unvegetated side bars (maximum possible value 670, f) through the four surveys

Notable changes	Subreach							
	A1	A2	B1	B2	C1	C2	D1	D2
Increase in areal extent of silt substrate				\checkmark	\checkmark	\checkmark	\checkmark	\checkmark
Increase in areal extent of continuous superficial silt layer					\checkmark	\checkmark	\checkmark	\checkmark
Decrease in areal extent of discontinuous superficial silt layer	\checkmark	✓	✓	✓			✓	
Increased number of pools		\checkmark	\checkmark	\checkmark	\checkmark	\checkmark	\checkmark	
Increased linear extent of marginal backwaters				✓	✓			\checkmark
Increased linear extent of unvegetated side bars			✓	✓	✓			\checkmark

Table 3: Summary of notable secondary physical consequences of the restoration actions

DISCUSSION

Control Subreaches

Although no restoration actions were applied to the control subreaches A1 and A2, one large fallen tree was present at the junction between A1 and A2 at the start of the monitoring period and another large tree fell naturally into subreach A2 during the monitoring period. The fallen tree at the junction between the two subreaches bridged the channel and was suspended above the river bed. It gradually settled into the channel through the monitoring period so that by June 2020 it was touching the water surface and had started to accumulate large floating wood pieces on its upstream side. Apart from this minor effect on the river at its downstream limit, control subreach A1 was unaffected by tree fall or other significant wood accumulation during the observation period.

However, a tree that fell into subreach A2 (at the junction between modules 4 and 5) had a far stronger impact on the river bed than that at the junction between the two control reaches. Figure 6 illustrates the tree's location taken looking downstream from approximately the same position on each monitoring date. In December 2018, there was a small fallen, heavily decayed tree aligned along the toe of the left bank. Between December 2018 and June 2019, a large tree fell diagonally across the river, covering the pre-existing smaller tree and touching the river bed. By June 2019, this tree was already trapping organic material including small wood pieces and had induced the development of a scour pool towards the right bank and gravel bar on the downstream river bed. Higher water levels disguise some of these bed features in the December 2019 photograph but more wood and organic material had accumulated around the fallen tree. By June 2020, following further trapping of wood and organic material, a major pool was ponded upstream of the tree, a scour pool was present towards the right bank and immediately downstream of the tree, with a large gravel bar further downstream (the bar is just visible on the right side of the June 2020 photograph, Figure 6). These changes are typical consequences of natural tree fall. The complex and rapid rate of change in the channel form results not only from the

presence of the tree but also the fact that it is not tethered and so has been able to move both laterally and vertically as it interacts with different flow events.



Figure 6: Changes in the presence of wood and organic material and in the morphology of the river bed at a site in control subreach A2 before and after natural tree fall.

Treatment subreaches

The post-restoration evolution of the treatment subreaches is most easily established by comparing any changes with control subreach A1. However, control subreach A2 provides a different perspective by illustrating the effect of natural tree fall and thus untethered wood over the same time period.

Treatment subreaches B1, B2, C1 and D2 received the most wood and showed the greatest corresponding reduction in bank tree cover, particularly on the right bank. All treatment subreaches experienced over 50% removal of toe reinforcement, with B1, C1 and D2 experiencing close to 100% removal (Figure 3).

While all of the treatment subreaches showed some response to the restoration actions when compared with the negligible changes observed in the control subreach A1, the strongest responses were consistently observed in subreaches B1, B2, C1 and D2. This confirms that greater restoration actions delivered greater responses. At this early stage in the river's response / recovery, there has been continued accumulation of wood coupled with retention of discrete accumulations of smaller organic material, all of which have

reduced flow velocities across the affected areas of the river bed and resulted in an increase in the area with no perceptible flow (Figure 4d). While the MoRPh surveys were conducted during periods of relatively low flow, the effects of the accumulations of wood and organic material during higher flows would have been to increase flow velocities across the woodfree areas of the river bed. These hydraulic impacts of the wood and organic material can explain the increase in the area of the bed under thick or continuous superficial silt. Silt being transported by the river is likely to move from areas of higher velocity into the areas of lower flow velocity covered by wood and organic material and to accumulate there. This explains the appearance of unvegetated silt side bars towards the end of the observation period as the silt has built up beneath the wood and organic material. In addition, areas of the bed unaffected by wood and organic material are likely to be subject to relatively higher flow velocities, leading to the scouring of pools in the river bed and the erosion of the toes of banks exposed by reinforcement removal. Such bank scour produces marginal backwaters or embayments at the channel edge. Although erosion of the bed is occurring, as evidenced by pool development, this is not leading to a notable increase in the exposure of bed gravel. This is explained by the input of substantial amounts of silt from bank scour. Figure 7 visualises how the river has changed as the result of the described responses to the restoration actions.



Figure 7: Visualisation of how the river has responded to restoration actions over the monitoring period and how it may continue to respond in the future.

The accelerated response to the untethered fallen tree in subreach A2 illustrates some of marginal backwaters, the presence of extensive unvegetated silt side bars, an increasing

number of pools (Figure 5) and the mobilisation of the gravel bed to produce a ponded pool, a scour pool and a gravel bar (Figure 6) and a riffle downstream (not visible in Figure 6).

Figure 7 also visualises how the river may continue to evolve over the next 5 to 10 years. Bed scour and pool development is likely to continue in parallel with the development of side bars and backwaters (recesses in the bank line). As the side bars aggrade and transition from unvegetated to vegetated bars and then in some cases to berms, benches and eventually extensions of the river bank, the channel will narrow. A narrowing channel will induce faster flow velocities, particularly across wood-free areas of the bed, and as a result the mobilisation of gravel to produce distinct gravel riffles and bars. If the channel narrowing also promotes significant bank erosion, particularly opposite developing bars, berms and benches, the channel will become sinuous and trees on the eroding banks will fall into the channel.

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