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Assessing the Decay and Integrity of Timber Structures used for Natural Flood Management on Sutherland Beck, Pickering, North Yorkshire

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Forest Research

April 2020

The Research Agency of the Forestry Commission

Introduction

Natural Flood Management (NFM) involves implementing measures that help to protect, restore and emulate the natural functions of catchments, floodplains, and rivers. NFM takes many different forms and can be applied in a range of different environments. Timber structures placed in watercourses and on their floodplains are effective NFM measures, restricting the flow and potentially holding large volumes of water during flood events, helping to reduce downstream flood risk. In an environment where constant wetting and drying occurs, timbers used for NFM measures have a high susceptibility to rot, and over time will degrade to a point of failure and collapse, potentially increasing the risk of damage to property and assets downstream.

The use of timber structures in NFM is becoming increasingly popular, yet very little is known as to how quickly the timbers degrade and how this affects their lifespan and thus effectiveness. The aim of this project was to carry out an assessment of the degree of decay in two timber flood storage bunds and three in-stream leaky woody dams (LWD) installed within or adjacent to the beaver reintroduction enclosure on Sutherland Beck, near Pickering. The timber flood storage bunds were constructed in August 2011 as part of the Defra funded, Slowing the Flow partnership project and thus are now eight and a half years old, whilst the three in-stream structures were constructed as part of the beaver reintroduction project and installed in 2019.

A ‘microdrill’ (IML Resi-PD microdrill) was used to survey and measure the extent of decay within the timber structures. The results can help determine their lifespan and inform the development of guidance on appropriate maintenance schedules for repair and/or replacement, thereby increasing confidence in the overall integrity and safety of the structures over time. The microdrill technique is already extensively used on trees, utility poles (BT Openreach for example use the devices to test their wooden utility poles for timber degradation) and other wooden structures, including play equipment, lock gates, jetties and historic timbers.

Methodology

The microdrill measures resistance through a given depth of wood (Figure 1). A consistent force is applied and the percent amplitude of resistance recorded. As the probe penetrates the timber, the difference in resistance between dense and less dense wood, including areas of decay, is measured, giving an indication of timber condition.

An example of the output from the microdrill is given in Figure 2, which shows the set of drill readings from a single drill point, indicating an area of decay at between 22 mm and 40 mm depth. The device returns high resolution data, with a reading taken every 0.1 mm depth. The full diameter of each log was drilled.

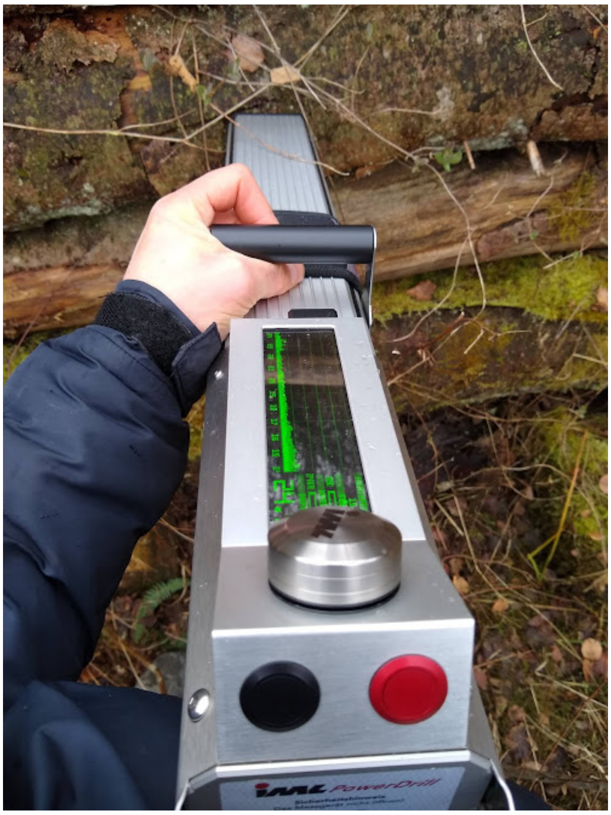

Figure 1 The microdrill being used to measure decay in one of the logs in a timber bund

There are several adjustable controls on the operation of the drill, including drill feed and rotational speed. These were selected from a manual according to tree species (e.g. hardwood or softwood). All the logs used in the selected NFM structures were softwood/conifers and therefore a drill feed of 100 cm/min and rotational speed of 2500 rpm were applied. The device has a failsafe to protect the drill from damage if excessive decay or voids are detected. When this occurs a zero value is recorded by the drill.

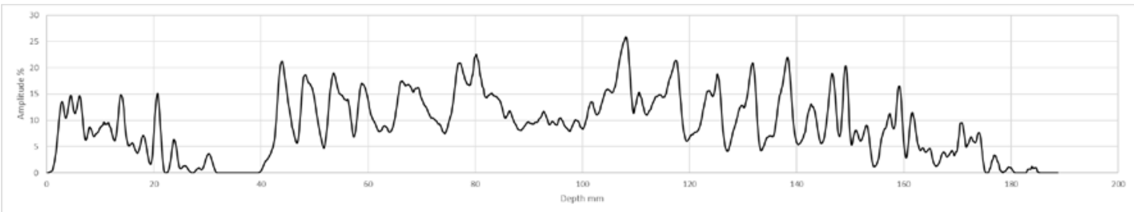

Figure 2 Output from the microdrill showing distinct areas of potential timber decay between 22 mm and 40 mm depth in the sampled log

Multiple measurements of amplitude were taken along each log (at 1.0 m intervals) in the timber flood storage bunds and LWD to assess their condition. This allowed the pattern of decay to be determined and potential relationships between the degree of decay and the height of the log above the ground or distance from the watercourse to be assessed. Measurements were also taken from the upright posts and tall tree stumps used to support the timber bunds.

To help calibrate the readings a set of measurements were taken from several living, healthy trees of the same species and age as the logs in the timber structures. Average values were calculated for each drill point in the logs and reference trees, and the ratio of decay used to assess log condition. A provisional threshold ratio of 0.4 was selected to define an excessive level of decay that would seriously weaken the structure, although this value remains subject to debate and requires checking through further study.

Results

Reference Tree Readings

Three healthy, living trees of the same age and species as the logs used in the NFM structures were selected to define reference conditions for the assessment of the degree of decay. Two measurements were taken at each of 50 cm, 100 cm and 150 cm distances up the stem of the three trees, giving a total of six sets of amplitudes per tree.

An average amplitude was calculated to obtain a reference value for the strength/condition of healthy trees. This is compared to typical amplitudes recorded for the two bunds and LWD in Figures 3a and 3b. The drill profile for the healthy trees showed consistently higher readings in the outer 7 cm depth of the circumference compared to the logs from the two timber bunds, indicating that this could be the progression of the decay front to date (Figure 3a). It is notable that the state of decay appeared to be worse on one side of the log compared to the other, with one side showing almost complete decay. Another observation was that the lower bund generally displayed lower readings compared to the upper bund, suggesting that the rate of decay was greater here. Decay appeared to be progressing throughout the width of the log from the lower bund, with pockets of complete decay close to the centre of the log (e.g. at 10 cm depth).

In contrast, the traces for the selected logs from the three LWD generally overlapped with those of the healthy trees, indicating little decay to date (Figure 3b). This accorded with the relatively young age of the structures, which were only installed in 2019. Aside from the outer 10 mm of the circumference, nearly all values for the three LWD were >5.

Assessment of Downstream/Lower Flood Storage Bund

The downstream flood storage bund on Sutherland Beck has a maximum height of 1.26 m, made up mostly of stacked, full length (ranging between 5 m and 13 m long) conifer timbers, extending 51 m across the floodplain. An additional stack of three timbers are located below the structure into the main channel to create the hydraulic throttle necessary to hold back water during high flows. The structure is made up of a total of 23 individual timbers/logs split between five sections. Each timber section is supported by a vertical wooden post driven into the ground or a standing tall tree stump, or both, either on the upstream or downstream face of the structure.

Figure 4 shows the relative condition of each log in the bund based on the ratio of the average amplitude to that of healthy standing trees. Using the selected threshold ratio of 0.4 for an acceptable level of decay, around half of the logs had more than 50% of their length below this value. The extent and level of decay was generally greatest in the top timbers and towards the northern side of the structure (right bank). This is likely to be due to the open ground on the right bank, leaving the structure more exposed to the weather and to wetting and drying. The southern side is sheltered by the steep valley side, being north facing and partly sheltered by the remaining standing trees and shrubs. Figure 5 displays an image looking across the structure to the south.

The top timber within the channel (Timber No. 0) is unusual in showing evidence of significant decay compared to those below and immediately above, which appeared to be sound (Figure 3a). However, the bottom two logs were replaced in 2019 after scouring of the south bank led to these timbers becoming loose and dropping down at the outside edge, causing more scouring. The decay was greatest at one end of the log and could have spread out from where it abuts the riverbank. Figure 6 shows the generally poor condition of the fifth log from the top, with moss extending across its surface from both banks.

The bottom timbers closest to the river channel appeared to be in the best condition, despite being subject to almost permanent dampness and occasional inundation. This suggests that the damp/wet conditions are slowing down the rate of decay, probably due to low or zero oxygen levels within the timbers.

The condition of the two supporting posts at 11 m and 16 m distance, on either side of the river channel, were also tested and showed significant areas of decay, with readings near or below the 0.4 threshold (Figure 3a). There is also a related issue with the degree of decay in the end logs at the junctions of the structure, possibly linked to supporting posts, wedges and wiring, or simply decay progressing from the exposed ends. In particular, there was a significant level of decay in the end logs at the junction between 17 and 18 m, where the depth and force of flood waters is likely to be greatest during high flows, placing additional strain on an already weakened part of the structure. Figure 7 shows a close-up of the decayed timbers at this junction.

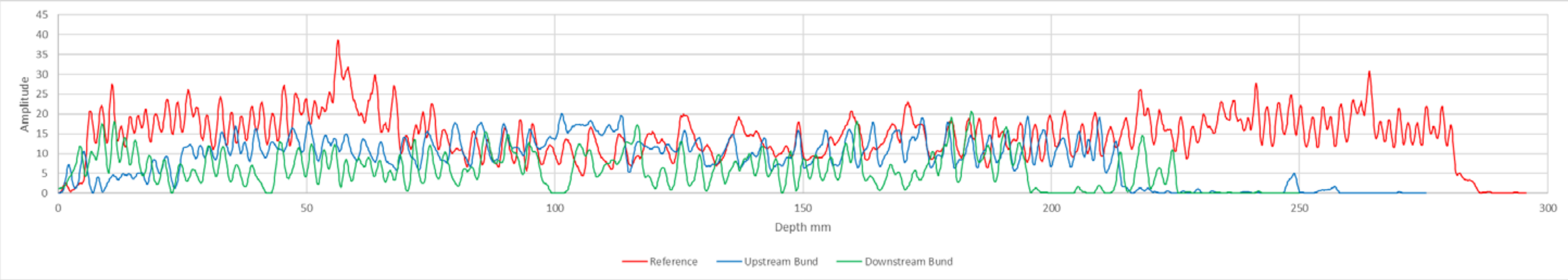

Figure 3a Typical drill profiles of the reference drill sample and the upstream and downstream timber flood storage bunds

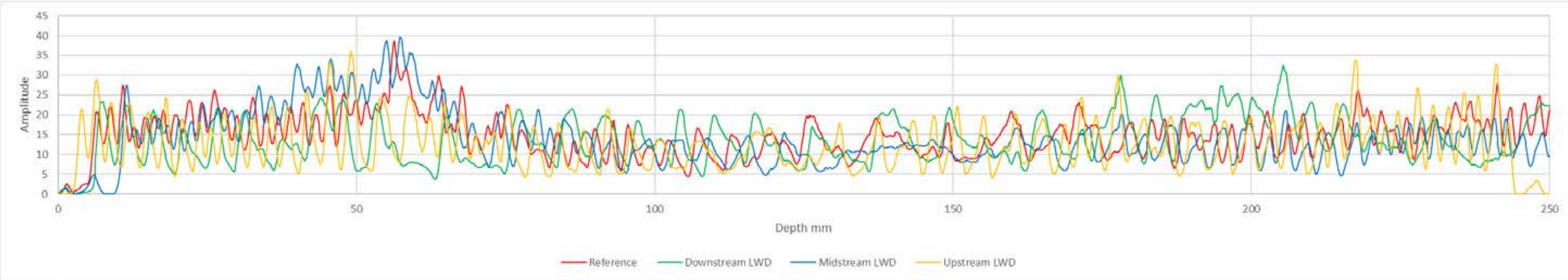

Figure 3b Typical drill profiles of the reference drill sample and in-stream LWD

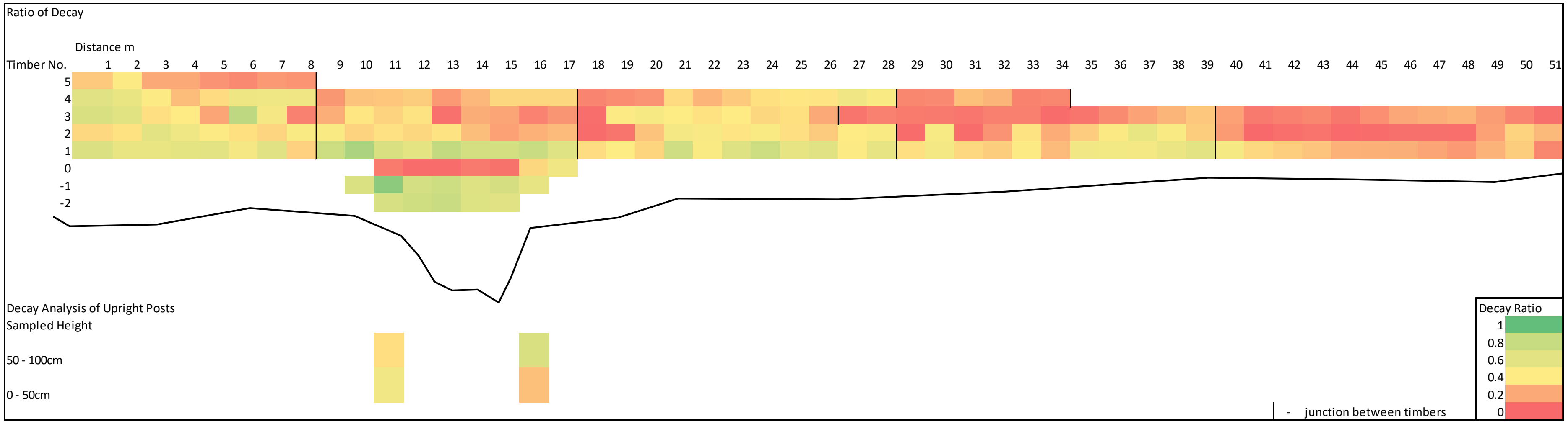

Figure 4 Diagram showing drill readings for the lower timber flood storage bund, expressed as the ratio of decay versus reference live trees. Measurements are displayed for the individual one-metre subsections of each log, with the number of stacked logs varying across the structure (black vertical lines demarcate junctions between each log stack). The surveyed cross section of the site is shown for orientation, with the negative timber numbers corresponding to those logs that extend below ground level into the river channel. Ratios are also displayed (below the cross section) for the two upright posts supporting the timber bund on either side of the river channel.

Figure 5 Photograph showing the downstream bund looking to the south/left side of the structure as represented in Figure 4.

Figure 6 Image showing the timbers spanning the river channel on the lower bund, with the most decayed log covered by moss (fifth timber down from the top). The two bottom timbers (numbers -1 and -2 in Figure 4) were replaced in 2019 and therefore much less degraded.

Figure 7 Close up image of decayed timber at the 18 m junction on the downstream flood storage bund.

Assessment of Upstream/Upper Flood Storage Bund

The upstream flood storage bund on Sutherland Beck is slightly larger than the downstream one, having a maximum height of 1.49 m and extending 55 m across the floodplain. The depth of the flow throttle within the river channel is also greater, comprising six stacked timbers, in addition to the five above ground. In total, the structure is made up of 42 logs in seven sections, with individual logs ranging between 4 m and 16 m in length. Each junction between sections is supported by a vertical post driven into the ground, a tall tree stump, or both, positioned on either the upstream or downstream face of the structure. There is a total of 14 supporting posts or stumps, all of which were measured.

Overall, the upstream bund was in a much better condition than the lower one, with only four of the 42 logs having more than 50% of their length at below the 0.4 decay threshold (Figure 8). This is likely to be due to the more sheltered nature of the bund, which lies below a closed canopy of mature conifer trees. The bund was originally constructed using trees from thinning the overhead stand. The end sections of the bund were the least decayed and the centre one the most, which lies to the side of the river channel, perhaps reflecting the additional shelter provided by the adjacent steep slopes. However, there was significant variation in condition between the five logs in the central section, with two very decayed and an intermediate one almost unaffected. This variation is difficult to explain but could be related to the original condition of the source tree(s).

The timber section above the river channel was the most uniformly degraded, with around 40% of the total length of above-ground logs with ratios <0.4. In contrast, the logs at ground level and within the channel throttle were generally in a good condition. There is some evidence of greater decay in logs abutting section junctions, but the effect is inconsistent. It is most notable at 27 m (Figure 8). Top logs were once again generally more degraded than ground level ones, especially within the middle of the structure.

Analysis of the upright timbers and posts across the full length of the structure showed most of these to be sound, with ratios of decay >0.6 (Figures 8 & 9).

Assessment of In-stream Leaky Woody Dams (LWD)

The three LWD within the beaver enclosure were built in 2019 from stacked single timbers spanning the full length of the structure, ranging between 4 m and 13 m in length. The upstream and downstream dams comprise three stacked timbers, while the middle dam is taller with five logs. All of the logs exceed 350 mm diameter.

Figure 10 shows the relative condition of each log in the three LWD based on the ratio of the average amplitude to that of healthy standing trees. All were in good condition and appeared structurally sound, with most ratios >0.8. The middle log in the downstream LWD was the most decayed but still had ratios >0.6. A small amount of scouring was noted on the left and right bank of the channel at each dam, where the timbers had been slotted into the riverbank.

Predicting Lifespan of Timber Structures

It is clear from the study measurements that structural timbers can vary greatly in their rate of decay. This is to be expected given the wide range of factors that affect wood decay and their temporal and spatial variation, such as temperature, moisture content, degree of exposure, tree species and age, damage caused by handling and the original condition of logs. Consequently, it is difficult to predict their lifespan without a certain degree of monitoring work.

The use of the micro-drill has allowed an assessment of timber condition across a range of structures. While it is difficult to relate the individual measurements of signal amplitude to timber strength, this can be done by comparing values with those of reference trees and calculating ratios of decay. By selecting a critical or acceptable ratio, an assessment can then be made of the average condition of individual logs or entire structures. Ideally, the critical ratio should be tried and tested but this awaits further studies and accumulating experience from the wider use of timber structures in flood risk management schemes.

One notable difficulty is the uneven nature of decay within timber structures. It can easily be argued that a structure is only as strong as its weakest component, but individual components are unlikely to be subject to the same forces and strains during a flood event. For example, the generally greater level of decay/weakness found in top timbers in this study will have to withstand much lower water pressures during floods and probably only come into play in the largest/rarest of events. Similarly, a structure may be able to survive the failure of an individual, decayed log, providing the surrounding logs are in a much better condition. The greatest risk is probably posed by the loss of one of the upright posts or tall stumps, which could lead to the collapse and washout of two complete sections in the case of a timber bund.

Notwithstanding these issues, it is nevertheless informative to calculate average ratios for timber structures or individual sections of these in the case of bunds to explore potential lifespans based on selected decay thresholds. Unfortunately, this study has only yielded decay measurements for two ages of structures (aged one and eight and a half years) but the resulting average ratios and an assumed linear relationship with age is plotted in Figure 11 (the value of one being based on healthy live trees; i.e. age 0). This shows the bunds to have an average ratio of 0.45, above the 0.4 threshold. Simple extrapolation suggests that they will breach the assumed critical threshold at 9.3 years. However, it must be noted that this is average ratio for the two bunds and the lower bund has already passed the critical threshold (current ratio of 0.35).

While the three measured LWD were all young structures, it is possible to separately assess the condition of the within channel timbers that are part of the two timber bunds aged eight and a half years. The combined average ratio for these is also plotted in Figure 11 and gives a value of 0.48. Extrapolating the relationship indicates that the LWD have a slightly longer lifespan than the timber bunds, reaching the 0.4 threshold at 9.9 years.

The plotted relationships can also be used to predict the remaining lifespan of individual logs or timber sections within structures based on their age and present ratio. For example, a log with a current average ratio of 0.6 in the timber bund would be predicted to have a remaining lifespan of 2.8 years before it reached the 0.4 threshold.

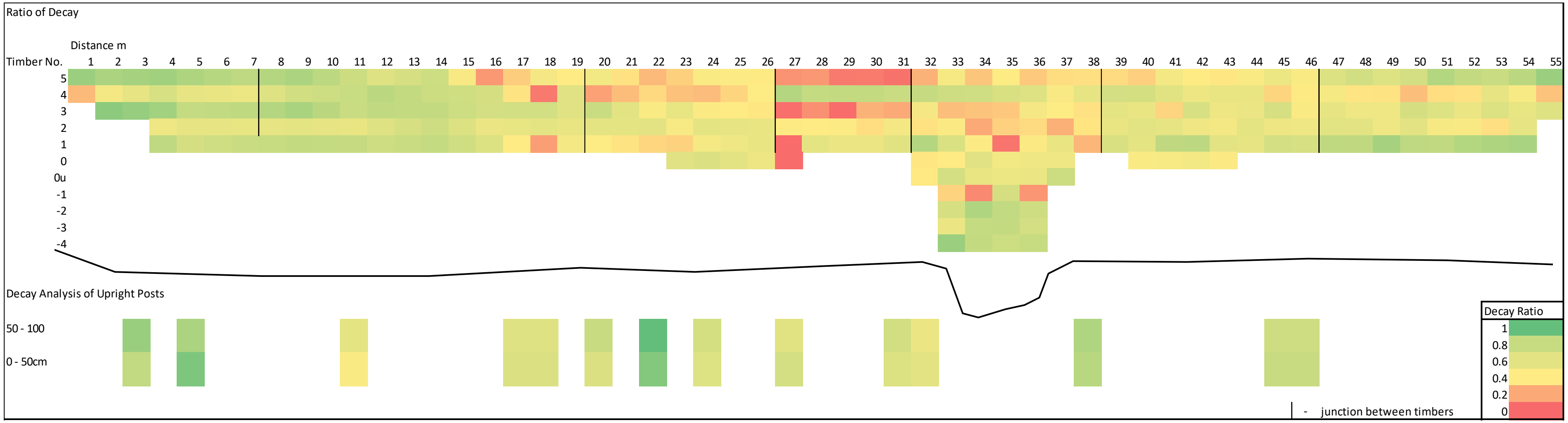

Figure 8 Diagram showing drill readings for the upstream timber flood storage bund, expressed as the ratio of decay versus reference live trees. Measurements are displayed for the individual one-metre subsections of each log, with the number of stacked logs varying across the structure (black vertical lines demarcate junctions between each log stack). The surveyed cross section of the site is shown for orientation, with the negative timber numbers corresponding to those logs that extend below ground level into the river channel. Ratios are also displayed (below the cross section) for the two upright posts on either side of the river channel.

Figure 9 Image of the decaying timbers at the junction at 27m from the left edge of the upstream flood storage bund, partly damaged by the windblown tree falling onto the structure.

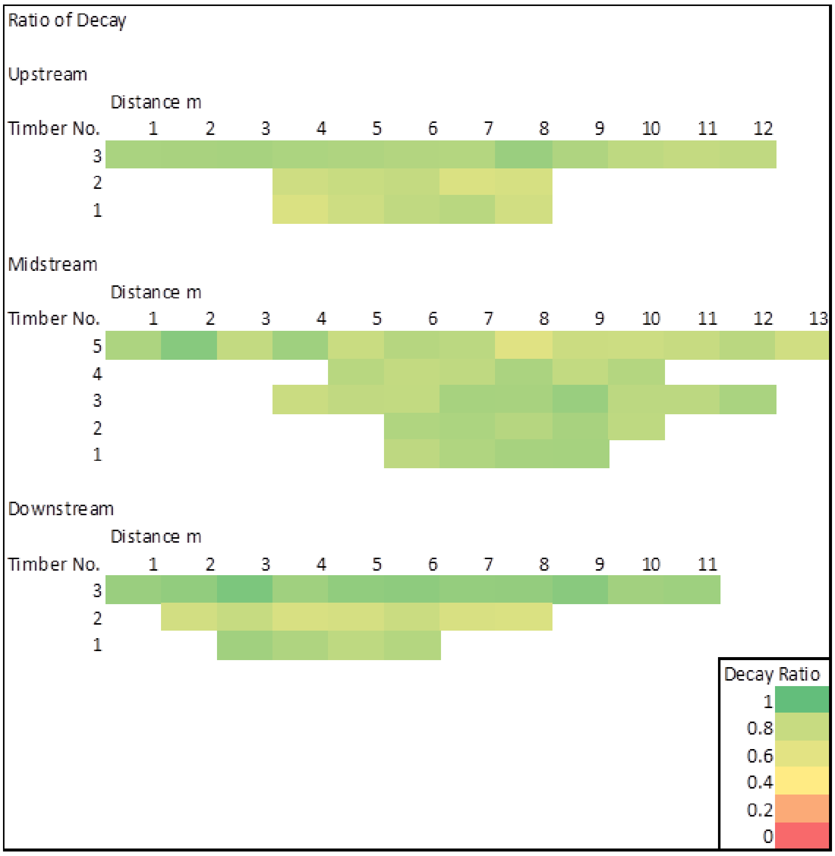

Figure 10 Diagram showing drill readings for the three in-stream LWD, expressed as the ratio of decay versus reference live trees. Measurements are displayed for the individual one-metre subsections of each log.

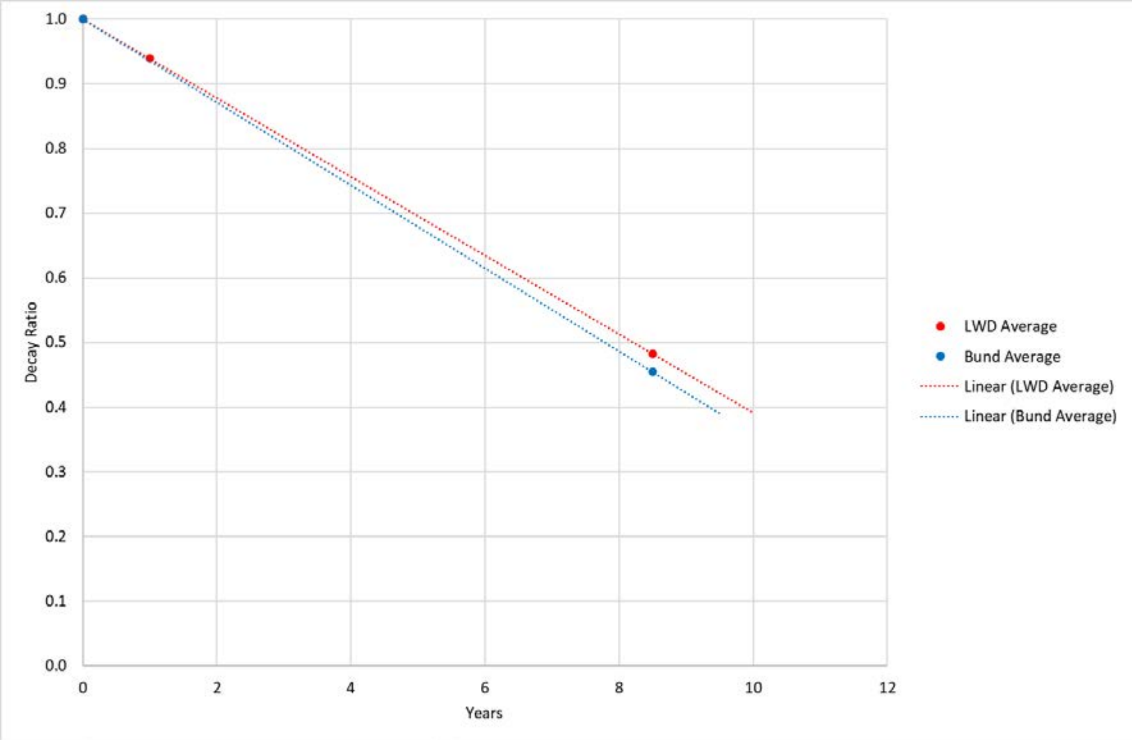

Figure 11 Relationship between recorded ratio of decay and age of timber structure (in years), with ratios based on average decay ratio values of the timber bund and the three LWD versus the average for selected healthy, live trees. Linear regression has been used to predict the lifespan of the timber structures before the average ratio reaches the critical threshold of 0.4.

This plot should be used with particular caution due to the limited age range of the measured NFM structures, the fact that the older LWD were a component of the timber bunds and not separate structures, and the measurements being based on a single location and tree species (conifer/softwood). It is also important to note that the plot uses average ratios and the decay rates of individual timbers are likely to vary greatly across a large structure such as a timber bund, depending on local conditions.

Recommendations

The following recommendations are based on the findings of the timber decay survey as well as on-site observations. It should be noted that the downstream risk to any assets (structures, bridges, culverts etc) from the collapse or washout of timbers remains low. Any material that is released is highly likely to become trapped either by the other existing downstream NFM structures, or by natural features such as channel constrictions, instream deadwood and bankside trees and shrubs along Sutherland Beck.

Of the measured structures, the condition of the downstream flood storage bund is the main cause for concern, having been considerably weakened by decay. Around half of the logs in the structure have more than 50% of their length below the assumed 0.4 critical threshold, while the two central supporting posts are also significantly decayed. It is questionable whether the structure would now support a major flood event and in view of the extensive nature of the decay, probably past the stage of maintenance.

Consideration therefore needs to be given to its replacement if there is a desire to maintain its original contribution to catchment flood storage. However, it is important to note that the volume of flood storage provided by the downstream bund is relatively small (~1,260 m^3) compared to the upstream bund (~3,620 m^3) and thus less significant. There is a strong case for leaving it as it is to gain greater knowledge of how the bund continues to degrade, at what point it breaks and how far the released timbers move. The within channel part of the structure and lower timbers across the bund are also in a better condition and thus will continue to offer some flood storage and a slowing effect.

On balance, it is recommended that the downstream bund is left to degrade naturally and continued to be monitored to improve understanding of its operation and lifespan, including to help test the 0.4 critical threshold. The main intervention would be to consider replacing timber 0 at ground level in the channel, which is significantly decayed. A decision about whether to replace the entire structure should await its final collapse. An alternative option would be to plant and try to establish closely spaced willow or alder trees along the line of the timber bund to create a more "living" and supporting structure that might extend the lifespan of the bund.

The condition of the upstream timber bund is generally good and in much less need of attention. The priority is probably to replace or shore-up the central section (from 27 m to 31 m distance from the left) where the timbers are the most degraded (Figure 9). This is not urgent but recommended in the next one to two years. Depending on how quickly the level of decay progresses in the two adjoining sections, it may also be worthwhile replacing the top two logs in the 20 m to 26 m section as well as the complete above ground section from 32 m to 38 m at the same time. An alternative to replacing these timbers would be to construct an additional stack of timbers adjacent to the downstream side of these sections of the bund. It would also be wise to replace or double-up the channel timber numbered -1.

No significant areas of decay were found in any of the three in-stream LWD and thus no maintenance is currently required.

It is recommended that the two timber bunds are visually inspected after each high flow event, while the three LWD should be subject to at least annual inspections. Repeat monitoring using the micro-drill should be carried out every three years to capture the progression and rate of decay.

When any timbers are removed from the bunds as part of maintenance or replacement work it is recommended that they are set aside and kept intact for further testing to help calibrate the micro-drill amplitude readings and the critical decay threshold.

Acknowledgements

We would like to thank Forestry England for funding this study and providing access to the beaver enclosure to undertake the micro-drill measurments.

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