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Independent Panel Review of Track Materials Used for Track Stability and Root Protection in Kauri Forests

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Prepared for the Kauri Dieback Programme

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Executive Summary:

Soil-borne plant diseases, often with introduced *Phytophthora* species as causal organisms, are threatening and degrading forests worldwide. Within these forests, hiker movement along walking tracks is a known cause of diffusion of these diseases, with soils containing disease spores moved on boots and other hiking accessories. Within New Zealand, *Phytophthora agathidicida* causes kauri dieback within northern forests, and spread of infection along tracks is one of the likely pathways of disease spread.

The Kauri Dieback Programme has sought an independent review to recommend materials and techniques for construction of hiking tracks within kauri forest that will minimise the risks of spread of *P. agathidicida*. The objectives of this review were to:

(a) Give a detailed view of the advantages of implementing different track construction techniques in Kauri Forest Areas, including the costs and the longevity of each option.

(b) Assess whether such track construction techniques and their use:
- Prevent or minimise track user exposure to soil and soil contamination that could facilitate the accidental spread of kauri dieback.
- Create an environment unfavourable for *P. agathidicida* sporulation and spread; and
- Do not harm but can improve kauri and kauri forest health.

(c) Recommend how track construction could be improved in Kauri Forest Areas and how uncertainties around this construction with respect to kauri dieback could be reduced.

A review panel was engaged for this purpose consisting of experts from a range of relevant viewpoints and disciplines. The panel gathered and reviewed the available evidence, interviewed key stakeholders and track construction professionals, and discussed various approaches.

To minimise the risks of tracks acting as infection sources for further spread, tracks can be closed, re-routed away from kauri, or re-constructed. If the decision is to re-construct them in place, tracks should be rebuilt such that there is a physical barrier between infected roots/soils and the track surface, and the surface is kept hard, dry and well drained, i.e. the risk of mud developing is minimised so soil won't attach to footwear. Such remediated tracks should also provide the opportunity for damaged root plates to re-establish where historic track location and wear has destroyed or severed parts of kauri feeder root systems.

The review panel confirmed that the construction materials and techniques recommended in the National Kauri Dieback Track Infrastructure Guidelines (Butler 2019) are state-of-the-art and designed to achieve these requirements. The approaches detailed in Butler (2019) attempt to isolate track surfaces from any infected roots or soils using boardwalks, or by use of a compacted surfacing aggregate. Additionally, filled Geocell or Geoweb inert cellular confinement panels under the compacted aggregate surface can stabilise the track base and lift the surface of the track to create dry surface conditions.

Although all four approaches (boardwalk, compacted surfacing aggregate alone, surfaced Geocell, and surfaced Geoweb) will provide effective separation of feet from roots if constructed correctly, each is more effective in different situations. Compacted surfacing aggregate alone is recommended for sites where kauri feeder roots in soil are unlikely. Geocell is recommended for high traffic areas and steep tracks. Geoweb is preferred over Geocell generally but especially in muddy areas with kauri roots because it is more flexible and deeper, it can be filled with a coarser bark aggregate mix allowing greater root growth beneath tracks than Geocell, and the required compaction of the sub-base is lower than under Geocell. Boardwalks are recommended for the most sensitive areas and flatter sites.

Tracks using either of the cellular panels (Geocell, Geoweb) are about 4 times more expensive than compacted aggregate by itself. Boardwalks are about 10 to 15 times more expensive than compacted aggregate. All these options have an expected life of about 50 years.

Although these materials and techniques hold great promise of creating durable tracks that will mitigate the risks of tracks acting as sources for diffusion of *P. agathidicida* spores, we could find no evidence that such track reconstructions had been tested for their efficacy with regard to these mitigations. We recommend testing is carried out of surfaces of various tracks reconstructed through Kauri Forest Areas (or on footwear that have used these tracks) to look for the presence of *P. agathidicida* spores. As well, trials should also be carried out to establish the level of compaction (i.e. penetration resistance) necessary to prevent kauri feeder roots from penetrating track surfaces.

In terms of materials available for track reconstruction, we also considered the situation when kauri roots grow into the fill within Geoweb cells. This may increase the risk of infected roots being exposed on the track surface and makes it difficult to decommission a track as roots would need to be cut to remove the Geoweb panels (although the panels could be left in place on decommissioning to avoid such damage). Investigation of a water-permeable, root barrier that could be emplaced between natural soil and composite fill material used to level the ground surface before placement of any Geoweb or similar, seems prudent.

Other suggested research includes:

- the possible use of calcium oxide within track surfacing aggregates to create an alkaline track substrate. High pHs are known to suppress *Phytophthora* presence and sporulation;
- confirming the absence of any potential negative effects on the kauri soil chemical environment near to products such as Geoweb (even though marketed as inert and stable);
- seeking natural alternatives for HDPE products, e.g. Geoweb.

The panel did not recommend halting track reconstruction programmes while such research was conducted, but that implementing results of any research would be part of a culture of continuous improvement.

The review also found that the National Kauri Dieback Track Infrastructure Guidelines (Butler 2019) and the National Technical Specification for Track Mitigation Measures (MPI 2019b) were generally sufficient to guide the design of mitigation actions for track or boardwalk construction. There needs to be more harmony achieved, however, between the two documents, as there seems to be differences in terminology that leads to doubt in the interpretation of the Guidelines as applied to a specific situation. For example, the Guidelines use the terms "high" and "low" value kauri, and these terms need clarification and remain consistent through the two documents. The descriptions of the mitigation actions would ideally be turned into "prescriptions", using some form of "decision tree" or flow chart-like format, as a decision support tool.

The increased emphasis on including mātauranga perspectives in environmental management demands that the continued development of tracking techniques within kauri forest should be considered through both western science-based and mātauranga lenses.

In terms of monitoring track integrity, no timing for monitoring events was provided in the Guidelines. The frequency of such monitoring should be estimated in the Guidelines, based on likely rates of track wear, to ensure that these function as safeguards once mitigated tracks are in place and subject to foot-traffic and episodic rainfall events. Testing for presence of *P. agathidicida* spores on track surfaces or footwear using tracks could be incorporated as a part of regular monitoring. Interpretation of data collected in this way should be fed-back into the continuous improvement of track installation and management guidelines.

1. Independent Panel Membership:

- Dr Bruce Burns

Dr Burns is an Associate Professor within the School of Biological Sciences, University of Auckland specializing in plant and forest ecology. His research includes kauri forest ecology and the impacts of kauri dieback on kauri populations and kauri ecosystems (https://unidirectory.auckland.ac.nz/people/profile/b-burns).

- Kevin Prime

Kevin Prime currently works 75% as an Environment Commissioner for the Environment Court. He has spent most of his life in governance in areas pertaining to Health, Sport, Farming, Conservation, Environment, Philanthropy, Forestry, and Māori Land Development at local regional and national level. He has also served on Boards of Trustees for schools, Marae Committees, Runanga and conducted mediations for the Environment Court, the Maori Land Court, the Office of Treaty Settlements, the Waitangi Tribunal and was recently part of an Independent Panel appointed to review the Resource Management system.

- Dr Stan Bellgard

Dr Bellgard is a plant pathologist and biosecurity consultant, working for BioSense Ltd. His research and extension activities have included description of the kauri dieback pathogen, and DNA-based diagnostics to support evidence-based decision-making.

- Tadeas Mejdr

Tadeas has over 13 years of experience with design of walking and cycle path projects across New Zealand. He has experience in both cycling and walkway projects across all stages of project delivery from feasibility assessment to design and project management of construction and is experienced in all tracks from urban high use assets to remote bush tracks, which means he is able to provide appropriate, site specific solutions.

As a chartered structural/civil engineer, he has the experience and capability to develop practical and efficient designs and as a keen cyclist himself, Tadeas also incorporates the user perspective in his design approach.

2. *Introduction:*

Worldwide, introduced soil-borne diseases are attacking and degrading indigenous forests and natural ecosystems, and are spreading (Ghelardini et al. 2017, Roy et al. 2014, Santini et al. 2013). Once present after long-distance dispersal to a forest, further diffusion of these soil-borne diseases can often occur through animal or human foot traffic (Jules et al 2002, Dunne et al 2011). In California, Cushman and Meetenmeyer (2005) found that *Phytophthora ramorum* occurred more commonly in soil of heavily used hiking tracks than in soils from adjacent off-track areas. Also in California, Davidson et al. (2005) found that approximately one-half of hikers who had used tracks through *P. ramorum* diseased areas carried infested soils on their shoes. In Britain, Elliott et al. (2015) successfully identified invasive *Phytophthora* of three species from soil taken from forest tracks, and from soil taken from boots that had walked those tracks.

Walking tracks through areas infected with forest soil pathogens therefore can be key sources of pathogen spread through human agency. In order for this pathway of movement to occur, however, tracks need to be close enough to infected roots or soils such that oospores will be present in or around soil on the track surface, and wet enough such that mud attaches itself to footwear allowing transport (Worboys and Gadek 2005). Mitigation of tracks to prevent them acting as infection sources therefore requires:

- re-routing tracks away from actual and potential plant hosts;
- where re-routing is not feasible, separation of infected roots and soils from tracks so that oospores cannot access the track surfaces; and/or
- adjusting the surfaces so that they are hard, dry, and well-drained, and therefore the surfaces are not muddy and surface soil won't attach to footwear (O'Gara et al. 2005, Suddaby and Liew 2008).

Some kauri (*Agathis australis*) forest areas in New Zealand are infected by kauri dieback disease, which is caused by the oomycete *Phytophthora agathidicida* (Weir et al. 2015, Bradshaw et al. 2020). This oomycete is pathogenic and is known to infect kauri trees of all ages and sizes. The main infection occurs through the kauri feeder roots and then spreads to the trunk and lower roots often leading to tree death. The disease spreads in soil water and with soil movement and the main vectors in the movement of this disease are most likely: foot traffic, vehicles, walking poles, and domestic and/or feral animals (Hill et al. 2017). The challenge for walking tracks that traverse kauri dieback areas is to reroute them or upgrade them to both protect kauri roots and to eliminate/minimise the risk of spreading *P. agathidicida* infection through track use.

The Kauri Dieback Programme is a partnership of organizations with the primary objective to sustain the mauri and health of New Zealand kauri forests in the presence of kauri dieback beyond the next 1000 years (MPI 2019a). The Programme has sought an independent review to recommend materials and techniques for construction of hiking tracks within kauri forest that will not spread *P. agathidicida*. The objectives of this review were to:

(a) Give a detailed view of the advantages of implementing different track construction techniques in Kauri Forest Areas, including the costs and the longevity of each option.
(b) Assess whether such track construction techniques and their use:

- Prevent or minimise track user exposure to soil and soil contamination that could facilitate the accidental spread of kauri dieback.
- Create an environment unfavourable for *P. agathidicida* sporulation and spread; and
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(c) Recommend how track construction could be improved in Kauri Forest Areas and how uncertainties around this construction with respect to kauri dieback could be reduced.

3. *Approach:*

The panel considered approaches to the upgrade of existing tracks where the track formation was already formed and was within a Kauri Forest Area as defined in Butler (2019) and MPI (2019b). The panel reviewed the available evidence, undertook a field visit to view track construction at several locations in the Waitakere Ranges, interviewed key stakeholders and track construction professionals, and discussed actual and potential approaches. The terms of reference for the panel are provided in Appendix 1.

Direct iwi consultation involved meeting with S. Lomas (Heritage and Environment Manager) of the Te Kawerau Iwi Tribal Authority and Settlement Trust on 17th June. 2020. Representatives of the panel (Dr B Burns, Dr S Bellgard) held a korero with S. Lomas to review concerns of the use of Geoweb, and to explore alternative safeguards. Focus was on the desired results of: 1) root protection, 2) future tree health, 3) low maintenance that prevents redundancy in community investment, and 4) separation of "feet from the *whenua*" to prevent the spread of kauri dieback, and protect the Waitakere Ranges Heritage Area as a case study.

4. *Key findings*

4.1 Current options for track construction techniques in Kauri Forest Areas

The panel recognized that the most effective mitigation decisions to minimize the risk of transfer of kauri dieback along tracks is to either close tracks (PD1 in Butler 2019) or to realign tracks away from susceptible (kauri) areas (PD2).

Assuming that the mitigation decision for a track in a Kauri Forest Area has been for track mitigation (PD3 in Butler 2019) rather than closure (PD1) or realignment (PD2), then a range of different mitigation systems are currently recommended to provide separation between any kauri tree surface feeder roots and any foot traffic along the track (MPI 2019b). These different systems occur in different parts of a track network as detailed in Butler (2019).

a. The standard track construction system currently recommended for Kauri Forest Areas *where kauri feeder roots are unlikely* is to place and compact local or imported fill material to provide an even walking surface of the required width, and top the base formation with a 50 mm thick cap of compacted GAP20 surfacing aggregate[1] (MPI 2019b). This cap provides the separation between

[1] For Standard Aggregate Track formation see detail 01 drawing number 19/015 SHT P01, Kauri Dieback National Mitigation Details, Track Formation Within Kauri Forest Area, Ministry of Primary Industries.

any possibly infected soil and roots, and the feet of track users.

The top aggregate surfacing also provides an even, stable, durable walking surface that resists erosion and protects underlying track formation from water infiltration. The aggregate surfacing must be a well-graded broken stone with enough fines. The range of stone sizes, together with the fines, ensures that once compacted the aggregate particles will interlock and form a well-bound layer. This, together with typical 3% cross slope, ensures that any precipitation is shed from the track surface instead of penetrating the track formation.

Compaction of the track base formation is the most important factor in providing a durable track formation otherwise it will not be able to withstand the foot traffic load. If the sub-base has insufficient bearing strength, the middle of the track, where many track users walk, will become depressed, and water ponding will occur.

Benefits of standard aggregate track formation are the low construction cost, straightforward construction, and the flexibility to adjust track formation to different grades and obstacles. This type of track construction also allows for easy decommissioning of the track by either removing the aggregate from the site or simply breaking up the aggregate surface to allow moisture to penetrate the track base formation to allow vegetation regrowth.

Where kauri feeder roots are likely to occur, a concern with this standard track formation is the possible negative impact of compaction on any feeder roots under the track. Besides any physical damage during the construction, the track formation will limit the amount of air and water that can reach the surface feeder roots. Based on preliminary trials of track surfaces, however, the surface feeder roots do not propagate into the compacted track formation (Beauchamp and Upperton 2012). Nevertheless, determining the optimum level of compaction for this type of track is critical.

b. Track formation with rigid or semi-rigid Geocell panels (e.g., Jakmat) is one of the mitigation options used currently in areas with feeder roots (although not recommended by Butler 2019 in favour of Geoweb). These panels typically are 40mm deep with 60-80mm diameter cells. Construction of a track base is identical to standard track construction, and compaction of the subbase is still required. Placing an additional 20mm layer of bedding sand is recommended before the installation of the Geocell panels. Once panels are placed and anchored, the cells are filled with GAP20 and compacted. The compacted thickness of GAP20 should be 10-15mm above the Geocell profile. The base formation, Geocell panels and the aggregate should all have a cross slope of 3% to ensure that surface water is shed off the track in the same way as with the standard aggregate formation.

   In terms of separation of the foot traffic from the kauri feeder roots, the Geocell panel formation performs in the same way as standard aggregate track formation. The degree of compaction of the subbase needed might be reduced from standard tracks as the Geocell panel will provide additional strength to the final track formation, however, no studies or trials are available at the time of this review to confirm this. Reduced compaction could potentially allow surface feeder roots to grow under the Geocell, but the manufacturer's recommendation for installation of Geocells is a level of compaction similar to the standard aggregate track formation. Therefore, we expect that impact on any kauri feeder roots will be identical to standard aggregate track.

There are examples of Geocell track formation where the surfacing layer has deteriorated due to water erosion or high track use and the top of Geocell panels became exposed. In those cases, the Geocell is still able to contain the majority of the GAP20 fill and provide a good walking surface, maintain the integrity of the track, and provide separation from foot traffic. There are currently no data that would suggest that feeder roots would grow through the Geocell and the compacted GAP20, therefore it appears that if the track is decommissioned, the Geocell panels could be removed without any significant damage to the surface feeder root system.

c. Track formation with Geoweb cells filled with bark and aggregate 50/50 mix (BAM) in areas with feeder roots is another alternative mitigation method that has been adopted by the Department of Conservation and in some track upgrades in the Waitakere Ranges by Auckland Council. The track base under the Geoweb does not need to be as even as with Geocell, because the cell walls are flexible and will accommodate tree roots, rocks, or other small obstacles. Also, the track formation subbase and the fill material does not need to be compacted to the same degree as the other types of track formation mentioned above as the cells will prevent any lateral spread. The deeper cell allows the point load from foot traffic to be distributed over a larger area.

   Typically, the Geoweb cells are 75mm deep and 300mm diameter but 150mm deep cells can be used in extremely wet and muddy areas to lift the track formation even more and create a dry surface. The Department of Conservation has used Geoweb for tracking muddy sites in non-kauri areas for this reason. BAM can also be used as fill on the existing track formation where necessary or can be used specifically to provide a medium for root plate development. The Geoweb cells are filled with BAM and hand compacted with a hand soil tamper or similar. Aggregate surfacing placement is identical to the standard track formation. The less compacted BAM layer beneath gives permeability and acts as a cushion to provide air and enough moisture to the roots to expand.

   Kauri feeder roots grow and develop through this layer and penetrate through the openings in the Geoweb walls. When capped with adequate surfacing aggregate, the integrity of the BAM layer is preserved, and minimises the probability of *Phytophthora agathidicida* oospores coming in contact with foot traffic. However, if the track is decommissioned and the Geoweb needs to be removed, this will cause disturbance to the feeder roots. Alternatively, consideration should be given to the relative merits of leaving the Geoweb in place upon decommissioning, similar to culverts and embedded boardwalk posts, whereby removing them is likely to do more damage than leaving them. Monitoring could be put in place to ensure that the Geoweb does not inhibit or debilitate root plate regeneration in this case. Geoweb is made from an inert HPDE material (the same as that used for several geofabric and drainage products adopted widely in road and track construction; eg culvert pipes, weed mat, filter fabric, geocells, tensar soil reinforcement etc), so will not leach breakdown products into the natural environment.

We agree that Geoweb offers significant advantages over Geocell for many applications.

d. Low timber boardwalks are another effective mitigation method for Kauri Forest Areas. In the most sensitive areas, boardwalks can be constructed without any need for heavy machinery and this minimises any negative impact. Depending on ground conditions, the boardwalk piles are typically treated *Pinus radiata* piles of 100 to 150mm diameter that can be driven into the ground with a two-man post hammer. Boardwalks provide a good durable walking surface, while the air and water flow to the feeder roots remains unchanged. However, the boardwalk surface does not provide sufficient slip resistance on steeper gradients and therefore maximum longitudinal slope is limited to 12%.

   Typical aggregate track, Geocell or Geoweb formations can be built in up to 17% longitudinal gradient or even 20% for short sections. Timber staircases can be used to provide access over steeper gradients with the same minimal impact on kauri roots as the boardwalk. The staircase option should only be used after careful consideration of how this will affect the accessibility for different track users.

4.2 Construction cost estimates

The estimated costs provided here are for the upgrade of any existing tracks with reasonable access to the site and without any other challenging conditions. It is likely that the price will be above the given range for more difficult sites, e.g. those with access issues, steep gradients, or especially wet sites. This caveat also applies to the other end of the spectrum where there is well-formed existing track formation on a flat gradient. In this case, the cost is expected to be at or below the range provided.

The standard track formation that only requires some backfilling of the track base and the new aggregate surfacing is the most economical. The expected cost per linear metre of track 1.2m wide is between $40 and $60.

The Geocell track formation requires an additional sand layer, the Geocell panels and all labour and transport cost associated with it. We estimate that the cost is in the range of $160 to $240 per linear metre of 1.2m wide track. The cost of Geocell alone is approximately $50 per square metre.

The Geoweb cells are around $15 per square metre. There is an extra cost over Geocell, however, associated with treating and mixing of the fill, its placement and the volume required to fill the deeper Geoweb cells. From recent projects completed in the Auckland Region and elsewhere it appears that the overall cost of installing Geoweb is identical to Geocell track formation (i.e. $160 to $240 per linear metre of 1.2m wide track) and approximately four times the cost of standard track formation.

The low boardwalk walkway is by far the most expensive system with estimated rates ranging from $500 to $750 per linear metre of 1.2m wide low boardwalk.

4.3 System lifespan and long-term longevity

The standard aggregate formation life span is very dependent on the site conditions, the volume of traffic and track gradient. However, in typical conditions and with regular maintenance, these tracks are proven to last 25 – 50 years.

Both the Geocell and Geoweb formations will likely require similar maintenance of the aggregate surfacing as the standard aggregate track formation. There is no longevity data about the BAM fill for the Geoweb cells other than a two-year trial from 2012 over which it was stable. It is expected that the bark nuggets in the BAM mix will start breaking down and track formation will settle over time. The Geoweb cells can be topped up with surfacing aggregate if necessary. Both the Geocell and Geoweb themselves have a design life of a minimum of 50 years and will likely last longer than that.

A boardwalk typically has a design life of 50 years and allows for any of the components to be replaced if necessary.

4.4 Assessment of likely track user exposure to contaminated soils or roots

Where access to or through the Kauri Forest Area is to be maintained these track options need to be constructed in a way that ensures separation between the foot traffic and the surface feeder roots of kauri. Especially in wet and muddy areas, it is essential that the walkway surface remains dry and well bound to limit the risk of transporting contaminated particles along the track system.

We expect that all of the track formations mentioned above will provide a walking surface separated from infected soil and roots if constructed correctly. The Geocell panels are recommended for use in high traffic areas and on tracks steeper than 17%. In those cases, the Geocell layer will retain aggregate even if the top layer deteriorates.

Geoweb formation is particularly recommended for sites that are wet and muddy as the formation's overall height provides extra separation from the wet subbase. This formation can also be constructed without the subbase compaction and can accommodate uneven ground. This is beneficial in more sensitive areas. The surface roots will not be as negatively impacted during construction as in the case of standard aggregate track and Geocell formation. It has been shown that tree roots can grow into the formation if Geoweb is filled with BAM which even when compacted has enough voids for air and water movement. With tree roots integrated into the structure, decommissioning might then need to include cutting of those tree roots in a hygienic manner if the Geoweb needs to be removed.

The low boardwalk is the lowest impact solution while still providing access to the most ecologically sensitive areas. Other than during construction there is essentially no long-term impact to existing surface roots, no change to hydrology of the site, it can be used in high traffic areas and decommissioning is not an issue. However, low boardwalk will typically be 10 to 15 times more expensive per linear metre than standard track formation.

4.5 *Testing of reconstructed track surfaces for efficacy against* Phytophthora agathidicida

Although the track construction options discussed above appear likely to provide adequate separation between possibly infected kauri soil and roots, and foot traffic along tracks, no sampling along these tracks has been undertaken to confirm their effectiveness as barriers, nor how this effectiveness may change with time. We recommend testing is carried out of surfaces of various tracks reconstructed through Kauri Forest Areas to check for the presence of *P. agathidicida* spores. This could be carried out by testing the surfaces of tracks and/or by testing soil taken from boots that had walked those tracks (e.g., methods used in Pau'Uvale et al. 2011 and Elliott et al. 2015). Best times of the year for such sampling would be at the end of summer, as this is the end of the busiest period for park visitation and/or at the end of winter, because this is arguably the highest risk time for track degradation and pathogen movement – i.e. wet soil conditions. Such testing could also be undertaken on tracks of different age (as much as possible) to test for changes in track integrity over time.

As well, trials should also be carried out to establish the level of compaction (i.e. penetration resistance) necessary of the aggregate surface to prevent kauri feeder roots from penetrating this barrier. This is the mechanical resistance that the surface would need to provide against the force applied by roots trying to push into them (Bassett et al 2005). Plant species vary considerably in the soil compaction necessary to prevent root growth. Trials could be designed to measure kauri root penetration strength similar to experiments in Bassett et al. (2005) without digging up existing tracks, although the penetration resistance of these tracks would still need to be measured with a penetrometer or equivalent.

Beauchamp and Upperton (2012) undertook trials in Northland to test the efficacy of different geotechnical track products in terms of whether they would disrupt hydrology around the track, avoided muddy surfaces, and whether root penetration occurred within them. They found that Geoweb particularly was promising in that it prevented mud, did not disrupt hydrology, allowed and maintained leaf litter build-up, and provided feeder root penetration.

Dick and Kimberley (2013) showed that *P. agathidicida* spores were deactivated by exposure to alkaline pH. For track, box step, and boardwalk applications, in and around positive *P. agathidicida* Kauri Forest Zones, therefore, consideration could be given to use of calcium oxide (CaO) materials integrated with appropriately sized fill. This could be used to deliver some degree of disease suppression though the development of an alkaline pH in the surface aggregate that is antagonistic to any *Phytophthora* inoculum (Bellgard and Probst 2018). As identified in Bellgard and Probst (2018), however, consideration must also be given to the down-stream impacts of run-off water with an altered pH.

4.6 *Possible effects of track construction or decommissioning on kauri forest health*

The process of upgrading existing tracks in Kauri Forest Areas (or constructing new tracks) will have several effects on kauri forest health. The motivation for undertaking such upgrading is to improve the overall health of Kauri Forest Areas by containing and preventing diffusion of *P. agathidicida* from any existing areas of infection to other kauri, within either the contiguous forest or elsewhere.

Negative effects may occur, however, through:

(i) changes in hydrology that lead to water pooling improving habitat for *Phytophthora* species presence and sporulation,
(ii) importing plant disease, including *P. agathidicida*, on construction materials,
(iii) damage to surface roots from construction,
(iv) introduction of toxic chemicals into the ecosystem through leaching from construction materials (e.g. plastics), and
(v) severing kauri root networks that have grown into fill materials contained in Geocell or Geoweb track containment structures when tracks are decommissioned.

Processes to avoid these negative effects associated with track reconstruction are mostly detailed adequately in Butler (2019) and MPI (2019b). The potential introduction of non-natural chemicals into ecosystems through use of tantalised timber (e.g., for boardwalks) or by introducing synthetic polymers into ecosystems (e.g. as Geocell or Geoweb) is not discussed, however, and is of importance to Māori (Scott Lomas, Te Kawerau ā Maki, pers. comm). An investigation of the impact of tanalised posts on kauri root structure indicated that kauri root systems were not negatively affected by proximity to such posts (Silvester 2006). Although marketed as inert and stable, further studies of any potential negative effects on the kauri soil environment near to products such as Geoweb, would be useful. As well, further consideration should occur to replace such products with natural alternatives.

The possibility of disruption to kauri root networks that have grown into cellular track containment structures (i.e. Geocell or Geoweb) could be possibly avoided if a water-permeable, root barrier is emplaced between natural soil and composite fill material used to level ground before placement of any Geoweb or similar.

4.7 Iwi considerations

Several different iwi occupy the northern regions within which kauri grows, and are keenly concerned with management of *P. agathidicida* to prevent kauri dieback. The main interface for iwi Māori in kauri dieback policy and management has been through the Tangata Whenua Roopu of the Kauri Dieback Programme. This group was made up of representation from various iwi and met regularly to discuss options on addressing *P. agathidicida*. One of the primary focuses of the Tangata Whenua Roopu has been on having mātauranga Māori recognised in the same way that western science is being recognised in addressing *P. agathidicida*.

For years, this recognition of mātauranga Māori in addressing *P. agathidicida* has been sought by iwi. The earliest intervention based on mātauranga involved imposing a rāhui on kauri forests to limit the spread of *P. agathidicida*, leading eventually to a rāhui in the Waitakere Ranges. Māori have long argued that we are part of the ecosystem and our actions influence what happens on the ground and in the forests. This has led to iwi opposing invasive science programmes that involved drilling into or injecting kauri trees - a clash of cultures. In a similar manner, the Māori tikanga of "waste not" is implicit in suggestions that dead kauri trees above the infected collar should not be wasted and available for iwi use.

The value of mātauranga Māori as a solution needs to be recognised within research and management approaches. The EPA has recently published a Mātauranga Framework and a Mātauranga Guide to assist government departments in acquiring a greater understanding of, and the relevance of mātauranga (Environmental Protection Authority 2020). Rauika Māngai in conjunction with the 11 National Science Challenges, Te Pae o Te Māramatanga, MBIE, AUT and The Macdiarmid Institute have also published A Guide to Vision Mātauranga to guide all the Science Challenges and other participants on using and responding to mātauranga (Rauika Māngai 2020). This increased emphasis on including mātauranga perspectives in environmental management demands that the continued development of tracking techniques within kauri forest should be considered through both western science-based and mātauranga lenses.

Te Kawerau ā Maki are the mana whenua with *kaitiaki* custodial guardianship over the Waitakeres Regional Heritage Area. The Te Kawerau Iwi Tribal Authority and Settlement Trust provided a letter to the Kauri Dieback Programme (23rd October 2019), expressing concerns over the use of Geoweb, especially because of the potential for root growth through the Geoweb matrix. Specifically they sought assurance over the durability of Geoweb and risk of erosion of applied aggregate materials. They also sought to minimize the impacts of any future removal of Geoweb, and reduce any concomitant damage to tree roots that have penetrated and grown into the matrix.

Prevention of tree roots from entering the Geoweb matrix could be achieved by ensuring tracks are located to avoid kauri tree root zones. If a track needs to be aligned in kauri areas, then a minimum buffer distance of "three times the drip-line" of any kauri tree from the track boundary was recommended by the Te Kawerau Iwi Tribal Authority and Settlement Trust.

Separation of the tree roots from track-building materials (i.e. Geoweb/Geocell/aggregate materials) may be achieved using water-permeable, root barriers, to exclude roots from the track zone. Organic/natural materials are preferred by Te Kawerau Iwi Tribal Authority and Settlement Trust to synthetic geotextiles (e.g., Merfield 1999). Te Kawerau Iwi Tribal Authority and Settlement Trust recommend further research into the availability and use of such materials.

Auditing of various track installations, in kauri reserves, especially those older than 10-years to quantify the amount of root growth into and under the track zone will help inform long-term suitability of the various options. The objective would be to minimise follow-up maintenance for cost-efficiencies.

Te Kawerau Iwi Tribal Authority and Settlement Trust suggest that the best-management track design guidelines must be a "living" document, which actively up-dates and integrates constant improvement opportunities as a product of periodic monitoring of track performance to protect kauri roots and minimise the spread of kauri dieback. The panel notes that most management agencies involved (e.g. Auckland Council, Department of Conservation) already operate under such continuous improvement processes and endorse this approach.

5 Panel recommendations:

The materials and techniques detailed in Butler (2019) for upgrading tracks within Kauri Forest Areas hold great potential to create durable tracks that will mitigate the risks of tracks acting as sources for diffusion of *P. agathidicida* spores. We could find no evidence, however, that such track reconstructions have been tested for their efficacy with regard to this mitigation. We recommend testing is carried out of surfaces of various tracks reconstructed through Kauri Forest Areas or on soil on footwear that have walked these tracks to look for the presence of *P. agathidicida* spores. As well, trials should also be carried out to establish the level of compaction (e.g., a measure of penetration resistance) necessary in the aggregate surface to prevent kauri feeder roots from penetrating this barrier.

In terms of materials available for track reconstruction, we were uncertain of the benefit of kauri roots growing into the fill within Geoweb cells. Although this may help ensure the integrity of root plates around the track, it may also increase the risk of infected roots being exposed on the track surface. It may also make it difficult to decommission a track as roots would need to be cut to remove the Geoweb panels (note that the panels could be left in place on decommissioning to avoid such damage). Investigation of a further water-permeable, root barrier that could be emplaced between natural soil and composite fill material used to level ground before placement of any Geoweb or similar product seems prudent. Also, the possible use of calcium oxide within track surface aggregates to create an alkaline track environment that is known to suppress *Phytophthora* presence and sporulation should be further investigated.

The review also found that the National Kauri Dieback Track Infrastructure Guidelines (Butler 2019) and the National Technical Specification for Track Mitigation Measures (MPI 2019b) were generally sufficient to guide the design of mitigation actions for track or boardwalk construction (subject to verification by sampling described above). There needs to be more harmony achieved, however, between the two documents, as there seems to be differences in terminology which leads to doubt in the interpretation of the guidelines as applied to a specific situation (Appendix 2).

The Guidelines use the terms "high" and "low" value kauri and these terms need to be clarified and remain consistent through the two documents. The descriptions of the mitigation actions would ideally be turned into "prescriptions", using some form of "decision tree" or flow chart-like format, as a decision support tool (Appendix 2).

In terms of monitoring track integrity, no timing for monitoring events was provided in the Guidelines. The frequency of such monitoring should be estimated in the Guidelines, based on likely rates of track wear, to ensure that these function as safeguards once mitigated tracks are in place and subject to foot-traffic and episodic rainfall events. Testing for presence of *P. agathidicida* spores on track surfaces or footwear using tracks could be incorporated as a part of regular monitoring. Interpretation of data collected in this way should be fed-back into the continuous improvement of track installation and management guidelines.

The panel did not recommend halting track reconstruction programmes while such research as recommended was conducted, but that implementing results of any research would be part of a culture of continuous improvement in the future.

The increased emphasis on including mātauranga perspectives in environmental management demands that the continued development of tracking techniques within kauri forest should be considered through both a western science-based and mātauranga lenses.

The three guiding principles for future track design and implementation from the Te Kawerau Iwi Tribal Authority and Settlement Trust are as follows:

5.1 Track design and installation needs to take into consideration future forest health, especially future track removal and potential to damage roots that have grown into the track materials.

5.2 The chosen track design should be easy to manage and minimise on-going investment for maintenance.

5.3 Whichever design is chosen in any situation, it must achieve the primary objective, to separate the "feet from the *whenua*" and mitigate the spread of kauri dieback.

6 Acknowledgements

We acknowledge Travis Ashcroft and Shruti Mewara from Ministry for Primary Industries for their critical assistance in initiating and supporting this review. We thank S. Lomas of the Te Kawerau Iwi Tribal Authority and Settlement Trust for participating in the review consultation process.

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Appendix 1:

TERMS OF REFERENCE

Kauri Dieback Programme

Independent Review of track materials used for track stability and root protection in kauri forests

Version 2.1 – FINAL

Name and role of approver	Signature/Date
Rebecca Murrie Manager, Kauri Dieback Management Group Ministry for Primary Industries	Rebecca Murrie 04 September 2019

1 Background

The Kauri Dieback Programme (the Programme) has been in place since 2009. It is a collective effort involving central government, local government, tangata whenua, scientists, industry and communities, to protect kauri forests from the soil-borne pathogen, *Phytophthora agathidicida*.

A National Pest Management Plan, which is currently under consideration, has been developed as a vehicle to drive an improvement in efficiency and effectiveness of national and local efforts. To support the requirements proposed by the plan, the Programme is currently developing national track standards, track specifications and track guidelines for all walking tracks in kauri lands.

The Programme seeks an independent review to determine which track materials best achieves the objectives outlined below.

2 Objectives

The objective of the review is to ensure that track materials and their use:

- Does not harm but can improve kauri and kauri forest health; and
- Prevents or minimises track user exposure to soil and subsequent soil contamination.

3 Scope

The best available options for track construction over Kauri roots that best fit the assessment criteria, listed in Section 4.

Two of the systems that we wish to include as part of the review are two Polymer-based cellular confinement systems such as 'Geoweb' and 'Geocell' which are used to stabilise bark, aggregate and other granular products during track construction and subsequent track use.

Both 'Geoweb' and 'Geocell' terms are loosely applied and interchangeable by various suppliers. In the context of this review, we define the two mitigation systems as follows:

System	***Definition***	***Specification***
Geoweb	*Bark/Aggregate mix (BAM) filled flexible web type Geocell confinement*	*A bark/aggregate layer with an aggregate capping layer, placed within and stabilised by a flexible HDPE cellular confinement web of at least 75mm thickness and with cells measuring typically 330mm x 250mm.*
Geocell	*Aggregate filled rigid panel type Geocell*	*An aggregate layer stabilised by a rigid polypropylene cellular confinement grid of typically 40mm thickness with cells of nominal 60-80mm diameter.*

Photos. (Left): ‘Presto’ Geoweb based system used to stabilise BAM on walking tracks. (Right): ‘Jakmat’ Geocell system being used to stabilise aggregate walking track surfacing (Photos courtesy of T. Butler, Frame Group Ltd).

Aside from the two mitigation options, other options should be explored and reviewed. Alternative cellular confinement systems including non-polymer-based materials as well as different granular types, mixes and sizes (as fill media), edging, compaction methods and the use of geofabric linings should also be considered.

Each option should be viewed as assessing the whole 'system' as one unit, instead of reviewing each individual material on its own merit. Unless the review determines a particular material that fulfils the assessment criteria on its own.

Are there certain situations where a combination of systems could be used in a kauri forest? If so, list these and provide reasoning.

4 Assessment Criteria

The Programme seeks an independent review to determine which 'system' best achieves the objectives by assessing each mitigation option against the below criteria;

#	• ***Criteria***
1	*Is fit for purpose as a construction material/s used for mechanical stabilisation.*
2	*Ensures track user safety.*
3	*Is culturally appropriate.*
4	*Manages water by appropriately dispersing water and avoids damming or bulk loading (water pooling) preventing mud accumulation on the track surface.*
5	*Protects living roots from damage and encourages root growth.*
6	*Causes negligible harm to kauri health and minimal impact to the surrounding environment during its construction and use. Includes impacts from track decommissioning or repairs such as removal of track material or material left in situ.*
7	*Provides a clear separation between the track surface and kauri roots.*

5 Other Considerations

In addition to the above criteria we request commentary on the following:

- System lifespan and long-term longevity.
- Advantages & disadvantages of each system or product.
- Cost implications (fiscal analysis) for each system during track construction and ongoing operational costs.
- Are there situations where a combination of different options could be used i.e. can some systems/products be used in certain areas while other alternative systems/products are more suitable for other areas?

6 Associated Documents

- Kauri Dieback Disease Management: National Technical Specifications for Track Mitigation Measures. Ministry for Primary Industries. Frame Group Ltd. *In Development.*

- Beauchamp T. Preliminary trial of track surfaces as possible mitigation for routes with Kauri dieback (*Phytophthora* taxon Agathis). Department of Conservation. Unpub.

Other documents may be provided.

7 Expected Benefits

The review will provide advice and assurance to stakeholders that these products used in track construction have been independently reviewed and that the products recommended as part of the review are the best available product(s) that fulfil each (or majority) of the criteria listed.

8 Timing and Deliverables

Key tasks/deliverables for the independent review panel and associated timing are as follows:

Task/Deliverable	***Estimated Date****
• *Draft report provided to MPI*	*Oct 2019*
• *Partner organisations feedback to Independent Panel*	*Oct 2019*
• *Final report on the independent review of track products.* *Final report should include:* o *Executive Summary:* ▪ *Overview of the review. Summary of the principle features of the report.* o *Independent Panel Membership:* ▪ *Panel members - biographies and independence* o *Introduction:* ▪ *Background, context and reasoning for the review.* o *Approach:* ▪ *Sets out the approach to this review, its Terms of Reference, and the methodology undertaken.* o *Findings & Recommendations:* ▪ *Key findings* ▪ *Alignment with assessment criteria.* ▪ *Additional commentary on (1) cost/fiscal analysis;* *(2) System lifespan and long term longevity; (3)*	*Oct-Nov 2019*

Advantages & disadvantages of each system or product; and (4) Are there situations where a combination of different options could be used i.e. can some systems/products be used in certain areas while other alternative systems/products are more suitable for other areas? ▪ *Uncertainties, barriers, caveats.* ▪ *Key Recommendations* o *Acknowledgements* o *References cited* o *Appendices* ▪ *Included supporting documentations, terms of reference, meeting agenda (including list of participants); list of background documents provided including independent research.* ▪ *Consultation (who did the panel consult during the course of this review).*	
• *Verbal report back on the outcomes of the review (if required).*	*Nov 2019*

**Final deliverable date(s) to be confirmed upon negotiation with the panel.*

9 Membership and Governance

Independent review panel members will be appointed by the Kauri Dieback Programme as soon as possible, and will meet as necessary, in order to provide independent review and advice to the Kauri Dieback Programme and others.

The panel members (as a collective) must exhibit the following competencies:

- Ability to take a broad view and provide independent perspective
- Relevant technical and science expertise and knowledge of dieback management within natural forest.
- Relevant mātauranga Maori expertise with recognised standing in the Maori community.
- Relevant expertise in engineering, preferably track engineering
- Relevant expertise in landscape (track construction)
- Relevant ecological expertise relating to forest ecosystems.
- Relevant hydrological expertise relating to hydrological processes in a forest ecosystem

A chair must be selected from the panel.

Knowledge required:

- An understanding of kauri dieback is preferred, but not essential for all panel members.
- A good understanding of the natural forest environment is desirable.

10 Communications

The panel members may not make statements publicly about the work or anything in connection with the work of the panel without prior approval from MPI.

11 Conflicts of Interest

Where peer reviewers face potential conflicts of interest, or the perception of a conflict, these will be declared to MPI as early as possible, when they arise.

12 MPI Contact

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Appendix 2:

Critique of the National Kauri Dieback Track Infrastructure Guidelines and the National Technical Specification for Track Mitigation Measures

Design Criteria	Pros	Cons
a. Track design criteria within Kauri Zone, Construction details	#01: Composite, sub-surface fill material will increaser porosity and drainage. The design accommodates the health of kauri feeder roots #02: lightly compacted bark aggregate composite mix will increase porosity, avoid compaction and promote root health #03: Discharge produce water away from kauri root zones will prevent waterlogging.	#01: Define "Low value kauri" more carefully Durability of 50 mm graded aggregate under high foot-traffic / episodic rainfall events (1 in 100 year)? #03: Filled Grade Dip Detail how durable is the batter slope after episodic rainfall event (i.e. 1 in 100 year)?
b. Cellular Confined Bark	#01: Bark/aggregate composite will increase permeability to avoid ponding Local fill from outside kauri zone to minimise risk of introduction of PA Any source of material from "certified" PA disease free origin.	#1A: Has anyone carried out an in-use examination of the Geoweb™ in operation? Is there root penetration? Could consider emplacement of water permeable, root barrier between natural soil and composite fill material used to level ground before placement of the Geoweb™
c. Track design criteria outside Kauri Hygiene Area	#01: Number of design criteria to minimise water logging	Need to designate "diseased" from "healthy" stands, as this should affect access to/from the hygiene areas. #01: How durable is the 50 mm thickness of the aggregate used in association with the edge board in episodic rainfall event (i.e. 1 in 100 year)? #03: how durable is edge-boarding in episodic rainfall event (i.e. 1 in 100 year)? Use of "ground-hog" instead of pegs? #04: More detail needed around direction of diverted water from Grade Dip Detail. #04: More detail on design of "side-drain" depending upon whether max. or min. fall in grade, and how robust is the design after an episodic rainfall event (i.e. 1 in 100 year) and/or wet-season? How does this relate to placement of wash-down facilities between accessing these two zones? How feasible is this at forest margins, i.e. where paddocks adjoin a kauri forested area?
d. Box Step Design		#01: Solid edge, disrupts lateral water flow Allows for ponding in box step-cells, which provides environment for sporulation of *Phytophthora* #02: what is the allocation for the provision of room for installation of handrail needs to take into consideration kauri roots where installing in kauri zone?
e. Low Boardwalks	#01: a number of design features to minimise transfer of soil.	#01: Filled imported inside kauri zones must from certified supplier Alternatives to "driven piles", e.g. "ground-hogs" What is the action if major kauri root encountered? Any excavations of kauri root mats to be noted in construction notes by supervisor and reported for follow-up auditing for any signs of disease ingress. #02: Consider addition of anti-slip material e.g. Geoweb™? What is the opportunity for high boardwalk (with railing) to discourage people from leaving boardwalk? #03A: Use of "ground-hogs" instead of driven piles?
f. Timber Fence handrails	#01: fencing is good deterrent from leaving the track.	#01: Aperture of lower gap could allow dogs/pigs Screening using Geocell™ material What is the action if kauri roots intersected? #04: provision of handrails adjacent to box-step will increase the disturbance footprint associated with box step design.