Safeguarding Iconic Tree Species, Dependent Ecosystems, and Regional Economies: A New Zealand Perspective on Controlling Kauri Dieback

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Summary

This study explores the economic impacts of Kauri Dieback disease on recreational services in New Zealand’s Waitākere Ranges Park. Employing a risk-assessment framework and probabilistic Cost-Benefit Analysis, it evaluates the costs associated with management plans against the benefits of avoiding park closure. A novel aspect of the research is the calculation of the minimum probability of closure required for protection measures to be economically justified. Results indicate that interventions are cost-effective at probability thresholds ranging from 0.2% to 8.9%. Scenarios with higher visitor expenditures yield significant net benefits, underscoring the necessity for strategic investment in conservation efforts.

Keywords: recreation; outbreak; kauri dieback; probabilistic CBA; policy decision.

1 Introduction

Native forest species around the world are invaluable for sustaining a multitude of ecosystem services, playing a vital role in maintaining ecological balance and supporting biodiversity. However, the prevalence of plant disease outbreaks is on the rise, driven by the increasing frequency and intensity of abiotic climate change-induced stressors, coupled with the escalating biotic threat from pathogens and pests. Understanding and mitigating these risks have become pressing priorities, as the ramifications of more frequent plant disease outbreaks extend beyond ecological concerns, impacting agriculture, economies, and human wellbeing.

In New Zealand, kauri trees (*Agathis australis*) are of high significance due to their cultural, ecological, and economic importance. Serving as integral components of the native landscape, these iconic trees also hold deep cultural value for the indigenous population. Kauri Dieback (KD) disease, caused by the microscopic pathogen (*Phytophthora agathidicida*) has rapidly spread across New Zealand, posing a significant threat to those native trees. The disease manifests as extensive root rot, canopy thinning, and the shedding of bark, ultimately leading to the decline and death of infected trees. The inadvertent transfer of infected soil to previously uninfected areas has been a key factor in the disease's rapid spread throughout New Zealand, impacting kauri populations across the country (Bradshaw *et al.*, 2020).

As climate patterns shift and disease vectors expand, the vulnerability of kauri trees is amplified. Their potential loss has far-reaching consequences, not only ecologically but also socially, given their role as cultural symbols and catalysts for conservation efforts. This matter also reverberates economically, as kauri trees play a role in New Zealand's economy, impacting sectors like forestry and tourism. Despite the ecological value of kauri is well-recognized, yet it remains a complex endeavor to quantify this value comprehensively.

Mitigation measures for KD typically focus on reducing the risk of disease spread when entering or leaving affected areas. Control measures, such as soil prevention methods like footpath cleaning stations and walking boards, are typically employed as first-responder actions. Although uncommon, in situations where alternative mitigation measures prove ineffective or where the rate of disease spread is high, natural areas closure may be used as an effective measure, especially in cases involving diseases transmitted through soil movements (Bradshaw et al, 2020). Some examples include the temporary closure of parks and natural areas in California in response to the presence of *Phytophthora ramorum*, causing Sudden Oak Death (e.g., Alexander & Lee, 2010). Also, Japan implemented temporary closures in pine forests to combat the spread of *Bursaphelenchus xylophilus* responsible for the Pine Wilt Disease (e.g., Futai, 2008). Nonetheless, the decision to close a natural area is characterized by a complex and challenging process, and the associated social and economic consequences are not easily quantified.

1.1 Previous Literature

The application of probabilistic approaches within Cost-Benefit Analysis (CBA) has seen significant development in various disciplines over time. In the epidemiology and disease control field, those probabilistic approaches have been used to manage outbreaks. In the agricultural domain, Breukers *et al.* (2012) developed a protocol for conducting CBA tailored to the control of pest and disease incidence. This protocol is exemplified through case studies including *Thrips palmi* (Melon Thrips) in the UK, *Anoplophora glabripennis* (Asian Longhorn Beetle) in Italy, and *Diabrotica virgifera virgifera* (Western Corn Rootworm) in Germany. The dynamic nature of infectious diseases, where uncertainty surrounds both the spread and containment efforts, offers parallels to the challenges posed by KD.

Within the probabilistic CBA literature, the simplified cost-loss decision-making model, initially developed by Katz and Lazo (2011) to prove the value of climate forecasts, has been widely applied in natural hazard' literature, specifically in the context of volcanic hazards. Marzocchi and Woo (2007, 2009), Woo (2015) and more recently Wild *et al.* (2023) used the cost-loss approach to contrast the socio-economic cost of evacuation versus the potentially avoided loss of lives in the event of a volcanic eruption. The advantage of this approach over a probabilistic CBA is that the resulting metric, i.e., cost-loss ratio, can be compared to the probability of an adverse event estimated ex-ante by a decision-maker or subject matter expert (Stewart, 2010).

Considering a potential application of the cost-loss framework in the context of fragile ecosystems that hold great societal values (e.g., urban forests), the potential losses from an adverse event should not be limited to the potential loss of iconic species but should include the potential loss of their ecosystem services (e.g., recreation). For example, Monge and McDonald (2020) measured potential risks associated with wind damage and evaluated the economic implications for forest recreational services. This work was based upon the travel cost literature attempting to measure the value of recreational ecosystem services through methods such as those proposed by Loomis (1995) and Loomis *et al*. (2001).

1.2 Objective

In light of these challenges, this study aims to assess the multifaceted economic repercussions of the KD disease on the local, regional, and national economy of New Zealand. By investigating a specific case study, we aim to uncover the economic and ecological complexities of this issue, with the goal of contributing to the preservation of the kauri tree and the sustainability of local economies impacted by its decline.

While the value of kauri includes several ecosystem services, such as carbon sequestration and water regulation, the most tangible and quantifiable service that kauri provides is recreation. Prior studies conducted in New Zealand have recognized the significance of recreation in the context of the broader economic impact of KD, they refrained from incorporating recreation impacts in their CBA due to a set of challenges (Clough & Hensen, 2021). These challenges include the New Zealand-specific nature of recreation value, which exhibits considerable variation across locations. While bespoke studies tailored to each location are deemed the most reliable, they are infrequently conducted in New Zealand due to their expense. In 2018, Deloitte conducted a CBA for the National Pest Management Plan (NPMP) for KD, comparing various scenarios such as the status quo, kauri extinction, and forest closure. However, this study had limitations, including a focus only on government and regional council program costs, and benefits that solely considered the value of kauri as sawn timber and carbon sequestration. From their findings, the suggested forest closure presented the highest net benefits, yet it did not account for the loss of forest access for recreational purposes (Deloitte, 2018). In their subsequent work (Deloitte, 2019), CBAs qualitatively discussed the value of kauri as a tourism attraction, comparing tourism expenditure in regions with kauri to the overall value added in those regions. Therefore, our study seeks to address this gap by considering the potential reduction in ecosystem services provided by kauri forests, with a focus on recreation.

Specifically, this research presents a probabilistic CBA for evaluating the provision of recreational services and assessing the impacts of KD in the Waitākere Ranges/Auckland Region. The research draws from probabilistic CBA in the natural hazards field and cost-loss decision-making (Katz & Lazo, 2011), and explores the inclusion of both direct and indirect economic impacts. The proposed framework sets a threshold by evaluating the cost of specific actions (e.g., mitigation measures) against potential losses resulting from inaction (e.g., loss of recreational expenditures due to park closure, or loss of kauri trees) (Tab. 1). This assessment involves comparing the derived ratio to an expert-elicited probability of facing an unfavorable scenario (i.e., the likelihood of park closure due to a KD outbreak). Should this probability surpass the predefined CBA threshold (where probability > cost of action/loss of inaction), the contemplated action, such as implementing mitigation measures, is considered economically advantageous (Woo, 2008; Wild *et al.*, 2023). Yet, determining the expert-assessed probability of park closure relies on various factors, including the likelihood of a KD outbreak and other challenges in quantification posed by limited information, particularly monetary data. The absence of existing literature on outbreak risk has presented its own set of obstacles, preventing us from making direct comparisons between the threshold and probabilities developed by experts. Importantly, our decision not to explore the scenario of an outbreak with the park remaining open is not a deliberate choice to omit valuable insights but rather a pragmatic approach. We have worked diligently with the information at hand, such as monetary data, recognizing its inherent limitations. This decision is grounded in the acknowledgment of potential adverse consequences, including an elevated risk of heightened kauri tree loss and increased disease spread alongside recognizing the perceived improbability of such an event. To comprehensively address this scenario, it would be necessary to assess both the use and non-use values of kauri trees, requiring the application of non-market valuation techniques.

Table 1: Cost-Loss Decision Making Model, Adapted from Katz and Lazo (2011).

Kauri dieback states	Decision scenario	Without mitigation actions	With mitigation actions
No outbreak (Y_1=0)	No park closure (Y_2=0)	None	Cost of actions
Outbreak (Y_1=1)	No park closure (Y_2=0)	Permanent loss of kauri trees (L_{tree}) and ecosystem services	Cost of actions
	Park closure (Y_2=1)	Temporary loss of recreational services ($L_{expenditure}$)*	Cost of actions

* In other words, no loss of kauri trees and their other ecosystem services.

The study is structured as follows: Section 2 describes the method and data sources used, Section 3 provides an interpretation of the results, and Section 4 provides conclusions and recommendations for further studies.

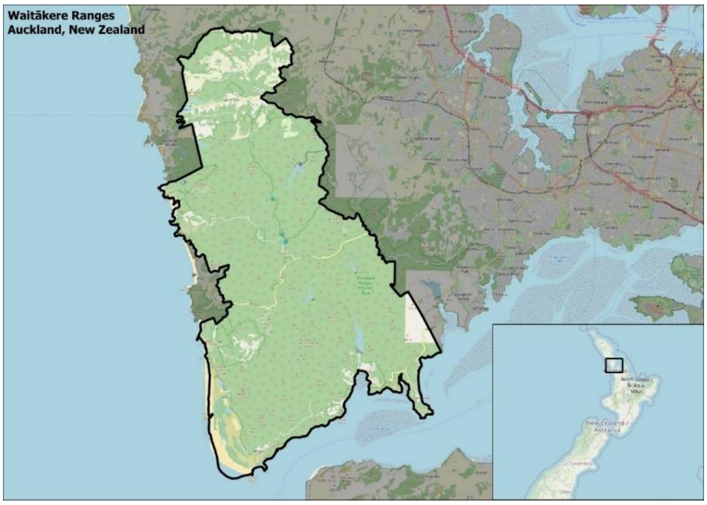
2 Materials and Methods

2.1 Study Area: Waitākere Ranges, New Zealand

Kauri forests are distributed throughout various parts of the North Island and draw countless visitors, sustaining New Zealand's tourism industry. Those native trees are a symbol of New Zealand's natural heritage and hold deep cultural and spiritual significance for indigenous Māori communities (Bradshaw *et al.*, 2020). Additionally, kauri forests are vital components of New Zealand's ecosystem, playing a crucial role in carbon sequestration and maintaining biodiversity.

The Waitākere Ranges are a regional park located in the West of the Auckland city, in the upper North Island of New Zealand (Fig. 1). It is the home to a recreational center, with over 1 million visitations per year. In addition to the ecological, cultural, and public significance of this natural area, the Waitākere Ranges also provide the opportunity to comprehensively address the impacts of the disease and generate insights that can be applied to protect kauri trees across New Zealand.

Figure 1: Waitākere Ranges Regional Park, New Zealand.



KD was first found in New Zealand on Aotea/Great Barrier Island in the 1970s. However, it was not until 2006 that KD was first detected in the Auckland's Waitākere Ranges. Between 2011 and 2016, the occurrence of dieback symptoms in this area more than doubled. By 2016, 19% of all kauri trees in the forest showed signs of infection, and around 58% of kauri forest patches larger than 5 hectares had symptomatic trees (Hill *et al.*, 2017). Hence, local iwi, *Te Kawerau ā Maki*, imposed a *rāhui* (i.e., placing restrictions or prohibitions on a particular area to protect it) in late 2017, followed up a few months later by Auckland Council's decision to close the forest to the public due to the risk of further disease transmission. This crucial step led to the implementation of comprehensive track and park closures, effective from May 1, 2018. There were 142 existing tracks within the regional park. Of these, nine were permanently closed, 62 were temporarily closed, and 71 tracks were scheduled for upgrades and reopening. Following the park closure and rāhui, only 25 tracks remained open to the public (Stuart Leighton, personal communication, 8 May 2023).

As a result, the rapid spread of KD disease has imposed limitations on leisure activities, resulting in decreased local spending, as well as expenses related to containment and mitigation measures. Among those, the installation of hygiene stations at tracks entrance, the extensive educational campaigns led by the Department of Conservation (DOC) to raise visitor awareness, and the closure of high-risk areas to prevent further contamination. Also, tramping tracks have been upgraded with boardwalks and gravel paths to minimize soil disturbance, and strict guidelines have been put in place to ensure people adhere to biosecurity protocols.

2.2 Data Collection

Visitor Counts

To determine the number of visitors to the Waitākere Ranges, monthly visitor counts by park location was provided by the Auckland Council for the period spanning from 2015 to 2022 (Wayne Carlson, dataset, April 2023). In 2022, the total number of visitors reached 1,169,178. This data indicates a consistent annual increase in total visitations from 2015 to 2022, with a noticeable decline in 2019-2020, likely attributed to the impacts of Covid-19. It is important to acknowledge that the accuracy of these counts may be subject to variations and potential inaccuracies related to data collection methods, disruptions affecting park accessibility, and reduction in international visitors due to border closure during Covid-19 outbreaks.

Domestic Visitor Expenditures

Visitor expenditure data for the Waitākere Ranges region was obtained from the Domestic Travel Survey (DTS) conducted by the New Zealand Ministry of Tourism. On average, visitors spent around NZ$348 per person per trip (adjusted to NZ$$_{2023}$), with individual spending ranging from NZ$72 to NZ$4,127. Notably, food and beverages constituted the largest portion of the expenses.

This comprehensive survey provided insights into the travel habits of domestic tourists, collecting data on the purpose of trips, trip durations, modes of transport, destinations visited, and expenditure by category. The dataset covers the period from 1999 to 2012, and is specific to the Waitākere Ranges trips and types of recreation activity (e.g., walking, sports, sightseeing). Regrettably, no more recent data is available as the survey was discontinued in 2012. The dataset excludes expenditure information from international visitors, who constitute a minor segment of the park's total visitors. As such, our analysis focuses on domestic visitors exclusively, particularly in light of the recent Covid-19-related border closures.

Mitigation Costs for Kauri Dieback

Information on tracks upgrade expenditure was obtained from the Auckland Council's reports (Auckland Council, 2019, 2020, & 2021). Data was collected from 2018 to 2022, focusing on the financial resources allocated for upgrading the quality, accessibility, and safety of specific tracks to prevent the spread of KD.

Specific expenditures for track upgrades in the Waitākere Ranges were extracted from the Auckland Council's latest report and adjusted to 2023 values using the Consumer Price Index (CPI) from Statistics New Zealand (StatsNZ), amounting to NZ$$_{2023}$ 6,518,203. Additionally, operational costs for surveillance and treatment, totaling NZ$953,884, were calculated by assuming a proportionate allocation from the

Auckland Council's overall expenditure on KD management programs across a range of parks beyond the specific area under study.

2.3 Cost Benefit Analysis

In a traditional deterministic context, the CBA would consist of weighing the benefits, derived from preventing the loss of recreational expenditures avoiding the closure of the Waitākere Ranges, against the costs including the expenses associated with implementing preventive measures. Using the Benefit Cost Ratio (BCR) as a starting point, the project's economic feasibility would be determined if the BCR is greater than one, i.e., the benefits outweigh the costs:

$$\mathrm{BCR} = \frac{\text{Benefits}}{\text{Costs}} \tag{1}$$

If BCR > 1 then the investment is economically feasible

However, in a probabilistic context, we have considered the 'expected benefits' (i.e., probability-weighted benefits) due to the random nature of the disease's outbreaks and potential subsequent park closure. Solving for the probability as will be formulated later, we estimated a probability threshold that equates benefits and costs, which in turn determines the optimal investment level for track improvement and mitigation measures. This estimation will serve as the "value at risk" in the event of another KD outbreak and potential closure of the tracks.
In the probabilistic CBA, the criterion that the expected avoided impacts ($E[I]$) should be greater than or equal to the added costs (C) is a crucial threshold, indicating when an intervention becomes economically viable by ensuring that the benefits of impact reduction outweigh the associated costs, i.e., positive net benefits:

$$\boldsymbol{E[I] \geq C} \tag{2}$$

Where:
$E[I]$ represents the expected value of avoided impacts (i.e., avoided loss of recreational expenditure), and C stands for the added costs associated with the preventative measures to reduce KD spread.

Including the probability of closure due to a KD outbreak, the equation can be expressed as:

$$p(\boldsymbol{I}\ without\ mitigation - \boldsymbol{I}\ with\ mitigation\ ) \geq \boldsymbol{C}\text{with mitigation} - \boldsymbol{C}\text{without mitigation} \tag{3}$$

Where:

- p represents the probability of a closure due to an outbreak.
- $\boldsymbol{I}\ without\ mitigation$ signifies the impacts with no mitigation measures (i.e., no actions).
- $\boldsymbol{I}\ with\ mitigation$ represents the impacts with mitigation measures in place.
- $\boldsymbol{C}$with mitigation represents the costs associated with the mitigation measures (e.g., tracks upgrade, surveillance, and monitoring).
- $\boldsymbol{C}$without mitigation represents the costs with no mitigation measures.

If you consider impacts with mitigation to be zero ($\boldsymbol{I}\ with\ mitigation$ = 0) and costs with no mitigation to be zero ($\boldsymbol{C}$without mitigation = 0), then the equation simplifies as follows:

$$p \cdot \boldsymbol{I}\ without\ mitigation \geq \boldsymbol{C}\text{with mitigation} \tag{4}$$

We considered that impacts with no mitigation represent the loss of recreation, and costs with mitigation represent the track improvements and other mitigation measures. The above condition states that if the probability-weighted (i.e., expected) loss of recreational expenditures is greater than or equal to the cost of track improvements, it is economically favorable to proceed with the mitigation measures. This suggests that the economic benefits of preventing potential losses from the outbreak's impact on recreation should outweigh the costs of track improvements to make the decision economically justifiable.

To calculate the threshold value (denoted as "$p_{threshold}$") where the expected impact without mitigation is equal to the costs with mitigation, we rearrange the equation as follows:

$$p_{threshold} = \frac{\boldsymbol{C}\text{with mitigation}}{\boldsymbol{I}\ without\ mitigation} = \frac{Costs}{Benefits} = \frac{1}{BCR} \tag{5}$$

This equation provides the probability threshold at which the expected impact without mitigation matches the costs associated with mitigation. In other words, if the probability of closure due to an outbreak (p_{expert}), estimated by a subject matter expert (i.e., plant pathologist), exceeds this threshold value ($p_{threshold}$), it would be economically justified to implement the mitigation measures, as the expected impact without mitigation would outweigh the costs of mitigation.

If:

$$p_{expert} > p_{threshold} \quad \text{OR} \quad p_{expert} > \frac{\boldsymbol{C}\ with\ mitigation}{\boldsymbol{I}\ without\ mitigation} \tag{6}$$

Then,

$$p_{expert} * \boldsymbol{I}\ without\ mitigation > \boldsymbol{C}\text{with mitigation}$$

Therefore, the expected benefits exceed the costs, which indicates a favorable economic outcome and provides a compelling rationale for investing in protection measures against KD. When considering p_{expert} in a BCR context we obtain:

$$BCR > 1 \quad \text{OR} \quad \frac{p_{expert} * \boldsymbol{I}_{without\ mitigation}}{\boldsymbol{C}_{with\ mitigation}} > 1 \tag{7}$$

Costs

The expenditure data acquired covers tracks upgrade for kauri safety standards in the entire Auckland Region, including both capital and operational expenses (e.g., surveillance, monitoring, treatment and research, compliance/engagement, and tracks upgrade within regional and local parks). However, data specifically pertaining to tracks upgrades in the Waitākere Ranges is available only for years 2020 and 2021. To provide a current estimate, we have adjusted the costs from the latest available year to

2023 values. Furthermore, a portion of the Auckland Council's operational expenditure for KD management in the broader Auckland Region from previous years has been extrapolated and applied to the Waitākere Ranges, also adjusted to 2023 values.

Benefits

The benefits of protection against KD disease spread were calculated as avoided loss of recreational expenditures. The potential recreational losses were calculated as the average recreational expenditure per visitor multiplied by the number of visitors to the Waitākere Ranges in 2022 (approximately 1,169,178 visitors). In our analysis, we calculated the direct benefits, but also the indirect and induced benefits for selected scenarios using economic multipliers.

Input-Output Multipliers

The economic multipliers measure the impact of a change in one sector of the economy on other sectors and the overall economy. They are calculated from the Input-Output Tables (I-O tables) (Miller & Blair, 2009) published by Statistics New Zealand, which provide detailed information on the interrelationships between industries and the various components of final demand in the economy.

We categorize these effects into three main types:

- *Total Direct Impacts:* The direct impacts refer to the immediate consequences of a KD outbreak with closure of the Waitākere Ranges Park. These include sectors and businesses that experience a direct loss in revenue because visitors are not able to recreate in the Waitākere Ranges. Businesses like restaurants and hotels that rely directly on park visitors for their revenue would experience a direct impact due to reduced customer numbers.
- *Total Direct and Indirect (Type I) Impacts:* Added to the direct impacts, the indirect impacts are the secondary effects on other sectors of the local economy that are not directly tied to the park itself but are affected due to the decline in park-related activities and spending (e.g., reduced demand for goods and services provided by local suppliers of restaurants and accommodation that cater to park visitors).
- *Total Direct, Indirect and Induced (Type II) Impacts:* Added to direct and indirect impacts, the induced impacts represent the tertiary effects resulting from the closure of the park due to an outbreak. These effects would occur as employees who have lost their jobs or experienced reduced income due to the park closure adjust their spending habits. Reduced consumer spending in the broader economy could affect various sectors, including retail, entertainment, and services, as households tighten their budgets.

To quantify those impacts, we obtained the National Accounts Input-Output tables from NZ.Stat for a specific year (2020 ending March 31st). Using the methodology employed by Smith *et al.* (2015), we generated the sub-regional multi-regional input-output (SRMRIO) tables for the specific sub-regions (i.e., the Waitākere Ranges). While Smith *et al.* (2015) produced economic tables who separated a specific region to the rest of New Zealand, our study followed a similar approach but at a more granular level. We distinguished the Waitākere Ranges from the remainder of the Auckland Region and subsequently from the rest of New Zealand. Then, we estimated output multipliers for three distinct sub/regions: the Waitākere Ranges, the rest of

Auckland, and the rest of New Zealand, as detailed in Table 2. We refer to Miller and Blair (2009) for the calculation of the multipliers.

The multipliers allowed us to estimate the magnitude of these impacts, felt by other sectors of the economy and by the community in the three regions. They provide information on how the initial loss of revenue (direct impact) ripples through the local economy, affecting businesses that indirectly depend on park-related activities (indirect impact) and, subsequently, how reduced consumer spending by affected individuals affects various sectors (induced impact).

Table 2: Economic Multipliers for Three Regions: Waitākere, Rest of Auckland, and Rest of New Zealand.

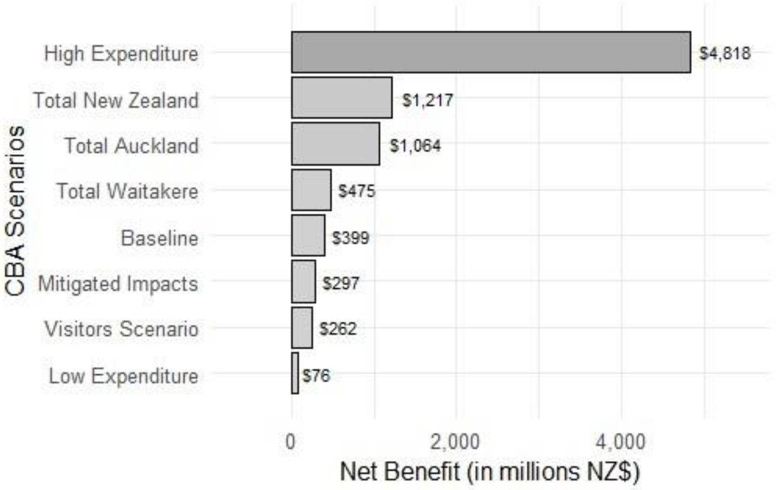
Linkages	Regions	Accommodation	Transport	Alcohol	Food & beverage	Gambling	Gifts & souvenirs	Other shopping	Recreation
Type I	Waitākere	1.08	1.07	1.08	1.08	1.03	1.06	1.06	1.08
	Rest of Auckland	0.57	0.67	0.63	0.63	0.44	0.63	0.63	0.72
	Rest of NZ	0.11	0.08	0.15	0.15	0.10	0.08	0.08	0.08
Type II	Waitākere	1.18	1.18	1.20	1.20	1.13	1.18	1.18	1.18
	Rest of Auckland	1.31	1.39	1.47	1.47	1.10	1.49	1.49	1.48
	Rest of NZ	0.36	0.32	0.43	0.43	0.32	0.35	0.35	0.34

3 Results

We conducted a probabilistic CBA to evaluate the economic impacts of KD across eight “what-if” scenarios, including four baseline scenarios with different scopes of impact assessment, a scenario focusing on visitor types, those considering varying visitor expenditures (low and high), and a scenario exploring partial mitigation effects compared to the baseline's total mitigation.

Among these scenarios, the one with the highest expenditure per visitor, yields the highest net benefit, approximately NZ$5 billion dollars for one year of park closure. Conversely, the lowest net benefit is associated with the scenario featuring the lowest expenditure per visitor, totaling NZ$76,148,466 per year (Fig. 2). These scenarios are based on a one-year park closure, and a more extended closure would likely have even greater economic implications.

Figure 2: Net Benefits of the “What-If” Scenarios.



As a starting point, we have assessed the project's viability in a deterministic manner (i.e., not considering the random nature of a potential closure) using the BCR. Without considering a closure probability, the BCR is greater than one in all scenarios indicating that the project yields a net benefit, affirming its economic viability (Tab. 3). In a probabilistic context this result would change as the benefits would be substantially less when weighted against the probability of a closure. However, without an exact probability of closure we cannot estimate an expected (or probability weighted) BCR. Hence the need to estimate a threshold probability, which is the inverse of the BCR (or 1/BCR). The threshold probabilities, ranging from 0.2% to 8.9%, highlight the economic viability of investing in KD protection measures, even for extremely low probabilities.

Table 3: CBA "What-If" Scenarios.

CBA Scenario (NZ$$_{2023}$)	1. Baseline scenario - Direct impact	2. Total impacts for the Waitakere Ranges	3. Total impacts for the Auckland Region	4. Total impacts for New Zealand
Costs				
Capital expenses	$6,518,203	$6,518,203	$6,518,203	$6,518,203
Operating expenses	$953,884	$953,884	$953,884	$953,884
Total costs	$7,472,087	$7,472,087	$7,472,087	$7,472,087
Benefits (Avoided Impacts)				
Direct impacts	$406,359,570	$406,359,570	$406,359,570	$406,359,570
Indirect impacts	$0	$29,261,672	$287,031,291	$331,633,774
Induced impacts	$0	$46,737,514	$378,011,225	$486,417,190
Total benefits	$406,359,570	$482,358,756	$1,071,402,086	$1,224,410,534
Results				
Net benefit	$398,887,483	$474,886,669	$1,063,929,999	$1,216,938,447
Benefit cost ratio	54.38	64.55	143.39	163.86
Threshold probability	1.8%	1.5%	0.7%	0.6%

CBA Scenario ($NZ\$_{2023}$)	5. Local and overnight visitors scenario	6. Lowest expenditure scenario	7. Highest expenditure scenario	8. Partially mitigated impacts
Costs				
Capital expenses	$6,518,203	$6,518,203	$6,518,203	$6,518,203
Operating expenses	$953,884	$953,884	$953,884	$953,884
Total costs	$7,472,087	$7,472,087	$7,472,087	$7,472,087
Benefits (Avoided Impacts)				
Direct impacts	$269,006,185	$83,620,553	$4,825,319,648	$304,769,677
Indirect impacts	$0	$0	$0	$0
Induced impacts	$0	$0	$0	$0
Total benefits	$269,006,185	$83,620,553	$4,825,319,648	$304,769,677
Results				
Net benefit	$261,534,099	$76,148,466	$4,817,847,562	$297,297,591
Benefit cost ratio	36.00	11.19	645.78	40.79
Threshold probability	2.8%	8.9%	0.2%	2.5%

3.1 Baseline Scenarios

Four baseline scenarios have been considered, each subject to assessment for varying impacts, including direct, indirect, and induced effects.

Exclusive focus on direct impacts

In this baseline scenario, we assume that no residual impacts result from the implementation of effective mitigation measures. This calculation is based solely on the average expenditure per person, derived from the DTS data, and multiplied by the number of individuals visiting the Waitākere Ranges area. This calculation takes into account only the direct impacts for the Waitākere Ranges, estimated at NZ$406,359,570, with almost a third (NZ$123,907,258) attributed to the food and beverage sector (Tab. 3, Tab. 4). This scenario yields a net benefit of NZ$398,887,483 and a BCR of 54.38. The threshold probability, calculated at 1.8%, signifies that mitigation measures are economically justifiable when the likelihood of park closure due to a KD outbreak exceeds this value.

Total impacts for the Waitākere Ranges

This scenario includes not only the direct impacts but also considers the additional indirect and induced effects specific to the Waitākere Ranges region. The total impact for this region amounts to approximately NZ$482,358,756, comprising NZ$406,359,570 in direct impacts, NZ$29,261,672 in indirect impacts, and the remaining NZ$46,737,514 in induced impacts (Tab. 3). These impacts are further categorized by expenditure types, such as accommodation, transport, and recreation, with their respective contributions remaining consistent.

By factoring in the indirect and induced impacts specific to the Waitākere Ranges region, the threshold probability decreases from 1.8% to 1.5%, indicating that implementing preventative and mitigation measures against KD is even more economically justifiable when the likelihood of park closure exceeds this lower threshold. This adjustment underscores the increased benefits not only for the affected sectors but also for the broader local economy and community in the Waitākere Ranges.

Total impacts for the Auckland Region

For the Auckland Region, the direct impacts remain consistent with those of the Waitākere Ranges, as it is the area directly affected (NZ$406,359,570). However, the indirect and induced impacts are a combined result of both the Waitākere Ranges region and the rest of the Auckland Region. Therefore, we add the indirect impacts of NZ$287,031,291 experienced by both the Waitākere Ranges and the rest of Auckland. Similarly, the induced impacts have two components, including both the Waitākere Ranges and the rest of the Auckland Region, totaling approximately NZ$378,011,225 (Fig. 3). Consequently, the total impact for the Auckland region is estimated to be around NZ$1,071,402,086 (Tab. 4). However, the total impacts on the Auckland Region and New Zealand as a whole may not be entirely accurate. Several factors can contribute to this discrepancy, including: *i)* a substitution effect, where visitors opt to explore alternative parks within the Auckland Region or New Zealand instead of the Waitākere Ranges due to its closure. While this represents a loss for the Waitākere Ranges region, it does not necessarily translate to a loss for the broader Auckland Region or New Zealand; *ii)* some individuals may choose to allocate their funds towards different expenditures, such as purchasing other goods or services, rather than recreate, given their inability to visit the Waitākere Ranges; *iii)* a portion of the potential visitors may opt to stay at home and forgo recreational activities altogether. This, in turn, results in a loss for all of New Zealand. Hence, the total impacts must be regarded as the worst-case scenarios, with the impacts on the Waitākere Ranges remaining constant regardless of other actions or decisions people might make.

The threshold probability demonstrates sensitivity, becoming even smaller when accounting for indirect and induced impacts. Specifically, for the Auckland Region, it reaches an exceedingly low 0.007 (0.7%). This can be attributed to the substantial benefits associated with avoiding indirect and induced impacts.

Total impacts for New Zealand

In Table 4, the total impacts for New Zealand are derived from the sum of the total impacts across the three regions, totaling approximately NZ$1,224,410,534. This comprises NZ$406,359,570 in direct impacts, NZ$331,633,774 in indirect impacts, and NZ$486,417,190 in induced impacts (Tab. 4). This cumulative impact figure is substantial, particularly when considering that it represents the calculation for a single year for the closure of the Waitākere Ranges due to a KD outbreak (Fig. 3). The threshold probability has decreased further to a 0.006 (0.6%). This implies that the benefits of mitigation and preventative measures far outweigh the costs, especially when factoring in the cascading impacts of a closure due to an outbreak on all of New Zealand.

Table 4: Total Direct, Indirect, and Induced Impacts for the Three Regions: Waitākere, Rest of Auckland, and Rest of New Zealand.

Impact (NZ\$million$_{2023}$)	Accommodation	Transport	Alcohol	Food & beverage	Gambling	Gifts & souvenirs	Other shopping	Recreation	Total
D	\$33	\$43	\$42	\$124	\$5	\$22	\$99	\$39	\$406
DI – Waitākere	\$36	\$46	\$45	\$134	\$5	\$23	\$105	\$42	\$436
DI – Auckland	\$55	\$75	\$72	\$212	\$7	\$37	\$167	\$69	\$693
DI – New Zealand	\$58	\$78	\$78	\$230	\$8	\$38	\$175	\$72	\$738
DII – Waitākere	\$39	\$51	\$50	\$148	\$5	\$26	\$117	\$46	\$482
DII – Auckland	\$83	\$111	\$112	\$330	\$11	\$58	\$265	\$103	\$1,071
DII – New Zealand	\$95	\$124	\$130	\$383	\$12	\$66	\$299	\$116	\$1,224

Note: D – direct, DI – direct & indirect, DII – direct, indirect & induced impacts.

Figure 3: Direct, Indirect and Induced Impacts on Waitākere, Auckland Region and New Zealand.

3.2 Local and Overnight Visitors Scenario

In this scenario, we maintain the general parameters of the baseline scenario, focusing solely on direct impacts, but introduce a significant adjustment to account for variations in visitor spending habits. We recognize that not all visitors spend equally during their visits. Daily visitors, for instance, do not incur accommodation costs and have relatively lower expenses for items such as transport, gifts, souvenirs, and gambling, as well as other shopping. While quantifying the exact reduction in food and beverage spending is challenging, we make deductions in these other expenditure categories based on the average spending data from the DTS. We then multiply the adjusted figure by the proportion of daily visitors (68%), as determined from our calculation using an anonymized phone dataset, covering all of New Zealand over a twelve-month period from July 2020 to July 2021 (refer to Appendix A). Conversely, we calculate the average overnight visitor expenditure from the DTS and multiply it by the proportion of overnight visitors (32%). The total expenditure per year is now equal to NZ$269,006,185. As in the baseline scenario, we continue to assume no impact thanks to the mitigation measures. A decrease in per-visitor expenditure due to a higher proportion of daily visitors compared to overnight visitors has a notable impact on the net benefits, resulting in a value of NZ$261,534,099, compared to NZ$398,887,483 of the baseline scenario. Additionally, this change is reflected in the BCR, which decreases from 54.38 in the baseline scenario to 36. The threshold probability experiences an increase, rising from 1.8% to 2.8% because of these assumptions about daily visitors' spending patterns.

3.3 Lowest Expenditure Scenario

For this particular case, we explore the economic consequences of a lower visitor expenditure within the Waitākere Ranges. To calculate the total expenditure, we multiply the decreased expenditure per visitor by the total number of visitors, with the lowest expenditure in this range being NZ$128 per person. As in the baseline scenario, we assume that the effects of KD are entirely mitigated through the implementation of mitigation measures.

The results indicate that the threshold probability increases to 8.9% due to the lower total expenditure. Additionally, the net benefit amounts to NZ$76,148,466, with the BCR being the lowest among the scenarios presented, standing at 11.19. This scenario highlights the significance of considering an expert-elicited probability assessment, as a probability below the threshold of 8.9% could imply that investing in mitigation measures might not be economically justifiable due to the lower likelihood of a KD outbreak.

3.4 Highest Expenditure Scenario

In this specific context, we consider the upper limit of total expenditure derived from the DTS survey. The highest recorded expenditure within this range is NZ$880 per person. As with the baseline scenario, we assume that the impacts of KD are fully mitigated through the implementation of appropriate measures.

With a remarkable net benefit of NZ$4,817,847,561, this scenario demonstrates the most favorable economic outcome among all the scenarios. The BCR soars to 645.78, reflecting the exceptional benefits (i.e., avoided impacts). Furthermore, the threshold probability approaches zero (0.2%). In this situation, regardless of the expert-elicited probability, the interventions would be economically justified.

3.5 Partially Mitigated Impacts

Considering that the assumption of zero impacts with mitigation measures may not align with reality, we adopt a conservative approach by assuming that 25% of the impacts persist despite the efforts. This percentage has been deliberately chosen to facilitate a sensitivity analysis, acknowledging that non-zero impacts can reduce the overall benefits. Here the calculated net benefit amounts to NZ$297,297,591, with a corresponding BCR of 40.79. Although certain impacts remain unmitigated, the threshold probability remains relatively consistent with that of the baseline scenario, albeit slightly elevated at 2.5%.

4 Discussion and Conclusions

The data collected and analyzed in this study underscores the critical importance of addressing the economic impacts resulting from plant disease outbreaks in specific regions, as well as their flow-on effects on other regions and the overall national economy. To evaluate the economic impacts of KD, we considered the expected benefits from preventing the loss of recreational spending, and we balanced those against the economic costs of taking steps to prevent the spread of KD disease in the Waitākere Ranges, as well as its broader implications for the Auckland Region and New Zealand as a whole.

In examining various scenarios, our research has revealed a range of potential economic outcomes, each of which shows the importance of investments in track improvements and proactive preventive measures. Those scenarios span from the most optimistic, with the highest total visitor expenditure, resulting in a robust net benefit of almost NZ$5 billion per one year, to the most conservative scenario, which assumes a significant reduction in visitor expenditures by considering the lowest range expenditure value. The net benefit in this scenario is substantially lower, at NZ$76 million per one year. We have also explored a more realistic scenario with 25% of the impacts unmitigated despite the implementation of prevention measures, which demonstrated to slightly affect the economic outcomes. In the pursuit of advancing our understanding and decision-making in addressing the threat of KD, our research has established a critical threshold probability that varies between scenarios, ranging from 0.2% to 8.9%. These thresholds signify the point at which investing in KD protection measures becomes economically justifiable, balancing mitigation costs against potential impacts without intervention. Highlighting the economic viability of such investments, the identified threshold probabilities accentuate the feasibility of safeguarding against KD, even in the face of low probabilities of outbreak.

However, it is essential to acknowledge the limitations and potential uncertainties associated with our data and findings. Certain challenges arose during data collection, particularly due to the limited availability of up-to-date data for our small-scale case study in the Waitākere Ranges. Additionally, the lack of available percentage-based data on the efficacy of preventative measures against KD in New Zealand adds complexity to assessing the full extent of their success. Furthermore, several factors related to disruptions of park accessibility and visitor counting may have influenced the accuracy of the number of visitations, especially during the Covid-19 outbreak. Taking the above points into account, we must exercise caution when considering the total expenditure and its derived calculations, as well as the indirect and direct impacts for Auckland and New Zealand, as mentioned in the results section. Therefore, these impacts should be treated as maximum estimates rather than definitive figures.

This research holds current relevance, especially in the context of potential closures of park and other natural areas, a matter of increasing concern. This is particularly pertinent in light of recent closures of tracks and forests following the discovery of kauri disease in the Kaimai Mamaku Ranges, situated on the eastern side of the North Island in New Zealand. The ongoing monitoring of other parks across regions further indicates their potential vulnerability to closure in the event of an outbreak, emphasizing the urgency of implementing effective strategies to safeguard these precious natural areas.

Future studies may look at seeking expert assessments of the probability associated with KD outbreaks and regional park closures. While existing literature lacks specific probabilities for KD outbreaks in the Waitākere Ranges or New Zealand, broader studies on outbreak probabilities for other plant disease and regions may offer insights. By comparing these expert-derived probabilities with our estimated threshold, decisionmakers can obtain valuable insights into the economic feasibility of dedicating resources to protection measures. Should the expert assessments exceed the threshold, it would provide compelling evidence that such investments are indeed economically viable. This comparison will enable a comprehensive evaluation of the economic viability of investing in KD protection measures. Furthermore, the use of human mobility big data (for e.g., the Near GPS data) holds the potential for conducting spatial CBA on a per-trail basis. For example, studies such as Colbert *et al.* (2022) used anonymized phone dataset to analyze the impact of Covid-19 on tourism in New Zealand and develop machine learning-driven classifications of tourist types based on their movement patterns. Applying similar techniques to the Waitākere Ranges could provide insights into how different types of visitors interact with the park facilities and trails, how the use varies between local visitors and domestic tourists, and whether there are seasonal differences. Other related research has been conducted on GPS trajectories in hiking path analysis and its utility in trail and park management (Lera *et al.,* 2017), as well as recent studies on tourist spatial and temporal patterns using GPS data (Huang *et al.*, 2020; Yao *et al.*, 2020; Choe *et al.*, 2023). In fact, the use of GPS data would help to overcome the limitations of using counters and surveys by painting a detailed spatiotemporal picture of trail usage across a potentially large number of visitors.

To conclude, the results of this study bear significant implications, not only for safeguarding the kauri trees but also for ensuring the sustained economic prosperity of the local community and the broader regional economy. As we navigate the complex challenges posed by KD, as well as other biotic stressors, this study serves as a valuable foundation for informed decision-making and future actions.

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Appendix A. Supplementary Information

We utilized an anonymized phone dataset of approximately 3 billion GPS pings purchased from Near Intelligence, covering all of New Zealand over a twelve-month period from July 2020 to July 2021. Due to the sheer volume of data, we have applied a spatiotemporal data mining algorithm to discover visit occurrences within the raw GPS trajectory data. The result of this data mining process is what we call Visits Data Product (VDP). The VDP reduces the data volume to a more manageable approximately 50 million visits, while retaining important information about when and where a visit occurred, how long it lasted, and the home neighborhood of each device. From this visits data we query the VDP to produce destination profiles, origin-destination matrices, and use in spatial interaction modelling, amongst other things.
For this research, we focused on the two Waitākere Ranges Statistical Areas 2 (SA2s; geographic unit) as the destinations. We queried the VDP for all visits to these two SA2s, while also excluding any devices that resided in these same SA2s (to avoid capturing observed visits within a user's home, which would distort the analysis), resulting in 2,356 observed visits. Figure A.1 visualizes the distribution of these visits by aggregating the visit points into approximately 58-meter-wide hexagon tessellation. The purpose of this analysis was to determine the proportion of daily and overnight visitors to be used in one of the CBA scenarios. As the VDP records the home neighborhood, we were able to set a 40 kilometers Euclidean distance threshold to classify visits as being daily or overnight, in line with the DTS criteria, which defines them as travelers covering a maximum of 40 kilometers one way. Among these observed visits, 68% were classified as daily visitors and the remaining 32% were identified as overnight visitors.

Figure A.1: Aggregated Visits to the Waitākere Ranges in 2020-2021 Using the Near Intelligence Dataset.