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Establishing loss of net stocked forest post-Cyclone Gabrielle

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Report information sheet

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Executive summary

Scion's novel forest detection model, ForestMap, was trialled in Te Arai Waingake, Gisborne, to assess whether the technology could be used to estimate the losses in net stocked area as a result of large storm events, such as Cyclone Gabrielle. The ForestMap model was used to delineate boundaries around planted forest on imagery pre- and post-Cyclone Gabrielle. The difference between the pre-event and post-event layers was refined and used to produce a layer describing the loss of planted forest as a result of Cyclone Gabrielle. A loss of over 60 hectares of planted forest was detected, representing approximately 3.1% of the total productive forest in the study area. Slope and aspect layers of the site also indicated that losses of net stocked area generally occurred on northeast and easterly facing sites with slope greater than 26°. Furthermore, nearly half of the standing forest losses occurred within 50 metres of a waterway.

The results of this study indicate that the ForestMap model shows promise as a tool for detecting and estimating the area of planted forest lost in the aftermath of severe weather events. While the detection of standing forest loss was imperfect in some areas, Scion's ongoing development of the model should improve future performance in the generation of detailed forest boundaries as well as the detection of impacted areas. Automating the detection of standing forest loss should reduce the laborious and time-consuming task of manually digitising forest boundaries. Using ForestMap to identify areas of planted forest loss could inform larger-scale assessment of the effects severe weather events have on planted forests and could help in determining the risk posed by woody debris to infrastructure and people.

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Introduction

The widespread failure of areas of standing planted forest and mobilisation of large woody debris (LWD) as a result of Cyclone Gabrielle had a significant impact on communities and infrastructure across the Gisborne region. LWD has been identified as the primary cause of failure and severe damage to critical regional infrastructure, including numerous bridges and the main water supply pipeline for Gisborne City. As such, further failures in standing forest and mobilisation of LWD during future severe storm events represents a serious risk to downstream infrastructure and communities.

There is still considerable uncertainty about the volumes of LWD present that could act as a reservoir of material that could potentially be mobilised in forested upper catchments during future events. Estimating the losses of net stocked area is therefore a necessary first step in determining the areas at highest risk. This information could aid steps to mitigate the risk this material poses to critical infrastructure.

Scion has been developing a method to map planted forests using artificial intelligence (AI) applied to aerial imagery. Although designed for the task of mapping planted forests, the technology presented an opportunity to leverage these models to estimate losses of net stocked forest area in the wake of Cyclone Gabrielle. The ForestMap AI model is a novel algorithm based on deep learning. The model produces spatial polygons outlining the boundary of planted forests at a very high resolution using 3-band (RGB) aerial imagery with resolution ranging from 7.5 - 40 cm. The model is primarily trained to map planted radiata pine forest using aerial imagery captured by regional councils and re-published by Land Information New Zealand (LINZ) under a Creative Commons License on the Amazon Web Services ‘S3’ cloud storage platform. Scion’s testing shows that the model can produce forest stand boundaries as early as 2-3 years after planting, depending on the resolution of the source imagery. The ForestMap AI model is trained to produce finely delineated boundaries around planted forest and works effectively across imagery with varying visual properties and spatial resolutions.

Gisborne District Council (GDC) has tasked Scion with trialling the ForestMap AI model to identify the area of mature planted forest lost to storm damage in one test area known to have been damaged by Cyclone Gabrielle. Because the model produces precise boundaries of the standing forest, there is the potential to apply the model to pre- and post-event imagery and compare the boundaries produced to identify ‘lost’ areas of forest. If this approach is successful, the ‘difference map’ produced could be a viable tool for helping to quantify the volume of LWD available to be mobilised from forests after a significant weather event and the potential risk this might pose to critical infrastructure in affected areas.

Methods

Study area

The study was undertaken at the head of Te Arai and Mangapoike Rivers in the Waingake Valley Ranges, Gisborne. The study site (Figure 1) covered approximately 6,000 ha of planted forest, primarily *Pinus radiata*, as well as areas of native forest and pasture. The area also contains the Mangapoike dams which supply water to Gisborne City.

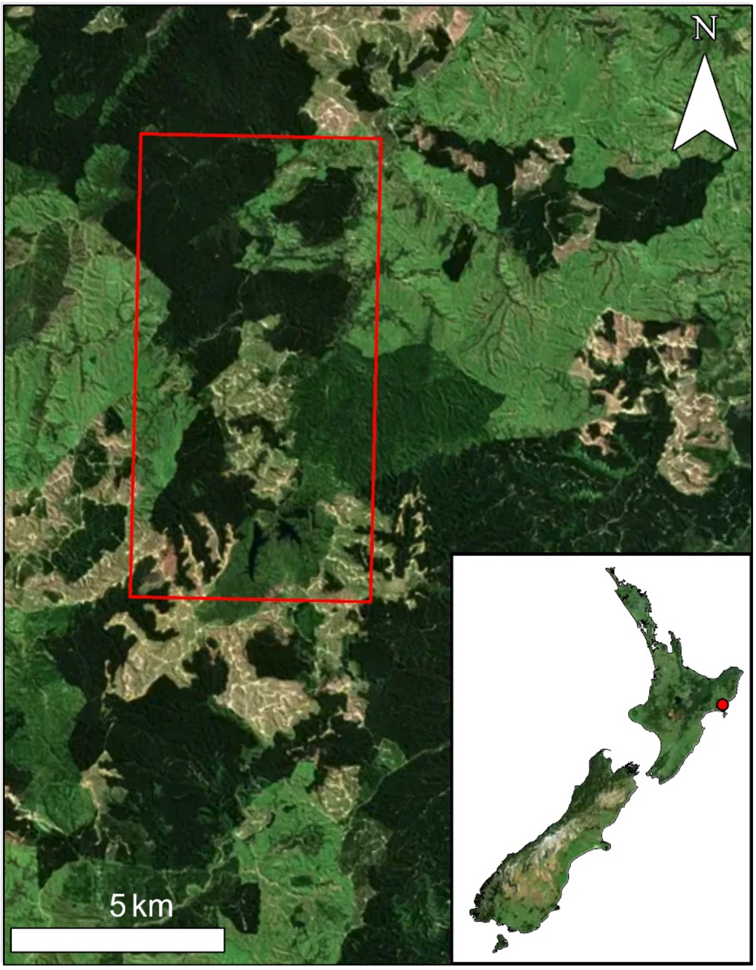

Figure 1: Location of Te Arai Waingake in Aotearoa New Zealand (Imagery: LINZ).

Data/Imagery

Aerial photographs from before and after Cyclone Gabrielle (Figure 2) were sourced from the LINZ Data Service (LDS). Pre-cyclone imagery was sourced from the Gisborne 0.3m Rural Aerial Photos (2017-2019) dataset and the post-cyclone imagery was sourced from Gisborne 0.2m Cyclone Gabrielle Aerial Photos (2023). Aspect and slope surfaces were derived from the Gisborne LiDAR 1m DEM (2018-2020) also published on LDS. The rivers and streams layer used in the analysis was sourced from the NZ River Centrelines (Top 1:50k) layer within the Topo50 map series published on LDS as of June 2023.

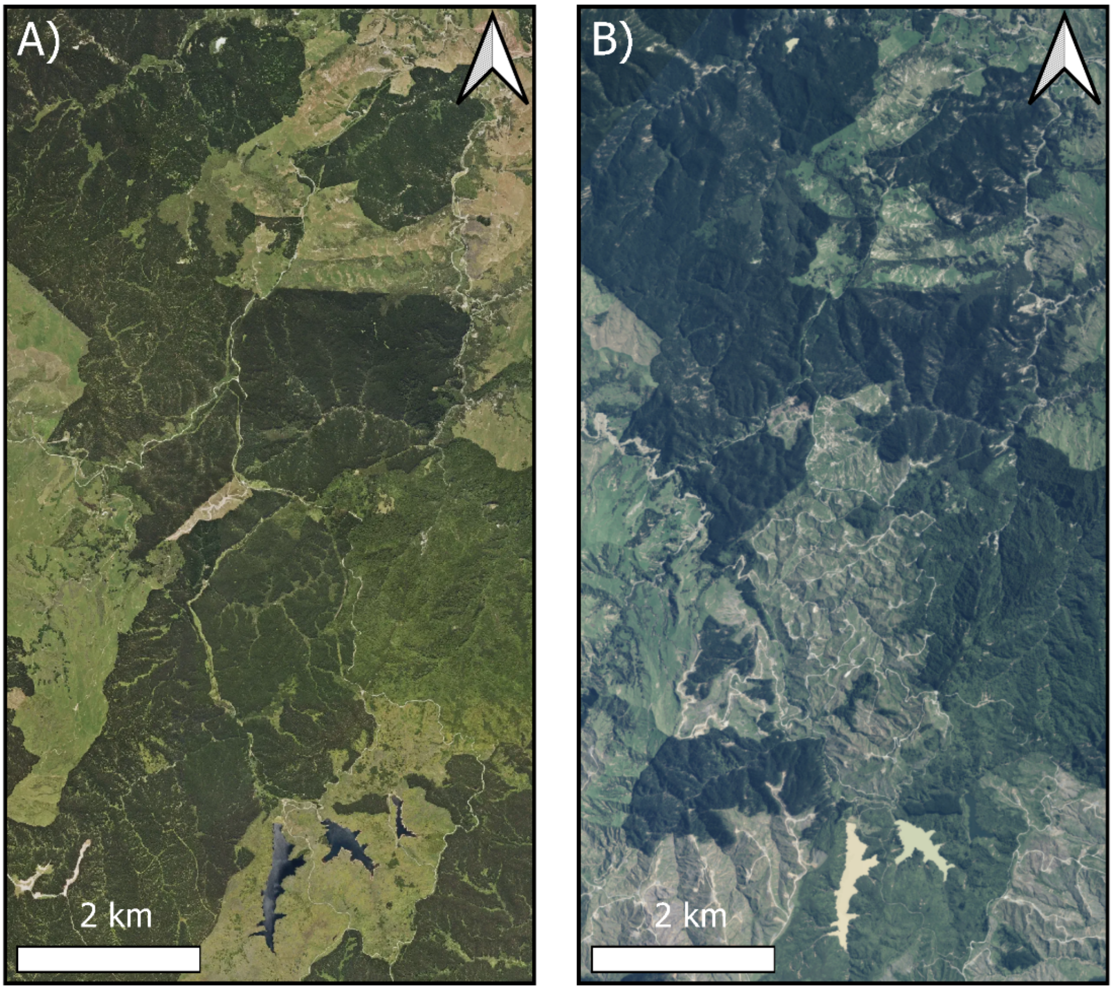

Figure 2: Imagery datasets used in the study. A) Gisborne 0.3m Rural Aerial Photos (2017-2019). B) Gisborne 0.2m Cyclone Gabrielle Aerial Photos (2023) (Source: LINZ).

Generation of forest boundaries and areas of standing forest loss

The ForestMap model was deployed over the study site on both pre and post Cyclone Gabrielle aerial photographs to generate forest boundaries for each image set (Figure 3).

Model predictions were post-processed using a scripted cleaning pipeline in ArcGIS Pro to remove small, inconsequential polygons as well as simplifying and smoothing polygon geometry to improve performance and appearance. The minimum size threshold for polygons and interior holes within polygons was set to 225m^2 with polygon geometry below this threshold considered to be noise and irrelevant for the task.

Manual correction of forest boundaries by analysts was employed minimally and reserved for areas of failure which were readily observable and could reasonably be expected to be corrected by analysts at wider regional scales. This ensured that the results were representative of an approach that could be scaled to regional-scale analysis tasks.

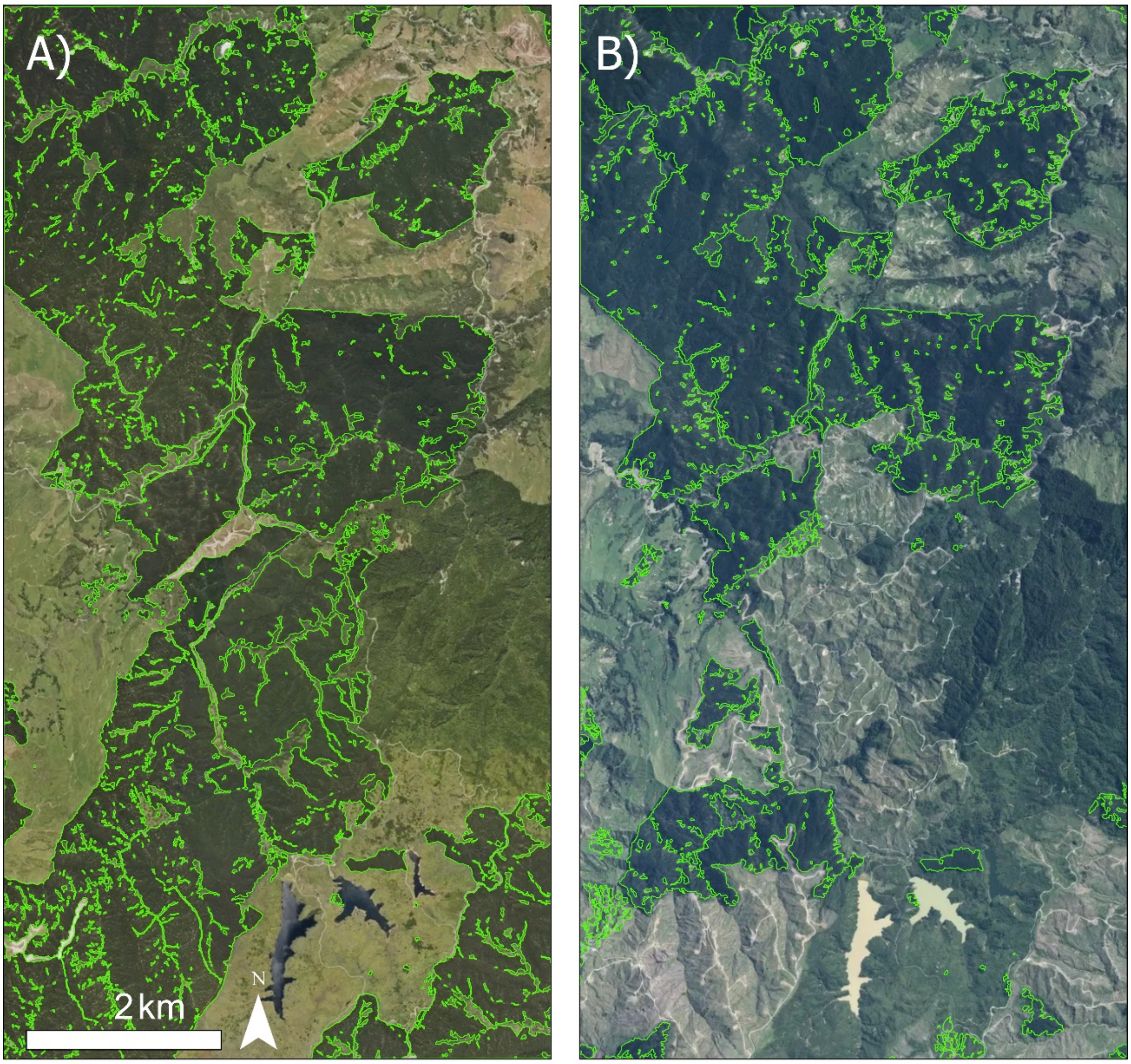

Figure 3: **A)** ForestMap boundaries pre cyclone (2017 - 2019) and **B)** post cyclone (2023)

Areas of standing forest loss were generated by differencing pre and post cyclone forest boundaries and cleaned using the same scripted methods as the boundaries.

Polygons which were the result of misalignment between forest boundaries due to differing visual characteristics such as shadow or the angle of trees were typically easily identifiable by characteristic thin, snaky geometry (Figure 4A) and were removed.
Some forested areas within the study site had been harvested between the pre and post storm image captures leading to large polygons of empty land bordering standing forest (Figure 4B). The edges of harvested polygons were checked for areas of cyclone damaged forest and the relevant boundaries traced and added to the analysis before removal of the harvested area.

The remaining polygons were visually assessed to verify whether they were the result of forest loss or were caused by other differences between the pre and post cyclone forest boundaries or model error (Figure 4C). Polygons which did not show evidence of forest loss were removed.

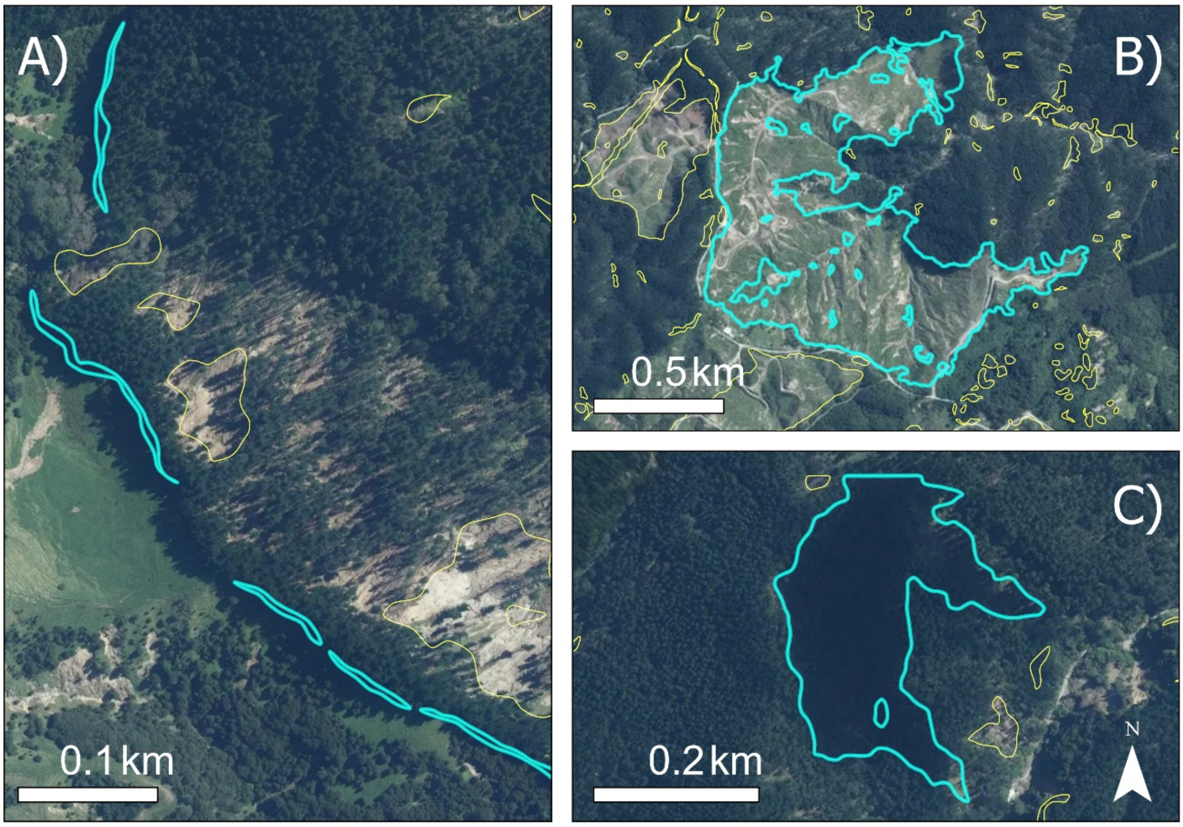

Figure 4: Examples of polygons which were removed after differencing forest boundaries. **A)** Misalignment of forest edges caused by differences in shadows and angles between the pre and post cyclone imagery. **B)** Areas which had been harvested between image captures. **C)** Other differences and model error.

Results

Model generation of pre and post cyclone forest boundaries was largely successful, with only a few areas of confusion which were easily observed and manually corrected using ArcGIS Pro's feature editing tools. For example, some areas of damaged forest with fallen trees were incorrectly included within the forest boundaries (Figure 5).

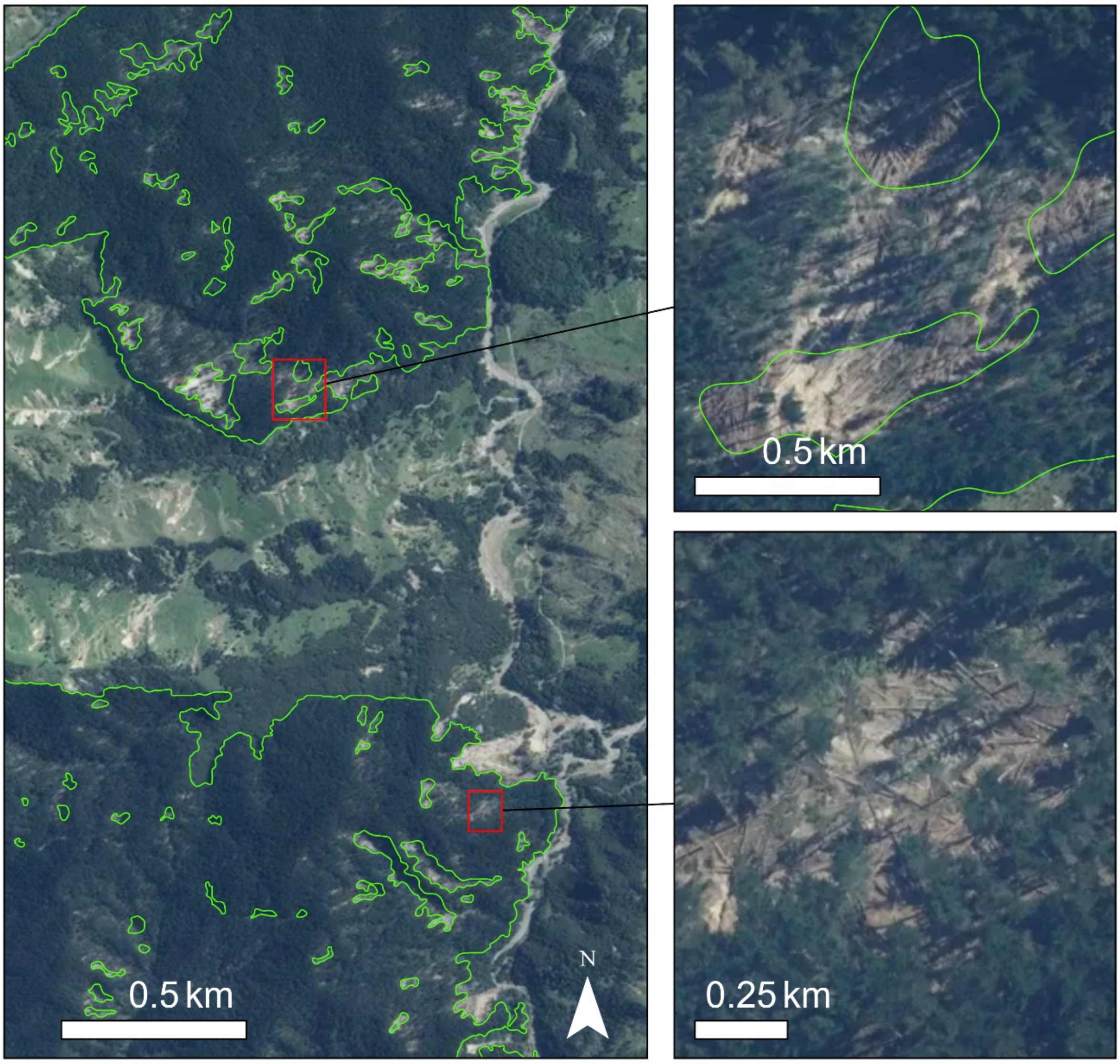

Figure 5: Examples of where cyclone damaged forest was not fully detected by the model

In total, 455 sites of standing forest loss were identified across the study site covering a total area of approximately 61 ha (Figure 6). Most impacted sites across the study area showed visual characteristics of slips and landslides with a smaller number of sites affected by windthrow, typically around the edges of harvested areas. Areas of loss ranged from 0.02 ha to 1.41 ha with a median area of 0.08 ha (Table 1). Figure 7 shows the distribution of impact sites by size.

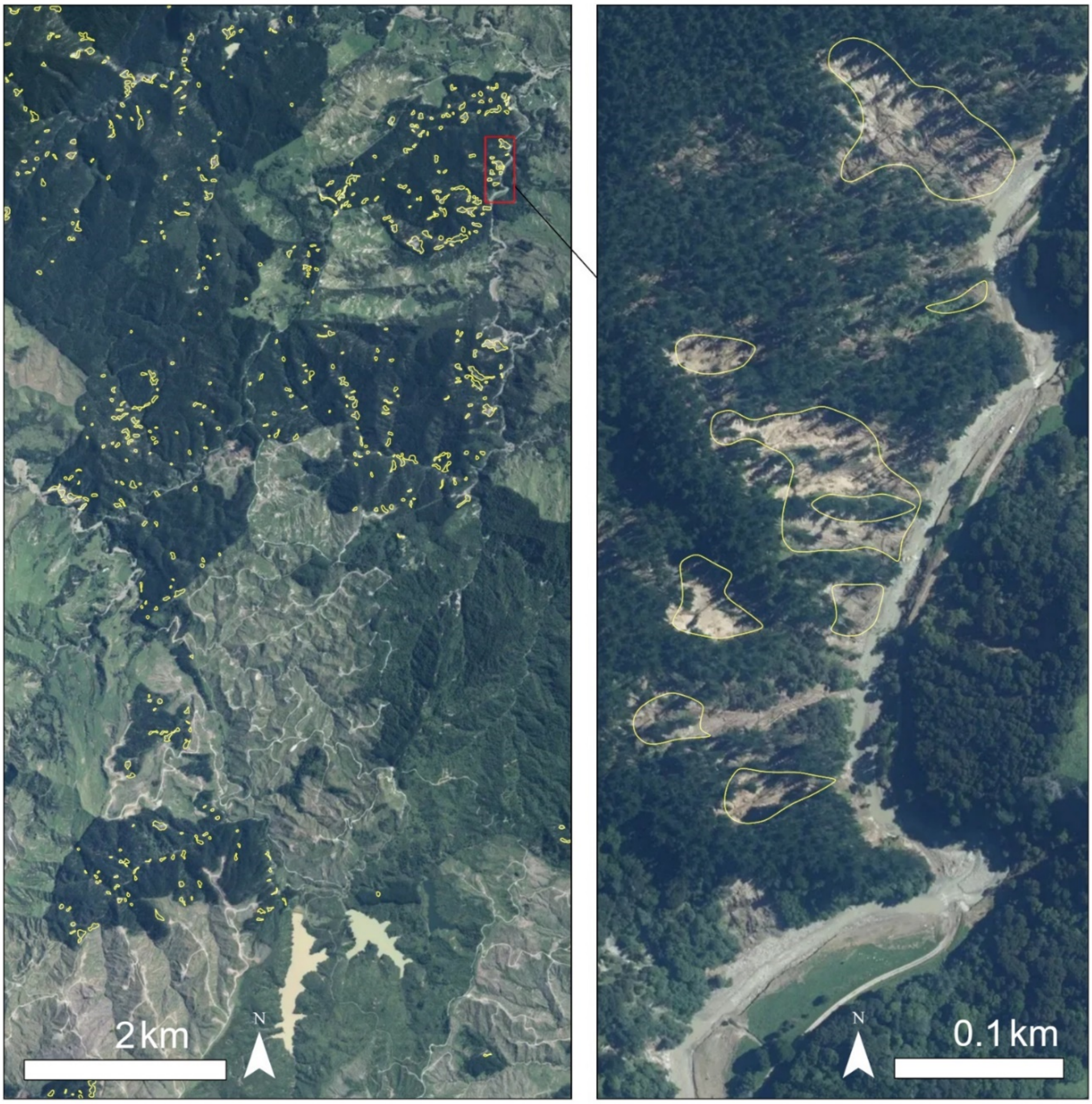

Figure 6: Sites of standing forest identified by the differencing process as being lost due to cyclone impacts.

Table 1: Summary statistics for standing forest loss by area of impact

Summary statistics

	Area (ha)
Min	0.023
Mean	0.133
Median	0.079
Max	1.407
Total	60.74

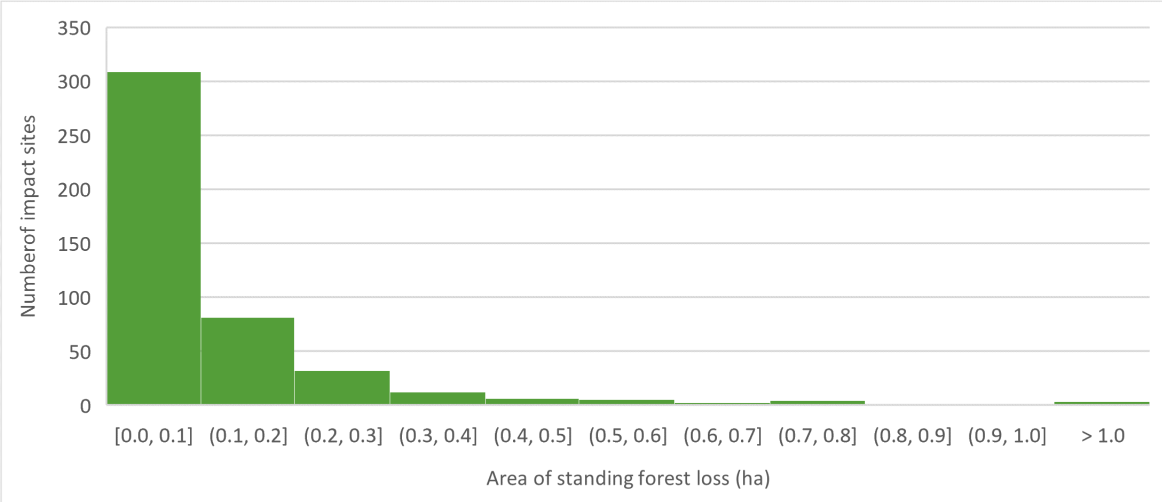

Figure 7: Distribution of the area (ha) of forest parcels within the study location identified as being lost or damaged due to cyclone impacts.

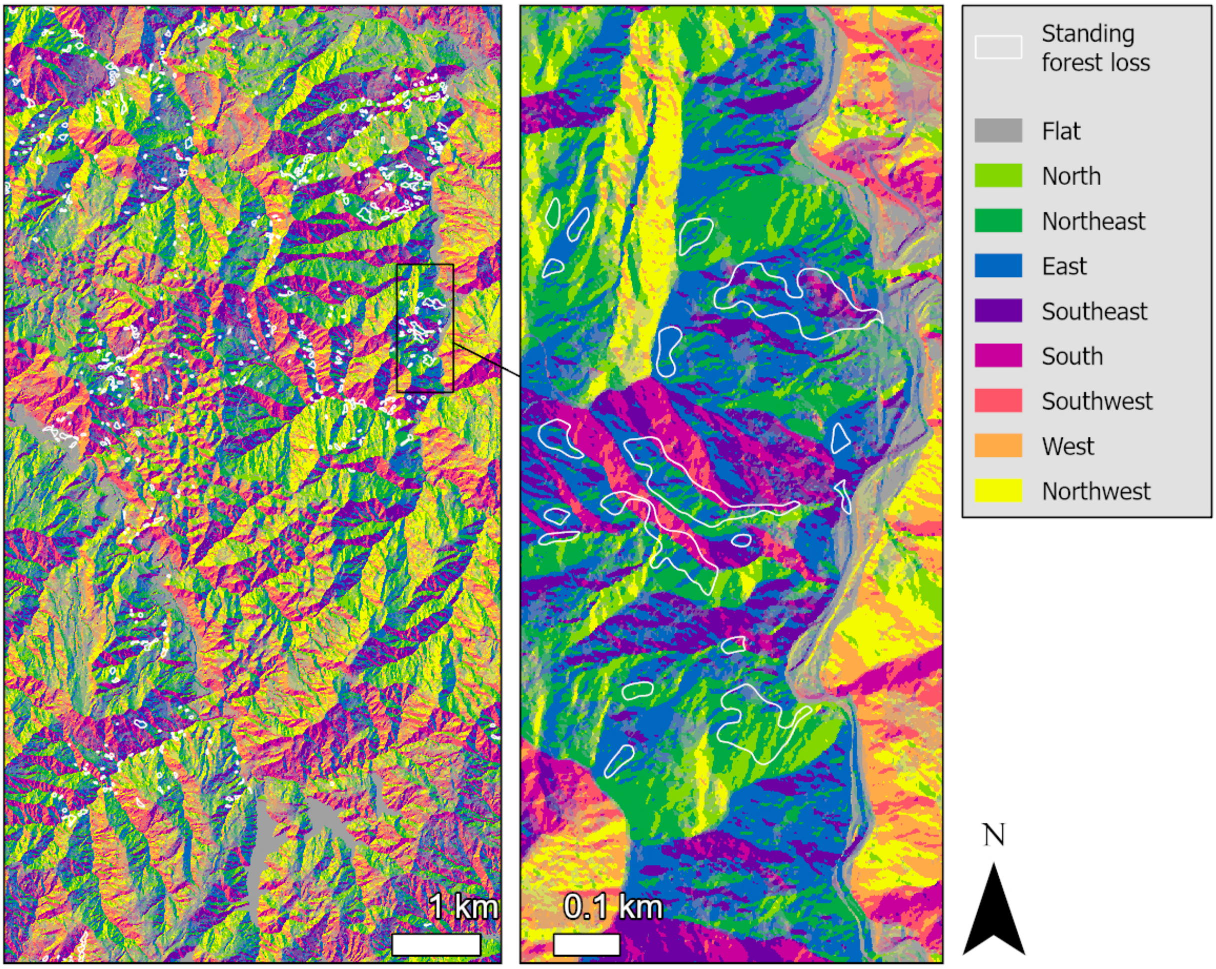

Figure 8: Aspect (downslope direction) of the terrain within the study area with parcels of standing forest loss identified by the differencing approach overlaid.

Aspect was derived from the Gisborne LiDAR 1m DEM using ArcGIS Pro and each impact site was assigned an aspect value based on the majority value of the cells within the parcel. The majority of impact sites (53%) were located on northeast and easterly facing slopes (Figure 8; Figure 9).

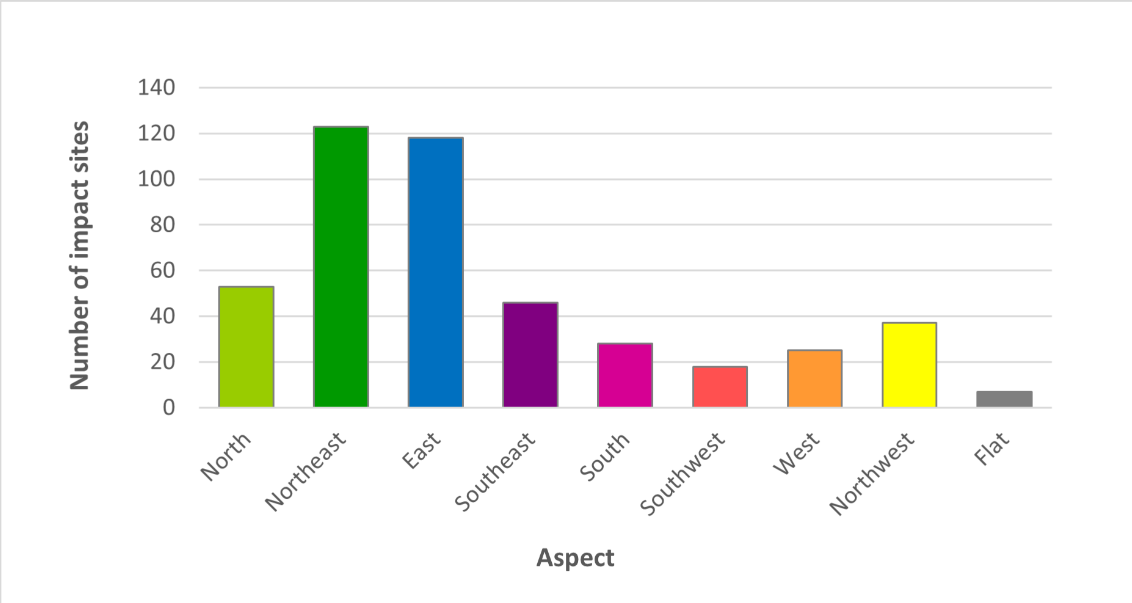

Figure 9: Number of impact sites at each slope aspect

A slope angle layer was generated for the study area using ArcGIS Pro from the Gisborne LiDAR 1m DEM (Figure 10). Impact sites were classed using slope descriptors from the New Zealand Land Resource Inventory (NZLRI) land use capability database created by Manaaki Whenua - Landcare Research (Figure 11). Most sites of standing forest loss (74%) occurred on steep to very steep slopes (26-42°).

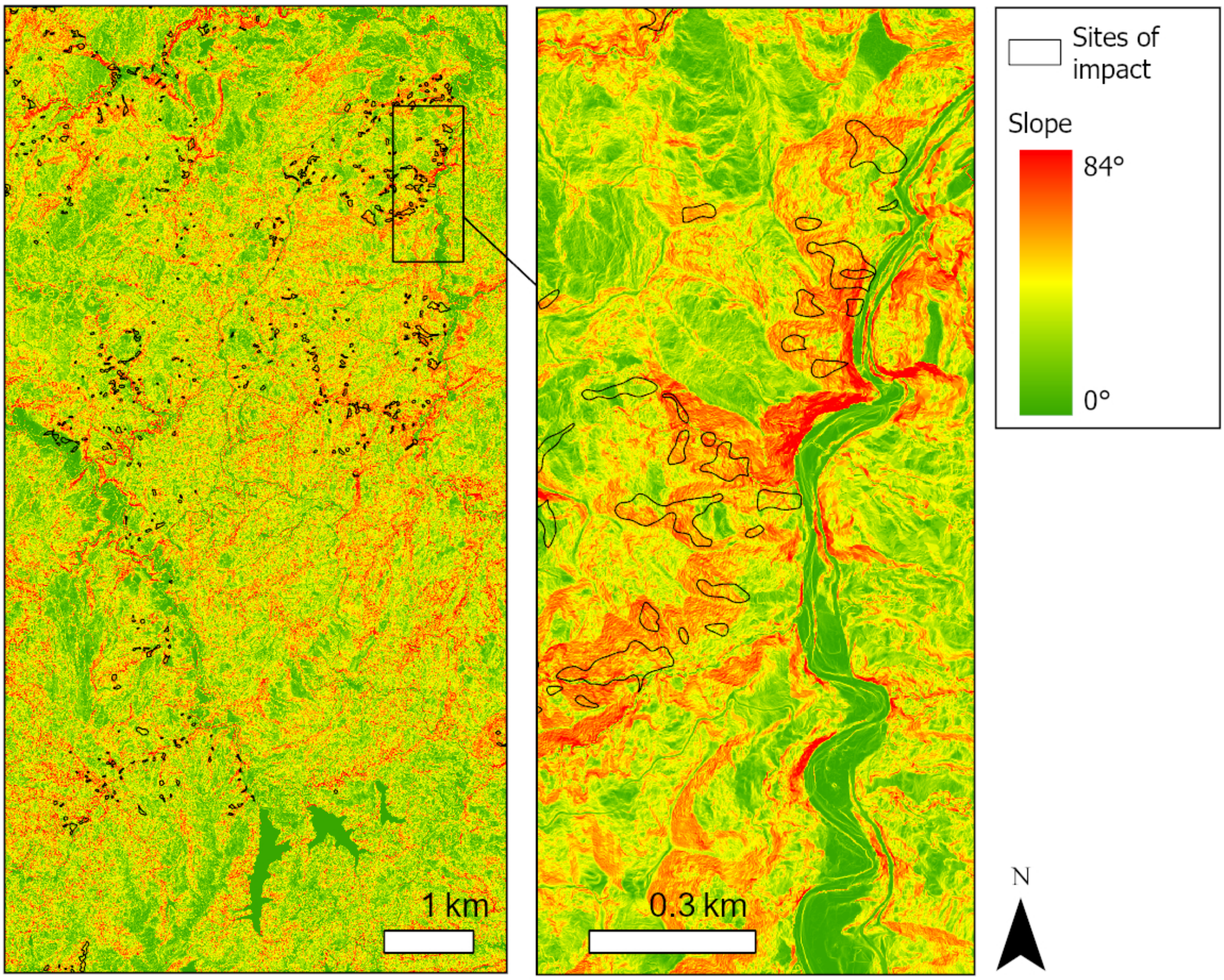

Figure 10: Slope angle of terrain within the study area and on sites identified having lost standing forest. Slope descriptors were derived from the NZLRI.

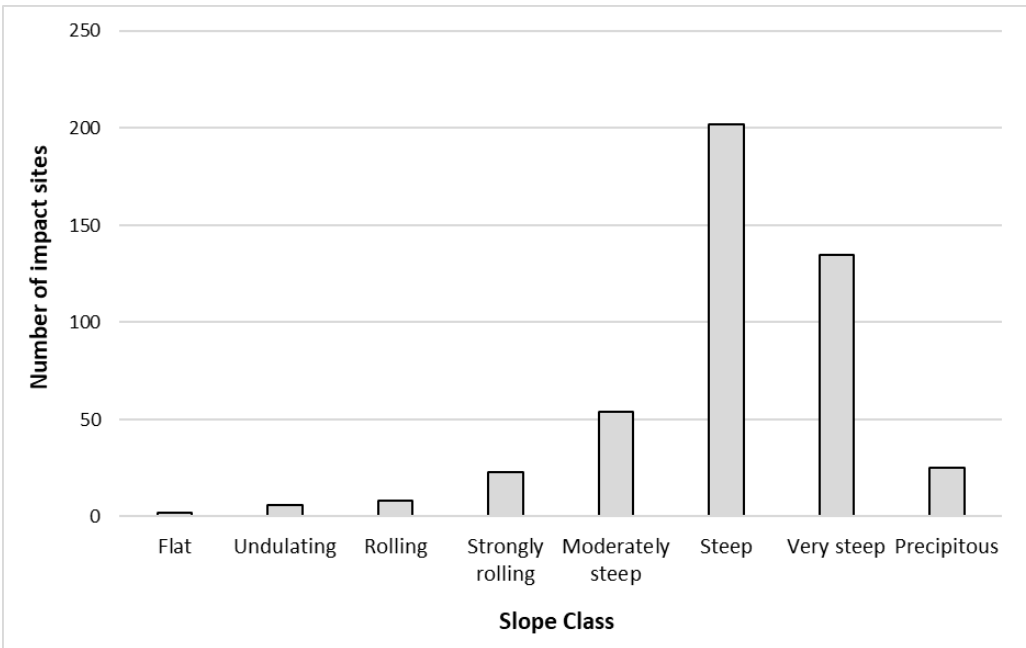

Figure 11: Number of impact sites located on each NZRI slope class.

The proximity of impacted sites to nearby streams and rivers was analysed as a preliminary means of identifying areas where there was a greater likelihood of LWD being mobilised downstream.

Figure 12 shows the sites of standing forest loss which were located within 50 m, 100 m, and 150 m of streams and rivers as recorded within the Topo50 topographic map layer on LDS. Figure 13 shows streams which were within 50 m, 100 m, and 150 m of the Te Arai river and its tributaries, along which the Gisborne City water supply pipeline is situated.

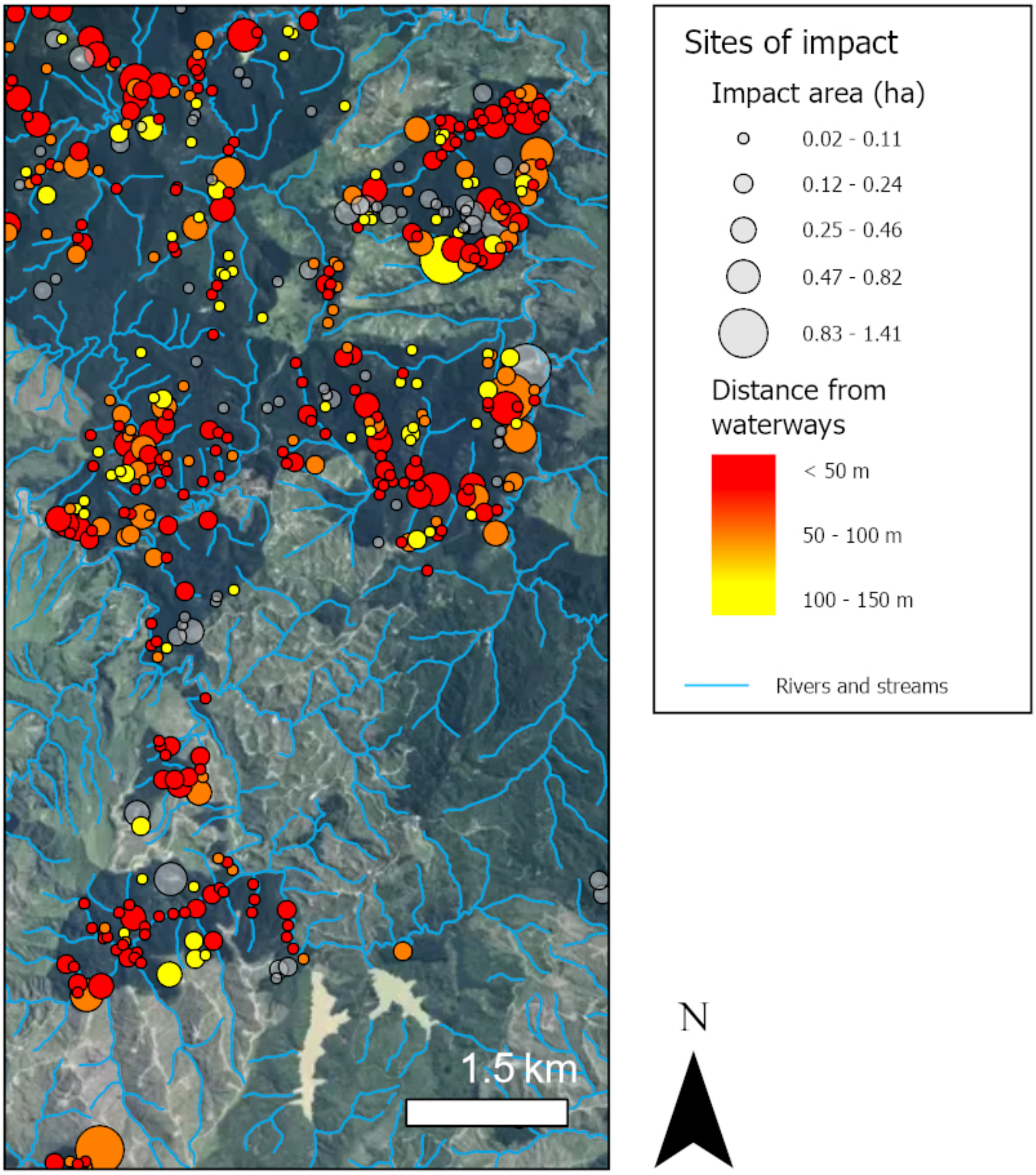

Figure 12: Sites of standing forest loss shown by area and proximity to waterways over the entire study site

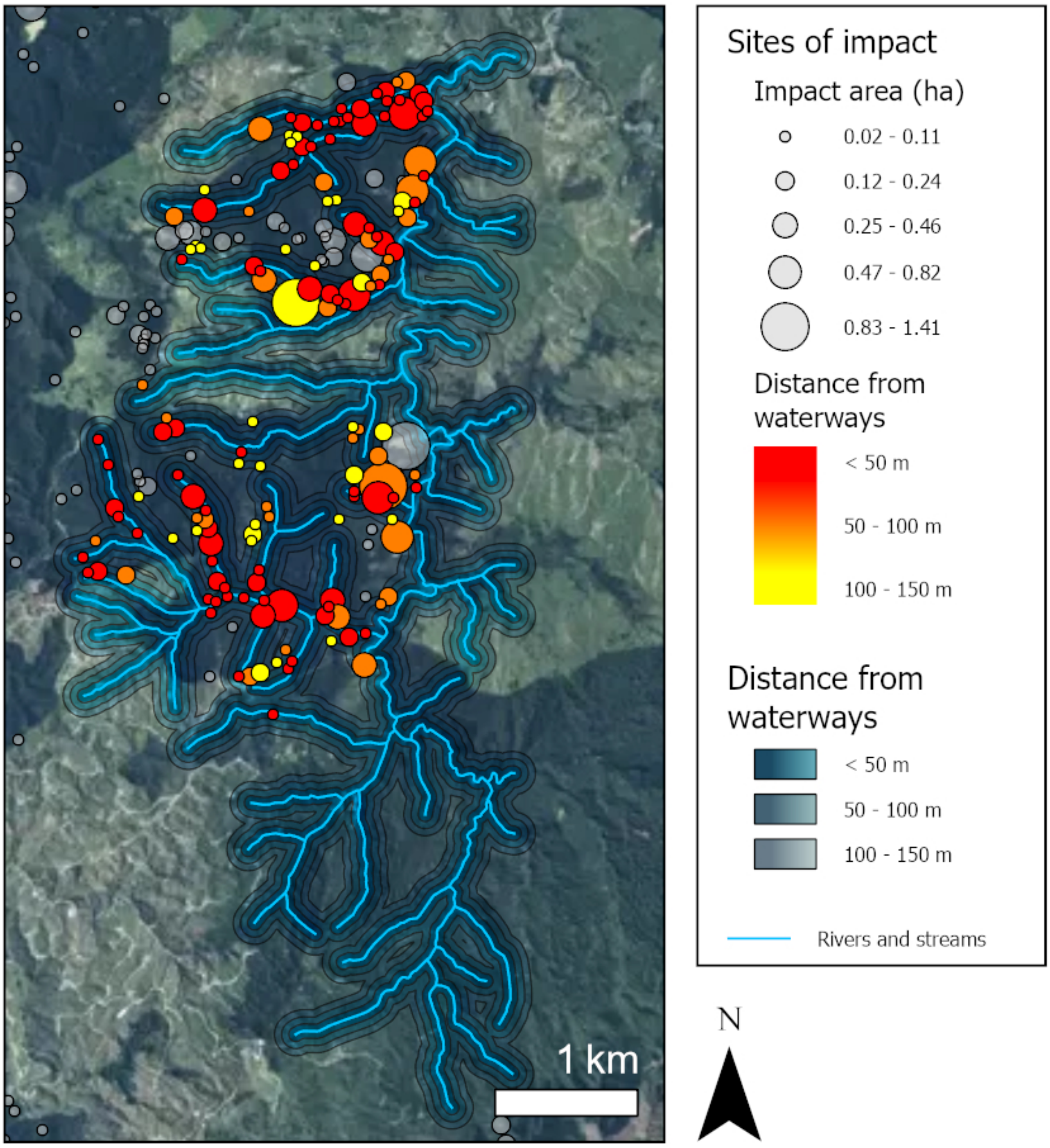

Figure 13: Sites of standing forest loss shown by area and proximity to the Te Arai river and its tributaries.

In total, 224 impact sites across the study area were within 50 m of waterways and covered an area of 28.60 ha (Table 2). Of these, 84 impact sites with a total area of 11.90 ha were within 50 m of the Te Arai river and its tributaries.

Table 2: Proximity of cyclone damaged sites to nearby waterways.

Distance from waterway (metres)	Number of impact sites	Total damaged area (ha)
< 50	224	28.60
50 - 100	93	15.09
100 - 150	72	7.48
> 150	66	9.57
< 50 metres of Te Arai River	84	11.90

Discussion and recommendations

The ForestMap forest detection AI model was deployed at a trial site in Te Arai Waingake to estimate losses of net stocked area of productive forest because of recent cyclone activity and assess whether it could be a viable tool to help estimate the volume of woody debris likely to migrate downstream over time.

Detailed forest boundaries were successfully produced using the ForestMap model over pre and post Cyclone Gabrielle imagery with limited manual processing by analysts needed to correct some areas of model confusion. Differencing of pre and post cyclone forest boundaries showed an estimated loss of over 60 ha of net stocked area, representing 3.1% of the total productive forest area within the study site. Impact areas were primarily small, localised parcels which appeared to be affected by landslides and slips, as opposed to large contiguous areas of forest. In total, 455 impact sites were detected across the study site, of which 75% individually covered an area less than 0.15 ha. Using ancillary datasets such as slope, aspect, and locations of waterways, it was found that most impacted sites occurred on northeast and easterly slopes that were steeper than 26°. Approximately 47% of the area of standing forest loss occurred within 50 metres of a waterway.

An advantage of the AI method presented is that it produces very detailed boundaries and can detect small, localised changes to forest cover such as those caused by Cyclone Gabrielle while excluding pockets of bare land or native vegetation within forests. Detailed change detection between pre and post cyclone forest boundaries allows for a more accurate estimate of net stocked area loss than directly identifying the area of visible landslides or fallen trees on post cyclone imagery as disturbed land does not always reflect where forest was standing before the event.

Deployment of the model at regional scale is possible but retaining the level of detail used in this analysis would require a large amount of manual cleaning of the forest boundaries to remove areas of ‘loss’ arising from other differences between the image sets rather than cyclone impact. Ongoing development of the model will likely improve performance on forest boundary delineation, reducing the need for manual correction and resulting in less false positives and improved delineation of impact sites upon differencing. For best results, it is recommended to target key areas for model deployment such as forest stands directly upstream of critical infrastructure where a high level of detail can be retained without requiring extensive manual cleaning over areas that are not of primary importance.

Some areas of cyclone damaged forest were not detected by the model, and it is recommended for examples of damaged forest be included in future training datasets to improve performance in this area. A specially purposed model based on existing ForestMap architecture and trained on a dataset of storm-damaged forest would likely achieve very accurate results but would require time and expense to develop.

As the technique relies upon change-detection between pre and post event imagery, the main limitation is the availability of imagery in the target area. At the time of analysis, the most recent available imagery pre-Cyclone Gabrielle was the 2017 – 2019 Gisborne Rural 0.3m aerial photo dataset which was captured around 5 years prior to Cyclone Gabrielle. The temporal difference between captures made it difficult to isolate change to recent storm damage and meant that damage to forest stands which had been planted after the pre cyclone imagery was captured was not able to be automatically detected using this methodology. In addition, the post-storm imagery was captured outside of the optimal seasonal window for imagery capture - resulting in deeper shadows and some visible cloud cover. However, removing errors arising from excessive shadow was relatively straightforward.

The eventual goal is for the ForestMap AI forestry stand boundaries to be combined with surfaces describing the age class, stocking (stand density), and timber volume. These surfaces are being derived from the regional LiDAR data and this will enable estimates of the volume and age of the forests affected by future events. While these models are still under development, normal forest stocking rates for *radiata* pine could be used to derive a simple estimate.

The results of the trial indicate that ForestMap shows promise as a viable tool for rapidly detecting areas of damage to standing planted forest and for estimating the net stocked area lost as a result of severe weather events. The approach relies on the availability of aerial imagery, but these datasets are frequently captured by regional authorities in the wake of significant natural disasters. This approach could significantly reduce the need for time-consuming manual assessment and digitisation. The resulting maps could also provide valuable insight into the total impact of these events on the planted forest estate and help determine the areas which are at highest risk from potential future LWD mobilisation.