Longer term monitoring of red needle cast: plot establishment and initial data collection

Authors: Ian Hood and Judy Gardner

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Cover photo
Red needle cast at future Plot 30, Pureora, 22 August, 2015, six weeks prior to trial establishment.

Longer term monitoring of red needle cast: plot establishment and initial data collection

Ian Hood and Judy Gardner

Scion (NZ Forest Research Institute), Private Bag 3020, Rotorua 3046

July, 2017

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EXECUTIVE SUMMARY

1.1 The Problem.

Research is underway to resolve the life cycle of the red needle cast pathogen, *Phytophthora pluvialis*, in order to complement a planned study to determine the best time of year to apply a chemical control treatment. However, besides a seasonal periodicity, this disease also shows an irregular, longer term variability whereby outbreaks occur in some years but not others, in different regions. Are there indicators that will make it possible to forecast years in which the disease will not occur, making treatment unnecessary?

1.2 This Project

A series of 52 plots have been set up in *Pinus radiata* stands at locations in the central and eastern North Island where red needle cast occurs in some years. These are being monitored two to three times each year, more specifically in late winter-early spring (between July and October) when symptom expression is at its greatest, in order to build up a disease database.

1.3 Key Results

The disease database was initiated late in 2015 and records have been accrued from then up until the present time. There is a suggestion that disease years may be associated with higher rainfall during the preceding summer, but more data are needed to determine if this supposition is true.

1.4 Further Work

It is intended that regular monitoring will continue in order to extend the database until at least one cycle of disease occurrences has been completed in different regions. Local NIWA “virtual” data will be acquired and both datasets systematically investigated for possible mutual associations using appropriate statistical analyses. The end result will be an indication as to whether or not the prediction of red needle cast years may be implemented using weather variables.

1 Introduction

Work is underway to resolve the seasonal epidemiology of *Phytophthora pluvialis* Reeser, W.L. Sutton & E.M. Hansen, the cause of red needle cast of *Pinus radiata* D. Don. This information is necessary to assist in deciding the time of year best suited for applying a chemical control treatment for the disease (Williams et al. 2016; Hood et al. 2017). Recent work has shown that several copper based compounds are effective against *P. pluvialis*, with potential for use on an operational scale, once a timing schedule has been determined (Rolando et al. 2017). But, in addition to an annual seasonality, red needle cast also demonstrates a perennial variation in disease expression, with outbreaks occurring in some years but not others, in an uneven manner between regions. If the factors governing these patterns can be understood, it may be possible to anticipate years in which control measures will be unnecessary, with a consequent reduction in costs, improvement in treatment efficiency and minimal environmental impact. The question, then, is: are there predictive factors that will signal when red needle cast is unlikely to develop and hence treatment will not be required?

In order to address this issue, monitoring plots have been set up in parts of the North Island to follow and record the course of the disease over the longer term. A disease database has been initiated that will in due course be evaluated in association with a matching data set of local weather variables. Ideally the study will run for sufficient time to encompass one or more cycles of high and low disease severity in different areas. The intention is to discover environmental aspects that may lead to outbreaks in particular years and conversely indicate lulls when control treatments will not need to be applied. As presented in the work plan, the objectives of this research are twofold:

- to undertake annual monitoring of red needle cast extent and severity at selected North Island sites over a protracted period, in relation to weather variables, in order to:
- accrue data which will identify weather and potentially other variables that influence the development of red needle cast, with a view to possible prediction.

This report describes the inauguration of the study and reports on early data collection.

2 Materials and methods

2.1. Plots

In October, 2015, during a period when red needle cast was well visible (cover figure), a series of 52 monitoring points ("plots") was selected in the central and eastern North Island using GPS (Global Positioning System) coordinates to define their locations. A list of the points is provided in Table 1[1] and their locations are shown broadly in Fig.1 and in greater detail in App. A (p. 13).

Most plots were selected in stands demonstrating crown symptoms of red needle cast, but a small number were sited in healthy stands as "controls". Plots were situated as far as possible along public roads to simplify access and minimise administrative dealings with a variety of different owners. All plots are positioned at stand edges where full symptom expression is visible on the complete, unsuppressed crown length in order to facilitate disease assessment and ensure a comprehensive evaluation. Depending on the situation, plots consist of either a small group of affected trees or, where possible, a "transect" of defined length up to (usually) a maximum of about 1 km along the stand edge.

[1] Two plots are labelled 3 and 3a, bringing the full number of plots to 52. However, there has been some attrition.

Table 1: Longer term monitoring plots

No[1].	Brief description/name	Run: Start Easting (NZTM)	Run: Start Northing (NZTM)	Run: Finish Easting (NZTM)	Run: Finish Northing (NZTM)	Approx. stand age (Pre- or post-mid-rotation/ mature)	Road length (km); est. or by odometer; dash (-) = limited sized stand, or spot check.	Side of road evaluated (N, S, E, W)
1	Manawahe 3	1921987E	5791106N	-	-	Post mid	ca. 0.2	S
2	Manawahe 2	1919642E	5787719N	-	-	Post mid	1	E
3	Pongakawa Valley 9	1911098E	5788359N	1910840E	5788584N	Mature	1 (0.4?)	S and N
3a	Pongakawa Valley 18	1911637E	5788122N	-	-	Post mid	1	S
4	Pongakawa Valley 7	1910088E	5789352N	1909252E	5789222N	Mature	1	N
5	Pongakawa Valley 15	1908952E	5797234N	1909053E	5798149N	Mature	1	E and W
6	Te Matai Rd. 12	1877871E	5794382N	1878862E	5794400N	Mature	1	S and N
7	Tauranga Back Road 1	1877070E	5794527N	-	-	Post mid	-	W
8	Tauranga Back Road 2a	1876963E	5798701N	1876990E	5798598N	Post mid	0.12	E
9	Tauranga Back Road 2b	1876971E	5798644N	-	-	Post mid	ca. 0.2	W (and back)
10	Tauranga Back Road 3	1877121E	5797563N	1877372E	5797938N	Pre mid	0.4	E
11	Kaharoa Road	1882085E	5789246N	-	-	Post mid	ca. 0.3	NW
12	Kaharoa Boarding	1882354E	5785948N	-	-	Mature	-	W
13	Kapenga 1	1881973E	5762958N	-	-	Post mid	0.1	E
14	Kapenga 2	1882184E	5763857N	1882057E	5764076N	Post mid	0.1	E
15	Kapenga	1881973E	5762958N	1882210E	5764060N	Post mid	1.3	E
16	Paradise Valley	1878801E	5779062N	1879299E	5779083N	Post mid	0.4	S
17	Tarukenga	1872014E	5782450N	-	-	Pre mid	-	SW
18	Kinleith Road 1	1853421E	5759297N	1853299E	5759541N	Mature	ca. 0.2	W
19	Wawa Road	1853187E	5759236N	1853448E	5759096N	Post mid	ca. 0.3	SW
20	Kinleith Road 2	1853210E	5759720N	1852770	5760660	Post mid	ca. 0.8	W
21	Side Rd (Nth)	1851959E	5760675N	-	-	Mature	ca. 0.2	SE
22	Farm Driveway (West)	1852003E	5760398N	-	-	Mature	ca. 0.3	NE
23	The Mill (Sth)	1852177E	5760234N	-	-	Mature	ca. 0.3	N
24	Nr Kinleith logyard	1851563E	5759444N	-	-	Post mid	ca. 0.5	E
25	Access Road, Kinleith	1851525E	5759082N	1850952E	5759193N	Mature	0.5	S
26	Smythe Road	1850307E	5758494N	-	-	Pre mid	0.2	SE
27	SH1_1	1859053E	5756736N	-	-	Pre mid	ca. 0.15	S
28	SH1_2	1862599E	5752771N	-	-	Post mid	ca. 0.15	W
29	SH1 Upper Atiamuri	1862613E	5750926N	1862585E	5750495N	Mature	0.5	W
30	Pureora jnctn Ranginui Rd	1827878E	5739481N	1828471E	5740447N	Post mid	1.0	E
31	Pureora 2	1833207E	5744025N	1832445E	5743296N	Post mid	1.0	SE

[1]Points 1-12 approximate to sites of previous monitoring assessments by Judy Gardner and points 32-36 to locations of earlier records by Liam Wright (Scion).

Table 1 (continued): Longer term monitoring plots

32	Kaingaroa Low Level	1900047E	5713656N	1899104E	5713630N	Pre mid	1	S
33	Kaingaroa Kiorenui Road	1906097E	5705798N	1905622E	5706705N	Post mid	1.0	S/W
34	Kaingaroa Pukuriri Road	1887661E	5707141N	1889297E	5705967N	Pre mid?	2	N and E
35	Kaingaroa Kiorenui Rd_2	1914388E	5727592N	1913920E	5726938N	Post and pre	0.7	N (post)/S (pre)
36	Kaingaroa, Taupiri Road	1912292E	5728121N	1911936E	5728392N	Pre mid	0.5	S
37	Kaingaroa, Goudies Road	1905937E	5742421N	1906013E	5742971N	Post mid	0.6	W
38	Kaingaroa, High Level Road	1891176E	5712082N	1891785E	5712902N	Mature	1	E
39	Kinleith Forest, Rahui Road	1864270E	5760090N	1864810E	5760090N	Post mid	0.6	S
40	Waimata Valley Road	2040910E	5733900N	-	-	Post mid	ca. 0.1	E
41	Tauwhareparae 1	2046702E	5750312N	2046792E	5750366N	Post mid	ca. 0.1	W
42	Tauwhareparae 2	2046788E	5751246N	2046798E	5751429N	Post mid	0.2	Mostly W
43	Tauwhareparae 3	2046447E	5752097N	2046412E	5752015N	Mature	ca. 0.05	E
44	Tauwhareparae 4	2045983E	5752488N	2045927E	5752633N	Pre mid	ca. 0.2	W
45	Tauwhareparae 5	2044578E	5753675N	2044601E	5753742N	Post mid/mat.	ca. 0.05	N
46	Tauwhareparae 6	2043635E	5754891N	2043657E	5754850N	Pre-mid	ca. 0.03	W
47	Tauwhareparae 7	2043809E	5754746N	2043906E	5754710N	Pre-mid	ca. 0.15	W
48	Tauwhareparae 8	2044269E	5754588N	2044060E	5754671N	Pre-mid/mid		W
49	Tauwhareparae 9	2047393E	5751847N	2047170E	5751792N	Post mid	0.2	S
50	Wharerata 1	2020012E	5683009N	2019698E	5682545N	Pre-mid	0.5	W
51	Wharerata 2	2022740E	5683667N	2023065E	5684576N	Pre-mid	1.0	W

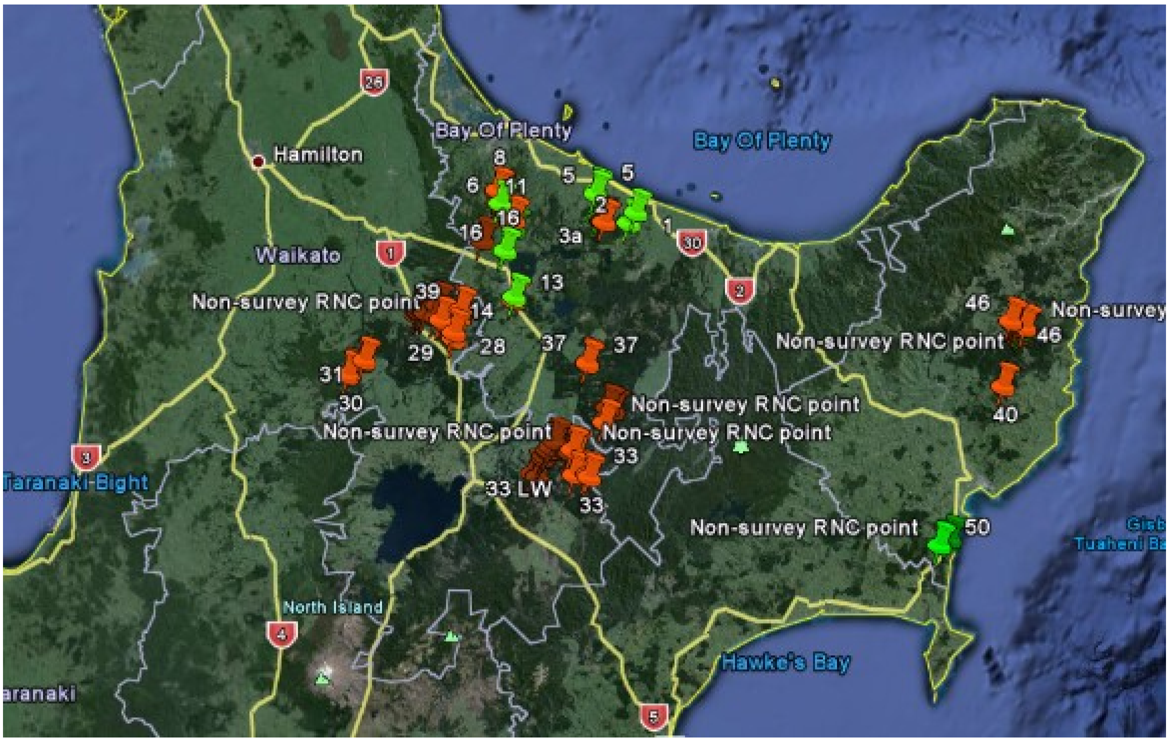

Fig. 1. Google map of part of the North Island showing locations (compressed) of 52 red needle cast longer-term monitoring points (plots). A number of points not selected as survey plots are also shown. Green pins indicate healthy stands and orange pins those that showed some disease in October, 2015. Numbers identify the monitoring plots. For full display see App. A (pp. 13-28).

2.2. Disease data

Plots are being assessed two or three times each year, generally targeting the maximum period of disease expression between July and October (an assessment was made earlier during 2017, to investigate crown appearance near the beginning of seasonal disease expression).

On each occasion, assessments are made for each plot of:

(1) Extent: the proportion of (trees along) the transect length (or of the non-transect group) affected by red needle cast, expressed according to the scale in Table 2.
(2) Severity: the proportion of crown depth diseased on the tree in the plot worst affected by red needle cast according to the scale in Table 2.

Table 2: Scale used to assess both extent and severity of red needle cast.

Score	Percentage of plot (extent) *or* of crown height (severity) with visible foliage reddening or browning due to red needle cast
0	0%
1	1-25%
2	26-50%
3	51-75%
4	76-80%
5	81-100%

To date, all scoring has been made by one assessor to minimise variation due to observer bias.

Images of crown appearance of trees within most plots are being stored on file for future comparison.

If present, foliage with typical red needle cast lesions (short, discrete, khaki-coloured lengths of needle, generally accompanied by small black resinous marks) is sampled at least once from each plot for laboratory confirmation of the presence and identity of *Phytophthora* species. This is done by means of isolation, "ImmunoStrip"[2] testing and if appropriate by subsequent molecular sequencing.

2.3. Weather data

For a moderate monetary charge, daily "virtual" weather data are available for downloading from the website of the National Institute of Water and Atmospheric Research (NIWA) for locations distributed across a simulated 5 km grid covering the whole of New Zealand (https://www.niwa.co.nz/climate/our-services/virtual-climate-stations). These values are calculated

[2] The ImmunoStrip kit (Agdia Inc., Elkhart, Indiana, USA) indicates the presence of a phytophthora (i.e. identification to genus); subsequent sequencing from the ImmunoStrip (and/or morphological examination of isolates), identifies the species.

by means of algorithms from records collected using real meteorological stations operating in the general vicinity. Appropriate data will be downloaded for virtual stations closest to each of the disease monitoring plots, for the full study period and slightly earlier. Appropriate daily variables will include: maximum and minimum air temperature, rainfall, relative humidity and solar radiation. Other daily data also available for use include: wind speed, soil moisture, earth temperature, air pressure at sea level, vapour pressure and Penman evaporation.

2.4. Evaluation

At a suitable time, analyses will be undertaken to examine potential associations between the meteorological and monitoring data that may point to any weather variables that may be influencing the irregular perennial development of red needle cast in different regions.

3 Results

Results collected so far are shown for 2015 in App. B (p. 29), for 2016 in App. C (p. 32) and for the first half of 2017 in App. D (p. 35). Graphical representations of results for selected plots are shown in Fig. 2. Red needle cast was extensive and severe in some plots in the central North Island in both 2015 and 2016 (e.g. in Plots 18, 19, 24, 25, 30). In other plots the disease was moderate in 2015 but severe in 2016 (e.g. in Plots 8, 35, 44, 45). In the stands in Plots 50 and 51, where there has been extensive red needle cast in years before the beginning of this study, the disease was absent in 2015 and only moderate in 2016. An example of the type of changes occurring between years in different locations is shown in Fig. 3 for Plot 43 (however, it is possible that disease may still develop in this plot later in 2017).

Phytophthora pluvialis was identified in a number of plots where samples were tested in the laboratory. *Phytophthora kernoviae* Brasier, Beales & S.A. Kirk was present in Plot 3a when sampled in 2016 (App. C, p. 32).

4 Discussion

4.1. Risks and challenges

There are some hurdles to surmount in identifying and assessing red needle cast in the field. The general crown appearance of *P. radiata* trees affected by this disease can generally be distinguished from other pine foliage disorders with some experience (Bulman and Gardner, 2014), but occasionally there may be ambiguity (e.g. physiological needle blight can be problematic). Timing is helpful (crown symptoms of red needle cast are more common from April through to November) and in contrast to both dothistroma needle blight and cyclaneusma needle cast, older trees also succumb to red needle cast[3]. However, it is virtually essential to assess crown symptoms in full sunlight as shading or overcast skies render diagnosis and assessment values questionable. Assessment is being undertaken conservatively i.e. considered positive for red needle cast only when beyond reasonable doubt. A diagnosis of red needle cast can be verified by the presence of characteristic needle symptoms confirmed, if necessary in the laboratory (Section 2.2), but these are transitory and may not always be present for examination and sampling at the time of assessment. Scoring is subjective and, as has been shown (Williams et al., 2016), liable to observer bias. This aspect has been minimised in this study by the use of just one assessor and by employing a relatively coarse scale with a limited number of score categories. For the purposes of this work it is considered more important to recognise extremes (outbreak years, lull years) than to discriminate between fine levels of disease.

[3] Suggesting that the resistance mechanism(s) to these diseases in older trees (e.g. Franich et al. 1983) may not be applicable to red needle cast and also implying that a chemical control treatment may be necessary throughout the full rotation, whenever the disease is likely to appear.

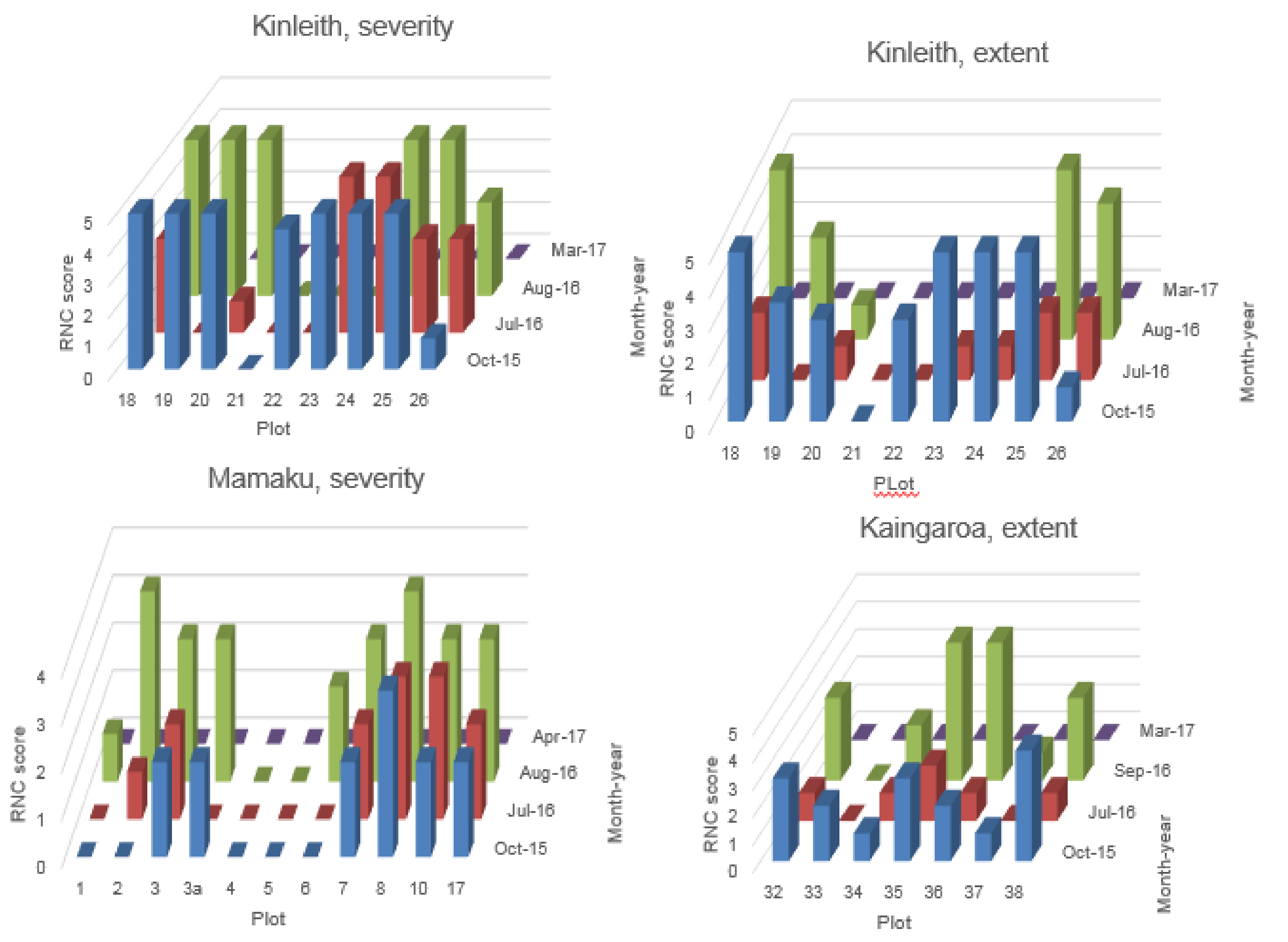

Fig. 2. Extent and severity of red needle cast in selected plots between late 2015 and early 2017

Fig. 3. Part of Plot 43 (Tauwhareparae, inland from Tolaga Bay). Upper, 17 May 2016 (scores: extent, 4; severity, 5; App. C, p. 34). Lower, 2 May, 2017 (scores: extent, 0; severity, 0; App. D, p. 37).

It was unavoidable that some monitoring plots were selected in stands approaching maturity and a small number have already been fully or partially felled since the start of the study. This was one reason for selecting a comparatively large number of plots, so that enough will remain to provide sufficient information when the work is completed. A partial solution may be to replace eliminated plots by substitutes in adjacent stands, if this does become a serious issue. Some plots are in younger stands that should outlive the course of the study. It has been observed that the results of this research are likely to be affected to a greater or lesser degree by any operational aerial control spraying for dothistroma needle blight that may occur during the monitoring period. Many of the plots are in rural plantations not subject to aerial spraying, but it will clearly be necessary to obtain stand records in case this effect needs to be factored into the analyses.

4.2. Influencing factors

It is stressed that the purpose of this work is not to survey and record the distribution of the disease year-by-year, since red needle cast occurs in other regions besides those in which the plots have been selected (Fig. 4; App. E, p. 38). Its main outcome will be to discover if red needle cast epidemic years are determined by conditions occurring *prior* to the outbreak, which should therefore be predictable, or whether the level of severity is governed mainly by environmental variables (e.g. rainfall) prevailing *during* the time that the disease is developing (Williams et al., 2016; Hood et al., 2017). It is reasonable to expect that the degree of rainfall during disease development will influence its severity, but is there also an initial activating factor? There is precedent for disease prediction with other foliage infecting *Phytophthora* species, in particular for *P. infestans* (Mont.) de Bary, the cause of late blight of potato (Taylor et al. 2003). Various empirical models for forecasting this disease incorporate different time-based combinations of variables such as temperature, rainfall and relative humidity (like *P. pluvialis*, *P. infestans* is favoured by cool, moist conditions). Other factors that have been included comprise solar radiation as well as wind speed and direction (*P. infestans* disperses by means of dehiscent, airborne sporangia, seemingly unlike *P. pluvialis*; Hood et al., 2017). In some of these models, certain measures of rainfall and humidity serve as surrogates for period of leaf wetness, the property which promotes spore germination and infection, but which can be difficult to measure (e.g. surface wetness does not feature in NIWA data).

Comparison with what is known for other *Phytophthora* species that infect foliage of trees is also instructive. These include such pathogens as *P. pinifolia* Alv. Durán, Gryzenh. & M.J. Wingf. in Chile, also a winter disease of *P. radiata*, and *P. ramorum* Werres, De Cock & Man in 't Veld, the cause of sudden oak death. In a recent paper, Petersen et al. (2015) compared the extent and severity of sudden oak death with averaged three-monthly weather data collected over a 13 year period in forests in Oregon. They found that the extent of disease modelled best to the size of an infested area and to the level of spring precipitation during the previous year.

It may be noteworthy that in a red needle cast infection period study at Wharerata Forest, south of Gisborne, disease developed during the winter of 2016, but not in that of the previous year, despite the prevalence of similar weather conditions during both monitoring periods. Instead, rainfall was noticeably greater during the preceding summer (November to January) at the beginning of 2016 than at the commencement of 2015 (details in Hood et al., 2017, pp. 33, 44). During earlier infection period studies near Rotorua between 2011 and 2014, the research stands[4] likewise became diseased during winter only in the years in which the preceding January rainfall was substantially greater than in years in which little or no disease occurred (details in Hood and Uaea, 2015, p. 12). Thirdly, red needle cast was observed late in 2015 in parts of the Tokoroa-Mamaku Plateau area of the central North Island, becoming extensive and severe during the following year (e.g. plots 18-26, Fig. 2). Rainfall was substantially greater than in previous years during the January-March period preceding this widespread disease occurrence in 2016 (App. F, p. 40). These three separate observations seem to suggest a broad pattern which bears some similarity to that of Peterson et al. (2015), referred to above, even if the timing is a little different. It is the aim of the present study to verify or refute the implications of these observations in a more systematic manner.

If there *is* any substance to the idea that wetter summers lead to disease outbreaks (i.e. that there *is* a genuine association and that it is causative), it begs the question as to the mechanism by which this progression may be realized. We are hampered because at present we do not know how *P. pluvialis* survives between seasons and between years. A brief discussion of possibilities is

[4] In one of these stands disease was associated with infection by *P. kernoviae*, not *P. pluvialis*, but it is possible that the same environmental conditions influence both *Phytophthora* species in a similar way (Williams et al., 2016).

provided in an earlier report (Hood et al., 2017, p. 30), but it is clear that this needs to be determined. The instigation of a potential epidemic is likely to depend on the nature and quantity of the initial inoculum early in the season and how it is affected by environmental conditions at that time. Could this mean that an initial chemical control application should be made earlier than autumn, to “neutralise” any inoculum that may triggering the very first infections of a disease cycle at this time? Studies are planned to resolve this question.

It cannot be disregarded that, in the end, no clear relationship may be confirmed between disease and meteorological variables which, if so, would indicate that other factors besides the latter are involved. It may be that there is a complex interaction of conditions of which the weather forms only an important component. One explanation suggested for the longer term periodicity shown by red needle cast is that defoliation due to disease removes inoculum from the system, after which several years elapse before fresh inoculum builds up sufficiently for a new outbreak to occur. It is interesting that red needle cast has recently been observed for the first time at one of the monitoring points in this study near Rotorua (Fig. 5) while it has yet to appear at a number of sites in the same region where disease was severe during the previous year. On the other hand, comparatively high levels of disease have been observed in some other monitoring plots in at least two successive years (Fig. 2).

To end this Discussion it should be stated that a number of the plots in this study were deliberately selected in the same stands that were used for monthly monitoring of red needle cast over a one year period during 2008-2009, shortly after the disease was first recognised (J.F. Gardner, unpublished data; Table 1). Although there are differences[5], it may be possible to incorporate the data from this earlier study in order to extend the value of the present work, when this is eventually analysed.

Fig. 4. Red needle cast in a mature *P. radiata* stand north of Tapuiwahine, between Te Kuiti and Taumarunui, 5 December, 2106.

[5] The earlier records span just one year and employ only one assessment score (severity at one “point” or tree group rather than along a transect) using a more detailed assessment scale, so that a “translation” will be required to make both sets of data compatible,

Fig. 5. The first occurrence of a small amount of red needle cast in Plot 16 (Paradise Valley, Rotorua), mid 2017 (scores: extent, 1; severity, 2). Photo taken 4 July, 2017.

It is the hope of this work that outbreaks of red needle cast may be anticipated sufficiently early to enable the application of a corrective chemical control treatment only when it is needed. It may in fact become possible to make this judgement by noting the nature and appearance of the earliest crown symptoms of red needle cast if and when they first become visible in the forest in question as well as in neighbouring plantations. However, organised forecasting will ideally provide this essential information more precisely, earlier in the season, based on systematic measurements of meteorological data.

5 Conclusions

- 52 plots set up in stands of *P. radiata* in the central and eastern North Island are being monitored for extent and severity or red needle cast on an annual basis.
- In due course these disease data will be analysed alongside local weather data obtained from a NIWA online source, in order to see if there are any relationships, potentially contributory, between the two.
- The eventual aim is to see if it is possible to anticipate periodic outbreaks of red needle cast before they occur, as an aid to disease management.

6 Acknowledgements

Funding was provided by the New Zealand Forest Owners' Association and the Ministry of Business, Innovation and Employment.

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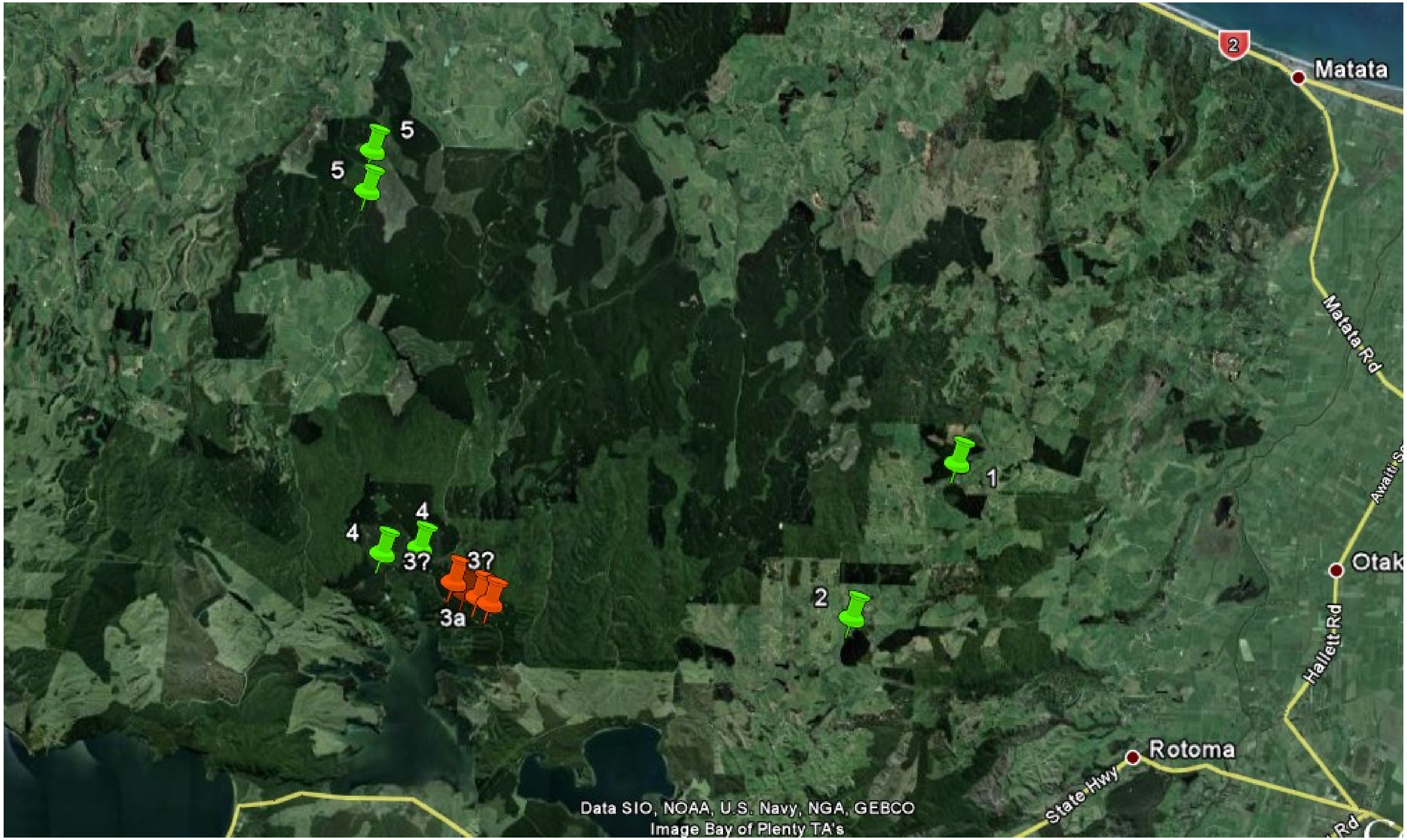
Appendix A – detailed map of plot locations

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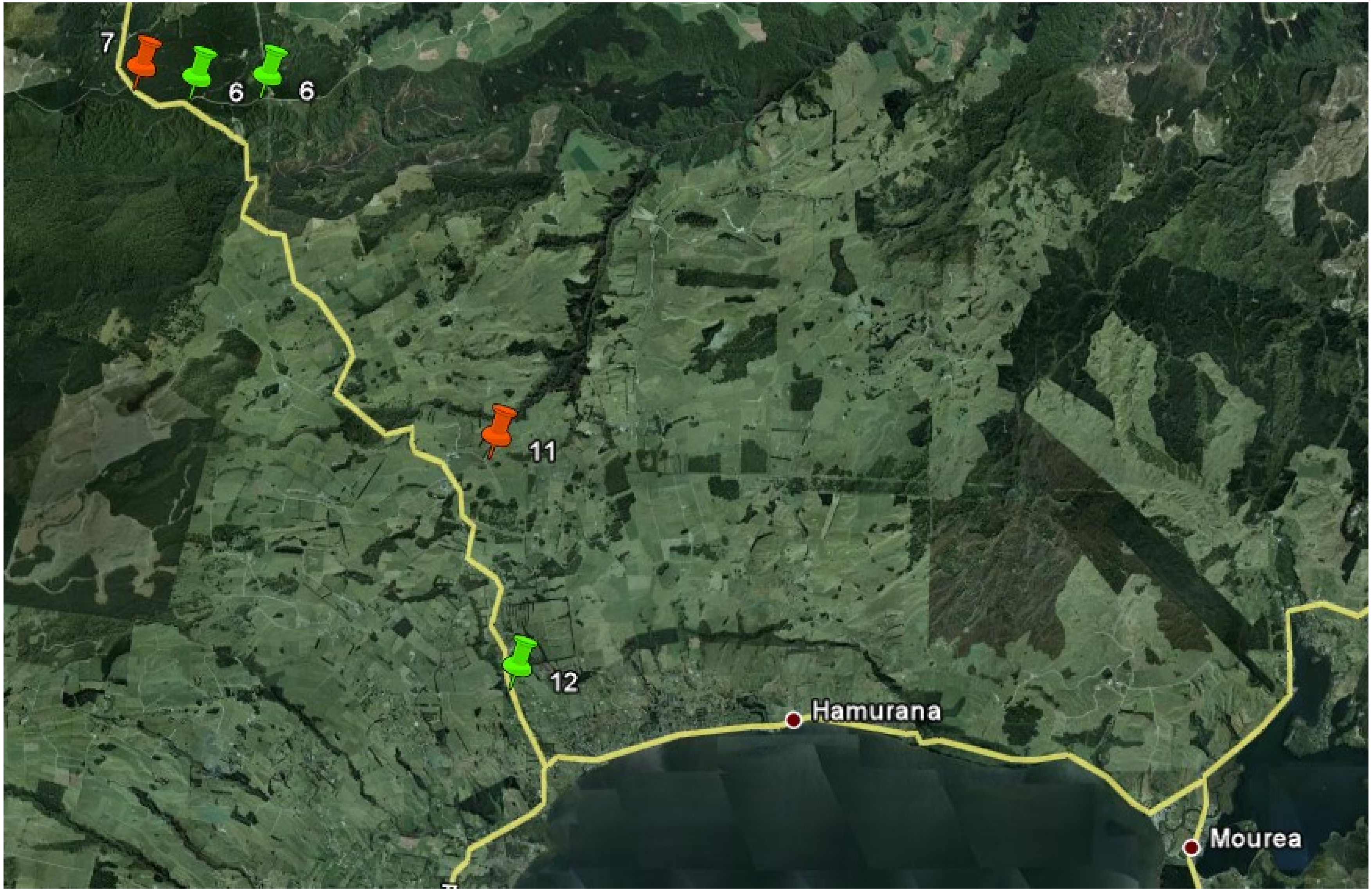
Lake Rotoehu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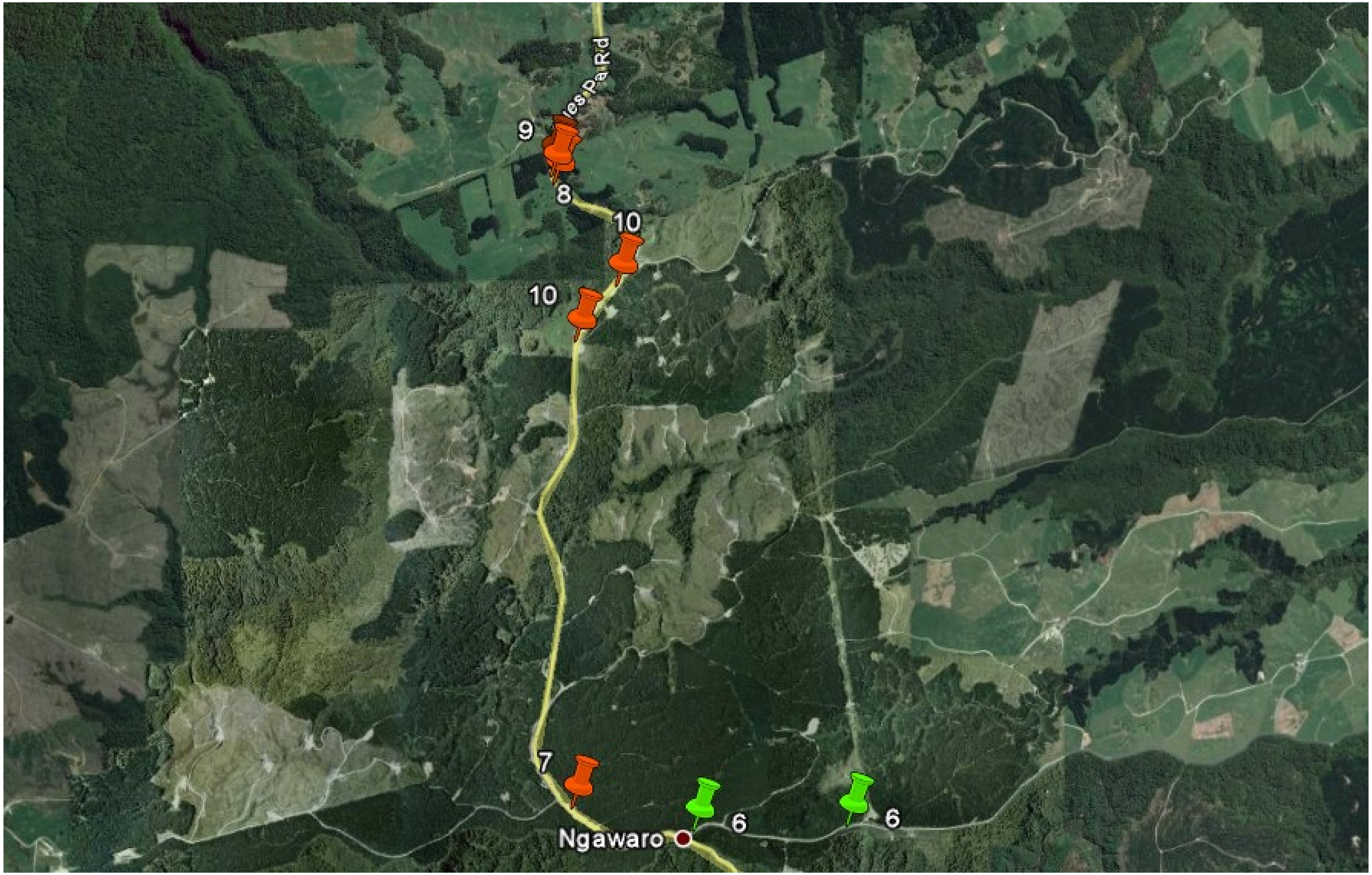
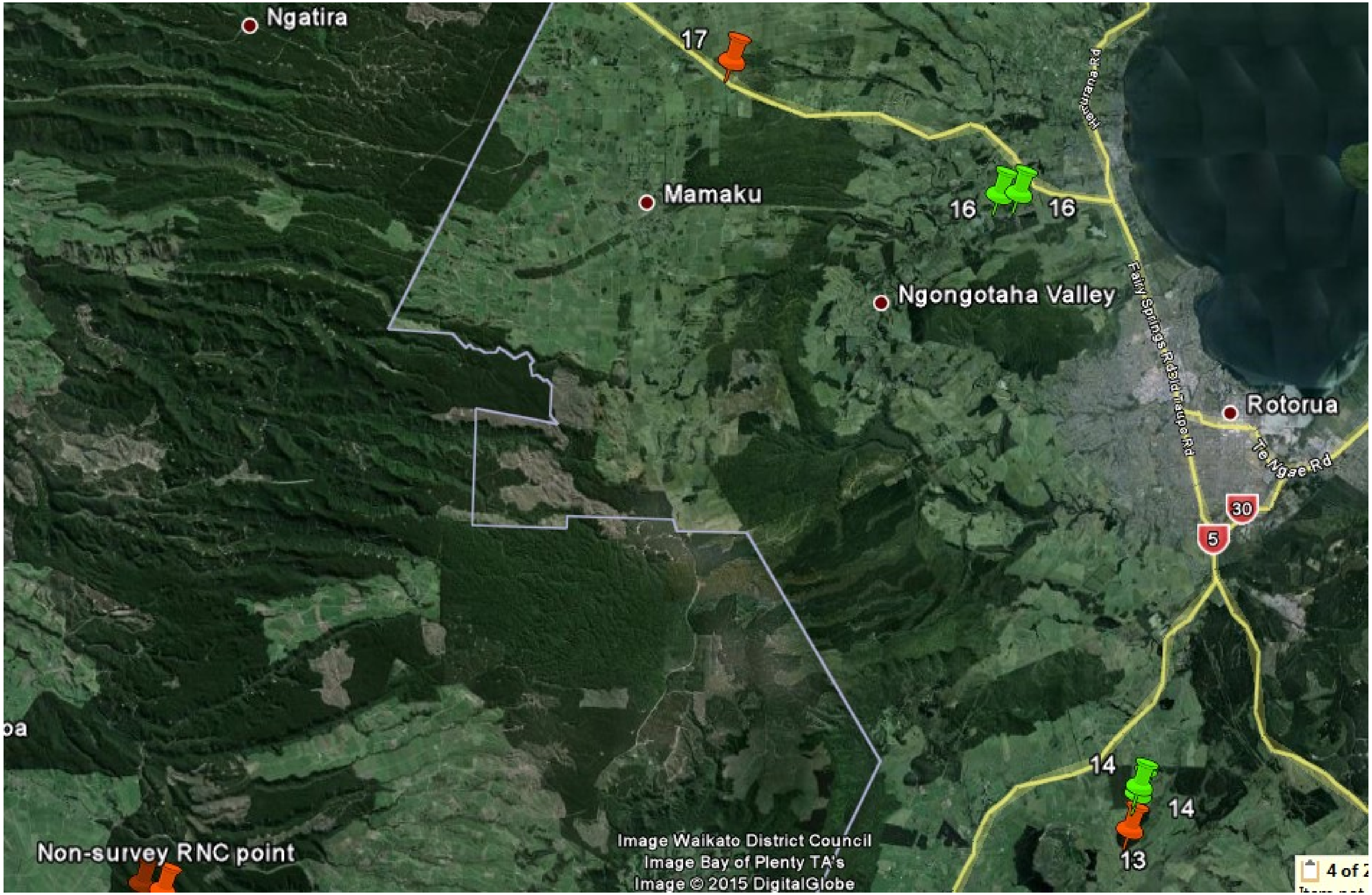
Hamurana
Mourea



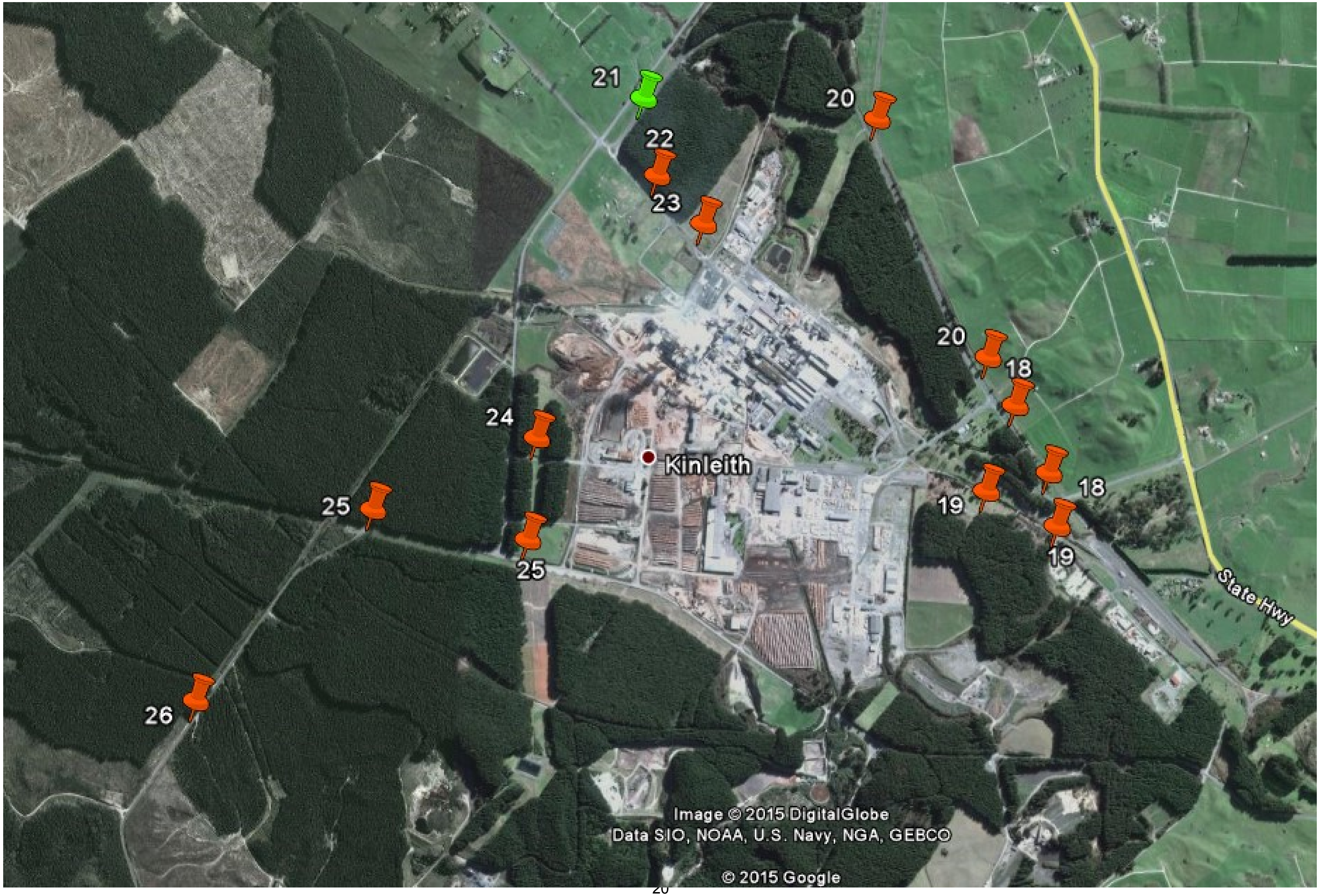
Pa Rd
9
8
10
10
7
Ngawaro
6
6


8
Fyes Pa R
9
8
36

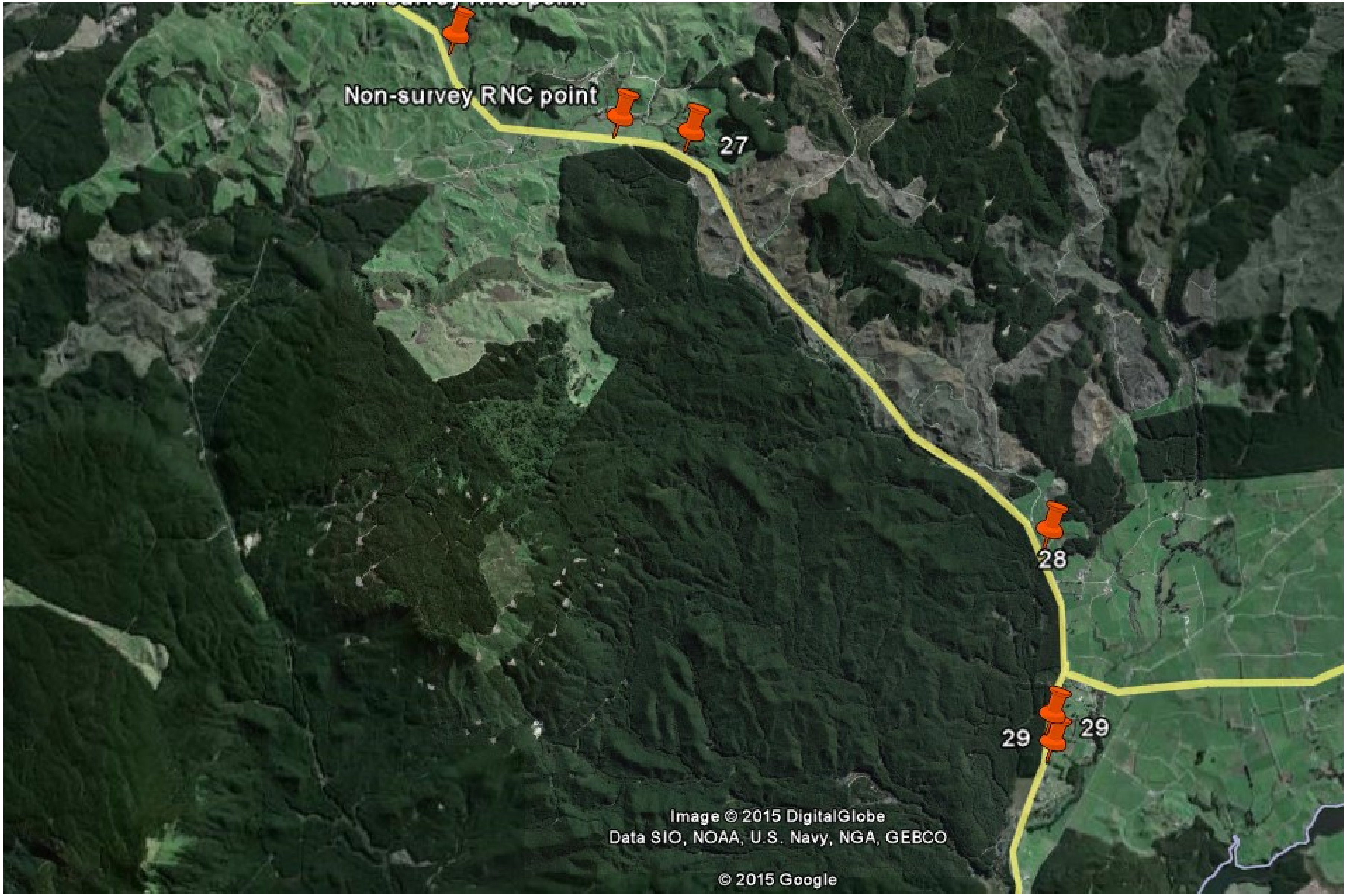


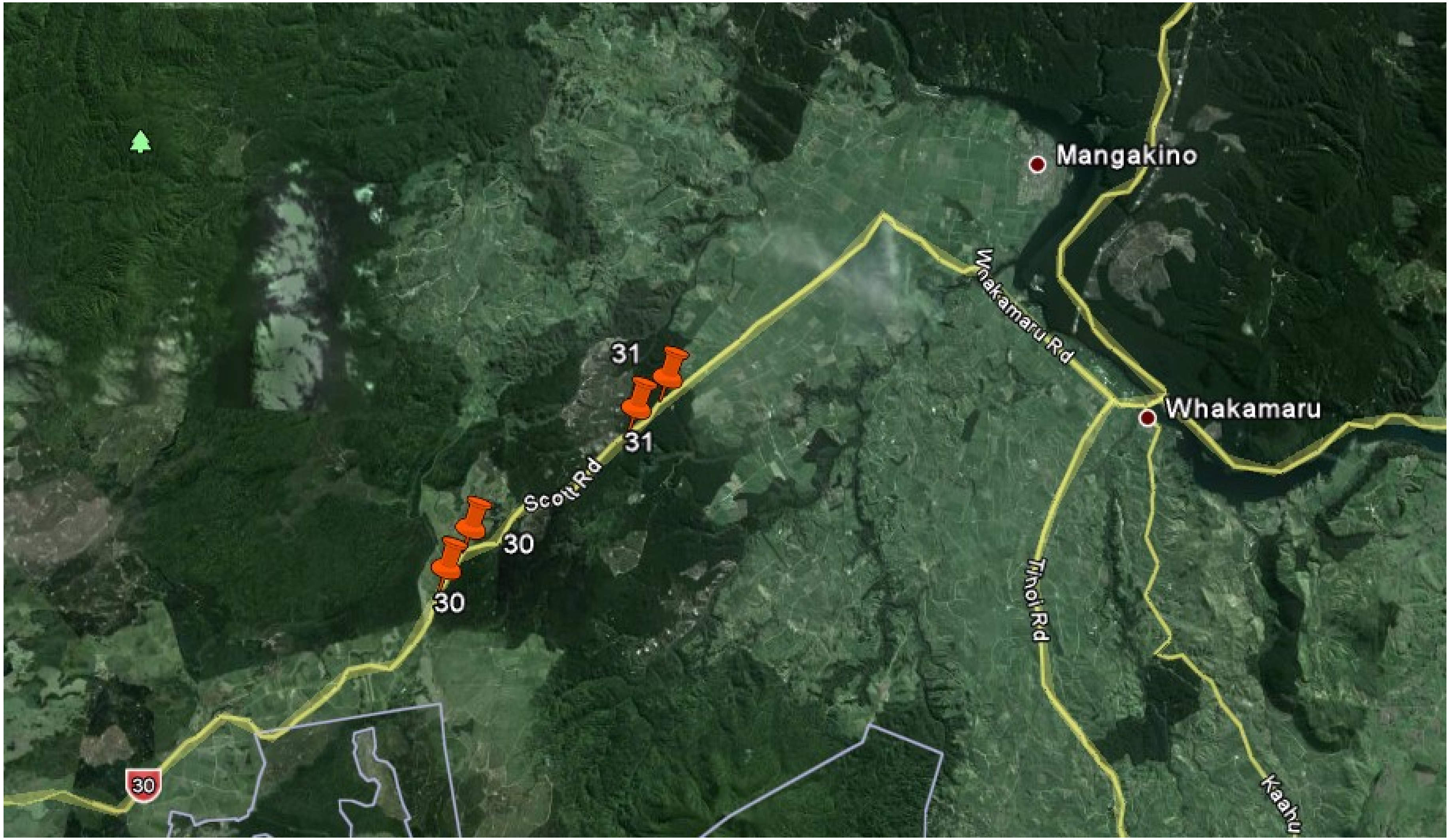
Monitoring point 15 runs between points 13 and 14.

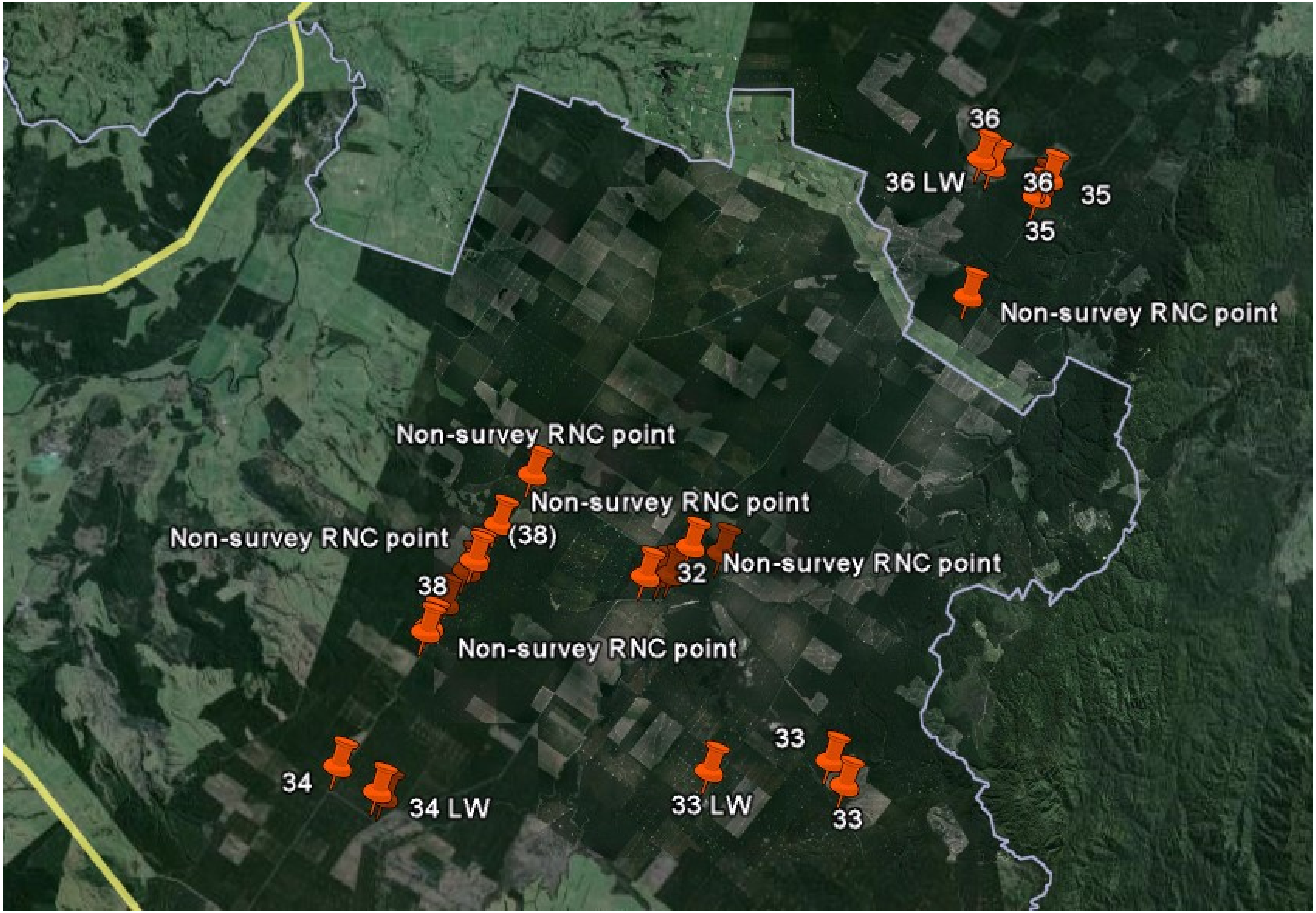

Tokoroa
Maraetai Rd
Main Rd
Non-survey RNC point
20
20
25
23
19
18
Non-survey RNC point
Non-survey RNC point
27
39
39
28
29
29
14
14
13
Ngakuru
Atiamuri



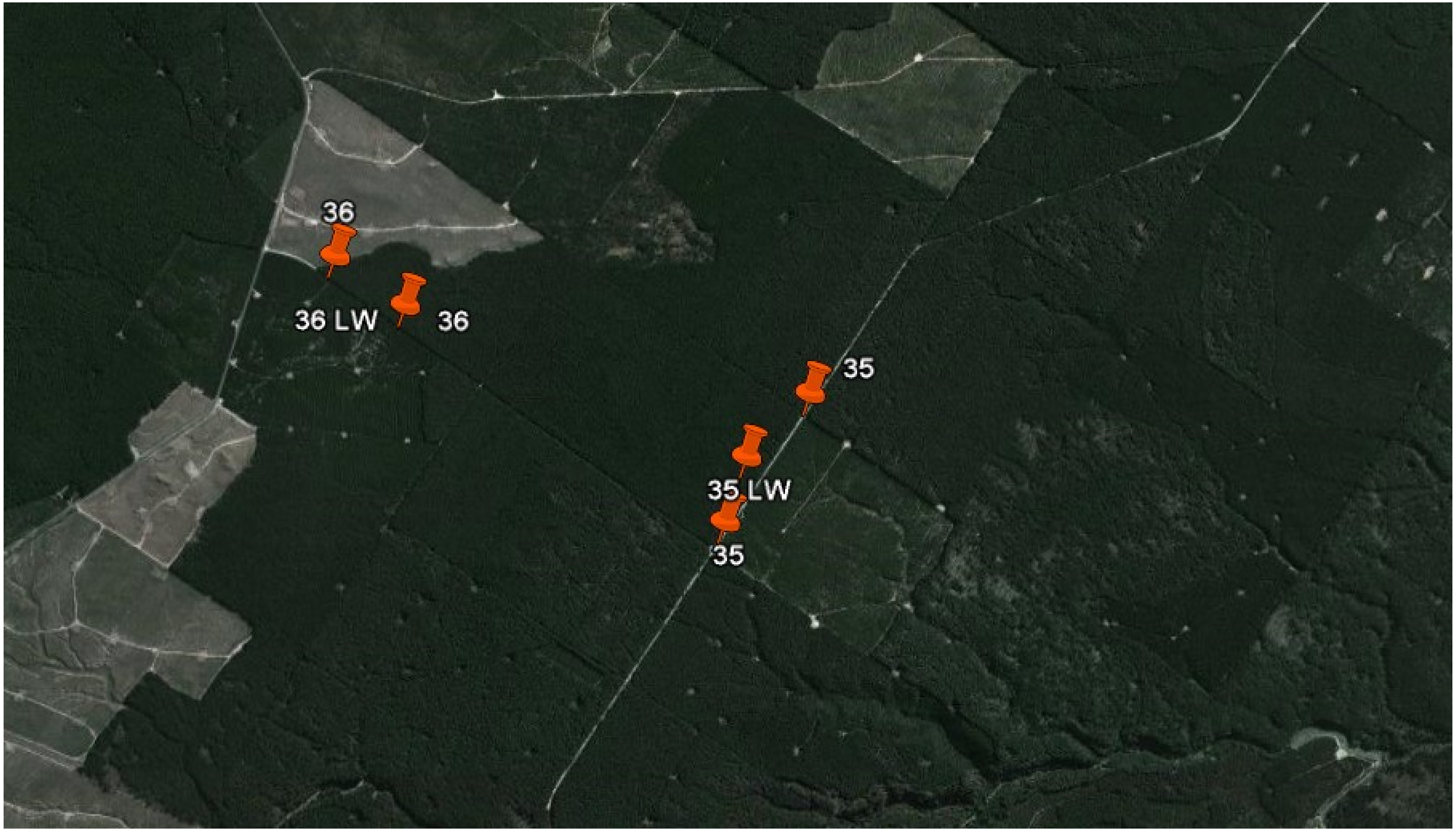
21
20
22
23
20
18
24
Kinleith
18
25
19
25
19
26
State Hwy
Image © 2015 DigitalGlobe
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
© 2015 Google

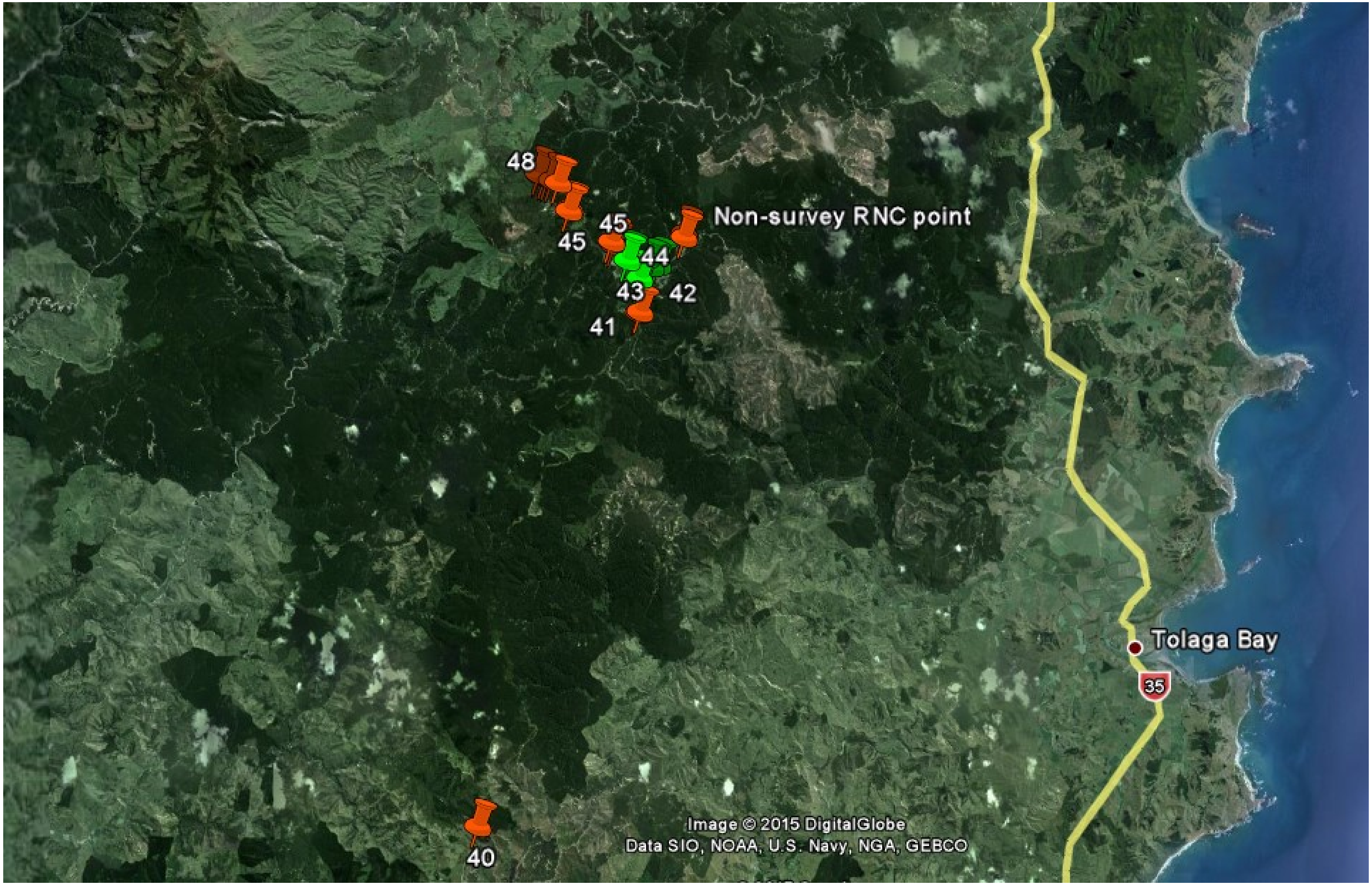

Non-survey RNC point
27
28
29
29
Image © 2015 DigitalGlobe
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
© 2015 Google

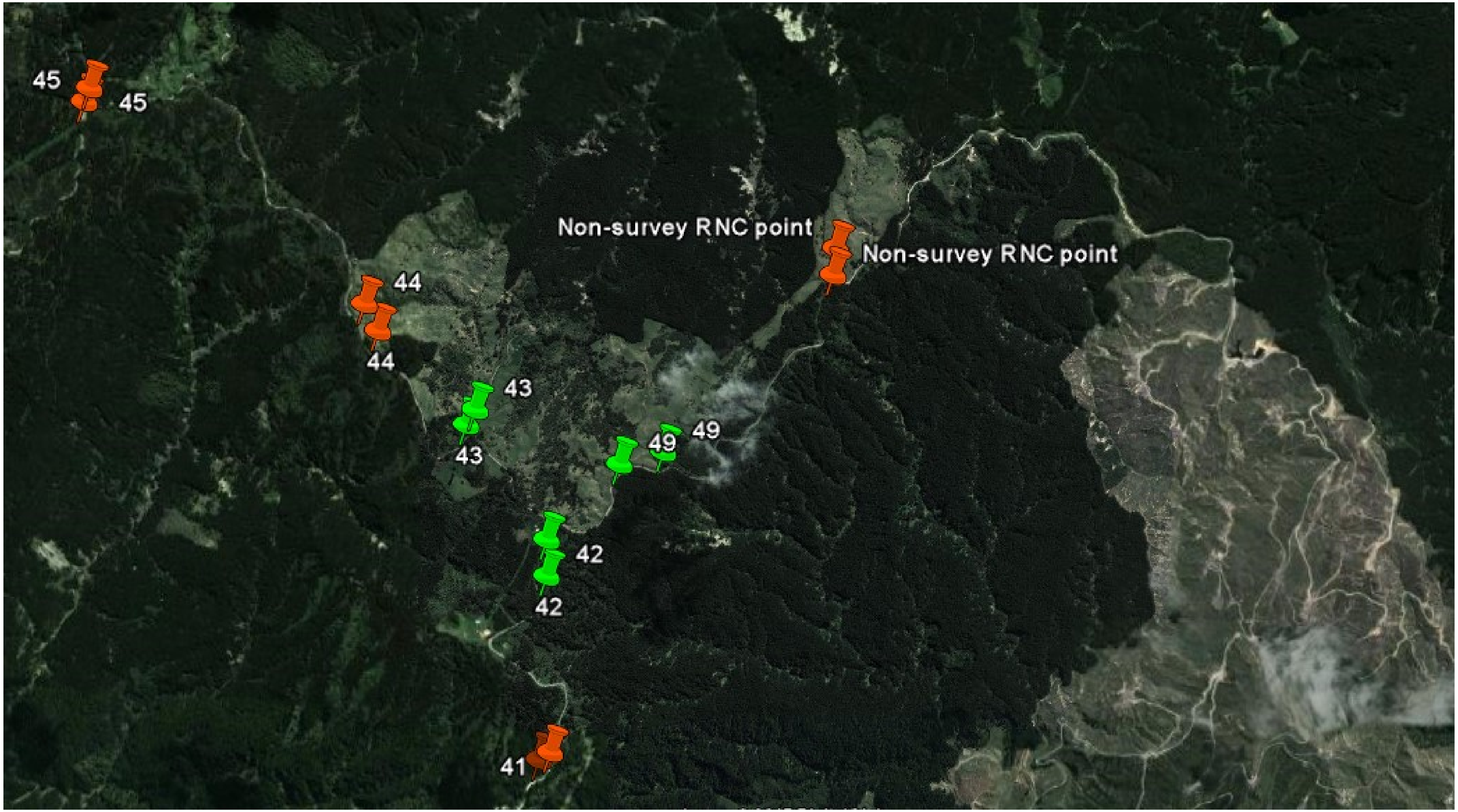

Mangakino
Whakamaru Rd
Whakamaru
31
31
Scott Rd
30
30
Tihoi Rd
Kaahu
30

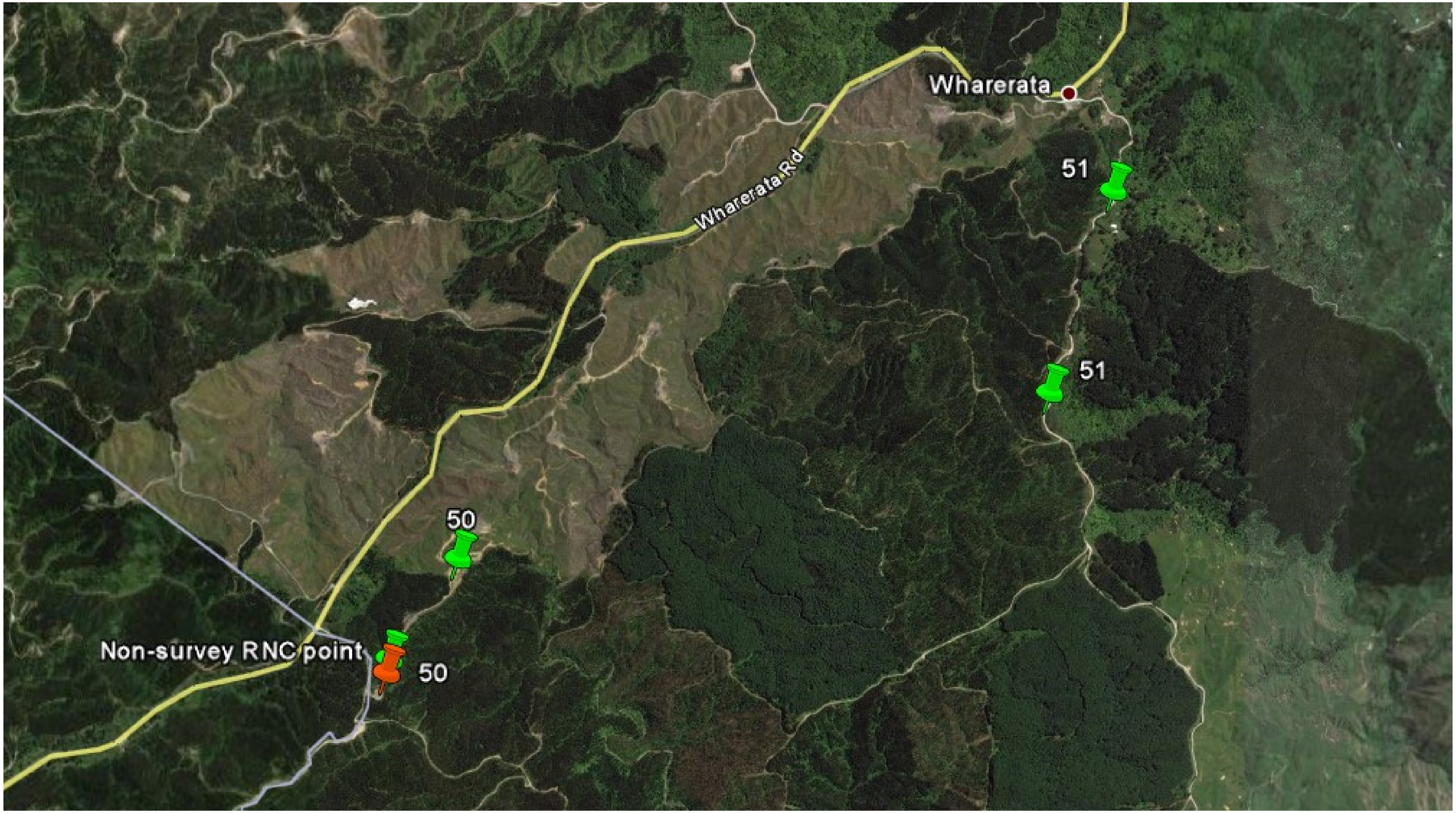

36
36 LW
36
35
35
Non-survey RNC point
Non-survey RNC point
Non-survey RNC point
(38)
Non-survey RNC point
32
Non-survey RNC point
38
Non-survey RNC point
33
34
34 LW
33 LW
33


(38)
Non-survey RNC point
(38)
38
38
Non-survey RNC point
Kaingaroa
32
32
34
34 LW
34
33 LW
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2015 DigitalGlobe
© 2015 Google


36
36 LW
36
35
35 LW
35


48
45
45
Non-survey RNC point
44
43
42
41
40
Tolaga Bay
35
Image © 2015 DigitalGlobe
Data SIO, NOAA, U.S. Navy, NGA, GEBCO


45
45
Non-survey RNC point
Non-survey RNC point
44
44
43
43
49
49
42
42
41


Wharerata
Wharerata Rd
51
51
50
Non-survey RNC point
50

Appendix B – assessment results, 2015 (summarised)

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Monitoring point No.	Brief description/name.	➔ * *Phytophth-ora* confirmed	➔ *P. pluvialis* confirmed ** *P. kernoviae* confirmed ***	Oct-15 Transect affected (extent)	Oct-15 Worst tree (severity)
1	Manawahe 3			0	0
2	Manawahe 2			0	0
3	Pongakawa Valley (redefined) 9			1	2
3a	Pongakawa Valley (redefined) 18			-	2
4	Pongakawa Valley 7			0	0
5	Pongakawa Valley 15			0	0
6	Te Matai Rd. 12			0	0
7	Tauranga Back Road 1			-*	2
8	Tauranga Back Road 2a			4	3-4
9	Tauranga Back Road 2b			1	-
10	Tauranga Back Road 3			1?	2
11	Kaharoa Road			1	2

12	Kaharoa Boarding	-	0
13	Kapenga 1	-	4
14	Kapenga 2	-	0
15	Kapenga	1	4
16	Paradise Valley	0	0
17	Tarukenga	1	2
18	Kinleith Road 1	5	5
19	Wawa Road	3-4	5
20	Kinleith Road 2	3	5
21	Side Rd (Nth)	0	0
22	Farm Driveway (West)	3	4-5
23	The Mill (Sth)	5	5
24	Nr Kinleith logyard	5	5
25	Access Road, Kinleith	5	5
26	Smythe Road	1	1
27	SH1_1	3	4
28	SH1_2	1	1
29	SH1 Upper Atiamuri	5	5
30	Pureora jnctn Ranginui Rd	4	4
31	Pureora 2	1	2-3
32	Kaingaroa Low Level	3*	2
33	Kaingaroa Kiorenui Road	2	2
34	Kaingaroa Pukuriri Road	1*	2(-3)
35	Kaingaroa Kiorenui Rd_2	5(N)/3(S)*	2/2
36	Kaingaroa, Taupiri Road	2	2
37	Kaingaroa, Goudies Road	1	3
38	Kaingaroa, High Level Road	4	2(-3)
39	Kinleith Forest, Rahui Road	2	1-2
40	Waimata Valley Road	2*	2

41	Tauwhareparae 1	1	2
42	Tauwhareparae 2	0	0
43	Tauwhareparae 3	0	0
44	Tauwhareparae 4	1	2
45	Tauwhareparae 5	1	3
46	Tauwhareparae 6	2	3
47	Tauwhareparae 7	1	2
48	Tauwhareparae 8	1	2
49	Tauwhareparae 9	0	0
50	Wharerata 1	0	0
51	Wharerata 2	0	0

Appendix C – assessment results, 2016 (summarised)

		Apr-16	Apr-16	May-16	May-16	Jul-16	Jul-16	Aug-16	Aug-16	Sep-16	Sep-16
Monitoring point No.	Brief description/name	Transect affected (extent)	Worst tree (severity)	Transect affected (extent)	Worst tree (severity)	Transect affected (extent)	Worst tree (severity)	Transect affected (extent)	Worst tree (severity)	Transect affected (extent)	Worst tree (severity)
1	Manawahe 3					0	0	1	1		
2	Manawahe 2					1	1	2	4		
3	Pongakawa Valley (redefined) 9					1	2	1	3		
3a	Pongakawa Valley (redefined) 18					0***	0	1	3		
4	Pongakawa Valley 7					0	0	0	0		
5	Pongakawa Valley 15					0	0	0	0		
6	Te Matai Rd. 12					0	0	1*	2		
7	Tauranga Back Road 1					-(*)	2	2*	3		
8	Tauranga Back Road 2a					3	3	5	4		
9	Tauranga Back Road 2b					0	0	3	3		
10	Tauranga Back Road 3					1**	3	2	3		
11	Kaharoa Road					-	-	-	-		

12	Kaharoa Boarding			-	0	0	0		
13	Kapenga 1			1	3	3	4		
14	Kapenga 2			0	0	0	0		
15	Kapenga			1	3	1	4		
16	Paradise Valley			0	0	0	0		
17	Tarukenga			1	2	5	3		
18	Kinleith Road 1			2	3	5*	5		
19	Wawa Road			0	0	3*	5		
20	Kinleith Road 2			1	1	1	5		
21	Side Rd (Nth)			0	0	0	0		
22	Farm Driveway (West)			0	0	0	0		
23	The Mill (Sth)			1	5	?	0		
24	Nr Kinleith logyard			1	5	2	5		
25	Access Road, Kinleith			2	3	5	5		
26	Smythe Road			2*	3	4	3		
27	SH1_1			0	0	1	5		
28	SH1_2			0	0	1	1		
29	SH1 Upper Atiamuri			0	0	0	0		
30	Pureora jnctn Ranginui Rd			(1)	(4)	3*	4		
31	Pureora 2			(1)	(3)	3*	2		
32	Kaingaroa Low Level			1*	3			3	2
33	Kaingaroa Kiorenui Road			0	0			0	0
34	Kaingaroa Pukuriri Road			1	2,2			2?	3
35	Kaingaroa Kiorenui Rd_2			(2)*	(3)			5	3
36	Kaingaroa, Taupiri Road			(1)**	(3)			5	3
37	Kaingaroa, Goudies Road			0	0			1	3
38	Kaingaroa, High Level Road			1**	2			3	3
39	Kinleith Forest, Rahui Road								
40	Waimata Valley Road							5	5

41	Tauwhareparae 1			0	0					0	0
42	Tauwhareparae 2			2	3					2	2
43	Tauwhareparae 3			4	5					5	5
44	Tauwhareparae 4			5	4					4	5
45	Tauwhareparae 5			5	5					5	5
46	Tauwhareparae 6			4	4					4	3
47	Tauwhareparae 7			4	4					5	3
48	Tauwhareparae 8			4	3-4					5	3
49	Tauwhareparae 9			5	4					5	4
50	Wharerata 1	1	1	1	3-4					1	5
51	Wharerata 2	1	2	1	3					1	3

Appendix D – assessment results, early 2017 (summarised)

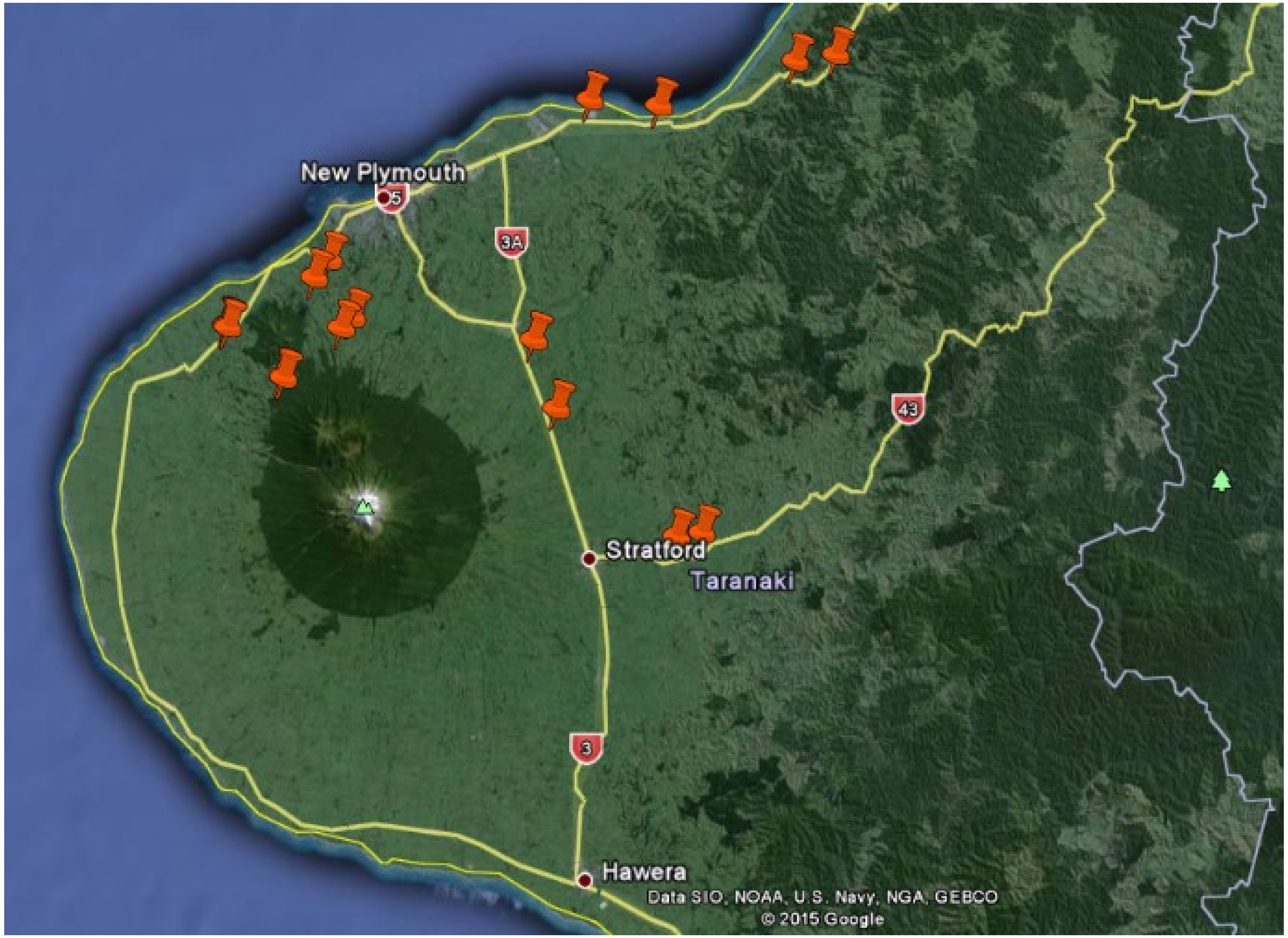
Monitoring point No.	Brief description/name ~~Strikethrough~~: stand felled.	➔ * *Phytophth-ora* confirmed	➔ *P. pluvialis* confirmed ** *P. kernoviae* confirmed ***	(Brackets show level of defoliation from earlier RNC) Mar-17 Transect affected (extent)	Mar-17 Worst tree (severity)	(Brackets show level of defoliation from earlier RNC) Apr-17 Transect affected (extent)	Apr-17 Worst tree (severity)	May-17 Transect affected (extent)	May-17 Worst tree (severity)
1	Manawahe 3					0 (2)	0 (2)		
2	Manawahe 2					0 (1)	0 (1)		
3	Pongakawa Valley (redefined) 9					0 (0)	0 (0)		
3a	Pongakawa Valley (redefined) 18					0 (1)	0 (2)		
4	Pongakawa Valley 7					0 (0)	0 (0)		
5	Pongakawa Valley 15					0 (0)	0 (0)		
6	Te Matai Rd. 12					0 (1)	0 (2)		
7	Tauranga Back Road 1					0 (4)	0 (2)		
8	Tauranga Back Road 2a					0 (4)	0 (3)		
9	Tauranga Back Road 2b					-	-		
10	Tauranga Back Road 3					0 (1)	0 (1)		
11	Kaharoa Road					-	-		
12	Kaharoa Boarding					0 (0)	0 (0)		
13	Kapenga 1			0 (1)	0 (2)				

14	Kapenga 2	0 (0)	0 (0)		
15	Kapenga	0 (0)	0 (0)		
16	Paradise Valley	0 (0)	0 (0)		
17	Tarukenga	0 (3)	0 (2)		
18	Kinleith Road 1	0 (0)	0 (0)		
19	Wawa Road	0 (2)	0 (2)		
20	Kinleith Road 2	0 (1)	0 (1)		
21	Side Rd (Nth)	0 (0)	0 (0)		
22	Farm Driveway (West)	0 (0)	0 (0)		
23	The Mill (Sth)	0 (0)	0 (0)		
24	Nr Kinleith logyard	0 (0)	0 (0)		
25	Access Road, Kinleith	0 (1)	0 (4)		
26	Smythe Road	0 (3)	0 (1)		
27	SH1_1	0 (0)	0 (0)		
28	SH1_2	0 (0)	0 (0)		
29	SH1 Upper Atiamuri	0 (0)	0 (0)		
30	Pureora jnctn Ranginui Rd	0 (1)	0 (1)		
31	Pureora 2	0 (1)	0 (2)		
32	Kaingaroa Low Level	0 (0)	0 (0)		
33	Kaingaroa Kiorenui Road	0 (0)	0 (0)		
34	Kaingaroa Pukuriri Road	0 (-)	0 (-)		
35	Kaingaroa Kiorenui Rd_2	0 (1)	0 (2)		
36	Kaingaroa, Taupiri Road	0 (3)(**)	0 (3)		
37	Kaingaroa, Goudies Road	0 (3)	0 (3)		
38	Kaingaroa, High Level Road	0 (4)	0 (3)		
39	Kinleith Forest, Rahui Road				
40	Waimata Valley Road				
41	Tauwhareparae 1			0	0
42	Tauwhareparae 2			0	0

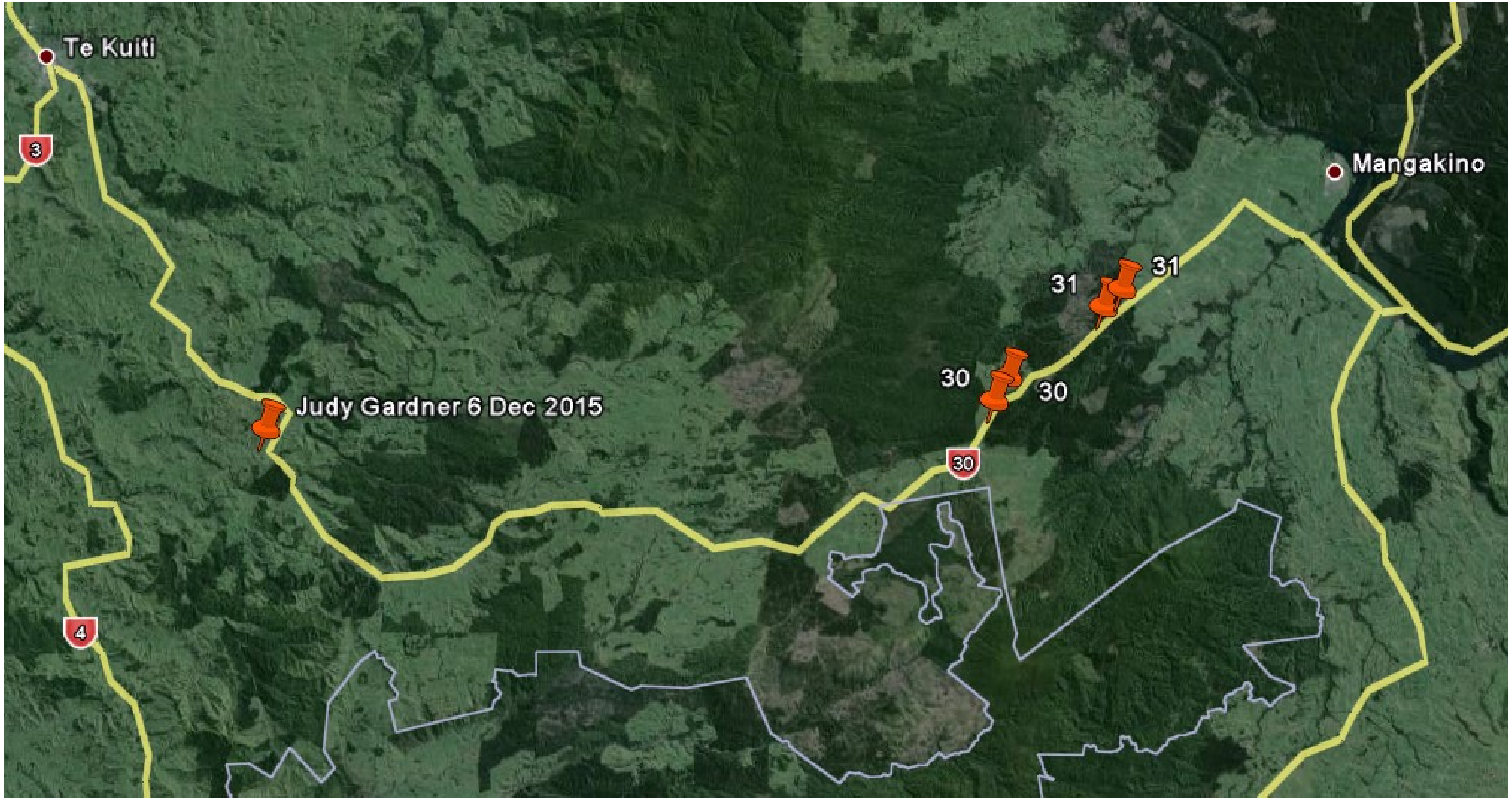
43	Tauwhareparae 3			0	0
44	Tauwhareparae 4			0	0
45	Tauwhareparae 5			0	0
46	Tauwhareparae 6			0	0
47	Tauwhareparae 7			0	0
48	Tauwhareparae 8			0	0
49	Tauwhareparae 9			1**	1
50	Wharerata 1			0	0
51	Wharerata 2			1	2

Appendix E – some locations of red needle cast in Taranaki in 2015

Judy Gardner (Scion), 30 October-2 November, 2015.



A further red needle cast record by J.F. Gardner (6 December 2015), Scion, shown in relation to nominated study monitoring points 30 and 31.

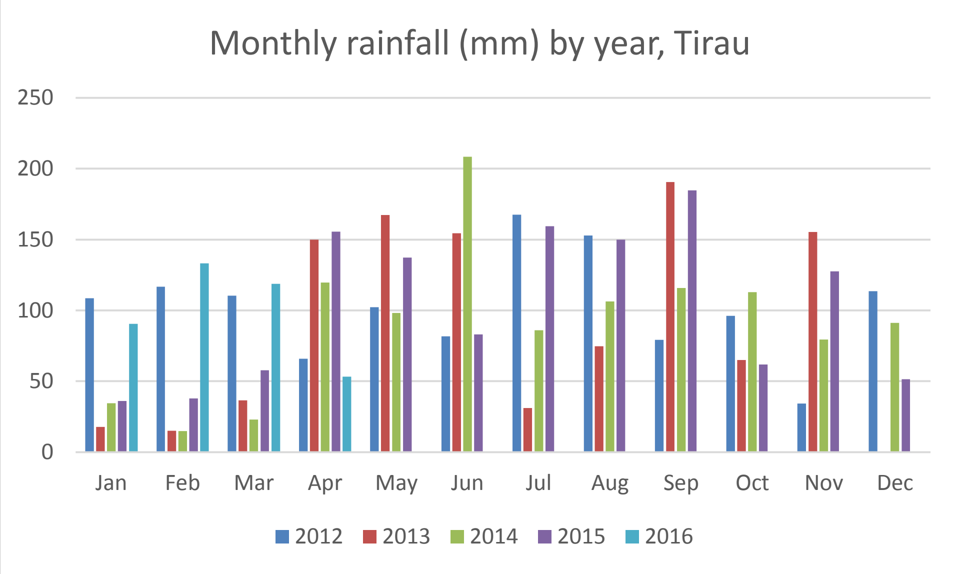


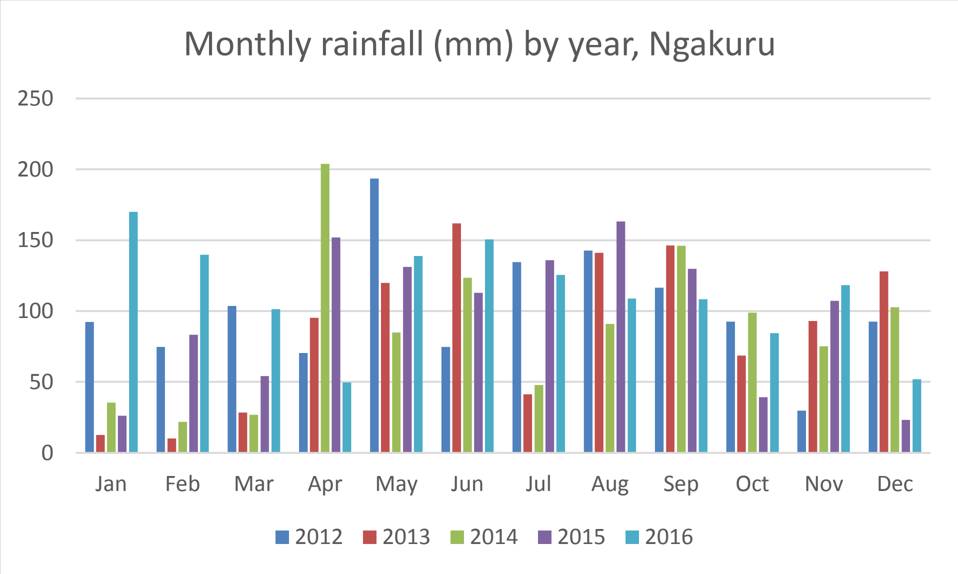
Appendix F – rainfall, Tokoroa-Mamaku area, 2012-2017

Late spring and summer rainfall

Summer	Disease in following winter	Meteorological station[1]	Rainfall (mm)					No. rain days > 1mm				
			Nov.	Dec.	Jan.	Feb.	Total	Nov.	Dec.	Jan.	Feb.	Total
2012-13	Little/none	Tirau	34.3	113.5	17.9	15.0	180.7	6	11	-	3	20+
		Ngakuru	29.7	92.6	12.6	10.1	145.0	5	14	4	2	25
2013-14	Little none	Tirau	155.4	-	34.4	14.9	204.7+	9	-	5	3	17+
		Ngakuru	93.1	127.9	35.5	21.9	278.4	10	11	8	3	32
2014-15	Some	Tirau	79.5	91.3	36.1	38.0	244.9	10	10	3	7	30
		Ngakuru	75.1	102.7	26.1	83.4	287.3	-	9	3	5	17+
2015-16	Much	Tirau	127.6	51.4	90.6	133.2	402.8	11	-	8	10	29+
		Ngakuru	107.3	23.2	170.0	139.8	440.3	9	5	12	10	36

[1]Refer p. 42.


Monthly rainfall (mm) by year, Tirau
250
200
150
100
50
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2012
2013
2014
2015
2016


Monthly rainfall (mm) by year, Ngakuru
250
200
150
100
50
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2012
2013
2014
2015
2016

Locations of NIWA meteorological stations Tirau (top) and Ngakuru (bottom).
Tirau, Taumangi Road: 38915; -38.02312/175.75763
Ngakuru: 1792; -38.369/176.164