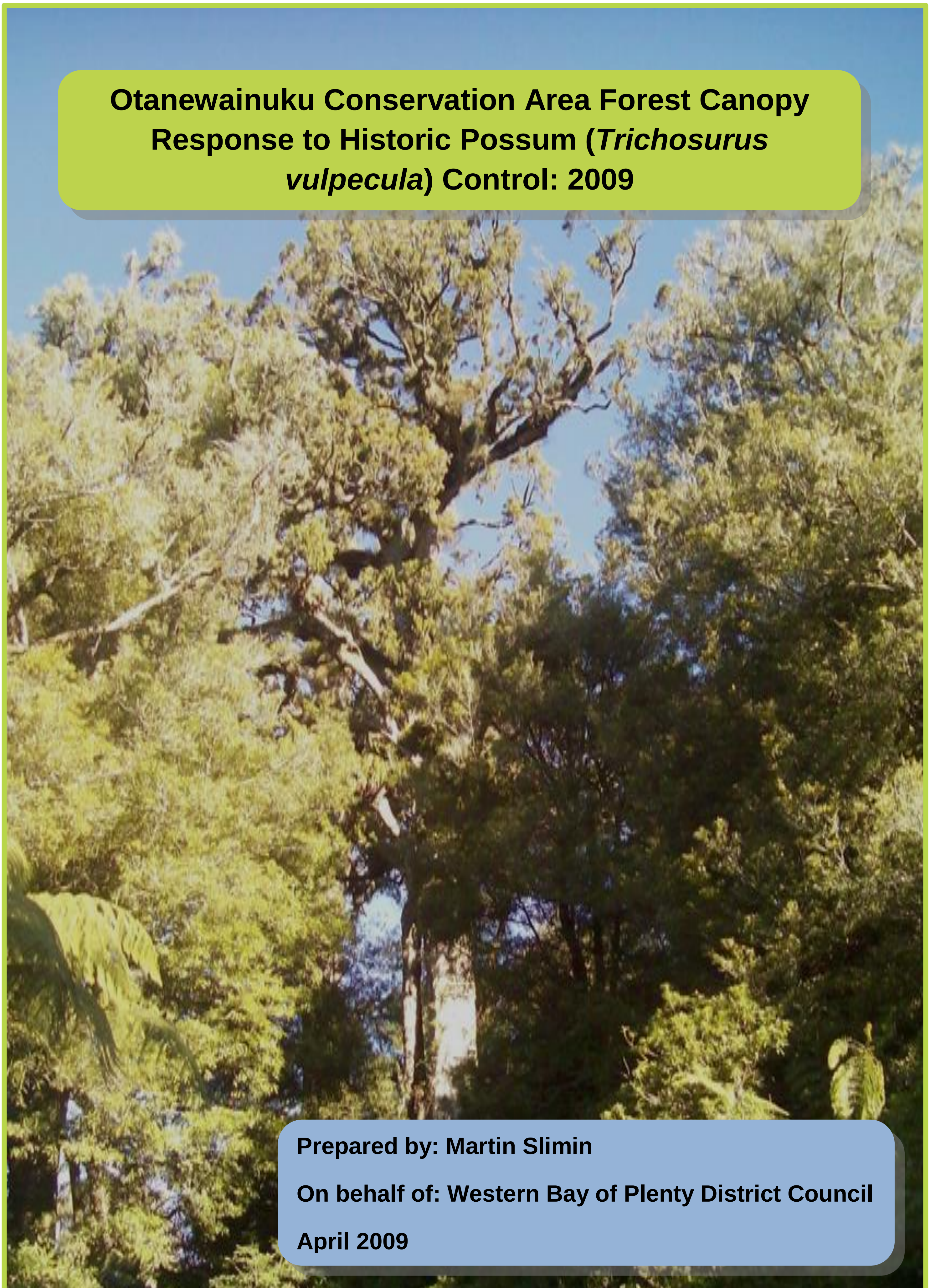
Otanewainuku Conservation Area Forest Canopy Response to Historic Possum (*Trichosurus vulpecula*) Control: 2009



Prepared by: Martin Slimin

On behalf of: Western Bay of Plenty District Council

April 2009

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Western Bay of Plenty District Council

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Prepared for: Western Bay of Plenty District Council

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22 April 2009

Cover Plate: Mature podocarp/angiosperm forest, Otanewainuku Conservations Area

Executive Summary

This report has been prepared on behalf of Western Bay of Plenty District Council, with regard to the re-measure of Foliar Browse Index (FBI) transects within the Otanewainuku Conservation Area. This is to enable a quantifiable understanding to be gained of changes in canopy cover condition due to variations to possum densities in response to pest control operations. This information is of value to WBoPDC and the Department of Conservation in sustaining this rare remnant example of the highly underrepresented semi-coastal/lowland forest. It will also support the Otanewainuku Kiwi Trust (OKT) in managing pest control strategies and provided a quantitative measure in advocacy of this community group's efforts.

Possum control operations have occurred in the conservation area since 1994/1995. Initial efforts were performed by the Department of Conservation until 1999 at which time control for possums was suspended until 2006 when resumed on an annual basis by the Otanewainuku Kiwi Trust. Canopy cover condition was initially monitored in 1994 at which time six (6) FBI transects were established, four species were selected as suitable indicators (kohekohe, mahoe, pate and kamahi). These were re-measured in 1996, 1998 and in 2000 at which time an additional three (3) transects were established to improve statistical robustness. Another re-measure occurred in 2003 at which time it was found that many of the tagged indicator trees were inadequate and removed from the sample. For the 2009 re-measure six (6) of the eight (8) transects were sampled, with the two (2) remaining considered to be in a separate stratum as they were outside the pest control area.

Results showed that in years where possum control was performed canopy condition for all indicator species was healthy with kohekohe being close to optimum foliar cover of 60-70 percent. However in the period where control did not occur (2000-2005) canopy condition seriously declined leading to concerns that the forest may be close to collapse. Fortunately this was not the case and the resumption of control saw canopy condition return to levels observed earlier. Some concern exists over the high mortality and poor recruitment of pate and it is unsure if this is the legacy of high possum browse of due to other impacts such as ungulate browse.

It is clear that the efforts of the Otanewainuku Kiwi Trust are pivotal to the ongoing holistic health of this precious taonga and it is vital that possum control continues and that greater effort be applied to supporting and advocating for the trusts initiatives. It is also important that FBI monitoring continue, to enable a picture of forest health to be maintained and that the results kept in a central database so that the value of this robust historic dataset be preserved.

Acknowledgement

Many thanks must go to the Department of Conservation Tauranga Area Office in particular Brad Angus for access to historic records for the Otanewainuku Conservation Area and assistance with field work. Also to the members and volunteers of the Otanewainuku Kiwi Trust who tirelessly serve as kaitiaki in preserving this precious natural treasure for generations to come.

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1 Introduction

1.1 Purpose

This report has been prepared on behalf of Western Bay of Plenty District Council (WBoPDC), with regard to the re-measure of Foliar Browse Index (FBI) transects within the Otanewainuku Conservation Area. This is to enable a quantifiable understanding to be gained of changes in canopy cover condition due to variations to possum densities in response to pest control operations. This information is of value to WBoPDC and the Department of Conservation (DoC) in sustaining this rare remnant example of the highly underrepresented semi-coastal/lowland podocarp/angiosperm indigenous forest. It will also support the Otanewainuku Kiwi Trust (OKT) in managing pest control strategies and provided a quantitative measure in advocacy of this community group's efforts.

1.2 Scope

The scope of work to be carried would encompass:

- Re-measure of the six existing FBI transects contained within the Otanewainuku Conservation Area current possum control area.
- Establish new indicator trees to maintain adequate sample size as required due to dieback
- Liaise with the Department of Conservation Tauranga Area Office to ascertain transect locations and source historical FBI and pest control (Residual Trap Catch Indices (RTCI) for possum abundance) data.
- Liaise with the Otanewainuku Kiwi Trust to ascertain historic pest control (RTCI) data
- Compile, analyse and present current and historic data in a manner which demonstrates the decline or recovery the forest canopy and the relationship between forest canopy condition and possum abundance
- Perform all FBI data collection and analysis in accordance with *Foliar Browse Index: A Method for Monitoring Possum Damage To Plant Species and Forest Communities* (Payton, Pekelharing and Frampton, 1999)
- Generate a comprehensive yet succinct report to present data and results in a manner which enables ease of future monitoring complete with electronic files of historic data and transect locations

1.3 Otanewainuku Conservation Area

Located 25 km south of Tauranga the 1200 ha Department of Conservation (DoC) administered Otanewainuku Conservation Area (Appendix A) occupies portions of the Otanewainuku and Te Matai forests; ranging from 300 to 645 m asl within the Otanewainuku Ecological District. The vegetation cover comprises one of the countries few remaining examples of remnant semi-coastal and lowland forest dominated by large emergent rimu (*Dacrydium cupressinum)*, tawa (*Belischmienia tawa)*, pukatea (*Laurelia novae-zelandiae),* totara (*Podocarpus totara)*, miro (*Prumnopitys ferruginea)* and kahikatea (*Dacrycarpus dacrydioides),* in addition to para (*Marattia salicina,* king fern), kohurangi (*Brachyglottis kirkii* var. *kirkii,* Kirks daisy) and mida (*Mida salicifolia*); all classified as Chronically Threatened (Beadel, 2006). Small birdlife is prolific with toutouwai (*Petroica australis longipes*) particularly abundant along with miromiro (*Petroica macrocephala toitoi*), piwakawaka (*Rhipidura fulginosa placabilis*), riroriro (*Gerygone igata*), popokatea (*Mohoua albicilla*), pipiwharauroa (*Chrysococcyx lucidus*), koekoea (*Eudynamys taitensis,* Gradual Decline), korimako (*Anthornis melanura*) and tui (*Prosthemadara novaeseelandiae)* (personal observation). The mature forest provides ample food for a strong resident kereru (*Hemiphaga novaeseelandiae,* Gradual Decline) population, the frequency of North Island kaka *(Nestor meridionalis septentrionalis,* Nationally Endangered) in the forest indicate that a resident population is not far away (personal observation), and karearea (*Falco novaeseelandiae,* Nationally Vulnerable) are believed to have been observed hunting around Otanewainuku summit. (Equivalent English bird names are given in Appendix C)

The ecological intactness and ecosystem underrepresentation displayed by the Otanewainuku Conservation Area make it of national importance as expressed in The State of New Zealand's Environment (Ministry for the Environment, 1997):

> *"Biodiversity decline is New Zealand's most pervasive environmental issue, with 85 percent of lowland forest and wetlands now gone."*

The plight of the North Island brown kiwi (*Apteryx australis mantelli,* Serious Decline) (from estimations of 50 birds in 1986 to only 5 in 2005) has been the basis for the majority of recent conservation efforts in the forest. The Department of Conservation commenced initial pest control operations in 1994/1995 and in 2002 The Otanewainuku Kiwi Trust (OKT) was established with a Memorandum of Understanding between the Trust and the DoC. The Trust immediately embarked on trapping operations aimed at mustelids as a key predator of kiwi, this then being expanded to include rats and feral cats in 2005. The return to toxin control began in 2006 with the trust targeting the full suite of exotic mammals using 1080 and has since continued annual operations targeting possums and rats.

After the success of the OKT's pest control operations, DoC agreed to the Trust translocating captive breed kiwi to Otanewainuku to bolster the population of 5 known existing birds; in 2007 3 female and 1 male were released. This success not only supported the kiwi but the ecology of the forest in general with other birdlife flourishing and species such as kohekohe (*Dysoxylum spectabile*) developing lush foliage and showing prolific masting and understory growth (personal observation). This has lead to the OKT to shift from being species based in its direction to more of a holistic approach and as such opened the door to the possibility of Otanewainuku being once again suitable to sustain a healthy population of North Island Kokako *(Callaeas cinerea wilsoni*, Nationally Endangered); as such these aspects have been included in the trusts 2008-2010 Operational Plan (OKT, 2008).

1.4 Pest Control History

A complete history of coordinated possum control in the Otanewainuku Conservation Area is given in Table 1, including methods used and possum abundances pre and post control expressed as percentage Residual Trap Catch Indices (RTCI). Initial Department of Conservation (DoC) efforts incorporated the entire North Block (Appendix A) however the terrain meant that coverage in the northern most portion was sparse; in addition the 1997 operation did not include the Mountain Block (Appendix A). Since control in 1997 and 1999 employed varying control methods RTCI were carried out independently of each other in the varying control areas, to enable these results to be analysed in the context of the Conservation Area as a whole; the mean of these RTCI scores was calculated weighted to the proportion of the area sampled. No RTCI were carried out prior to control in 1999 and 2006, the figure given for 1999 is an estimation based around possum recovery rated following previous control. The pre-control RTCI estimation for 2006 is based around the observations of experienced Department of Conservation Biodiversity Rangers with extensive knowledge of pest impacts on indigenous forest locally and nationally (D. Wills, March 2009, pers. comm.). Since the Otanewainuku Kiwi Trust (OKT) have administered pest control it has been based around an approximately 900 hectare area of control lines (Appendix A).

TABLE 1: OTANEWAINUKU CONSERVATION AREA POSSUM CONTROL HISTORY.

Otanewainuku Conservation Area Possum Control History				
Year	Organisation	Method	Pre-control RTCI	Post-control RTCI
1994/1995	DoC	Trapping / Cyanide	36%	6%
1997	Doc	Nth Block: 1080 in baitstations Sth Block: Trapping / Cholecaliferol	30.14%	6.73%
1999	DoC	Nth & Sth Block: Brodificum in baitstations Mountain Block: 1080 in baitstations	*30%**	21.41%
2006	OKT	OKT control area: 1080 in 150x150m baitstation network	*45%**	5.30%
2007	OKT	OKT control area: Cholecalciferol in 150x150m baitstation network	15.60%	8.10%
2008	OKT	OKT control area: Cholecalciferol in bags at 25m spacings on 150m spaced control lines	9.90%	1.66%
**estimation based on experienced qualatative observation*				

1.5 Monitoring

The Ministry for the Environment ([MftE], 2007) recognised that one of the biggest issues with regard to the protection of our indigenous biodiversity is a lack of quality information. The key to addressing this issue is recognising sound indicators of ecological health and developing monitoring packages which are spatially comparable and temporally repeatable. The importance of quality continuous local objective observation cannot be underestimated or substituted when assessing ecological health. However if measurements of change over time or indications of performance are required for an organisation to judge achievement or to justify resources allocated by external parties; then robust quantitative monitoring is required (Jongman *et al*., 1987).

Residual Trap Catch Indices (RTCI) is a results monitoring method to assess relative abundances and pest control performances for possums (*Trichosurus vulpecula*). As introduced mammals particularly ship rats (*Rattus rattus*) and possums are the biggest threat to New Zealand's indigenous terrestrial biodiversity (MftE, 2007), the majority of resource allocations for New Zealand indigenous forest management are directed at controlling these species; as such some form of quantifiable monitoring is vital. While alternative monitoring methods exist, primarily the wax block method (Hanford, 2000), RTCI is the nationally recognised protocol and utilised historically in this and surrounding management projects; enabling comparison both spatially and temporally.

The wax block method utilises scented and flavoured wax block which attract possums and rodents to bite them but not being palatable they will not consume them. This method has the advantage of monitoring both possums and rodents simultaneously, is cheaper and requires less operator skill. However there are concerns about the ability to accurately identify some bite marks and the possibility that one animal may bite multiple blocks; consequently this method is not yet nationally recognised or frequently used.

RTCI provide the ability to monitor the success of control operations and set targets; many historical projects have displayed that indices for both possums and rats below 5% can result in a marked increase in both canopy and avian health (Allen, Rodgers and Stewart, 2002 and Boulton, Richard and Armstrong, 2008). Often targets such as these are set as requirements for the reintroduction of endangered species or for attaining project support, in these situations it is important that prescribed protocols are adhered to; this is particularly relevant to the work of the Otanewainuku Kiwi Trust.

Whilst RTCI provides a way of monitoring the success of control operations the reason for these operations is to improve ecosystem health and as such this is requires to be monitored to ensure the true objectives of any project are being met; this is referred to as outcome monitoring. Foliar Browse Index (FBI) provides a way of monitoring changes in canopy condition induced by possum browse by observing percentage of canopy cover, dieback and evidence of possum browse and stem use; of possum palatable indicator tree species (Payton *et al.*, 1999).

A variety of methods have been utilised in assessing forest canopy condition involving either scoring from the ground (as in FBI) or a variety of remote sensing technologies. In addition to FBI, ground scoring techniques include Point Height Intercepts, Photopoints and Hemispherical Photography. Point Height Intercepts can be time consuming do not specifically target possum palatable species or identify specifically possum damage, and it is difficult to repeatedly sample the same point. Photopoints provide a good visual record of change over time but no quantitative or specific browsing data (Beadel, 1987), they are also dependant on photos being taken at the same time of year, in similar light conditions with equipment producing identical exposure, quality, contrast and tint; changes in understory can also obscure the picture position. Hemispherical Photography is an accurate method of assessing canopy cover and light penetration (Lasko, 1980), but requires specialised equipment and analysis software, damage caused by browse cannot be identified and the equipment must be relocated precisely.

Recent times have seen great advances in the use of remote sensing technologies with aerial photography, airborne video and satellite imaging being used to assess forest canopy condition. These methods tend to lend themselves to large and difficult to access areas, due to the complexity and expense and in many cases need to be combined with ground surveys to calibrate the imagery. (Payton *et al.*, 1999)

Foliar Browse Index is dependent on the presence of sufficient possum palatable tree species so statistical inference can be derived of the quantitative data. Finding adequate quantities of observable ideal indicator species in logged and heavily browsed forest can be difficult as can observing the canopy of taller indictors (e.g. tawa (*Beilschmiedia tawa*)), yet sub-canopy trees are undesirable indicators; as possums prefer foliage exposed to direct sunlight. Despite these issues FBI's ability to provide repeatable quantitative data observing specifically the impacts of possum browse; have made it the most widely nationally recognised method of monitoring the effects of possums on forest canopy condition. An abundance of suitable indicator species such as kohekohe (*Dysoxylum spectabile*) and historic data originating and repeated since 1994 have resulted in a robust Foliar Browse dataset from the Otanewainuku Conservation Area.

1.6 Electronic Supplement

Hard copies of this report supplied to Western Bay of Plenty District Council (WBoPDC), Department of Conservation (DoC), Otanewainuku Kiwi Trust and any other agency as requested by WBoPDC will include a supplementary compact disc containing files of:

- This report in Microsoft Word 2007 and PDF formats
- Historic pest control and Foliar Browse Index data in Microsoft Excel 2007 format
- Transect and plot location data as provided in Appendix B in Microsoft Excel 2007 format
- Transect and plot spatial data as provided in Appendix B in ESRI shapefile format

2 Methodology

2.1 Foliar Browse Index Transect Establishment and Historic Re-measure

A map showing the Otanewainuku Conservation Area and the location of monitoring transects and plot locations for transects 3 – 8 is given in Appendix A and a table with transect and plot locations and bearings is given in Appendix B. The first five FBI transects (Transects1 – 5, Appendix A and B) were established in a non-random fashion, in August 1994 by Greg Corbett: a then Bay of Plenty Polytechnic student (Corbett, 1994). These transects were subsequently re-measured in September 1996 and 1998. In an effort to increase sample size and statistical robustness an additional 3 transects were established (Transects 6 – 8, Appendix A and B) were established in August/September of 2000; these were placed randomly but with bearings which avoided existing lines, roads and the area boundaries (Williams, 2000). In August 2003 transects 1, 3, 4, 6, 7 and 8 were re-measured. Transects are marked with orange marker triangles with start points and plots marked with red and white triangles overlaid in a star pattern.

Four suitable indicator species were identified as present within the study area, kohekohe (*Dysoxylum spectabile*), Mahoe (*Melicytus ramiflorus*), pate (*Schefflera digitata*) and kamahi (*Weinnmania racemosa*). Kohekohe is an ideal indicator as it is an easily observed possum palatable canopy species (possums prefer foliage exposed to direct sunlight) and found in high numbers in the study area, kamahi is also a canopy species but its low representation in the study area makes it difficult to attain the ideal sample size of n≥50. Mahoe and pate tend to be sub-canopy species and whilst palatable to possums the lack of direct exposure to sunlight makes them less suitable as indicators as the canopy species. At each plot site an example with an easily observed canopy of each indicator species (>5 cm dbh (diameter breast height = 1.35 m above ground level)), where present within a 20 m radius; is located and tagged with a sequentially numbered phenology tag, so as to enable it to be identified for subsequent re-measures.

All transects were established and re-measured utilising the Landcare Research developed Foliar Browse Index protocol (Payton *et al.,* 1999), however some discrepancies have occurred when implementing this protocol. Firstly in accordance with the protocol all indicator trees must be >5cm dbh, many tagged trees were below this and these were subsequently removed from the sample as part of the 2003 re-measure; significantly reducing the sample size. The addition of three transects in 2000 combined with attempts to add indicator trees where ones had been removed helped restore the sample size for the abundant kohekohe; but numbers remain inadequate for the other indicator species. The second discrepancy is an oversight which frequently occurs in the application of the FBI protocol, this being the belief that each tagged tree of a species has a value of one (1) when calculating the sample size (n). However when more than one (1) tree of a species is tagged on a plot the mean of the measured values is taken for the plot and hence the sample size is calculated as the number of plots where an indicator of that species is present. As many of the indicator species tagged for this survey are found clumped together on plots, it serves to again reduce the sample size, but since this aspect of the protocol is overlooked by many operations it was decided to disregard this discrepancy. Despite these two discrepancies the repeated long term surveying on the study area with the inclusion of a quality indicator such as kohekohe in significant numbers have resulted in a robust and valuable dataset.

2.2 Foliar Browse Index Re-measure and Analysis: 2009

To enable the impact of possum browse on forest canopy recovery or decline to be understood the Foliar Browse Index (FBI) transects were re-measured in accordance with Payton *et al.,* (1999). At each plot tagged trees are identified and assessed for a percentage canopy cover score and non-parametric interval class scoring for dieback (for the upper third and whole of the tree), possum browse (for the upper third and whole of the tree) and possum stem use (Table 2). Where possible new indicator trees with an easily observed canopy, within a 20 m radius of the plot centre; are tagged with a sequentially numbered phenology tag; so as to replace trees lost to mortality and discrepancies in earlier samples. The species, tag number and dbh are recorded along with the canopy cover and class scores.

As transects 1 and 2 do not lie within the area controlled for possums by the Otanewainuku Kiwi Trust (OKT) they were considered to lie in a separate stratum and were not re-measured in 2009 nor was the historic data from these transects utilised for data analysis as pest control has always been less intensive in the area where these transects lie. In February 2009 transects 2 – 8 were re-measured and where possible additional indicator trees added to the sample (8 mahoe, 8 pate and 6 kamahi). New and historic data was collated on a common spreadsheet to be included as an electronic supplement to this report and data analysed in accordance with (Payton *et al.,* 1999).

TABLE 2: FOLIAR BROWSE INDEX INTERVAL SCORES.

Dieback		
0	No dieback	Affecting <5% of the canopy
1	Light	Affecting 5-25% of the canopy
2	Moderate	Affecting 26-50% of the canopy
3	Heavy	Affecting 51-75% of the canopy
4	Severe	Affecting >75% of the canopy
X	Unable to estimate	
Browse		
0	Nil	No possum browsed leaves
0.5	Some	<5% possum browsed leaves
1	Light	5-25% possum browsed leaves
2	Moderate	26-50% possum browsed leaves
3	Heavy	51-75% possum browsed leaves
4	Severe	>75% possum browsed leaves
X	Unable to estimate	
Stem Use		
0	Nil	No scratching or bite marks on trunk
1	Light	Occasional scratching or bite marks
2	Moderate	Numerous clearly defined scratches and bite marks
3	Heavy	Bark worn smooth, evidence of a well developed possum run
X	Unable to estimate	Trunk obscured my moss or epiphytes

3 Results

3.1 Kohekohe

The removal of kohekohe indicator trees from the data set due to lines being outside the control stratum and inappropriate trees has resulted in the sample size (Table 3) being significantly reduced below the ideal n≥50 up to 1998. However the addition three (3) FBI transects in 2000 has seen the sample size adequately restored. When comparing mean canopy cover data for kohekohe against possum abundances (Figure 1), it can be observed that canopy cover remains consistently in the 60-70 percent range during periods where possum control is occurring (1994-1999 and 2006-2008). Over the period from 2000-2005 when no control occurred and possum abundances rose to an estimated 45 percent a significant decline ($p<0.01$) in mean canopy cover was observed down to 35 percent.

TABLE 3: KOHEKOHE FBI SAMPLE SIZE.

year	1994	1996	1998	2000	2003	2009
n	26	26	26	62	53	56

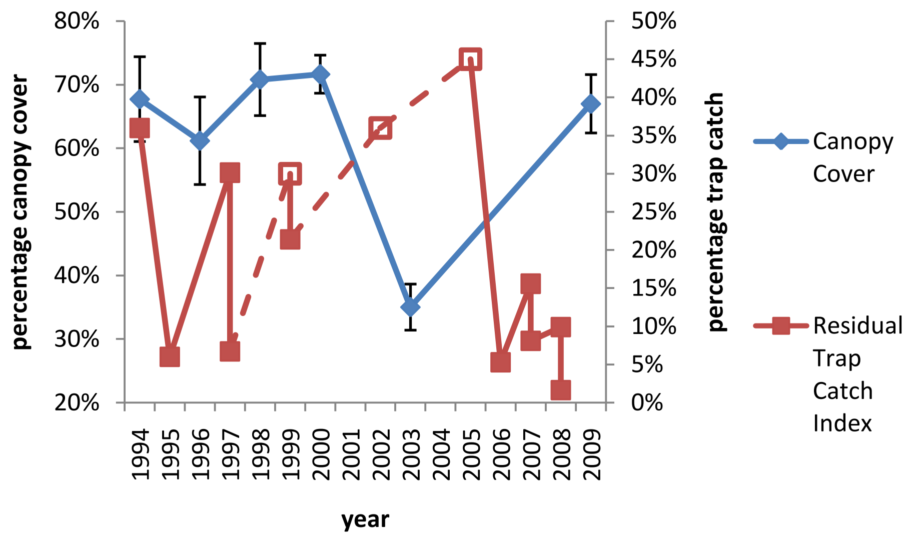

FIGURE 1: KOHEKOHE MEAN CANOPY COVER / POSSUM ABUNDANCE COMPARISON (ERROR BARS = 95% C.I.).

Mean possum stem use on kohekohe (Figure 2) has always been recorded as light with the exception of in 1996 where it was moderate but seems to display little relationship to possum densities, though an overall decline has been observed over time. Possum browse on kohekoke (Figure 3) displays a clear relationship with possum abundance changes with pest control. Light to moderate browse was initially observed in 1994 when control was initiated progressively declining to negligible levels in 2000. The cease of control saw browse climb back to light to moderate levels with the increase in possum abundance, then dropping again to negligible levels as possum abundances decrease dramatically by 2008.

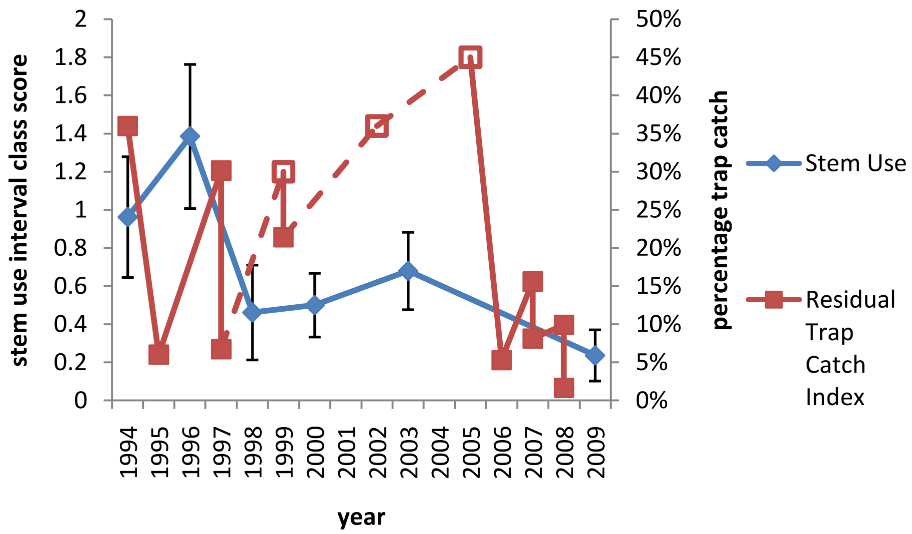

FIGURE 2: KOHEKOHE POSSUM STEM USE / POSSUM ABUNDANCE COMPARISON (ERROR BARS = 95% C.I.).

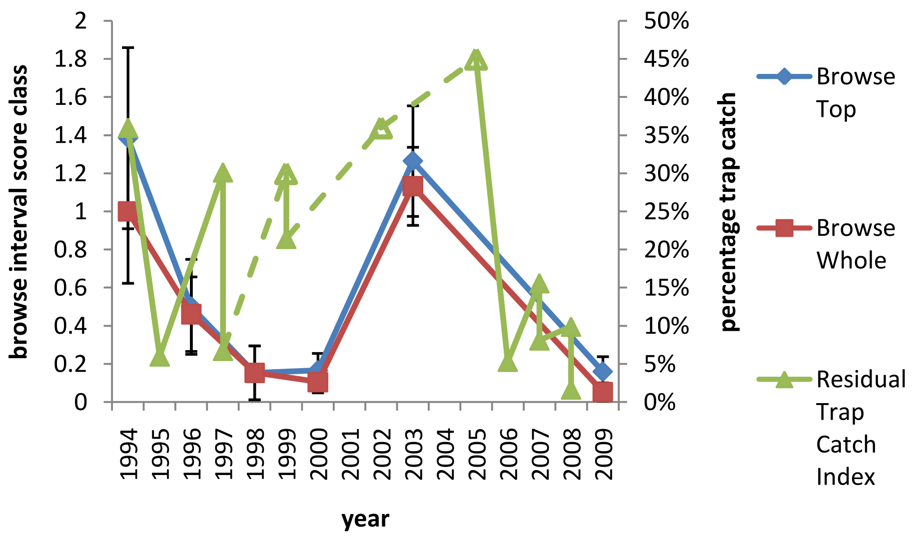

FIGURE 3: KOHEKOHE POSSUM BROWSE (TOP THIRD AND WHOLE OF TREE) / POSSUM ABUNDANCE COMPARISON (ERROR BARS = 95% C.I.).

Mean dieback levels for kohkohe (Figure 4) have remained relatively constant at light to moderate over the sample years and display no trends consistent with changes in possum abundance.

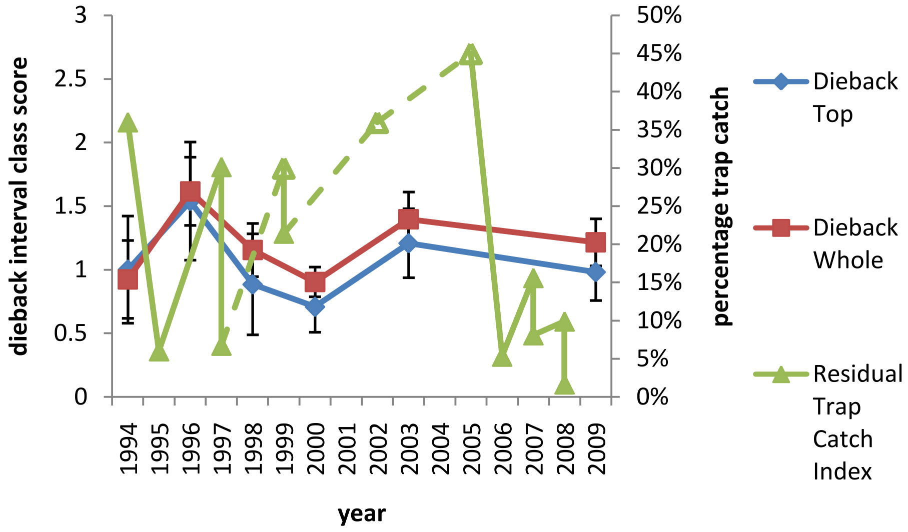

FIGURE 4: KOHEKOHE DIEBACK (TOP THIRD AND WHOLE OF TREE) / POSSUM ABUNDANCE COMPARISON (ERROR BARS = 95% C.I.).

3.2 Mahoe

The removal of mahoe indicator trees from the data set due to lines being outside the control stratum and inappropriate trees has resulted in the sample size (Table 4) being significantly reduced below the ideal n≥50 across all years. The addition three (3) FBI transects in 2000 and addition indicator trees in 2009 has seen the sample size increase more statistically significant levels (≥30) though still less than the 50 recommended by Payton *et al.*, 1999. When comparing mean canopy cover data for mahoe against possum abundances (Figure 5), it can be observed that canopy cover remains consistently in the 55-65 percent range during periods where possum control is occurring (1994-1999 and 2006-2008). Over the period from 2000-2005 when no control occurred and possum abundances rose to an estimated 45 percent a significant decline (p<0.01) in mean canopy cover was observed down to 28 percent.

TABLE 4: MAHOE FBI SAMPLE SIZE.

year	1994	1996	1998	2000	2003	2009
n	22	22	23	31	25	38

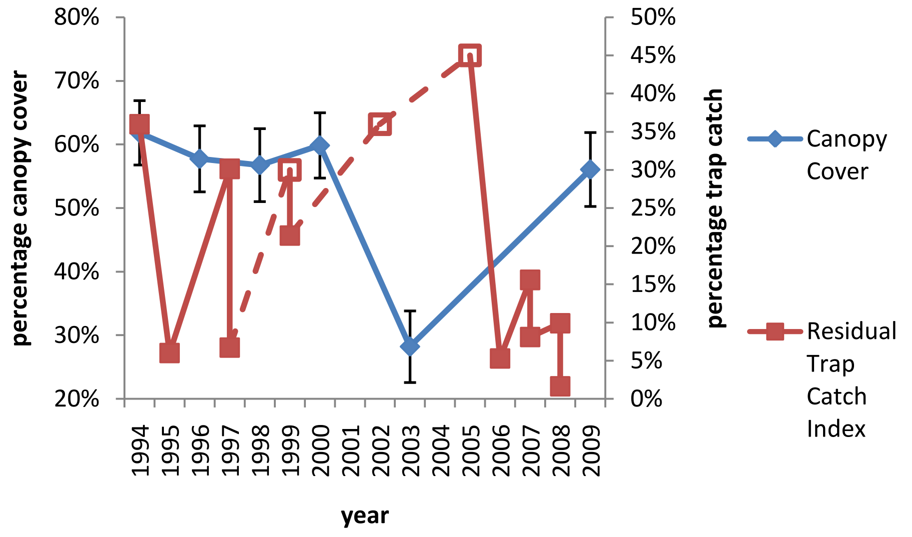

FIGURE 5: MAHOE CANOPY COVER / POSSUM ABUNDANCE COMPARISON (ERROR BARS = 95% C.I.).

Mean possum stem use on mahoe (Figure 6) has always been recorded as light with the exception of in 1996 where it was moderate but seems to display little relationship to possum densities, though an overall decline has been observed over time. Possum browse on mahoe (Figure 7) displays little relationship with possum abundance changes with pest control. Light browse was initially observed in 1994 when control was initiated progressively declining to negligible levels in 2000 where it remained with only light fluctuation until 2009.

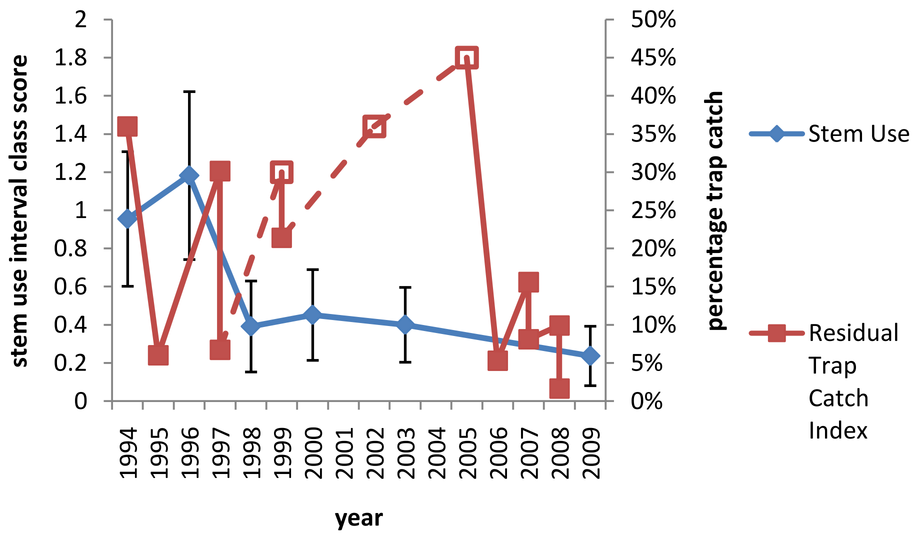

FIGURE 6: MAHOE POSSUM STEM USE / POSSUM ABUNDANCE COMPARISON (ERROR BARS = 95% C.I.).

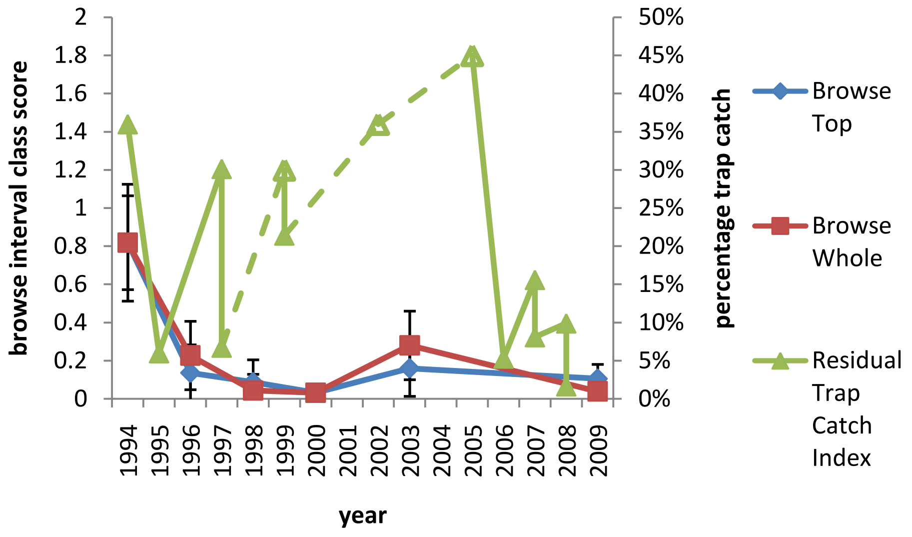

FIGURE 7: MAHOE POSSUM BROWSE (TOP THIRD AND WHOLE OF TREE) / POSSUM ABUNDANCE COMPARISON (ERROR BARS = 95% C.I.).

Mean dieback levels for mahoe (Figure 8) have remained relatively constant at light to moderate over the sample years and display no trends consistent with changes in possum abundance.

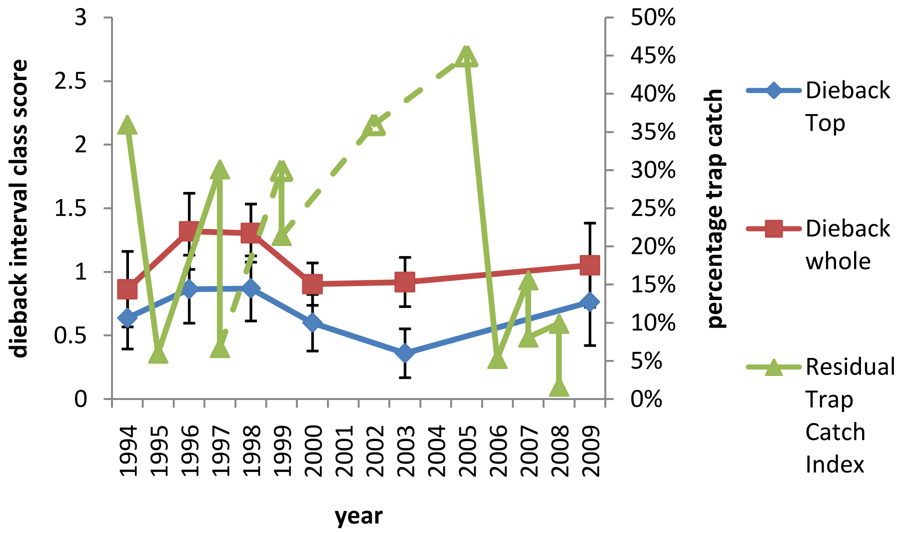

FIGURE 8: MAHOE DIEBACK (TOP THIRD AND WHOLE OF TREE) / POSSUM ABUNDANCE COMPARISON (ERROR BARS = 95% C.I.).

3.3 Pate

The removal of pate indicator trees from the data set due to lines being outside the control stratum and inappropriate trees has resulted in the sample size (Table 5) being significantly reduced below the ideal n≥50 across all years. The addition three (3) FBI transects in 2000 and addition indicator trees in 2009 has seen the sample size increase more statistically significant levels (≥30) though still less than the 50 recommended by Payton *et al.,* 1999; this was further exacerbated by high mortality. When comparing mean canopy cover data for pate against possum abundances (Figure 9), it can be observed that canopy cover fluctuates over the sample years with varying significance (p<0.05-0.01). Mean canopy cover is observed to be significantly lower (p<0.01) at 29 percent than any other year in 2003, which corresponds with the sharp peak in possum abundance over the period from 2000-2005 when no control occurred and possum abundances rose to an estimated 45 percent. The highest mean canopy cover score occurred in 2009 with 55 percent which was significantly greater (p<0.05) than all years except 2000; this also corresponds with the low RTCI score of 1.6 percent in 2008.

TABLE 5: PATE FBI SAMPLE SIZE.

year	1994	1996	1998	2000	2003	2009
n	18	18	18	38	31	30

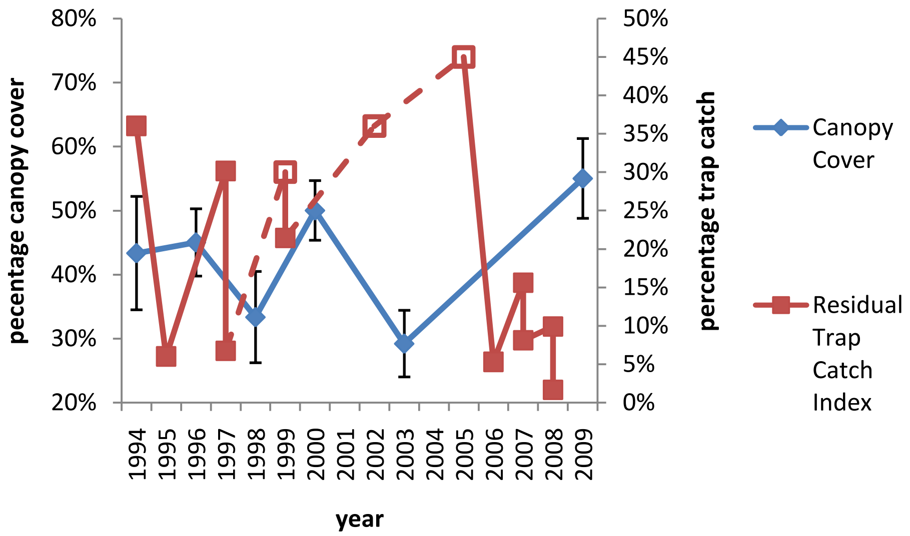

FIGURE 9: PATE CANOPY COVER / POSSUM ABUNDANCE COMPARISON (ERROR BARS = 95% C.I.).

Mean possum stem use on pate (Figure 10) has always been recorded as light but seems to display little relationship to possum densities, though an overall decline has been observed over time. Possum browse on pate (Figure 11) displays little relationship with possum abundance changes with pest control. Light to moderate browse was initially observed in 1994 when control was initiated progressively declining to negligible levels in 2000 where it remained with only light fluctuation until 2009.

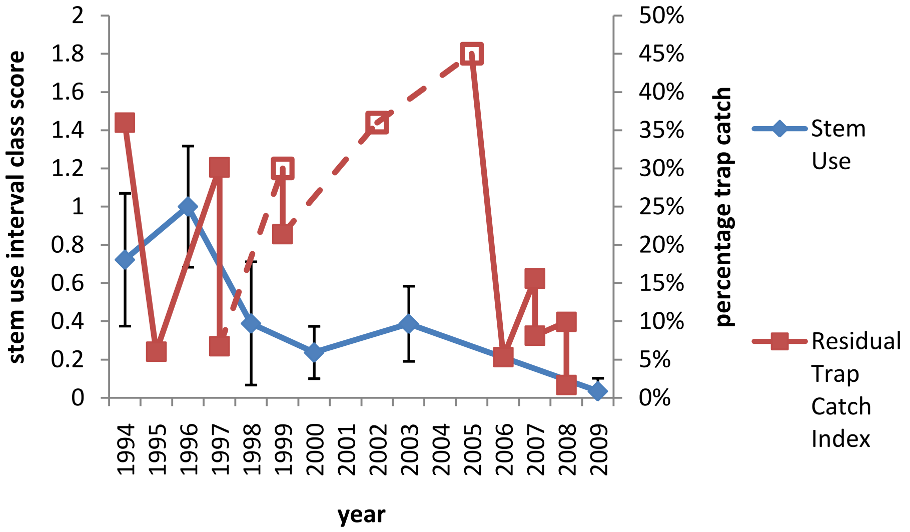

FIGURE 10: PATE POSSUM STEM USE / POSSUM ABUNDANCE COMPARISON (ERROR BARS = 95% C.I.).

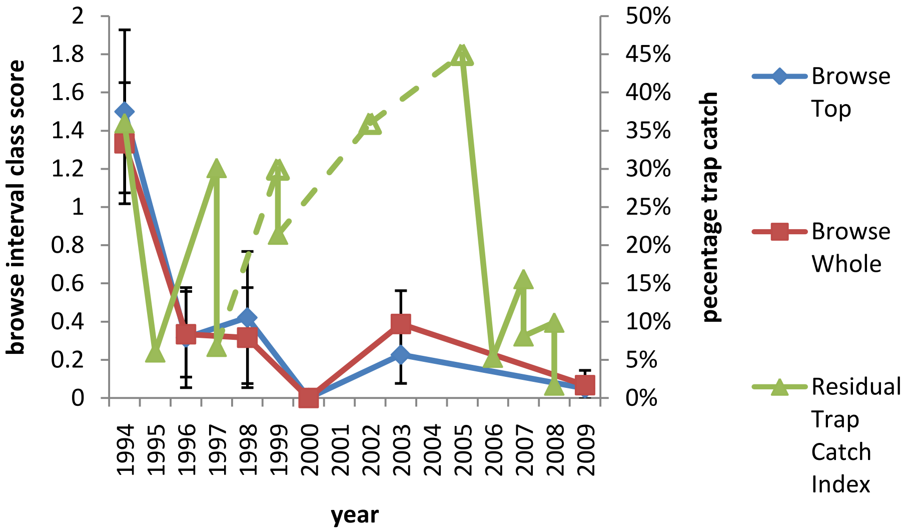

FIGURE 11: PATE POSSUM BROWSE (TOP THIRD AND WHOLE OF TREE) / POSSUM ABUNDANCE COMPARISON (ERROR BARS = 95% C.I.).

Mean dieback levels for pate (Figure 12) have remained relatively constant at light to moderate over the sample years and display no trends consistent with changes in possum abundance.

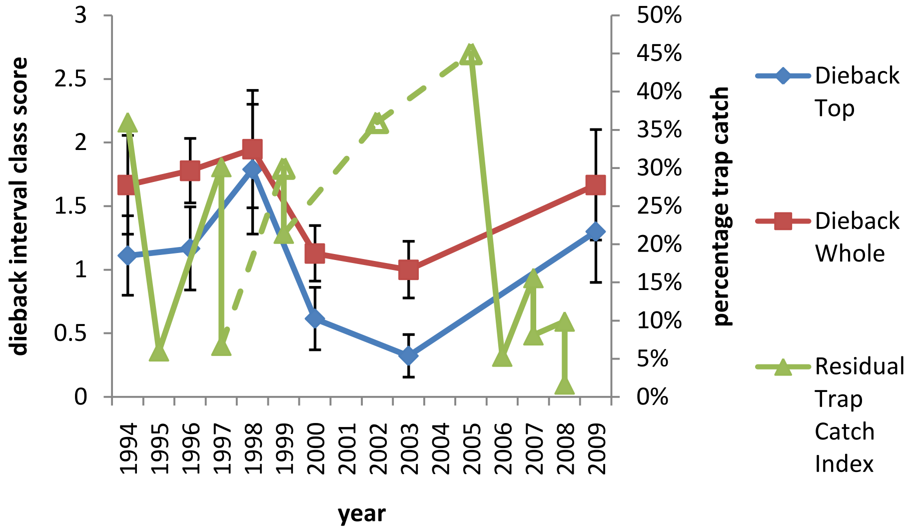

FIGURE 12: PATE DIEBACK (TOP THIRD AND WHOLE OF TREE) / POSSUM ABUNDANCE COMPARISON (ERROR BARS = 95% C.I.).

3.4 Kamahi

The removal of kamahi indicator trees from the data set due to lines being outside the control stratum and inappropriate trees has resulted in the sample size (Table 6) being significantly reduced below the ideal n≥50 across all years. The addition three (3) FBI transects in 2000 and addition indicator trees in 2009 has seen the sample size increase though still considerably less than the 50 recommended by Payton *et al.,* 1999. When comparing mean canopy cover data for kamahi against possum abundances (Figure 13), it can be observed that canopy cover remains consistently in the 50-60 percent range during periods where possum control is occurring (1994-1999 and 2006-2008). Over the period from 2000-2005 when no control occurred and possum abundances rose to an estimated 45 percent a significant decline ($p<0.01$) in mean canopy cover was observed down to 14 percent.

TABLE 6: KAMAHI FBI SAMPLE SIZE.

year	1994	1996	1998	2000	2003	2009
n	16	16	16	19	10	22

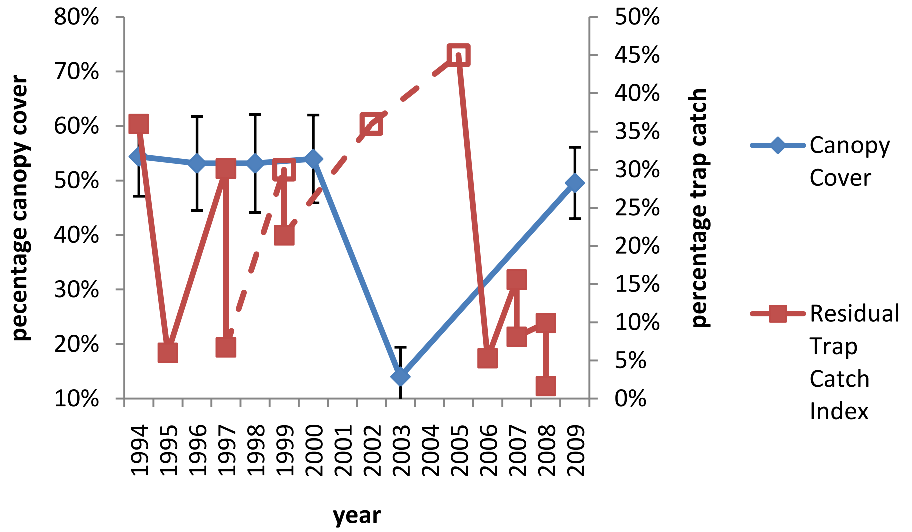

FIGURE 13: KAMAHI CANOPY COVER / POSSUM ABUNDANCE COMPARISON (ERROR BARS = 95% C.I.).

Mean possum stem use on kamahi (Figure 14) has was initially recorded as light to moderate in 1994-1996 but seems to display little relationship to possum densities, though an overall decline has been observed over time. Possum browse on kamahi (Figure 15) displays a clear relationship with possum abundance changes with pest control. Light to moderate browse was initially observed in 1994 when control was initiated progressively declining to negligible levels in 2000. The cease of control saw browse climb back to light to moderate levels with the increase in possum abundance, then dropping again to negligible levels as possum abundances decrease dramatically by 2008.

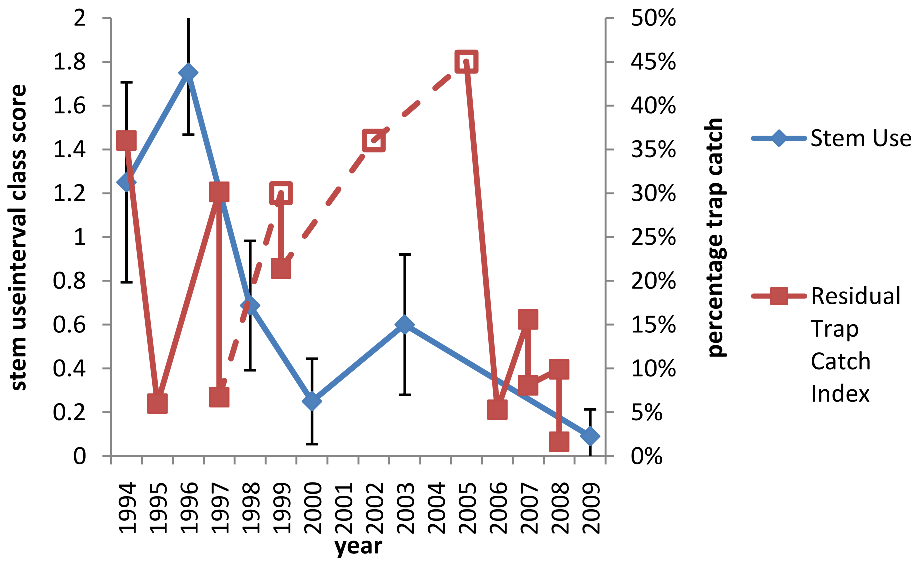

FIGURE 14: KAMAHI POSSUM STEM USE / POSSUM ABUNDANCE COMPARISON (ERROR BARS = 95% C.I.).

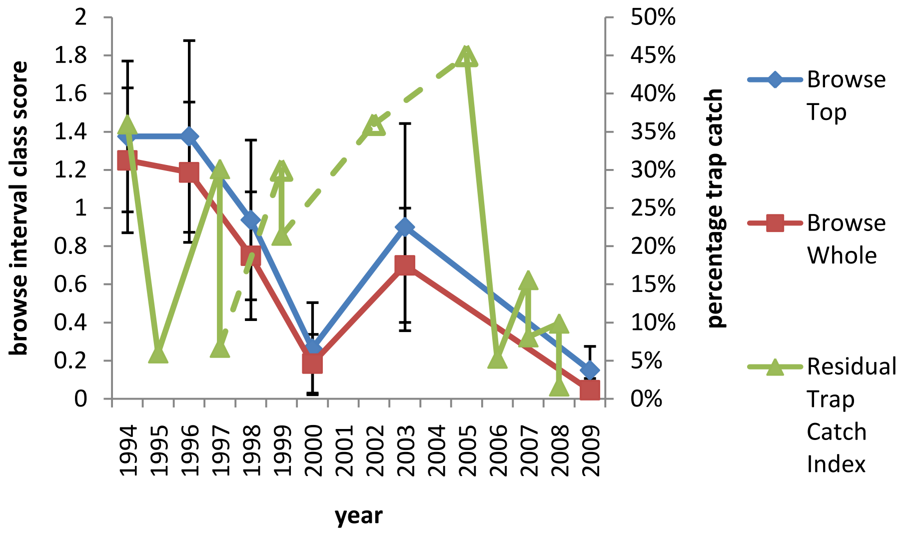

FIGURE 15: KAMAHI POSSUM BROWSE (TOP THIRD AND WHOLE OF TREE) / POSSUM ABUNDANCE COMPARISON (ERROR BARS = 95% C.I.).

Mean dieback levels for kamahi (Figure 16) have remained relatively constant at light to moderate over the sample years and display no trends consistent with changes in possum abundance.

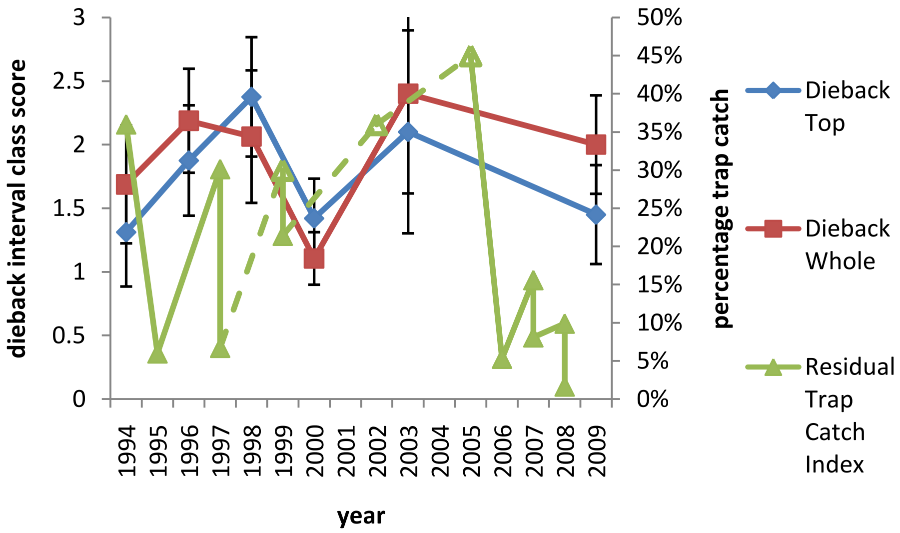

FIGURE 16: KAMAHI DIEBACK (TOP THIRD AND WHOLE OF TREE) / POSSUM ABUNDANCE COMPARISON (ERROR BARS = 95% C.I.).

3.5 Mortality

The rate of mortality of tagged indicator trees during sample periods from 1998-2009 is given in Figure 17, with attrition divided into those trees felled by windfall directly or indirectly and those found dead either as lying or still standing. Numbers are minimal for kohekohe and mahoe. The high percentage of kamahi (30%) which died in the 2003-2009 period can be largely attributed to two (2) trees felled in a more extensive windfall. High mortality rates were observed for pate with 15.8 percent of indicator trees found dead in the 2000-2003 period and 38.7 percent of those pate which remained observed as dead following the 2003-2009 period.

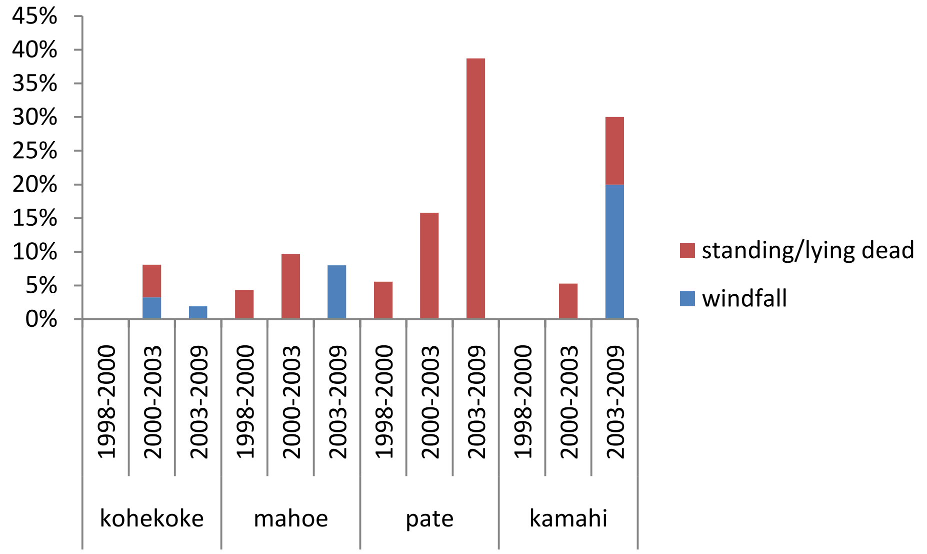

FIGURE 17: PERCENTAGE MORTALITY OF REMAINING TAGGED INICATOR TREES BY SPECIES.

4 Discussion

The relationship between canopy condition, possum abundance and pest control is clearly displayed in Figures 1, 5, 9 and 13. Early possum control efforts occurred every second year, with RTCI scores fluctuating between approximately 30 and 5 percent. At this time kamahi mean foliar cover fluctuates in the 50-60 percent range (Figure 13), slightly lower than the optimal kamahi cover of 60-70 percent observed in the Northern Te Urewera (Moorcroft *et al.,* 2005) and with scores in the 60-70 percent range kohekohe (Figure 1) displayed canopy cover akin to that observed in possum free forests (Nugent, Whitford, Innes, and Prime*,* 2002). However in the years where possum control was not performed and RTCI scores were estimated to have been in the region of 45 percent, canopy cover of all indicator species seriously declined with kamahi and kohekohe dropping to 14 and 35 percent respectively. With the reinstatement of possum control in 2006 annually to 2008 lower RTCI scores were achieved and maintained (1-15 percent) and canopy cover scores returned to the levels which were observed during prior possum control (1994-1999).

Whilst many factors other than possum browse may influence canopy cover such as climate, weather events, other browsers, disease and intensity of flowering and fruiting, it can be little doubt that the dramatic recovery observed form 2003-2009 was primarily in response to the decline in possum abundance. Initial concerns following the 2003 study were that the forest may be approaching its tipping point from which recovery would not be possible (Corson, 2003) and was described as the worst possum induced forest decline observed by the author. Fortunately this was not the case and control initiated by the Otanewainuku Kiwi Trust alleviated ecological collapse and whilst canopy cover scores of 35 percent are low for kohekohe, forests in Northland are known to have recovered from as low as 16 percent (Nugent *et.al,* 2002). While canopy cover levels have returned to those first observed, whether they will continue to improve is uncertain; though they are likely to already be close to if not already at optimum levels. Whilst many indigenous flora and fauna (e.g. mistletoe (*Tupeia Antarctica)* and kiwi) are susceptible to decline in anything above minimal possum levels (<5 percent RTCI) (Robertson, 2003, Brown, Innes and Shorten, 1993 and Sweetapple, Nugent, Whitford and Knightbridge, 2002), most forest trees seem to be able to withstand some possum presence (10-20 percent RTCI) with minimal impact (Nugent *et.al,* 2002); though this resistance would certainly vary with region and forest type.

Mean possum browse scores for all species have only ranged from moderate at the highest through to levels so low to be considered negligible (Figures 3, 7, 11 and 15). Regardless of this the relationship between canopy cover and possum abundances is supported by the observations of possum browse on both kohekohe (Figure 3) and kamahi (Figure 15), with. A consistent decline in browse observed during initial years of possum control followed by a significant increase in browse in the 5 years period (2000-2005) where control did not occur; with the resumption of control browse levels again drop. A similar pattern is seen with mahoe (Figure 7) but the increase in browse observed in 2003 cannot be considered to be statistically significant, though a clear decline is observed since the study commenced; as is the case for pate (Figure 11). The failure of pate to demonstrate any browse pattern may in part due to observer inexperience and the difficulty to observe possum browse on this species. Possum browsing on pate do not consume the leaf blades, but rather the fleshy petiole at the base resulting in a mass of litter around the browsed tree (Payton *et al.,* 1999). The fact that the variations in possum browse are most clearly observed on kohekohe and kamahi is likely indicative of possum preference for canopy trees with foliage exposed to sunlight.

Stem use patterns are consistent for all species (Figures 2, 6, 10 and 14), showing an overall decline from the studies commencement; similar to the pattern observed for mahoe and pate browse. It is unclear as to why stem use does not necessarily emulate fluctuations in canopy cover and browse. One possibility is that possum runs developed prior to the commencement of initial possum control were still evident in early sample periods, fading as possum numbers declined with control. The period where no control occurred (2000-2005) may have been too brief for well established possum runs to re-establish.

Dieback remains reasonable constant throughout the study for all indicator species (Figures 4, 8, 12 and 16) and shows no relationship with either possum abundances or canopy cover. Die back is however a natural phenomenon affecting all indicator species to varying degrees and unlike other interval classes recorded its cause cannot be positively identified as being related to possum activity.

Some concern exists over the high mortality rate observed for pate (Figure 17), the attrition of tagged indicator trees may be natural as pate have a relatively short lifespan (approximately 30 years) and trees >5cm dbh would already be reasonably mature (Cashmore, Feb 2009, pers. comm.). This may have been compounded by the inability of the species to recover from heavy browse over the 2000-2005 period or the impacts of disease or insect browse; but being a sciophytic climax species is unlikely to be a natural successional process. The main concern exists over the lack of replacement trees present with the cause of this possibly related to ungulate browse to seedlings and juveniles or consumption of fruit/seed by ungulates, possums, rats or mice.

One unusual aspect to the study to which a definitive answer cannot be found is as to why initial canopy cover results 1n 1994 were relatively healthy especially when compared to the decline observed without possum control in 2003 and why possum abundances estimated pre 2006 control were so much greater to those prior to initial control in 1994/1995. This could be due to biases in sampling, in particular variations between observers, but is unlikely as it would suggest that this failing occurred in estimation of both RTCI and Foliar Browse simultaneously despite the monitoring protocols being performed independently. It is also unlikely that a decline in canopy health as severe as observed in 2003 would fail to be recorded if present in earlier surveys.

If sampling biases are not the primary cause of discrepancies then some environmental factors have likely enabled possum abundances to increase in the absence of pest control over the 2000-2005 period, to well over those observed prior the initiation of control in 1994; this consequently resulted in a serious decline in forest canopy condition. If such high possum abundances are still present in surrounding forest outside the control area, then the consequences for forest health in those areas could be serious, in addition to continuing to place excess stress on the study site through an increased possum re-invasion threat.

Ogden and Buddenhagen (1995) describe kohekohe as the “critical indicator” of the health of conifer-angiosperm forests of the northern North Island. Given the results observed for kohekohe and the other indicator species in this study it is undoubted that the pest control activities initiated by the Department of Conservation and continued by the Otanewainuku Kiwi Trust are pivotal to sustaining the vitality and ongoing future health of the nationaly significant Otanewainuku Conservation Area. Whilst maintaining very low possum abundances (<5 percent RTCI) may be necessary for the Otanewainuku Kiwi Trusts species based recovery efforts (e.g. kiwi and kokako), this study demonstrates the importance of possum control, though not necessarily as intense (<10 percent RTCI), to meeting the trusts objective of supporting forest health in a holistic manner. This study has also demonstrated that by combing regular Foliar Browse monitoring, particularly of kohekohe, with records of possum abundance; a robust quantitative indication of overall forest health can be observed. Given concerns over the decline of such species as pate it may also be necessary to investigate ways to monitor the interactions between other pest species and suitable forest indicators.

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5 Recommendations

- Foliar Browse Index lines should continue to be re-measured within the control area of the Otanewainuku Conservation Area at least every two (2) years.
- Records of Otanewainuku Conservation Area possum abundances should continue to be kept in a common database with Foliar Browse Index results.
- Managers of surrounding forests areas should be encouraged to establish Foliar Browse Index lines adjacent to the Otanewainuku Conservation Area (may include the two (2) existing lines established but omitted from this study) and monitor possum abundances.
- Ensure that sample size for kohekohe be maintained at $n \geq 50$ and attempts be made to increase the sample sizes of other indicator species to $n \geq 50$, including if necessary establishing additional plots to existing transects or establishing a new transect.
- Continue to observe pate mortality and recruitment to better understand species health.
- Investigate potential results and outcome monitoring options to better understand the impacts of other pest species on forest health.
- Better publicise the success and importance that the Otanewainuku Kiwi Trusts non-species specific efforts have in sustaining this nationally important ecosystem type.

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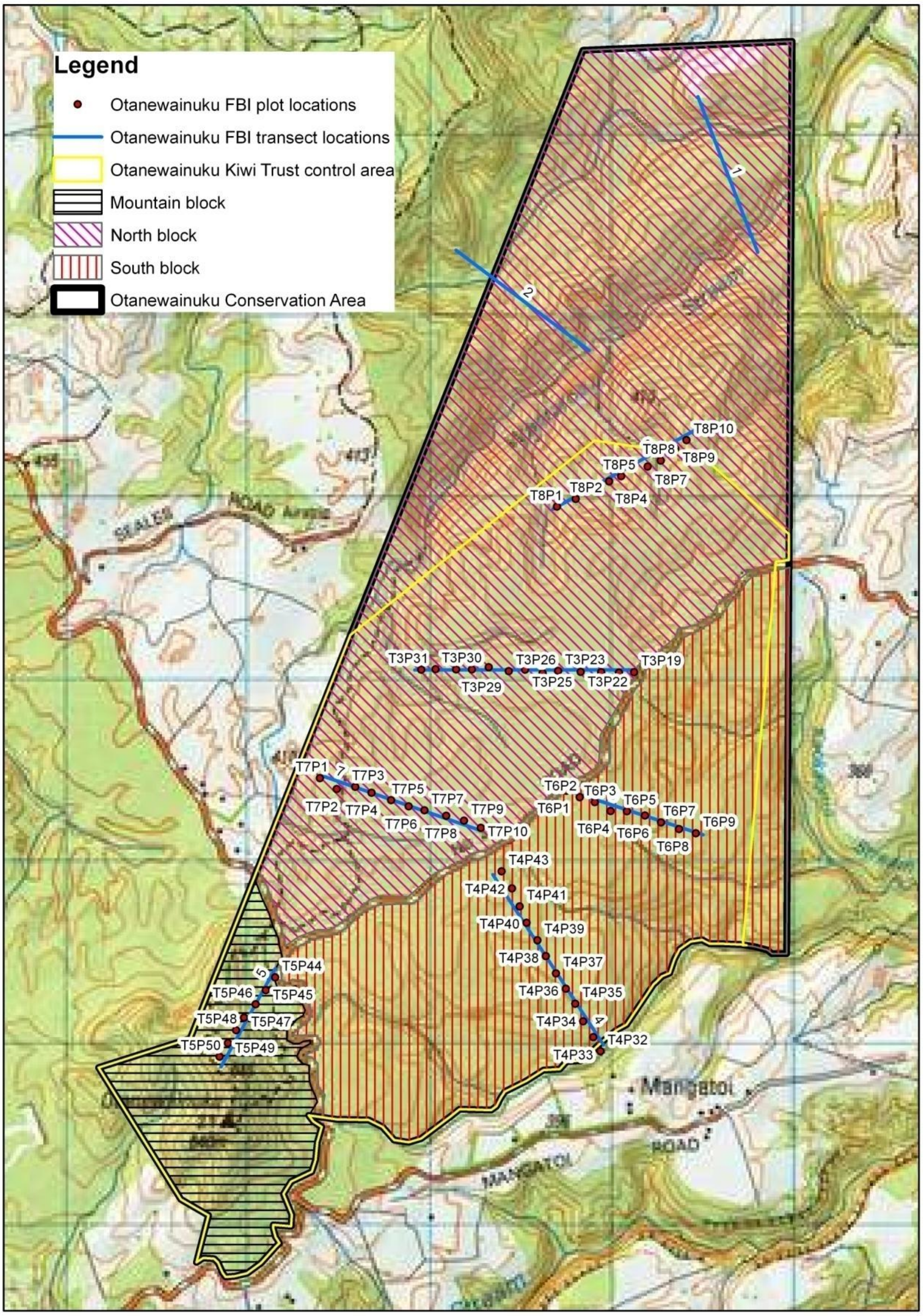
Appendices

Appendix A: Otanewainuku Conservation Area Map



Appendix B: Foliar Browse Transect and Plot Locations

Otanewainuku Conservation Area Foliar Browse Index Transect and Plot Locations													
Transect	Start Point (NZMG)		Bearing	Plot	Plot Location (NZMG)		Transect	Start Point (NZMG)		Bearing	Plot	Plot Location (NZMG)	
	Eastings	Northings	(°mag)		Eastings	Northings		Eastings	Northings	(°mag)		Eastings	Northings
1	2794500	6367200	137°				5	2792168	6362341	186°	T5P44	2792168	6362341
2	2793900	6365800	285°								T5P45	2792117	6362269
3	2794148	6364025	247°	T3P19	2794148	6364025					T5P46	2792060	6362192
				T3P20	2794065	6364022					T5P47	2791997	6362119
				T3P21	2793967	6364024					T5P48	2791952	6362048
				T3P22	2793853	6364026					T5P49	2791908	6361978
				T3P23	2793730	6364031					T5P50	2791862	6361903
				T3P24	2793644	6364019	6	2793776	6363370	85°	T6P1	2793776	6363370
				T3P25	2793548	6364039					T6P2	2793848	6363334
				T3P26	2793457	6364030					T6P3	2793931	6363307
				T3P27	2793347	6364051					T6P4	2794019	6363258
				T3P28	2793254	6364040					T6P5	2794109	6363257
				T3P29	2793167	6364039					T6P6	2794208	6363234
				T3P30	2793053	6364041					T6P7	2794297	6363195
				T3P31	2792975	6364038					T6P8	2794397	6363159
4	2793963	6361932	304°	T4P32	2793963	6361932					T6P9	2794489	6363135
				T4P33	2793924	6362010	7	2792416	6363440	86°	T7P1	2792416	6363440
				T4P34	2793868	6362097					T7P2	2792508	6363379
				T4P35	2793824	6362195					T7P3	2792611	6363392
				T4P36	2793772	6362278					T7P4	2792700	6363359
				T4P37	2793718	6362363					T7P5	2792807	6363317
				T4P38	2793662	6362457					T7P6	2792905	6363283
				T4P39	2793615	6362544					T7P7	2792992	6363262
				T4P40	2793556	6362642					T7P8	2793112	6363232
				T4P41	2793517	6362732					T7P9	2793210	6363205
				T4P42	2793475	6362831					T7P10	2793303	6363165
				T4P43	2793418	6362925	8	2793723	6364937	38°	T8P1	2793723	6364937
											T8P2	2793827	6364980
											T8P4	2794011	6365078
											T8P5	2794078	6365106
											T8P7	2794223	6365159
											T8P8	2794296	6365192
											T8P9	2794376	6365257
											T8P10	2794438	6365305

Appendix C: Bird Name Variations

Maori name	English name	Scientific name
Toutouwai	North Island robin	Petroica australis longipes
Miromiro	Tomtit	Petroica macrocephala toitoi
Piwakawaka	Fantail	Rhipidura fulginosa placabilis
Riroriro	grey warbler	Gerygone igata
Popokatea	whitehead	Mohoua albicilla
Pipiwharauroa	shining cuckoo	Chrysococcyx lucidus
Koekoea	longtailed cuckoo	Eudynamys taitensis
Korimako	bellbird	Anthornis melanura
tui		Prosthemadara novaeseelandiae
kereru	wood pigeon	Hemiphaga novaeseelandiae
kaka	North Island kaka	Nestor meridionalis septentrionalis
karearea	New Zealand falcon	Falco novaeseelandiae
kokako	North Island kokako / blue wattled crow	Callaeas cinerea wilsoni
kiwi	North Island brown kiwi	Apteryx australis mantelli
kahu	Australaisian harrier	Circus approximans
ruru	morepork	Ninox novaeseelandiae novaeseelandiae