Canopy Indicator Assessment: A Method for Monitoring Brushtail Possum (*Trichosurus vulpecula*) Damage to Pine Plantations

Ian J. Payton[1] & Chris Frampton[2]

[1] Landcare Research
PO Box 69, Lincoln 8152
New Zealand

[2] 377 Halkett Road
RD1, Christchurch
New Zealand

Landcare Research Contract Report: LC0203/100

PREPARED FOR:
Forest Health Research Collaborative

DATE: May 2003

Reviewed by:	Approved for release by:
	for: O.R.W. Sutherland
Gordon Hosking Hosking Forestry Rotorua	Phil Cowan Science Manager Biosecurity and Pest Management

Contents

Abstract

Brushtail possums (*Trichosurus vulpecula*) now occupy most areas within New Zealand that are suitable for plantation forestry. Possums browse the terminal shoots of pine seedlings, bite and strip the bark of young stems to get at the cambial tissue, remove needles and cones, and bend or break terminal shoots and lateral branches in the upper portion of the tree. Damage is most commonly reported from young stands. It rarely kills established trees, but can lead to reduced vigour, loss of apical dominance, and an increased incidence of fungal diseases. Where possums are suspected of damaging pine plantations forest managers need to be able to determine when control is required, which areas should have priority, whether control achieves its goals, and when further control measures will be necessary. Reliable inferences and predictions about possum damage can only be obtained from robust, quantitative data. In this manual we discuss the design of surveys to monitor possum damage in pine plantations, and describe a new method for assessing possum damage to pine trees. Canopy Indicator Assessment is a scoring method that uses ground-based assessment of individual trees to determine the nature and extent of possum damage within pine stands, and the degree to which this is reduced as a result of possum control operations. Options for analysing data are outlined.

Keywords: pine plantations, *Pinus* spp., possum damage, *Trichosurus vulpecula*, vegetation monitoring

1. Introduction

A new method for assessing possum damage to pine trees was developed by Landcare Research, Lincoln, for the Forest Health Research Collaborative. The method provides a standardised means of describing possum damage to pine trees, assessing the extent and severity of possum damage to pine plantations, and monitoring changes associated with possum control operations.

2. Background

2.1 Liberation and spread of brushtail possums

Australian brushtail possums (*Trichosurus vulpecula*) celebrated the sesquicentennial of their arrival in New Zealand in 1987. The 1837 liberation almost certainly didn't survive, and there is some doubt about the fate of the next recorded release in 1840. The first successful liberation, which is credited to a Mr C. Basstian, took place near Riverton in Southland in 1858. Nearly 150 years and over 450 liberations later few areas on the main islands of New Zealand, and even fewer that are suitable for plantation forestry, remain uncolonised (Pracy 1974; Clout & Ericksen 2000).

2.2 History of possum damage to pine plantations

Despite early recognition of the potential for possums to damage pine plantations, appreciation of the nature and extent of the damage caused by this nocturnal, arboreal folivore and its economic consequences for the timber industry was slow to develop (Clout 1977; Keber 1987). Early reports of barkstripping by brushtail possums in young plantations of *Pinus halepensis* and *P. maritima* in South Australia (Gill 1919) prompted Kirk (1920) to recommend to the New Zealand government: "opossums should not be liberated at any place from which they could spread to the plantations of the Rotorua district …", and "if they are now present in that area they should be destroyed". This despite his being "unable to find that any damage to plantations has at present been done in New Zealand".

Notwithstanding the Australian evidence, New Zealand State Forest Service reports as late as 1931 routinely contained statements to the effect that possums did not pose a threat to plantation forests, and were a valuable source of fur. Forest Service Annual Reports during the 1930s and 1940s record increasing concern at damage caused by possums to a range of pine species, including *P. ponderosa, P. palustris, P. muricata, P. nigra* var. *laricio, P. taeda,* and *P. echinata*, but it is not until the 1950s that possums are recorded as damaging *P. radiata* stands (summarised from Clout 1977).

Extensive possum damage to *P. radiata* stands was first reported from the central North Island volcanic plateau during the 1960s, as forests originally established in 1925–35 (before possums were present) were harvested, replanted, and further expanded. Localised and at times severe damage, most often to young pine stands, continued to be reported throughout the 1970s (Bathgate 1973; Clout 1977). As the 1960s' plantings matured possum damage became less of an issue (Martin 1973) and by 1980 possums were considered to be of minor importance in pine plantations and to have no significant influence on the economics of timber production (Agricultural Pests Destruction Council 1980). A sharp increase in reported possum damage in pine forests in the mid-1990s, which is also associated with young stands, suggests a pattern of intermittent damage initiated by pulses of plantation establishment or replanting (Purey-Cust & Hammond 1995; Hosking 2000).

2.3 Characteristics of possum damage to pine species

When compared to many other New Zealand habitats (e.g., podocarp/hardwood forests) possums typically occur at low densities (0.9–3.0/ha) in pine plantations (Clout 1977; Warburton 1978; Triggs 1982). This reflects the unpalatable nature of the dominant plant species and the low diversity of alternative plant foods (Efford 2000). Populations are greatest in young stands (Keber 1987), and decline as canopy closure shades out the understorey shrub layer.

Possums browse the terminal shoots of pine seedlings, bite and strip the bark of young stems to get at the cambial tissue (Clout 1977), remove needles and cones, and bend or break terminal shoots (leaders) and lateral branches in the upper portion of the tree (Fig. 1). Most damage occurs in winter and spring when alternative food sources are scarce and animals are foraging for pollen cones (McNally 1955; Harvie 1973; Warburton 1978). Damage rarely kills established trees but can lead to reduced vigour, loss of apical dominance, and an increased incidence of fungal diseases such as *Sphaeropsis sapinea* (= *Diplodia pinea*) (Gilmour 1966; Chou 1984).

2.4 Risk of possum damage to pine plantations

Not all pine species are equally attractive to possums. Australian studies (How 1968, 1972), which are borne out by New Zealand observations, rank *P. radiata* among the pine species least preferred by possums, behind species such as *P. ponderosa, P. contorta, P taeda, P. elliottii* and *P. echinata* (G. Jane in Clout 1977).

Surveys of possum damage in New Zealand radiata pine plantations (Bathgate 1973; Martin 1973; Clout 1977; Agricultural Pests Destruction Council 1980; Keber 1987; Batcheler & Cowan 1988; Jacometti et al. 1997) describe locally severe damage in young stands, which is greatest where pines have been planted near cutover native forest or adjacent to remnant native forest or scrub. Damage is patchy and includes browsing of terminal shoots (Mamaku Plateau), barkstripping (Kinleith, Kaingaroa, Eyrewell forests), leader breakage (Tauhara forest) and lateral damage (Tairua forest). Overall, reported levels of damage are low leading Clout (1977) to conclude: "Because both browsing and barkstripping are mainly problems of young stands, there is a large amount of scope for minimising losses by thinning. Only in stands where stocking is already poor because of losses from other causes is possum damage likely to have any serious impact." Clout's conclusions, while valid for the period they were written, need to be re-evaluated in the light of the marked decline in initial stocking levels over the last 2–3 decades, and the increased cost of specialised tree stocks (e.g., high GF-rated tree seedlings and/or physiologically aged cuttings) (Maclaren & Knowles 1995).

Fig. 1 Bent and broken branches in the upper crown – often the first signs of possum activity.

In addition to stand age and proximity to native vegetation, recent analysis of records from the Forest Health Database (Hosking 2000) has highlighted topography as an additional risk factor (damage over-represented in valley bottoms, gullies and riparian strips), and identified substantial regional variation in reports of possum damage (relative to the area of planted forest) over the last decade (1988–98). Risk of possum damage was highest in Bay of Plenty and Taupo forests, and low in Northland, Waikato, Auckland, Wairarapa, and most areas of the South Island.

2.5 Benefits of possum control in pine plantations

Few studies have attempted to quantify the economic losses associated with possum damage to pine forests, or to determine whether the costs of animal control are offset by the increased value of the final crop. For Tauhara forest near Taupo, Keber (1987) estimated maximum losses attributable to possums at 1–2% of the final crop value, and concluded that in most cases the costs of traditional animal control methods such as poisoning exceeded the potential benefits of control. A similar analysis by Griffiths (in Butcher 2000) showed that benefits exceeded costs where possums reduced the value of the final crop by around 15%, leading Butcher (2000) to suggest that even at 5% reduction in wood value there were significant savings to be made by reducing or eliminating animal damage.

3. Objectives

- To provide guidelines for designing surveys to monitor possum damage to pine plantations.
- To develop a standardised method of describing possum damage to the terminal leaders, lateral branches, stems and needles of pine trees.
- To outline options for data analysis of Canopy Indicator Assessment variables.

4. Designing a Survey to Monitor Possum Damage to Pine Plantations

4.1 Objectives

The design of a monitoring programme needs to be based on a clear statement of the problem that is to be investigated and the specific objectives of the study. This forms the basis for decisions about sampling strategies and design, and will help to ensure that the data you collect can be validly used to answer the questions the study was set up to examine (Green 1979; Underwood 1994). Unless you are a qualified statistician, seek competent statistical help at the outset of the study. It will pay dividends later (see Section 7).

Where a study has multiple objectives the choice of sampling strategy and design needs to be able to accommodate the requirements of each of the objectives. Similarly, where objectives change during the course of a long-term monitoring programme, it is important to ensure that any changes to the sampling strategy, design, or data collection methodology do not compromise the ability of the study to answer both the original and revised objectives.

4.2 Sampling strategies

A well-chosen sampling strategy is important because it determines the way in which your data are collected, the statistical techniques you can validly used to analyse them, and hence the questions you will be able to answer.

Your purpose of monitoring possum damage in pine plantations will usually be either to determine whether expenditure on animal control is justified, or to judge the success of a control operation. In either case you will need to determine whether the objectives of the study require an overall assessment of damage or the assessment of only damaged individuals, and whether or not the proposed sampling will form part of a longer-term monitoring programme (see Section 4.3.2). These scenarios require different sampling strategies (choice of individuals) if current and future possum impacts are to be reliably determined. Whatever sampling strategy you adopt, be sure it is clearly written down and available to everyone involved with the data collection, analysis and interpretation of the study.

4.2.1 Overall assessment of damage

To determine the extent and severity of possum damage to a whole compartment or plantation, you need to include a representative selection of the trees from throughout the study area in your monitoring programme. Unless the objectives of the study dictate otherwise this should include both dominant and suppressed individuals, and should not be biased by current tree health (e.g., insect or fungal damage) or the degree of past or present possum damage.

4.2.2 Assessment of damaged individuals

If the objectives of the study relate to the ongoing decline or recovery of possum-damaged individuals, you can target your sampling strategy towards those trees that show evidence of past or present possum damage. Note that while this sampling strategy will allow you to assess the current and future status of this population (i.e., the damaged individuals), it will not allow you to make similar statements about the status of all the trees over the whole sample area. Before adopting this type of sampling strategy think very carefully about whether it will enable you to fulfil the objectives of your study, and whether it will limit the usefulness of the data for other (e.g., comparative) studies.

4.3 Sampling design

The critical issues you need to consider when determining the sampling design for a monitoring study are the selection (stratification, random representative sample) and number (sample size) of the individuals to be monitored.

4.3.1 Stratification

Where you suspect factors such as landform, stand type (e.g., pine species, tree age), distance from the forest margin, or the patchy nature of the possum population are systematically affecting the level of possum damage, you need to stratify your sample. Stratification serves two purposes. Firstly, it enables you to make separate generalisations about different parts of the larger study area. This is appropriate when, for whatever reason, the trees being monitored differ markedly in different parts of the study area (e.g., where possum damage is largely confined to trees growing in gullies). The second purpose of stratification is to reduce sample variability, and in doing so increase the sensitivity (precision) of the estimates of damage.

Stratification involves dividing the study area into a series of units or strata based on the factor(s) thought to be influencing the variability in possum damage, and randomly selecting individuals to be monitored from within each stratum. If the primary objective of your study requires an assessment of possum damage:

- Over the whole study area, base the sample size for each stratum on the relative area of that stratum within the wider study area (e.g., the proportional area of gully sites within the forest compartment).
- For individual strata, monitor a similar, sufficiently large (see Section 4.3.3) sample in each stratum.

Where monitoring is associated with possum control operations and the strata represent control and non-control treatments, divide the sampling resources equally.

4.3.2 Representative sample

To draw valid conclusions about the extent and severity of possum damage within the area you are monitoring, you need to:

- Sample throughout the study area or stratum.
- Select the individuals to be monitored in a randon (non-biased) manner.

The individuals sampled must be representative of the total population of pine trees within the stratum or study area. If trees are selected on a non-random basis (e.g., readily accessible by being adjacent to a road or fire break) the sample will not be representative of the wider population, and cannot be used to validly estimate the actual level of damage in that population. The individuals being monitored also need to be independent, to ensure the sample is representative and to satisfy the underlying assumptions of the standard statistical tests. Where individuals are sampled non-independently (e.g., from a small area or along planting rows) they are likely to be affected by similar conditions (e.g., climatic, edaphic), and will therefore not represent the full range of variation present in the population.

Genuine random sampling is rarely practical. Because of the nature of the topography in many plantation forests, sampling is typically carried out along randomly located transects that traverse the variability (e.g., topographic, edaphic) present within the study area or stratum (Jacometti et al. 1997). Where individual strata occur as small or extremely localised habitats within the wider study area (e.g., riparian or gully sites), additional transects may need to be selected within those habitats to ensure an adequate sample size is obtained (see Section 4.3.3)

Locating transects and sample trees

For smaller pine plantations (e.g., farm woodlots) the study area will normally encompass the whole forest stand. Within larger-scale production forests the compartment/block system will usually provide logical boundaries for damage assessment surveys. Because individual forest blocks are typically comprised of trees of a single age class, provenance (e.g., GF23 rooted cuttings), and silvicultural regime, they can also be a useful means of stratifying a study area.

The following description of sampling procedures is based on methodologies described in Goulding & Lawrence (1992), and the Department of Conservation's standard operating procedure for weed control monitoring (Module 4, March 2003).

Wherever possible visit the study area before the fieldwork commences to verify the stand records and identify issues (e.g., access, topography) that may affect the field sampling. Decide on the sampling scheme to be used, in the office, before the fieldwork commences. Once the number and placement of the transects and sample points has been determined, transfer this information to the maps and/or aerial photos that will be used by the field crews. As a general rule you should aim to minimise the number of sampling decisions that need to be made by the field crew.

Systematic sampling schemes are generally recommended for forest inventories. Sample points are located at equal intervals along transects that are regularly spaced throughout the study area. The location of the first transect and the first sample unit along each transect is determined randomly. The distance between transects and between sample points on a transect is determined by the number of samples that are required (see Section 4.3.3), and the size of the study area. Transects are run on a restricted random bearing that follows an obvious environmental gradient. Examples of environmental gradients include:

- hilly terrain – transects should run up and downhill.
- major rivers – transects should be run perpendicular to the watercourse.
- changes in stand characteristics – transects should be run across the observed changes.

Where there is no obvious environmental gradient, it is generally more efficient to run transects along the longest axis of the study area.

Transects may also be randomly located within a study area or stratum. Where this option is chosen, determine the origin of each transect by taking a random point on the edge of the study area, and run the transect on a restricted random bearing, where possible following an obvious environmental gradient. Other criteria listed in the previous paragraph also apply.

A list of equipment required to establish or remeasure Canopy Indicator Assessment transects is provided in Appendix 1. Record the data using the format in Appendix 2A.

For each transect record the following information on

(i) Location

- **Forest/Compartment/Block/Transect:** The name of the forest (e.g., Tairua), and the compartment/block/transect identifier.

- **Stratum:** Note whether the study area has been stratified, and where appropriate record the name of stratum sampled by the transect (e.g., stratified / animal control area).

- **Topomap/Aerial photo:** The NZMS 260 map sheet number and name (e.g., T12, Thames), and where available the survey name, run and number of the aerial photo.

- **Transect origin and bearing:** The seven-figure NZ Map Grid coordinates (e.g., 2761212, 6441360) and compass bearing (e.g., 65^o) used to define the origin and direction of the transect. Note that the compass bearing should be corrected for magnetic declination.

- **Forest owner:** The person or company (e.g., Carter Holt Harvey) who owns the pine forest.

- **Wood Supply Region/Territorial Authority/Bioregion:** The name of the wood supply region (e.g., Auckland), territorial authority (e.g., Thames/Coromandel district) and bioregion code (e.g., CL). See Appendices 3 & 4 for details. The first two descriptors align with the National Exotic Forest Description (Ministry of Agriculture and Forestry 2002), and the third with the New Zealand Forest Health Database (Bulman 1990).

- **Approach:** A brief description of how to find the transect. This should contain sufficient detail to enable persons revisiting the transect to locate it without extensive searching.

- **Location diagram:** A sketch of the transect emphasising prominent landscape features (e.g., roads, skidder sites, ridges, streams), and including grid references for significant way-points.

- **Notes:** Provide a 2–3 sentence description of the vegetation in the area (e.g., gorse and broom prominent in the understorey), other damaging agents (e.g., mid-crown yellowing), and any other pertinent observations and impressions.

(ii) Data collection

- **Date:** The day / month / year in full (e.g., 10 October 2002)

- **Measured/recorded by:** The full name (e.g., Gordon Hosking) of the person collecting/recording the data.

- **Agency responsible:** The full name (e.g., Hosking Forestry) of the organisation responsible for the data collection.

(iii) Stand characteristics

- **Pine species/provenance:** The species of pine (e.g., *Pinus radiata*) and the provenance (e.g., GF23 rooted cuttings) where this is known.

- **Stand age:** The age of the forest stand as at 1 April of the survey year. A forest stand is age one at 1 April 2002 if it was planted in the preceding 12-month period, i.e., between 1 April 2001 and 31 March 2002.

- **Canopy height and stem diameter:** The average height (e.g., 6–8 m) and stem diameter at breast height (e.g., 12–15 cm) of trees forming the canopy of the stand (i.e., excluding suppressed individuals).

- **Silvicultural regime:** Include information on initial stocking, thinning and pruning, where this is available.

Selecting a representative sample

In selecting the trees to be sampled the main aims are to:

- Choose individuals in a random and independent manner.
- Select a sample that is genuinely representative of the individuals throughout the study area.

At each sample point along the transect (determined by the distance along the hipchain) choose the nearest tree in which the upper crown is clearly visible. All sample trees must be within a 20-m radius of the sample point. Where no suitable tree is present within this distance the sample point should be abandoned.

Where the survey is intended solely as a one-off assessment of possum damage within a pine stand, there is no need to permanently mark the sample trees. Where the assessment forms part of a longer-term monitoring programme, you will need to determine whether it is more cost efficient to mark and remeasure the same set of trees on each occasion, or to select a new sample each time the stand is assessed. The tradeoff is between a reduction in sample size (c.

40%) required to achieve the same level of precision when the same set of trees is remeasured, and the additional costs associated with marking trees and refinding them on successive occasions.

Where trees are to be permanently marked use a numbered tag and highlight this with a coloured marker (permolat flagging or spray paint). Trees should be tagged at breast height (1.4 m) on the side facing the sample point to make them easier to locate on future occasions.

4.3.3 Sample size

If you select a sample that is too small you may be unable to detect significant changes that are taking place, and your estimate of damage may be so imprecise as to be of little value. Conversely, if you select a sample that is too large for the objectives of your study you will waste effort, time and money.

Two factors need to be considered when deciding on the number of trees that need to be assessed. The first is the proportion of trees in the stand that has been damaged by possums. Table 1 provides a guide to the sample size required to estimate the percentage of possum-damaged trees in a forest block or compartment. For most stands the percentage of possum-damaged trees will be low (<10%), enabling precise estimates to be obtained without the need to sample large numbers of trees.

Table 1. Sample size required to estimate the percentage of possum-damaged trees to a given degree of precision, with a 95% level of confidence.

		Degree of precision required				
		± 0.5%	**± 1%**	**± 2%**	**± 5%**	**± 10%**
Estimated percentage of possum-damaged trees in the stand	**1**	1584				
	2	3136	784			
	5	7600	1900	475		
	10	14400	3600	900	144	
	15	20400	5100	1275	204	51
	20	25600	6400	1600	256	64
	25	30000	7500	1875	300	75
	30	33600	8400	2100	336	84
	35	36960	9100	2275	364	91
	40	38400	9600	2400	384	96

The second consideration in determining the number of trees to be sampled is the degree of precision that is required on the estimates of damage. For most Canopy Indicator Assessment variables (e.g., leader damage, needle loss, bark damage to the basal stem) a damaged tree will either be affected or not affected. For example, a possum-damaged tree may or may not have a damaged leader or show signs of needle loss. For these variables the sample size calculations are the same as those used to estimate the percentage of possum-damaged trees (see Table 1). The situation is a little different when considering the extent of possum damage to lateral branches. Most possum-damaged trees will have a number of damaged lateral branches, but in few if any cases will all the lateral branches have been damaged. Data collected during the development of the Canopy Indicator Assessment methodology showed that in possum-damaged trees an average of 30% of the laterals in the top three whorls were either depressed or broken. Based on these figures a sample sizes of around 200 possum-damaged trees can be expected to provide estimates of the percentage of damaged lateral branches/damaged tree to a precision of ± 3%, with a 95% level of confidence.

For the more common forms of damage, reasonable levels of precision can be obtained without the need to sample large numbers of trees. Where a variable (e.g., bark damage to the basal stem) is uncommon or rare, describe what you observe rather than attempting to estimate it precisely.

5. Canopy-Indicator-Assessment Method

The Canopy Indicator Assessment method has been developed to describe and quantify damage caused by brushtail possums to the terminal leaders, lateral branches, stems and needles of pine trees. Where trees are permanently marked it can also be used to monitor temporal changes to forests such as those associated with animal control or silvicultural operations.

We recommend the use of two-person teams for establishing or remeasuring Canopy Indicator Assessment transects. A list of the equipment needed by each team is provided in Appendix 1.

5.1 Assessment of sample trees

The Canopy Indicator Assessment sheet (Appendix 5) summarises the data to be collected from each sample tree. For each sample tree use the format in Appendix 2B to record the following information.

5.1.1 Tree and site characteristics

Life history stage

Identify the life history stage of the tree using one of the following categories:

1 Seedling/Sapling <2 m tall.

- All of the plant is accessible to all of the potential damaging agents (e.g., rabbits, hares, rats, possums, wallabies, cattle, sheep, goats).
- All plant parts (e.g., stems, leaders, laterals) are vulnerable to damage.
- Damage is easy to observe, but difficult to attribute to a causal agent (Fig. 2).
- Generally not more than 2–3 years old.

2 Immature tree >2 m tall; basal portion of the stem still vulnerable to herbivore damage.

- The main leader is out of reach of ground browsers.
- The basal log is still vulnerable to damage from bark biting, bark stripping, or rubbing.
- Generally less than 10–12 years old.

3 **Mature tree** height growth not yet complete; basal log no longer vulnerable to herbivore damage.

- Strong apical growth, which is vulnerable to arboreal browsers (possums, rats).
- Bark on the basal log is sufficiently developed to withstand damage from ground-browsing animals.
- The main crop trees in most plantation forests.

4 **Overmature tree** height growth complete; main stem fully formed.

- Rounded crown lacking apical dominance; little if any continuing height growth.
- Damage by possums or other vertebrate herbivores no longer an issue.
- Typically found as specimen trees, or in established shelterbelts.

Fig. 2 Bark damage to a pine seedling that may result from possum activity.

Terrain

Described using five categories – **R**idge (including spurs), **S**lope, **G**ully, **T**errace or **U**ndulating.

5.1.2 Possum damage

Assessing possum damage requires a clear view of the tree crown and a good pair of binoculars. Ideally observers should be able to view the tree from all sides. Damage can be assessed at any time of the year, but is probably most noticeable during late winter and spring when possums are actively foraging for pollen cones in the upper canopy.

When describing possum damage to pine trees observers need to be able to:

- Recognise the distinctive characteristics of possum-related damage, and how these differ from that of other causal agents (e.g., insect pests, fungal pathogens, other animal species).
- Identify the parts of the tree that are affected, and assess how severely they are affected.
- Determine how recently the damage was caused.

Formally assess and record only damage you consider to be the result of possum activity. Where the standard descriptors provided in the following section do not adequately describe the observed damage, or where there is uncertainty over what caused the damage, record this in the notes column.

Record both the presence and absence of damage. Blank spaces on completed survey forms create uncertainty over whether the variable (e.g., needle loss) was assessed as a nil value, or was not scored.

For each sample tree use the format in Appendix 2B to record the following information about:

Leader damage

Classify the status of the leader using one of the following categories. For multileadered trees assess only dominant or co-dominant stems.

1 Single, undamaged primary leader
2 Primary leader undamaged but overtopped by one or more lateral branches
3 Primary leader damaged but remains dominant
4 Primary leader damaged or dead and/or overtopped by a single lateral branch (hockey stick) (Fig. 3A)
5 Primary leader damaged or dead and/or overtopped by two lateral branches (double leader)
6 Primary leader damaged or dead and/or overtopped by more than two lateral branches (multileader)
7 Primary leader broken, dead or missing and not overtopped by one or more lateral branches (dead top) (Fig. 3B).

Where the primary leader is overtopped by a lateral branch (Classes 2, 4, 5, 6) record the whorl from which the overtopping lateral originated (e.g., a primary leader overtopped by a single lateral from whorl 3 would be recorded as 4/T-2).

Fig. 3 Primary leader (A) overtopped by a single vigorous lateral branch (class 4) from the top whorl (T) and (B) dead and not overtopped by one or more lateral branches (class 7) – damage clearly possum-related.

Lateral branch damage

Record the number of lateral branches in each of the top three whorls (T, T-1, T-2), and in other damaged whorls (e.g., T-4) that are

• Unaffected	at the normal angle to the main stem
• Depressed – above the horizontal plane	at > normal angle but < 90° to the main stem
• Depressed – below the horizontal plane	at > 90° to the main stem.

Assess only branches originating from distinct whorls on the main stem. Exclude small isolated branches on the main stem, and whorls in which the lateral shoots have not yet developed needles. When comparing branch angles within a whorl, take into account that smaller ‘secondary’ branches are frequently at a greater angle to the stem than their more vigorous counterparts.

Classify damage to lateral branches as recent (r) or older (o), and identify branches that have died (d). Recently damaged laterals do not have the upturned tips characteristic of branches re-orienting themselves to the light (Figs 4A, 4B).

Fig. 4. Lateral branch damage to (A) the top whorl and (B) successive whorls that is attributable to possums. Note the upturned tips on all but the most recently depressed lateral branches.

Lateral branch damage can safely be attributed to possums where branches are depressed below the horizontal plane and/or the damage is accompanied by other signs of possum activity (e.g., leader or bark damage). Minor displacement of lateral branches, particularly in the upper whorls, is also caused by magpies and other larger bird species (Fig. 5).

Fig. 5 Displacement of young lateral branches in the uppermost whorl. In the absence of other evidence of possum activity it would be unwise to assume this is caused by possums.

Needle loss and displacement

Except for seedlings, which are reportedly hedged by possums (J. Haack, pers. comm.), animals typically strip pine needles from the stem before eating them (Fig. 6). Stripped needles leave behind the pair of papery scales at the base of the fascicle allowing them to be distinguished from newly emerging fascicles. They can also be confused with the remnants of pollen cones (Keber 1987), which are highly sought after by possums in late winter and spring (Fig. 7).

Fig. 6 Needle loss on the main leader associated with possum damage to lateral branches in the top two whorls (T, T-1).

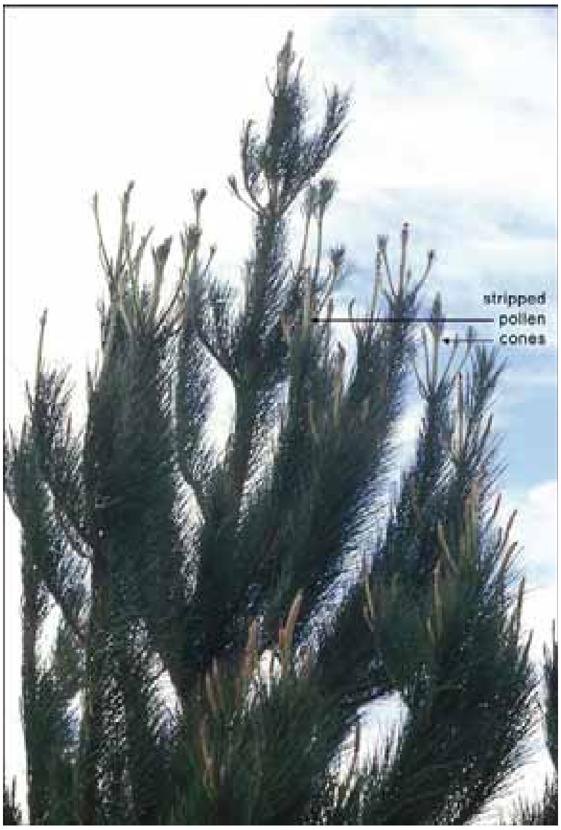


Fig. 7 Stripped pollen cones, which may be the result of possum activity.

Record the degree of needle loss on the leader and the top two whorls of lateral branches using the following scale.

0	Nil	no visible loss of needles
0.5	Few	minimal (< 5%) loss of needles
1	Light	< ⅓ needle loss
2	Moderate	⅓ – ⅔ needle loss
3	Severe	> ⅔ needle loss.

Possums and other arboreal animals also displace needles as they move about in the canopy. Where needle loss/displacement is associated with other evidence of possum damage (e.g., bent or broken laterals) it is reasonable to attribute this to possum activity. Where this is not the case, ship rats (*Rattus rattus*) are more likely to be the culprits (Fig. 8).

Fig. 8 Severe needle loss (class 3) to the leader and upper whorls of lateral branches. In the absence of supporting evidence (e.g., bent or broken lateral branches) this should not be attributed to possums.

Record the degree of needle displacement over the upper third of the canopy as:

n	none	no (or only very slight) visible displacement of needles
s	some	some needles (< 20%) show signs of displacement
a	a lot	a lot (> 20%) of needles displaced.

Bark damage

Possums (and other animal pests such as rabbits and hares) gnaw the bark from young stems and branches to get at the cambial tissue. Bite marks are usually transverse (Keber 1987), although occasionally bark is torn off in long strips (McNally 1955).

Record the severity of bark biting or stripping to the basal stem (below 2 m) (Fig. 9A), main stem (above 2 m) (Fig. 9B), leader, and lateral branches using the following scale.

0	Nil	no visible damage
1	Light	< ⅓ stem or branch circumference affected
2	Moderate	⅓ – ⅔ stem or branch circumference affected
3	Severe	> ⅔ stem or branch circumference affected
4	Extreme	stem or branch completely girdled.

Use the notes column to record the whorls in which lateral branches have been damaged. For example, bark damage to lateral branches in the top three whorls of the tree would be recorded as T, T-1, T-2.

Fig. 9 Bark damage to (A) the basal (< 2 m) stem of *Pinus radiata* and (B) the main (>2 m) stem of *P. contorta*.

Record the age of bark damage as recent (r) or older (o). Recent bark damage is characterised by the presence of sap/resin stains similar to those associated with pruning wounds (Fig. 10). Older wounds are typically calloused.

Fig. 10 Recent bark damage to a pruned *Pinus radiata* stem.

5.2 Reassessment of sample trees

Regular (annual, biennial etc.) reassessment of Canopy Indicator Assessment transects is not necessary. However, because possum damage of pine trees has a strong seasonal component, transects should be reassessed in the same season (spring, summer, autumn, winter) as earlier assessments.

For each transect, record the information described in Section 4.3.2. This provides an update of any changes to the location (e.g., roading) and stand characteristics (e.g., silvicultural regime), and will hopefully improve the ease with which future survey parties can re-locate the transect.

For each tree being reassessed follow the procedures set out in Section 5.1.

- **Take** a copy of any information that will help you re-locate the sample trees.
- **Do not take** a copy of the vegetation data from the previous assessment, as this is likely to influence your assessment of variables such as leader and lateral branch damage.

Where a tree cannot be found or has died it may be replaced by another individual. In this case choose the nearest tree to the sample point that meets the selection criteria in Section 4.3.2. Be sure to clearly identify replaced individuals in the dataset. Note also that the replacement of dead or missing trees will distort analyses of changes between sampling periods (see Section 7). If tree mortality from possum damage or other causes (e.g., windthrow) is severely reducing the sample size, it is usually preferable to select another group of trees from the population or stratum (see Section 4.3.2) and treat these as a separate sample.

6. Technical Considerations

Because a number of the components of the Canopy Indicator Assessment method rely on individual assessment of a categorical variable rather than on counts or measurements, questions of reliability and repeatability take on an increased importance (Strand 1996).

As part of the development of the method, we tested the variation within and between observers for assessed (as opposed to measured) variables that form part of the Canopy Indicator Assessment methodology. Testing was carried out at several localities within Whakarewarewa Forest, near Rotorua, in May 2002.

Where two observers independently assessed the **life-history stage** of sample trees, they agreed on all occasions (n=100) that the individual should be classified as either a seedling/sapling, an immature tree, a mature tree or an overmature tree (Fig. 11A). For **leader damage** observers independantly reached the same conclusion on 98% (n=100) of occasions, and never differed by more than one class (Fig. 11B).

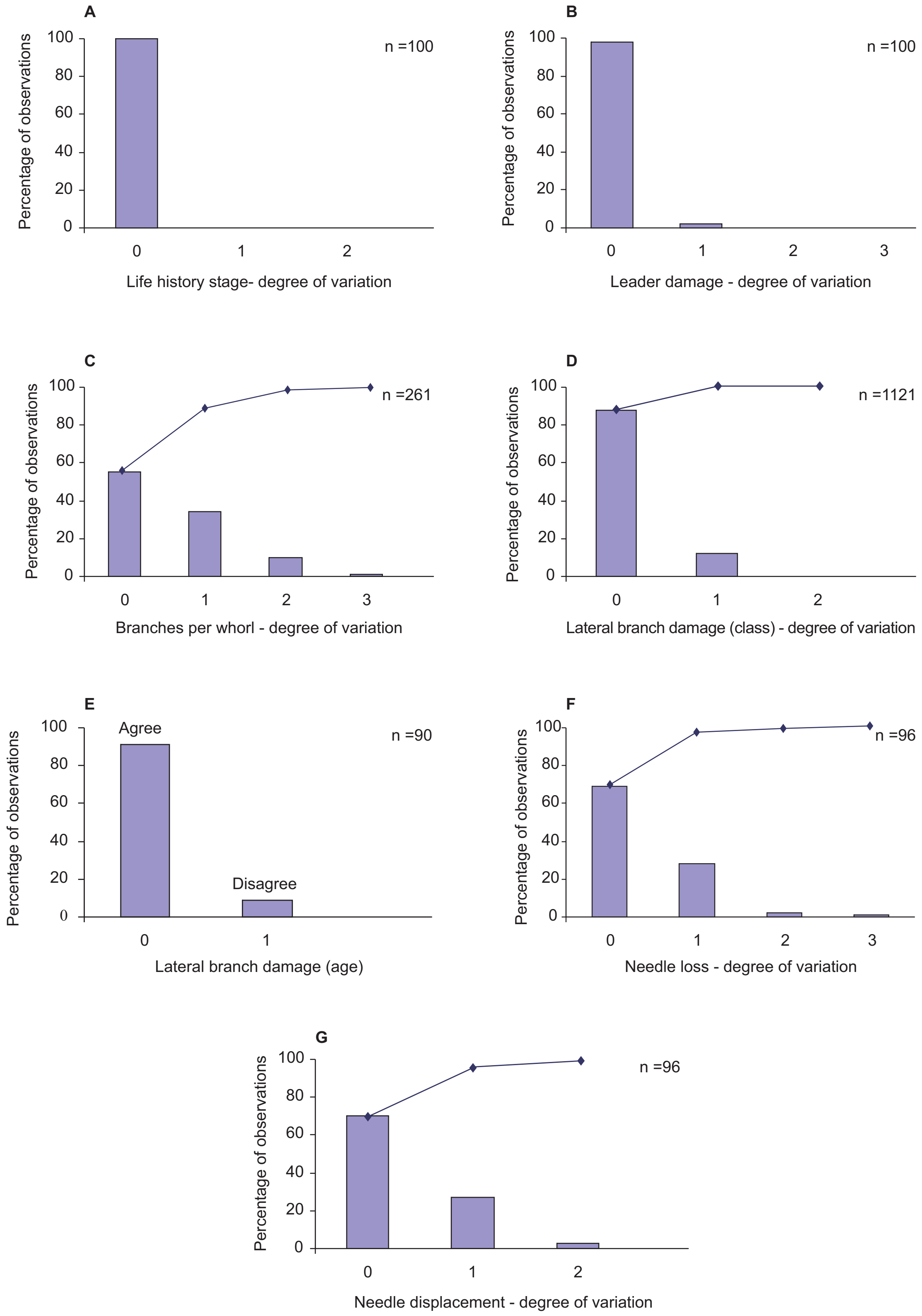


Fig. 11 Variation between observers for assessed variables in the Canopy Indicator assessment methodology.

Both observers agreed on the **number of lateral branches within a whorl** on 55% of occasions (n=261), and were not more than one branch different 89% of the time or two branches different 99% of the time (Fig. 11C). Differences were greater and more frequent in taller trees, and when the tree could not be viewed from all sides. Observers allocated **lateral branch damage** to the same class (unaffected, depressed but remaining above the horizontal plane, depressed below the horizontal plane) on 88% of occasions (n=1121), and never differed by more than one class (Fig. 11D). Most disagreement was associated with depressed branches at or near the horizontal plane. Where both observers assessed the **age of damage to lateral branches** (recent, old) agreement was obtained on 91% (n=90) of occasions (Fig. 11E).

Agreement on the degree of **needle loss** (nil, few, light, moderate, severe) on the leader and top two whorls of lateral branches was obtained in 69% (n=96) of cases, and observers were not more than one or two classes different on 97% and 99% of occasions respectively (Fig. 11F). Most disagreements occurred at the low end of the scale. **Needle displacement** in the upper portion of the canopy was assessed with a similar level of consistency. Observers agreed on 70% of occasions and were only one class different a further 27% of the time (Fig. 11G).

Only a few cases of bark damage that could be attributed to possums were seen during the course of the method development study, and none in the group of trees used to assess observer variability. Based on the number of classes to which the variable can be allocated, observers can be expected to agree on the **severity of damage** (nil, light, moderate, severe, extreme) in approximately two-thirds of cases.

When a single observer reassessed a subset (n=42) of these trees the following day, the level of repeatability was either similar to the variability between observers (life-history stage, leader damage, number of branches within a whorl, needle loss, needle displacement) or a little better (lateral branch damage, age of damage to lateral branches).

In the present study there was no consistent bias between observers. Some observers, however, do consistently assess variables above or below the mean value obtained by a group of observers (Payton et al. 1999). The ideal means of ensuring consistency is to use the same observer throughout (Meads 1976; Payton 1988). This is rarely practical, except where datasets are small and timeframes short. To minimise the possibility of systematic bias in Canopy Indicator Assessment datasets and to maximise consistency between sampling periods we recommend that:

- Both members of a two-person team be required to agree on the score of assessed variables.
- Where there is more than one team, personnel are rotated between teams.
- At least one member of each team should be present for successive remeasurements.

7. Data Analysis Options

Canopy Indicator Assessment data are amenable to display and analysis by a wide range of standard graphics and statistics packages. The following section outlines analyses that can be used to determine the significance of changes occurring within and between pine plantations. It assumes that the data are a random, representative sample of the individuals in the stratum or study area (see Section 4.3.2).

7.1 Data classification

The Canopy Indicator Assessment variables can be classified as one of the following three types:

Numeric data – e.g., percentage of damaged branches per damaged tree. These variables are usually best summarised as means and standard deviations. If, however, the distribution of the collected data is highly skewed then medians and inter-quartile ranges are more appropriate.

Ordered categorical score data – e.g., needle loss or leader damage. These variables are summarised as medians and inter-quartile ranges, and in situations where damage levels are very low, as percentages and confidence intervals.

Nominal categorical class score data – e.g., percentage in a specific damage class (moderate needle damage) or group of classes (any form of bark damage). These variables are summarised as percentages and confidence intervals.

7.2 Statistical tests

Although descriptive summaries are the primary form of analysis for Canopy Indicator Assessment variables, statistical tests can be used to compare changes between sampling periods and between sampled areas. The two criteria for determining the appropriate statistical test are (i) whether the data being compared represent repeat assessments of the same trees (paired samples) or are comparing two independent samples, and (ii) which of the three data types (see Section 7.1) are being compared. Table 2 provides a list of appropriate statistical tests. The list is not exhaustive. Rather it is intended as a guide, to help non-statisticians identify appropriate statistical procedures for each of the Canopy Indicator Assessment variables.

Table 2. Statistical tests for Canopy Indicator Assessment variables.

Variable type	**Paired samples**	**Independent samples**
Numeric	Paired t-test	Independent Sample t-test
Ordered categorical	Wilcoxon Signed Rank test	Mann-Whitney U test
Nominal categorical	McNemar’s Chi-square test	Pearson’s Chi-square test

8. Data Storage

Routine archiving of data is an essential part of any monitoring system. In the current constantly changing employment environment, we need to plan for the possibility that Canopy Indicator Assessment transects will be remeasured by people who were not involved with their establishment or earlier remeasurement. Because data from previous sampling periods form part of a time series, it is not possible to re-acquire datasets that have been lost.

For these reasons it is important to ensure that a copy of all Canopy Indicator Assessment plotsheets, maps, aerial photos, and computer datafiles are archived in secure, preferably fire-proof storage. Unless this procedure becomes an integral part of a monitoring programme, datasets will rarely outlive the employment tenure of the person or persons responsible for their collection.

9. Acknowledgements

We express our appreciation to Roger Lorigan, John Haack, and Kane Stafford (EPRO), Phill Wishnowsky (PF Olsen & Co. Ltd), Robin Blake, (Wellington Regional Council), and Gordon Hosking (Hosking Forestry) for advice and assistance in locating areas of possum-damaged pine forest. Gordon Hosking helped test the reliability of the method. Dave Morgan contributed Fig. 9A. SIR Publishing gave permission to reproduce the New Zealand Bioregion boundaries map (Appendix 4). Gordon Hosking and John Parkes reviewed the text, Kirsty Cullen scanned the pictures and drew the figures, and Wendy Weller completed the final word processing. Development of the method and production of the report were funded by the Forest Health Research Collaborative.

10. References

Agricultural Pests Destruction Council 1980: Opossum survey report 1980. 39 p.

Barnett, J.L.; How, R.A.; Humphries, W.F. 1977: Possum damage to pine plantations in north-eastern New South Wales. *Australian Forest Research* 7: 185–195.

Batcheler, C.L.; Cowan, P.E. 1988: Review of the status of the possum (*Trichosurus vulpecula*) in New Zealand. Unpublished FRI contract report to the Technical Advisory Committee (Animal Pests) for the Agricultural Pests Destruction Council, Department of Conservation, and Ministry of Agriculture and Fisheries. 129 p.

Bathgate, J.L. 1973: Summary of questionaire returns. Pp. 102–113 in: Orwin, J. (ed.). Assessment and management of introduced animals in New Zealand. Forest Research Institute Symposium No. 14.

Bulman, L.S. 1990: Bugs and health – integral part of forest protection strategy. What's New in Forest Research No. 197. Forest Research Institute, Ministry of Forestry, Rotorua, New Zealand. 4 p.

Butcher, S. 2000: Impact of possums on primary production. Pp. 105–110 in: Montague T.L. (ed.). The brushtail possum: biology, impact and management of an introduced marsupial. Manaaki Whenua Press, Lincoln, New Zealand. 292 p.

Chou, C.K.S. 1984: *Diplodia* leader dieback, *Diplodia* crown wilt, *Diplodia* whorl canker. In Gadgil, P.D. (ed.) Forest Pathology in New Zealand No. 7. Forest Research Institute, Rotorua. 4 p.

Clout, M. N. 1977: The ecology of the possum (*Trichosurus vulpecula* Kerr) in *Pinus radiata* plantations. Unpublished PhD thesis, University of Auckland, Auckland, New Zealand. 346 p.

Clout, M.; Ericksen, K. 2000: Anatomy of a distastrous success: The brushtail possum as an invasive species. Pp. 1–9 in: Montague T.L. (ed.). The brushtail possum: biology, impact and management of an introduced marsupial. Manaaki Whenua Press, Lincoln, New Zealand. 292 p.

Crosby, T.K.; Dugdale, J.S.; Watt, J.C. 1976: Recording specimen localities in New Zealand: an arbitrary system of areas and codes defined. *New Zealand Journal of Zoology 3*: 69 (with separate map).

Efford, M. 2000: Possum density, population structure, and dynamics. Pp. 47–61 in: Montague T.L. (ed.). The brushtail possum: biology, impact and management of an introduced marsupial. Manaaki Whenua Press, Lincoln, New Zealand. 292 p.

Gill, W. 1919: Journal discussion: the forests as a sanctuary for birds and game: an opponent. *The Australian Forestry Journal 2*: 10–12.

Gilmour, J.W. 1966: The pathology of forest trees in New Zealand. New Zealand Forest Service Technical Paper 48.

Goulding, C.J. 1995: Measurement of trees. Pp. 104–107 in: Hammond, D. (ed.). Forestry handbook. 3rd edition. The New Zealand Institute of Forestry (Inc.), Christchurch, New Zealand. 240 p.

Goulding, C.J.; Lawrence, M.E. 1992: Inventory practice for managed forests. Forest Research Institute Bulletin 171. 52 p.

Green, R.H. 1979: Statistical methods and sampling designs for environmental biologists. Wiley-Interscience, New York. 257 p.

Harvie, A.E. 1973: Diet of the opossum (*Trichosurus vulpecula* Kerr) on farmland northeast of Waverley, New Zealand. *Proceedings of the New Zealand Ecological Society 20*: 48–52.

Hosking, G. 2000: Possum risk and impact on radiata pine. Progress report to the Forest Health Research Collaborative. 10 p.

How, R.A. 1968: Animal damage in state forests. Report to the Forestry Commission of New South Wales. 12 p.

How, R.A. 1972: The ecology and management of *Trichosurus* species (Marsupialia) in New South Wales. Unpublished PhD thesis, University of New England, Armidale, Australia.

Jacometti, M.A.A.; Frampton, C.; Hickling, G.J. 1997: Brushtail possum damage and abundance in a New Zealand *Pinus radiata* plantation. *New Zealand Journal of Forestry Science 27*: 313–323.

Keber, A.W. 1987: An enquiry into the economic significance of possum damage in an exotic forest near Taupo. Unpublished PhD thesis, University of Auckland, Auckland, New Zealand.

Kirk, H.B. 1920: Opossums in New Zealand: report on Australian opossums in New Zealand. *Appendix to the Journals of the House of Representatives of New Zealand H–28*: 1–12.

Maclaren, J.P.; Knowles, R.L. 1995: Silvicultural regimes – radiata pine. Pp. 83–86 in: Hammond, D. (ed.). Forestry handbook. 3rd edition. The New Zealand Institute of Forestry (Inc.), Christchurch, New Zealand. 240 p.

Martin, J.T. 1973: Report on opossum damage in New Zealand Forest Products exotic forests. Unpublished report, New Zealand Forest Products.

McNally, J. 1955: Damage to Victorian exotic pine plantations by native animals. *Australian Forestry 19*: 87–99.

Meads, M.J. 1976: Effects of opossum browsing on northern rata trees in the Orongorongo Valley, Wellington, New Zealand. *New Zealand Journal of Zoology 3*: 127–139.

Ministry of Agriculture and Forestry 2002: A national exotic forest description as at 1 April 2001. Ministry of Agriculture and Forestry, Wellington, New Zealand. 63 p.

Payton, I.J. 1988: Canopy closure, a factor in rata (*Metrosideros*) – kamahi (*Weinmannia*) forest dieback in Westland, New Zealand. *New Zealand Journal of Ecology 11*: 39–50.

Payton, I.J.; Pekelharing, C.J.; Frampton, C.M. 1999: Foliar Browse Index: A method for monitoring possum (*Trichosurus vulpecula*) damage to plant species and forest communities. Manaaki Whenua – Landcare Research, Lincoln, New Zealand. 62 p.

Pracy, L.T. 1974: Introduction and liberation of the opossum (*Trichosurus vulpecula*) into New Zealand. Information Series No. 45. 2nd edition. New Zealand Forest Service, Wellington. 28 p.

Purey-Cust, J.; Hammond, D.R. 1995: A condensed history of forestry in New Zealand. Pp. 26–29 in: Hammond, D. (ed.). Forestry handbook. 3rd edition. The New Zealand Institute of Forestry (Inc.), Christchurch, New Zealand. 240 p.

Strand, G-H. 1996: Detection of observer bias in ongoing forest health monitoring programmes. *Canadian Journal of Forestry Research 26*: 1692–1696.

Triggs, S.J. 1982: Comparative ecology of the possum, *Trichosurus vulpecula*, in three pastoral habitats. Unpublished MSc thesis, University of Auckland, Auckland, New Zealand.

Underwood, A.J. 1994: Things environmental scientists (and statisticians) need to know to receive (and give) better statistical advice. Pp. 33–61 in: Fletcher, D.J.; Manly, B.F.J. (eds). Statistics in ecology and environmental monitoring. Otago Conference Series No. 2. University of Otago Press, Dunedin.

Warburton, B. 1978: Foods of the Australian brush-tailed opossum (*Trichosurus vulpecula*) in an exotic forest. *New Zealand Journal of Ecology 1*: 126–131.

11. Appendices

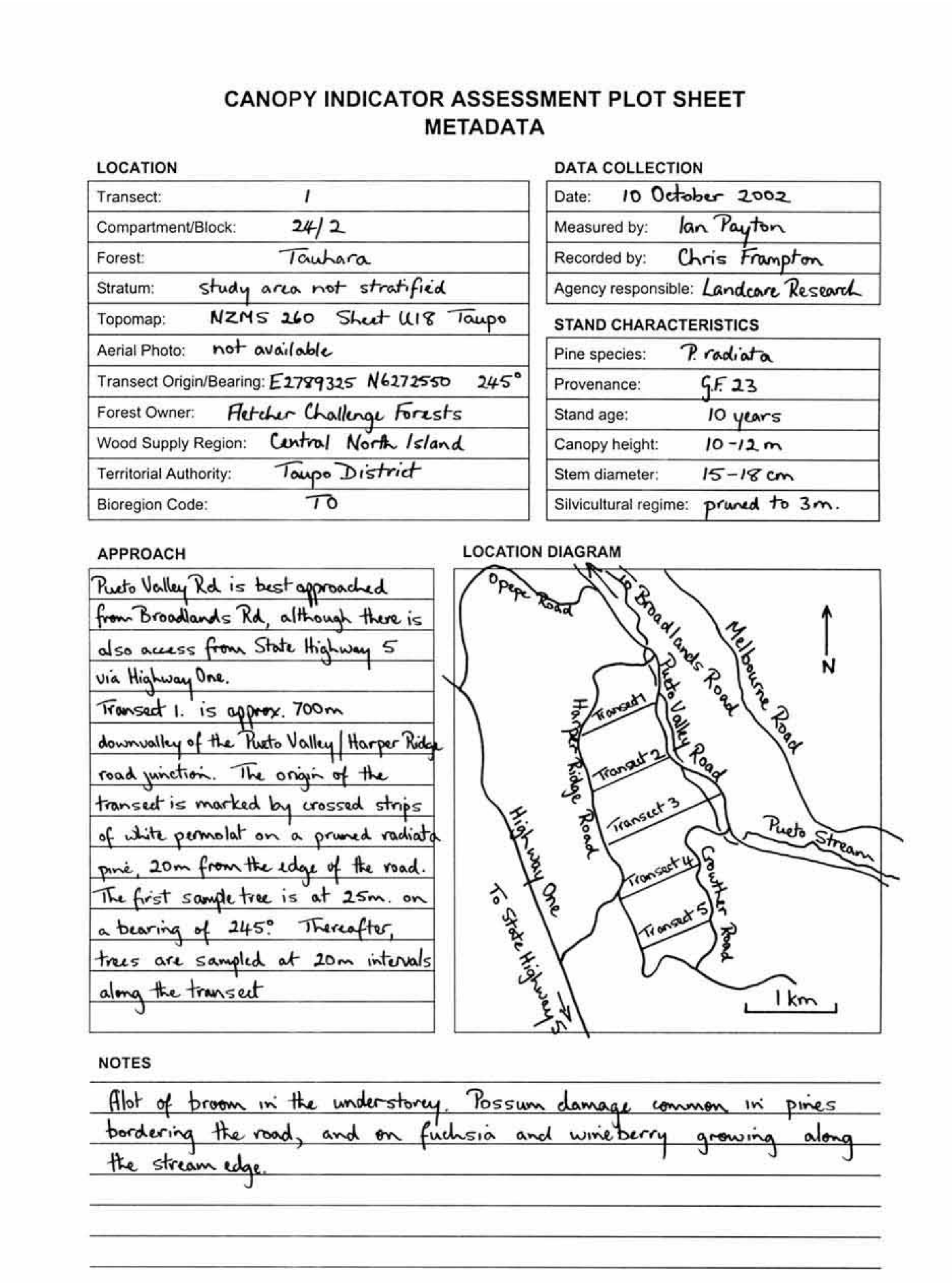
Appendix 1	List of equipment required to establish or remeasure Canopy Indicator Assessment transects. Spares should be carried in case of loss or breakage
Appendix 2	A. Canopy Indicator Assessment plotsheet – metadata B. Canopy Indicator Assessment plotsheet – assessment of sample trees
Appendix 3	Wood supply regions and constituent territorial authorities
Appendix 4	New Zealand Bioregion boundaries
Appendix 5	Canopy Indicator Assessment codes for scoring possum damage to pine trees

Appendix 1 List of equipment required to establish or remeasure Canopy Indicator Assessment transects

Plot measurement equipment
Canopy Indicator Assessment manual
Topographical map and aerial photo
Compass
Hipchain dispenser
20-m tape
Stem diameter tape
Vertex or Suunto hypsometer
Hammer
Binoculars

Consumable items
Clipboard, pens, pencils
Canopy Indicator Assessment plotsheets
Hipchain cotton
‘Permolat’ flagging
Nails (40-mm galv. flathead)
Aluminium tree tags (numbered series)
Batteries for Vertex hypsometer

Appendix 2A Canopy Indicator Assessment plotsheet – metadata



CANOPY INDICATOR ASSESSMENT PLOT SHEET
METADATA

LOCATION

Transect:	1
Compartment/Block:	24/2
Forest:	Tauhara
Stratum:	study area not stratified
Topomap:	NZMS 260 Sheet U18 Taupo
Aerial Photo:	not available
Transect Origin/Bearing:	E2789325 N6272550 245°
Forest Owner:	Fletcher Challenge Forests
Wood Supply Region:	Central North Island
Territorial Authority:	Taupo District
Bioregion Code:	TO

DATA COLLECTION

Date:	10 October 2002
Measured by:	Ian Payton
Recorded by:	Chris Frampton
Agency responsible:	Landcare Research

STAND CHARACTERISTICS

Pine species:	P. radiata
Provenance:	G.F. 23
Stand age:	10 years
Canopy height:	10-12 m
Stem diameter:	15-18 cm
Silvicultural regime:	pruned to 3m.

APPROACH

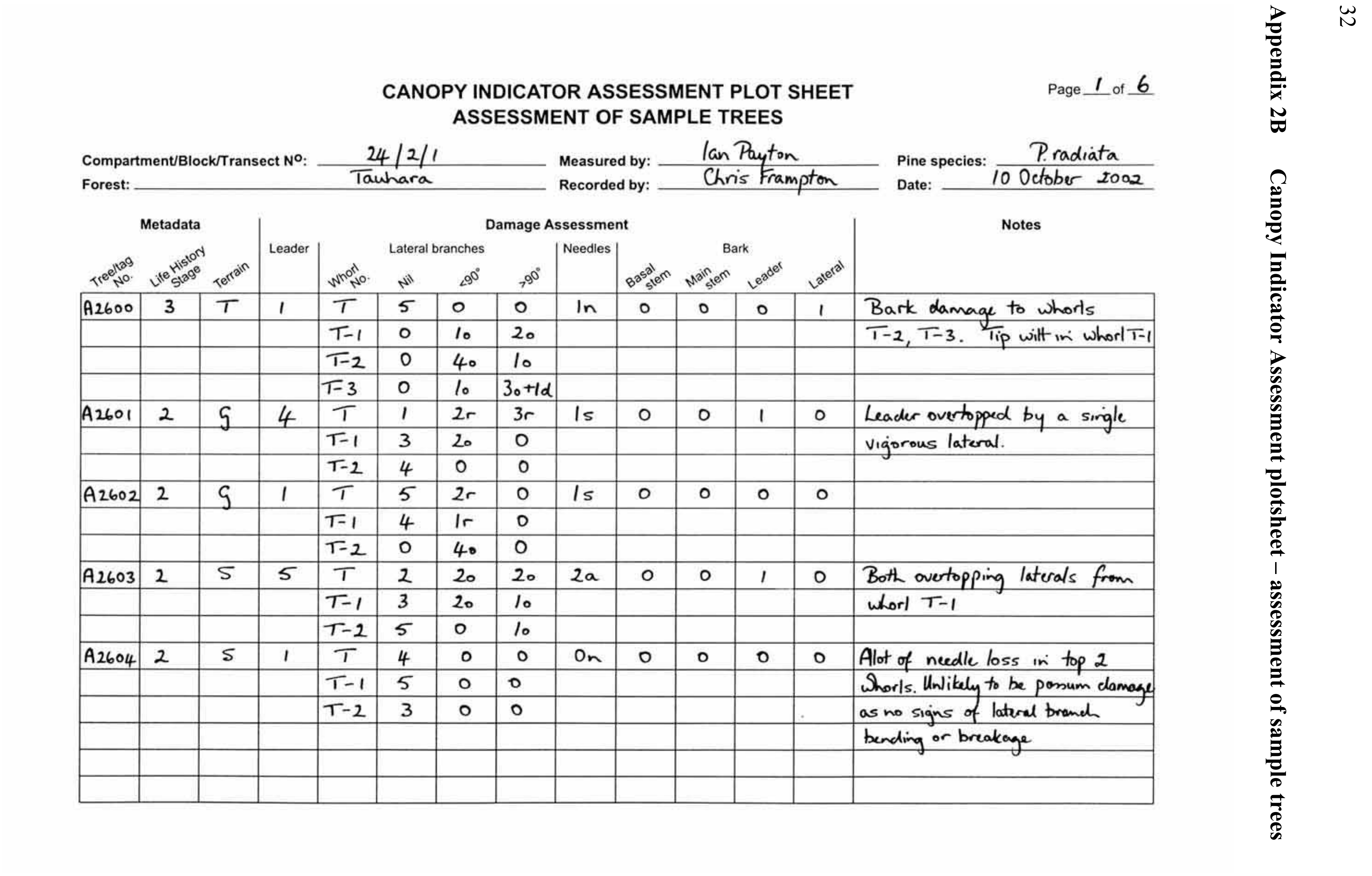
Pueto Valley Rd is best approached
from Broadlands Rd, although there is
also access from State Highway 5
via Highway One.
Transect 1. is approx. 700m
downvalley of the Pueto Valley / Harper Ridge
road junction. The origin of the
transect is marked by crossed strips
of white permolat on a pruned radiata
pine, 20m from the edge of the road.
The first sample tree is at 25m. on
a bearing of 245°. Thereafter,
trees are sampled at 20m intervals
along the transect

LOCATION DIAGRAM

NOTES

Alot of broom in the understorey. Possum damage common in pines
bordering the road, and on fuchsia and wineberry growing along
the stream edge.

Appendix 2B Canopy Indicator Assessment plotsheet – assessment of sample trees



Page 1 of 6

CANOPY INDICATOR ASSESSMENT PLOT SHEET
ASSESSMENT OF SAMPLE TREES

Compartment/Block/Transect Nº: 24/2/1
Forest: Tauhara
Measured by: Ian Payton
Recorded by: Chris Frampton
Pine species: P. radiata
Date: 10 October 2002

Metadata			Damage Assessment										Notes
			Leader	Lateral branches				Needles	Bark				
Tree/tag No.	Life History Stage	Terrain		Whorl No.	Nil	<90°	>90°		Basal stem	Main stem	Leader	Lateral	
A2600	3	T	1	T	5	0	0	1n	0	0	0	1	Bark damage to whorls
				T-1	0	1o	2o						T-2, T-3. Tip wilt in whorl T-1
				T-2	0	4o	1o						
				T-3	0	1o	3o+1d						
A2601	2	G	4	T	1	2r	3r	1s	0	0	1	0	Leader overtopped by a single
				T-1	3	2o	0						vigorous lateral.
				T-2	4	0	0						
A2602	2	G	1	T	5	2r	0	1s	0	0	0	0	
				T-1	4	1r	0						
				T-2	0	4o	0						
A2603	2	S	5	T	2	2o	2o	2a	0	0	1	0	Both overtopping laterals from
				T-1	3	2o	1o						whorl T-1
				T-2	5	0	1o						
A2604	2	S	1	T	4	0	0	0n	0	0	0	0	Alot of needle loss in top 2
				T-1	5	0	0						whorls. Unlikely to be possum damage
				T-2	3	0	0						as no signs of lateral branch
													bending or breakage

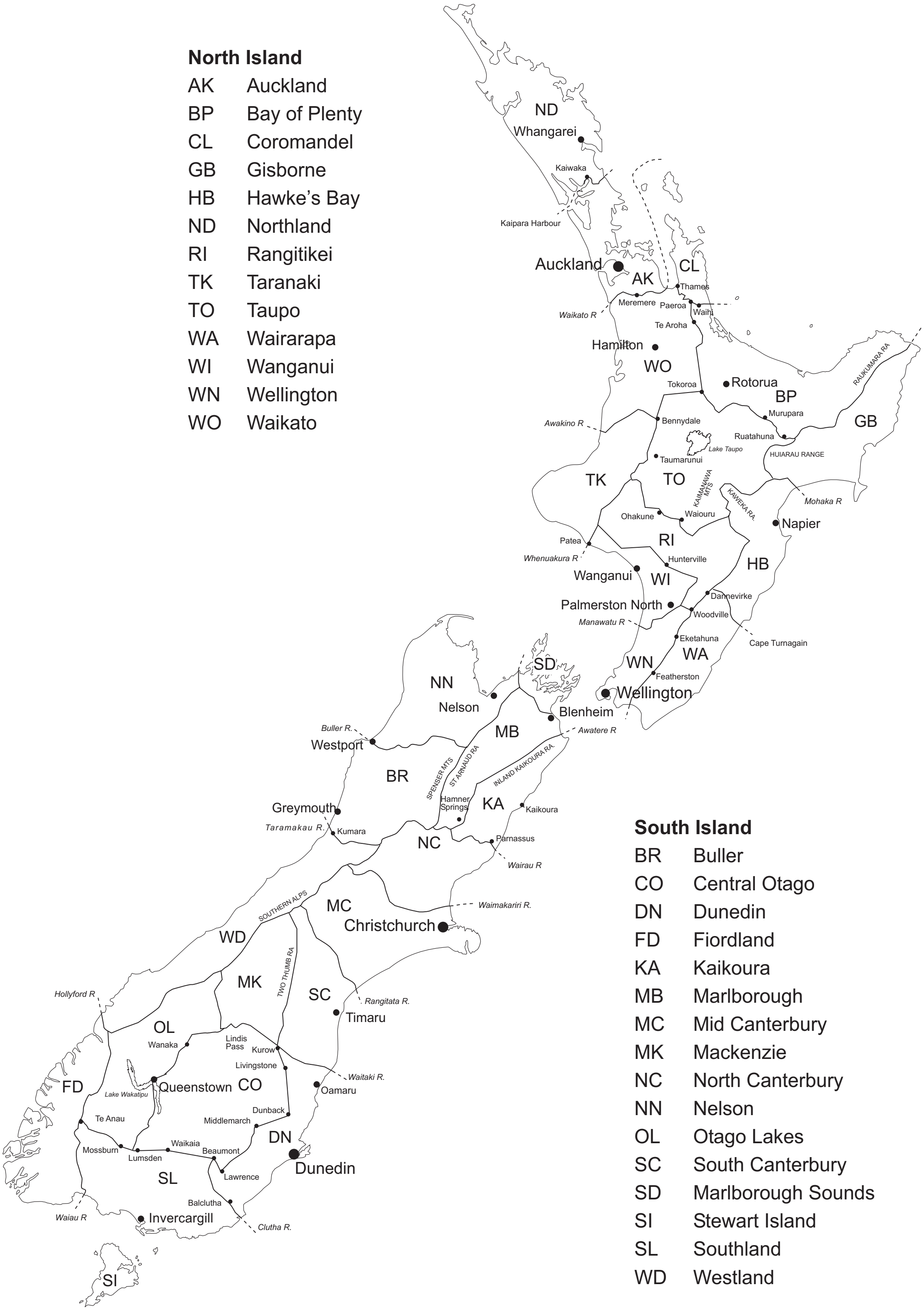
Appendix 3 Wood supply regions and constituent territorial authorities

There are currently 73 district and city councils in New Zealand. These are grouped to form 10 wood supply regions of broadly similar growth patterns for radiata pine, representing wood supply and processing catchments.

Wood Supply Region	Territorial Authority
North Island	
Northland	Far North District
	Whangarei District
	Kaipara District
	Rodney District
Auckland	North Shore City
	Auckland City
	Waitakere City
	Manukau City
	Papakura District
	Thames-Coromandel District
	Hauraki District
	Franklin District
	Waikato District
	Matamata-Piako District
Central North Island	Hamilton City
	Waipa District
	Otorohanga District
	Waitomo District
	Ruapehu District
	South Waikato District
	Taupo District
	Tauranga District
	Western Bay of Plenty District
	Rotorua District
	Kawerau District
	Whakatane District
	Opotiki District
East Coast	Gisborne District
Hawke's Bay	Wairoa District
	Hastings District
	Napier City
	Central Hawke's Bay District
Southern North Island	New Plymouth District
	Stratford District
	South Taranaki District
	Wanganui District
	Rangitikei District
North Island (continued)	
Southern North Island (continued)	Manawatu District
	Palmerston North City
	Tararua District
	Masterton District
	Horowhenua District
	Carterton District
	South Wairarapa District
	Kapiti Coast District
	Upper Hutt City
	Porirua City
	Wellington City
	Lower Hutt City
South Island	
Nelson & Marlborough	Nelson City
	Tasman District
	Marlborough District
	Kaikoura District
West Coast	Buller District
	Grey District
	Westland District
Canterbury	Hurunui District
	Waimakariri District
	Christchurch City
	Banks Peninsula District
	Selwyn District
	Ashburton District
	Timaru District
	Mackenzie District
	Waimate District
Otago & Southland	Waitaki District
	Dunedin City
	Queenstown-Lakes District
	Central Otago District
	Clutha District
	Gore District
	Southland District
	Invercargill City

Source: *National Exotic Forest Description* as at April 2001, Ministry of Agriculture and Forestry, Wellington, New Zealand.

Appendix 4 New Zealand Bioregion boundaries (after Crosby et al. 1976)



North Island

AK	Auckland
BP	Bay of Plenty
CL	Coromandel
GB	Gisborne
HB	Hawke's Bay
ND	Northland
RI	Rangitikei
TK	Taranaki
TO	Taupo
WA	Wairarapa
WI	Wanganui
WN	Wellington
WO	Waikato

South Island

BR	Buller
CO	Central Otago
DN	Dunedin
FD	Fiordland
KA	Kaikoura
MB	Marlborough
MC	Mid Canterbury
MK	Mackenzie
NC	North Canterbury
NN	Nelson
OL	Otago Lakes
SC	South Canterbury
SD	Marlborough Sounds
SI	Stewart Island
SL	Southland
WD	Westland

Appendix 5 Canopy Indicator Assessment codes for scoring possum damage to pine trees

Life-history stage

Identify the life-history stage of the tree using one of the following categories:

1	Seedling/Sapling	< 2 m tall.
2	Immature tree	> 2 m tall; basal portion of the stem still vulnerable to herbivore damage.
3	Mature tree	strong apical growth, which is still vulnerable to arboreal browsers; basal log no longer susceptible to herbivore damage.
4	Overmature tree	rounded crown lacking apical dominance; little if any continuing height growth; damage by possums or other vertebrate herbivores no longer an issue.

Leader damage

Classify the status of the leader using one of the following categories:

1 Single, undamaged primary leader
2 Primary leader undamaged but overtopped by one or more lateral branches
3 Primary leader damaged but remains dominant
4 Primary leader damaged or dead and/or overtopped by a single lateral branch (hockey stick)
5 Primary leader damaged or dead and/or overtopped by two lateral branches (double leader)
6 Primary leader damaged or dead and/or overtopped by more than two lateral branches (multileader)
7 Primary leader broken, dead or missing and not overtopped by one or more lateral branches (dead top)

Where the primary leader is overtopped by a lateral branch record the whorl from which the overtopping lateral originated (e.g., a primary leader overtopped by a single lateral from whorl 3 would be recorded as 4/T-2)

Lateral branch damage

Record the number of lateral branches in each of the top two whorls (T, T-1), and in other whorls (e.g., T-4) that are

• Unaffected	at the normal angle to the main stem
• Depressed – above the horizontal plane	at > the normal angle but < 90^{o} to the main stem
• Depressed – below the horizontal plane	at > 90^{o} to the main stem

Assess only branches originating from distinct whorls on the main stem. Exclude whorls in which the lateral shoots have not yet developed needles.

Needle loss/displacement

Record the degree of needle loss on the leader and the top two whorls of lateral branches using the following scale.

0	Nil	no visible loss of needles
0.5	Few	minimal (< 5%) loss of needles
1	Light	< ⅓ needle loss
2	Moderate	⅓ – ⅔ needle loss
3	Severe	> ⅔ needle loss

Record the degree of needle displacement over the upper third of the canopy as

n	none	no (or only very slight) visible displacement of needles
s	some	some needles (< 20%) show signs of displacement
a	a lot	a lot (> 20%) of needles displaced

Bark damage

Record the severity of bark biting or stripping to the basal stem (below 2 m), main stem (above 2 m), leader, and lateral branches using the following scale. Use the notes column to record whorls with lateral branches that have been damaged.

0	Nil	no visible damage
1	Light	< ⅓ stem or branch circumference affected
2	Moderate	⅓ – ⅔ stem or branch circumference affected
3	Severe	> ⅔ stem or branch circumference affected
4	Extreme	stem or branch completely girdled.

Record the age of bark damage as recent (r) or older (o). Recent bark damage is characterised by the presence of sap/resin stains similar to those associated with pruning wounds. Older wounds are typically calloused.