Foliar Browse Index: A Method For Monitoring Possum *(Trichosurus vulpecula)* Damage To Plant Species And Forest Communities

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Summary

Since their initial introduction in c.1840 Australian brushtail possums (*Trichosurus vulpecula*) have colonised most forested areas on the main islands of New Zealand. Damage caused by this nocturnal arboreal marsupial includes the progressive reduction and elimination of preferred food species, and can lead to the collapse of forest canopies over large areas. Possum control is now a large and growing industry in New Zealand. Where the protection of vegetation is the primary reason for reducing possum populations, 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 review existing techniques for monitoring possum damage to forests, discuss the design of vegetation surveys to monitor possum damage, and describe a new method for assessing possum damage to plant species and forest communities. The Foliar Browse Index method uses ground-based assessment of plant indicator species to determine the impact of possums on forests and/or vegetation response to possum control. It can also be used to monitor the impact of possum browsing or other damaging agents (e.g., insects, wind, frost) on individual plant species. The method uses permanently marked individuals to determine trends in the foliar cover of tree canopies, and possum damage to leaves and stems. Options for analysing data are outlined.

Keywords: conservation, forest, plant indicator species, possum damage, *Trichosurus vulpecula*, vegetation monitoring.

1 Introduction

Brushtail possums (*Trichosurus vulpecula*) were first introduced from Australia c.1840 to establish a fur trade. The subsequent spread of this nocturnal arboreal marsupial was accelerated by over 450 liberations (Pracy 1974), and today few forested areas on the main islands of New Zealand remain uncolonised (Cowan 1990).

Possums are opportunistic feeders, browsing the foliage, flowers and fruit of a wide range of plant species (Kean & Pracy 1953, Green 1984) and predating forest birds and invertebrates (Cowan & Moeed 1987, Brown *et al.* 1993). However, a few key plant species characteristically form the bulk of the diet. Where these species are major structural components of forests, possum damage is extensive and may lead to complete canopy collapse over large areas (Batcheler 1983, Payton 1987, Rose *et al.* 1992). Conversely, where browsing of the dominant tree species is minimal (e.g., *Nothofagus* spp.), floristic composition but not forest structure is typically affected (Wardle 1984).

Possum control is now a large and growing industry in New Zealand. Where the protection of indigenous forest vegetation is the main reason for control, we need to be able to monitor possum damage to vegetation to help determine:

- When possum control is required.
- Which areas should have priority for possum control.
- Whether control operations achieve their goals.
- When further control measures will be necessary.

Sound quantitative techniques are needed to make reliable inferences and predictions about the nature, severity and extent of possum damage. In this manual we review existing techniques for monitoring possum damage to forests, discuss the design of vegetation surveys to monitor possum damage, and describe a new method for assessing possum damage to plant species and forest communities.

1.1 Techniques for monitoring possum damage to forest canopies

The influence of introduced animal pests on native forest ecosystems has been extensively monitored throughout New Zealand over the last 40-50 years (Stewart *et al.* 1989). Most studies have focused on the impact of ground browsers (deer, goats) on forest understorey vegetation. Only in the last 25 years have attempts been made to quantify damage to forest canopies caused by possums (Meads 1976, Leutert 1988, Payton 1988, Pekelharing & Batcheler 1990, Atkinson 1992, Payton *et al.* 1997).

1.1.1 Descriptive accounts

There are numerous descriptive accounts of possum damage to indigenous forests, ranging from broad overviews (e.g., Kean & Pracy 1953, Batcheler & Cowan 1988) to detailed descriptions of possum impacts in specific areas or vegetation types (e.g., Zotov 1949, Pekelharing & Reynolds 1983). These accounts are largely subjective and strongly influenced by the authors' observational skills and perceptions (e.g., Kirk 1920, Batcheler 1983). The RECCE plot, a standardised non-area method of vegetation description (Allen 1992), records animal (deer, goat, possum etc.) damage to plant species as light, medium or heavy. Data of this kind have been used to describe the impact of ungulates on forest understorey vegetation (e.g., Wardle 1974) and could be used to assess the extent of possum damage to forest canopies.

1.1.2 Permanent forest plots

The traditional approach to monitoring change in forest communities is to tag and make repeated measures of trees, saplings, and seedlings on permanently marked plots (Allen 1993). This approach will give some information about changes taking place in the forest canopy in that it will identify turnover in the canopy tier. However, because individual trees are normally only recorded as live or dead, changes in parameters such as stem density and basal area are not sensitive short-term indicators of canopy damage. In the longer term, permanent plots provide detailed information on changes in both the composition and structure of the vegetation that is not readily obtainable using other methods.

1.1.3 Point-height intercept (PHI)

The point-height-intercept approach involves projecting a point or cylinder up (or down) through the vegetation and recording what it intercepts. In short (< 3m) vegetation a graduated pole is commonly used (Scott 1965, Dickinson *et al.* 1992). For taller vegetation a sighting device (usually a rifle scope or a monocular lens) is used, mounted on a gimble to ensure a vertical line of sight (Park 1973, Leathwick *et al.* 1983).

Point-height-intercept methods can provide a range of information on the composition and structure of forests (Park 1973). With repeat measurement this technique should be able to be used to detect changes in both forest canopy and understorey vegetation. However it will only provide information on browsing impacts if the foliar intercepts are recorded as browsed/unbrowsed and the browser identified.

In forests the major problems with PHI techniques are the multi-layered nature of the vegetation and the accurate measurement of the height of intercepts. Data collection is also time consuming. PHI has proved effective for monitoring non-forest communities (Scott 1965, Dickinson *et al.* 1992), but has little to recommend it as a method for monitoring canopy vegetation in tall forest.

1.1.4 Photopoints

Photopoints, usually an oblique photograph taken from a marked point, have been used in many parts of New Zealand to record vegetation change. They can provide a good visual record of changes in the foliage cover and extent of dieback in tree canopies but are not readily ammenable to quantitative analysis (Beadel 1987), and cannot be used to assess the extent or severity of browsing. Their use is most appropriate where tree canopies are clearly visible, and where there have been no changes in the understorey which would obscure the field of vision.

1.1.5 Hemispherical (fish-eye) photography

The technique uses an extremely wide-angle (fish-eye) lens to take photographs looking up through the forest canopy. In New Zealand it has been used to quantify understorey light environments in conifer-broadleaved (Veblen & Stewart 1982) and mountain beech[1] (Hunt & Hollinger 1988) forests.

Fish-eye photography can provide an accurate measure of canopy cover and light penetration (Lasko 1980). It does not allow individual plant species to be identified or browsing to be quantified. The development of computerised analysis systems (Chan *et al.* 1986, Rich 1989) has largely eliminated the lengthy time required for image analysis, making fish-eye photography a practical means of assessing changes in forest canopy cover. To monitor change (i.e., repeat measurement) the ability to relocate the exact position from which the original photo was taken is critical. As with other photographic techniques, it is easy to amass a much larger number of photographs than are needed or can be readily processed.

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[1] See Appendix 7 for botanical names of plant species mentioned in the text

1.1.6 Canopy scoring

Direct observation of tree canopies has been widely used to assess the impact of insect populations (Wickman 1979, Fox & Morrow 1983, Landsberg 1989), nutrient deficiency (Will 1985, Hunter *et al.* 1991), and pollutants (Innes 1988) on forest health. Most studies are of one or a few dominant, timber producing species. Tree canopies are assigned to one of a series of predetermined classes, often defined using diagrams or photographs (Innes 1990). Because it is a scoring methodology rather than one based on counts or measurements, careful attention needs to be paid to questions of reliability and repeatability (Innes 1988, Innes & Boswell 1990).

In New Zealand several studies have quantified possum damage to forest canopies by direct observation of either individual leaf bunches (Meads 1976, Payton 1988) or whole tree canopies (Leutert 1988, Atkinson 1992, Payton *et al.* 1997). The Foliar Browse Index method described in this manual combines a canopy-scoring approach with the use of indicator species to provide an assessment of possum damage to forest communities.

1.1.7 Remote sensing

Aerial photography

The use of aerial photographic images to assess damage and monitor change in New Zealand forest canopies is still at an experimental stage. Trials using colour-infrared aerial photographs of pohutukawa forest on Rangitoto Island in the Hauraki Gulf have shown a good relationship between remotely-sensed measures of total green leaf biomass and field scores of percentage leaf cover (Trotter 1992). This work is being extended to more complex forests and steeper terrain (Trotter & Brown 1999).

Visual aerial photographic interpretation has been used for some decades for large-scale mapping of forest vegetation and damage to forest canopies (Avery 1966). In New Zealand, Rose *et al.* (1988) have shown that the amount of dieback visible on aerial photographs is strongly correlated with ground-based measures of defoliation (cf. section 1.1.4) in major canopy tree species such as southern rata and Hall's totara. Conspicuous dieback is mapped using a predetermined damage scale in spatial units defined by topographic features such as creeks, ridges, or bluff systems. Data analysis and map production are achieved with the aid of a geographic information system. Recent studies include mapping possum damage to forests in central and southern

Westland (Rose *et al.* 1988, 1992, 1993) and a study of possum-vulnerable forests in the Department of Conservation's Nelson/ Marlborough Conservancy (Rose *et al.* 1995).

Airborne video

This is a technology developed by the USDA Forest Service and recently evaluated in New Zealand by the New Zealand Forest Research Institute (Hosking *et al.* 1992, Hosking 1995). It involves using a video camera fitted to a fixed-wing plane or helicopter to obtain images of the forest canopy and includes a video image-processing system (Pywell & Myhre 1990). Advantages of the airborne video approach include the low cost of video tapes, ability to acquire video images in weather conditions not suitable for aerial photography, and the immediate availability of the video images. Disadvantages include difficulty with the accurate relocation of flight paths for repeat measurement, a lower resolution than for photographic film, and the potentially less permanent nature of video film as a storage medium. As with other remote sensing techniques the usefulness of airborne video hinges on the ability of the image-processing system to resolve and quantify forest canopy characteristics from the video footage.

Satellite imagery

Remote sensing of satellite images has major potential for the large-scale assessment of changes in forest canopy condition in New Zealand, once smaller areas are able to be resolved and the relationships between spectral signature, vegetation type, and degree of damage have been established (Trotter & Brown 1999). In common with other remote sensing techniques, satellite image analysis must be accompanied by adequate ground survey to confirm the validity of the analyses and to determine the cause of the changes or damage observed (Payton 1990).

2 Designing A Survey To Monitor Possum Damage To Vegetation

2.1 Objectives

You need to base the design of a vegetation monitoring programme on a clear statement of the problem to be investigated and the objectives of the study (Jongman *et al.* 1987). This will form the basis for decisions about sampling strategies and design, and will help ensure that the data you collect can be reliably used to answer the questions your study was set up to examine.

Where a study has multiple objectives care needs to be taken to ensure that the sampling strategy and design can 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 in sampling strategy, design or methodology do not compromise the outcomes of both the original and the revised monitoring programmes.

2.2 Sampling strategies

A well chosen sampling strategy is important because the results of your survey depend not only on clearly defined objectives and appropriate methods of analysis, but also on the data you collect (Jongman *et al.* 1987).

Your purpose in monitoring possum damage to vegetation will usually be either to justify possum control through documenting ongoing vegetation decline, or to judge the success of control in improving vegetation condition. You need to determine whether the objectives of the study require an assessment of the overall condition of and degree of possum damage to forest communities or species, or the ongoing decline or recovery of possum-damaged individuals. These scenarios require different sampling strategies (choice of species and 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.

2.2.1 Monitoring possum damage to forest communities or plant species

To determine the extent and severity of possum damage to the health of forest communities, you need to include all or at least a representative selection of commonly occurring possum-preferred species in the monitoring programme. This should include subcanopy, canopy, and where appropriate emergent species. When selecting individuals for inclusion in a monitoring programme you need to ensure a representative sample of each species, which is not biased by current tree health or the degree of past or present possum damage. These constraints also apply when the health of individual (e.g., rare or endangered) species is being monitored.

2.2.2 Monitoring possum-damaged individuals

If the objectives of the study relate to the ongoing decline or recovery of possum-damaged individuals, you can bias your sampling strategy towards plant species which are highly possum-preferred and individuals that are currently being browsed by possums. Note however that while this latter approach will allow you to assess the current and future status of the sample population of browsed individuals, it will not allow you to make similar statements about the status of the species over the whole sample area. Before adopting this type of sampling strategy think very carefully about whether it will enable you to fulfill the objectives of your study, and whether it will limit the usefulness of the data for other (e.g., comparative) studies.

2.3 Sampling design

The crucial 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 individuals to be monitored.

2.3.1 Stratification

Where you suspect factors such as landform, forest type, distance from the forest margin, or the patchy nature of the possum population are systematically affecting the level of possum damage to a plant species being sampled, you need to stratify the sample of that species. Stratification serves two purposes. Firstly, it enables separate generalisations to be made about different parts of a larger study area. This is appropriate when, for whatever reason, the condition of the plant species being monitored differs markedly in different parts of the study area (e.g., a plant species that is browsed heavily in the gullies but is largely unbrowsed on the exposed ridges). The second purpose of stratification is to reduce sample variability, and thereby increase the sensitivity of statistical testing. Stratification involves dividing the study area into units or strata based on the factor(s) influencing the variability in possum damage, and randomly selecting individuals to be monitored from within each stratum. If the objectives of your study require an assessment of possum damage:

- Over the whole study area, base the sample size for each stratum on the relative abundance of the species in that stratum.
- For each stratum, monitor a similar sufficiently large (see Section 2.3.3) sample in each stratum.

In the case of monitoring associated with possum control operations, where the strata represent control and non-control treatments, divide sampling resources equally.

2.3.2 Representative sample

To draw valid conclusions about the extent and severity of possum damage to the plant species you are monitoring you need to:

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

The individuals sampled must be representative of the total population of the species within the stratum or study area. If plants are selected non-randomly (e.g., those that are close to a track and therefore readily accessible) the sample will not be representative of the wider population, and cannot be used to validly estimate the parameters (e.g., foliage cover, possum browse) of that population. The individual plants 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 within a small area) 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 indigenous forests, sampling is typically carried out along a series of transects which traverse the full extent of habitat types within the study area or stratum. Where individual species are not present within all plots or are confined to specific habitats (e.g., riparian or gully communities), additional transects may be needed within those habitats to ensure an adequate sample size is obtained.

Locating transects and sample plots

The following methods for determining the placement of transects are based on Allen (1992, 1993).

- Use a grid pattern based on the X and Y coordinates found on a NZMS 260 metric map. Where monitoring is being carried out over a large area (> 200 km^2) divide the survey area into 10 x 10 km blocks. Subdivide each block (or stratum) into 1 x 1 km squares, and use random X and Y coordinates or a set of random numbers (Appendix 1) to select one square for each of the transects you propose to establish. Identify the point on a watercourse that is nearest to the centre of the selected 1-km square. This point becomes the transect origin. Randomly assign the transect to one side of the watercourse. Draw a line from the origin to the nearest main ridge or timberline.
- Divide the survey area into blocks, catchments or strata and allocate the required number of transects to each. Start at the head or mouth of a river and run a planimeter along the main stream and all tributaries. Select a random number (usually two-figured) and stop when the planimeter reaches that number. This point is the transect origin. Randomly assign the transect to one side of the watercourse, and draw a line from the origin to the nearest main ridge or timberline. Continue the process until all transects are allocated.

The compass bearing to be used in the field is determined from the transect on the map, with correction for magnetic declination.

Mark the origin of the transect with crossed pieces of "permolat" flagging containing the block/line number and transect bearing, and the transect route with sufficient horizontal "permolat" markers to make it easy to follow on future occasions. Make a generous allowance for tree growth when attaching line markers and tree tags. Along each transect establish a maximum of 10 equally spaced sample plots. The first plot should be a minimum of 20 m from the transect origin, and subsequent plots not less than 100 m apart. The minimum distance of 100m is set to ensure that adjacent plots are independent, and not subject to very similar environmental influences. Mark each plot with crossed pieces of "permolat" bearing the line/plot number, attached to the tree nearest the plot centre. The area of the plot is defined by a circle with a radius of 20 m around the plot centre tree. A list of equipment required to establish a transect is given in Appendix 2.

Record the data you collect using the format in Appendix 3A.

For each transect record

Approach: a brief description of the terrain and vegetation. Include notes on damage caused by wind, snow, insects, fire, or other influences.

Location: a sketch of the transect and plot locations emphasising landscape features (e.g., slips, gullies, creeks) that will help to relocate the transect.

Notes: any other pertinent observations and impressions.

Birds: record only species positively identified by sight or sound.

For each plot record

Altitude: measured to the nearest 10 m. Barometric altimeters should be reset each morning, or more frequently during changeable weather, from points of known altitude on the topographical map.

Aspect: measured to the nearest 5° at right angles to the general lie of the plot.

Slope: the average slope of the plot, measured with an Abney level or hypsometer. Describe the shape of the slope as convex, concave, or linear.

Physiography: described using four categories - Ridge (including spurs), Face, Gully, or Terrace.

Drainage: record as Good (little accumulation of water after rain), Moderate (water accumulates in hollows for several days), or Poor (water stands for lengthy periods). More refined drainage scales (e.g., Taylor & Pohlen 1962) are available and may be used. They do not, however, overcome the problem that subjective point-in-time assessments of soil drainage are difficult to interpret at other than the extreme ends of the scale.

Canopy height: the average height of the dominant canopy species, recorded to the nearest metre. Observer accuracy should be checked regularly by actual measurement, using a rangefinder or a triangulation method (Goulding & Lawrence 1992, Goulding 1995).

Canopy dominants: record the species which provide the majority of the canopy cover on the plot, in order of importance.

Browsing:	record damage caused by species other than possums as light (< 10% browsed leaves), moderate (11 - 50% foliage browsed), or heavy (> 50% foliage browsed). Record the animal species responsible where this can be reliably determined, or state unknown.

Selecting a representative sample

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

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

For each species you sample select the individual nearest the plot centre that meets the criteria for the selection of sample trees (Section 3.2). All sample trees must be within a 20 m radius of the plot centre. Where indicator species are uncommon or have highly clumped distributions more than one individual may be sampled on each plot. In this case sample trees must be at least 10 m apart, and data from all individuals must be combined (i.e., the average calculated) to give a single value for each indicator species present on the plot.

Tag sample trees at breast height (1.4m) with the tag and a vertical "permolat" marker facing the plot centre, and record the direction (degrees) and distance (m) of the tree from the plot centre. This will make it easier to relocate the tree on future occasions.

2.3.3 Sample size

If you select a sample that is too small you may be unable to detect significant changes that are taking place, and may have difficulties interpreting the results of the survey. Conversely, if you select a sample that is too large for the objectives of your study you will waste effort, time, and money.

The data we have analysed during the course of our trials indicate that you require a sample of 50 permanently marked individuals to reliably detect (with a probability of 80%) whether a 10% change in the foliar cover score is statistically significant ($P<0.05$). When more than one individual of a species is sampled on a plot the individuals do not constitute independent replicates, and cannot be used to reduce the number of sample plots required for that species. Where trees are not permanently marked there is a loss of statistical sensitivity through not remeasuring the same individuals. To overcome this the sample size should be increased to 70 individuals of each indicator species.

Where you are monitoring uncommon species or small patches of forest you may not be able to find or clearly observe (Section 3.2) 50 individuals of a species. When the percentage of individuals sampled exceeds c.10% of the population, a modification to the standard variance calculations is required. This reduces the width of the confidence intervals for the estimated parameters (e.g., foliage cover), provides greater precision from the sample, and may allow the sample size to be reduced. The modification requires the standard error to be multiplied by the square root of (1- n/N) where n is the sample size and N represents the estimate of the population size. For example if the estimated population size is 100, and 50 of these individuals are sampled, the standard error will be 70% of the value calculated without this correction. To work out the required sample size in this situation use the following formula.

$$\text{New sample size} = 50 \times N/(N + 50)$$

where N represents the estimated population size. For the example above this gives a required sample size of 33.33, or 34 individuals. Where you sample all or nearly all the individuals in the population, the sample of individuals ceases to be a sample and approaches or becomes a census. The standard variance calculations required for statistical comparisons no longer apply as a census determines parameters without sampling error. For a more detailed discussion of sampling-related issues see Jongman *et al.* (1987) or Underwood (1994).

3 The Foliar Browse Index Method

The Foliar Browse Index method uses plant indicator species to assess the impact of possums on forest health and/or vegetation response to possum control. It can also be used to monitor the impact of possum browse on individual (including rare or endangered) plant species. The method uses the assessment/reassessment of permanently marked individuals to determine trends in the foliar cover and possum damage to leaves and stems. It can also be used to monitor canopy damage from a wide range of other biotic (e.g., insects) and abiotic (e.g., wind, frost) agents.

We recommend you use two-person teams for establishing or remeasuring Foliar Browse Index plots. A team can usually complete up to 10 plots along a transect within a day, although this will vary with the number of indicator species chosen and the nature of the terrain. A list of equipment you will need is given in Appendix 2.

3.1 Choice of indicator species

Several factors need to influence your choice of plant indicator species. Whether the objectives of your study are to monitor changes in forest health or possum damage, indicator species should be:

- Preferred possum food species.
- Moderately common and well distributed through the study area.
- Readily visible (multi-tiered emergent species such as northern rata are frequently difficult to observe from the ground).

The use of epiphytes (e.g., mistletoe species) as indicator species is not a problem, provided you have a good pair of binoculars and can devise a method for tagging and relocating the individuals being monitored (see Section 3.5). Appendix 6 contains a list of commonly used indicator species.

Browsing damage can be more readily distinguished in larger-leaved, shorter species (e.g., fuchsia, pate) than in small-leaved, tall species such as northern rata and totara. Where possums typically remove whole leaves or young shoots (e.g., totara) the severity of browsing but not defoliation tends to be under-estimated or impossible to detect.

Where you suspect factors other than possum browsing (e.g., frost, salt spray, wind damage) are causing damage to forest canopies the use of a non possum-palatable indicator species can help determine the extent to which the observed damage is possum-related.

3.2 Criteria for selecting sample trees

Two factors are important when selecting individuals to be monitored.

- Trees should have a canopy out of reach of ungulates (> 2m above ground level) and a stem diameter of at least 5cm.
- The majority of the canopy needs to be clearly visible from ground level and unlikely to be obscured by understorey regrowth. Avoid individuals where the canopy is obscured by vines (e.g., supplejack, lawyer, Old Man's Beard) or epiphytes (e.g., *Collospermum, Astelia*).

3.3 Assessment of sample trees

The **Indicator species assessment** sheet (Appendix 4) summarises the data to be obtained from each sample tree. Using the format in Appendix 3B, **for each tree record:**

- **Transect/plot number (Column 1), direction** (compass bearing) **(Column 2)** and **distance** (m) **(Column 3)** from the plot centre.
- **Species (Column 4)**, using the first three letters from both the generic and specific names. For example *Metrosideros robusta* (northern rata) is recorded as MET rob (see Hall 1992).
- **Tag number (Column 5)** and **stem diameter** (cm) **(Column 6)**, measured at breast height (1.4m), 1 cm above the tree tag, with the diameter tape at right angles to the axis of the stem.
- **Abundance (Column 7)** on and around the plot as Abundant (> 35% individuals), Common (11-35% individuals), Occasional (1-10% individuals), or Rare (< 1% individuals). This can be expected to change over time where possums are progressively eliminating individuals of preferred food species (Campbell 1984).
- The **Tier (Column 8A)**, Emergent (canopy isolated and above that of neighbouring trees), Canopy (forming part of the main canopy), or Subcanopy (below the main canopy), and **Segment (Column 8B)**, single Stem or whole Tree. Possums prefer foliage growing in full sunlight (Payton 1988). In emergent trees most foliage is exposed to direct sunlight, in canopy trees this is reduced to the top third of the canopy, and subcanopy individuals usually have little or no sun foliage.

- **Foliage cover (Column 9)** using the 10-point **Foliage Cover Scale** (Appendix 5). Wherever possible score foliage cover (and other parameters) from the side of the tree nearest the plot centre. Stand near the base of the tree where you have a good view of the canopy foliage. Do not include the trunk and major branches, areas of the canopy that are dead, or foliage below two metres (i.e., within range of ground browsing animals) in your assessment. Using the scale first determine which of 5 broad classes (denoted by horizontal lines) best fits the foliage cover of the whole canopy. Within that class select the square which most closely resembles the foliage cover of the canopy. From left to right, the columns on the scale represent a more to less uniform distribution of foliage.

  Where a tree canopy can be clearly divided into several discrete segments, each segment may be scored separately. Draw a sketch to enable reliable identification of the canopy segments when the tree is reassessed, and also to score the tree canopy as a whole. For analysis purposes canopy segments cannot be regarded as being independent of each other (see Section 2.3.2).

  We recommend that both the Foliage Cover Scale and the Indicator Species Assessment sheets be laminated to reduce wear and tear during fieldwork.

- The extent of **dieback** in the upper third of the canopy **(Column 10T)**, and the average for the whole of the canopy **(Column 10W)**. Dieback is the **conspicuous presence** of dead branches or branchlets, but not recently defoliated live twigs. It may be caused by a range of biotic or abiotic agents, including possums. Record the presence of dieback only if it is conspicuous, using the following categories:

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**	

  Use **X** only when you cannot see the canopy sufficiently clearly to assess the parameter (e.g., dieback, recovery, browse, use), NOT when you suspect the parameter is present but cannot observe it.

- Where dieback has been recorded, determine the extent of any **conspicuous recovery (Column 11)** using the following categories:

NR	**No recovery**	no visible recovery
Flush of epicormic growth on the trunk and major branches in the		
U	**Upper**	upper of the canopy
L	**Lower**	lower of the canopy
W	**Whole**	throughout the whole canopy
X	**Unable to estimate**	

Epicormic growth refers to the presence of new shoots on the trunk and major branches. It does not include twig regrowth which is assessed using the Foliage Cover scale.

- The proportion of **possum-browsed leaves** (or in the case of small-leaved species such as totara, the severity of **possum-related hedging**) in the top third of the canopy **(Column 12T)**, and averaged over the whole canopy **(Column 12W)** using the following categories:

0	**Nil**	no possum-related hedging no browsed leaves
0.5	**Some**	minimal hedging <5% leaves browsed
1	**Light**	lightly hedged 5-25% leaves browsed
2	**Moderate**	moderately hedged 26-50% leaves browsed
3	**Heavy**	heavily hedged 51-75% leaves browsed
4	**Severe**	severely hedged >75% leaves browsed
X	**Unable to estimate**	

Scoring browse in canopy and emergent trees requires a good pair of binoculars and an ability to distinguish possum damage to leaves from that caused by insects and other agents (e.g., wind, frost). For most indicator species possum-browsed leaves are characterised by torn edges and jagged leaf stubbs (Fig. 1). In species such as five finger, mountain five finger and pate where possums may eat only the fleshy base of the leaf petiole, look for a carpet of freshly discarded leaves as evidence of possum foraging. Insect damage typically consists of holes and wavy, clean-edged patterns (caterpillars) or straight, finely milled edges (stick insects) (Fig.1, Meads 1976).

For totara, where the leaves are small and needle-like and browse is difficult to distinguish, hedging is used as a measure of browsing damage. Look for a hedged,

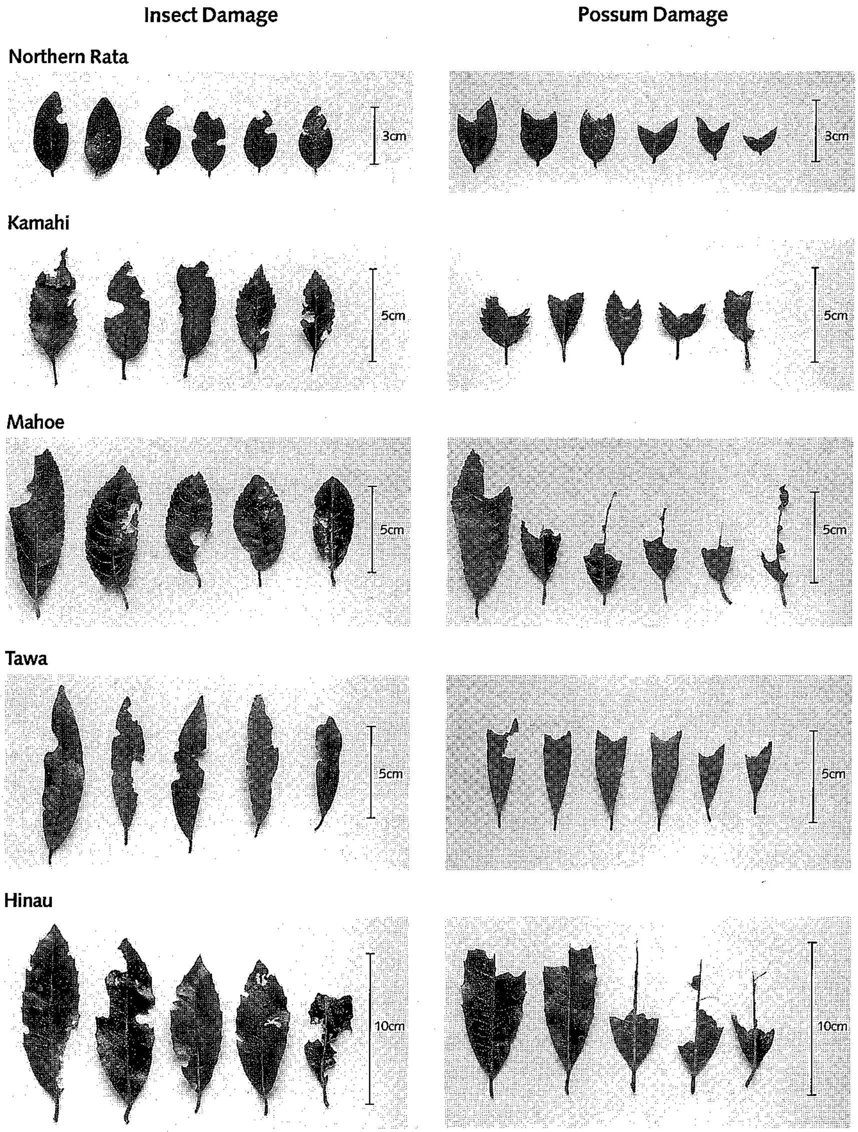

Figure 1. *Possum and insect-damaged leaves of northern rata, kamahi, mahoe, tawa and hinau.*

windshorn appearance to the canopy on the leeward side of the tree and in trees on sheltered sites. Do not take into account hedging that occurs only on the exposed windward side of trees. Where possum-induced hedging is heavy to severe few of the current season's light green shoots will remain, and the canopy will take on the dull green coloration characteristic of older totara leaves.

- Recent **possum use** of the lower 2 m of **the trunk or stem (Column 13)** using the following categories:

0	**Nil**	no scratching or bite marks on the trunk
1	**Light**	occasional scratch and bite marks
2	**Moderate**	numerous clearly defined scratch and bite marks
3	**Heavy**	bark worn smooth and evidence of a well developed possum "run".
X	**Unable to estimate**	trunk obscured by epiphytes or moss.

Evidence for possum use of trunks or stems typically takes the form of scratching and bite marks. It is most readily visible on indicator species with soft, light-coloured bark (e.g., mahoe), but may be difficult or impossible to detect where stems are covered in vines (e.g., climbing rata) or where indicator species have hard (e.g., haumakaroa) or flaky (e.g., fuchsia) bark.

- The presence and abundance of flowers **(Column 14A)** and fruit **(Column 14B)**. Flowering includes the presence of flower buds, and fruiting the presence of current season's seed capsules. Be sure you know how to recognise the flowers/fruit of the indicator species you have chosen and the period of the year over which flowering/fruiting occurs. Locally, flowering and fruiting peaks are frequently short (days, weeks) events. A list of flowering/fruiting periods for a range of plant indicator species is given in Appendix 6. Use the following categories:

0	**Nil**	no flowers or fruit visible
1	**Rare**	few flowers or fruit visible, often only in part of the canopy
2	**Occasional**	sparse flowering/fruiting, usually throughout the canopy
3	**Common**	flowers or fruits common throughout the canopy
4	**Abundant**	flowering/fruiting heavy, highly visible, and present on most branchlets.

Flowering and fruiting are assessed because of the impact possums are suspected of having on this food source for native bird species, and the regeneration potential of species such as hinau (Cowan & Waddington 1990), kohekohe, supplejack, tawa (Atkinson 1985, 1992), mistletoe (Wilson 1984), and nikau (Cowan 1991).

Interpretation of data on flowering and fruiting is not straightforward. Possum browsing is not the only reason for poor flowering and fruiting. Rats and bird species such as kereru can consume large amounts of fruit and seed (Atkinson 1992), and climatic conditions may also contribute to variability in the data. For example, at Craigieburn in inland Canterbury, what would have been scored as abundant mistletoe (*Peraxilla tetrapetala*) flowering on 18 January 1995 rated only an occasional or common score the following week, after a southerly storm stripped many of the flowers from the plants.

Intermittent (often referred to as mast) fruiting or seeding, which is a characteristic of many potential indicator species, can also lead to large differences in flowering/fruiting between years, between areas, and between individuals within the same population. Despite these difficulties, records of flowering/fruiting from permanently marked individuals can provide useful data for control vs. non-control comparisons (Pekelharing 1996), and to ascertain whether residual possum numbers are sufficiently low to allow the production of viable seed.

3.4 Emergent species

Emergent tree species are not ideal candidates for a ground-based scoring system such as the Foliar Browse Index method. Their canopies are usually multi-tiered and difficult to observe from ground level. They frequently have small leaves which makes it difficult to assess browsing damage, and they are often only present as isolated individuals. Nevertheless emergent species are conspicuous components of a wide range of native forest ecosystems and in some cases (e.g., northern rata, totara) are vulnerable to possum damage.

Unless an emergent indicator species is common in the study area, it is may be difficult to get an adequate sample (Section 2.3.3) that meets the criteria for sample trees (Section 3.2) using the transect method described in Section 2.3.2. In most instances you will need to assess emergent tree species from a series of subjectively chosen observation points. You should locate these, as far as possible, throughout the study area (Section 2.3.2). Treat each observation point as a transect containing between one and three plots. Where more than one plot is scored from an observation point, all plots must be a minimum of 100m apart to ensure their independence.

For a prominent tree at each observation point record

- **Species (Column 4)**, **tag number (Column 5)** and **stem diameter (Column 6)** of the marker tree.

For each emergent tree record

- **Direction** (compass bearing) **(Column 2)** and **distance** (m) **(Column 3)** from the marker tree.

- **Species (Column 4). Tag number (Column 5)** and **stem diameter (Column 6)**, where it is possible to get to the tree being assessed.

- **Abundance (Column 7)**, **tier (Column 8A)**, and **segment (Column 8B)** using the following categories:

U	upper third of the canopy
M	middle third of the canopy
L	lower third of the canopy
W	whole canopy

  Draw a sketch or use a photograph to ensure each segment can be reliably relocated on future occasions, and also score the tree canopy as a whole (see Section 3.3).

- **Other vegetation parameters (Columns 9-14)** as described in Section 3.3. Score dieback (top-third), recovery, browse (top-third), and stem use for the whole tree only (Appendix 3B).

3.5 Epiphytes

Epiphytes are not inherently difficult to assess using the Foliar Browse Index method, provided they are clearly visible from a relocatable vantage point. As for canopy and emergent trees a good pair of binoculars is essential. Treat each host tree as a single plot.

For the host tree record

- **Plot number (Column 1), direction** (compass bearing) **(Column 2)** and **distance** (m) **(Column 3)** from the plot centre.
- **Species (Column 4), tag number (Column 5)** and **stem diameter (Column 6)**.

For each epiphyte (e.g., mistletoe) **record**:

- **Species (Column 4)**, and **size** of the plant **(Column 6)** using the following categories

XS	extra small	$< {}^{1}/_{2}$ m wide
S	small	${}^{1}/_{2}$ -1 m wide
M	medium	1-2 m wide
L	large	2-3 m wide
XL	extra large	> 3 m wide

- **Abundance (Column 7), tier (Column 8A)** as Epiphyte, and **position** on the host tree **(Column 8B)** using the following categories:

B	lower third of the host tree canopy
M	middle third of the host tree canopy
U	upper third of the host tree canopy

T	epiphyte attached to the main trunk
I	epiphyte on the inner branches
O	epiphyte on the outer branches

- **Other vegetation parameters (Columns 9-14)** as described in Section 3.3. Dieback (top-third), recovery, browse (top-third) and stem use will usually only be applicable for large or extra large individuals (Appendix 3B).

3.6 Reassessment of sample trees

Regular (annual, biennial etc) reassessment of Foliar Browse Index plots is not necessary. However, because many of the parameters vary seasonally, plots should be reassessed in the same month as earlier assessments (see Section 4.2). Based on experience with other types of permanent plots (e.g., 20x20m forest plots), tree tags and "permolat" markers need to be checked every few years to ensure that they have not become overgrown (Allen 1993).

For each transect and plot, record the parameters set out in Section 2.3.2. This provides an update of any changes to the physical environment, and will hopefully improve the ease with which future survey parties can relocate the vegetation plots.

For each tree being reassessed follow the procedures set out in Section 3.3.

- **Take** a copy of species location data **(Columns 1-5)**, to help locate the trees to be reassessed. **Do not take** a copy of the vegetation data **(Columns 6-14)** from the previous assessment, as this is likely to influence your assessment of parameters such as foliage cover, browse and stem use.

- Where trees have been completely defoliated since the previous assessment check they have died by cutting the bark with a knife to determine whether sap is still present and the cambium intact. Supposedly dead trees have been known to spring back to life.

- Where a tagged tree is alive but completely defoliated, or has died, record the foliage cover **(Column 9)** as:

0	**Completely defoliated living tree**	No leaves remaining. Bark is intact and contains sap.
1	**Recently dead**	Fine twigs present. Bark intact but no sap present.
2	**Long dead**	Fine twigs absent. Most larger branches remain. Bark not intact.

Remove the tag from trees recorded as long dead.

- Where trees have died they may be replaced by another individual from the same plot. In this case select the live individual that is closest to the plot centre. Note that the replacement of dead trees will distort analyses of changes between sampling periods (see Section 5). If tree mortality from possum damage or other causes (e.g., windthrow) is severely reducing the size of your sample, select another sample of the species (see Section 2.3) and treat this as a separate indicator species.

4 Technical Considerations

Because many of the components of the Foliar Browse Index 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).

4.1 Observer variability

As part of the development of the method we tested variation between observers for the assessed (as opposed to measured) variables (see Section 3.3) on the Foliar Browse Index plot sheet (Appendix 3B). Testing was carried out at 6 sites using indicator species from emergent (northern rata, totara), canopy (kohekohe, mahoe, pohutukawa, toro, towai), and subcanopy (five finger, heketara, pate) forest tiers.

Where 2 observers independently assessed indicator species **abundance (Column 7)**, they agreed on 94% of occasions (n=676) that the species was either common, occasional or rare on the plot (Fig. 2A). For **tier height (Column 8)** observers independently reached the same conclusion (emergent, canopy or subcanopy) on 79% (n=676) of occasions (Fig. 2B). Two-thirds of the disagreements related to whether the tree or stem was in the canopy or subcanopy tier.

Both observers agreed on the **foliage cover** score **(Column 9)** on 42% of occasions (n=707), were not more than one class (10%) different 85% of the time or two classes (20%) different 95% of the time (Fig. 2C). Variation between observers was lowest when foliage cover scores were high (> 75%) or low (< 15%).

Observers agreed on the presence / absence of **dieback (Column 10)** in 83% (n=670) of cases (Fig. 2D). Where dieback was recorded as being present (n=252), observers agreed on its' severity (light, moderate, heavy or severe) on 72% of occasions. Most instances of disagreement related to whether dieback should be classed as light (affecting 5-25% of the canopy) or moderate (affecting 26-50% of the canopy). For trees affected by dieback, both observers agreed on the presence or absence of **recovery (Column 11)** (prominent epicormic shoots on the trunk and major branches) on 70% of occasions (Fig. 2E).

Agreement on the proportion of **possum-browsed leaves** or **possum-related hedging (Column 12)** was obtained in 73% (n=432) of cases (Fig. 2F). Where both observers were able to score damage, less than 3% of cases varied by more than 1 browse class.

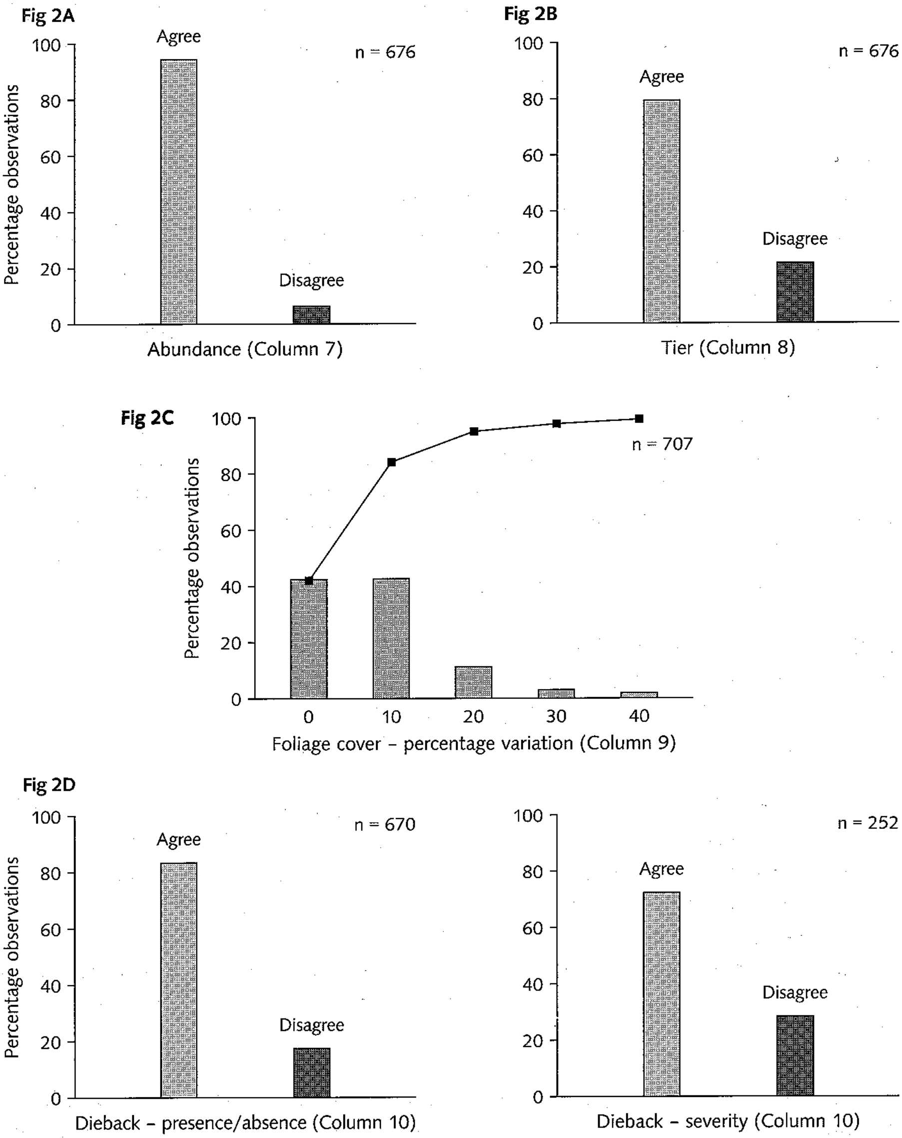

Figure 2 *Variation between observers for assessed variables in the Foliar Browse Index methodology*

Fig 2E

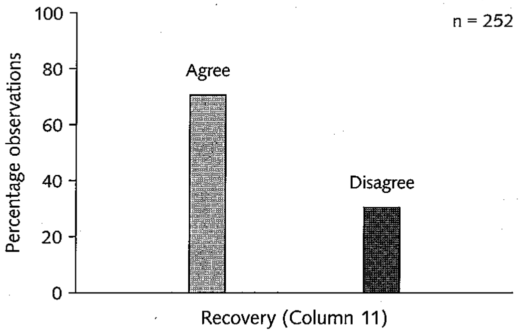

Fig 2F

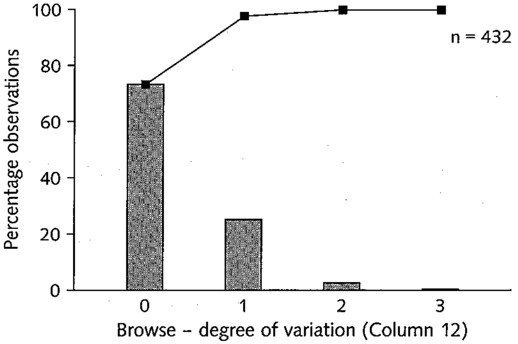

Fig 2G

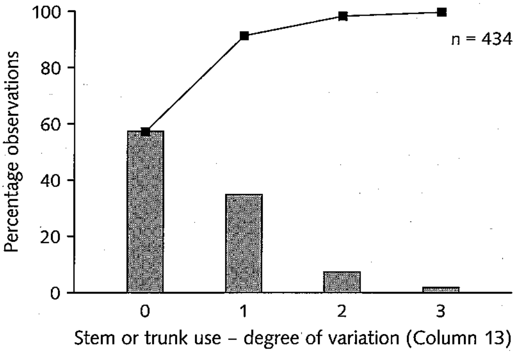

Figure 2 *Variation between observers for assessed variables in the Foliar Browse Index methodology*

The main source of disagreement was between observers who were unable to estimate browse and those who decided there were no possum-browsed leaves or possum-related hedging.

Assessment of **possum damage to trunk or stem (Column 13)** followed a similar pattern with 57% (n=434) of cases agreeing on the damage class, and less than 9% differing by more than 1 damage class (Fig. 2G). As with browsing the main source of variation was between the unable-to-estimate and no-damage classes.

Observer variability of **flowering (Column 14A)** and **fruiting (Column 14B)** was not tested, but can be expected to follow the pattern of variables such as browse or trunk damage which have a similar number of categories.

Some observers did consistently assess variables above or below the mean value obtained by a group of observers. 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 Foliar Browse Index 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.

4.2 Seasonal variability

Foliage cover, flowering and fruit production (e.g., Burrows 1994, O'Donnell & Dilks 1994), and possum browsing (e.g., Fitzgerald 1976, Coleman *et al.* 1985) vary seasonally. The optimal sampling time will depend on the objectives of the study and the choice of indicator species. Foliage cover tends to peak in mid-late summer when leaf expansion has been completed (Fig. 3A) and possum damage is usually most visible during winter and spring, before it is masked by the new season's leaf growth (Fig. 3B). Possum damage to stems did not show a seasonal pattern (Fig. 3C). Flowering and fruiting times for a range of indicator species are given in Appendix 6. They are based on available reports and publications and will vary between regions.

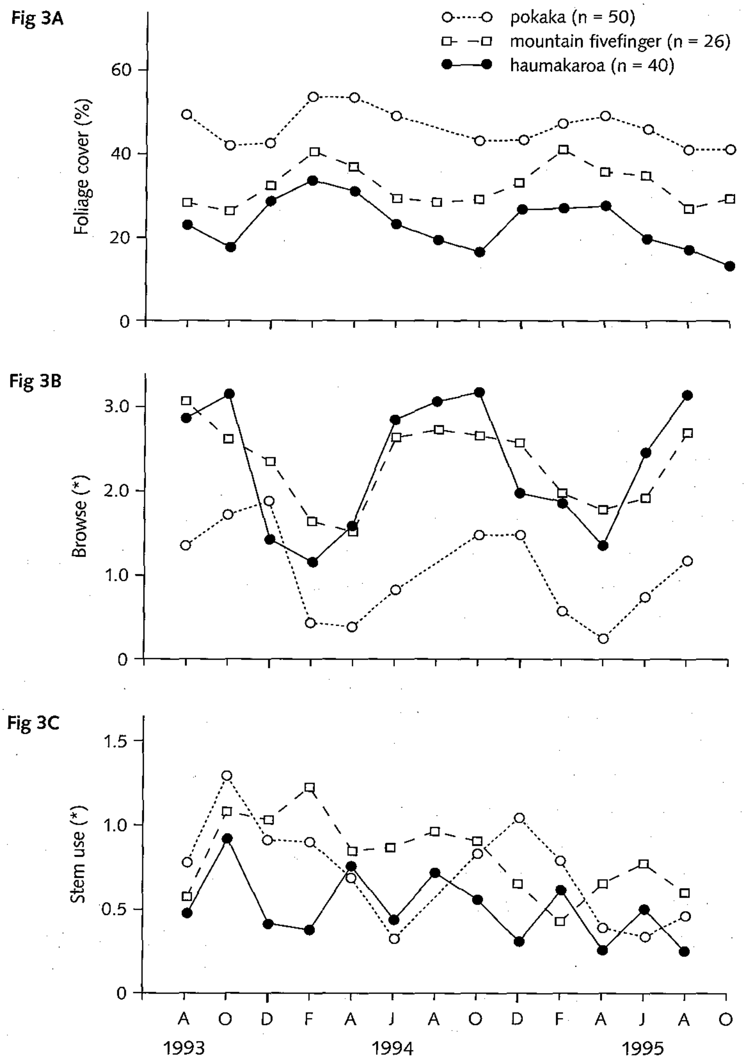

Figure 3 *Seasonal variation in foliage cover and possum browsing of three plant indicator species, Alfred River, Maruia. August 1993 - October 1995. (*see Section 3.3 for an explanation of browse and stem use scales).*

Avoid periods of rapid leaf growth or foliage loss. This is especially important for deciduous species such as fuchsia and wineberry, which at higher altitudes and in southern latitudes may only be able to be monitored over a 3-4 month period in mid-late summer.

Because seasonal changes may mask annual trends, reassessment of sample trees (Section 3.6) should be carried out in the same month as previous assessments. If during the course of a long-running study it becomes necessary to change the timing of the data collection, trees should be assessed at both the old and new times in the year the change is made. This will allow you to determine the extent to which the change in the time of data collection is affecting the results.

4.3 Background noise

Persistent possum browsing defoliates tree canopies and leads to the death of some individual trees. Possums, however, are not the only cause of damage to native tree species. A wide range of biotic (e.g.,fungi, insects) and abiotic (e.g., drought, flooding, frost, salt spray, wind) agents have been reported as damaging or killing trees in New Zealand forest ecosystems (Wardle 1991).

To determine the extent to which foliar cover estimates might be expected to vary from causes other than possum browsing we assessed annual changes over 4 years in three indicator species (kohekohe, mahoe, pohutukawa) on possum-free Waiheke Island in the Hauraki Gulf, and at two mainland North Island sites (Cape Brett, Northland and Te Tapui Scenic Reserve, Waikato) where non-controlled possum populations were present (Fig. 4). In the absence of possum browsing, foliage cover estimates for these species changed by up to 15% between annual assessments. At sites where possums were present, annual variation in foliage cover was either similar to (Cape Brett) or greater than (Te Tapui Scenic Reserve) that at the possum-free site. These results demonstrate that possum browsing is not the only factor influencing changes in foliage cover. To attribute changes in foliage cover to possum activity they need to be supported by evidence of possum browsing.

For kohekohe and pohutukawa, but not mahoe, foliage cover values on Waiheke Island were significantly greater ($P<0.001$) than those at mainland sites.

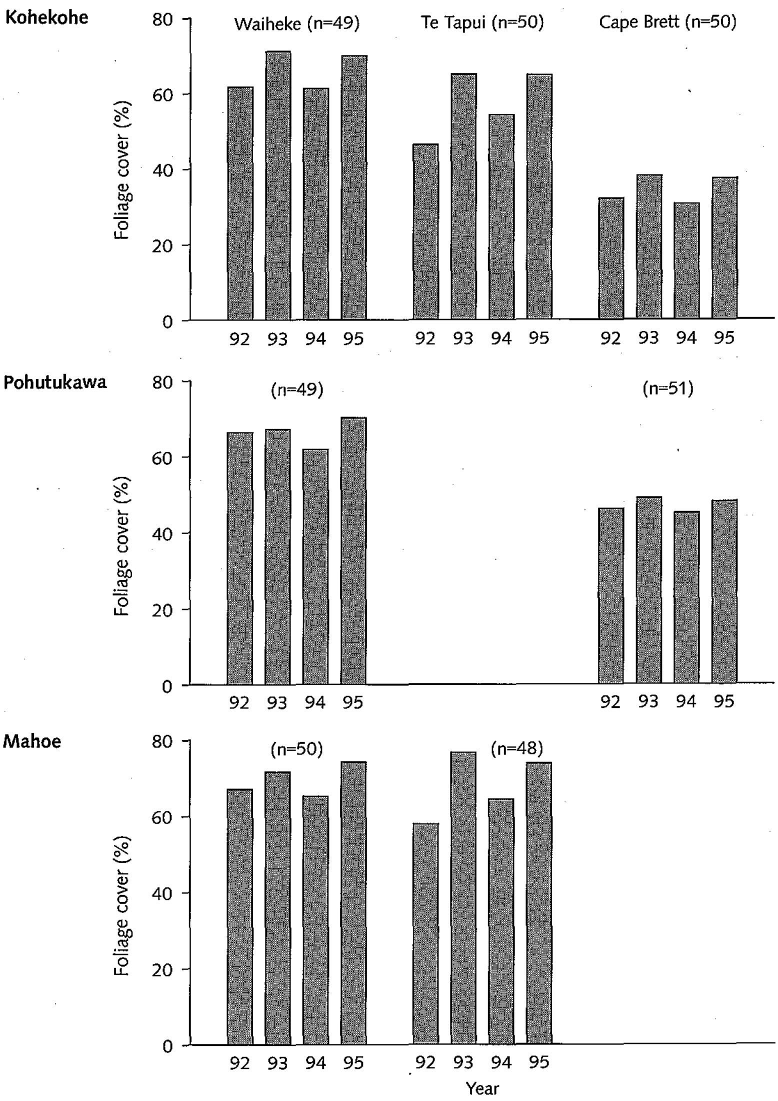

Figure 4. *Annual changes in foliage cover for three plant indicator species on possum-free Waiheke Island, and at two mainland North Island sites where possums are present.*

4.4 Relationship between foliage cover and leaf biomass

One of the questions frequently asked about indicies such as foliage cover is how they relate to actual measurable quantities, in this case leaf biomass. We tested the relationship between foliage cover and leaf biomass using subcanopy individuals of two indicator species (mahoe, pate) at Granville Forest, Westland. Trees of each species were assessed for foliage cover by one observer, partially defoliated by a second observer, and reassessed for foliage cover by the first observer. They were then totally defoliated and the foliage from both defoliations dried, and weighed.

For both species there was a significant linear relationship (mahoe, $P<0.001$; pate, $P<0.01$) between foliage cover (assessed using the foliage cover scale) and foliage biomass, for foliage cover scores below 60 percent (Fig. 5A). There was also a significant linear relationship (both species, $P<0.001$) between percentage changes in foliage cover and dry weight (Fig. 5B).

While it would be unwise to extrapolate these findings to all plant indicator species, the results do indicate that estimates of foliage cover can provide a reliable index of foliage biomass. We would expect this relationship to hold best for indicator species with relatively few leaf layers, and to be least reliable for multi-tiered (e.g., emergent) species.

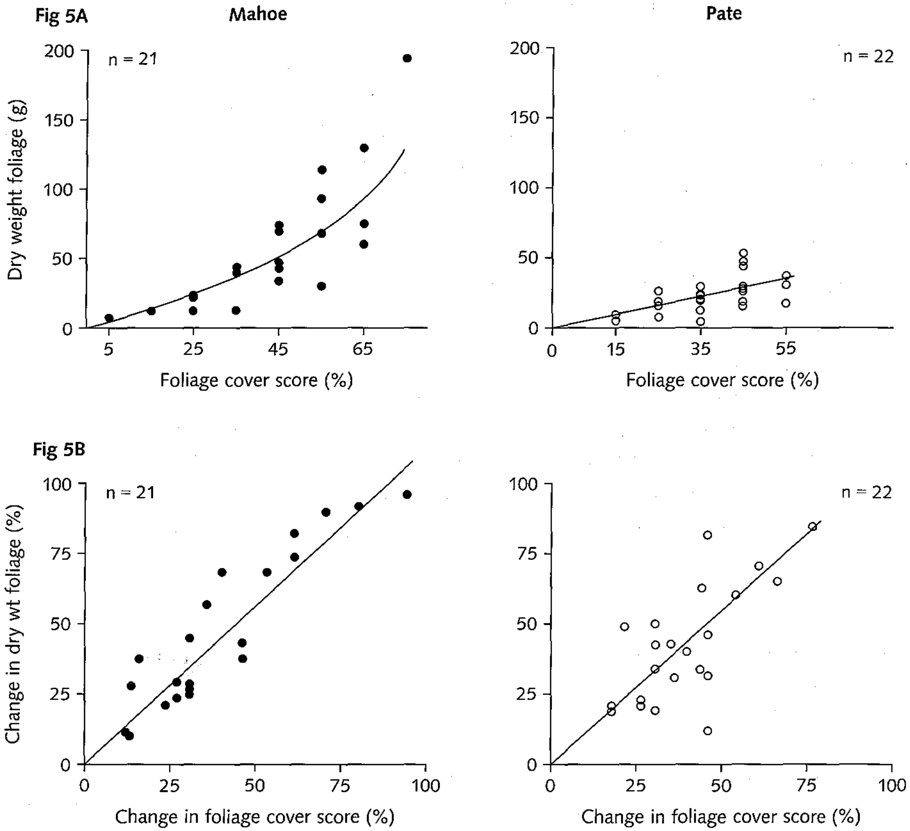

Figure 5. *Relationship between foliage cover score and foliage biomass in two plant indicator species (mahoe, pate), Granville Forest, Westland.*

5 Data Analysis Options

Foliar Browse Index 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 populations of an indicator species, and relationships between Foliar Browse Index parameters. It assumes that the data are a random, representative sample of the individuals in the stratum or study area (see Section 2.3.2).

5.1 Data classification

The Foliar Browse Index parameters can be classified as:

- **Numerical data** (stem diameter).
- **Numerical class score data**
  - *with equal interval classes* (foliage cover)
  - *without equal interval classes* (browse, dieback, stem use, flowers, fruit).

  The browse and dieback parameters can be viewed as having equal interval classes if the nil-light categories are combined.
- **Nominal (alphabetic) class score data** (abundance, tier, segment, recovery, epiphyte diameter).

5.2 Data transformation

Numerical data

- No transformation required for statistical analyses.

Numerical class score data with equal interval classes

- Delete foliage cover values of 1 and 2 (dead trees) if analyses are to include only living trees, or replace by 0 if the analyses are to include both living and dead trees. Unless your analysis is comparing changes in mortality, we recommend using only data from living trees.

Numerical class score data without equal interval classes

- Remove X (unable to estimate) values.
- For chi-squared tests replace non-zero class scores (e.g., 1,2,3 ...) with a value of 1.

Nominal (Alphabetic) class score data

- Remove X (unable to estimate) values.

- Convert to a numeric scale to produce frequency summaries.
- For chi-squared tests replace non-zero class scores (e.g., 1,2,3 ...) with a value of 1.

5.3 Data analyses

5.3.1 Statistical tests

Statistical tests that can be used to compare changes between sampling periods and between sampled areas are outlined in Table 1. The list is not exhaustive. Rather it is intended as a guide, to help non-statisticians identify appropriate statistical procedures for each of the Foliar Browse Index parameters.

5.3.2 Correlation

When correlating Foliar Browse Index parameters (e.g., foliage cover and browse) use Pearson's correlation coefficient for parameters with equal interval classes, and Spearman's non-parametric correlation coefficient for parameters without equal interval classes.

Table 1. Statistical tests for use with Foliar Browse Index data

Statistical comparison		**Data classification**		
	No. of groups	**Numerical**	**Numerical class score**	**Nominal (Alphabetic) class score**
		Equal interval classes	**Unequal interval classes**	
Between sampling periods (1)	2	Paired t-test	Wilcoxon signed rank	McNemar's Chi-square test
	>2	Repeated measures ANOVA Polynomial regression (eg. linear)	Freidman's non-parametric ANOVA	
Between sampled areas (2)	2	Independent t-test	Mann-Whitney U-Test	Chi-square test
	>2	One-way ANOVA	Kruskal-Wallis non-parametric ANOVA	Chi-square test

(1) Same group of individuals sampled on each occasion

(2) Independent groups of trees

6 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 Foliar Browse Index plots 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 recover data that have been lost.

For these reasons it is important to ensure that a copy of all Foliar Browse Index plotsheets, maps, aerial photos, location diagrams, and computer datafiles is 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 responsible for their collection.

Landcare Research, in conjunction with the Department of Conservation and other external agencies, holds and manages the National Vegetation Survey database. This incorporates data from indigenous vegetation surveys carried out by the former New Zealand Forest Service (now Department of Conservation and Landcare Research), the National Forest Survey (1946-55), and the Protected Natural Areas Programme. The database, which is located at Lincoln near Christchurch, comprises hardcopy, computerised datafiles and analysis software (Hall 1992, 1994a,b) for a range of standardised monitoring methodologies. Persons wishing to make use of this facility should contact Dr Ian Payton at Landcare Research, PO Box 69, Lincoln.

7 Acknowledgements

A wide range of people contributed to the development of the Foliar Browse Index methodology. The project was conceived by Ian Payton, Chris Frampton and Richard Sadleir. Case Pekelharing took primary responsibility for method development and field testing. Chris Frampton devised the sampling strategy and determined the data analysis options. Ian Payton managed the project and wrote the manual.

We express our appreciation to Hamish Owen, Mark Smale, Phil Suisted and other Department of Conservation and Landcare Research staff who helped test the method. Ngaire Bruerton computerised the datasets, Robert Lamberts took the photographs, Megan Ogle-Mannering, Geoff Rogers and Mark Smale critically reviewed the manuscript, Thomas Pearson and Kirsty Cullen drew the figures, and Kirsty Cullen prepared the manual for publication. Development of the method and publication of the manual were funded by the Department of Conservation.

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9 Appendices

Appendix 1.	Random number (1-50) sets for use in determining the placement of transects.
Appendix 2.	List of equipment required for establishing or remeasuring Foliar Browse Index plots. Spares should be carried in case of loss or breakage.
Appendix 3.	A. Foliar Browse Index plotsheet - transect and plot data B. Foliar Browse Index plotsheet - indicator species data
Appendix 4.	Indicator species assessment sheet
Appendix 5.	Foliage cover scale
Appendix 6.	Flowering and fruiting periods for a range of plant indicator species.
Appendix 7.	Botanical names of plant species referred to in the text.

9.1 Random number (1-50) sets for use in determining the placement of transects

1	41	2	17	15	23	12	6	29	32	25
2	47	20	36	12	24	30	42	4	26	12
3	28	33	50	45	9	39	14	14	25	27
4	22	48	35	4	50	42	4	37	36	42
5	42	44	12	13	16	8	27	13	42	39
6	31	7	10	50	34	1	23	25	33	50
7	35	28	27	31	10	41	5	31	15	40
8	14	8	30	35	1	15	13	47	1	18
9	34	45	22	40	36	21	32	6	40	15
10	45	15	13	27	38	47	9	21	16	28
11	17	22	14	23	40	18	31	23	43	46
12	43	10	26	20	44	29	18	36	13	33
13	49	3	37	42	14	34	44	15	24	48
14	19	32	6	1	19	16	34	40	38	17
15	8	46	33	39	25	44	25	5	41	41
16	33	14	18	36	15	50	15	11	27	47
17	15	49	48	16	46	38	10	33	11	44
18	46	17	31	29	27	25	43	18	35	7
19	4	13	28	30	18	4	40	42	23	5
20	50	31	39	5	30	6	16	20	18	11
21	13	4	47	47	37	35	45	35	14	34
22	24	42	42	26	11	28	50	45	30	29
23	12	23	1	11	21	27	39	46	17	20
24	6	24	15	3	47	33	47	50	48	4
25	27	26	5	38	33	26	20	43	2	43
26	36	37	23	10	20	31	48	10	9	21
27	30	34	46	8	31	48	35	7	45	30
28	39	12	24	33	7	11	49	27	6	8
29	23	38	40	32	45	10	37	28	20	16
30	3	35	11	48	5	23	46	12	4	3
31	2	5	16	25	28	45	41	49	50	1
32	40	36	41	41	12	13	38	30	31	49
33	38	30	21	22	13	37	36	8	7	38
34	48	43	32	44	22	2	26	26	21	14
35	32	25	49	17	39	3	17	9	37	32
36	26	19	2	7	35	49	19	2	28	22
37	11	50	9	28	4	19	30	16	19	31
38	16	6	43	2	6	20	33	41	8	37

39	21	40	3	46	49	24	28	24	10	2
40	44	29	19	9	29	43	1	38	49	26
41	9	1	45	19	43	46	2	22	44	36
42	20	47	8	6	32	36	21	32	34	23
43	5	11	4	21	26	9	11	44	12	6
44	7	16	25	43	17	7	29	1	47	10
45	18	27	20	24	3	40	12	17	29	24
46	37	18	7	18	42	14	3	48	3	9
47	29	21	44	37	8	22	22	34	39	13
48	10	9	38	34	2	32	24	3	46	35
49	1	39	29	49	48	5	7	19	22	45
50	25	41	34	14	41	17	8	39	5	19

9.2 List of equipment required for establishing or remeasuring Foliar Browse Index plots. Spares should be carried in case of loss or breakage.

- Topographic map and aerial photo
- Foliar Browse Index plotsheet
- Indicator species assessment sheet
- Foliage Cover scale
- Pen and pencil
- Abney level or clinometer
- Altimeter
- Binoculars
- Compass
- Diameter tape
- Rangefinder
- Tape - 20m
- Tape or nylon cord - 100m
- Tree tags (numbered)
- Nails (flathead, galvanised)
- Hammer
- Flagging ("permolat")

9.3A Foliar Browse Index Plot Sheet – transect and plot data

FOLIAR BROWSE INDEX PLOT SHEET

Transect Number 2

Survey Puketi Forest, Northland

Catchment or Block Waipapa River

Area of Stratum upper Puketea Stream

Map or Aerial Photo Nº NZMS 260 Sheet P05

Transect Origin (grid ref.) & Bearing Grid Ref. 780625 Bearing 75°

Forest Type: Podocarp-hardwood

Parent Material: Sandstone

Observer: C. J. Pekelharing

Recorder: C. Frampton

Date: 8.3.94

APPROACH

Access from Puketi Forest HQ is via the Puketea Ridge logging road. Turn off at the Takapau Track.

Transect 2 starts 200 m upstream from where this track crosses Puketea Stream. Transect origin marked on a large rimu at the junction of a major fork in the stream.

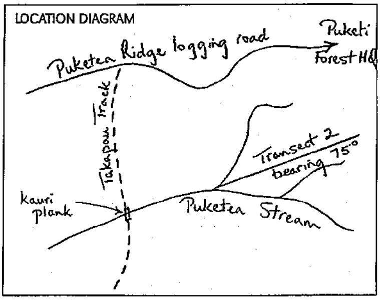
Plot 1. is 20 m from the origin, across a small terrace

NOTES

Occasional emergent northern rata. In places dense kiekie and supplejack makes travel difficult.

BIRDS fantail, tui

LOCATION DIAGRAM

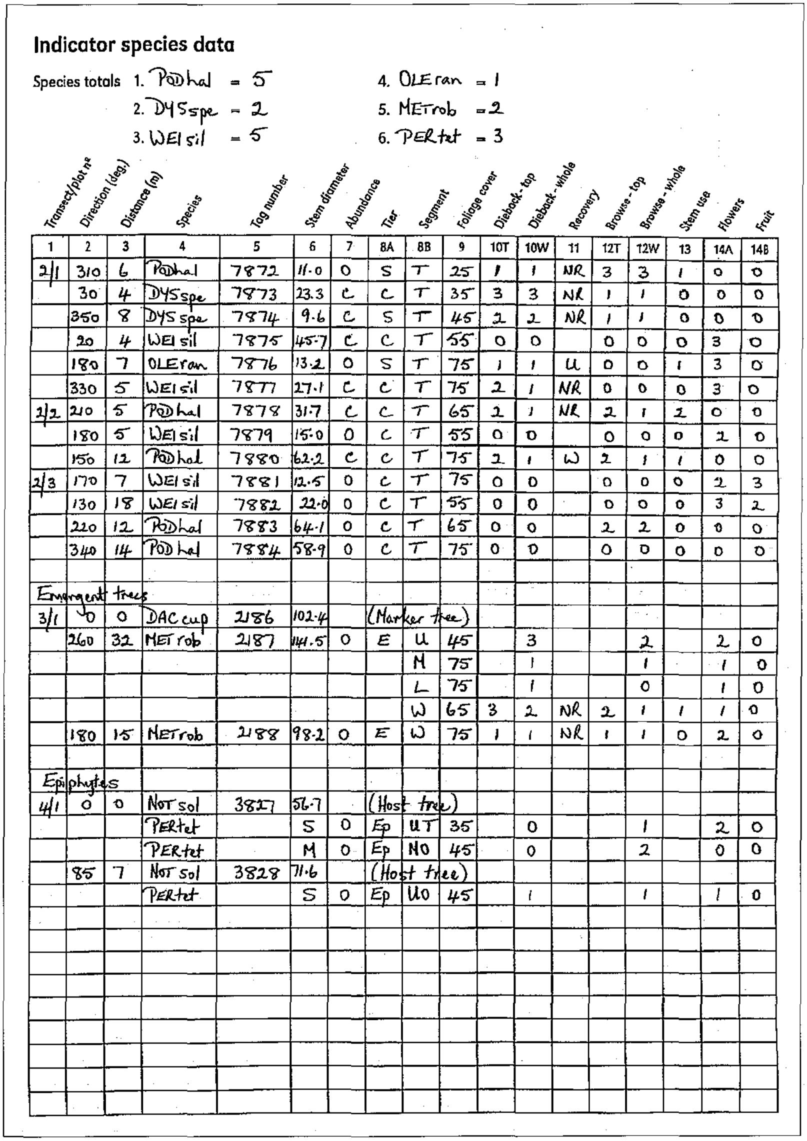


Non possum-related browse

Plot Nº	Plant species	Low	Medium	Heavy	Animal
1	SCH dig		✓		Goat
2	PSE arb	✓			"
2	MEL ram	✓			Insect

Plot Nº	Altitude	Aspect	Slope	Physiography	Drainage	Canopy Ht.	Canopy dominants
1	260	160	5 linear	T	M	26	DAC cup, POD hal, WEI sil, DYS spe
2	290	185	20 concave	F	G	28	WEI sil, DYS spe, POD hal, MET rob
3	310	145	25 concave	F	G	25	WEI sil, POD hal, MET rob

9.3B Foliar Browse Index Plot Sheet – indicator species data



Indicator species data

Species totals
1. PODhal = 5
2. DYSspe = 2
3. WEIsil = 5
4. OLEran = 1
5. METrob = 2
6. PERtet = 3

Transect/plot nº	Direction (deg.)	Distance (m)	Species	Tag number	Stem diameter	Abundance	Tier	Segment	Foliage cover	Dieback - top	Dieback - whole	Recovery	Browse - top	Browse - whole	Stem use	Flowers	Fruit
1	2	3	4	5	6	7	8A	8B	9	10T	10W	11	12T	12W	13	14A	14B
2/1	310	6	PODhal	7872	11·0	0	S	T	25	1	1	NR	3	3	1	0	0
	30	4	DYSspe	7873	23.3	C	C	T	35	3	3	NR	1	1	0	0	0
	350	8	DYSspe	7874	9·6	C	S	T	45	2	2	NR	1	1	0	0	0
	20	4	WEIsil	7875	45·7	C	C	T	55	0	0		0	0	0	3	0
	180	7	OLEran	7876	13·2	0	S	T	75	1	1	U	0	0	1	3	0
	330	5	WEIsil	7877	27·1	C	C	T	75	2	1	NR	0	0	0	3	0
2/2	210	5	PODhal	7878	31·7	C	C	T	65	2	1	NR	2	1	2	0	0
	180	5	WEIsil	7879	15·0	0	C	T	55	0	0		0	0	0	2	0
	150	12	PODhal	7880	62·2	C	C	T	75	2	1	W	2	1	1	0	0
2/3	170	7	WEIsil	7881	12·5	0	C	T	75	0	0		0	0	0	2	3
	130	18	WEIsil	7882	22·0	0	C	T	55	0	0		0	0	0	3	2
	220	12	PODhal	7883	64·1	0	C	T	65	0	0		2	2	0	0	0
	340	14	PODhal	7884	58·9	0	C	T	75	0	0		0	0	0	0	0
Emergent trees																	
3/1	0	0	DACcup	2186	102·4		(Marker tree)										
	260	32	METrob	2187	114.5	0	E	U	45		3			2		2	0
								M	75		1			1		1	0
								L	75		1			0		1	0
								W	65	3	2	NR	2	1	1	1	0
	180	15	METrob	2188	98·2	0	E	W	75	1	1	NR	1	1	0	2	0
Epiphytes																	
4/1	0	0	NOTsol	3827	56·7		(Host tree)										
			PERtet		S	0	Ep	UT	35		0			1		2	0
			PERtet		M	0	Ep	NO	45		0			2		0	0
	85	7	NOTsol	3828	71·6		(Host tree)										
			PERtet		S	0	Ep	UO	45		1			1		1	0

9.4 Foliar Browse Index - Indicator Species Assessment Sheet

FOLIAR BROWSE INDEX
INDICATOR SPECIES ASSESSMENT SHEET

Assess only trees / plants with canopies above 2m (above the level of ungulate browse) and (excepting epiphytes) stems > 5cm dbh.

ABUNDANCE (Column 7) Abundance of the species on and around the plot as:

A	**Abundant**	> 35% individuals
C	**Common**	11-35% individuals
O	**Occasional**	1-10% individuals
R	**Rare**	< 1% individuals

TIER (Column 8A) Tier height class of the tree as:

E	**Emergent**	canopy isolated above that of neighbouring trees
C	**Canopy**	forming part of the forest canopy
S	**Subcanopy**	below the forest canopy

SEGMENT (Column 8B) Segment of the tree being assessed as:

S	**Stem**	one of a group of stems or branches
T	**Tree**	the whole tree canopy

FOLIAGE COVER (Column 9)

From the Foliage Cover Scale select the square which most closely resembles the foliage cover of the canopy. Where a tagged tree is alive but completely defoliated, or has died, record the foliage cover as:

0	**Completely defoliated living tree**	no leaves remaining. Bark is intact and contains sap.
1	**Recently dead**	fine twigs present. Bark intact, but no sap present.
2	**Long dead**	fine twigs absent. Most larger branches remain. Bark not intact. Remove the tag from trees recorded as long dead.

DIEBACK (Column 10)

The **conspicuous presence** of dead branches or branchlets (but not recently defoliated live twigs) in the upper third of the canopy (Column 10T), and over the whole of the canopy (Column 10W). Record dieback as:

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**	

RECOVERY (Column 11)

Where dieback has been recorded determine the extent of any **conspicuous recovery** as:

NR	**No recovery**	no visible recovery

Flush of epicormic growth on the trunk and major branches in the

U	**Upper**	upper of the canopy
L	**Lower**	lower of the canopy
W	**Whole**	throughout the whole canopy
X	**Unable to estimate**	

BROWSE (Column 12)

The proportion of **possum-browsed leaves** (or in the case of small-leaved species such as totara, the severity of **possum-related hedging**) in the top third of the canopy (Column 12T), and averaged over the whole canopy (Column 12W) as:

0	**Nil**	no possum-related hedging	no browsed leaves
0.5	**Some**	minimal hedging	< 5% leaves browsed
1	**Light**	or lightly hedged	5-25% leaves browsed
2	**Moderate**	or moderately hedged	26-50% leaves browsed
3	**Heavy**	or heavily hedged	51-75% leaves browsed
4	**Severe**	or severely hedged	76-100% leaves browsed
X	**Unable to estimate**		

STEM USE (Column 13)

Recent **possum** use of the lower 2 m of the trunk or stem as:

0	**Nil**	no scratching or bite marks on the trunk
1	**Light**	occasional scratch and bite marks
2	**Moderate**	numerous clearly defined scratch and bite marks
3	**Heavy**	bark worn smooth, evidence of a well developed possum "run".
X	**Unable to estimate**	trunk obscured by epiphytes or moss.

FLOWERING AND FRUITING (Column 14)

The presence and abundance of flowers (Column 14A) and fruit (Column 14B) as:

0	**Nil**	no flowers or fruit visible.
1	**Rare**	few flowers or fruit visible, often only in part of the canopy.
2	**Occasional**	sparse flowering/fruiting, usually throughout the canopy.
3	**Common**	flowers or fruits common throughout the canopy.
4	**Abundant**	flowering/fruiting heavy, highly visible, and present on most branchlets.

EMERGENT TREES

Segment (Column 8B)

U	upper third of the canopy
M	middle third of the canopy
L	lower third of the canopy
W	whole canopy

EPIPHYTES

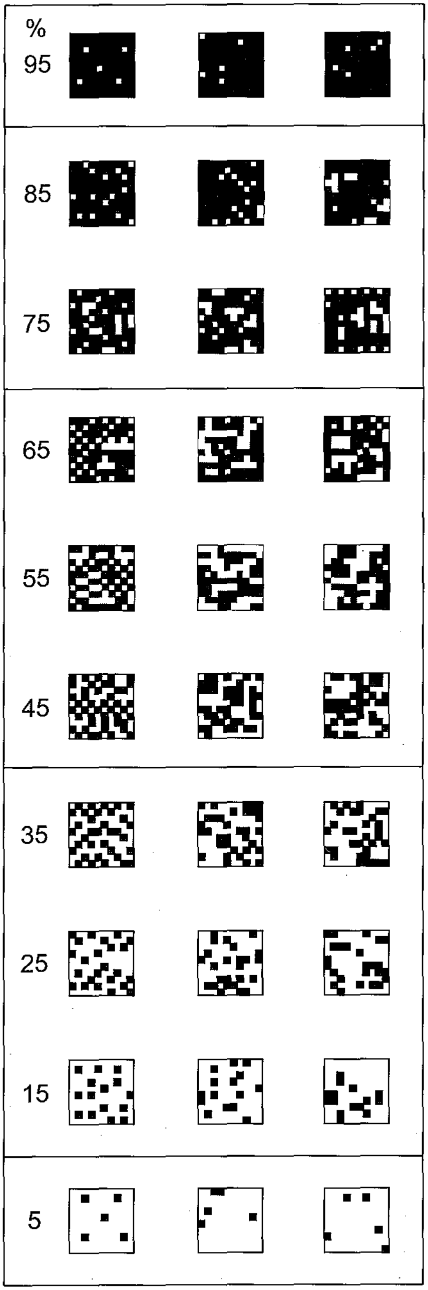
Plant size (Column 6)

XS	extra small	< $^1/_2$m wide
S	small	$^1/_2$-1m wide
M	medium	1-2m wide
L	large	2-3m wide
XL	extra large	>3m wide

Position on the host tree (Column 8B)

B	lower third of the host tree canopy
M	middle third of the host tree canopy
U	upper third of the host tree canopy
T	epiphyte attached to the main trunk
I	epiphyte on the inner branches
O	epiphyte on the outer branches

9.5 Foliage Cover Scale



Indicator Species			**Area & information source**							
		(a)	NZ (1)	NZ (3,b)	Northland (4)	C. North Is. (5)	Wellington (6)	Canterbury (7)	Westland (8)	Stewart Is. (9)
Emergent trees										
Metrosideros robusta	northern rata	Fl.	Nov-Jan	Nov-Jan	Dec-Feb		Dec-Jan			
		Fr.	Dec - Jan		Jan-Apr		May			
Podocarpus totara	lowland totara	(c)		Sep-Oct		Dec	Oct-Dec			
& P. hallii	& Hall's totara	(d)		Apr-May	Jan-Dec	Jan-Dec	Feb-May	Jan-Jun	Feb-Aug	
Canopy trees										
Alectryon excelsus	titoki	Fl.	Oct-Dec	Oct-Nov						
		Fr.	Oct-Dec							
Beilschmiedia tawa	tawa	Fl.	Sep-Dec	Sep-Nov	Nov-Dec	Dec-Feb				
		Fr.	Oct-Feb		Jan-Dec	Dec-May				
Dysoxylum spectabile	kohekohe	Fl.	Mar-Jun	Apr-May	May-Jul	Apr-Jul				
		Fr.	Apr-Aug	Jul-Aug	Jan-Dec	Aug-Feb				
Elaeocarpus dentatus	hinau	Fl.	Oct-Feb	Oct-Feb	Nov-Dec	Oct-Jan	Nov-Apr			
		Fr.	Dec-May		Jan-Jul	Dec-Jun	Mar-Aug			
E. hookerianus	pokaka	Fl.	Oct-Jan							Jan
		Fr.	Nov-Mar						Feb-Jun	Mar
Melicytus ramiflorus	mahoe	Fl.	Nov-Feb	Sep-Apr	Oct-Mar	Oct-Mar	Oct-Apr	Dec-Jan		
		Fr.	Nov-Mar	Feb-Jun		Nov-Jun	Nov-Jul	Jan-Jul	Feb-Aug	

Indicator Species			Area & information source							
		(a)	NZ (1)	NZ (3,b)	Northland (4)	C. North Is. (5)	Wellington (6)	Canterbury (7)	Westland (8)	Stewart Is. (9)
Canopy trees										
Metrosideros excelsa	pohutukawa	Fl.	Dec-Jan	Dec-Jan						
		Fr.	Jan-Feb							
M. umbellata	southern rata	Fl.	Nov-Mar	Nov-Jan					Oct-Feb	Nov-Feb
		Fr.	Dec-Apr							Mar-May
Weinmannia racemosa	kamahi	Fl.	Dec-Jan	Nov-Jan		Oct-Jan	Sep-May		Sep-Feb	Oct-Dec
		Fr.	Jan-Apr			Dec-Mar				Jan-Apr
W. silvicola	towai	Fl.	Sep-Dec	Sep-Dec	Jan-Aug					
		Fr.	Nov-Feb		Dec-Oct					
Subcanopy trees & shrubs										
Aristotelia serrata	wineberry, makomako	Fl.	Sep-Dec	Sep-Dec	Oct-Nov	Oct-Dec	Oct-Nov	Nov-Dec	Sep-Dec	Nov
		Fr.	Nov-Jan	Jan-Feb	Nov-Mar	Nov-May		Dec-Mar	Jan-Apr	Jan-Mar
Fuchsia excorticata	fuchsia	Fl.	Aug-Dec	Aug-Dec	Jun-Nov	Sep-Apr		Sep-Jan	Jul-Dec	Jul-Dec
		Fr.	Sep-Feb	Dec-Mar	Jul-Feb	Oct-May		Dec-Aug	Dec-Feb	Dec-Apr
Myrsine salicina	toro	Fl.	Aug-Jan		Jul-Sep					
		Fr.	Sep-May		Oct					
Olearia rani	heketara	Fl.	Aug-Nov	Sep-Oct	Sep-Nov	Nov-Dec	Oct-Apr			
		Fr.	Nov-Jan		Nov-Dec	Jan-Feb	Jan			

Indicator Species			Area & information source							
		(a)	NZ (1)	NZ (3,b)	Northland (4)	C. North Is. (5)	Wellington (6)	Canterbury (7)	Westland (8)	Stewart Is. (9)
Subcanopy trees & shrubs										
Pennantia corymbosa	kaikomako	Fl.	Nov-Feb	Sep-Oct		Nov-Feb	Nov-Dec	Dec-Jan	Nov-Dec	Dec-Jan
		Fr.	Jan-May	Feb-May		Jan-May	Mar	Jan-Apr	Feb-Apr	
Pseudopanax arboreus	five finger	Fl.	Jun-Aug	Jun-Aug	Feb-Sep	Jul-Dec	Dec-Feb	Jul-Nov		
		Fr.	Aug-Feb		Jan-Dec	Jan-Dec		Jan-Dec		
P. colensoi	mountain five finger	Fl.	Jun-Mar						Sep-Dec	Jan-Dec
		Fr.	Jun-Mar						Dec-Oct	Jan-Dec
P. crassifolius	lancewood	Fl.	Jan-Apr	Jan-Apr	Mar-May	Mar		Dec-Feb	Jan-Feb	Feb
		Fr.	Jan-Apr		Mar-Oct	Mar-Jan		Jan-Oct	Apr-Oct	Jan-Dec
P. edgerleyi	raukawa	Fl.	Nov-Mar		Dec-Feb	Nov-Dec				Nov-Feb
		Fr.	Nov-Mar		Jan-Mar	Jan-Dec			Feb-Oct	Feb-Mar
P. simplex	haumakaroa	Fl.	Jun-Mar						Dec-Feb	Dec-Feb
		Fr.	Jun-Mar						Apr-Dec	Jan-Dec
Schefflera digitata	pate	Fl.	Feb-Mar	Jan-Mar	Mar-Apr	Dec-Mar		Dec-Jan		Feb-Mar
		Fr.	Feb-Mar		Mar-Aug	Jan-Oct	Mar-Aug	Jan-Sep	Jan-Dec	Mar
Lianes										
Metrosideros fulgens	climbing rata	Fl.	Feb-Jun	Feb-Jun	Mar-Aug		Jan-Dec		Jan-Dec	
		Fr.	Oct-Dec		Mar-Feb		Jan-Oct			
Ripogonum scandens	supplejack	Fl.	Dec-Jan (2)	Oct-Nov	Oct-Dec	Nov-Feb	Dec-Apr			Dec-Feb
		Fr.	Jan-Dec (2)	Jan-Dec	Jan-Dec	Jan-Dec	Jan-Dec		Jan-Dec	Jan-Dec

Indicator Species			**Area & information source**							
		(a)	NZ (1)	NZ (3,b)	Northland (4)	C. North Is. (5)	Wellington (6)	Canterbury (7)	Westland (8)	Stewart Is. (9)
Epiphytes										
Alepis flavida	mistletoe	Fl.	Dec-Feb							
		Fr.	Jan-Jun							
Peraxilla colensoi	mistletoe,	Fl.	Nov-Feb	Oct-Jan					Nov-Mar	
	korukoru	Fr.	Dec-Mar						Feb-Aug	
P. tetrapetala	mistletoe,	Fl.	Oct-Jan	Oct-Jan					Nov-Feb	
	pirirangi	Fr.	Dec-Feb						Feb-Jun	

(a) Fl. flowers; Fr. fruit (unripe & ripe); (b) ripe fruit only; (c) male cones; (d) female cones

(1) Allan 1961; (2) Moore & Edgar 1970; (3) Salmon 1967; (4) Best & Bellingham 1991; (5) Leathwick 1984; (6) Brockie 1992; (7) Burrows 1994; (8) O'Donnell & Dilks 1994; (9) Wilson 1982.

9.7 Botanical names of plant species referred to in the text. Nomenclature follows Allan (1961), Moore & Edgar (1970), Connor & Edgar (1987).

Emergent trees

Dacrydium cupressinum	rimu
Metrosideros robusta	northern rata
Podocarpus hallii	Hall's totara
P. totara	lowland totara

Canopy trees

Alectryon excelsus	titoki
Beilschmiedia tawa	tawa
Dysoxylum spectabile	kohekohe
Elaeocarpus dentatus	hinau
E. hookerianus	pokaka
Melicytus ramiflorus	mahoe
Metrosideros excelsa	pohutukawa
M. umbellata	southern rata
Nothofagus solandri var *cliffortioides*	mountain beech
Weinmannia racemosa	kamahi
W. silvicola	towai

Subcanopy trees and shrubs

Aristotelia serrata	wineberry
Fuchsia excorticata	fuchsia
Myrsine salicina	toro
Olearia rani	heketara
Pennantia corymbosa	kaikomako
Pseudopanax arboreus	five finger
P. colensoi	mountain five finger
P. crassifolius	lancewood
P. edgerleyi	raukawa
P. simplex	haumakaroa
Rhopalostylis sapida	nikau
Schefflera digitata	pate

Lianes

Clematis vitalba	Old Man's Beard
Freycinetia baueriana subsp. *banksii*	kiekie
Metrosideros fulgens	climbing rata
Ripogonum scandens	supplejack
Rubus spp.	lawyer

Epiphytes

Alepis flavida	mistletoe
Astelia spp.	
Collospermum spp.	
Peraxilla colensoi	mistletoe / korukoru
P. tetrapetala	mistletoe / pirirangi