The Foliar Browse Index field manual

An update of a method for monitoring possum (*Trichosurus vulpecula*) damage to forest communities

May 2014

Department of Conservation
Te Papa Atawhai

This field manual has been produced by the Department of Conservation and updates the original document: Payton, I.J.; Pekelharing, C.J.; Frampton, C.M. 1999: A Foliar Browse Index: a method for monitoring possum (*Trichosurus vulpecula*) damage to plant species and forest communities. Manaaki Whenua Landcare Research, Lincoln, New Zealand.

The recommended citation for the revised field manual is: Department of Conservation 2014: The Foliar Browse Index field manual. An update of a method for monitoring possum (*Trichosurus vulpecula*) damage to forest communities. Department of Conservation, Christchurch, New Zealand.

Contents

Summary

Possum control in New Zealand is necessary to protect the biodiversity of native forests and other communities. Measuring the results and outcomes of this work is an important aspect of control programmes and helps managers plan and determine the efficacy of their work. The Foliar Browse Index (FBI) method uses ground-based assessment of permanently marked plant indicator species to determine the impact of possums on forest trees/mistletoes and their response to possum control. It has been used extensively around New Zealand since its development in the late 1990s by Payton et al. (1999). This updated field manual incorporates changes and improvements to the method based on the knowledge that has been gained over the last decade.

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

1. Introduction

Since their introduction in c. 1840, Australian brushtail possums (*Trichosurus vulpecula*; subsequently termed 'possums') have colonised virtually all forested areas on the three main islands of New Zealand (Montague 2000; Cowan 2005). Possums have been intensively studied and managed in New Zealand for over 50 years (Lee et al. 2005) and their feeding habits and impacts are well documented. They are opportunistic feeders, supplementing foliage with seasonally available fruits, flowers, and invertebrates, and will eat bird eggs and occasionally chicks (Nugent et al. 2000; Brown et al. 1993). Possums usually focus their feeding on a small set of 'key species', and often only target particular individuals of those species at a site (Nugent et al. 2010). This can cause the progressive reduction and elimination of preferred food species (Campbell 1990; Bellingham et al. 1999b; Nugent et al. 2000; Fitzgerald & Gibb 2001; Sweetapple et al. 2004; Nugent et al. 2010) and even lead or contribute to the collapse of forest canopies over large areas (see Payton 2000 for a review).

Due to the implication of possums in widespread canopy deterioration of forests and the key role they play in the transmission of bovine tuberculosis, extensive possum control programmes have been undertaken since the 1960s (Payton 2000; Cowan 2005). Initially these operations were one-off attempts to avert canopy collapse (Nugent et al. 2010), but considerable advances in control techniques since that time and a better understanding of possum behaviour, ecology and demographics (Montague 2000) have meant that most control programmes are now conducted on a long-term basis with clear goals to permanently reduce unwanted possum impacts (Parkes et al. 2006). However, current financial limitations mean that most of New Zealand still contains unmanaged possum populations (Parliamentary Commissioner for the Environment 2011), resulting in an estimated total population of around 30 million individuals (Warburton et al. 2009). Eradication from mainland sites is generally not feasible, so the ongoing control of possums is inevitable.

Conservation managers often need to determine when possum control is required and subsequently whether the control, if undertaken, achieves its goals. A robust quantitative method is therefore needed to make reliable assessments and predictions about the nature, severity and extent of possum damage on selected indicator species[1]. The Foliar Browse Index method (Payton et al. 1999; subsequently termed 'FBI') measures the impacts of possums and can also provide evidence of conservation benefits to susceptible tree species after possum control has been conducted (Gormley et al. 2012). The method uses repeated measures of permanently marked individuals to determine possum browse of their leaves and trends in the foliar cover of tree or mistletoe canopies.

In order to properly understand changes in forest condition as measured by FBI data (the dependent variable), it is necessary to also obtain adequate data on possum abundance (the independent variable). Possum abundance[2] is usually measured in New Zealand using the residual trap catch (RTC) index (NPCA 2011), wax tags (NPCA 2010) and chew cards (Sweetapple & Nugent 2011). FBI data are most informative when complemented by possum abundance indices collected from an area before and (repeatedly) after possum control (Sweetapple et al. 2004; Nugent et al. 2010; Duncan et al. 2011; Gormley et al. 2012). It is strongly recommended that researchers and managers monitor both possum abundance and impacts as part of an integrated monitoring programme.

The FBI method has been used extensively around New Zealand since its development in the late 1990s by Payton et al. (1999). This manual describes and updates the FBI method and is designed both as a guide to planning studies and undertaking field work. It draws on the 15 years of experience and analyses by practitioners and researchers using the previous manual.[3]

---

1 'Indicator species' are species that help define the character of an environment. Here, they are defined as plant species that reflect possum-related canopy damage in New Zealand forests (refer to Appendix 4).

2 True possum density is difficult to measure and therefore usually not done, but each index has a known relationship to density, so is sufficient for reporting changes in possum abundance and interpreting other results in relation to these.

3 In general, studies set up prior to the publishing of this revision should not change sampling methods or compromise the goals of those studies to comply with the changes presented here.

2. Designing a survey to monitor possum damage to vegetation

2.1 Objectives

As with any vegetation monitoring programme, designing FBI surveys requires a clear statement of the problem to be investigated and the monitoring objectives (Jongman et al. 1987; Elzinga et al. 1998; DOC 2012). This forms the basis of sampling strategies and ensures that data can be used reliably to answer the programme's questions. Objectives of monitoring possum damage to vegetation will usually be to:

- Compare trends in canopy condition before and after possum control
- Provide evidence of damage to forest canopies (or sensitive species) in the absence of possum control
- Initiate possum control when it is necessary

2.2 Choice of indicator species

Several factors influence the choice of plant indicator species. Appendix 1 contains a list of common indicator species and recommendations for their inclusion in a sampling programme. In general, indicator species should be:

- Preferred food species of possums that will respond quickly to possum control
- Moderately common and well distributed through the study area (most plots should contain at least one individual of a species)[4]
- Readily visible (multi-tiered emergent species are often difficult to observe from the ground)

Browsing damage can be more readily distinguished in larger-leaved, shorter species such as māhoe (*Melicytus ramiflorus*), fuchsia (*Fuchsia excorticata*), haumakaroa (*Raukaua simplex*) and wineberry (*Aristotelia serrata*) than in small-leaved, tall species such as northern and southern rātā (*Metrosideros robusta, M. umbellata*) and tawa (*Beilschmiedia tawa*). While kohekohe

[4] Restriction of study areas may be necessary for species with patchy or localised distributions (see section 2.3).

(*Dysoxylum spectabile*) and kāmahi (*Weinmannia racemosa*) are tall, their large leaves make them useful indicator species when they are present. Where possums typically remove whole leaves or young shoots (e.g. tōtara) the severity of possum-related browsing can be under-estimated or even impossible to detect unless it is observed during spring, when possums often focus their feeding on these species. In species such as lancewood (*Pseudopanax crassifolius*), five finger (*P. arboreus*), mountain five finger (*P. colensoi*) and patē (*Schefflera digitata*) where possums often only eat the fleshy base of the leaf petiole, a carpet of freshly discarded leaves is evidence of possum foraging, but can make it difficult to determine the proportion of possum-browsed leaves on the tree being assessed. However, as long as observers base assessments on truncated stems or leaf stubs, these species are still useful indicators. Also, large-leaved mistletoes *Peraxilla tetrapetala, Peraxilla colensoi, Tupeia antarctica, Ileostylis micranthus* and *Alepis flavida* can be useful as indicator species by using a good pair of binoculars and following small modifications to the method (see section 3.4).

Ultimately, the choice of indicator species is a balance between the suitability of the species for the method and the abundance of the species within the monitoring site. Appendix 2 gives recommendations for a wide range of species that have been used in FBI assessments over the last 15 years. Start with a group of at least five potential species from this list prior to undertaking field work and reduce this to approximately three species before establishing a monitoring programme. In many cases, the final list of indicator species can only be confirmed during a pilot study.

Further advice on choosing indicator species and estimating browse is available later in the manual, including reference pictures of browse on many indicator species (Appendix 3).

2.3 Sampling design

To draw valid conclusions about the extent and severity of possum damage, sampling must be conducted in a non-biased (i.e. random) way. If an adequate number of individuals are sampled this way, they will be representative of the population within the study area. Extensive sampling also allows for variation in associated environmental factors (such as soil type, climate, aspect, altitude and physiography) to be incorporated. This means that these abiotic variables can be correlated with FBI results if they are thought to be having some influence and/or discounted if they are not.

Due to the nature of the topography in most New Zealand forests and the difficulty in moving between different areas of the forest, an efficient sampling regime is achieved via plots along a series of transects in the study area. These transects should be randomly located (origin and bearing), which helps to ensure they traverse the full extent of habitat types within the study area and reduces bias in data collection. Genuine random sampling is now easy to establish using modern Global Positioning System (GPS) technology and geographic information systems (GIS).

If a chosen indicator species has a very restricted distribution (e.g. fuchsia, wineberry, patē and mistletoes, which are often confined to specific habitats such as gullies, river banks or forest edges), species are highly unlikely to be present within all plots along transects. Carefully consider whether the species is still going to be an adequate indicator of forest health, and if so, transects may need to be restricted within particular habitats to ensure an adequate sample size is obtained. If a restricted sampling plan is used, statistical advice is likely to be needed at the design and analysis stage and will need to be clearly described when reporting results. Some prior knowledge of the species' distribution is required to create an accurate sampling plan. This can be obtained via:

- Aerial photography
- GIS layers that contain information such as ecosystem and forest type
- Topographical maps
- Local and expert knowledge
- A pilot study

In some cases, the sample of individuals from a restricted-distribution species may actually be approaching the whole population within a study area. In this case, results may still be valuable for reporting the impacts of possums on that species, specifically in the study area. Statistical analyses will also be very simple because there is no error in a sample that is equivalent to a population. However, random and stochastic adverse events such as weather, flooding, large tree-falls or insect outbreaks can have large effects on small populations. If a small sample size is further and suddenly reduced, misleading or confusing results can appear. Therefore, do not rely on collecting these data at the expense of setting up more robust, extensive monitoring of the more common indicator species in an area.

2.4 Locating transects, plots and selecting sample trees

Study areas are usually from several hundred up to 10 000 hectares[5] in size. In theory, there is no minimum area for study sites, although the problems associated with low sample sizes that will result from small surveys are the same as for species with restricted distributions listed above. Ultimately, the size of the area and time required for surveys should be determined by acquiring sufficient data along transects. The total number of transects will depend on the availability of target species (see section 2.5 below), but embark on surveys with pre-determined start points for at least 10 transects. Every point along the transect should be at least 400 m away from points along any other transect. To create transects, choose one of the following options:

a. Select a random point in the study area and then select the nearest point to it on a medium/large-sized watercourse or walking track. This is the transect origin. Randomly assign the transect start to one side of the watercourse and draw a line from the origin towards the nearest main ridge or treeline[6]; or
b. As above, but take a random bearing from the transect origin; or
c. Randomly assign the origin and bearing of all transects in the study area.

Use a GPS unit to navigate to the transect origin. Locate the first plot 20 m from the origin along the bearing, and subsequent plots at 100 m intervals. The area of the plot is defined as a circle with a radius of 10 m around the tree at the plot centre. Some modifications to this method are recommended below to ensure that an adequate sample size is achieved (section 2.5; Appendix 3).

As well as avoiding bias by random placement of transects and systematic (regular) placement of plots along transects, it is important to avoid bias in the selection of individual trees to be scored. For each indicator species, select up to three individuals[7] closest to the plot centre that meet the following criteria:

---

5 This is the maximum area realistically covered by a small survey team of two people over a 7–10 day field trip.

6 This technique has been used most extensively in previous FBI surveys and was designed to take advantage of travel up watercourses if there are no other forms of 'easy' access in the area.

7 The actual number of trees sampled will depend partly on how common they are in the area. See Appendix 5 for advice on this.

- Sample trees should be easily re-locatable within a 10 m radius of the plot centre.[8]
- Trees should have a canopy out of reach of ungulates (> 2 m) and a stem diameter of at least 5 cm at diameter breast height (DBH; 1.35 m).
- The majority of the canopy needs to be clearly visible from ground level and not obscured by epiphytes, climbers, understory or regrowth.
- If possible, avoid using subcanopy individuals of canopy species as they are less likely to be targeted by possums.

2.5 Sample size

The overall aim of sampling is to ensure that enough data are collected to detect real changes in measured variables over time, if they occur. This concept is referred to as statistical power.

Using basic or descriptive statistics, a sample of 50 independent, permanently marked individuals is required to reliably detect (with a probability of 80%) that a 10% change in the foliar cover score is statistically significant ($P < 0.05$) (Payton et al. 1999). Measuring more than one individual of a species on a plot does not constitute independent replicates for the purpose of this test, but these data can still be analysed in a generalised linear mixed model and do add power to detect change, largely because possum browsing is so variable between individual trees (Nugent et al. 2010). If an extra objective of the monitoring is to measure tree mortality[9], 200 trees of each species are required per site to have an 80% chance of detecting the effect of possum control on annual tree survival where the difference in annual mortality between treatment and non-treatment areas is ≥ 2% and the interval between each measurement is at least 4 years (Gormley et al. 2012).

Some trees are likely to die during the course of a study (usually 1–2% p.a., but possibly as high as 6% p.a. if a species is heavily browsed; Bellingham et al. 1999a; Nugent et al. 2010) so having more than 50 independent individuals from each site will increase the longevity of monitoring programmes and preclude the need to add in new individuals. New individuals, plots and

[8] If targeted individuals are consistently outside the radius, extend this radius to 20 m, but make sure that the individual can be easily re-located. Also, note that a 20 m radius was used in the previous FBI manual.

[9] Tree mortality has been shown to be a useful trigger for possum control (Nugent et al. 2010).

transects can be added into a study over time to replace those that have been lost or died, but these (new) data create analytical complexity because the sample group has changed. As such, statistics that compare the two time periods based on averages will no longer be valid, but multilevel/hierarchical models can be used (see Duncan et al. 2011). If it is likely that new individuals will be needed during the course of the study, consult a statistician before re-measuring plots.

Aim to sample a minimum of 50 plots containing individuals of each indicator species. It is highly unlikely that every indicator species will be present at every plot, so more than 50 plots will need to be sampled in total. Plots should initially be 100 m apart along each transect, but if indicator species are present in less than half of the first 10 plots, return along the transect and choose one of the following options, in the following order:

a. Establish extra plots in between existing ones (i.e. at 50 m spacing); or
b. Increase the plot radius to 20 m; or
c. Revert to a belt transect 10 m wide, sampling all individuals[10]; or
d. Abandon the transect.

Establish between five and fifteen plots per transect, bearing in mind that future re-measurement of the whole transect should be possible in one day. Complete a minimum of five transects overall and as many transects and plots overall as are required to obtain at least 50 plots containing each indicator species. See Appendix 4 for a diagrammatic flow chart of this process.

2.6 Sampling time and re-measurement frequency

The optimal sampling time depends on:

- The objectives of the study
- Possum abundance data
- Study location
- The choice of indicator species

Avoid sampling during periods of rapid leaf growth or foliage loss (spring and autumn). This is especially important for deciduous species such as fuchsia

10 In this case, consult a statistician prior to analysing data.

and wineberry, which at higher altitudes and in southern latitudes may only be able to be monitored over a short period in mid- to late summer. Foliage cover of most species fluctuates throughout the year and tends to peak in mid- to late summer. Possum damage is often most visible after this period of seasonal growth, although for some species this may be later in the year, or even in the winter when canopies may be naturally sparse. Some species[11] may also be preferentially browsed during winter when other food sources (e.g. fruits and palatable deciduous species) are unavailable. In general, conduct surveys in mid to late summer when new foliage has fully developed, possum-related browse is less likely to be masked by abundant foliage and day length and weather conditions are usually more conducive to doing fieldwork.

If possum control is planned for the area, the first FBI survey should be made as close to, but prior, to the initiation of control. If surveys are conducted too long before control, indicator species may continue to decline in foliar condition, potentially masking any effect of the subsequent control. Similarly, if surveys are conducted after control, results may reflect recovery from (rather than impact of) possum browsing. Collecting pre-treatment FBI data should approximately coincide with the collection of pre-treatment (i.e. pre-control) possum abundance data.

FBI plots should be re-measured at regular intervals every 2–5 years[12] depending on the indicator species, site, control history and other criteria considered when setting up the programme. In general, repeat surveys when indicator species have had adequate time to respond and (any change in) possum abundance is known. Because foliage cover and browse often varies seasonally, always aim to re-measure plots in the same month as for earlier surveys.

---

[11] Māhoe, kāmahi, rātā, patē and five finger.

[12] Tree tags and permolat may also need maintenance after 5 years to ensure they are not swallowed by trees or overgrown by epiphytes (Hurst & Allen 2007).

3. The Foliar Browse Index method

Use two-person teams for measuring FBI plots. A team can usually complete between 10 and 15 plots along a transect within a day, although this will vary with the number of indicator species chosen, number of individuals tagged, the nature of the terrain, the experience of the survey team and the time taken to access the transect.

A list of equipment required for surveys is given in Appendix 5.

3.1 Transect data

Mark the origin of the transect clearly with at least two permolat crosses inscribed with 'FBI line number X' and transect bearing. Mark the location of each plot using a GPS and record the coordinates on the transect data sheet (Appendix 5A). Use a compass to follow the pre-assigned bearing carefully, marking the transect route with sufficient permolat or plastic 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 the transect, use an accurate GPS to calculate the distance between plots and mark each plot centre with crossed pieces of permolat bearing the line and plot number attached to the nearest sturdy tree, which then becomes the plot centre.

For each transect, use Appendix 6A to record:

Survey details:	Survey name, transect number, date, observers and recorders.
Forest type:	The dominant (> 20% overall cover) canopy species for the whole transect. This can be more than one species.
Transect origin:	The GPS point (in NZTM) of the transect origin. Also record the make and model of the GPS receiver and record the accuracy of the fix.
Bearing:	The magnetic bearing of the transect.
Location diagram:	A sketch of the transect and plot locations emphasising landscape features (e.g. slips, gullies, rivers, creeks, ridges, bluffs, roads, tracks and large tree-fall gaps) that will help to re-locate the transect. Record GPS points of these features wherever possible.

Approach:	Clearly describe how to access the transect from a known location, such as a hut, field camp or helicopter drop-off site.
Notes:	Any other relevant observations and impressions. Include notes on damage caused by wind, snow, insects, salt spray or other influences. Information on birds and/or other pest species seen and heard can also be recorded here.

3.2 Plot data

For each plot, use Appendix 6A to record the following information:

Location:	Easting and Northing (in NZTM) using a GPS receiver and the accuracy (i.e. error) of the point.
Altitude:	Measured to the nearest 20 m. Obtain altitude from a topographic map once the GPS waypoint has been obtained for the plot, or use an altimeter. Do not use the GPS-calculated altitude.
Aspect:	The general lie of the plot, measured to the nearest 5°.
Slope:	The average slope of the plot to the nearest degree, measured with a clinometer (or equivalent instrument).
Physiography:	Describe using one of four categories—Ridge (including spurs), Face, Gully, or Terrace. Where more than one category could apply, select the predominant physiography and record any major discrepancies in the notes.
Non-possum browse:	Assess the vegetation for evidence of browse from other animals or insects and record as low, moderate or high.
Canopy dominants:	Record up to three tree species that provide the majority of the canopy cover on the plot, in order of decreasing abundance.

3.3 Assessment of indicator species

Use the indicator species data sheet (Appendix 6B) to collect data from each sample tree:

Transect/plot number, direction (magnetic compass bearing), distance (m):	Measure from the plot centre.
Species:	Use the first three letters from both the generic and specific names (in capitals and lower case respectively). For example, *Dysoxylum spectabile* is recorded as 'DYS spe'.
Tag number:	A unique, sequential number from a unique series for each study. Nail tree tags to trees (or stems of trees) at 1.35 m along the stem facing the plot centre, avoiding bulges or branching if they occur. Ensure the tag can be seen from the plot centre and place a piece of permolat, a plastic triangle or flagging tape behind each tree tag to increase visibility.
Stem diameter:	Measure directly above the tree tag, with the diameter tape at right angles to the main axis of the stem.
Living status:	Alive (**A**), Dead (**D**) or Not Found (**NF**). Use a dash (–) in any other circumstance, e.g. forgetting to check for a tree or not measuring a plot. In this case, clearly identify the reason in the notes column.

Use the indicator species data sheet (Appendix 6B) to help collect the following additional data:

Abundance of the indicator species in the plot:	Abundant (**A**): > 35% individuals; Common (**C**): 11–35% individuals; Occasional (**O**): 1–10% individuals; or Rare (**R**): < 1% individuals.
Tier:	Emergent (**E**): canopy isolated and above that of neighbouring trees); Canopy (**C**): forming part of the main canopy; or Subcanopy (**S**): below the main canopy; and **Segment**, and whether the assessed foliage is a whole Tree (**T**) or single Stem (**S**) of a multi-leader tree. A stem may be more appropriate to assess if it is more visible than the rest of the tree.

Foliage cover:	Estimate using the 10-point foliage cover scale (Appendix 7). Wherever possible, stand under the centre of the tree canopy in a position that gives a good view of the canopy. Typically this will be close to the base of the tree but where trees are leaning; it may be necessary to stand some distance from the base of the tree to assess foliage cover. If possible, use the notes column to record a distance and bearing from the host tree to the viewing position. For larger trees it may also be necessary to move around under the canopy of the tree to make an accurate overall assessment of foliage cover. Draw a line around the perimeter of the canopy (including both live and dead areas) incorporating any gaps/holes less than 1 m wide. Indent the circumference for larger gaps and holes. Do not include the trunk and major branches (> 10 cm DBH) in the assessment. Using the scale, first determine which of 5 broad classes (denoted by horizontal lines) best fits the foliage cover of the whole canopy, then select the square within that class that most closely resembles the foliage cover of the canopy and record the percentage beside the figure.
The proportion of possum-browsed leaves in the whole canopy:	Two observers should assess foliage cover and agree on a score. 0 Nil no browsed leaves 1 Light up to 25% of leaves browsed 2 Moderate 26–50% of leaves browsed 3 Heavy 51–75% of leaves browsed 4 Severe > 75% of leaves browsed X Canopy obscured It may be necessary to move away from the base of the tree to properly assess possum browse throughout the canopy. 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 factors such as wind or frost. For most indicator species, possum-browsed leaves are characterised by torn edges and jagged leaf stubs (Appendix 3). Possums often prefer foliage growing in full sunlight, so pay particular attention to the uppermost portion of the canopy when scoring browse. Insect damage typically consists of holes and wavy, clean-edged patterns (caterpillars) or straight, finely-milled edges (stick insects). Do not include individual, isolated torn leaves in the browse assessment.[13]

[13] Possums are unlikely to target an individual leaf in a whole clump, and observers often overestimate the amount of browse if including these.

Dieback—the conspicuous presence of dead stems (excluding both very recently and historically defoliated stems or those which are greater than 1 cm in diameter) in the whole tree:	0	Nil	no dieback
	1	Light	affecting up to 25% of canopy
	2	Moderate	affecting 26–50% of canopy
	3	Heavy	affecting 51–75% of canopy
	4	Severe	affecting > 75% of canopy
	X	Canopy obscured	
Notes:	Use the notes column to record any specific observations about the tree that might help with interpretation of data, or be useful for subsequent re-measurements.		

3.4 Large-leaved mistletoes

Mistletoes can be assessed using the FBI method, provided they are clearly visible from a re-locatable vantage point and the same individual is being assessed at each measurement. Mistletoes normally have patchy distributions and are highly palatable to possums (Sweetapple et al. 2002). As such, they are often in such small numbers that they will no longer be useful as an indicator species unless the sampling is applied to specific areas (strata) where they remain, or a whole population is monitored. Monitoring mistletoes may also be appropriate if the objectives of possum control are directly related to maintaining or enhancing the mistletoe population. This population monitoring may end up as a census of the remaining individuals within a clearly defined area. In all cases, use the following modifications to the indicator species data collection.

Select host trees in the same fashion as for indicator species. Only assess one mistletoe per (tagged) host tree.[14] Take a photograph of every individual to aid relocation. Ensure there is enough surrounding vegetation (e.g. distinctive branches) to clearly identify the mistletoe's location in the tree during future visits. Always place the mistletoe in the centre of the photo.

Use the separate score sheet for recording data (Appendix 6C).

[14] If there are multiple clearly defined mistletoes on the host tree, randomly choose one.

For each mistletoe, record:

Host species and mistletoe species:	Use the first three letters from both the generic and specific names (in capitals and lower case respectively). For example, *Peraxilla tetrapetala* is recorded as ‘PER tet.
Tag number:	A unique, sequential number from a unique series for each study. Nail tree tags to trees (or stems of trees) at 1.35 m along the stem facing the plot centre, avoiding bulges or branching if they occur. Ensure the tag can be seen from the plot centre and place a piece of permolat, a plastic triangle or flagging tape behind each tree tag to increase visibility.
Stem diameter:	Measure directly above the tree tag, with the diameter tape at right angles to the main axis of the stem.
Mistletoe status:	Alive (**A**), Dead (**D**) or Not Found (**NF**) or other (–) with an accompanying note if necessary.
Viewing direction:	The magnetic bearing from the host tree to a fixed observation point.
Viewing distance:	The distance from the host tree to the observation point.
Height (m):	The distance from the ground to the point of attachment to the host tree.
Living status:	Alive (**A**), Dead (**D**), Not Found (**NF**) or other (–) with an accompanying note if necessary.
Size in three dimensions (height, longest horizontal width, and the width perpendicular to this):	Measure as accurately as possible. Size will usually be estimated but where individual mistletoes are close to ground level their dimensions can be measured directly with a retractable tape measure. Height and width can be estimated from the viewing point, but depth is measured at right angles to width.
Foliage cover:	Estimate using the 10-point foliage cover scale (see Appendix 7 and section 3.3).

Dieback:	0	Nil	no dieback
	1	Light	affecting up to 25% of canopy
	2	Moderate	affecting 26–50% of canopy
	3	Heavy	affecting 51–75% of canopy
	4	Severe	affecting > 75% of canopy
	X	Canopy obscured	
The proportion of possum-browsed leaves:	0	Nil	no browsed leaves
	1	Light	up to 25% of leaves browsed
	2	Moderate	26–50% of leaves browsed
	3	Heavy	51–75% of leaves browsed
	4	Severe	> 75% of leaves browsed
	X	Canopy obscured	
Photo number:	Use the file number of a photo that has been taken to help identify where the individual is located in the host tree.		
Notes:	Any specific instructions that might help observers relocate the plant, e.g. whether there is an additional location diagram, or if the photograph has not been taken from the viewing point. This is particularly important if there is more than one plant in the host tree		

3.5 Reassessment of indicator species

When re-surveying sites, record all parameters described in sections 3.1 and 3.2. This provides an update of any changes to the physical environment, increases data accuracy and may improve the ease with which future survey parties can relocate the plots.

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

- Take a copy of the species location data, previous DBH of stems and any previous notes. Do not take a copy of the vegetation data from the previous assessment, as this is likely to influence estimates of parameters such as foliage cover, browse and recovery.
- For mistletoe plots, take a copy of previous photos to aid relocation.

- If trees have been completely defoliated since the previous assessment, check whether they have died by cutting the bark with a knife to determine whether sap is still present and/or the cambium is intact.
- If a tagged tree is alive but completely defoliated, record the foliage cover as 5%. Make a note that the tree has been completely defoliated.
- If a tagged tree has died, record the foliage cover as 'NA'. Make a brief, clear note on the death of the tree (such as 'dead standing', 'destroyed by treefall', or 'host (branch) died'. These notes assist with interpretation of causes of mortality, particularly to distinguish between 'natural' causes and possum-related mortality.
- Do not remove tags from dead trees.
- Do not replace dead trees with new ones unless this has been previously discussed and agreed with a statistician.
- Photographs of mistletoes can be re-taken to add evidence of changes in foliage and browse, or to further help the re-location, e.g. if the plant has changed considerably between sampling occasions.

4. Technical considerations and tips

Most of the variables measured in FBI are categorical estimates and are therefore subject to observer bias. Payton et al. (1999) provide an analysis of the subjective variables and how much they vary between different observers. A number of techniques have also been developed to help reduce bias in estimates:

- Prior to initiating a study, or re-measuring an ongoing one, conduct an observer calibration exercise (Appendix 8).
- Spend time estimating foliage cover and always use the scale (Appendix 7) to help with estimates.
- The foliage cover of many trees is in the mid-range. An easy way to determine whether a tree has foliage cover of 45% or 55% is to decide whether there is more foliage than light, i.e. foliage cover over 50%.
- Where a tree canopy can be clearly divided into several discrete segments, assess foliage cover in each segment separately before determining an overall score that is a weighted average of the segment scores.
- Estimate foliage cover as the first variable from the base of the tree and avoid being influenced by any dieback or possum browse that is subsequently observed.
- Two observers should agree on the foliage cover, dieback and browse scores.
- Aim for at least one member of each team to be present for successive re-measurements.
- Where there is more than one team, rotate personnel between teams if possible.
- When scanning for possum-browsed leaves, it is usually necessary to move around to obtain a range of viewing positions of the foliage.
- When estimating mistletoe size, use a retractable device with a 0.5 m ruler at the end. Alternatively, try to find a fallen leaf of the species to estimate the size of the canopy leaves (assuming this leaf is indicative of the plant).
- Where possible, use a retractable device or rangefinder to accurately measure mistletoe height.

Other tips can help create efficiency on the plot, or in the office:

- Transects should be clearly marked so that new observers can easily follow the transect without needing to refer to a GPS. This can be done with permolat and/or plastic coloured triangles.
- Place something distinctive and bright, such as flagging tape or a high-visibility vest, around the plot centre tree to assist navigating around the plot.
- Gently shaking the trunk or stem of the tree can help determine the limits of the tree's canopy.
- Laminate both the foliage cover scale and the indicator species assessment sheets to reduce wear and tear during fieldwork.
- Make sure each team member has copies of both the cover scale and indicator assessment sheets.
- For mistletoe photos, use a basic editing program (e.g. Microsoft Paint) to draw a circle around the mistletoe and note details (study, line, plot, tag number and date) in a text box.
- Print the photos and take a copy into the field next time to help with re-location.
- For mistletoes that are very difficult to see, a small diagram describing the location can be useful. This can be used when back in the office to help locate the mistletoe in the photo.

5. Data analysis and storage

Designing data entry and storage well at the outset of a monitoring project will save time and make subsequent analyses easier. Before storing data, check carefully for missing information and errors on all data sheets, and ensure metadata are recorded. Preferably, use someone who did not conduct the survey to carefully check the data before they are entered. Enter data into a standardised Excel worksheet template that resembles the way data were collected in the field (Appendices 6A, 6B and 6C). Add data from successive surveys as additional rows (not columns) to existing observations, i.e. in long format. Enter the transect data separately from plot data but ensure that the spreadsheets or worksheets clearly reference each other using a unique survey ID that reflects both the location and time of the survey, e.g. Wairaurahiri2012. Do not include any analyses or summaries in the raw data.

Store physical data in an organised fashion in a safe place where the data can be easily accessed in the future. Hard copies of raw data, metadata sheets, photographs, GPS waypoints, copies of reports and correspondence, and a list of the relevant electronic file locations should be stored in a clearly labelled folder in the appropriate physical records system. Electronic data should likewise be clearly labelled and saved in the appropriate file storage system.

Unless specific file extensions (usually .csv or .txt) are needed for a statistical package such as 'R' (R Development Core Team 2013), use standard Excel file formats (.xls). Back up all electronic data, preferably offline if the primary storage location is part of a networked system.

This manual does not specify data analyses for FBI data, but readers are referred to the previous manual for advice on straightforward descriptive statistics. Users are also advised to seek advice from a statistician for further options, such as analysing data using generalized linear models, or mixed models which are now well developed for FBI data and usually more appropriate (Nugent et al. 2010; Duncan et al. 2011).

6. Acknowledgements

The original FBI methodology was developed, field-tested and written by Ian Payton, Chris Frampton and Case Pekelharing with input from many other staff of Landcare Research and DOC, and was funded by DOC. This update to the method—the 'field manual'—was initiated and coordinated by Phil Knightbridge and Kate McNutt and written by Richard Clayton with help from Peter Sweetapple, Amy Hawcroft, Steve Deverell, Cinzia Vestena, Ian Westebrooke, Mike Elliot, Ollie Gansell, Richard Ewans and the many staff and contractors who contributed to a workshop held in Christchurch in late 2010. The foliage cover score sheet was created by Pen Holland. The manual is dedicated to Phil Knightbridge.

7. References

Bellingham, P.J.; Stewart, G.H.; Allen, R.B. 1999a: Tree species richness and turnover throughout New Zealand forests. *Journal of Vegetation Science 10*: 825–832.

Bellingham, P.J.; Wiser, S.K.; Hall, G.M.J.; Alley, J.C.; Allen, R.B.; Suisted, P.A. 1999b: Impacts of possum browsing on the long-term maintenance of forest biodiversity. *Science for Conservation 103*. Department of Conservation, Wellington. 60 p.

Brown, K.; Innes, J.; Shorten, R. 1993: Evidence that possums prey on and scavenge birds' eggs, birds and mammals. *Notornis 40*: 169–177.

Campbell, D.J. 1990: Changes in structure and composition of a New Zealand lowland forest inhabited by brushtail possums. *Journal Pacific Science 44(3)*: 277–296.

Cowan, P.E. 2005: Brushtail possum. Pp. 56–80 in C. M. King (Ed.): The handbook of New Zealand mammals. 2nd edition. Oxford University Press, Melbourne.

Department of Conservation. 2012: A guideline to monitoring populations. 56 p. Retrieved from http://www.doc.govt.nz/upload/documents/science-and-technical/inventory-monitoring/guideline-to-monitoring-populations.pdf

Duncan, R.P.; Holland, E.P.; Pech, R.P.; Barron, M.; Nugent, G.; Parkes, J.P. 2011: The relationship between possum density and browse damage on kamahi in New Zealand forests. *Austral Ecology 36*: 858–869.

Elzinga, C.L.; Salzer, D.W.; Willoughby, J.W. 1998: Measuring and monitoring plant populations. U.S. Department of the Interior, Bureau of Land Management, National Applied Resource Sciences Center, Denver, CO, U.S.A. 477 p.

Fitzgerald, A.E.; Gibb, J. 2001: Introduced mammals in a New Zealand forest: long-term research in the Orongorongo Valley. *Biological Conservation 99*: 97–108.

Gormley, A.M.; Holland, E.P.; Pech, R.P.; Thomson, C.; Reddiex, B. 2012: Impacts of an invasive herbivore on indigenous forests. *Journal of Applied Ecology 49*: 1296–1305.

Hurst, J.M.; Allen, R.B. 2007: The Recce method for describing New Zealand vegetation— expanded manual, version 4. Landcare Research Contract report LC0708/029. https://nvs.landcareresearch.co.nz/Content/Recce_ExpandedManual.pdf

Jongman, R.H.G.; ter Braak, C.J.F.; van Tongeren, O.F.R. 1987: Data analysis in community and landscape ecology. Wageningen, Pudoc. 299 p.

Lee, W.; McGlone, M.; Wright, E. 2005: Biodiversity inventory and monitoring: a review of national and international systems and a proposed framework for future biodiversity monitoring by the Department of Conservation. Landcare Research Contract Report (LC0405/122), Landcare Research Ltd, Lincoln. 216 p.

Montague, T.L. (Ed.). 2000: The brushtail possum: biology, impact and management of an introduced marsupial. Manaaki Whenua Press, Lincoln.

NPCA (National Pest Control Agencies). 2010: Protocol for possum population monitoring using the wax tag method. National Pest Control Agencies: Wellington, New Zealand.

NPCA (National Pest Control Agencies). 2011: Protocol for possum population monitoring using the trap-catch method. National Pest Control Agencies: Wellington, New Zealand.

Nugent, G.; Sweetapple, P.; Coleman, J.; Suisted, P. 2000: Possum feeding patterns: dietary tactics of a reluctant folivore. Pp. 10–23 in T.L. Montague (Ed.): The brushtail possum: biology, impact and management of an introduced marsupial. Manaaki Whenua Press, Lincoln, New Zealand.

Nugent, G.; Whitford, J.; Sweetapple, P.; Duncan, R.; Holland, P. 2010: Effect of one-hit control on the density of possums (*Trichosurus vulpecula*) and their impacts on native forest. *Science for Conservation 304*. 64 p.

Parkes, J.P.; Robley, A.; Forsyth, D.M.; Choquenot, D. 2006: Adaptive management experiments in vertebrate control in New Zealand and Australia. *Wildlife Society Bulletin 34*: 229–236.

Parliamentary Commissioner for the Environment. 2011: Evaluating the use of 1080: Predators, poisons and silent forests. http://www.pce.parliament.nz/assets/Uploads/PCE-1080.pdf. (Viewed 5 August 2013.)

Payton, I.J. 2000: Damage to native forests. Pp. 111–125 in T.L. Montague (Ed.): The brushtail possum: biology, impact and management of an introduced marsupial. Manaaki Whenua Press, Lincoln.

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. 62 p.

R Development Core Team. 2013: R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Sweetapple, P.; Nugent, G. 2011: Chew-track-cards: a multiple-species small mammal detection device. *New Zealand Journal of Ecology 35*: 153–162.

Sweetapple, P.J.; Fraser, K.W.; Knightbridge, P.I. 2004: Diet and impacts of brushtail possum populations across an invasion front in South Westland, *New Zealand. New Zealand Journal of Ecology 28*: 19–33.

Sweetapple, P.J.; Nugent, G.; Whitford, J.; Knightbridge, P.I. 2002: Mistletoe (*Tupeia antarctica*) recovery and decline following possum control in a New Zealand forest. *New Zealand Journal of Ecology 26*: 61–71.

Warburton, B.; Cowan, P.; Shepherd, J. 2009: How many possums are now in New Zealand following control and how many would there be without it? Landcare Research Contract Report LC0910/060. Animal Health Board, Wellington, New Zealand.

8. Appendices

Appendix 1	FBI indicator species assessment sheet
Appendix 2	Suitability of indicator species that have been used in FBI assessments and their attributes
Appendix 3	Examples of possum browse on a range of indicator species
Appendix 4	FBI work flow chart
Appendix 5	List of equipment required for establishing or re-measuring FBI plots
Appendix 6	A FBI transect and plot data sheet
	B FBI indicator species data sheet
	C FBI mistletoe data sheet
Appendix 7	Foliage cover scale
Appendix 8	Observer calibration exercise

Appendix 1 FBI indicator species assessment sheet

Assess only trees/plants with canopies above the level of ungulate browse and stems > 5 cm DBH (except mistletoes).

Abundance 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 Tier height class of the tree as:

E	**Emergent**	above the forest canopy
C	**Canopy**	forming part of the forest canopy
S	**Subcanopy**	below the forest canopy

Segment Segment of the tree being assessed as:

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

Living status

A **Alive**

D **Dead**

NF **Not Found**

Foliage cover

From the foliage cover scale (Appendix 7) select the square that most closely resembles the foliage cover of the canopy. Include areas of the canopy that are dead in this assessment. Where a tagged tree is alive but completely defoliated, record the foliage cover as 5%. Record 'NA' under foliage cover when a tagged tree is dead and make notes to clearly describe the cause of death if known.

Browse

Record the proportion of possum-browsed leaves in the whole canopy as:

0	**Nil**	no browsed leaves
1	**Light**	up to 25% of leaves browsed
2	**Moderate**	26–50% of leaves browsed
3	**Heavy**	51–75% of leaves browsed
4	**Severe**	more than 75% of leaves browsed
X	**Unable to estimate**	

Dieback

Record the proportion of recently dead branches in the canopy as:

0	**Nil**	no dieback
1	**Light**	up to 25% of canopy dead
2	**Moderate**	26–50% of canopy dead
3	**Heavy**	51–75% of canopy dead
4	**Severe**	more than 75% of canopy dead
X	**Unable to estimate**	

Mistletoes

When collecting FBI data for mistletoe species, use Appendix 6C and record the following extra information:

- Clearly identify which individual mistletoe is scored using a combination of photos and compass bearings.
- Assess the whole plant.
- Estimate the size of the mistletoe in three dimensions.

Appendix 2 Suitability of indicator species that have been used in FBI assessments and their attributes

Canopy or emergent trees	Vernacular name[1]	Palatability	Response	Abundance	Ease of assessment	Overall suitability	References[2]	Notes
Alectryon excelsus	tītoki, tapitapi, titongi, tokitoki	Moderate	Moderate	Occasional to rare	Moderate to poor	Moderate	12, 15	
Beilschmiedia tawa	tawa	Moderate	Slow	Common	Moderate to poor	Moderate	11, 12	Fruit is a major possum food
Dysoxylum spectabile	kohekohe, kohe, koheriki	High	Rapid	Common to occasional	Good to moderate	Good	5, 16	
Elaeocarpus dentatus	hīnau	Low	Slow	Occasional to rare	Moderate	Poor	11	Possums only eat flowers and fruit
E. hookerianus	pōkākā	Moderate	Slow	Rare	Good to moderate	Moderate to poor	11	Possums also eat flowers and fruit
Libocedrus bidwillii	NZ cedar, kaikawaka, pāhautea	Moderate	Slow	Occasional to rare	Poor—difficult to score browse on	Poor	6	
Melicytus ramiflorus	māhoe	Moderate	Rapid	Common to occasional	Good to moderate	Good	11, 13, 14, 16	Possums eat fruit
Metrosideros excelsa	pōhutukawa, hutukawa	Moderate	Moderate	Common to occasional	Good to moderate	Moderate		

Canopy or emergent trees	Vernacular name[1]	Palatability	Response	Abundance	Ease of assessment	Overall suitability	References[2]	Notes
M. robusta	northern rātā, rātā	Moderate	Slow	Occasional to rare	Poor	Poor	1, 11, 12, 14, 15	Consider using existing permanent plot data to monitor this species
M. umbellata	southern rātā, rātā	Moderate	Slow	Common to occasional	Moderate to poor	Moderate	4, 11	
Podocarpus totara [3]	tōtara	Moderate	Slow	Occasional to rare	Poor—difficult to score browse and FC [3]	Poor	11	Consider using existing permanent plot data to monitor this species
P.cunninghamii [3]	Hall's tōtara, thin-barked tōtara, tōtara kōtukutuku	Moderate	Slow	Occasional to rare	Poor—difficult to score browse and FC [3]	Poor	2, 3, 16	Highly palatable in early summer. As above.
Weinmannia racemosa	kāmahi, tawhero, tōwai	Moderate	Slow	Common	Good to moderate	Moderate	4, 10, 11, 12, 13, 14, 15, 16, 18	
W. silvicola	tōwai, tawhero	Moderate	Slow	Common	Good to moderate	Moderate		

Sub-canopy trees and shrubs	Vernacular name[1]	Palatability	Response	Abundance	Ease of assessment	Overall suitability	References[2]	Notes
Aristotelia serrata	wineberry, makomako, mako	High	Rapid	Occasional to rare—patchy	Good	Good	10, 11, 16	Deciduous. Short-lived (usually < 20 years).
Cyathea medullaris	black tree fern, mamaku, katātā, kōrau	Moderate	Moderate	Occasional—patchy	Moderate	Moderate	none	
Fuchsia excorticata	fuchsia, kōtukutuku	High	Rapid	Occasional to rare—patchy	Good	Good	7, 9, 11, 15, 16	Deciduous. Possums eat fruit.
Myrsine salicina	toro	Moderate	Moderate	Common to occasional	Good to moderate	Moderate	12	Possums eat fruit.
Olearia rani	heketara	Low–mod	Moderate to poor	Occasional to rare—patchy	Good	Moderate to poor	11,17	Moderate to high palatability in Northland.
Pennantia corymbosa	kaikōmako	Low–mod	Moderate	Rare	Good to moderate	Moderate to poor		Possums eat foliage and fruit.
Pseudopanax arboreus	five finger	Mod–high	Rapid to moderate	Occasional to rare—patchy	Poor	Moderate	12, 15	Browsed leaves usually dropped. Possums eat flowers and fruit.

Sub-canopy trees and shrubs	Vernacular name[1]	Palatability	Response	Abundance	Ease of assessment	Overall suitability	References[2]	Notes
P. colensoi	mountain five finger	Mod–high	Rapid to moderate	Occasional to rare	Poor	Moderate		Browsed leaves are usually dropped.
P. crassifolius	lancewood	Moderate	Slow	Occasional to rare	Moderate	Moderate	11	
Raukaua edgerleyi	raukawa	Moderate	Moderate	Rare	Moderate	Moderate to poor		
R. simplex	haumakaroa	Moderate	Rapid to moderate	Occasional	Good	Good	11, 16	Possums eat fruit.
Schefflera digitata	patē, kohi, patatē, patētē	Mod–high	Rapid to moderate	Occasional—patchy	Good for FC, but poor for browse	Moderate		Browsed leaves usually dropped. Possums eat fruit. Short-lived.

Mistletoes	Vernacular name[1]	Palatability	Response	Abundance	Ease of assessment	Overall suitability	References[2]	Notes
Alepis flavida	mistletoe, pirinoa, pirita	High	Rapid to moderate	Occasional to rare—patchy	Good to moderate	Moderate–good	16, 19	Possums eat fruit. Can be difficult to score browse after defoliation.
Peraxilla colensoi	mistletoe, korukoru pirita	High	Rapid to moderate	Occasional to rare—patchy	Good to moderate	Moderate–good	16, 19	Possums eat fruit. Can be difficult to score browse after defoliation.
P. tetrapetala	mistletoe, pikirangi, pirirangi, roeroe	High	Rapid to moderate	Occasional to rare—patchy	Good to moderate	Moderate–good	16, 19	Possums eat fruit. Can be difficult to score browse after defoliation.
Tupeia antarctica	White mistletoe, tāpia, kohourangi, pirinoa, pirita	High	Rapid	Occasional to rare—patchy	Good	Moderate–good	8	Can be difficult to score browse after defoliation.
Ileostylus micranthus	Green mistletoe, pikirangi, pirinoa, pirirangi, pirita	Moderate	Rapid to moderate	Occasional to rare—patchy	Good	Moderate		Can be difficult to score browse after defoliation.

Notes

1 Vernacular names are taken from Ngā Tipu o Aotearoa—the New Zealand Plant Names Database (http://nzflora.landcareresearch.co.nz/) accessed April 2013.

2 The reference list is made up of studies that mention the species being eaten by possums. It is not exhaustive and does not take into account any results from the studies. References below that specifically use the FBI method are: Sweetapple et al. 2004 (16); Nugent et al. 2010 (11); Gormley et al. 2012 (17). The Nugent et al. (2010) paper also contains summary information on browse of many indicator species at different sites.

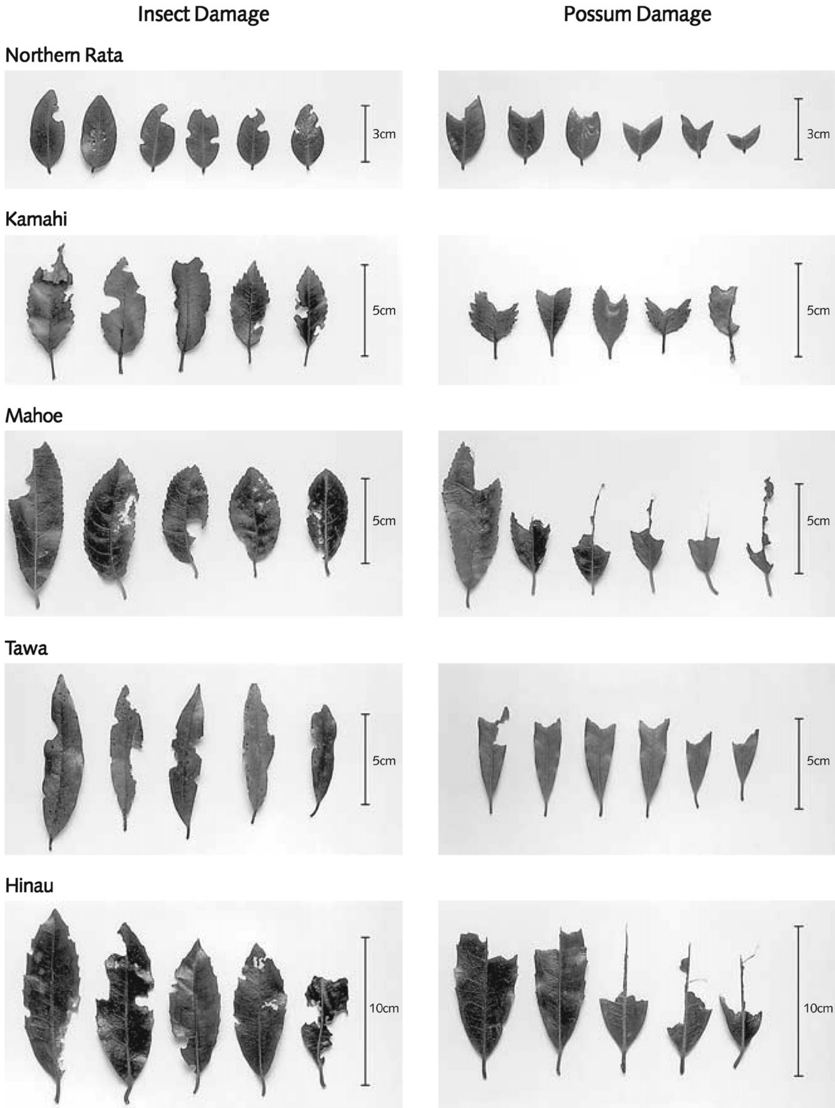
3 For tōtara, the leaves are small and needle-like and browse is difficult to distinguish unless it is on fresh growth which occurs in the spring. Where possum-induced browse (sometimes called 'hedging') is heavy, few of the current season's light green shoots will remain, and the canopy will take on the dull green colouration characteristic of older tōtara leaves.

References

1 = Meads 1976	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.
2 = Bellingham et al. 1999	Bellingham, P.J.; Wiser, S.K.; Hall, G.M.J.; Alley, J.C.; Allen, R.B.; Suisted, P.A. 1999: Impacts of possum browsing on the long-term maintenance of forest biodiversity. *Science for Conservation 103*. Department of Conservation, Wellington. 60 p.
3 = Nugent et al. 2000	Nugent, G.; Sweetapple, P.; Coleman, J.; Suisted, P. 2000: Possum feeding patterns; dietary tactics of a reluctant folivore. Pp. 10–13 in T.L. Montague (Ed.): The brushtail possum: biology, impact, and management of an introduced marsupial. Manaaki Whenua—Landcare Research, Lincoln.
4 = Smale et al. 1995	Smale, M.C.; Rose, A.B.; Frampton, C.M.; Owen, H.J. 1995: The efficacy of possum control in reducing forest dieback in the Otira and Deception catchments, central Westland. *Science for Conservation 13*. Department of Conservation, Wellington. 11 p.
5 = Nugent et al. 2002	Nugent, G.; Whitford, J.; Innes, J.; Prime, K. 2002: Rapid recovery of kohekohe (*Dysoxylum spectabile*) following possum control. *New Zealand Journal of Ecology 26*: 73–79.
6 = Rogers 1997	Rogers, G. 1997: Trends in health of pahautea and Hall's totara in relation to possum control in central North Island. *Science for Conservation 52*. Department of Conservation, Wellington. 49 p.
7 = Urlich & Brady 2005	Urlich, S.; Brady, P.L. 2005: Benefits of aerial 1080 possum control to tree fuchsia in the Tararua Range, Wellington. *New Zealand Journal of Ecology 29*: 299–309.

8 = Sweetapple et al. 2002	Sweetapple, P.J.; Nugent, G.; Whitford, J.; Knightbridge, P. 2002: Mistletoe (*Tupeia antarctica*) recovery and decline following possum control in a New Zealand forest. *New Zealand Journal of Ecology 26*: 61–71.
9 = Sweetapple & Nugent 1999	Sweetapple, P.; Nugent, G. 1999: Provenance variation in fuchsia (*Fuchsia excorticata*) in relation to palatability to possums. *New Zealand Journal of Ecology 23*: 1–10.
10 = Cochrane et al. 2003	Cochrane, C.H.; Norton, D.A.; Miller, C.J.; Allen, R.B. 2003: Brushtail possum (*Trichosurus vulpecula*) diet in a north Westland mixed-beech (Nothofagus) forest. *New Zealand Journal of Ecology 27*: 61–65.
11 = Nugent et al. 2010	Nugent, G.; Whitford, J.; Sweetapple, P.; Duncan, R.P.; and Holland, E.P. 2010: Effect of one-hit control on the density of possums (*Trichosurus vulpecula*) and their impacts on native forest. *Science for Conservation 304*. Department of Conservation, Wellington.
12 = Campbell 1990	Campbell, D.J. 1990: Changes in structure and composition of a New Zealand lowland forest inhabited by brushtail possums. *Pacific Science 44*: 277–296.
13 = Forsyth & Parkes 2005	Forsyth, D. M.; Parkes, J.P. 2005: Browse on mahoe and kamahi leaf-fall as a trigger for possum control. *New Zealand Journal of Ecology 29*: 311–320.
14 = Fitzgerald 1976	Fitzgerald, A.E. 1976: Diet of the opposum *Tricosurus vulpecula* (Kerr) in the Orongorongo Valley, Wellington, New Zealand, in relation to food-plant availability. *New Zealand Journal of Zoology 3*: 399–419.
15 = Mason 1958	Mason, R. 1958: Foods of the Australian opossum (*Tricosurus vulpecula*, Kerr) in New Zealand indigenous forest in the Orongorongo Valley, Wellington. *New Zealand Journal of Science 1*: 590–613.
16 = Sweetapple et al. 2004	Sweetapple, P.J.; Fraser, W.; Knightbridge, P.I. 2004: Diet and impacts of brushtail possum populations across an invasion front in South Westland, New Zealand. *New Zealand Journal of Ecology 28*: 19–33.
17 = Gormley et al. 2012	Gormley, A.M.; Holland, E.P.; Pech, R.P.; Thomson, C.; Reddiex, B. 2012: Impacts of an invasive herbivore on indigenous forests. *Journal of Applied Ecology 49*: 1296–1305.
18 = Duncan et al. 2011	Duncan, R.P.; Holland, E.P.; Pech, R.P.; Barron, M.; Nugent, G.; Parkes, J.P. 2011: The relationship between possum density and browse damage on kamahi in New Zealand forests. *Austral Ecology 36(7)*: 858–869.
19 = Sessions et al. 2001	Sessions, L.A.; Rance, C.; Grant, A.; Kelly, D. 2001: Possum (*Trichosurus vulpecula*) control benefits native beech mistletoes (Loranthaceae). *New Zealand Journal of Ecology 25*: 27–33.

Appendix 3 Examples of possum browse on a range of indicator species



Possum and insect-damaged leaves of northern rātā, kāmahi, māhoe, tawa and hīnau.

All following photos are courtesy of Steve Deverell, Amy Hawcroft, Phil Knightbridge, and Ollie Gansell.

Possum browse on *Raukaua simplex*.

Possum browse on *Alepis flavida*.

Possum browse on *Peraxilla tetrapetala*.

Possum browse on *Fuchsia excorticata*.

Possum browse on *Pseudopanax arboreus*.

Possum browse on *Beilschmiedia tawa*.

Possum browse on *Dysoxylum spectabile*.

Possum browse on *Melicytus ramiflorus*.

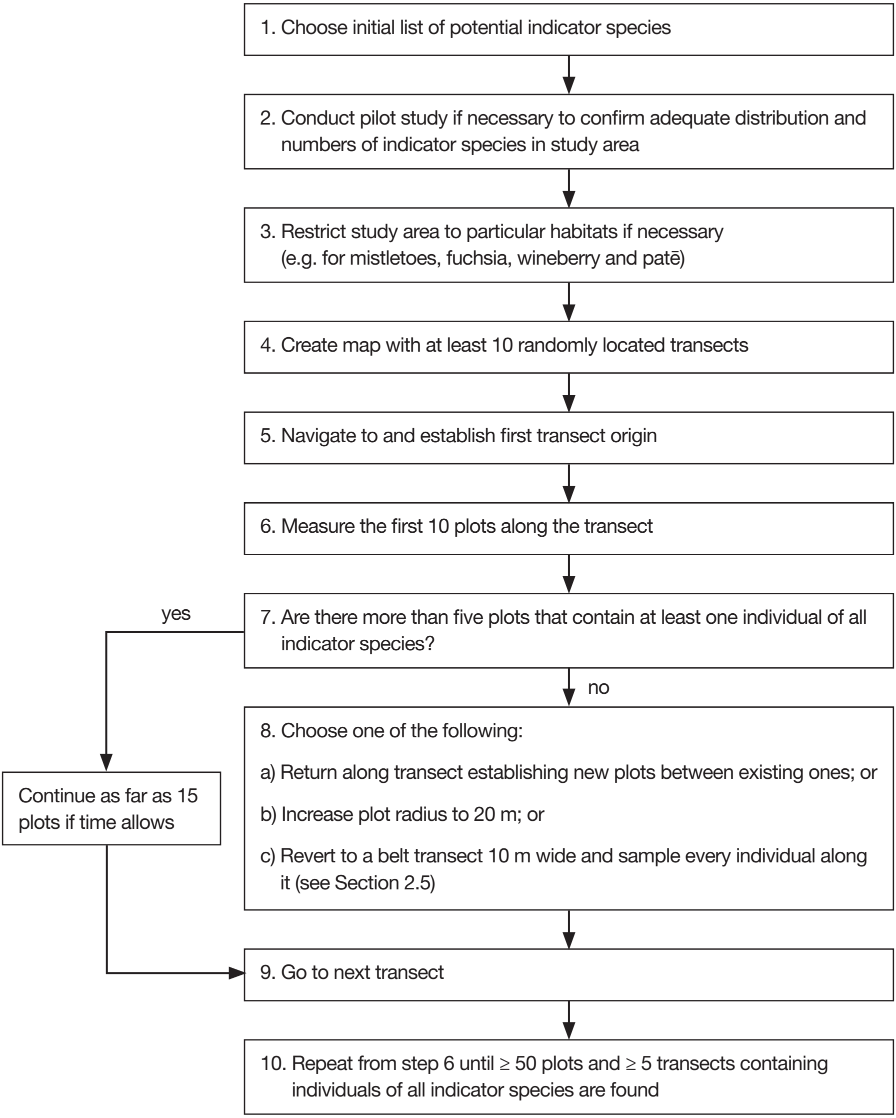
Possum browse on *Melicytus ramiflorus*.

Possum browse on *Metrosideros umbellata*.

Possum browse on *Aristotelia serrata*.

Appendix 4 FBI work flow chart

It is assumed that prior to undertaking the following work flow, studies already have clear goals and objectives; the timing of possum control and associated abundance indices are known; and field workers have undertaken the calibration exercise (Appendix 8).



Appendix 5 List of equipment required for establishing or re-measuring FBI plots

- Topographic map with line locations and treatment boundaries
- GPS and spare batteries
- Foliar Browse Index plot sheets
- Laminated indicator species assessment sheet
- Laminated foliage cover scale
- Pencils and clipboard
- Digital camera and spare batteries (for mistletoe photos)
- Binoculars
- Compass
- Diameter tape
- Tape—20 m
- Aluminium tree tags (individually and sequentially numbered)
- Nails (flathead, galvanised, some 50 mm, some 75 mm for larger trees)
- Hammer
- Flagging tape
- Permolat for marking lines and as backing to tree tags (coloured triangles can also be used for marking lines)
- Rangefinders, an 8 m builders tape or a hypsometer can be useful for estimating the height of mistletoes
- 8 m builders tape or a telescopic pole with a 0.5 m ruler at the end can be useful for estimating the size of mistletoes

Appendix 6A FBI transect and plot data sheet

SURVEY NAME			FOREST TYPE	
TRANSECT NUMBER			MEASURED BY	
CATCHMENT			RECORDED BY	
GPS MODEL			DAY/MONTH/YEAR	
TRANSECT ORIGIN	E	N	+/–	BEARING

APPROACH	LOCATION DIAGRAM

NOTES: e.g. birds, forest character, pests

NON-POSSUM BROWSE

Plot No.	Species	Low	Mod	Heavy	Animal

Plot No.	**Easting**	**Northing**	**Error**	**Altitude**	**Aspect**	**Slope**	**Physiog**	**Canopy Dominants**

Additional notes:

Appendix 6B FBI indicator species data sheet

Foliar Browse Index (FBI) Survey: ____________ Date: ____________ Page: ____ / ____

Indicator species data Measured by: ____________ Recorded by: ____________

Transect/plot	Direction (deg.)	Distance (m)	Species	Tag number	Stem diameter (dbh)	Status	Abundance	Tier	Segment	Foliage cover	Browse	Dieback	Notes

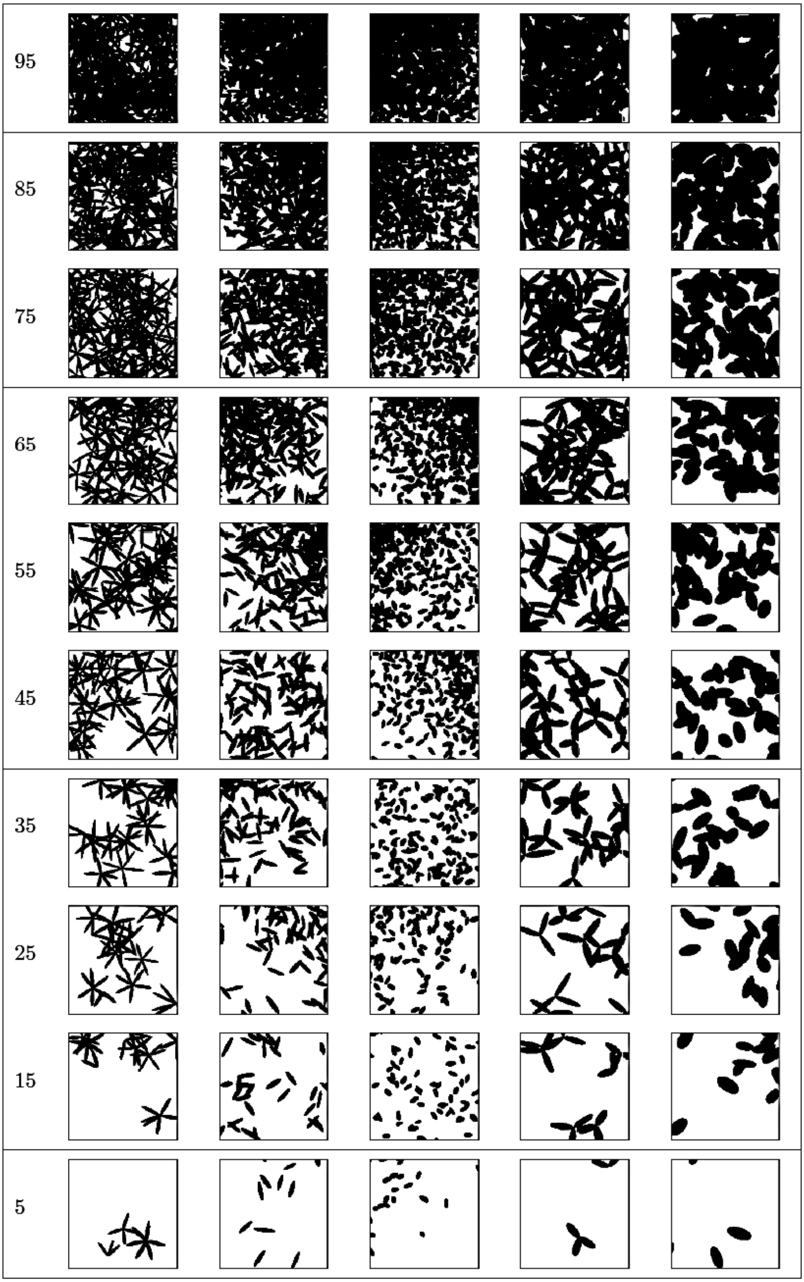
Appendix 6C FBI mistletoe data sheet

Foliar Browse Index (FBI) Survey: ______ Date: ______ Page: ___ / ___

Indicator species data Measured by: ______ Recorded by: ______

Transect/plot	Direction (deg.)	Distance (m)	Host species	Tag number	Stem diameter (dbh)	Mistletoe species	Viewing direction	Viewing distance	Height on host (m)	Mistletoe status	Dimension H (cm)	Dimension W1 (cm)	Dimension W2 (cm)	Foliage cover	Dieback	Browse	Photo number	Notes

Appendix 7 Foliage cover scale



Appendix 8 Observer calibration exercise

The purpose of this exercise is to provide a standard framework that helps to minimise observer bias in the subjective scoring of foliage cover and browse during FBI assessments. Before starting this field exercise, ensure each team member has read the foliar browse index field manual and understands how to estimate foliage cover possum browse and recovery.

1. Select five individual trees of at least three suitable indicator species that are accessible to a field or work base.[15]
2. Permanently mark trees using tree tags and permolat for future relocation and calibration exercises. Record the distance and bearing from a known point e.g. marked plot centre.
3. Each surveyor independently assesses foliage cover, browse and recovery for each tree.
4. For each tree, calculate[16] the average foliage cover score and the average browse and recovery scores for each observer.
5. Round this score to the nearest available cover value, or category for browse—50.0% becomes 55%, 49.9% becomes 45%; 0.67 becomes 1 and 0.4 becomes 0, etc.
6. Re-visit each tree and use the most experienced member of the team to help determine whether individuals are consistently under-scoring or over-scoring foliage cover. As a guide, if an observer has scored foliage cover 20% different from the calculated average, this needs to be discussed.
7. Discuss why individuals may have scored foliage cover differently—
    a. Was the observer positioned directly under the crown?
    b. Was the boundary around the canopy correctly estimated?
    c. Which picture on the foliage cover scale was most similar?
8. Point out browsed leaves and recovery and discuss whether everyone agrees the damage has been caused by possums. Use the average browse scores to determine if individuals are over- or under-estimating browse and/or recovery.
9. Discuss **any** difference in estimating amounts of browse and recovery where it is present.

---

15 The selection and location of these individuals can be based on convenience and does not need to be in accordance with the manual. Ideally the individuals and species will show some variety in their morphology so that observers can experience a wide range of situations that they will encounter when conducting surveys.

16 If it is not practical to use a computer, revisit each tree with the raw data and a pocket calculator.

Published by:
Department of Conservation
Christchurch Office
Private Bag 4715
Christchurch Mail Centre
Christchurch 8140
New Zealand
May 2014

Editing and design:
Publishing Team, DOC National Office

newzealand.govt.nz