Emission factors for managed and unmanaged Grassland with Woody Biomass

S.J. Wakelin, P.N. Beets

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EXECUTIVE SUMMARY

Objectives

The objective of this report is to provide defensible emission factors for use with GWB within New Zealand's greenhouse gas inventory, including:

- individual weighted emission factors for managed and unmanaged categories of GWB;
- a single weighted emission factor for all GWB sub-categories combined.

Key Results

- There are 190 intersections of the LUCAS grid within the GWB land use map; 83 of these were classified as managed and 87 unmanaged.
- An emission factor for unmanaged GWB was calculated from LUCAS plot data from unmanaged GWB plots. The mean carbon stock for the 58 measured plots (weighted by area) is 59.96 t C/ha, or 60.57 t C/ha with the addition of a contribution from non-woody biomass. The remaining 29 locations were unmeasured grid intersections.
- Only 32 of the 83 plots within managed GWB were measured. This data was not used to derive an emission factor – instead, an emission factor for managed GWB was derived from the yield table prepared from the LUCAS survey of post-1989 natural forest. The mean carbon stock at ages from 0-10 years after the GWB threshold stock of 2 t C/ha is achieved is 11.99 t C/ha. Inclusion of a contribution from non-woody biomass increases this to 13.05 t C/ha.
- The overall GWB emission factor (weighted by the number of plots in the managed and unmanaged sub-categories) is 36.54 t C/ha, or 37.37 t C/ha including non-woody biomass.

Conclusions and further work

- For emissions due to conversion of GWB to other land uses, it is appropriate to use the emission factor for managed GWB. For emissions due to conversion of other land uses to GWB, the managed GWB emission factor is still appropriate. The transition period can be retained at 28 years.
- For emissions due to wildfires and controlled burning in grasslands, the overall weighted emissions factor should be used.

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Introduction

UNFCCC greenhouse gas inventory reporting

New Zealand is a signatory to the Kyoto Protocol and the United Nations Framework Convention on Climate Change (UNFCCC). Under the UNFCCC, Parties must prepare an annual inventory report on their greenhouse gas emissions (MFE 2013). This includes reporting on carbon stocks and carbon stock changes within the Land Use, Land Use Change and Forestry (LULUCF) sector. Land is classified under six land uses: Forest land, Grassland, Cropland, Settlements, Wetlands and Other Land. New Zealand's LULUCF estimates are calculated using a programme of data collection and modelling called the Land Use and Carbon Analysis System (LUCAS).

A wall-to-wall land use mapping programme within LUCAS has been carried out to provide land use data that includes the four wooded land uses: natural forest, pre-1990 planted forest, post-1989 forest and grassland with woody biomass (MFE, 2013). Land use has been mapped as at 1 January 1990, 31 December 2007 and 31 December 2012. The Land Use Map (LUM) data is used to provide a land use change matrix, and these areas are combined with emission factors and yield tables to provide estimates of carbon stock changes associated with land use change.

A systematic network of permanently located sample plots has been installed in each of the four recognised forest sub-categories to allow carbon stocks and carbon stock changes in forests to be determined. These sub-categories are pre-1990 natural forest (Beets et al 2009), pre-1990 planted forest (Beets et al 2012), post-1989 planted forest (Beets et al 2011) and post-1989 natural forest (Beets and Paul 2012). Plot measurements form the basis for deriving emission factors for forests used in the greenhouse gas inventory (MFE 2013).

New Zealand has mapped three Grassland sub-categories: high-producing grassland, low-producing grassland and grassland with woody biomass (GWB). New Zealand's annual inventory report (MFE 2013) describes GWB as grassland with shrubland as vegetation where, under current management or environmental conditions the forest definition will not be met over a 30-40 year period. The definition also includes above-timberline shrubland and montane herb fields, and grassland with tall trees such as parkland or shelterbelts. GWB includes areas of vegetation that fall below (and are not expected to reach or exceed without human intervention) the national threshold for forest-land. This includes areas of shrubland commonly referred to in New Zealand as "scrub". Mapping GWB is particularly difficult, as in practice there is a continuous gradient between natural forest and GWB, wetland vegetation and GWB, and Grassland and GWB. GWB can be subject to relatively rapid change, particularly where it is within a mosaic of managed land uses rather than a situation where environmental rather than management conditions prevent transition into forest. Unlike the forest sub-categories, GWB has not been systematically sampled.

Grassland with woody biomass in the greenhouse gas inventory

Estimates of GWB biomass per hectare are used in the greenhouse gas inventory to estimate:

- net CO_2 uptake in lands converted to Grasslands;
- CO_2 emissions due to Grassland conversion to other land uses;
- CO_2 stocks in Grassland remaining Grassland;
- non-CO_2 emissions due to wildfires and controlled burning in grasslands.

Biomass stock changes are estimated for *land converted to and from Grasslands* based on the carbon stocks in all five UNFCCC pools (above-ground, below-ground, deadwood, litter and soil carbon) before and after the land use change. Removals for land use change to GWB are calculated by assuming that land converted will take ***t*** years to reach the maximum biomass level, ***B***. A constant carbon accumulation rate of ***B / t*** tonnes per hectare per year is therefore assumed for ***t*** years following conversion. For conversions to grassland, the UNFCCC Tier 1 assumption is that the new biomass density is obtained in the year of conversion. In New Zealand this assumption is applied to conversions to low- and high-producing grassland but a transition is still applied for conversion to GWB. Emissions resulting from conversions of GWB to another land use are calculated as an instant emission of ***B*** in the year of conversion. For wildfire and controlled burning emissions of non-CO_2 greenhouse gases, the default assumption is that only above-ground biomass is burned. However, countries are encouraged to include decaying of residues and below-ground biomass if possible.

Wildfire and controlled burn areas are provided independently of the LUM. Wildfire areas are assigned to vegetation type and captured in the National Rural Forest Authority (NRFA) database (Wakelin 2012a). There is little data for controlled burning of GWB, so only emissions from the conversion of GWB to planted forest is included in the inventory (Wakelin 2012b).

In 2011 there were 1,118,082 ha of GWB, equating to 4.2% of New Zealand's land area (MFE 2013). Land use changes involving GWB in the period 1990-2011 are given in Table 1. Conversion of GWB to post-1989 forest accounts for 58% of the total area of land use change involving GWB from 1990-2011.[1] The other main land use changes involving GWB are conversion to low and high producing grassland (combined 23%) and low producing grassland converted to GWB (13%).

Table 1. Land use change involving GWB 1990-2011 (from MFE 2013)

From	To	ha	%*
GWB	Post-1989 planted forest	133,700	58%
"	High producing grassland	18,100	8%
"	Low producing grassland	34,300	15%
"	Perennial cropland	100	0%
"	Settlements	200	0%
Total from GWB		**186,400**	**81%**
Natural forest	GWB	2,900	1%
Pre-1990 planted forest	"	200	0%
High producing grassland	"	9,500	4%
Low producing grassland	"	28,900	13%
Perennial cropland	"	400	0%
Other land	"	1,500	1%
Total to GWB		**43,400**	**19%**
All land use change involving GWB		**229,800**	**100%**

* % of the total area of land use change involving GWB from 1990-2011

Grassland with woody biomass emission factor

The current GWB emission factor is based on expert judgment rather than field measurements of plots within mapped GWB (Wakelin 2004). Although GWB has not been systematically sampled there are some measured plots within the GWB LUM because field work began before the mapping had been finalised.

Paul and Wakelin (2011) attempted to derive an emission factor for GWB based on data from the 142 Carbon Monitoring System grid intersections within mapped GWB. Of these, 68 had a measured plot within GWB and the remaining 74 had not been sampled. It was expected that the measured plots would be biased towards high biomass sites, as they had all been previously mapped within the Indigenous Forest and Shrubland class of Land

[1] The earlier (1962-1989) land use change matrix (MFE 2013) does show a greater area of land use change involving GWB and a more even split between planted forest and grassland as the post-GWB land use. The use of a 28 year transition period means that conversions to GWB before 1990 still result in soil and biomass stock changes during the inventory period.

Cover Database 2 (LCDB 2). This expectation was supported by a visual assessment of grid intersections for woody biomass cover, which showed that sampled plots were skewed towards high cover while unsampled points were skewed towards low cover. The cover assessment was used to establish a relationship between cover and biomass for the sampled plots which was then applied to the unsampled sites to allow biomass to be estimated.

Forty of the 68 measured plots within GWB contained vegetation consistent with the GWB definition (59%), whereas sixty-two of the 74 un-measured grid points within GWB contained vegetation consistent with GWB (84%).

Two alternative emission factors for GWB were derived:

- 42.0 t C ha-1 (based on all 68 measured plots and 74 unmeasured grid points mapped as GWB, including plots that did not meet the GWB definition);
- 17.5 t C ha-1 (based on 40 measured plots and 62 unmeasured grid points mapped as GWB, including only plots containing vegetation consistent with GWB according to our assessment of satellite imagery and available plot data).

A statistically valid emission factor would be based on measurement of all 142 potential plots within GWB, assuming that all areas within mapped GWB were equally likely to be affected by land use change (to or from GWB) and wildfires. However mapping of GWB is known to be inaccurate and the higher emission factor estimate includes a contribution from a number of plots containing natural forest. The lower estimate is still likely to be biased towards higher stocks because the measured plots were a biased sample (as sampling targeted tall forest and shrubland, rather than GWB which consists more of scattered shrublands) and estimates for unmeasured plots only took cover into account and not species composition or height.

Neither of the two estimated emission factors takes into account the fact that the type of GWB affected by land use change and wildfires is likely to be a distinct subcategory occurring in managed landscapes. The measured plots include a relatively high number of subalpine shrubland vegetation which would not be involved in land use changes. Vegetation classified as scrub in the National Rural Fire Authority database would also exclude these areas as they are not generally affected by wildfires.

The GWB land use map has since been improved and some plots reclassified, and is described in the *GWB land use map* section below. In addition, sample plots in Post-1989 regenerating natural forest have been measured (Beets et al 2013). These plots are in vegetation that is believed to be representative of the managed lands that are subject to land use change to and from GWB. There is potential to stratify GWB plots according to the likelihood of being involved in land use change. Two emission factors can then be calculated; one for GWB where land use is relatively stable (such as in subalpine shrublands) and one for GWB that is moving in and out of other land uses.

Report Objectives

The objective of this report is to provide defensible emission factors for use with GWB within New Zealand's greenhouse gas inventory, including:

- individual weighted emission factors for managed and unmanaged categories of GWB;
- a single weighted emission factor for all GWB sub-categories combined.

Materials and Methods

GWB land use map

New Zealand's annual inventory report (MFE 2013) describes GWB as grassland with shrubland as vegetation where, under current management or environmental conditions the forest definition will not be met over a 30-40 year period. The definition also includes above-timberline shrubland and montane herb fields, and grassland with tall trees such as parkland or shelterbelts.

Plots and unsampled grid intersections within the GWB classification in version 11 of the LUCAS LUM were identified by MFE. The grid intersections include points from the inclusion of an 'Environmentally Limiting Factors' (ELF) layer into the LUCAS LUM. The ELF layer is used to improve the classification of natural forest by identifying areas where shrubland was unlikely to reach the forest definition due to one or more limiting factors (e.g. soil type or altitude). This improvement activity reclassified approximately 196,000 ha of natural forest with the majority being transferred to GWB. However, this improvement has added areas of relatively high carbon vegetation to GWB that is unlikely to be subject to land use change or fire.

Plot data

Summary plot data was provided by MFE for the measured plots within GWB. Most plots were measured using the natural forest and shrubland field data collection methods (Payton et al 2004).

Carbon in the biomass and dead organic matter pools had been calculated as described in Beets et al 2009. The soil organic carbon pool is currently estimated by a separate, independent system within LUCAS. MFE assessed the vegetation at the unmeasured grid points and provided a classification based on satellite imagery, aerial photograph, and vegetation in adjacent plots with similar imagery signatures or land use.

Vegetation cover data obtained by Paul and Wakelin (2011) for grid intersections within an earlier version of the GWB LUM were used to determine the woody and non-woody vegetation cover.

GWB sub-categories

Scion classified grid locations as falling within either an intensively managed landscape or an unmanaged landscape. In this context, unmanaged landscapes were defined as areas with subalpine shrubland and natural forest, while intensively managed landscapes were defined as areas with low and/or high producing grassland as well as GWB. The assessment process was based on visual inspection of each location using Google Earth imagery. A comparison was made between unmanaged and managed categories in terms of the number of plots, vegetation consistency with the GWB definition at the grid intersection, and tree/shrub cover (where available from previous analyses).

The yield table for post-1989 regenerating natural forest prepared by Beets et al (2013) was used to determine a mean emission factor for managed GWB. This approach was based on the assumption that this represents vegetation that is cleared before reaching forest status and provides a plot-based estimate in the absence of systematic sampling. The data for this came from plots established in 20[2] of the 28 locations within post-1989 forest that appeared to contain valid post-1989 regenerating natural forest. Plot measurement and data analysis are described by Beets et al 2013.

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[2] Access to the remaining eight locations was denied.

Results

Grid intersections within GWB LUM

There were 170 points in total within the GWB LUM version 11; 90 sampled plot locations and 80 unsampled grid intersections. The net increase of 28 locations over the 142 included within the previous GWB LUM version was a result of the loss of 19 locations that are now outside mapped GWB and the gain of 47 new locations, mainly the result of the ELF layer improvement.

Classification into managed and unmanaged sub-categories

The grid intersections were evenly divided between unmanaged and managed landscapes, with 83 considered managed and 87 unmanaged. Examples are illustrated in Appendix II.

GWB-consistent vegetation

The 123 locations that were also included in the previous analysis by Paul and Wakelin (2011) had already been classified according to their consistency with the GWB definition. Of these, 47 (38%) were not considered to be within GWB-consistent vegetation.[3] Of the 47 new plots, 4 unmeasured points were assessed by MFE as not containing GWB and 18 measured plots were assessed by Scion as not containing GWB. This means that overall, 69 of the 170 plots locations (40%) were considered to not contain GWB. In most cases this is because there were tree species present above or very close to the 5 metre height threshold for classification as forest.

GWB that is converted to pasture and planted forests is generally shrubland of relatively low stature rather than forest. This suggests that an emission factor based on all plots within mapped GWB would not be a true reflection of the type of GWB involved in land use change and emissions would be over-estimated.

Vegetation cover

Vegetation cover at grid intersections within GWB had been previously assessed to allow double sampling to be used to estimate carbon at unmeasured locations (Paul and Wakelin 2011). The 47 new locations in version 11 of the GWB LUM had not had their vegetation cover assessed. The relationship between woody vegetation cover and carbon obtained previously was weak because mapped GWB was diverse, containing a high number of plots in natural or planted forest (Paul and Wakelin 2011). Plots with 100% tree/shrub cover varied in above-ground biomass by a factor of up to 16. Given that the revised GWB LUM

[3] Excludes one plot (AB154) now accepted as GWB for this report.

still contains a high proportion of plots in non-GWB vegetation, it was considered that there would be little to gain from obtaining cover estimates for the new locations. Double-sampling for cover is not able to overcome the bias in the original sampling; the addition of height and species composition would be required to improve the relationship.

Unmanaged landscapes tended to be targeted for measurement because they were more likely to be classified as Natural Forest and Shrubland in LCDB1 and tend to have higher vegetation cover. In unmanaged landscapes, 58 of 87 (67%) potential plot locations were measured, compared with 32 of 83 (39%) in managed landscapes. The mean tree/shrub cover at unmanaged points was higher; 70.7% (from 58 points with cover data) compared with 58.5% at managed points (from 65 points with cover data).

Managed GWB emission factor

Beets et al (2013) prepared a yield table based on the inventory of post-1989 regenerating natural forest (Table 2). The yield table begins at the mean age when an above-ground woody carbon threshold of 2 t C/ha is reached, rather than assuming that age zero represents a clear site. Historically the practice has been to periodically convert this vegetation to pasture. If it is assumed that this clearance takes place before the forest height threshold is reached, and conversion takes place in each age class, then the mean carbon stock at ages between 0 and 10 years after the GWB threshold biomass is established can be used as an emission factor for GWB on managed land. If more than ten years has elapsed since the threshold carbon stock was reached, then the vegetation is likely to have reached the threshold height to be defined as forest.

The managed GWB emission factor (total carbon) derived from the post-1989 natural forest yield table (mean ages 0-10) is **11.99 tC/ha**.

There are 32 measured GWB plots classified as being on managed land. The mean carbon stock in these plots was higher: 23.97 tC/ha. However this is reduced to 12.52 tC/ha when only the 19 plots that are considered to be consistent with GWB are included (range 0.2-46.6 tC/ha). This is similar to the estimate derived from the regenerating natural forest data, although the 19 plots do not represent a systematic sample of GWB in managed landscapes.

Table 2. Regenerating natural forest yield table (from Beets et al 2013, Table 7)

Age	Mean Total C stock at end of year (t C/ha)	AGB (t C/ha)	BGB (t C/ha)	Dead wood (t C/ha)	Litter (t C/ha)
0*	4.63	3.48	0.87	0.05	0.23
1	5.66	4.24	1.06	0.06	0.30
2	6.87	5.15	1.29	0.07	0.37
3	8.25	6.19	1.55	0.08	0.43
4	9.77	7.35	1.84	0.09	0.50
5	11.43	8.61	2.15	0.10	0.56
6	13.19	9.97	2.49	0.11	0.62
7	15.05	11.40	2.85	0.12	0.68
8	16.99	12.89	3.22	0.13	0.74
9	18.99	14.44	3.61	0.14	0.80
10	21.03	16.02	4.01	0.15	0.85
Mean 0-10	11.99	9.07	2.27	0.10	0.55

***** age zero is defined to be the first December when the AGB carbon exceeds 2 t/ha.

Unmanaged GWB emission factor

Carbon stock estimates were available for 58 of the 87 plots classified as unmanaged (the remaining 29 were unmeasured grid intersections). The mean carbon stock for these measured plots (weighted by plot area) was **59.96 t C /ha**.

Only 19 of these 58 measured plots had vegetation consistent with GWB – the mean carbon stock in these plots was 19.66 t C/ha compared with 79.47 t C/ha for the remaining 39 plots that were not consistent with GWB. Measured unmanaged plots are listed in Appendix I.

Weighted overall emission factor for GWB

An overall emission factor was calculated by weighting the individual emission factors by the number of plots in each category:

83/170 * 11.99 + 87/170 * 59.96 = **36.54** t C/ha

Table 3. GWB emission factors by pool

		Mean Carbon stock t C/ha				
	Points	Total Carbon	AGB	BGB	Deadwood	Litter
Managed GWB	83	11.99	9.07	2.27	0.10	0.55
Unmanaged GWB	87	59.96	45.02	11.26	3.68	0.00
Total weighted:	**170**	**36.54**	**27.47**	**6.87**	**1.93**	**0.27**

These estimates do not use the plot data from the managed component of GWB, replacing this with an estimate derived from the post-1989 regenerating forest yield table. For the unmanaged component, the grid points that have not been measured were not used (29 points). All the remaining points were used to determine the emission factor, regardless of actual vegetation present. Using the additional unmeasured points in a double sampling approach would require additional cover estimates for 24 measured plots and 5 unmeasured points. Eighteen of these plots do not contain GWB, so the relationship between carbon stock and cover alone would still be weak. Height and species composition would be needed to improve the relationship.

Contribution of non-woody biomass

The emission factors presented above ignore non-woody biomass. This is appropriate for forest sub-categories where non-woody biomass forms a small proportion of total biomass, but may be misleading for GWB – in particular when estimating net emissions from transitions between GWB and the other grassland categories. New Zealand currently uses IPCC default emission factors for the other two grassland sub-categories; high producing grassland (6.75 tC/ha) and low producing grassland (3.05 tC/ha).[4]

An estimate of the contribution of non-woody vegetation in managed and unmanaged GWB was made based on the non-woody vegetation cover data available and the IPCC default emission factor for unimproved pasture. Means were calculated separately for sampled points and unsampled grid intersections, and assumed to apply to the sampled and unsampled locations respectively for which cover was not available. An overall mean was calculated by weighting by the number of points (Table 4).

[4] Based on IPCC default biomass for warm temperate wet and dry grassland and a carbon fraction of 0.5.

Table 4. Non-woody vegetation cover in managed GWB

Sampled?	Cover available?	No. of points	% Non-woody cover
yes	yes	25	24.10
no	yes	40	41.50
yes	no	7	*24.10 assumed*
no	no	11	*41.50 assumed*
All	**all**	**83**	**34.79**

Multiplying the weighted mean non-woody vegetation cover of 34.79% (Table 4) by the emission factor for unimproved pasture gives an estimate of 1.06 t C/ha of additional carbon in managed GWB – a nine percent increase.

Applying the same approach to unmanaged GWB resulted in a non-woody vegetation cover estimate of 20.18% and an increase of 0.62 t C/ha in the emission factor due to the inclusion of non-woody biomass – a one percent increase (Table 5).

Table 5. Non-woody vegetation cover in unmanaged GWB

Sampled?	Cover available?	No. of plots	% Non-woody cover
yes	yes	34	12.35
no	yes	24	35.83
yes	no	24	*12.35 assumed*
no	no	11	*35.83 assumed*
all	**all**	**87**	**20.18**

Non-woody biomass was divided into above- and below-ground components using the IPCC default root:shoot ratio for "Warm Temperate – Dry" grassland (2.8), allowing revised GWB emission factors by pool to be estimated (Table 6).

Table 6. GWB emission factors by pool

		Mean Carbon stock t C/ha				
	Points	Total Carbon	AGB	BGB	Deadwood	Litter
Managed GWB	83	13.05	9.35	3.05	0.10	0.55
Unmanaged GWB	87	60.57	45.18	11.71	3.68	0.00
Total weighted:	**170**	**37.37**	**27.69**	**7.48**	**1.93**	**0.27**

Uncertainty

The emissions factors have not been calculated from a statistically valid sample of mapped GWB which makes it difficult to derive an estimate of uncertainty. This is also true for perennial cropland, where the emission factor is based on biomass studies in various types of crop and their proportions of total perennial cropland. In that case an uncertainty estimate of ± 75% has been assigned in the greenhouse gas inventory. A similar range would be appropriate for managed GWB; the values in Table 2 range from 4.63 to 21.03 t C/ha.

Discussion

The nature of GWB makes it difficult to provide a suitable national emission factor. It is highly variable, difficult to map and subject to land use change. The true extent of land use change to and from GWB is difficult to establish. Because the error in mapping GWB is relatively high, it is likely that some of the mapped change in land use involving GWB is not real. Even if there had been systematic sampling of GWB the derived emission factor could be misleading because a large number of plots contain vegetation that is not consistent with the GWB definition. Our approach has been to apply knowledge of the situations in which land use change involving GWB is most likely to occur.

Comparison with other estimates

There are no IPCC default emission factors for shrublands, but it is possible to derive a value from defaults used in estimating emissions from fires. The default value for biomass consumption (t dm/ha) in temperate shrubland wildfires is given as 26.7 (*GPG-LULUCF* Table 3A.1.13), referenced to Lavoue et al (2000). The default mean value for proportion of pre-fire biomass consumed in temperate shrubland is 0.95 (*GPG-LULUCF Table 3A.1.12*), which implies an initial biomass density value of **14.1 t C/ha** (28.1 t dm/ha).

The Planted Forest Sinks Initiative Accounting Design Team (PFSI Accounting Design Team, 2007) concluded that the amount of carbon stored in woody vegetation in pastoral landscapes prior to afforestation would be about **10 t C/ha** (37 t CO_2e/ha). This estimate assumes canopy cover of 30% (i.e. below the forest definition threshold) compared with 50% assumed by Wakelin (2004) for the estimate used in the greenhouse gas inventory. The authors stated:

> *"There is much uncertainty over the amount of above ground non-tree woody biomass that is likely to be cleared when planted forests are established. Analysis of the shrubland plots from the South Island transect (Coomes et al. 2002) shows that where vegetation cover is about 30 %, up to 10 tC/ha was measured. Plot-based measurements show that the mean net carbon accumulation rates for manuka and*

kanuka shrubland are in the range of 1.8 to 3.5 t C/ha/year, when averaged over the active growth phase (Trotter et al. 2005; Walcroft et al. 2002). Considering these estimates, it is estimated that a national average amount of carbon stored in the initial woody vegetation in pastoral landscapes would be about 10 t C/ha (using an average carbon accumulation rate of 2 t C/ha/year, a 30 % canopy cover, and the woody vegetation being on average 15 years old)."

This assumes 15 years of growth from a zero carbon base, rather than from the age at which the threshold GWB stock is achieved.

Transition period

The current assumption is that land converted to GWB will accumulate carbon over 28 years. This can be retained for land use change involving GWB.

Carbon in non-woody vegetation

Non-woody biomass is not included in emission factors for forest sub-categories or perennial cropland. GWB emission factors have been calculated with and without a contribution from non-woody biomass because it potentially makes up a larger proportion of total biomass in this category. This is particularly for managed GWB, where non-woody biomass was estimated to make up eight percent of total biomass. Excluding non-woody biomass from the emission factor could give misleading estimates of the net emissions from land use change to and from managed GWB.

Recommendations and Conclusions

This report provides emission factors for GWB that can be used in New Zealand's greenhouse gas inventory reporting.

- For emissions due to conversion of GWB to other land uses, it is appropriate to use the emission factor for managed GWB. This accounts for most of the land use change involving GWB.
- For emissions due to conversion of other land uses to GWB, the managed GWB emission factor is still appropriate. Most of the land use change to GWB is from the other grassland sub-categories. The transition period can be retained at 28.
- For emissions due to wildfires and controlled burning in grasslands, the overall weighted emission factor should be used. By default only the above-ground pools are assumed to be affected by fire.
- For stocks in Grassland remaining Grassland, the overall weighted emission factor should be used.

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Appendix I – Unmanaged measured GWB plots

	Location	Sampled	Total Carbon (t C/ha)	Plot area	subcategory	GWB?
1	AA142	Y	15.7951	0.0299	Unmanaged Land	N
2	AC149	Y	25.9440	0.0314	Unmanaged Land	N
3	AG140	Y	22.5836	0.0281	Unmanaged Land	N
4	AH136	Y	44.9099	0.0337	Unmanaged Land	N
5	AJ135	Y	32.8882	0.0337	Unmanaged Land	N
6	AM135	Y	15.9796	0.0358	Unmanaged Land	N
7	AR127	Y	98.9108	0.0290	Unmanaged Land	N
8	AW124	Y	249.5622	0.0305	Unmanaged Land	N
9	AW125	Y	62.0414	0.0369	Unmanaged Land	N
10	AX123	Y	33.4323	0.0257	Unmanaged Land	N
11	AX124	Y	145.5619	0.0319	Unmanaged Land	N
12	AY127	Y	34.1401	0.0299	Unmanaged Land	N
13	AZ109	Y	82.7433	0.0392	Unmanaged Land	N
14	BC107	Y	33.5889	0.0362	Unmanaged Land	N
15	BD119	Y	138.0073	0.0269	Unmanaged Land	N
16	BD123	Y	35.3892	0.0393	Unmanaged Land	N
17	BF125	Y	6.6645	0.0336	Unmanaged Land	N
18	BG97	Y	80.4989	0.0350	Unmanaged Land	N
19	BH95	Y	46.3730	0.0386	Unmanaged Land	N
20	BI100	Y	153.3668	0.0322	Unmanaged Land	N
21	BI121	Y	17.4352	0.0290	Unmanaged Land	N
22	BL99	Y	124.6260	0.0372	Unmanaged Land	N
23	BP105	Y	32.3898	0.0352	Unmanaged Land	N
24	CN96	Y	88.8694	0.0310	Unmanaged Land	N
25	CS69	Y	84.6503	0.0309	Unmanaged Land	N
26	CS71	Y	57.9291	0.0363	Unmanaged Land	N
27	CV82	Y	83.3718	0.0265	Unmanaged Land	N
28	CZ74	Y	140.5970	0.0349	Unmanaged Land	N
29	H164	Y	73.1016	0.0295	Unmanaged Land	N
30	H170	Y	322.1009	0.0389	Unmanaged Land	N
31	K158	Y	111.6309	0.0359	Unmanaged Land	N
32	P185	Y	43.5715	0.0339	Unmanaged Land	N
33	R154	Y	176.3865	0.0311	Unmanaged Land	N
34	R183	Y	54.6954	0.0364	Unmanaged Land	N
35	R184	Y	150.8842	0.0291	Unmanaged Land	N
36	S182	Y	70.5369	0.0382	Unmanaged Land	N
37	S183	Y	25.0728	0.0391	Unmanaged Land	N
38	T179	Y	99.8003	0.0395	Unmanaged Land	N
39	Z143	Y	8.8413	0.0469	Unmanaged Land	N
40	AA140	Y	0.2191	0.0335	Unmanaged Land	Y
41	AB146	Y	6.7049	0.0379	Unmanaged Land	Y

42	AK139	Y	14.9219	0.0389	Unmanaged Land	Y
43	AR128	Y	65.6689	0.0302	Unmanaged Land	Y
44	AU126	Y	9.9894	0.0383	Unmanaged Land	Y
45	AV126	Y	12.5822	0.0378	Unmanaged Land	Y
46	AW128	Y	26.4225	0.0269	Unmanaged Land	Y
47	AY122	Y	31.5103	0.0373	Unmanaged Land	Y
48	BB111	Y	38.9129	0.0284	Unmanaged Land	Y
49	BH106	Y	17.6925	0.0396	Unmanaged Land	Y
50	BR116	Y	32.0936	0.0276	Unmanaged Land	Y
51	CP93	Y	4.3205	0.0335	Unmanaged Land	Y
52	CQ91	Y	13.3504	0.0352	Unmanaged Land	Y
53	CV84	Y	73.1696	0.0322	Unmanaged Land	Y
54	S149	Y	3.0244	0.0296	Unmanaged Land	Y
55	U142	Y	8.5400	0.0385	Unmanaged Land	Y
56	U143	Y	5.3091	0.0357	Unmanaged Land	Y
57	W145	Y	5.3624	0.0279	Unmanaged Land	Y
58	W158	Y	19.1675	0.0289	Unmanaged Land	Y

	Location	Sampled	Total Carbon (tC/ha)	Plot area	subcategory	GWB?
1	AC143	N	na	na	Unmanaged Land	N
2	AI135	N	na	na	Unmanaged Land	N
3	AL133	N	na	na	Unmanaged Land	N
4	AQ128	N	na	na	Unmanaged Land	N
5	BB121	N	na	na	Unmanaged Land	N
6	BH98	N	na	na	Unmanaged Land	N
7	V142	N	na	na	Unmanaged Land	N
8	AD140	N	na	na	Unmanaged Land	Y
9	AE138	N	na	na	Unmanaged Land	Y
10	AE140	N	na	na	Unmanaged Land	Y
11	AE143	N	na	na	Unmanaged Land	Y
12	AG141	N	na	na	Unmanaged Land	Y
13	AG142	N	na	na	Unmanaged Land	Y
14	AH137	N	na	na	Unmanaged Land	Y
15	AH143	N	na	na	Unmanaged Land	Y
16	BI113	N	na	na	Unmanaged Land	Y
17	BK117	N	na	na	Unmanaged Land	Y
18	CP72	N	na	na	Unmanaged Land	Y
19	CW72	N	na	na	Unmanaged Land	Y
20	CX79	N	na	na	Unmanaged Land	Y
21	H166	N	na	na	Unmanaged Land	Y
22	J168	N	na	na	Unmanaged Land	Y
23	L159	N	na	na	Unmanaged Land	Y
24	O157	N	na	na	Unmanaged Land	Y
25	R151	N	na	na	Unmanaged Land	Y
26	R164	N	na	na	Unmanaged Land	Y

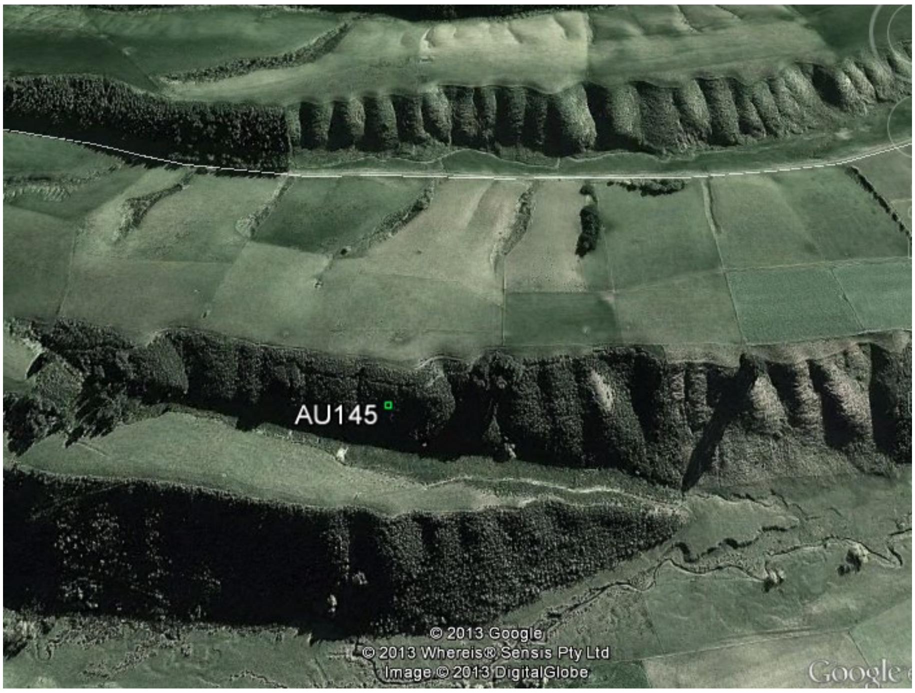
27	U148	N	na	na	Unmanaged Land	Y
28	V140	N	na	na	Unmanaged Land	Y
29	W153	N	na	na	Unmanaged Land	Y

Appendix II – Examples of managed and unmanaged GWB land

Managed GWB

W176. GWB plot in scrub on private land adjacent to a scenic reserve. Bluff hill. 46.6 t C/ha.

BI123 – GWB plot in valley bottom, unimproved pasture near conservation land. North Canterbury. 36.3 t C/ha



AU145 – GWB plot in dense gorse on a south-facing slope (note gorse has been cleared to the east and on a similar face to the north). South Canterbury. 32.6 t C/ha.

AA138 – GWB plot on previously cleared land near wetlands. South Westland. 28.6 t C/ha

BQ16 – GWB plot in landscape of dunes, natural and planted forest, pasture and shrubland. Ahipara. 23.3 t C/ha

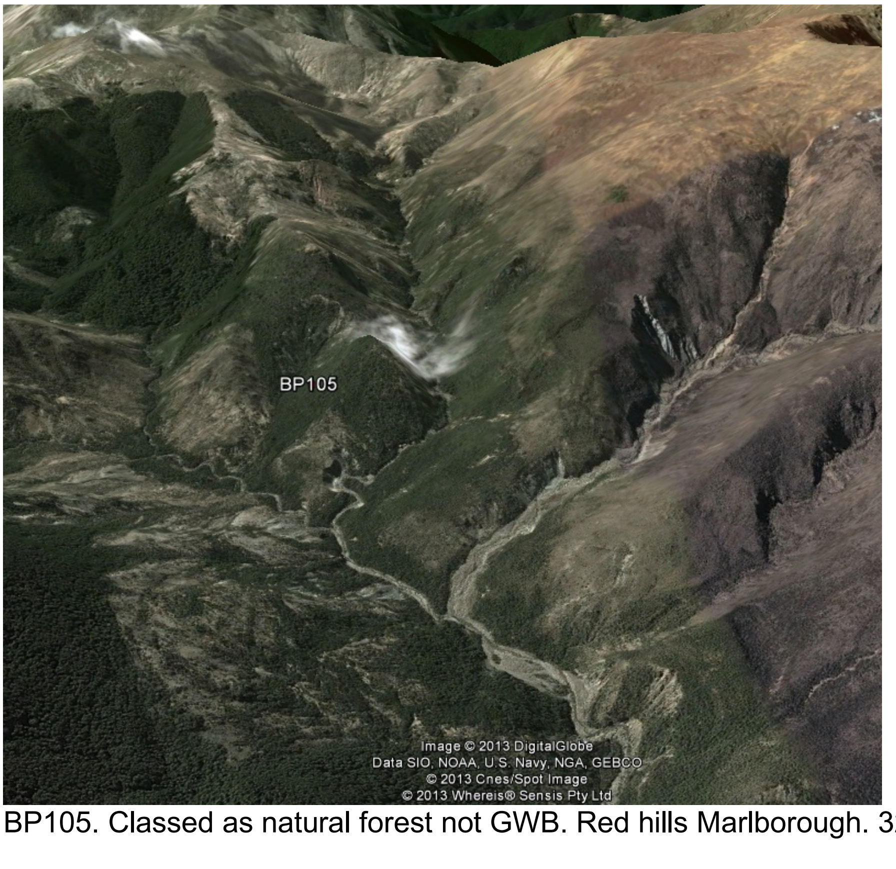
T165. GWB plot in scrub and unimproved grassland mixture. Southland. 11.3 t C/ha

AB154. Gibbston Valley (previously classed as forest) 4.1 t C/ha

Unmanaged GWB

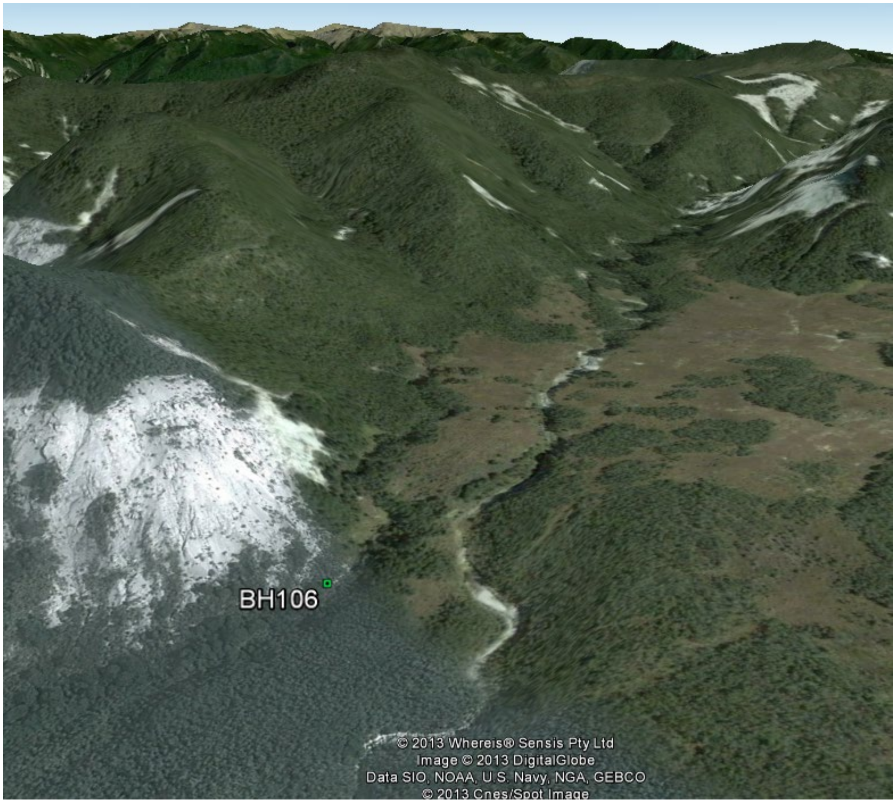
CN96 – classed as natural forest not GWB. Tararua ranges. 88.87 t C/ha

AW125 - classed as natural forest not GWB. Westland. 62.04 t C/ha.



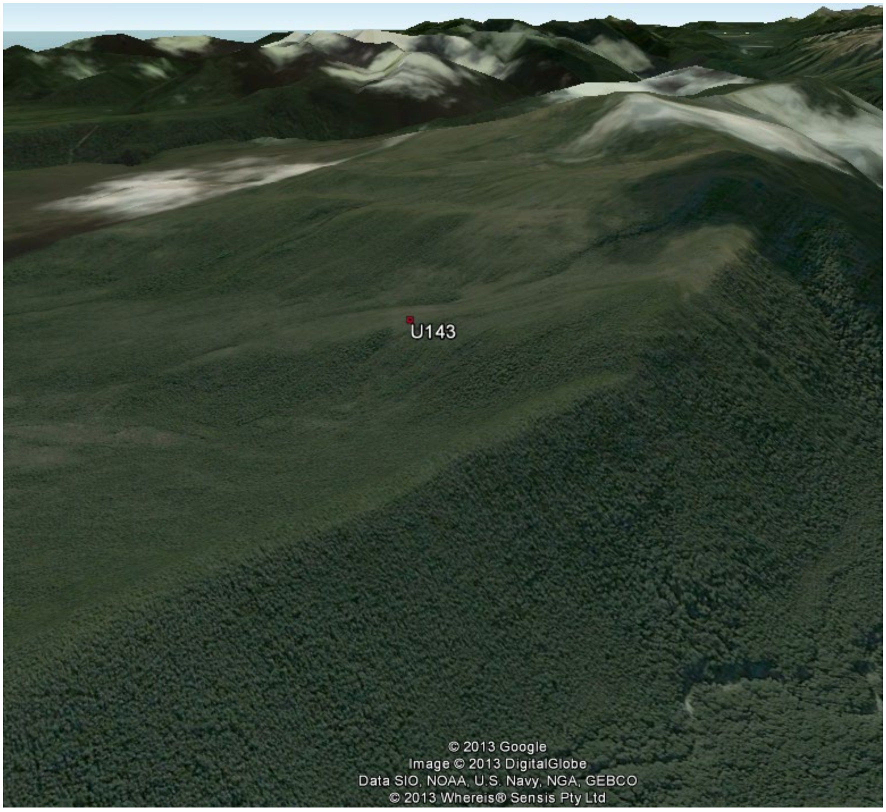
BP105. Classed as natural forest not GWB. Red hills Marlborough. 32.39 t C/ha.

BR116 – subalpine GWB. Marlborough. 32.09 t C/ha.



BH106 – GWB on edge of 1000 acre plateau, Matiri, Buller. 17.69 t C/ha

AU126 – subalpine GWB Westland 9.99 t C/ha.



U143 – GWB. South Westland 5.31 t C/ha.

CP93 – subalpine GWB, Tararua ranges 4.32 t C/ha