Performance Audit Report

FRAMES Net Harvest Area Modifiers

Issue

The Auditor General's Performance Audit "Sustaining Native Forest Operations: Forests NSW" of April 2009 included an action item (Recommendation 2), requiring Forests NSW to "finalise its net area and strike rate modifier studies to improve the accuracy of its estimates".

This report addresses the update of the Net Area Modifier, referred to in this report as Net Harvest Area Modifiers (NHAMs).

Background

The Net Harvest Area Modifiers (NHAMs) are a component of the net harvest area calculator in FRAMES (the Forests NSW Forest Resource And Management Evaluation System) as used in North East and Central Regions and Southern Region including South Coast and Tumbarumba sub-regions (SR) but currently excluding Eden SR. Use of the NHAM reduces the area available for harvesting over and above mapped harvest area exclusions. The NHAM is intended to account for unmapped areas that are excluded from harvesting, such as steep areas not previously mapped, areas that are inaccessible because of localised rock outcrops or topographic isolation, proximity to exclusion boundaries ("buffer-on-buffer"), unmapped drainage lines and incorrect stream network mapping. The NHAM needs to account for these errors because the errors are inherent in the Land Information Centre (LIC) mapped topographic layers used to define slopes and the existence and location of drainage lines. The LIC layers were derived predominantly from aerial photo interpretation and reflect the difficulty of defining surface features through a forest canopy.

There have been changes in harvest practice since the original NHAMs were developed in 1997[1,2] as part of the use of FRAMES to support the Regional Forest Agreement (RFA) process. Harvesting is now largely mechanised rather than manual, which has altered what is considered accessible and economically viable for harvesting. Mechanisation may increase the ability to harvest adjacent to exclusion boundaries through greater control over the direction of falling but conversely may have limitations on steeper areas. Mechanisation may also increase the effectiveness of dealing with localised obstacles and adverse conditions. Interpretation of drainage line issues has also changed, as have regulatory requirements relating to buffers. These changes in practice make the NHAMs developed in 1997 less relevant to current harvesting practices. As a result, this project was designed to develop new NHAMs to reflect current harvesting practices, rather than reviewing and refining the original NHAMs. Given the changes in harvesting practices, it was considered that data from the 1997 project was not relevant for modelling the impact of current unmapped net harvest area exclusions on overall harvest area availability.

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1. Upper North East and Lower North East CRA Regions Net Harvest Area Modifier Project Report. 17 May 2000.
2. Southern CRA Regions Net Harvest Area Modifier Project Report. 30 April 2001.

The existing NHAM for the area generally comprising North East and Central Regions (approximating the Upper North East and Lower North East Comprehensive Regional Assessment [CRA] areas) reduced the area available for harvesting after applying mapped harvest area exclusions by 27%, of which approximately half was a consequence of buffer-on-buffer, unmapped and incorrectly mapped drainage and the other half as a consequence of slope. For Southern Comprehensive Regional Assessment (CRA) Region (approximately the current Southern Region including Tumbarumba SR but excluding Eden SR) under the RFA process, the existing NHAM reduced the area available for harvesting after applying mapped harvest area exclusions by 21%, almost entirely as a consequence of buffer-on-buffer and unmapped drainage.

Project Design

Terminology for Forests NSW administrative areas in this report is as follows (abbreviations in brackets):

- Upper North East/Lower North East Comprehensive Regional Assessment Regions (UNE/LNE CRA)
- North East Region (North East)
- Central Region (Central)
- Southern Region excluding Tumbarumba sub-region and Eden sub-region (South Coast)
- Tumbarumba sub-region (Tumbarumba)
- Eden sub-region (Eden).

The project design adopted for this project was similar to that undertaken in 1997, but with a more objective approach taken to the selection of compartments.

1. Compartment Selection

Sufficient compartments needed to be selected to permit the generation of representative models for each region, while recognising that the detailed aerial photograph interpretation and analysis required to produce the data on harvesting exclusion is both time consuming and expensive. In the 1997 project, 20 compartments were selected for each of what was then UNE and LNE CRA Regions (not greatly different to the current North East and Central), covering the range of general harvesting conditions found in those areas. 27 compartments were selected for the project in the Southern CRA Region from both the South Coast sub-region and the Tumut sub-region. There was no specific project undertaken for then Eden CRA Region.

Although not included in previous studies, Eden was included in the current project, as future net harvest area calculation in Eden will be undertaken in a manner consistent with the other Regions. 20 compartments were selected from each of North East, Central and Eden, 15 for South Coast and 5 for Tumbarumba. The selection process was generally as follows:

1. Create a list of all compartments within which harvesting commenced after 1 January 2007 and was completed by 31 December 2010.
2. Exclude from the list compartments that comprised non-standard harvesting operations, such as road-line clearance, special purpose harvesting or with a net harvest area below 20 hectares.
3. Tag the compartments with the following classifications:

(i) High productivity or low productivity. This was determined separately for each Region. Average volume of high quality (HQ) logs (or all merchantable logs in the case of Eden and Tumbarumba) was calculated for each compartment from strategic inventory plots and yield association (an amalgamation of forest types). The average across all compartments was then calculated. Compartments with average volumes of HQ logs (or all merchantable logs for Eden and Tumbarumba) below the Regional average were classified as low productivity and the remainder classified as high productivity.

(ii) Steep or not steep. Using Land Information Centre (LIC) topographic data, the percentage of total compartment area ≥20° was calculated for each Region. If the percentage of area ≥20° in the selected compartment exceeded the regional average, the compartment was classified as "steep"; otherwise it was classified as "not steep".

(iii) Silvicultural treatment. The categories used were standard single tree selection [STS], regeneration-enhancing STS [STSRegen[1]], Australian Group Selection [AGS], Coupe selection (in Eden), Mixed or Thinning.

4. Define the number of compartments to be selected within each combination of productivity and steepness based on the frequency with which they occurred in the data and the expected contribution of the productivity and steepness combination to harvested volumes over the next decade.

5. Select at random from the compartment list at step 2 sufficient compartments to achieve both the total number of required compartments for each region and the number of compartments defined in step 4 within each productivity x slope category.

The resulting number of compartments selected for detailed NHAM analysis is set out in Table 1.

Table 1. Compartments for NHAM project by Region/sub-region and Productivity/Steepness Class

Region/sub-region	High productivity and <20°	High productivity and ≥20°	Low productivity and <20°	Low productivity and ≥20°	Total
North East	3	6	6	5	20
Central	3	6	6	5	20
Eden	3	6	6	5	20
Tumbarumba	1	1	2	1	5
South Coast	2	5	4	4	15

2. Data collection

Aerial photography, aerial photo interpretation (API) and digitising

Appendix 1 comprises a detailed explanation of the process involved in capturing aerial photographs, processing them, preparing images for API, conducting the API, field-checking the results and capturing the information digitally. Appendix 1 was prepared by the contractor engaged for this component of the project.

[1] Note that the term STSRegen used in this report is synonymous with the term 'Heavy STS' as defined in the FNSW Silviculture Manual and Guidelines for the Implementation of IFOA Silviculture. This harvesting system allows higher intensity harvesting in parts of the allowable harvest area to achieve improved regeneration outcomes, while leaving other parts of the allowable harvest area unharvested. This approach is permitted under the Integrated Forestry Operations Approval (IFOA).

In brief, aerial photographs at approximately 1:10 000 scale were taken by the contractor, covering each compartment selected for inclusion in the project. Interpretation of the aerial photographs was undertaking by overlaying the photos with the original Harvest Plan for the compartment (Harvest Plans are prepared for each compartment prior to the commencement of harvesting). Information shown on Harvest Plans includes:

- LIC-based drainage and pre-defined buffers around drainage lines
- Unavailable steep areas based on LIC slope class data
- Other mapped exclusions such as reserved areas, Forest Management Zones where harvesting is not permitted, old growth, plantation, rainforest and other vegetation types, and other information relating to the harvesting operation.

A "field-corrected Harvest Plan" was typically available that incorporated field-checked amendments to correct errors in the map-based Harvest Plan. These errors often related to incorrect location of drainage lines, roads or Forests Management Zone boundaries. Although of variable quality, the additional information available on the field-corrected plans assisted the interpreters in correctly tagging the reasons for harvesting occurring or not occurring in specific areas of the compartment.

Using the aerial photo/harvest plan overlays, skilled contract interpreters identified harvested and non-harvested areas and tagged these polygons using the labels listed in Table 2. The resulting line-work was digitised. The purpose of this was to identify those areas in which harvesting did not occur and the reason why they were not harvested. Areas that were not harvested because they were in mapped exclusion zones identified in the harvest plan were excluded from the analysis.

Table 2: Aerial photography tags for compartment polygons

Classification	Subclass	Polygon Code	Included in NHAM
H - Harvested and available for harvesting in Harvest Plan	Harvested using Australian Group Selection (AGS)	HA	Y
	Harvested using Coupe selection	HC	Y
	Harvested using Mixed silviculture	HM	Y
	Harvested using Single Tree Selection (STS)	HS	Y
	Harvested using Regeneration STS (STSRegen)	HR	Y
	Harvested using Thinning silviculture	HT	Y
N – Not harvested and available for harvesting in Harvest Plan	Buffer on buffer	NB	Y
	Unmapped filter strip	NC	Y
	Topographically/physically inaccessible	NT	Y
	Fauna or flora protection	NF	N
	Retained for required minimum average basal area	NG	N
	Rock	NK	Y
	Not commercial (trees)	NN	N
	Not commercial (economic accessibility)	NE	N
	Access impractical: adjacent/surrounding exclusion	NL	Y
	All other reasons where known	NO	N
	Missed by error/no explanation	NM	N
U – Harvested but unavailable for harvesting in Harvest Plan	Not harvested in an unavailable area	UN	N
	Harvesting in an area shown as unavailable due to incorrect mapped layers	UH	Y
	Harvested in correctly mapped unavailable area	XH	N

The categories applied to the mapped areas were based on: advice provided by the Harvest Planner and/or the Supervising Forest Officer who oversaw the harvesting operation; the field-corrected Harvest Plan; and/or field visits to the selected compartments. Approximately two-thirds of the compartments were field-verified.

During the API process, the interpreters identified a particular difficulty in correctly classifying the small number of compartments that were harvested using Australian Group Selection (AGS) silviculture. Given the process by which AGS is applied, it was difficult to identify if unharvested areas had been left because they could not be harvested or because they were being retained for the next AGS cycle. Appendix 1 has more detail on this issue. As a result, the small number of AGS compartments were excluded from the analysis. Where possible, AGS compartments were replaced with compartments in which the silvicultural treatment was STS or STSRegen.

After making the adjustments described above, the final data set comprised 20 compartments in North East, 19 in Central, 17 in Eden and 17 in South Coast plus Tumbarumba, a total of 73 compartments.

3. Data preparation

To ensure there is no "double accounting" for harvest exclusion features, modelling of NHAM data only incorporates a subset of the logging exclusion categories identified in Table 2. The subset comprises:

- Steep areas not previously mapped.
- Inaccessible (other than steep) including rocky areas and topographically isolated areas.
- Filter strip/riparian buffer extensions including unmapped drainage, incorrectly mapped drainage and buffers on buffers.

The subset of exclusion categories does not include any existing mapped layers. The subset also excludes areas where harvesting did not occur due to fauna or flora protection (as this is addressed via the Strike Rate Modifier; see separate report) or other reasons for non-harvesting that are not related to physical characteristics of the potential harvesting area (such as pre- or un-merchantable areas).

The column "Included in NHAM" in Table 2 below identifies the tagged polygons used to build models that predict the extent of areas that were not harvested for the specific reasons identified above. The outputs from the models determine the NHAM factors incorporated in the FRAMES calculation of area available for harvesting.

Prior to construction of any models, the raw data from the API process was analysed. Table 3 provides a summary on the progressive reduction in area available for harvesting arising from mapped exclusion areas, unmapped exclusion areas and the specific contribution of individual components of the NHAM.

A 5m x 5m grid was then overlaid on the Net Mapped Area for each compartment and the NHAM polygons (with tags) were then intersected with this grid. The following data, comprising both identifiers and potential stratification data for use in model development, were recorded for each compartment and assigned to each grid cell:

- State Forest name, State Forest number and compartment number
- forest productivity class (high/low) applied silviculture
- manual or mechanical harvesting
- whether or not LiDAR was used in harvest planning
- whether or not GPS was used in harvesting machinery
- a binomial value for presence or absence of harvesting.

A table was generated comprising the total area (based on number of grid cells) within each NHAM polygon for each unique combination of:

- slope in degrees
- distance to the nearest hard (i.e. net mapped area) boundary in metres.

Note that the Net Mapped Area is used for this process, rather than the field-corrected Harvest Plan. There are several reasons for this:

(i) Field correction of the Harvest Plan was often not undertaken systematically or with attention to detail sufficient to correct the standard mapped layers.

(ii) Where field corrections were undertaken, the information was often not used to update the standard mapped layers.

(iii) The NHAM polygon coding includes a code that identifies situations where harvesting occurred despite the Net Mapped Area identifying the area as one for which harvesting was excluded, because the Net Mapped Area incorrectly identified the location of features such as drainage lines.

(iv) The models derived from these data will be applied across the entire forest estate and so must be based on standard mapped exclusion layers rather than the variable-quality field-corrected mapped layers.

(v) The models predict the proportion of a grid cell that will be harvested given its location in reference to standard mapped layer boundaries (and potentially other variables such as slope, applied silviculture, use of LiDAR, manual or mechanical harvesting or use of GPS). Hence the models themselves incorporate the errors inherent in the actual field location of standard mapped layer boundaries: the likelihood of harvesting close to a “hard” boundary (noting that the hard boundary is not actually where the map says it is) is increased by a proportion equivalent to how often a mapped layer error occurs in the NHAM project compartments and assuming that same proportion applies across the Region.

A data set was produced for each of North East, Central and South Coast, Tumbarumba and Eden.

The data sets were large: a 200 ha compartment had 80,000 5m x 5m grid cells and each grid cell had 12 attributes (identifier codes, the potential stratification values mentioned above, binomial presence/absence of harvesting, distance from the nearest hard boundary and slope).

Table 3: Analysis of harvest exclusion categories by Region/sub-region

NHAM Project Compartment Attributes (coupes for Eden)	North East		Central		South Coast		Tumbarumba		Eden	
	Area	%	Area	%	Area	%	Area	%	Area	%
Gross area (GA)	3843		3369		6001		1906		926	
Net mapped area (NMA)[1]	2511	65[5]	1945	58[5]	4689	78[5]	1625	85[5]	703	76[5]
Planned harvestable area (PHA)[2]	2305	92[6]	1888	97[6]	3101	66[6]	1544	95[6]	686	98[6]
Net logged area (NLA)[3]	1362	59[7]	1239	66[7]	2041	66[7]	685	38[7]	456	66[7]
Planned harvestable area not harvested (total)[4]	943	41[8]	649	34[8]	1060	34[8]	1097	62[8]	230	34[8]
- due to “buffer-on-buffer”	47	2.8[9]	8	0.6	76	2.8	19	2.2	0	0
- due to unmapped drainage	167	9.8	38	2.8	389	14.5	135	15.7	63	9.7
- due to slope	101	5.9	63	4.6	138	5.1	17	2.0	128	19.7
- due to rock, topographically and logistically inaccessible	23	1.4	32	2.3	37	1.4	3	0.3	2	0.3

Notes:
1. NMA is compartment area not excluded from harvesting via mapped layers.
2. PHA is compartment area within NMA for harvesting before any unmapped area exclusions.
3. NLA is the area of the compartment actually harvested.
4. PHA – NLA.
5. NMA ÷ GA.
6. PHA ÷ NMA.
7. NLA ÷ PHA.
8. Planned harvestable area not harvested ÷ PHA
9. For each of the four dashed attributes which together comprise the components of NHAM, area of NHAM attribute ÷ (NLA + sum of all NHAM attributes) i.e. contribution of attribute to harvest area reduction.

4. Analysis of raw data

Table 3 shows the contribution of the NHAM components to the reduction in area available for harvesting in each of the five Region/MAs used in the project.

The contribution of “buffer-on-buffer” area reduction to overall area reduction ranged from 0% to 3% and was consistently small. Together with “unmapped drainage lines” (which ranged from 3% to 16%), these two categories make up the category referred to in the original NHAM project as “filter strip extensions”. Table 4 provides a comparison of results from the current project with the original NHAMs.

Table 4: Comparison of existing and revised NHAM contributions – for study compartments only

	UNE/LNE CRA	North East	Central	Southern CRA	South Coast+ Tumbarumba	Eden
Filter strip extensions	13.4%	12.6%	3.4%	20.7%	17.5%	9.7%
Slope, rock, inaccessible	11.6%	7.3%	6.9%	0.4%	5.5%	20.0%
Overall	25.0%	19.9%	10.3%	21.2%	23.0%	29.7%

Following the 2003 review of the 2001 models for North East and Central, average results from the North East were applied across the whole North Coast (North East and Central). As a result, there was not a separate value for Central for the comparison shown in Table 4. Hence the original NHAM project would be more appropriately compared to the result for this project for North East. On this basis, there has been little change in the contribution of filter strip extensions to the overall NHAM for North East. The most likely reason for the smaller contribution of filter strip extensions to the NHAM in Central is the 2003 Integrated Forestry Operations Approval (IFOA) Amendment No 2 that modified restrictions on harvesting adjacent to buffer zones, together with broader market access and more focused efforts on improving economic returns from harvesting.

NHAM reduction for slope and inaccessibility is somewhat smaller for both North East and Central compared to the original NHAM. The most likely reason for this is improved mechanised harvesting, which facilitates pursuit of more marginal trees and successful extraction of trees close to boundaries and improves accessibility around localised obstacles and adverse conditions.

The situation in South Coast plus Tumbarumba is somewhat different. There has been some reduction in the contribution to NHAM arising from filter strip extensions. However, NHAM area losses due to slope have increased significantly in South Coast and Tumbarumba, compared to the original NHAM. Few of the sample compartments selected for the original NHAM project in 1997/8 were located in the less accessible zones of the Region than was the case for this project. At that time harvesting operations were concentrated in more readily accessible zones. Due to the limited time available during the CRA process, selection of sample compartments focused on current areas rather than selecting study compartments that represented both current and likely future harvesting conditions. In contrast, compartments selected for this study cover the range of harvesting conditions. For this reason, the results of the current project are considered more representative of South Coast and Tumbarumba than the original project.

The contributions to NHAM for Eden are different again. Area reductions due to filter strip extensions are more akin to the results for North East and Central. The smaller area reductions for filter strip extensions compared to South Coast are likely to be due to the higher demand for logs of all grades providing economic justification for more accurate determination of buffer strips, as well as and the somewhat more intensive nature of the harvesting operations making boundary identification more straight-forward.

Net harvest area reductions for slope/rock/inaccessibility in Eden are significantly higher than for any other Region/sub-region. The most likely explanation for these differences is the location of harvesting operations in Eden over the last four years (which is the period from which sample compartments were drawn). Operations have been focused on harvesting the limited remaining area of multi-aged forest, most of which comprised the least desirable and thus more difficult to harvest areas of the sub-region. Consequently, area reductions due to slope/rock/inaccessibility are higher than is typical of the sub-region as a whole. Hence, while the NHAM result can be considered representative of current average harvesting operations, it will need to be reviewed as harvesting operations transition from the multi-aged forest into predominantly thinning operations in regrowth forest.

5. Development of the NHAM models

The NHAM project was designed to provide an area adjustment to cater for unmapped harvest exclusions, primarily arising from physical attributes. The model is based on the relationship between the eligible harvest area and the area actually harvested, expressing this as a proportion of harvesting.

The eligible grid cells were restricted to those comprising the subset of planned harvest area that is either harvested or not harvested but linked to the specific and primarily physical land attributes contributing to the NHAM.

Regression analysis was used to determine which of the reasons for areas not being harvested were significant, both with and without various potential stratifications. For those significant factors, statistically significant relationships were develop that defined the proportion of a 5 metre grid cell that was harvested given where that cell lay in relation to other physical site characteristics and/or harvesting attributes.

The resulting models had the form such as:

Proportion of harvesting = *f*(slope, distance to hard boundary, forest productivity class)

A comprehensive discussion of the modelling process is set out in Appendix 2.

The model parameters were then applied back to the 5 m grid cells to generate the proportion of that cell that was calculated to be harvested, given its particular slope, distance to hard boundary and forest productivity class attributes. Each model was applied to its region-wide dataset on the particular attributes of each cell of the 5 metre grid, calculating firstly the proportion of grid cell area harvested and then the modified area of that grid cell (proportion harvested x 0.0025 ha). For example, if the attributes of a particular cell were modelled to indicate that the proportion of harvesting for that particular grid cell was 70%, then the area nominally available for harvesting within that grid cell within the Net Mapped Area would be reset at 70% of 0.0025 ha or 0.0018 ha.

Region/sub-region available area, incorporating NHAM factors, was calculated by summing the amended net mapped area values for each 5 x 5m cell across each Region/sub-region. The Region/sub-region results of the modelling and area calculations are shown in Table 5. Note that these figures represent strategic level estimates of net harvestable area. Areas used for operational and tactical level resource modelling may be further reduced by operational factors such as excluding polygons below a harvestable threshold size eg 1 ha.

Table 5: Impact of new NHAMs at Region/sub-region level

Region/Sub-region	Gross Area (ha)	Area available for harvesting after mapped exclusions (ha)	Area available for harvesting after mapped exclusions and NHAM (ha)	Area reduction due to NHAM (%)
North East	454,980	256,609	206,620	19.5%
Central	409,005	228,352	203,311	11.0%
Eden	167,043	124,678	92,231	26.0%
Tumbarumba	65,072	48,326	39,407	18.5%
South Coast	203,331	141,540	102,813	27.4%
Overall	**1,299,431**	**799,505**	**644,382**	**19.4%**

The original NHAM for UNE/LNE was 27%. This project produced new NHAMs for North East of 19.5% and for Central of 11.0%. The most likely reasons for the reduction in NHAM are:

- improved mapping layers
- improved control through the use of mechanised harvesting
- improved in-forest tools for better boundary location
- the 2003 Integrated Forestry Operations Approval (IFOA) Amendment No 2 that modified restrictions on harvesting adjacent to buffer zones
- in the case of Central, more focused efforts on maximising the economic returns from harvesting through improved supervision and tighter field control of harvesting operations.

The results for both North East and Central are consistent with expectations. The new NHAMs will be progressively incorporated into yield reviews.

The original NHAM for Southern CRA Region was 21%. This project produced new NHAMs for South Coast of 27.4%, and for Tumbarumba of 18.5%. Tumbarumba was expected to have lower NHAM area reductions than South Coast because the former is generally flatter and less dissected. The fact that the area reduction due to NHAM across South Coast was higher (at 27.4%) than the area reduction for the study compartments (at 23%) indicates that the factors that contribute to NHAM are more prevalent across the sub-region than in the compartments selected for the project. For the reasons set out in Section 4, the NHAMs arising from this project are considered more representative of the area as a whole than was the case for the original NHAM project. The new NHAMs will be progressively incorporated into yield reviews.

The new NHAM for Eden across all compartments is 26.0%, somewhat lower than the 29.7% for the compartments selected for the project. This adds weight to the explanation in Section 4 that compartments harvested over the last four years may well be representative of current harvesting operations but may not represent as well the full suite of compartments to be harvested in the future. The new NHAM has already been included in the 2011/12 yield review for Eden. However, as future harvesting operations transition from multi-aged forests into thinning of regrowth stands, Forests NSW will review the NHAMs applicable to harvesting using different silviculture in forests with a different age structure.

Technologies such as LiDAR significantly improve the definition of slope, localised features such as rock and location of drainage lines. Once LiDAR coverage of managed forest areas becomes available, many of the reasons for requiring a NHAM model will no longer apply. At that time, a new study of harvesting operations will be needed to identify which if any NHAM factors still apply that arise from inability to harvest due to localised conditions not identified by new mapped layers.

Appendix 1

NHAM Project: Aerial Photography, Interpretation and Capture

Murray Webster, Aerial Acquisitions Pty Ltd

1. Introduction

The Net Harvest Area Modifier (NHAM) is a component of Forests NSW Forest Resource and Management Information System (FRAMES), a system designed to predict yield of timber from native forest. Yield of timber from native forest harvesting is influenced by a range of factors including accessibility of harvest machinery. Access impediments caused by geophysical features such as steep slope or rocky terrain reduce timber yield. These features are not currently mapped at the resolution needed to adequately inform FRAMES. The Net Harvest Area Modifier uses a spatial modelling approach to account for the reduction in timber yield through inability to access these areas.

Data used to inform NHAM are generated by mapping recently harvested compartments to explicitly identify areas harvested, the type of harvest, areas not harvested and reason for non-harvest. Mapping is carried out using a combination of aerial photography, aerial photo interpretation specialists, consultation with regional staff, and field inspection.

This report details methodology of the NHAM mapping process.

This document adopts the following terminology for regions and sub-regions (full names and then shortened name in brackets):

- North East Region (North East)
- Central Region (Central)
- Southern Region excluding Eden and Tumbarumba sub-regions (Southern)
- Eden sub-region (Eden)
- Tumbarumba sub-region (Tumbarumba).

2. Aerial photography and photogrammetry

A decision was taken to use Aerial Photo Interpretation (API) for NHAM mapping. Aerial photography has been the main source of information for map-makers since the 1950s but is being replaced for a range of uses by alternative digital sensors and GPS. For this project, API was considered the only realistic option for gathering the required information, primarily because alternative digital-sensor based methods require data collection before and after harvest, and the 'before' data did not exist.

It is recommended that Forest NSW examine the cost and benefit of using canopy height models before and after harvest as a method of monitoring harvest. Canopy height models do require an accurate digital terrain model (DTM), and therefore LiDAR. However once a LiDAR DTM is available, a canopy height model can be derived from digital aerial photography, which may be cheaper and has the benefit of allowing human interpretation as well as digital analysis.

Digital aerial photographs were captured with a pixel size of 20-30 cm over each compartment selected for inclusion in the project. Photo capture was hindered by:

- A late start to the project. Typically aerial photography is captured when the sun is relatively high in the sky, between October and March. Contracts for aerial photo capture were not signed until mid April.
- Low sun-angle and consequent long shadows reduced the number of hours per day that were suitable for aerial photo capture, which added days/weeks to initial estimates.
- A series of east coast low pressure systems which covered large areas of NSW in cloud for extended periods.
- Some of the Tumbarumba compartments had extensive snow on the ground at the time of capture.

Photography was captured between June 3 and July 28 2011.

The photography of each compartment - or group of compartments where contiguous - was processed using photogrammetric software to make ortho-photo mosaics, i.e. map-accurate, seamless digital images over each target area. Accuracy of the resulting ortho-photo mosaics was generally better than 5 metres. It is noted that accuracy refers to points at ground level. Tree crown locations can vary significantly more due to the viewing angle of the camera, and tree height.

Ortho-photo mosaics were named using the following convention:

<State Forest Name-Cpt no.>_<Date YYYYMMDD>_<pixel size>_<map projection>.format

For example the 25 cm ortho-photo mosaic for compartment 2234 in Tallaganda State Forest made from photography captured on June 19 2011 and produced with a pixel size of 25 cm in ECW format is named:

TallagandaSF-cpt2234_20110618_25cm_MGA55.ecw

Ortho-photo mosaics were enhanced with the addition of relevant mapped information for each compartment, such as net harvestable area as per harvest plan, mapped harvest area exclusions, compartment boundaries and roads. The subsequent 'photo-maps' were printed and/or prepared for use in GPS-enabled mobile devices. An example of a photo-map is presented as Figure 1.

Prints of each photo were produced for stereo 3D viewing at a scale of approximately 1:10 000. Stereo 3D viewing of photography means looking at a pair of overlapping photos using a stereoscope to create a magnified three-dimensional image of the target area - somewhat similar to 3D movies. This can be done with prints as well as in digital format using software such as Stereo Analyst. Stereo viewing allows the photo interpreter to see slopes and tree/stand heights which help inform reason for non-harvest and is used in field work to navigate by reference to individual trees and topographic position. Whereas LiDAR (or photogrammetry) can now be used to generate digital canopy height models for analysis, photo interpreters have been viewing analogue versions of canopy height models using Stereo 3D viewing for many decades.

The term 'net harvest area' can be used in different contexts, such as based on mapped information, harvest planning information or post-harvest mapping. The following definitions are used in this report:

- Net Mapped Area is gross area less known mapped exclusions such as rainforest, old growth forest, slopes of thirty degrees (modelled), and drainage and buffers.
- Base Net Area is the GIS representation of Net Mapped Area but without modelled steep slopes.

- Net Harvest Area is the Net Mapped area minus the Net Harvest Area Modifier and Strike Rate impact.
- Net Harvested Area is the area is mapped as harvested, after harvesting has finished.

3. Aerial photo interpretation and digitising

Aerial photo interpretation (API) is the process of generating information by visual assessment of aerial photography. Digitising is the process of capturing information into a digital format, in this case, for use in GIS. All the API sub-contractors selected for the project are acknowledged experts.

API sub-contractors were provided with a range of information to assist accurate mapping including:

- Harvest plans;
- Notes and sketch-maps prepared by the Supervising Forest Officer (SFO) for the harvesting operation;
- Discussions with SFOs and/or local staff for specific queries and assistance with field work.

The general process for API can be divided into three stages:

(i) Preparation:

- Gather all available information;
- View photos using stereo 3D;
- Transfer relevant boundaries on to prints as required to define the area to be mapped.

(ii) Interpretation:

- Determine which areas are clearly harvested or not harvested, and which areas require verification;
- Using provided information, subdivide harvested areas into type of harvest and subdivide not harvested areas into primary reason for non-harvest;
- Undertake field work to resolve areas of ambiguity and confirm reliability of office-based interpretation, accompanied by local staff if available;
- Perform final interpretation, by drawing boundaries around different categories of harvest/non-harvest.

(iii) Digitising:

- Convert interpreted information into digital format. Final interpretation and digitising were performed in one of two ways: perform final interpretation on printed ortho-photo maps and send to a GIS technician for digitising; or perform final interpretation on digital ortho-photo mosaics in GIS, in which case digitising is simultaneous.

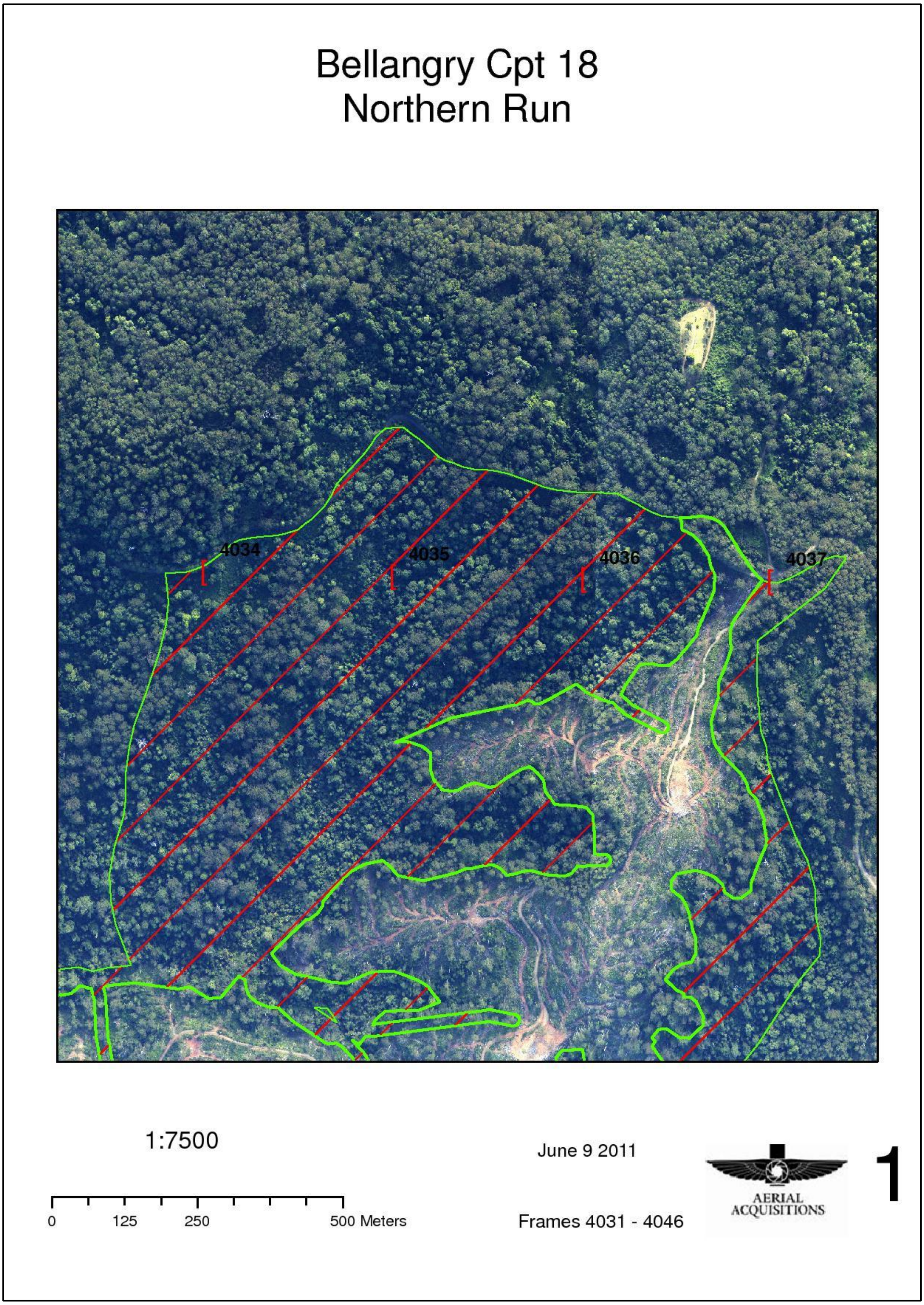


Figure 1: Photo Map example showing harvest plan net area and compartment boundary in green and mapped exclusions (from GIS) hatched red.

The preparation phase was straight-forward.

The interpretation phase varied in quality/timing of aerial photography, complexity, availability and type of information provided, and the difficulty of accessing various sites for field verification.

Timing of the aerial photography captured for the project varied from approximately six months to four years after completion of harvesting. Compartments that were photographed more than two years after logging were difficult to interpret. The forest canopy grows quickly. In areas harvested by Single Tree Selection (STS), the remaining trees quickly expand into canopy space created by removal of adjacent trees to mask the signs of logging. Fortunately most of these compartments did have photography captured closer to the harvest date by the Land and Property Management Authority (LPMA), using a Leica ADS40 sensor. It is recommended that remote sensing data (including aerial photos) be captured within twelve months of harvest to accurately and efficiently depict the extent of harvesting. This is expected to apply equally to aerial photography for interpretation or LiDAR for before and after digital analysis. From a silvicultural perspective, because eucalypt seedlings and saplings require abundant sunlight to survive, this observed rapid lateral expansion of remaining canopy trees reinforces the need to create large gaps in order to sustain regrowth of the forest ecosystem.

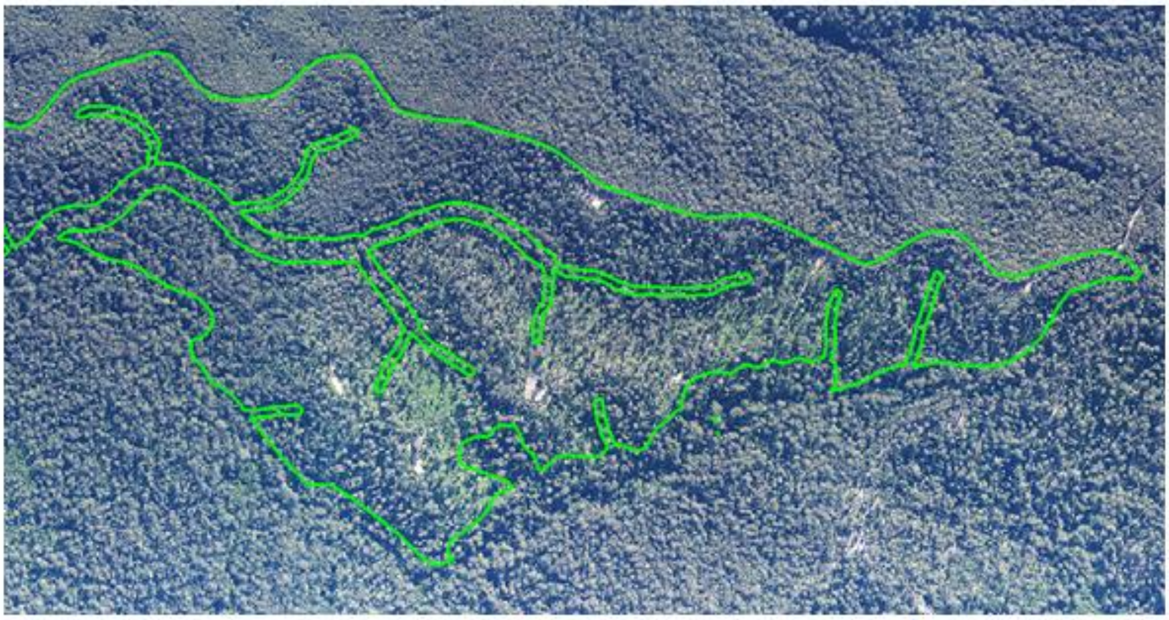
Figure 2 shows project photography that was captured over three years after completion of harvesting and LPMA ADS40 photography captured within 12 months of completion of harvesting. Harvesting is easily recognisable on the ADS40 photography due to capture close to harvest date, whereas on the older photography expansion of the remaining tree crowns and growth of seedlings and shrubs has obscured harvesting, making interpretation difficult.

In some areas, particularly further south in Eden in steeper topography, long shadows further complicated the identification of harvesting boundaries.

Access to some compartments was not practical because of long travel times and in some cases roads blocked by landslip. Forty-nine out of 73 compartments used in NHAM were visited in the field.

During the API process, the interpreters identified a particular difficulty in correctly classifying the small number of compartments that were harvested using Australian Group Selection (AGS) silviculture. AGS is a harvest method that creates gaps in around 25% of the harvestable forest in the first cycle, with a second cycle some years later that creates gaps in the next 25%, and so on for four cycles. The pattern of harvest in AGS is more influenced by the 25% objective than any physical reason for non-harvest. In contrast, areas not harvested in STS operations generally have an underlying reason such as inaccessibility or not economically viable to harvest. Therefore, in AGS compartments it can be difficult to determine the reason for non-harvest without extensive and expensive field inspection. Given this uncertainty, the small number of compartments where AGS was undertaken and the expectation that AGS as currently specified was not intended to be used as a silvicultural treatment in the foreseeable future, AGS compartments were excluded from the analysis. Where possible, AGS compartments were replaced with compartments in which the silvicultural treatment was STS or STSRegen.

The codes used in the process of tagging polygons during the API are set out in Table 1.



NHAM photography captured 3 + years after harvest

Lands Department ADS40 photography captured within 12 months of harvest

Figure 2: Comparison of photography captured close to harvest completion and photography captured years after, Compartment 59, South Brooman SF.

Digitising proceeded as expected. It is noted that there are always errors by interpreters in assigning codes, and also in the digitising process. Digitising errors are greater where digitising is performed by someone other than the interpreter. The digitised API went through several checks to ensure integrity. All API was scrutinised by the main contractor to ensure consistency in application of codes and detect errors. Southern and Tumbarumba in particular had poor quality photography (long shadows, snow, and long time since harvest) and significant errors were detected by Southern Region Resources staff. Close consultation with Southern Region resulted in mapping that was acceptable to both the region and the contractor. During summary data preparation for modelling as well as reporting, any codes that where questionable where highlighted for checking.

Table 1: List of Codes used in mapping Base Net Area

Code	Description
Harvested Codes	
HS	*Single tree selection*
HC	*Alternate coupe harvesting (Eden only)*
HA	*Australian group selection*
HM	*Using mix of harvesting methods*
HR	*Regeneration single tree selection*
HT	*Thinning*
Not Harvested Codes	
NE	*Not economically viable*
NU	*Unfinished*
NC	*Catchment protection, unmapped filter strip*
NS	*Steep*
NP	*Pre-merchantable*
NG	*Basal Area retention*
NW	*Wildlife*
NT	*Topographically isolated/inaccessible*
NB	*Buffer extension*
NR	*Unmapped Rainforest*
NL	*Logistic - inaccessible due to administrative or regulatory boundaries*
NN	*Non-commercial vegetation types*
NK	*Rock*
NM	*Missed*
NO	*Cleared (not forest)*
NI	*Easement (infrastructure)*
NF	*Flora or fauna protection*
NV	*Native forest within plantation*
NH	*Recently harvested < 5 yrs*
NX	*Unavailable - map error of commission*
NA	*Unmapped plantation*
Harvesting outside BNA (Unavailable areas)	
UA	*Available - map error of omission*
UH	*Harvested - generally errors in drainage line mapping*
UN	*Not harvested in unavailable area*
XH	*Harvested in correctly mapped unavailable area*

4. Results

A total of 73 compartments covering a gross area of over 15 000 hectares were sampled across North East, Central, Southern, Tumbarumba and Eden. The compartments used in the NHAM project are listed by Region/sub-region in Table 2, together with whether or not the compartment was visited for checking and validation of API. It was a contract requirement that at least 50% of compartments be visited for field checking and validation - this minimum target was exceeded in all Regions/sub-regions.

A large number of categories used in the API for this project, and an even larger number have been used by regional staff for a range of purposes over time. Within the context of this project the complexity of coding used is a vehicle to assist the consultation and interpretation process - codes are simplified for use in modelling. The codes used are grouped into subcategories as follows:

- Harvested: Codes beginning with "H" - Harvested areas that are within the Base Net Area.
- Not Harvested: Codes beginning with "N" – Areas that are within the Base Net Area but were not harvested
- Unavailable: Codes beginning with "U" - resulting from errors in base map data (i.e. errors within the geo data base)
- Permanent Exclusions: codes beginning with "X". These areas are not subject to API, except where harvesting occurred. API is performed on the Base Net Area which is defined as the complement of permanent exclusions. In cases where a mapped permanent exclusion is harvested - for example incorrectly mapped drainage buffers - a "U" code is used.

Data was supplied to Forests NSW for modelling as GIS polygons in ESRI shapefile format, with each polygon labelled according to the mapping classification.

5. Conclusion

This project used purpose-flown aerial photography to map harvesting in recently harvested compartments to gather data for the Net Harvest Area Modifier component of FRAMES. The overall level of harvest of the study compartments expressed as a percentage of gross compartment area is 36%, compared with 31% from the 2002 study.

It is recommended that Forests NSW examine use of improved technology in mapping harvested area, and in planning future projects be mindful that the time of year is a critical variable in collecting any remote sensing data that relies on sun reflection (i.e. visual/infrared imagery).

Table 2: Sample compartments and Field Visits

North East			**Central**		
State Forest	**Compartment**	**Visit**	**State Forest**	**Compartment**	**Visit**
Boonoo	96	Yes	Barrington	50	Yes
Clouds Creek	69	Yes	Bellangry	18	No
Dalmorton	415	Yes	Broken Bago	42	Yes
Dalmorton	457	Yes	Coopernook	206	Yes
Forestland	216	Yes	Cowarra	66	Yes
Gibberagee	116	No	Doyles River	1225	No
Girard	29	No	Doyles River	1237	No
Girard	68	No	Giro	2	Yes
Hyland	320	Yes	Kerewong	104	Yes
Mistake	357	No	Lansdowne	175	Yes
Nana Creek	628	Yes	Lorne	76	Yes
Newfoundland	456	Yes	Lorne	101	Yes
Newfoundland	459	Yes	Mount Boss	167	No
Newry	281	No	Myall River	49	Yes
Orara West	635	Yes	Myall River	54	Yes
Orara West	636	Yes	Nerong	102	Yes
Sugarloaf	450	Yes	Putty	532	No
Tuckers Nob	63	Yes	Putty	533	No
Washpool	722	No	Tamban	73	Yes
Wedding Bells	551	Yes			
Total	**20**	**14**	**Total**	**19**	**13**
Southern & Tumbarumba			**Eden**		
State Forest	**Compartment**	**Visit**	**State Forest**	**Compartment**	**Visit**
Badja	2015	Yes	Cathcart	1370	Yes
Bago	6	Yes	Coolangubra	1343	No
Bago	34	Yes	Gnupa	729	No
Bondo	8034	No	Nalbaugh	1302	Yes
Dampier	3105	Yes	Nalbaugh	1308	Yes
Dampier	3112	Yes	Nalbaugh	1402	No
Dampier	3123	No	Nullica	621	Yes
Dampier	3130	Yes	Nullica	625	Yes
Dampier	3156	No	Nullica	626	Yes
Dampier	3158	Yes	Nullica	711	No
Micalong	8079	Yes	Nullica	722	Yes
Micalong	8083	Yes	Tantawangalo	2434	No
Mogo	158	Yes	Yambulla	490	No
Mogo	160	Yes	Yambulla	520	Yes
South	59	Yes	Yambulla	557	No
Tallaganda	2234	Yes	Yambulla	575	Yes
Wandera	586	No	Yambulla	576	Yes
Total	**17**	**13**	**Total**	**17**	**10**

Appendix 2

NHAM Project: Statistical Methods

Dr. Amrit Kathuria, Department of Primary Industries, NSW Department of Trade and Investment, Regional Infrastructure and Services

Introduction

The NHAM study is designed to provide an area adjustment to cater for unmapped physical harvest exclusions. This adjustment between the eligible harvest area and the area actually harvested is expressed as a proportion of harvesting and is calculated as the ratio of actual harvested area to the eligible area. The eligible area is restricted to the subset of planned harvest area that is either harvested or not harvested but linked to physical land features not considered elsewhere in determining the area modelled as available for harvesting in FRAMES.

To ensure only eligible features are factored into the proportion, the analysis dataset for model development includes only those polygon tags associated with actual harvesting or physical limitation to harvest. Removing non-physical codes from both the denominator and the numerator ensures they do not influence the result.

The data considered for the model development was a 5m grid with the slope value for that cell, and distance of the cell to the hard (i.e. pre-existing mapped) boundary (the latter calculated using the shortest distance from the centre-point of each 5 metre grid cell to the nearest hard boundary using the Base Net Area cover and boundary classification matrix). The other variables used in the prediction model were the compartment level variables such as productivity class, silviculture and harvesting method. Some of these variables are only available after the harvesting is done so cannot be used in the final model. The NHAM codes were then recoded to either harvested or not harvested, to make the response a binomial variable.

This document adopts the following terminology for regions and sub-regions (full names and then shortened name in brackets):

- North East Region (North East)
- Central Region (Central)
- Southern Region excluding Eden and Tumbarumba sub-regions (South Coast)
- Eden sub-region (Eden)
- Tumbarumba sub-region (Tumbarumba).

Modelling approach

The response variable of interest in this analysis is whether a pixel is harvested or not. Contingency tables with the percentage harvesting are used as an exploratory tool. Harvest proportions were estimated for distance and slope classes for the two productivity classes and plotted as trellis plots to visually see the effect of the variables on the harvest proportion. The harvest proportions were plotted on the y axis against the distance from the hard boundary for the different slope classes and a different colour was used for the productivity classes. A loess curve was also fitted to the scatter plot.

Modelling of the data to look for the significant factors of importance is done using Logistic regression models. This regression is suggested when the dependent variable is binary and when the assumption of the normal distribution of data, requested by parametric techniques, is not respected (Harrell 2001). The logistic regression model used for analysis is:

$$\log it\ p = \log \frac{p}{(1-p)} = \beta_0 + \beta_1 x_1 + \cdots + \beta_k x_k$$

where p is the probability of harvesting and *x's* are the explanatory variables such as distance to the boundary, slope and productivity class. β_0 and β_i are the regression coefficients (β_0 is the intercept). The interaction effects were also tested. A Wald test is used to test the statistical significance of each variable in the model. The fitted models were validated using bootstrap samples. Calibration as proposed by Cox (1958) and further developed by Harrell and Lee (1985) and Miller et al (1991) was used to assess the relationship between the observed and the predicted values. If the fit is perfect (i.e. the predictions are very close to the observed values) then the intercept of the calibration equation is zero and the slope is 1. The corrected slope can be thought of as a shrinkage factor that takes into account over-fitting. The maximum absolute difference in predicted and calibrated probabilities and Area under the ROC Curve (or AUC for short) are popular indicators of the quality of a model. AUC values are estimated for the original sample as well as the bias corrected values from the bootstrap samples.

The estimation accuracies of the harvest proportions for the compartments were compared using the root mean square error (RMSE)

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(yi - \hat{yi})^2}{n}}$$

and bias

$$bias = \frac{\sum_{i=1}^{n}(yi - \hat{yi})}{n}$$

where n is the number of compartments, yi is the observed value of the harvested proportion y, and $\hat{yi}$, is the predicted value. Further weighted RMSE and weighted Bias values were estimated by using the size of the compartment as the weights, i.e. the bigger size compartment would have a bigger contribution to the RMSE and the Bias values.

Complete data was analysed with distance to the boundary, slope and productivity class as the factors of interest. All the analysis was done using R software (R Dev. 2011).

Results

1. Exploratory Analysis

The proportion of the pixels from each of the harvest codes for the different regions is presented in Table 1. The area harvested from Eden is 70.3%, Central is 89.0%, North East is 78.5%, South Coast is 76.0% and Tumbarumba is 79.8%. There are differences in the reasons for non-harvest in different regions. The main contributor to non-harvest in Eden is NS, whereas in North East, South Coast and Tumbarumba it is NC.

Harvest proportion was plotted against distance to the hard boundary for the different slope classes and is presented in Figures 1-4. As the shape of the relationship is different for the different regions, a separate model was fitted to each of the regions. Figure 4 is the plot of harvest proportions for South Coast and Tumbarumba. As can be seen from the plot the harvest proportions from the two are very different from one another and the shape of the relationships is also different, so it was decided to do separate analysis for each. As a general trend, as the distance to the boundary increases so does the proportion harvested. For lower slope values the harvest proportion increases to almost 1, but for the high slope values it is substantially less than 1.

Table 1: The percentage area under each of the NHAM codes for the different regions.

Code[1]	Eden	Central	North East	South Coast	Tumbarumba
HC	69.2%				
HM					7.6%
HS	0.3%	87.2%	77.3%	74.9%	71.6%
HT			0.1%		
NB		0.6%	2.7%	2.8%	2.2%
NC	9.7%	2.8%	9.6%	14.6%	15.7%
NK	0.3%		0.1%	0.0%	
NL		0.7%	2.2%	0.1%	
NS	19.7%	4.6%	5.8%	5.2%	2.0%
NT	0.1%	2.3%	1.2%	1.2%	0.3%
UH	0.6%	1.6%	0.9%	1.1%	0.6%
UX	0.2%	0.2%	0.1%	0.1%	
XS				0.0%	

1. See Table 2 in Main Report for definition of codes

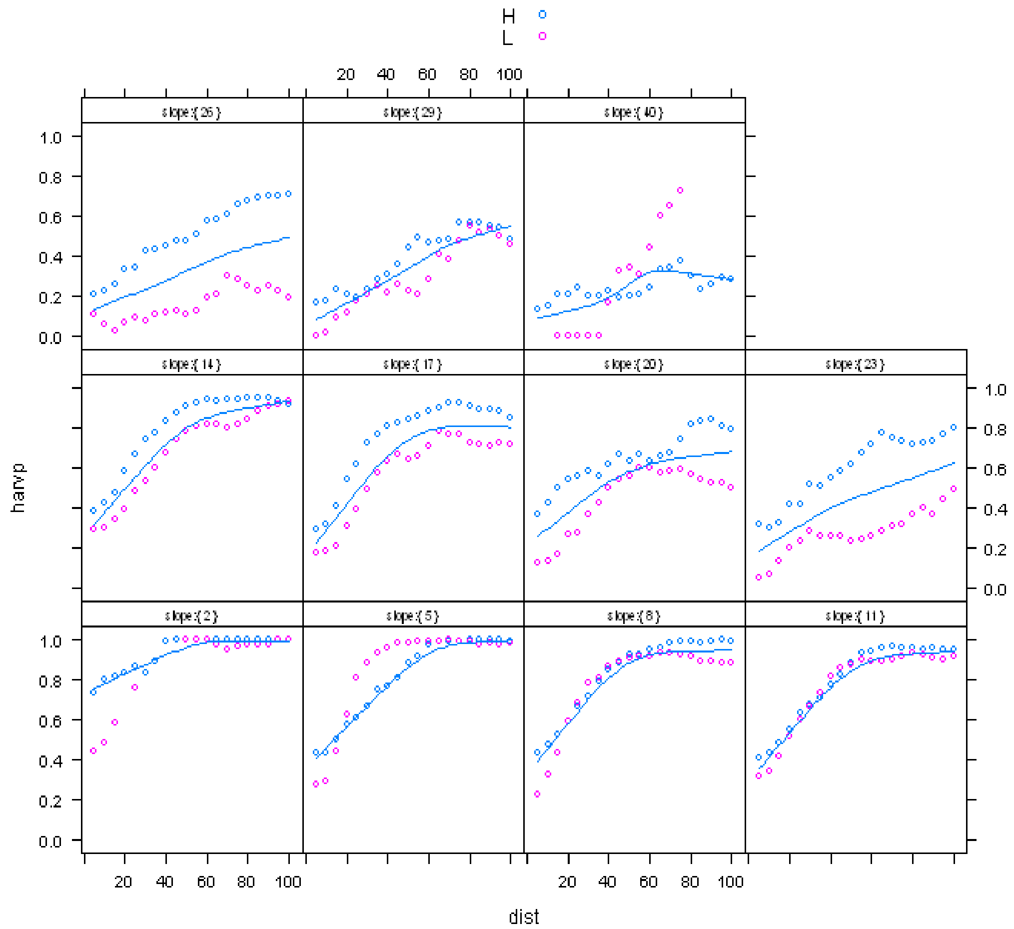


Figure 1: Plot of Eden data. Harvest proportion (harvp) is plotted on the y-axis against the distance to the boundary (dist). The different plots are for the different slope classes, with slope {2} for data in slope class 0-2 then slope {5} for slope class 2-5 and so on. The different colour symbols are for the different productivity class "Blue" for High and "Pink" for Low productivity class.

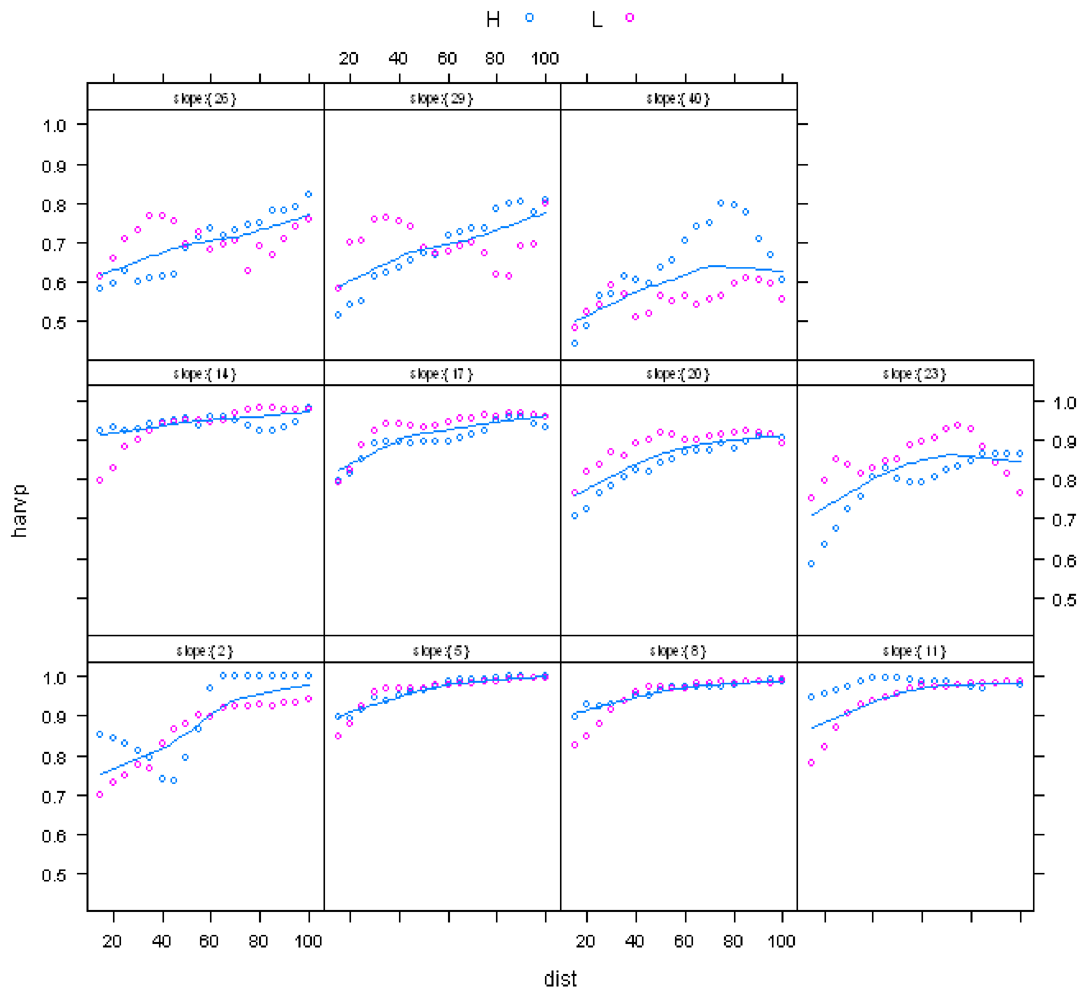


Figure 2: Plot of Central data. Harvest proportion (harvp) is plotted on the y-axis against the distance to the boundary (dist). The different plots are for the different slope classes, with slope {2} for data in slope class 0-2 then slope {5} for slope class 2-5 and so on. The different colour symbols are for the different productivity class "Blue" for High and "Pink" for Low productivity class.

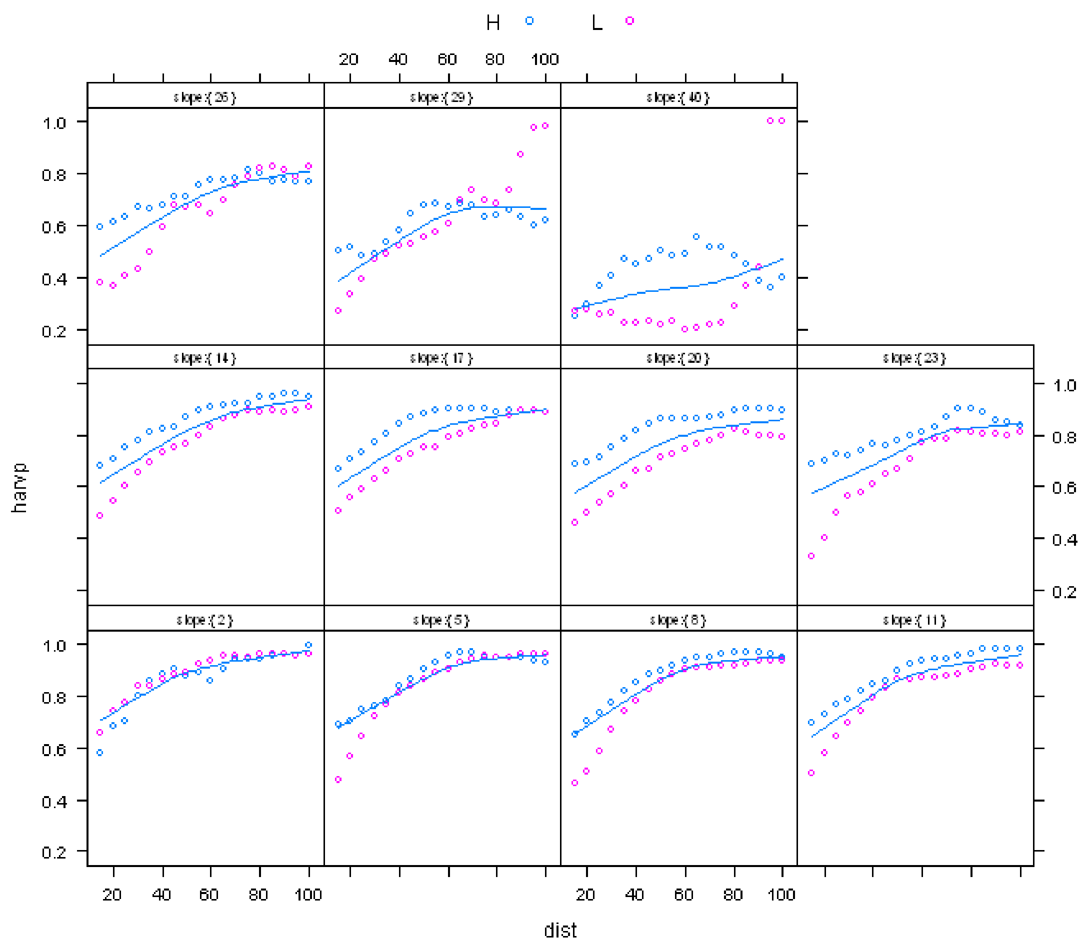


Figure 3: Plot of North East data. Harvest proportion (harvp) is plotted on the y-axis against the distance to the boundary (dist). The different plots are for the different slope classes, with slope {2} for data in slope class 0-2 then slope {5} for slope class 2-5 and so on. The different colour symbols are for the different productivity class "Blue" for High and "Pink" for Low productivity class.

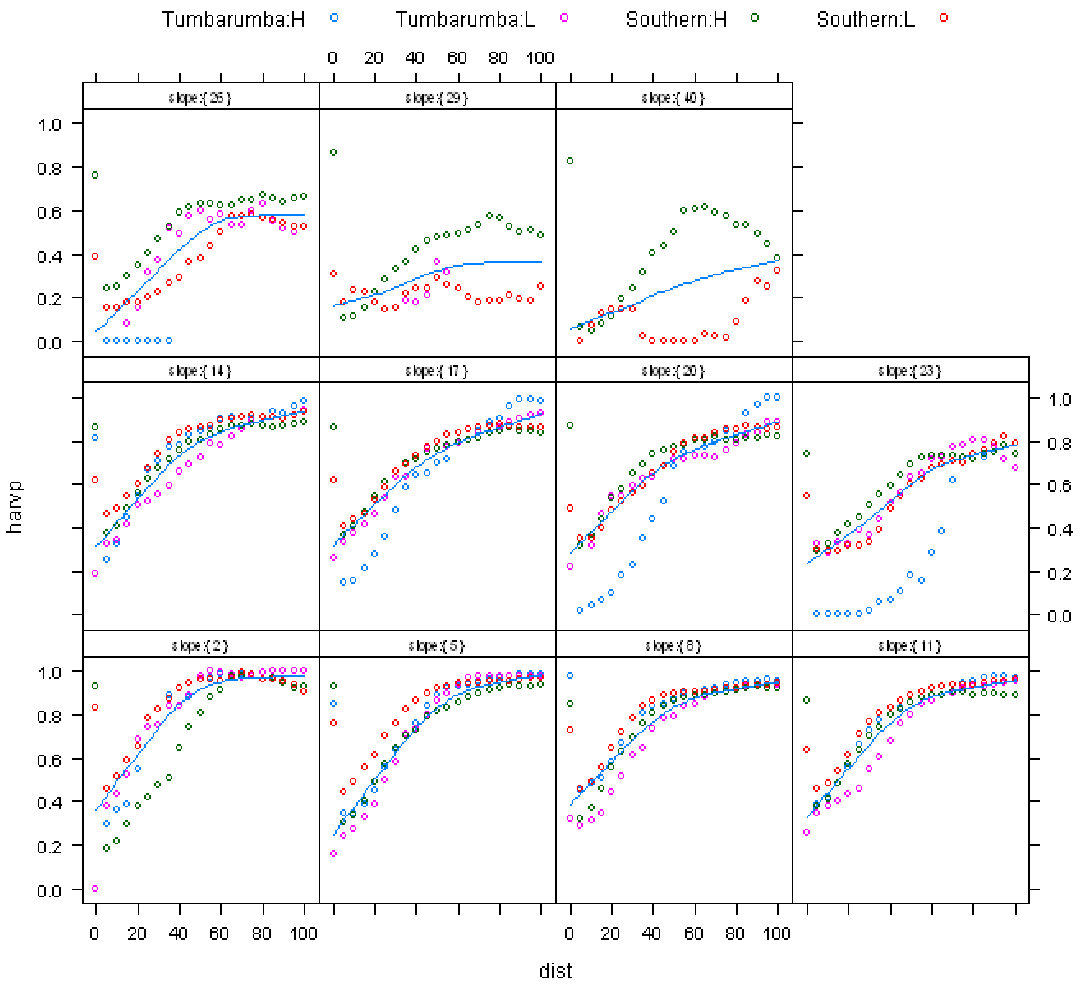


Figure 4: Plot of South Coast (labelled Southern) and Tumbarumba data. Harvest proportion (harvp) is plotted on the y-axis against the distance to the boundary (dist). The different plots are for the different slope classes, with slope {2} for data in slope class 0-2 then slope {5} for slope class 2-5 and so on. The different colour symbols are for the different productivity class and the different sub-regions; "Blue" for High and "Pink" for Low productivity class for Tumbarumba and "Green" for High and "Red" for Low productivity class for South Coast.

2. Model fitting

The logistic model was fitted with distance to the boundary, slope and productivity class as explanatory variables. A different model was fitted to each of North East, Central, Eden, South Coast and Tumbarumba. A subset of the data with distance to hard boundary less than 100 m was used for fitting the model as it was assumed that any distances to hard boundary greater than 100 m are for harvesting purposes similar to 100 m. Analysis of log likelihood and Wald statistics for the complete model and various sub-models showed that all three variables and their interaction effects were highly significant ($p < 0.01$). The results of logistic regression are presented in Table 2. Figures 5-9 are the plots of the predicted values from the model against the explanatory variables. These curves show the relationship between the harvest probability and the distance to the boundary and slope for the two values of the productivity class.

Table 2: The fitted values of the various variables and their interactions along with their Standard errors (SE)

Variables	Estimate	SE
Eden		
Intercept	-0.3104	0.0336
Slope	-0.0269	0.0019
Distance To Hard Boundary.	0.0726	0.0009
Productivity Class=L	0.2661	0.0554
Distance To Hard Boundary * Productivity Class=L	-0.0083	0.0014
Slope * Distance To Hard Boundary	-0.0021	0.0000
Slope * Productivity Class=L	-0.0462	0.0036
Slope * Distance To Hard Boundary * Productivity Class=L	0.0001	0.0001
Central		
Intercept	2.7399	0.0338
Slope	-0.0986	0.0016
Distance To Hard Boundary.	0.0251	0.0008
Productivity Class=L	-1.2394	0.0383
Distance To Hard Boundary * Productivity Class=L	0.0155	0.0010
Slope * Distance To Hard Boundary	-0.0004	0.0000
Slope * Productivity Class=L	0.0643	0.0020
Slope * Distance To Hard Boundary * Productivity Class=L	-0.0007	0.0000
North East		
Intercept	0.5970	0.0219
Slope	-0.0143	0.0012
Distance To Hard Boundary.	0.0474	0.0006
Productivity Class=L	-0.6388	0.0263
Distance To Hard Boundary * Productivity Class=L	-0.0036	0.0007
Slope * Distance To Hard Boundary	-0.0014	0.0000
Slope * Productivity Class=L	-0.0118	0.0016
Slope * Distance To Hard Boundary * Productivity Class=L	0.0005	0.0000
South Coast		
Intercept	-0.3378	0.0139
Slope	-0.0017	0.0009
Distance To Hard Boundary.	0.0454	0.0003
Productivity Class=L	0.4309	0.0198
Distance To Hard Boundary * Productivity Class=L	0.0117	0.0005
Slope * Distance To Hard Boundary	-0.0012	0.0000
Slope * Productivity Class=L	-0.0315	0.0014
Slope * Distance To Hard Boundary * Productivity Class=L	-0.0005	0.0000
Tumbarumba		
Intercept	0.2730	0.0356
Slope	-0.1119	0.0034
Distance To Hard Boundary.	0.0505	0.0010
Productivity Class=L	-1.7707	0.0458
Distance To Hard Boundary * Productivity Class=L	0.0195	0.0012
Slope * Distance To Hard Boundary	-0.0002	0.0001
Slope * Productivity Class=L	0.1573	0.0042
Slope * Distance To Hard Boundary * Productivity Class=L	-0.0022	0.0001

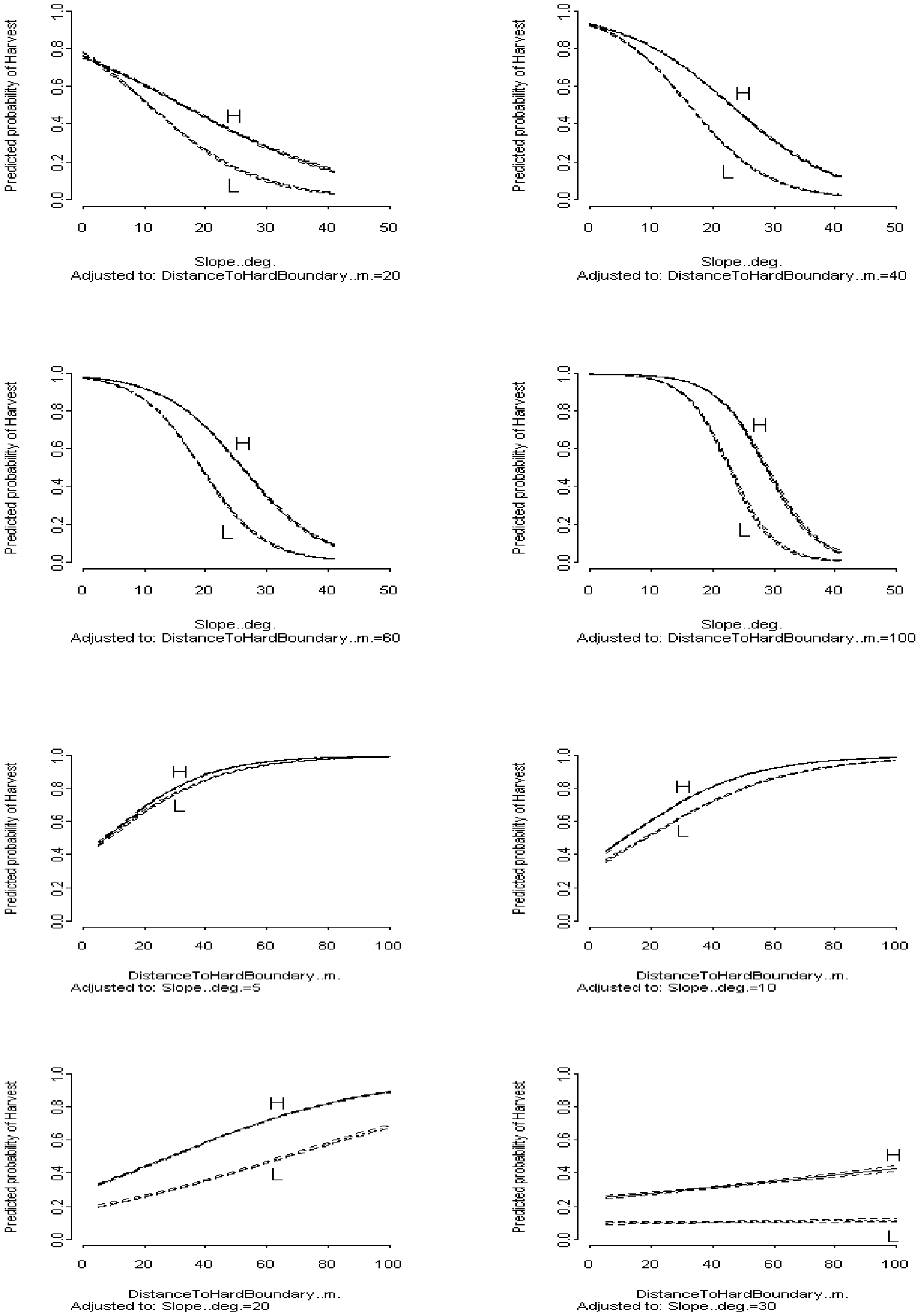


Figure 5: Predicted values for Eden data. The top four plots are the predicted probability of harvest against the slope values at different distance values. The bottom four plots are the predicted probability of harvest against the distance to the boundary values for different slope values.

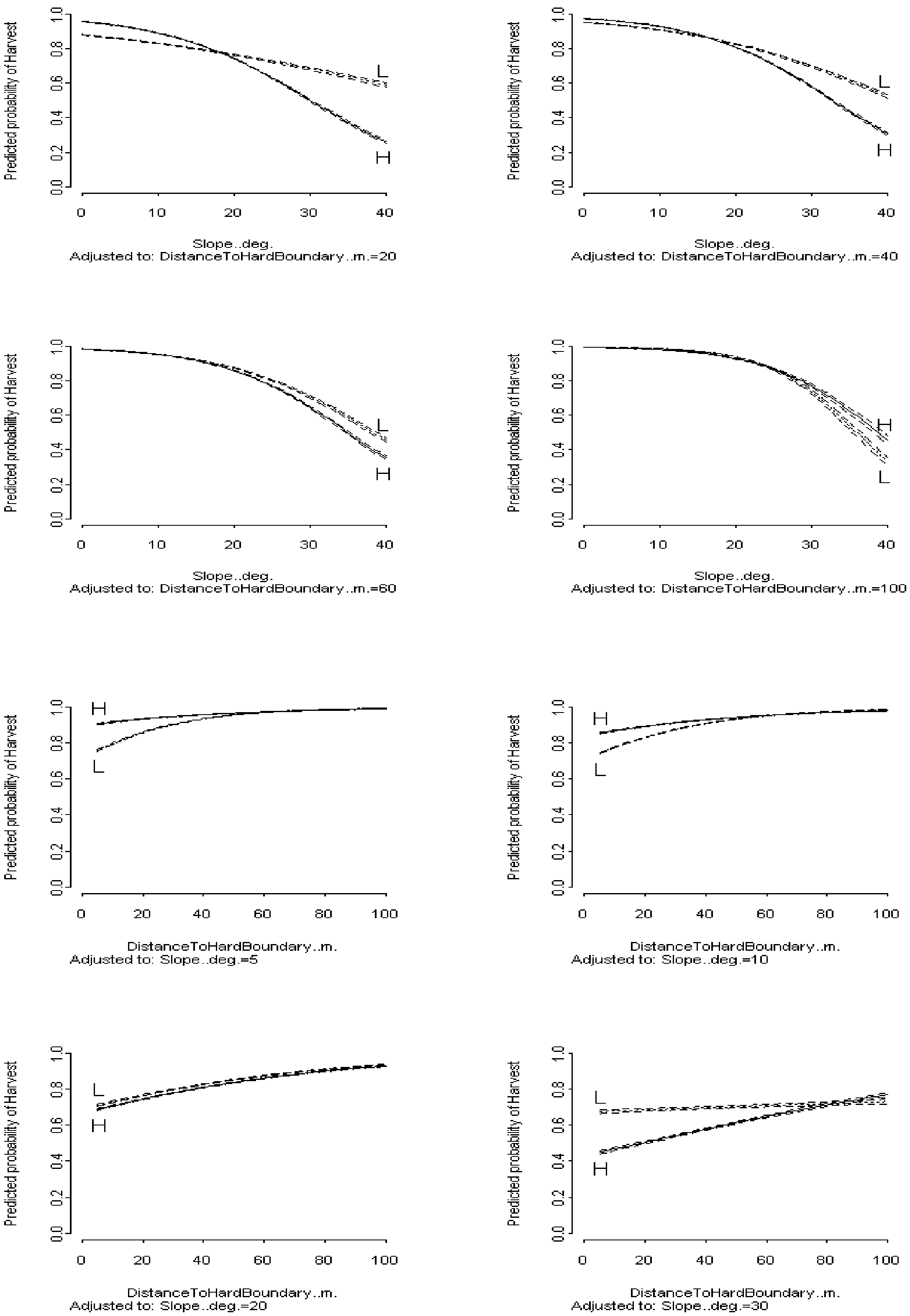


Figure 6: Predicted values for Central data. The top four plots are the predicted probability of harvest against the slope values at different distance values. The bottom four plots are the predicted probability of harvest against the distance to the boundary values for different slope values.

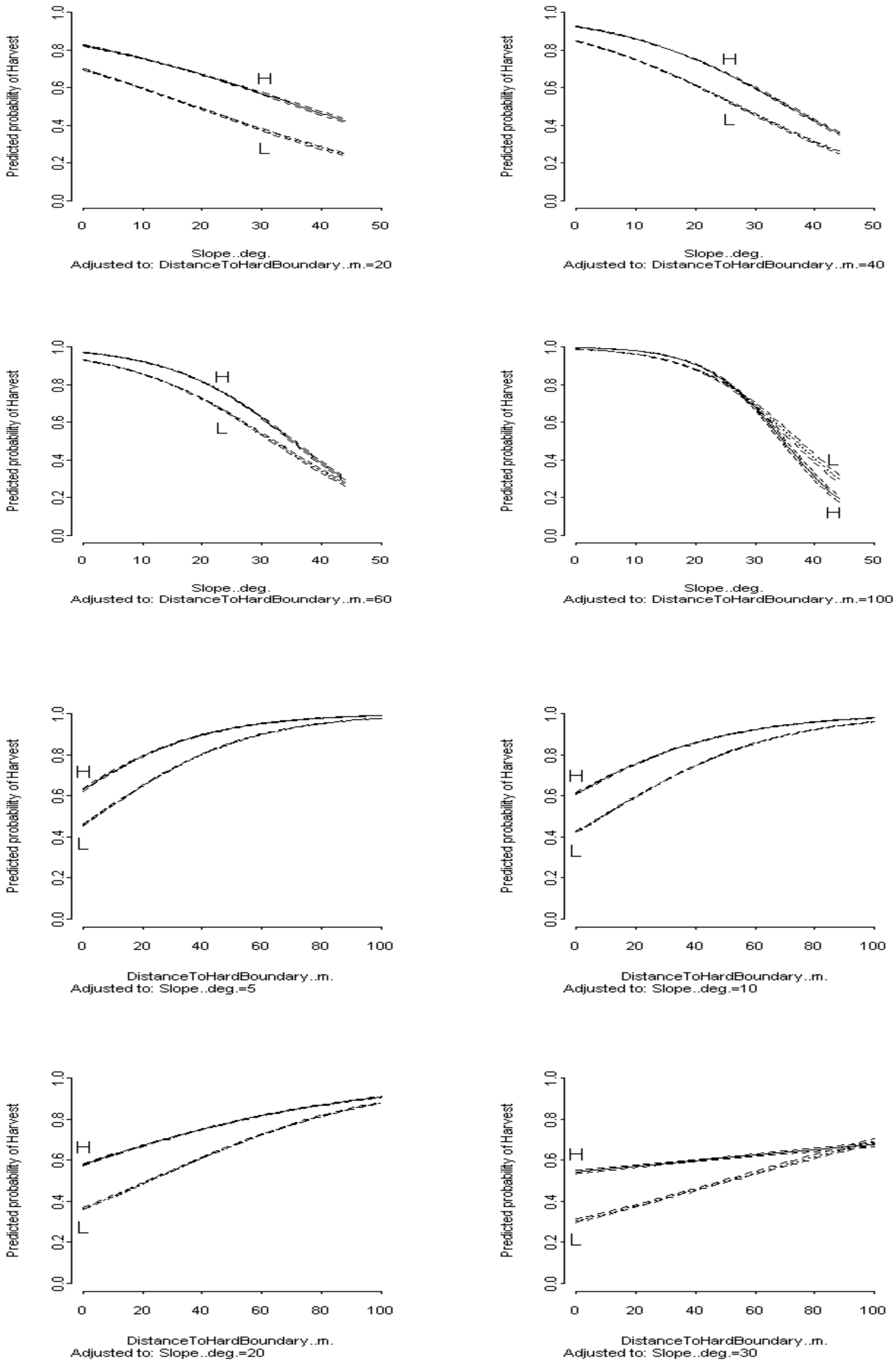


Figure 7: Predicted values for North East data. The top four plots are the predicted probability of harvest against the slope values at different distance values. The bottom four plots are the predicted probability of harvest against the distance to the boundary values for different slope values.

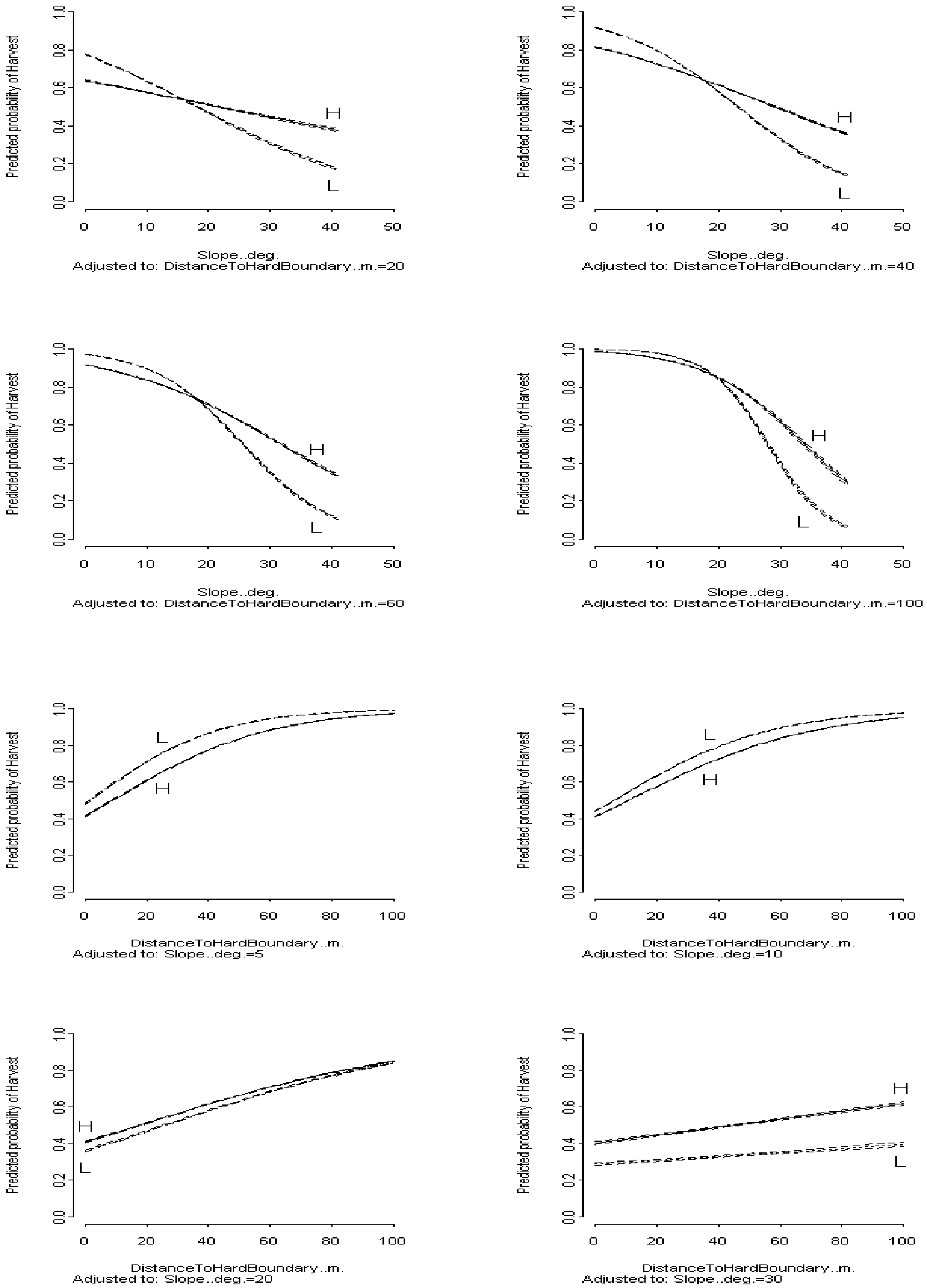


Figure 8: Predicted values for South Coast data. The top four plots are the predicted probability of harvest against the slope values at different distance values. The bottom four plots are the predicted probability of harvest against the distance to the boundary values for different slope values.

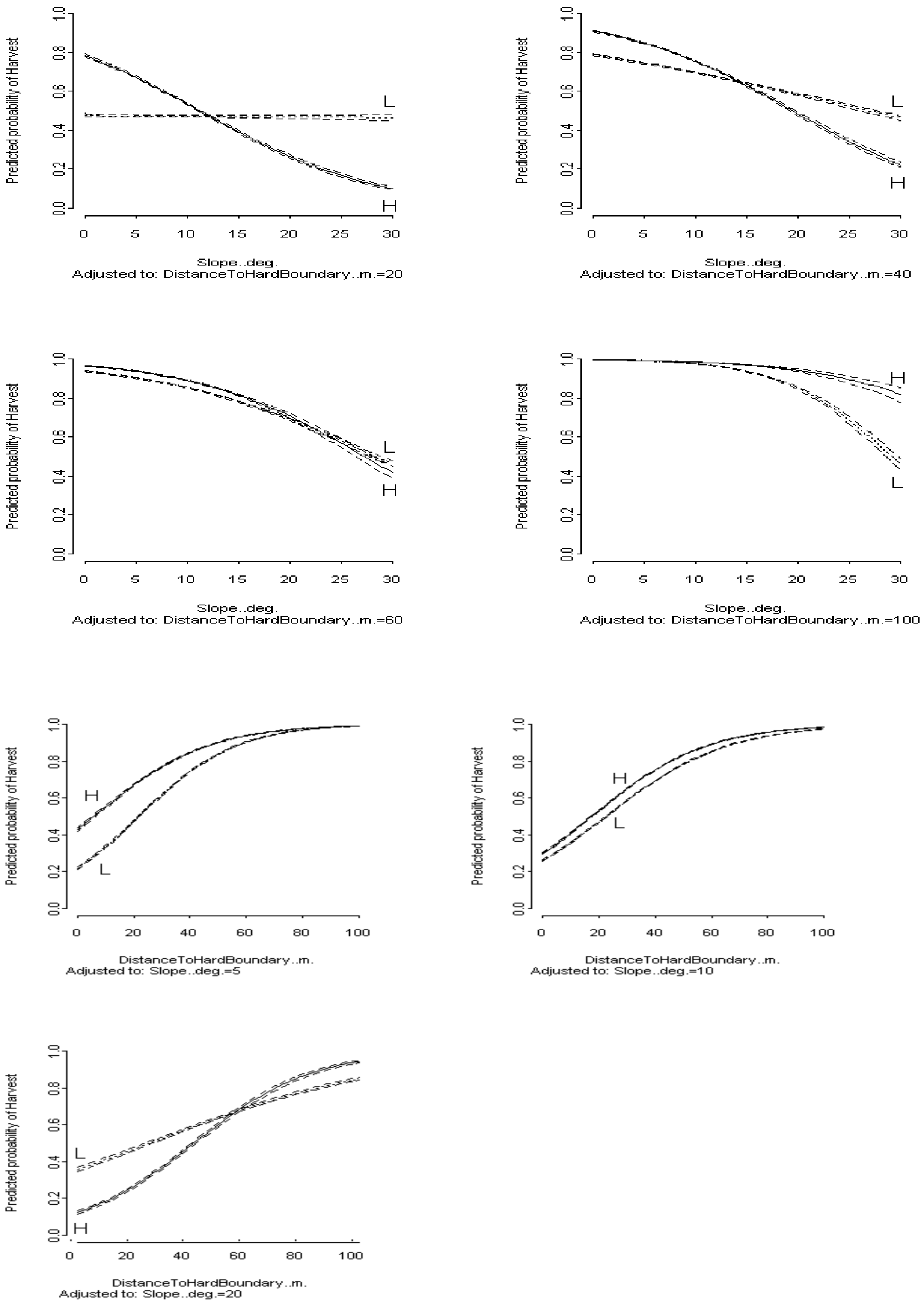


Figure 9: Predicted values for Tumbarumba data. The top four plots are the predicted probability of harvest against the slope values at different distance values. The bottom four plots are the predicted probability of harvest against the distance to the boundary values for different slope values.

3. Model Validation

The model was validated using 100 bootstrap samples. The calibration parameters measuring the fit of the observed values against the predicted values have intercept values very close to zero and a slope values close to 1. For a perfect fit these values would be 0 and 1 respectively. The fitted curves were very close to the ideal line passing from zero and with the slope value of 1, indicating a good fit. The ROC values were: Eden 0.82, Central 0.76, North East 0.74, South Coast 0.75 and Tumbarumba 0.81. These estimates indicate a reliable model has been fitted to the data. Table 3 presents the RMSE and Bias values at the compartment level. The weighted bias and RMSE values are also presented in the table, weights being the size of the compartment.

Table 3: The compartment level Bias and RMSE values for the different regions. The Wbias and WRMSE values are the weighted bias and RMSE values, weights are the size of the compartment.

Region/Sub-region	Bias	RMSE	Wbias	WRMSE
Eden	0.016	0.117	-0.012	0.118
Central	-0.012	0.123	-0.003	0.106
North East	-0.017	0.110	-0.006	0.091
South Coast	-0.041	0.141	-0.013	0.100
Tumbarumba	0.003	0.039	0.000	0.038

Further Comments

Only three variables are considered here in the model, distance to the boundary, slope and productivity class. There are a number of other factors that affect the percentage area harvested such as harvesting method which can be mechanical or manual. Central data was analysed and it was found that there were differences in the harvested proportion for the two harvesting methods. However, there was insufficient data to determine whether these differences were specific to contractor performance or were more generally present. Further, inclusion of this variable in the model is somewhat impractical, as this variable is not available in advance to be applied to future harvesting operations. It was also observed that the predominant silviculture in Central also affected the proportion harvested. However, inclusion of this variable in the NHAM model is also somewhat problematic for application to future harvesting operations.

There are API codes such as NL (not harvested for logistical reason) or NT (topographically/physically inaccessible). These codes are difficult to model with the variables considered (distance to the hard boundary, slope and productivity class), as none of these could model access to the area (if the area is contained within a native forest etc.), which could be one of the reasons for these codes. One way to deal with this type of non-harvest area is to filter out areas which have access problems and not include these codes in the model building. Alternatively, include variables such as accessibility of the area, in the model that would improve the model predictability for these compartments.

The distance to the hard boundary is estimated from the drainage line boundary. The use of LiDAR data could improve the location of the drainage lines and hence improve the accuracy of the input variable. Slope values could also be improved by the use of LiDAR data.

In the model above, a logit transform is used for the harvest probability and this was modelled as a linear function of a set of predictor variables. An alternative approach is to use a generalised additive model and also incorporate spatial autocorrelations in the error structure. However, this approach was not practical for this project due to both the time and complexity of the methodology and to the difficulties in implementing the resulting models into the Forests NSW GIS.

Last, but not least, is the issue of representativeness of the sample of compartments for the areas under consideration. The data was taken from the compartments harvested in the last three years. There is an assumption that this is a representative sample of the compartments in the whole of the region. The approach used in selecting compartments for inclusion in the project (stratification by slope and productivity class and allocation of the number of compartments being reflective of current and near-future harvesting conditions) would assist in addressing potential bias. Nonetheless, if these samples are atypical and are different to the rest of the area, then the estimates from this analysis could be biased. In addition, if there are changes to the rules applied or methods used for the harvesting, then that could further impact the accuracy of the estimates produced.

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