Australian Government
Department of Agriculture
ABARES

Improving Australia's forest area estimate using a Multiple Lines of Evidence approach

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Research by the Australian Bureau of Agricultural and Resource Economics and Sciences

Technical Report 13.07
November 2013

Cataloguing data
Mutendeudzi, M, Read, S, Howell, C, Davey, S & Clancy, T 2013, *Improving Australia's forest area estimate using a Multiple Lines of Evidence approach*, ABARES (Technical report 13.07), Canberra, November 2013.

ISSN: 189-3128
ISBN: 978-1-74323-160-9
ABARES project: 43453

Internet
Improving Australia's forest area estimate using a Multiple Lines of Evidence approach is available at: daff.gov.au/abares/publications.

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Acknowledgements
Work underpinning this technical report was funded by ABARES and is a culmination of the long-standing objective of the National Forest Inventory Steering Committee to improve Australia's forest-area estimate. The authors are grateful for the foresight, support and contribution of NFISC members.

The authors would also like to thank the following for guidance and technical advice in the development of the Multiple of Lines Evidence approach: Peter Scarth (Queensland Department of Science, Information, Technology, Innovation and the Arts), Leo Lymburner (Geoscience Australia), Juan Pablo Guerscham (CSIRO), Lucy Randall (ABARES), Darius Culvenor (CSIRO) and Shanti Reddy (Australian Government Department of the Environment).

Data provided by the following state and Australian government agencies enabled completion of this work: Australian Government Department of the Environment (National Vegetation Information System [NVIS] dataset, National Carbon Accounting System [NCAS] dataset and SPOT 5 imagery); Geoscience Australia (Dynamic Land Cover Mapping dataset); New South Wales Office of Environment and Heritage (NSW Statewide Landcover and Trees Study [SLATS] dataset) and Queensland Department of Science, Information, Technology, Innovation and the Arts (Qld Statewide Landcover and Trees Study [SLATS] dataset).

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Summary

The area of Australia's native forest, derived from a dataset compiled by the National Forest Inventory (NFI) and published in *Australia's State of the Forests Report* (SOFR) 2008, was estimated as 147 million hectares. However, a number of inaccuracies, particularly in the allocation of areas to forest or non-forest, have since become apparent in this estimate. The problems are highlighted by the fact that the National Carbon Accounting System (NCAS), which uses a similar forest definition to the NFI but different methodology, has a much lower forest area estimate of 108 million hectares. This large difference, and the uncertainty over time about Australia's actual forest cover, has implications for the credibility and applicability of the NFI's published national forest-cover statistics, and as a consequence the state and territory data from which the national figures are compiled. The spatial forest-cover layer derived from the NFI is particularly important as it forms the basis of many indicators in the SOFR.

ABARES has developed an innovative Multiple Lines of Evidence (MLE) approach to reduce uncertainty in Australia's native-forest cover. The approach examines suitable independent forest-cover datasets concurrently with an NFI dataset to identify areas of agreement and disagreement between the various datasets. Areas of disagreement highlight potential errors and are prioritised for validation, as a method of improving the veracity of the updated NFI forest-cover dataset. The MLE approach involves three stages:

- first, determining the areas of intersection (agreement) between an NFI dataset and external datasets and deciding an initial level of confidence in the NFI forest-cover dataset
- second, incorporating reliability scores for each external dataset and refining the level of confidence in the NFI forest-cover dataset, and
- third, validating the forest/non-forest status of areas where low confidence in the NFI forest-cover dataset allocation has been deduced. The outcome of the MLE process is an updated NFI forest-cover dataset.

The MLE approach showed highest confidence in the input datasets across closed forests and lowest confidence across woodland forests. Over time, the overall forest estimate can be continuously improved by implementing data-collection strategies that increase the reliability of datasets where confidence in the underlying data is lowest. In addition, the MLE approach could allow stratification of Australia's forest and non-forest areas according to the level of confidence associated with their attribution.

The MLE approach, whose development and implementation was supported by the National Forest Inventory Steering Committee (NFISC), does not eliminate or invalidate the need for the states and territories to continue providing forest-cover data to the NFI. Rather, the method facilitates harmonisation of the NFI forest-cover dataset with other key regional and national forest-cover datasets. The success and longevity of the MLE approach also depends on the continuation of programs that provide the required independent forest-cover datasets.

1 Introduction

Purpose

This technical report was written to:

- provide an overview of issues affecting the capacity of the NFI to develop a forest-cover dataset with sufficient robustness to allow the accurate national forest-cover assessments that are required for detection of forest-cover change over time
- outline the Multiple Lines of Evidence approach that ABARES, together with the National Forest Inventory Steering Committee, has developed to reduce the uncertainty associated with Australia's forest-cover estimates, and articulate the rationale for and benefits of the approach
- demonstrate implementation of the MLE approach by testing the veracity of the forest-cover data provided to the NFI for SOFR 2008 by three state agencies
- provide information to allow discussion and critical review of the MLE approach, including how it has been developed, how it could be improved in future, and possible implications for future Australian national forest-cover estimates when the MLE approach is implemented nationally
- underpin use of the MLE approach in Australia's State of the Forests Report 2013.

Background

The NFI, housed in ABARES, reports on Australia's forests every five years through *Australia's State of the Forests Report* (SOFR), to fulfil requirements of the National Forest Policy Statement and the *Regional Forest Agreement Act 2002*. The report provides critical scientific, economic and social information which underpins the development of evidence-based policies to improve the sustainability and profitability of Australia's forests and forest-based industries. Additionally, the SOFR is highly regarded as an authoritative source of forest information to inform public debate and industry investment, and to support Australia's international reporting requirements. With each successive report, there has been an expectation of increased capacity to report change across the range of indicators described in the SOFR's reporting framework.

One of the key objectives of the SOFR includes providing reliable area estimates of Australia's forest cover and trends over time. The area of forest cover by forest type and land tenure provides the footprint against which many other indicators of sustainable forest management are reported, including forest fragmentation, carbon stocks, forest-ecosystem services, forest production, forest-ecosystem health, and investment in forest management. Forest extent is also often used as a proxy for forest biodiversity—a reduction in forest cover is seen as a reduction in forest biodiversity and vice versa (Wilkinson 2006). However, these various uses of the forest-area indicator are appropriate only when the indicator is accurately and consistently measured across reporting periods.

The NFI has produced three forest-cover datasets (1998, 2003 and 2008), reported in the various SOFRs, which have shown large differences in Australia's forest cover (Table 1). These differences are attributable, primarily, to deficiencies in the data used to prepare the forest-cover datasets rather than real on-ground change, but have led to uncertainty about the actual extent of Australia's forest cover.

Table 1 Australia's forest cover as reported by the National Forest Inventory

Year	1998	2003	2008
Area of forest cover (millions of hectares)	156.9	164.3	149.2

Data published in: SOFR 1998, SOFR 2003 and SOFR 2008

A key concern for the NFI is that the 2008 figures in Table 1 could potentially be misinterpreted as representing clearing of Australia's forest cover since 2003, as discussed in the SOFR 2008 (pp. 9–11).

Under Australia's Constitution, the state and territory governments have control of land management and the collection of relevant land information, including for forests. NFI forest-cover datasets have relied largely on data provided by the relevant state and territory agencies for forest area and forest-type statistics and maps. Invariably, however, state and territory data are collected using inconsistent methods and scales across reporting timeframes, and across and within jurisdictions. Errors and their magnitude are often unknown, or are not provided with the data. Consequently, the NFI forest-cover datasets are unable to provide error estimates for the forest-area figures.

Supply of forest-cover data for each of the previous SOFRs was coordinated by the NFI and the NFISC. This committee has representatives from each of the eight states and territories. With the release of the first SOFR in 1998, the NFISC recognised the major weaknesses of the source data. As a consequence, the Continental Forest Monitoring Framework (CFMF) was designed to address these data deficiencies (Norman et al. 2003). However, the CFMF remains unfunded and has not been implemented.

The MLE concept was first presented to the NFISC at its 44th meeting (November 2010) where the committee supported and encouraged ABARES to pursue the methodology. Since then, ABARES has consulted peers from relevant state, territory and Australian government agencies and the CSIRO, on the concept, implementation and preliminary outputs of the MLE approach. NFISC members commented on a draft version of the MLE methodology report and their comments and recommendations are incorporated in this final report.

The MLE approach has therefore been developed, with the support of the NFISC, to address the issue of uncertainty associated with the pivotal SOFR forest-cover indicator. The MLE approach analyses a range of other national and sub-national (state/territory-wide) forest/tree-cover datasets to identify areas of agreement and disagreement with an NFI dataset. Through this approach, areas of complete data concordance can be identified and classified as having highly reliable forest-cover information. Conversely, areas of least data agreement can be identified and classified as areas where the NFI forest-cover data may be unreliable and require validation. This process will allow prioritisation of the validation work required, and efficient use of limited resources.

In the MLE approach, state and territory datasets supplied to the NFI are firstly compiled or integrated without any validation to produce a provisional NFI dataset. This provisional NFI dataset is then examined simultaneously with other independent national and sub-national datasets to identify potential errors in the provisional NFI dataset. The output, after validating the forest and non-forest status of areas suggested to be in error, is an updated NFI dataset. This process is repeated regularly as new state and territory datasets, and independent national and sub-national datasets become available, ensuring that the NFI dataset is continuously improved.

Forest-cover data from the states and territories will remain critical to the NFI and for the production of the SOFRs. The MLE approach does not intend to—and cannot—replace this important data source. Instead, the approach seeks to improve the reliability and robustness of the NFI forest-cover dataset derived from state and territory data by highlighting potential errors in the source data, and identifying validation priorities for improvement of the primary forest-cover information.

Further details of the MLE approach have been published in Mutendeudzi et al. (2013).

Rationale for MLE approach

The extent to which accurate and up-to-date information about forests is available provides a measure of the capacity to demonstrate sustainable forest management and the status and condition of Australia's forests. The NFI provides national and sub-national statistics on Australia's forests to support policy development, inform industry investment and public debate, and meet national and international reporting requirements. It does this through Australia's SOFR, produced every five years. However, there are several important issues that impact on the NFI's capacity to conduct rigorous forest-cover assessments. Most of the issues are articulated in detail in the CFMF report (Woods et al. 2006); a summary of these key issues is provided here.

The issues limiting the NFI's capacity to develop a stable and robust forest-cover dataset, and one capable of supporting forest-cover change analysis, can be characterised as:

Fitness for purpose

- The NFI is not funded to collect primary data on forest cover, extent and type. Rather, it relies mainly on data provided by relevant state and territory government agencies. Typically, native-forest-cover data are collected by agencies for their specific needs at the time and, rather than being state/territory-wide, often cover only certain tenures. Consequently, state and territory data are usually a mosaic of datasets consisting of data collected at inconsistent scales, from different sources (e. g. on-ground survey, aerial photography, remote sensing, etc.) and at different dates within and across jurisdictions.

- Furthermore, some jurisdictions provide the NFI with both tabular and spatial forest-cover data for the same extent of forest, yet the two datasets may differ. This data issue is often confounded when the supplying agency instructs that tabular data should be used for reporting the statistics and spatial data for map production.

- With the exception of Queensland and more recently New South Wales and Victoria, data collected by state and territory agencies have had a strong emphasis on mapping and describing vegetation boundaries but little, if any, emphasis on cover-change detection over time. Consequently the focus of most state and territory agencies has been to provide data for a state/territory-wide map of forest boundaries and forest descriptions. Subsequent improvements by data-collection agencies have focused on improving the scale of mapping rather than on mapping changes in forest cover and forest types.

Data gaps

- Large data gaps exist, particularly on leasehold and private forests (including Indigenous forests). These tenures collectively comprise in excess of 70 per cent of the total forest cover reported in SOFR 2008. With the exception of Tasmania, forests on private lands are often poorly mapped because state and territory agencies tend to focus on forests on publicly managed land.

- Gaps in forest-cover data are at times filled by sourcing data from Australian Government agencies, and research and industry institutions.

Diminishing resources

- Management agencies of public forests (conservation and production) are working in an environment of diminishing resources, frequent organisational restructures, and loss of expertise and corporate knowledge. These issues, the combined effect of which is a reduced capacity to contribute effectively to the NFI program, were raised in 2010 at the 44th NFISC meeting. The issues were also raised at the Forestry and Forest Products Committee Research Working Group 2 meeting (Mount Gambier, November 2010).

Data capture/collection design framework

- A national framework, such as the CFMF, to guide forest-cover data collection, could assist in improving the consistency of information supplied to the NFI. However, Victoria is the only jurisdiction to have adopted and implemented some of the forest-cover data collection principles espoused by the CFMF. Until the CFMF design and principles are widely adopted, the capacity of the NFI to produce consistent and comparable forest-cover statistics from disparate state and territory spatial data will remain limited.

Lack of validation

- In the past, the NFI has compiled the data provided by state and territory agencies with limited quality assurance or interrogation to determine data veracity. The lack of validation is largely attributable to the absence of, and cost of acquiring, appropriate and independent data to verify the state and territory agencies' data. Consequently, the nationally aggregated area statements presented in SOFRs have lacked statistical validity and error estimates. However, recent advances in geospatial technology and satellite data blending methodologies (Emelyanova et al. 2013) and the increasing diversity and availability of remote sensing technologies—high-resolution, multi-spectral, radar and Light Detection and Ranging (LiDAR)—available at low cost or free, present the NFI with an opportunity to reduce the uncertainty associated with Australia's forest-cover estimates for future forest reporting.

Data integration

- Historically, forest-cover mapping has involved human interpretation of aerial photography. Owing to high costs and lack of expertise, state and territory agencies are increasingly shifting towards automated and satellite-derived forest-cover products. However, integrating forest-cover mapping products derived from satellites with those derived through aerial photo-interpretation poses a number of challenges. For example, tree height, a key structural measure in the definition of forest, cannot be accurately determined from optical satellite data (e.g. Landsat and SPOT). Also, soil properties (e.g. colour and moisture) can affect tree-crown-cover densities calculated from optical satellite data. Therefore, a formal and transparent process is required to integrate land-based, aerial and satellite datasets on forest area.

2 Model concept

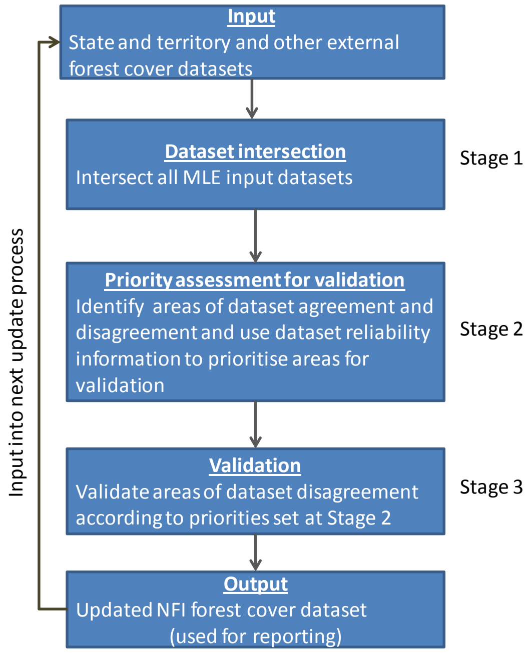
Using MLE to assess forest cover

ABARES, in consultation with the NFISC, has developed and tested use of the Multiple Lines of Evidence approach to reduce the uncertainty associated with Australia's forest-area estimates compiled by the NFI. In principle, the MLE approach combines any suitable, independent and external forest-cover datasets with a provisional NFI forest-cover dataset. Remotely sensed datasets derived from different sensors and using different methods are combined with the NFI dataset in this instance. The external datasets are examined concurrently with the NFI dataset derived from data provided by state and territory agencies, to identify areas where the datasets agree or disagree on the forest-cover status of an area. All the MLE datasets use a forest definition that is closely related to the one used by the NFI: an area dominated by usually single-stemmed trees (or eucalypt mallees) with actual or potential mature stand height of 2 metres or more, actual or potential mature overstorey crown cover of 20 per cent or more, no minimum patch size, and no restrictions on forest use. However, complete agreement of all datasets cannot be expected given that they are produced from different systems and mapping programs and for different purposes. Nevertheless, the MLE method allows the areas of dataset agreement and disagreement to be identified and prioritised for forest-cover validation.

Areas where all the examined datasets, including the NFI, agree are areas where users can have high confidence in the NFI dataset. Conversely, areas where all the datasets examined disagree with the NFI dataset are areas where users can have low confidence in the NFI dataset and are potential errors in the NFI dataset; these areas, which may be forest or non-forest, require validation work in order to improve the veracity of statistics derived from the dataset. Areas where some datasets agree with the NFI and some disagree with the NFI need further analysis through consideration of the reliability of individual datasets before a validation priority can be allocated.

The MLE process is summarised in Figure 1.

Figure 1 MLE summary diagram



Stage 1 of MLE: Intersection of suitable datasets

The first stage is spatial intersection of the multiple available datasets, and the identification of areas where the datasets agree or disagree on the forest-cover status. A colour-coded model for the area intersection is shown in Figure 2. Two external datasets plus the NFI dataset are used for simplicity in the illustration, although the same principle applies to intersecting the NFI with three or any other number of datasets. The summed footprint of all input datasets represents the total potential forest cover. The results from this stage of the MLE process can be grouped into three outcome categories, which represent three levels of confidence for the NFI allocation that can be deduced from the number of datasets in agreement with the NFI dataset:

- **Outcome 1**: High confidence areas where all the examined datasets, including the NFI, agree the areas are either forest or non-forest. Users can have high confidence in the NFI dataset for these areas.

- **Outcome 2**: Moderate confidence areas where some datasets agree and some disagree with the NFI. These are areas of moderate confidence in the NFI dataset. These areas need further analysis through consideration of the reliability of individual datasets.

- **Outcome 3**: Low confidence areas where all the examined datasets disagree with the NFI dataset. These are areas of potential error in the NFI dataset, where users may have low confidence in the NFI dataset, and where the NFI allocation as forest or non-forest requires validation.

In Table 2 the first set of three columns shows the matrix of possible attribute combinations when two datasets (Figure 2 – Dataset A and Dataset B) external to the NFI are available for the MLE approach. The second set of columns then shows how application of this first stage of the MLE approach can be used to deduce the varying levels of confidence in the NFI dataset across the area of interest, based solely on the number of datasets agreeing with the NFI dataset.

Stage 2 of MLE: Reliability and assessment of validation priority

The second stage allots each external dataset a weighting that measures its reliability, allocated solely for applying the MLE approach. It is important to note that the weighting does not reflect the reliability of the datasets with respect to the purposes for which they were developed. Forest and non-forest areas are randomly screen-digitised from high-resolution imagery (e.g. SPOT5) of a similar date-stamp to the datasets. These areas are then compared against the same areas in each candidate dataset. This allows candidate datasets to be given a single weighting from 1 to 5 depending on the area proportion of their cover classification that matched the classification derived from the SPOT5 imagery: high weighting values reflect high dataset reliability for the purposes of the MLE, and low weighting values reflect low dataset reliability for the purposes of the MLE.

The dataset reliability information captured in the weighting score is then used to assist in determining confidence in forest or non-forest allocations for areas where only some of the datasets external to the NFI agree with the NFI dataset. The third set of columns of Table 2 shows how incorporation of the assessed reliability for the MLE of external datasets given in Figure 2 (Dataset A and Dataset B) can be used to modify the levels of confidence attributed to areas in the NFI dataset. In this example, Dataset A has been allocated an arbitrary reliability weighting or value of 3 and Dataset B has been allocated an arbitrary reliability weighting or value of 1.

The validation priority for an area is set by the strength of the argument that the NFI dataset is wrong in regard to its forest/non-forest attribution for that area (Figure 3 and Table 2). Three validation priorities are identified: Low, Moderate and High. Areas where all input datasets agree with the NFI dataset, plus areas where datasets of high reliability agree with the NFI dataset, are regarded as being of high confidence for the NFI dataset and, therefore, having low validation priority. Conversely, areas where all datasets external to the NFI agree with each other but disagree with the NFI dataset, plus areas where datasets of high reliability disagree with the NFI dataset, are regarded as being of low confidence for the NFI dataset and, therefore, of high priority for validation.

Stage 3 of MLE: Validation

Stage 1 of the MLE approach assists with highlighting potential forest-cover errors that may warrant further investigation and Stage 2 assists with prioritising any required validation work. On-ground validation is expensive and often unfunded, yet is crucial to improving the reliability of, and confidence in, the NFI forest dataset. The ability to prioritise validation work is extremely important in order to optimise the use of limited resources. The MLE approach provides an objective, transparent and effective framework for prioritising validation.

The third column in Table 2 shows the forest-cover status in the input NFI dataset at the beginning of the MLE process. The last (eleventh) column in Table 2 shows how the forest-cover status of the same areas will be allocated in the MLE dataset after the validation process.

1. All areas of high validation priority (Table 2, Stage 2, column 3) are referred to the relevant state or territory agencies for validation. Where the agencies cannot validate the areas, ABARES uses the best available ancillary data to complete the validation.

2. Areas of moderate validation priority are also referred to state or territory agencies for validation. Where neither the agencies (state or territory) nor ABARES can perform the validation, the areas are allocated as stated in the right-hand side columns of Table 2.

3. Areas of low validation priority are not referred for validation since they are areas of highest confidence in the input NFI dataset. These areas are allocated the classification in the input NFI dataset.

The MLE approach uses desktop validation, involving appraisal of the NFI dataset against existing appropriate ancillary data. Validation is best performed by relevant state or territory agencies as they have better access to ancillary data and local knowledge. ABARES provides the agencies with GIS layers of polygon areas of potential forest-cover errors, stratified by the validation priority as derived in the section above and by National Vegetation Information System (NVIS) vegetation types. Agencies use local knowledge and a variety of data sources including aerial photos, high-resolution SPOT5 imagery and LiDAR to validate the forest-cover status of the polygon areas. Polygon areas are allocated the most appropriate category as follows:

- forest, if tree-crown cover is 20 per cent or greater, and actual or potential tree height is 2 metres or greater

- non-forest for all other areas.

SPOT5 is the fifth satellite in the SPOT series of satellites launched by CNES (Space Agency of France). The SPOT5 satellite produces both multi-spectral and panchromatic imagery. Combining the multi-spectral and panchromatic SPOT5 imagery allows production of high-resolution imagery (2.5–5 metres). This facilitates more accurate delineation of small patches of forest. SPOT5 imagery is therefore used as a reference for forest-cover classification data derived from medium-resolution and low-resolution satellite platforms such as Landsat and MODIS.

LiDAR data can be collected from airborne or spaceborne systems. State and territory agencies regularly collect airborne LiDAR data for a variety of purposes including forestry operations. Where available the agencies can use LiDAR data to determine whether the areas of potential forest-cover error conform to the forest definition with regards to tree-height and crown-cover thresholds. LiDAR data from the Ice Cloud and Land Elevation Satellite (ICESat) can also be used for this purpose with good accuracy (Scarth et al. 2010; Lee 2006), although the data points are much further apart that those collected from airborne LiDAR systems. NASA launched the Ice Cloud and Land Elevation Satellite (ICESat) with the Geoscience Laser Altimeter System (GLAS) in 2003 to collect information about the polar ice caps, global cloud cover, vegetation canopy, and other parameters of scientific interest.

Where state and territory agencies are unable to validate the areas of potential forest-cover error, ABARES may use a combination of high resolution SPOT5 (acquired by Department of the Environment to validate the NCAS Landsat products), Google Earth and Bing Maps imagery and ICESat data to complete the validation.

Summary of MLE

The complete MLE workflow, involving intersection of the provisional NFI and external datasets, reliability assessment, and desktop validation, is shown in Figure 3. The coloured oval on the top left of the diagram highlights how the provisional NFI dataset for input into the MLE approach is compiled. Previously, the output of this highlighted part of the diagram was the only basis for all subsequent forest-area statistics produced and reported by the NFI. In the MLE approach, however, the output of the highlighted part of the diagram (the provisional NFI dataset) is only one input into the process of determining Australia's forest-area statistics. As described in the sections above, the provisional NFI dataset is intersected with other suitable and independent datasets to generate three possible outcomes: Outcome 1, Outcome 2 and Outcome 3.

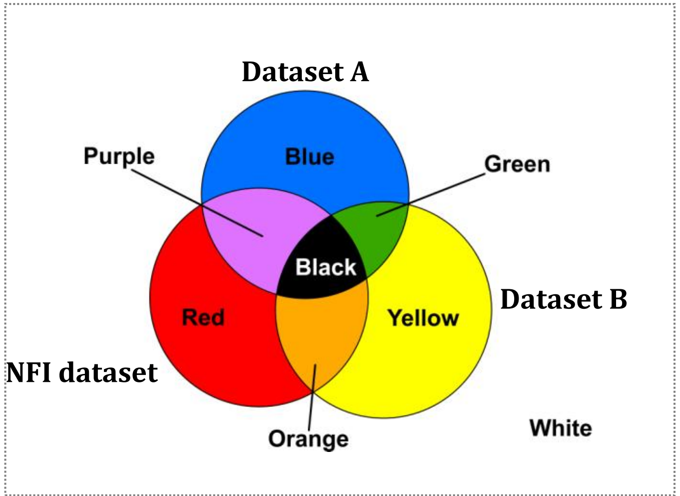
Validation is required for Outcome 2 and Outcome 3 areas. Figure 3 shows how the validation required is prioritised and Table 2 shows how dataset reliability information is incorporated to assist with this prioritisation. The output, after validating the forest and non-forest status of areas suggested to be in error, is an updated NFI dataset.

Figure 2 Conceptual model illustrating first stage of MLE approach: intersection of input data

The example shown intersects a provisional NFI dataset (Red, Purple, Orange and Black) with dataset A (Blue, Green, Purple and Black) and dataset B (Yellow, Green, Orange and Black). The same principle applies to intersecting the NFI with three or any other number of datasets.

Intersection

Total potential forest cover is the area covered by the summed footprint of all the input datasets



Outcomes

Outcome 1: High confidence in NFI dataset

Areas where forest cover status is supported by all three datasets:

- Black – all three datasets indicate forest
- White – all three datasets indicate non-forest

Outcome 2: Moderate confidence in NFI dataset

Areas where forest cover status is supported by NFI dataset and 1 other dataset:

- Purple – NFI dataset and Dataset A indicate forest
- Orange – NFI dataset and Dataset B indicate forest
- Blue – NFI dataset and Dataset B indicate non-forest
- Yellow – NFI dataset and Dataset A indicate non-forest

Outcome 3: Low confidence in NFI dataset

Areas where NFI dataset is not supported by any other dataset:

- Red – only NFI dataset indicates forest
- Green – only NFI dataset indicates non-forest

Figure 3 MLE approach flow diagram: intersection of provisional NFI and external datasets, reliability assessment, and desktop validation to produce updated NFI dataset

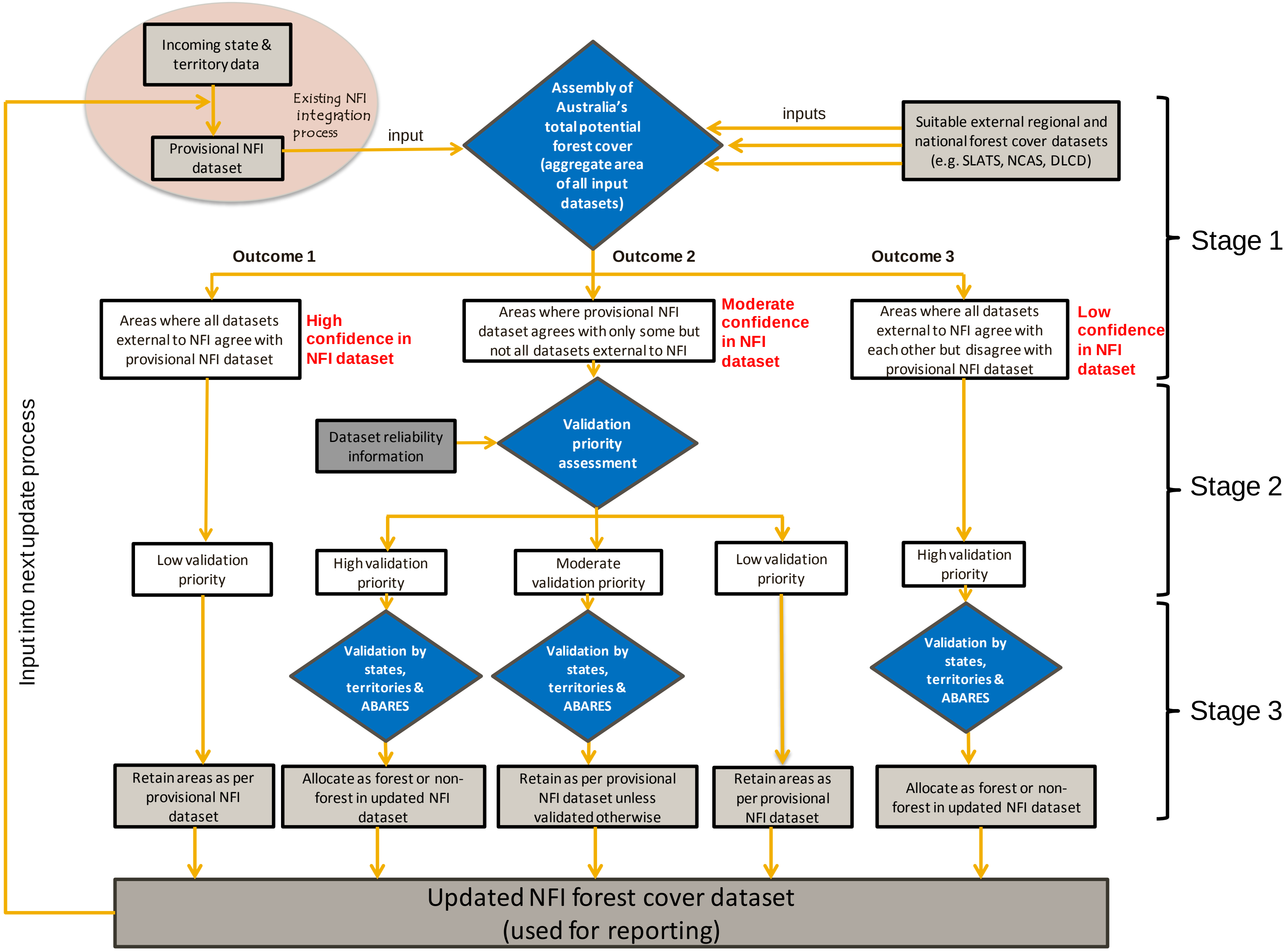


Table 2 Output matrix for MLE approach

This example results from the intersection of the provisional NFI dataset with two other datasets, as illustrated in Figure 2.

Input datasets: forest cover allocations			**Stage 1: Assessment based on number of datasets agreeing with provisional NFI dataset**				**Stage 2: Assessment incorporating dataset reliability values**			**Stage 3: Forest cover after MLE**
Datasets showing forest cover	Datasets showing non-forest cover	Forest cover status in provisional NFI dataset	Datasets agreeing with NFI dataset	Datasets disagreeing with NFI dataset	Outcome[1]	Deduced confidence in NFI dataset	Sum of weightings of datasets agreeing with NFI dataset	Deduced confidence in NFI dataset	Validation priority	Forest cover status in MLE dataset
–	N,D_A,D_B	Non-forest	2	0	1	High	4	High	Low	Non-forest
N	D_A,D_B	Forest	0	2	3	Low	0	Low	High	As per validation outcome
D_A	N,D_B	Non-forest	1	1	2	Moderate	1	Moderate	Moderate	Non-forest, unless validated differently
D_B	N,D_A	Non-forest	1	1	2	Moderate	3	Moderate	Low	Non-forest
N,D_A	D_B	Forest	1	1	2	Moderate	3	Moderate	High	As per validation outcome
N,D_B	D_A	Forest	1	1	2	Moderate	1	Moderate	Moderate	Non-forest, unless validated differently
D_A,D_B	N	Non-forest	0	2	3	Low	0	Low	High	As per validation outcome
N,D_A,D_B	–	Forest	2	0	1	High	4	High	Low	Forest

[1]Outcome: 1 = High confidence, 2 = Moderate confidence, 3 = Low confidence (Figure 2)

Note: Dataset codes (columns 1 and 2) used in this table are as described in Figure 2 where N = preliminary NFI Dataset, D_A = Dataset A and D_B = Dataset B.

Assumptions: Dataset A (D_A) has a reliability weighting or value of 3 and B (D_B) has a reliability weighting or value of 1.

3 Application of MLE

To demonstrate the implementation of the MLE, the method was applied in New South Wales (NSW), Queensland (Qld) and South Australia (SA) to highlight a variety of different and significant errors in the provisional NFI dataset. The three examples use, as input datasets, the NFI dataset published in SOFR 2008 for each jurisdiction and best-available external datasets of similar date or currency to identify and categorise areas of the NFI dataset into areas of forest-cover reliability or confidence.

In the New South Wales example, the MLE approach identifies significant errors in the NFI dataset mostly resulting from the use of old data that pre-dated land-use change from forest to agriculture. The Queensland example identifies significant errors in the NFI dataset mostly resulting from coarse-scale data that maps entire flood plains as forest when only a small percentage of the flood plain area is actually forest. In the South Australian example, the MLE approach identifies significant errors in the NFI dataset particularly where all woody vegetation in specific tenures, for example in national parks and other conservation reserves, is mapped as forest cover.

Description of MLE development input datasets

Appropriate candidate datasets for input into the MLE approach include a variety of national and sub-national (state/territory-wide) spatial forest-cover datasets. Datasets used in developing the MLE approach are listed in Table 3 and their details are provided below. More up-to-date datasets for all states and territories will be used when the method is implemented nationally for SOFR 2013.

Table 3 MLE development: input datasets

Dataset name and description	Dataset code	Responsible agency or organisation	Geographic coverage	Data date	Reference
National Forest Inventory (NFI)	N	NFI Steering Committee	National	2008	Montreal Process Implementation Group for Australia (2008)
Qld SLATS	W	Qld DSITIA	State of Qld	2008	Goulevitch et al. (2002)
NSW SLATS	W	NSW OEH	State of NSW	2008	NSW OEH (2008)
National Carbon Accounting System (NCAS)	A	Dept of the Environment	National	2006	Furby (2002); DCCEE (2011)
Dynamic Land Cover Mapping (DLCM)	D	Geoscience Australia	National	2008	Lymburner et al. (2010)

Note: Qld = Queensland; NSW = New South Wales; SLATS = State-wide Land-cover and Trees Study; OEH = New South Wales Government Office of Environment and Heritage; DSITIA = Queensland Government Department of Science, Information, Technology, Innovation and the Arts; Dept of the Environment = Australian Government Department of the Environment.

National Forest Inventory (NFI)

- The NFI dataset consists of a compilation of many historical (manually interpreted aerial photographs and historic maps) and contemporary (automatically classified satellite images) datasets obtained from many sources including state, territory and Australian government agencies, and research and industry bodies. In recent times, the state and territory forest cover datasets provided to the NFI have primarily been by-products of the National Vegetation Information System mapping program, with a primary focus on delineating vegetation floristic communities and less emphasis on structural attributes (crown cover and height) which are at the core of the forest definition used by the NFI. Often, the source datasets vary in scale (resolution), acquisition platform, age of data, attributes collected, and attribute classification. The NFI team endeavours to combine these best-available, albeit disparate, datasets to produce a seamless national dataset, but assumes that areas designated as forest by the providers of the datasets are correctly attributed and meet the NFI forest definition. The NFI forest-cover dataset developed for the SOFR 2008 was used in the MLE approach development, and incorporates about 30 different source datasets and was produced at 100 metres × 100 metres pixel resolution.

National Carbon Accounting System (NCAS)

- The NCAS dataset is produced from Landsat satellite Thematic Mapper ™ and Enhanced Thematic Mapper Plus (ETM+) images, and identifies woody vegetation of height or potential height greater than 2 metres, crown cover greater than 20 per cent, and a minimum patch size of 0.2 hectares (DCCEE 2011). The NCAS dataset is compiled from several time periods since 1972, and is produced at a 25 metres × 25 metres pixel resolution. This NCAS dataset was designed for national carbon accounting and monitoring changes in Kyoto-compliant forests over long time periods, and is updated using a consistent methodology and data source.

Statewide Landcover and Trees Study (SLATS): Qld and NSW

- The SLATS method calculates Foliage Projective Cover (FPC) values from Landsat satellite Thematic Mapper ™ and Enhanced Thematic Mapper Plus (ETM+) images. An empirically-derived relationship between FPC and crown-cover values (Scarth et al. 2008) is used to delineate the landscape into forest and non-forest areas based on a crown-cover threshold of 20 per cent. Both the Queensland and New South Wales SLATS datasets are produced and supplied at 25 metre × 25 metre pixel resolution and are supported by extensive on-ground validation (Goulevitch et al. 2002; NSW Office of Environment and Heritage 2008). The SLATS datasets were developed to support land-clearance legislation and monitoring of change, and are frequently updated using a consistent methodology and data source.

Dynamic Land Cover Mapping (DLCM)

- The DLCM dataset is produced from the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite. Long-term time series (2000–08) Enhanced Vegetation Index values are analysed, and pixels clustered based on their phenological and seasonal characteristics into International Organization for Standardization (ISO) classes. The tree-cover classes with crown cover 70–100 per cent (Closed), 30–70 per cent (Open), and 10–30 per cent (Sparse) are considered forest for the MLE approach, as their crown-cover ranges overlap with that of the NFI. The DLCM dataset is produced at a 250 metre × 250 metre pixel resolution. The DLCM dataset has a consistent treatment of the range of land-cover types, and is updated frequently.

In summary, all the MLE datasets use a forest definition that is consistent with the definition used by the NFI. However, differences include:

- NCAS, SLATS and DLCM datasets do not contain tree height as an attribute. The MLE approach therefore uses data from the NVIS to estimate tree height for areas identified as forest by these datasets. This facilitates the excision of areas where the estimated tree height is below the 2 metres specified in Australia's accepted definition of forest.

- Single-year SLATS and DLCM datasets do not record potential tree height and potential crown cover, which are part of the NFI forest definition. Previously forested areas recovering from fire events or drought are an example.

- DLCM dataset includes forest areas in the category 'Sparse Tree Cover' (crown-cover range 10–30 per cent), giving 10 per cent as the minimum crown-cover threshold for forest in this dataset.

- NCAS dataset specifies a minimum patch size of 0.2 hectares, and records observed cover rather than potential crown cover at maturity as specified in the accepted definition of forest.

Since different datasets are available for each state and territory, the MLE approach is run separately for each jurisdiction then aggregated nationally as required. The New South Wales SLATS and Queensland SLATS were allocated a weighting of 5, the NCAS dataset a weighting of 3, and the DLCM dataset a weighting of 1 by following the method described in Stage 2 of the MLE. However, it should be noted that these dataset weightings may change as the various datasets are updated.

The body of this report presents detailed interim results from the demonstration MLE application for New South Wales only; for Queensland and South Australia, examples of the most significant issues contributing to errors in the NFI 2008 dataset for these jurisdictions are provided. Detailed results for Queensland and South Australia are set out in Appendix A and Appendix B respectively. More up-to-date datasets for all states and territories will be used when the method is implemented nationally for SOFR 2013.

The results are presented as maps and tables showing areas of dataset agreement and disagreement. The table of results follows the same structure as the output matrix described in Table 2. Areas of highest confidence in the mapped forest cover are the areas where all datasets external to the NFI concur with the NFI dataset. Conversely, areas of lowest confidence in the mapped cover are the areas where all the datasets external to the NFI disagree with the NFI dataset.

Interim results for New South Wales

The following datasets, described earlier in this section of the report, were analysed to demonstrate the implementation of the MLE method in New South Wales:

- National Forest Inventory Dataset (NFI)

- New South Wales SLATS (NSW SLATS)

- National Carbon Accounting System (NCAS)

- Dynamic Land Cover Dataset (DLCM).

Table 4 presents area results from the spatial union of New South Wales input datasets across the various possible combinations of dataset agreement and disagreement, then incorporates reliability values for the various datasets to deduce the confidence in the NFI 2008 dataset and validation priorities for these areas.

Together, the four datasets indicate a combined mapped forest area (footprint) of 43.01 million hectares, which therefore defines the total potential forest cover for New South Wales (Table 4, sum of lines 1–16). Of this area, the NFI dataset identifies 26.51 million hectares as forest (sum of lines 2, 9–14 and 16). However, only 12.70 million hectares (48 per cent of the NFI area) is deemed forest by all four datasets (line 16).

About 3.62 million hectares of New South Wales are identified as forest by the NFI dataset only, but non-forest by the other three datasets (Table 4, line 1). Confidence in the NFI dataset for these areas is considered low; they are therefore allocated a high priority for validation. The areas will be referred to the appropriate New South Wales agencies for validation. The high priority for validation allocation is supported by high-resolution imagery (SPOT5, Bing Maps and Google Maps) which indicate very little or no tree cover, confirming that these areas may have been incorrectly classified in the NFI dataset.

A combined area of about 14.75 million hectares identified as non-forest by the NFI dataset is deemed forest cover by at least one but not all of the other three datasets (Table 4, lines 3–8). However, 8.92 million hectares of this area is identified as forest cover by the DLCM dataset only (line 3), which is considered the least reliable (for this purpose) of the three datasets external to the NFI and which therefore has the lowest weighting. Evidence of misclassification of the NFI dataset from the high-resolution imagery for this area is not strong, and consequently this area is considered a low priority for validation. A further 0.33 million hectares identified as forest only by the NCAS dataset (line 5) is also considered low validation priority. However, the 2.29 million hectares identified as forest by the NSW SLATS dataset only (line 4) is rated as a moderate validation priority because this dataset is assessed to be of high reliability (for this purpose) and given a high weighting.

Conversely, an area of 1.75 million hectares (Table 4, line 15) is identified as forest by the other three datasets but as non-forest by the NFI dataset. Confidence in the NFI dataset for these areas is considered low; they are therefore allocated a high priority for validation and will be referred to the appropriate New South Wales agencies for validation. The high-priority allocation is supported by high-resolution imagery (SPOT5, Bing Maps and Google Maps) which indicate the presence of dense tree cover, confirming that these areas may have been incorrectly classified in the NFI dataset.

Table 4 Output matrix from application of MLE approach to New South Wales

Line	Datasets showing forest cover	Datasets indicating non-forest cover	Forest cover status in NFI dataset	Area (million hectares)	Sum of weightings of datasets agreeing with NFI dataset	Deduced confidence in NFI dataset	Validation priority
1	–	NAWD	Non-forest	–	9	High	Low
2	N	AWD	Forest	3.62	0	Low	High
3	D	AWN	Non-forest	8.92	8	High	Low
4	W	ADN	Non-forest	2.29	4	Moderate	Moderate
5	A	WDN	Non-forest	0.33	6	High	Low
6	AW	DN	Non-forest	0.89	1	Low	High
7	AD	WN	Non-forest	0.33	5	Moderate	Moderate
8	WD	AN	Non-forest	1.99	3	Moderate	Moderate
9	ND	AW	Forest	1.61	1	Low	High
10	NW	AD	Forest	2.55	5	Moderate	Moderate
11	NA	WD	Forest	0.31	3	Moderate	Moderate
12	NWD	A	Forest	2.02	6	High	Low
13	NAD	W	Forest	0.34	4	Moderate	Moderate
14	NAW	D	Forest	3.36	8	High	Low
15	AWD	N	Non-forest	1.75	0	Low	High
16	NAWD	–	Forest	12.70	9	High	Low
	Total potential forest cover (summed footprint of all datasets)			43.01			
	Total NFI forest cover			26.51			

Note: Dataset codes are as described in first and second columns of Table 3: N = National Forest Inventory (NFI); D = Dynamic Land Cover Mapping (DLCM); A = National Carbon Accounting System (NCAS); W = NSW SLATS

Data source: ABARES 2013

Confidence in forest and non-forest allocations in New South Wales areas within and outside the NFI forest 2008 dataset is summarised in Table 5.

Table 5 Assessment of forest and non-forest areas in New South Wales using MLE approach

	Area (million hectares)			
	Total	**High confidence in NFI allocation**	**Moderate confidence in NFI allocation**	**Low confidence in NFI allocation**
NFI dataset indicates forest	26.51	18.08 a	3.20 b	5.23 c
NFI dataset indicates non-forest; at least one other dataset indicates forest	16.50	9.25 c	4.61 b	2.64 a
Total potential forest cover (summed footprint of all datasets)	43.01			
Sum of areas indicated as a	20.72	MLE approach suggests this to be forest		
Sum of areas indicated as b	7.81	MLE approach is uncertain if this is forest or non-forest		
Sum of areas indicated as c	14.48	MLE approach suggests this to be non-forest		
Total potential forest cover(summed footprint of all datasets)	43.01			

Data source: ABARES 2013

There is, therefore, high confidence in the forest allocation for 68 per cent (18.08 million hectares) of the 26.51 million hectares considered forest by the NFI 2008 dataset in New South Wales. Conversely, there is low confidence in the NFI non-forest allocation for 2.64 million hectares of the area for which at least one of NCAS, NSW SLATS and DLCM indicate forest. Taken together, this gives a total of 20.72 million hectares in New South Wales that the MLE approach indicates with high confidence is forest.

Confidence in the NFI dataset is rated moderate across about 12 per cent (3.20 million hectares) of the area the NFI classifies as forest. In addition, 4.61 million hectares that the NFI considers non-forest is considered forest by some of the datasets external to the NFI, but with only moderate confidence that it is forest. Taken together, this constitutes a total of 7.81 million hectares in New South Wales which the MLE approach indicates could be forest but with only moderate confidence, and which requires further investigation and validation.

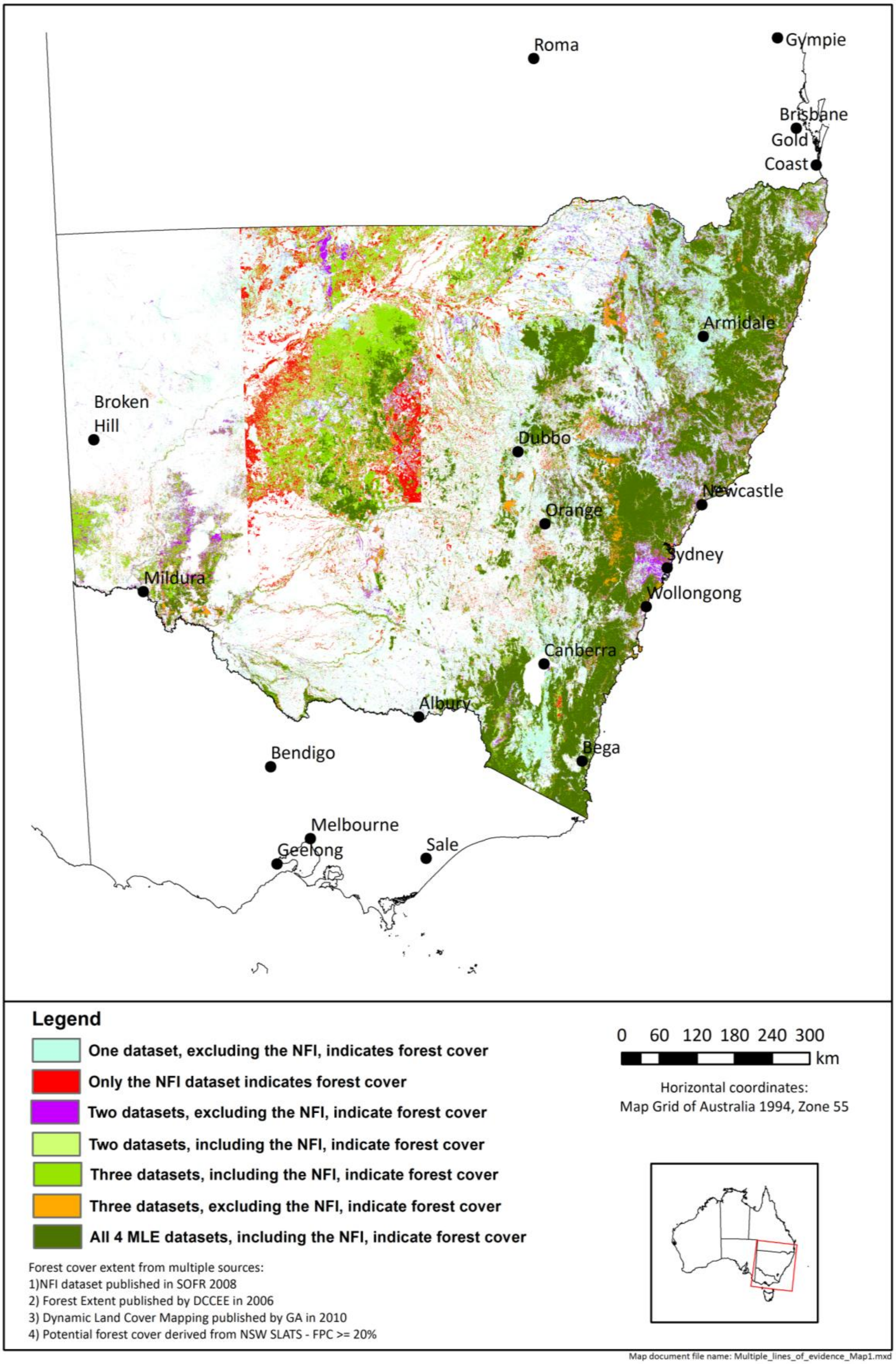
Lastly, there is high confidence in the non-forest allocation of 9.25 million hectares identified as such in the NFI 2008 dataset, even though it is considered forest by at least one of DLCM or NCAS (but not NSW SLATS, which has high reliability). Conversely, there is low confidence in the NFI dataset for 20 per cent (5.23 million hectares) of the 26.51 million hectares that the dataset considers forest. This gives a total of 14.48 million hectares within the total potential New South Wales forest cover that the MLE approach suggests with high confidence is not forest.

The MLE approach therefore indicates a forest area for New South Wales of between 20.72 million hectares (high-confidence forest) and 20.72 + 7.81 = 28.53 million hectares (high-confidence and moderate-confidence forest). Support from appropriate state agencies and additional ancillary data are required to investigate the 5.23 million hectares of low-confidence forest areas in the NFI dataset. Various areas classified as moderate-confidence forest and prioritised for validation also need assessment in order to arrive at a robust single value for the total area of forest in New South Wales.

The geographical distribution of the MLE output for New South Wales is shown in Map 1. Complete dataset agreement (dark green areas) occurs mostly along the coast and tablelands, where forests are taller, crown cover denser and rainfall relatively high. The 3.62 million hectares where only the NFI dataset indicates forest (red areas on the map) are localised in inland central New South Wales, with much of this allocation based on older and low-resolution vegetation mapping. SPOT5 satellite images in this area reveal very little tree cover. An example of such an area is shown in Map 2. After validation, these potentially non-forest areas may be reported as non-forest, together with other categories where the NFI allocation of forest is not confirmed.

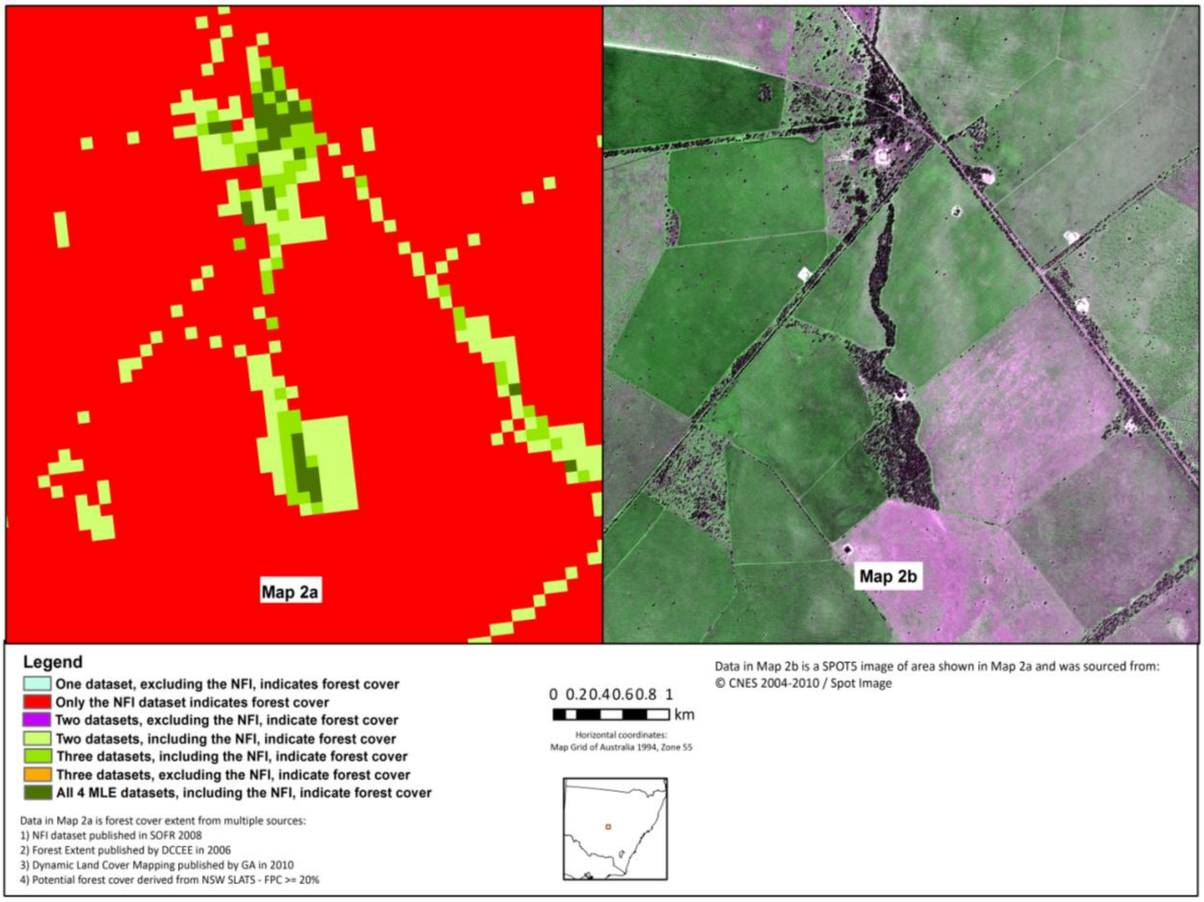
Areas (1.75 million hectares in total) where only the NFI dataset indicates non-forest while the other three datasets indicate forest (orange on Map 1) are scattered through the tableland and inland hill country of New South Wales. SPOT5 satellite images of such areas shows the presence of dense tree cover. An example of such an area is shown in Map 3. The areas will be referred to the appropriate New South Wales agencies for validation. After validation, these potentially forested areas may be reported as forest, together with other areas where the NFI allocation of non-forest is not confirmed.

Map 1 Location and distribution of MLE analysis output for New South Wales



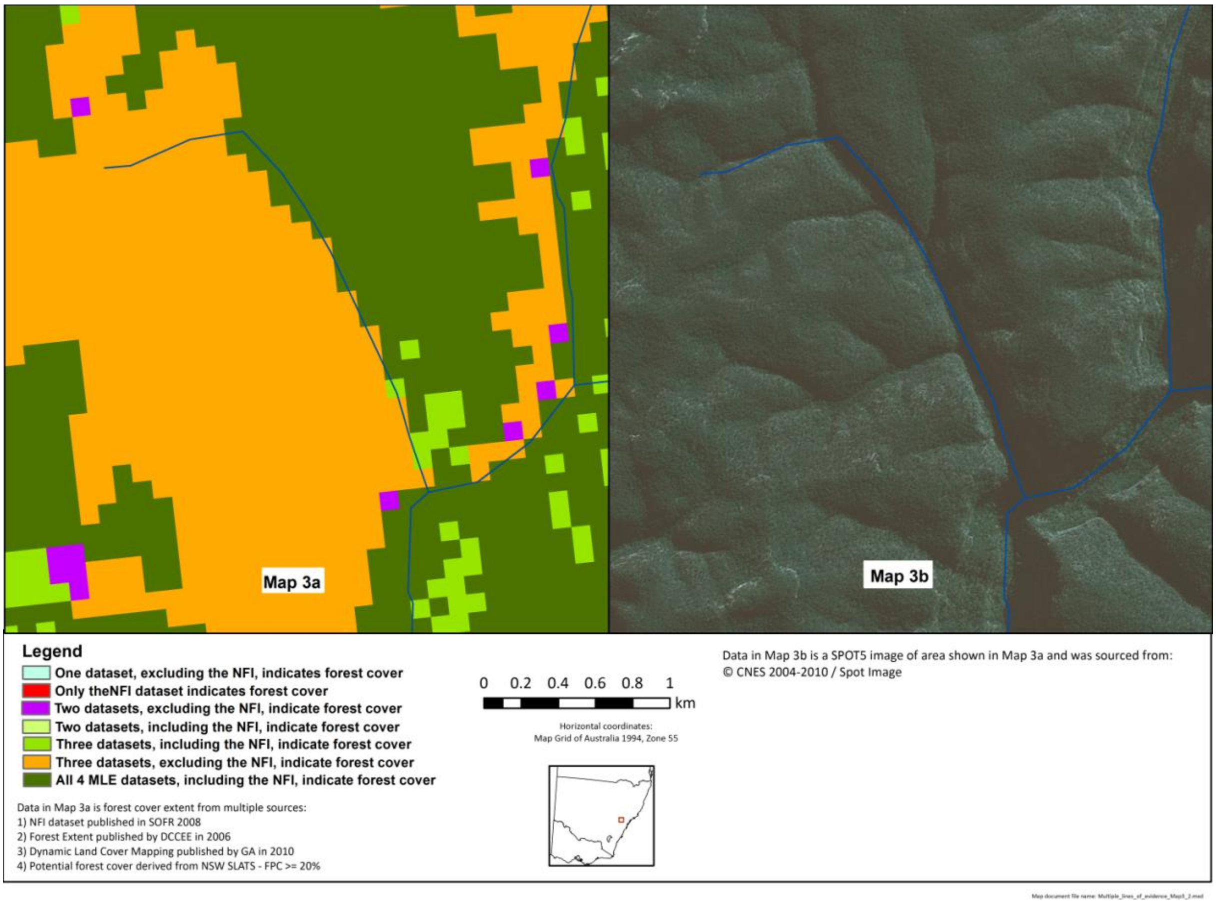
Map 2 Example area from New South Wales

Left image (Map 2a) shows an example area in New South Wales where 'Only the NFI dataset indicates forest cover'; other MLE datasets indicate non-forest. This area is a candidate for re-allocation as non-forest in the NFI dataset. Right image (Map 2b) shows exactly the same area in a SPOT5 satellite image.



Map 3 Example area from New South Wales

Left image (Map 3a) shows an example area in New South Wales where 'Three datasets, excluding the NFI, indicate forest cover' and the NFI dataset indicates non-forest. This area is a candidate for re-allocation as forest in the NFI dataset. Right image (Map 3b) shows exactly the same area in a SPOT5 satellite image.



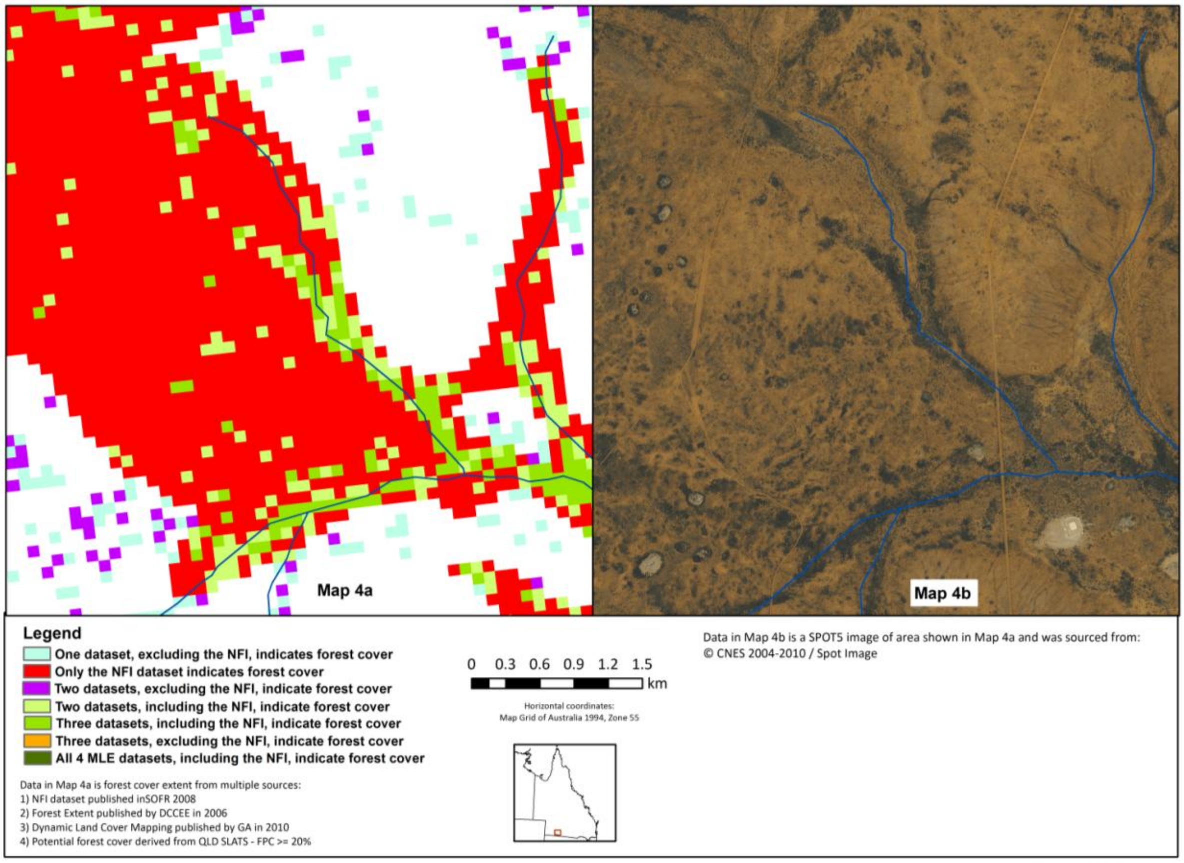
Examples from Queensland and South Australia

In Queensland the MLE identified 4.82 million hectares considered as forest by the NFI 2008 dataset, but non-forest by the other three datasets analysed using the MLE approach. In this state the MLE approach found that the use of coarse-scale data which mapped entire flood plains as forest when only a small percentage of the floodplain area is actually forest contributed significantly to the NFI 2008 dataset errors (Map 4). The MLE approach therefore has low confidence in forest-cover status of these areas as allocated in the NFI 2008 dataset.

Detailed results for Queensland are presented in Appendix A.

Map 4 Example area from Queensland

Left image (Map 4a) shows an example area in Queensland where 'Only the NFI dataset indicates forest cover'; other MLE datasets indicate non-forest. This is a candidate area for re-allocation as non-forest in the NFI dataset. Right image (Map 4b) shows exactly the same area in a SPOT5 satellite image.

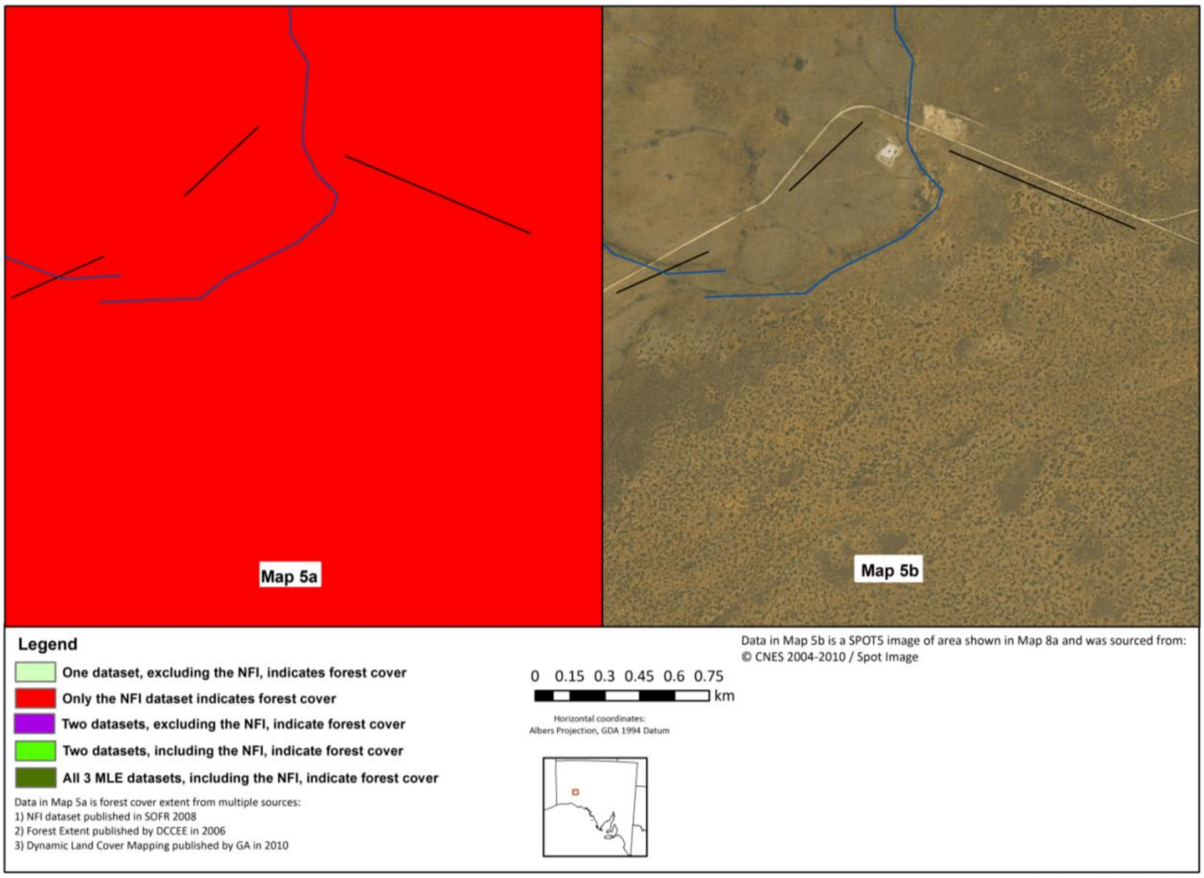


In South Australia the MLE identified 5.64 million hectares considered as forest by the NFI 2008 dataset but non-forest by the other two datasets analysed using the MLE approach. The MLE approach identified that the allocation as forest cover of woody areas with tree-crown cover below the 20 per cent threshold, as required by the forest definition, contributed most significantly to the errors in the NFI dataset in this state (Map 5). Most such errors appear to be tenure related, with all the land area within a national park, for example, being classified as forest cover. The large straight-edged blocks of land where 'Only the NFI dataset indicates forest cover' in Map 8 (Appendix B) in western parts of South Australia are a good example of this error. The MLE has low confidence in the forest-cover status allocated in the NFI 2008 dataset for these areas.

Detailed results for South Australia are presented in Appendix B.

Map 5 Example area from South Australia

Left image (Map 5a) shows an example area in South Australia where 'Only the NFI dataset indicates forest cover'; other MLE datasets indicate non-forest. This is a candidate area for re-allocation as non-forest in the NFI dataset. Right image (Map 5b) shows exactly the same area in a SPOT5 satellite image.



4 Discussion

The MLE concept was first presented to and received support from the NFISC at its 44th meeting (November 2010). Since then, the concept, implementation and preliminary outputs have been discussed with peers from all states and territories, as well as Geoscience Australia, the CSIRO, and the Australian Government Department of the Environment. The approach is being used in collaboration with agencies in all states and territories to refine Australia's forest-cover estimates, for compilation and reporting in Australia's State of the Forest Report 2013.

The MLE approach to improving the estimate of Australia's forest cover uses a range of remotely sensed national or state/territory-wide forest or tree-cover datasets, and compares these to a provisional NFI dataset. The MLE analysis involves first intersecting the various datasets to determine areas of overlap (agreement), then incorporating reliability (weighting) scores for each external (non-NFI) dataset, to give a deduced level of confidence in the allocation by the NFI of areas as forest or non-forest. The final stage in the MLE approach is validating the forest-cover status of areas where there is low or moderate confidence in the provisional NFI dataset.

Results of applying the MLE approach to New South Wales, Queensland and South Australia show a large scale of uncertainty in the extent of mapped forest cover in these jurisdictions. Across these three states the MLE approach indicates low confidence in the forest-cover status of 15.6 million hectares (18 per cent) of the area recorded as forest by the NFI 2008 dataset. In addition, there is another 12.4 million hectares across these three states recorded as non-forest by the NFI 2008 dataset in which the MLE has low confidence. High-resolution imagery from various sources indicates potential misclassification of the forest-cover status of these areas in the NFI 2008 dataset. Nationally, the total area where forest-cover status may have been misrepresented in the NFI 2008 forest-cover dataset is expected to be higher when the remaining five jurisdictions are included: some states and/or territories will have little change to forest areas, while some may increase and others decrease.

Results from New South Wales, Queensland and South Australia show highest confidence or agreement among the input datasets across closed forests, and lowest confidence across woodland forests. The MLE process would allow Australia's forest estate to be stratified and forest-area estimates to be reported in a way that reflects the level of confidence associated with the underlying data. Over time, the overall forest estimate can be improved by implementing data-collection strategies that increase the reliability of datasets where confidence in the underlying data is lowest.

The NCAS and DLCM datasets add considerable value to the MLE approach in improving Australia's forest-cover estimate; however, they are not individually appropriate for deriving Australia's forest extent as required for SOFR and other reporting. The NCAS dataset was developed for carbon accounting purposes and focuses on tracking woody cover change, not measuring forest area accurately. It also includes tall shrublands that do not meet the NFI's definition of forest. In addition, the NCAS dataset significantly under-represents woodland forest types (Montreal Process Implementation Group for Australia 2008). The DLCM is a coarse-scale dataset developed for tracking land-cover dynamics, particularly in response to natural disturbances including drought, fire, floods, cyclones and land clearing. The dataset includes all types of vegetation, and the tree-cover classes it uses, based on the International Standards Organization land-cover classification system, do not align well with the definition of forest accepted nationally and used by the NFI. Specifically, the DLCM dataset specifies 10–30 per cent crown cover for woodland forests, the lower end of which is significantly below the minimum of forest crown-cover value of 20 per cent used in the national forest definition. Consequently, the DLCM dataset significantly over-estimates woodland forest area. Future improvements to the DLCM may involve linking the dataset's tree-cover classes to a continuous scale (0–100 per cent) of Foliage Projective Cover (FPC) values, as is the case with the Qld SLATS and NSW SLATS datasets, to add flexibility in selecting tree crown-cover values that may meet the national forest definition use in the NFI (pers. comm. 2012, Leo Lymburner [Geoscience Australia]).

A Continental Forest Monitoring Framework would offer the advantage of being supported by regularly measured field plots and high-resolution satellite images of plots, allowing calculation of statistical reliability measures such as the standard error and relative standard error of forest cover. However, the costs associated with a CFMF would be significantly higher than for implementing the MLE. The CFMF would require regular fieldwork, development of reliable and efficient forest-cover classification algorithms applicable to remotely sensed images across Australia, purchase of high-resolution imagery, acquisition and maintenance of comprehensive computing infrastructure, and significant data-management overheads.

5 Conclusion

In the absence of a Continental Forest Monitoring Framework, veracity of Australia's forest-cover statistics can be improved by using the MLE approach. This approach is a transparent and cost-effective alternative for identifying and reducing potential errors in the NFI forest-cover dataset, subject only to resources being available within the NFI for analysis of high-resolution imagery (currently freely available). The MLE approach allows Australia's forest extent to be reported as a single best-available figure, reducing variability due to differences in measurement techniques and datasets, and may potentially enable monitoring and reporting of trends in the area of Australia's forest cover over time.

The MLE approach also enables objective prioritisation of validation work that will further reduce the uncertainty in Australia's forest-cover estimates. It provides the first opportunity to map the geographic distribution of areas of high and low confidence in the NFI forest-cover dataset, leading to a better understanding of the relationships between dataset confidence and forest-cover classes (closed forest, open forest, woodland forest), forest type and land tenure, and recognising the relatively large area of forest that falls close to boundaries separating woodland forest from open woodland (classified as non-forest), or close to the boundaries separating low forest from tall shrubland (classified as non-forest). The MLE approach also offers the NFI scope to allow meaningful analysis of forest-cover trends over time through examining and validating areas where land-cover change is detected in input datasets such as NCAS, DLCM and SLATS which present data in a consistent manner over time, especially if a SPOT5 archive containing a time-series of SPOT5 data becomes available.

The MLE approach compares datasets that have different emphases (floristics for most state and territory datasets, versus structural for most of the independent remotely-sensed datasets). Differences will, therefore, not always be errors but result from the different natures and functions of the datasets. Agreement on forest-cover status among the MLE-input datasets is greatest in taller and wetter forests, where tree-crown cover is well above the 20 per cent threshold. Least agreement occurs in inland woodland forests where the effects of drought and fire can readily bring crown cover temporarily below the 20 per cent threshold, and where the distribution of trees is uneven and patchy. Inclusion of a minimum patch size by the mapping program (e.g. for Landsat data) can exacerbate differences in these drier landscapes.

Forest-cover data from the states and territories will remain critical and central to the NFI. Success and longevity of the MLE approach are also dependent on the continuation of programs such as Qld SLATS, NSW SLATS, NCAS and DLCM that provide the required independent forest-cover datasets. The MLE approach efficiently builds on these data sources, seeking to improve the reliability and robustness of the updated NFI dataset by identifying potential errors in the source data, and allocating validation priorities for improvement of the primary information. The approach therefore facilitates harmonisation of the updated NFI forest-cover dataset with other key regional and national forest-cover datasets.

Overall, the innovative MLE approach to determining Australia's forest cover should lead to improved credibility of Australia's forest-cover statistics produced by the NFI and ensure that Australia maintains the capacity to produce accurate and reliable forest-cover information to meet its national and international reporting obligations.

Appendix A: Table and map results for Queensland

Table 6 presents area results from intersecting the Queensland forest-cover datasets across the various possible combinations of dataset agreement and disagreement, then incorporates reliability values for the various datasets, to deduce the confidence in the NFI 2008 dataset and validation priorities for these areas.

Table 7 summarises the assessment of confidence of forest and non-forest allocations for areas inside and outside the NFI 2008 forest-cover dataset for Queensland.

Map 6 shows the geographical distribution of the MLE approach output for Queensland.

Map 7 shows an example of an area with tree cover identified as non-forest in the NFI 2008 dataset but considered as forest cover by the other three Queensland MLE datasets.

Table 6 Queensland MLE output matrix

Line	Datasets showing forest cover	Datasets indicating non-forest cover	Forest cover status in NFI dataset	Area (million hectares)	Sum of weightings of datasets agreeing with NFI dataset	Deduced confidence in NFI dataset	Validation priority
1	–	NAWD	Non-forest	–	9	High	Low
2	N	AWD	Forest	2.32	0	Low	High
3	D	AWN	Non-forest	13.35	8	High	Low
4	W	ADN	Non-forest	13.97	4	Moderate	Moderate
5	A	WDN	Non-forest	0.60	6	High	Low
6	AW	DN	Non-forest	3.42	1	Low	High
7	AD	WN	Non-forest	0.33	5	Moderate	Moderate
8	WD	AN	Non-Forest	11.89	3	Moderate	Moderate
9	ND	AW	Forest	2.50	1	Low	High
10	NW	AD	Forest	2.95	5	Moderate	Moderate
11	NA	WD	Forest	0.12	3	Moderate	Moderate
12	NWD	A	Forest	16.83	6	High	Low
13	NAD	W	Forest	0.26	4	Moderate	Moderate
14	NAW	DN	Forest	2.16	8	High	Low
15	AWD	N	Non-forest	5.93	0	Low	High
16	NAWD	–	Forest	25.69	9	High	Low
17	Total NFI forest cover			52.82			
18	Total potential forest cover (summed footprint of all datasets)			102.29			

Note: Dataset codes are as described in first and second columns of Table 3 where: N = National Forest Inventory (NFI); D = Dynamic Land Cover Mapping (DLCM); A = National Carbon Accounting System (NCAS); W = Qld SLATS

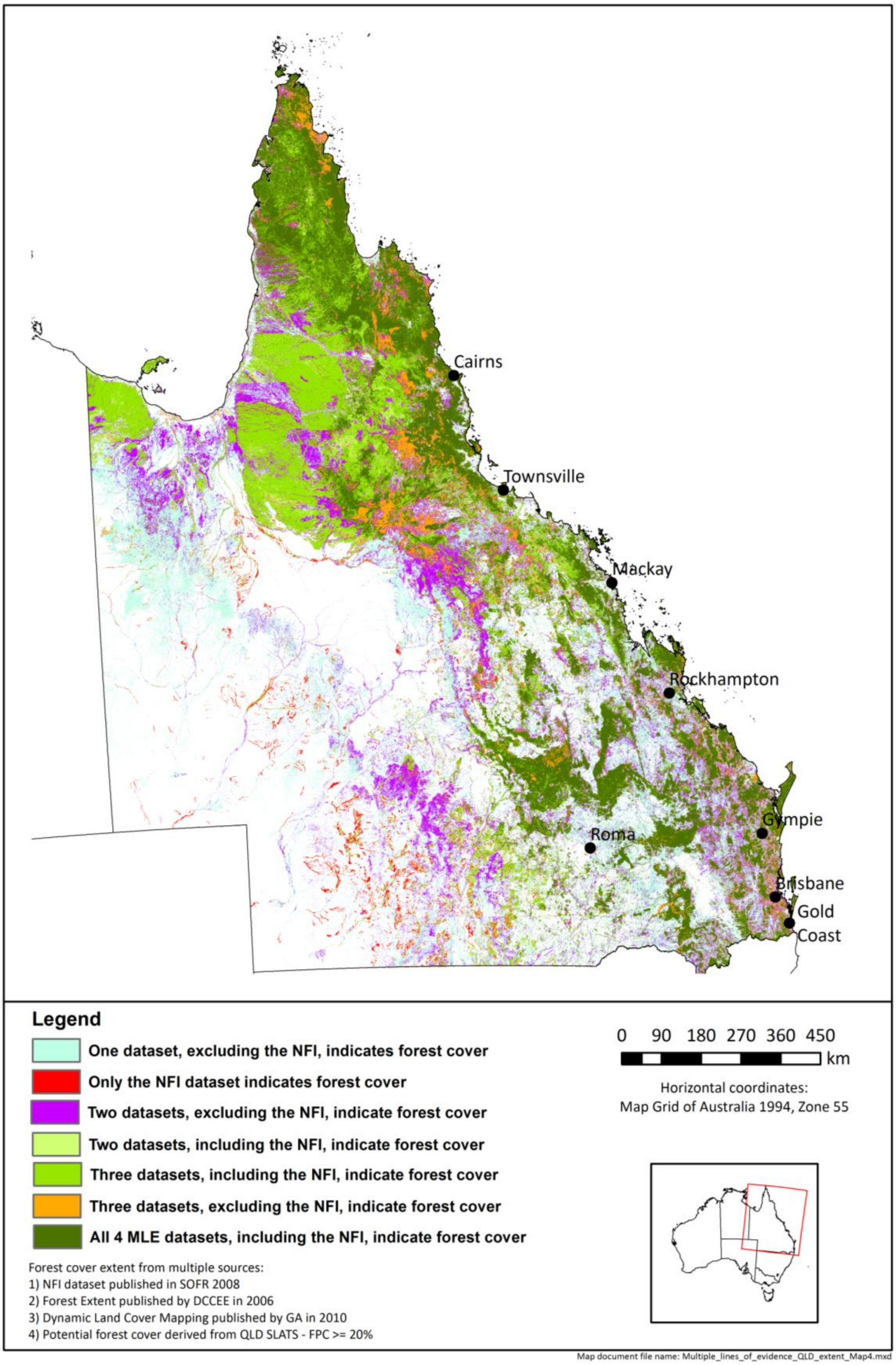
Data source: ABARES 2013

Table 7 Assessment of forest and non-forest areas in Queensland using MLE approach

	Area (million hectares)			
	Total	**High confidence in NFI allocation**	**Moderate confidence in NFI allocation**	**Low confidence in NFI allocation**
NFI dataset indicates forest	52.82	44.67 a	3.33 b	4.82 c
NFI dataset indicates non-forest; at least one other dataset indicates forest	49.47	13.95 c	26.18 b	9.35 a
Total potential forest cover (summed footprint of all datasets)	102.29			
Sum of areas indicated as a	54.02	MLE approach suggests this to be forest		
Sum of areas indicated as b	29.51	MLE approach is uncertain if this is forest or non-forest		
Sum of areas indicated as c	18.77	MLE approach suggests this to be non-forest		
Total potential forest cover (summed footprint of all datasets)	102.29			

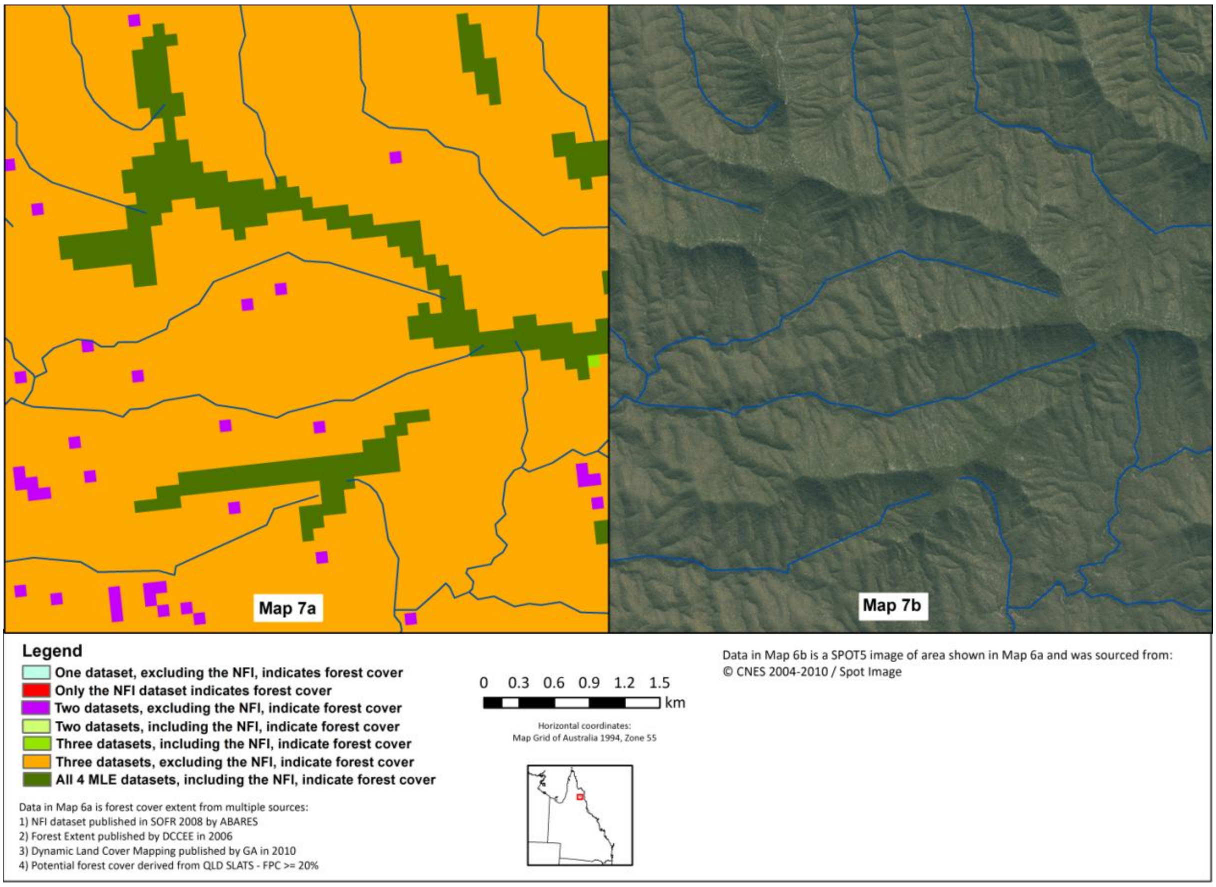
Data source: ABARES 2013

Map 6 Location and distribution of MLE analysis output for Queensland



Map 7 Example area from Queensland

Left image (Map 7a) shows an example area in Queensland where 'Three datasets, excluding the NFI, indicate forest cover'; the NFI dataset indicates non-forest. This is a candidate area for re-allocation as forest in the NFI dataset. Right image (Map 7b) shows exactly the same area in a SPOT5 satellite image.



Appendix B: Table and map results for South Australia

Table 8 presents area results from intersection of the South Australia forest-cover datasets across the various possible combinations of dataset agreement and disagreement, then incorporates reliability values for the various datasets, to deduce the confidence in the NFI 2008 dataset and validation priorities for these areas.

Table 9 summarises the assessment of confidence of forest and non-forest allocations for areas inside and outside the NFI 2008 forest-cover dataset for South Australia.

Map 8 shows the geographical distribution of the MLE approach output for South Australia.

Map 9 shows an example of where areas with tree cover are identified as non-forest in the NFI 2008 dataset but are considered as forest cover by the other two South Australia MLE datasets.

Table 8 South Australia MLE output matrix

Line	Datasets showing forest cover	Datasets indicating non-forest cover	Forest cover status in NFI dataset	Area (million hectares)	Sum of weightings of datasets agreeing with NFI dataset	Deduced confidence in NFI dataset	Validation priority
1	–	NAD	Non-forest	–	4	High	Low
2	N	AD	Forest	5.64	0	Low	High
3	A	ND	Non-forest	0.84	1	Moderate	Moderate
4	D	NA	Non-forest	1.97	3	Moderate	Moderate
5	NA	D	Forest	1.76	3	Moderate	Moderate
6	ND	A	Forest	0.38	1	Moderate	Moderate
7	AD	N	Non-forest	0.45	0	Low	High
8	NAD	–	Forest	1.23	4	High	High
9	Total NFI forest cover			12.28			
10	Total potential forest cover (summed footprint of all datasets)			9.02			

Note: Dataset codes are as described in first and second columns of Table 3 where: N = National Forest Inventory (NFI); D = Dynamic Land Cover Mapping (DLCM); A = National Carbon Accounting System (NCAS)

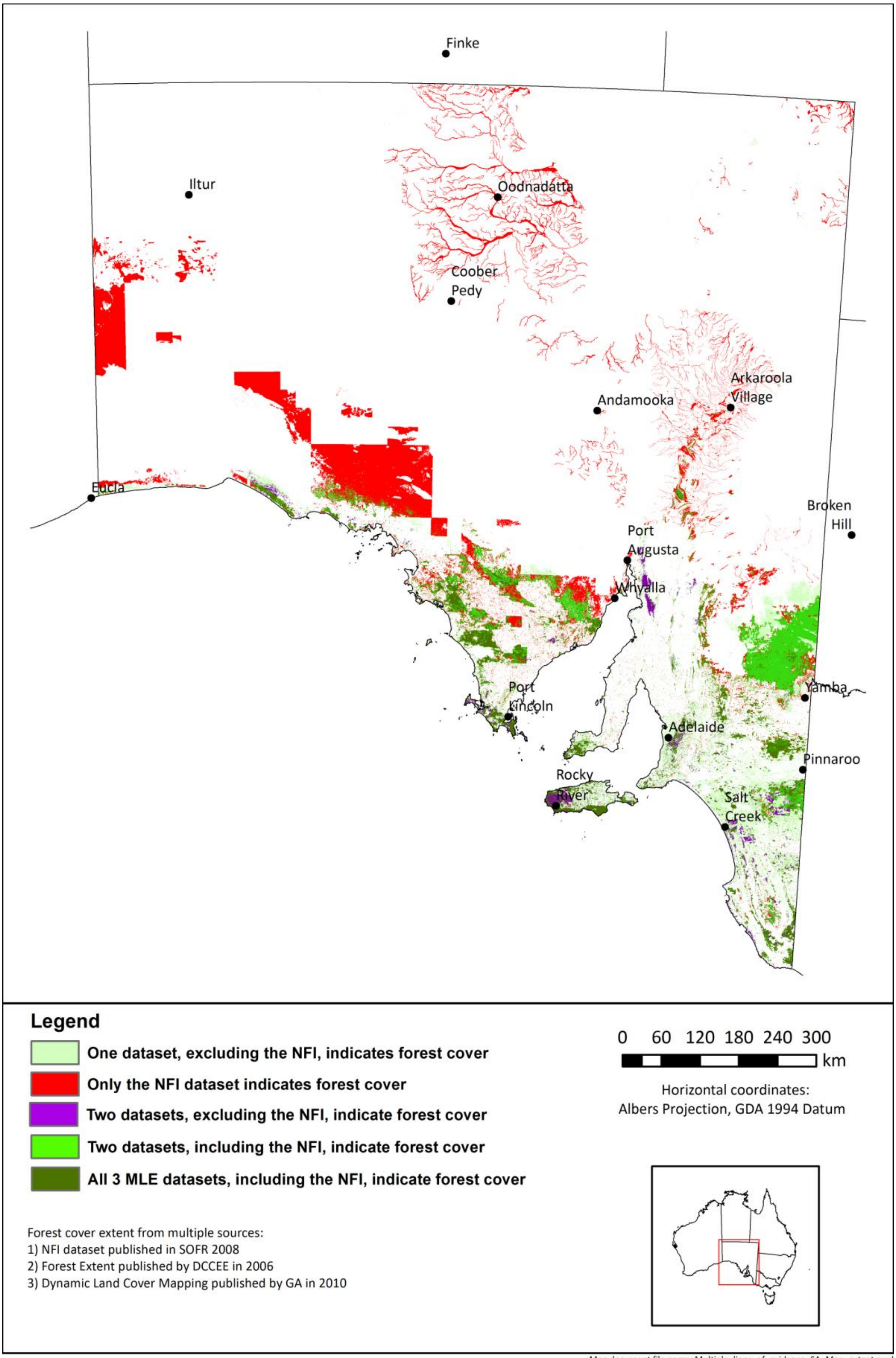
Data source: ABARES 2013

Table 9 Assessment of forest and non-forest areas in South Australia using MLE approach

	Area (million hectares)			
	Total	High confidence in NFI allocation	Moderate confidence in NFI allocation	Low confidence in NFI allocation
NFI dataset indicates forest	9.02	1.23 a	2.15 b	5.64 c
NFI dataset indicates non-forest; at least one other dataset indicates forest	3.26	0.00 c	2.81 b	0.45 a
Total potential forest cover (summed footprint of all datasets)	12.28			
Sum of areas indicated as a	1.68	MLE approach suggests this to be forest		
Sum of areas indicated as b	4.96	MLE approach is uncertain if this is forest or non-forest		
Sum of areas indicated as c	5.64	MLE approach suggests this to be non-forest		
Total potential forest cover (summed footprint of all datasets)	12.28			

Data source: ABARES 2013

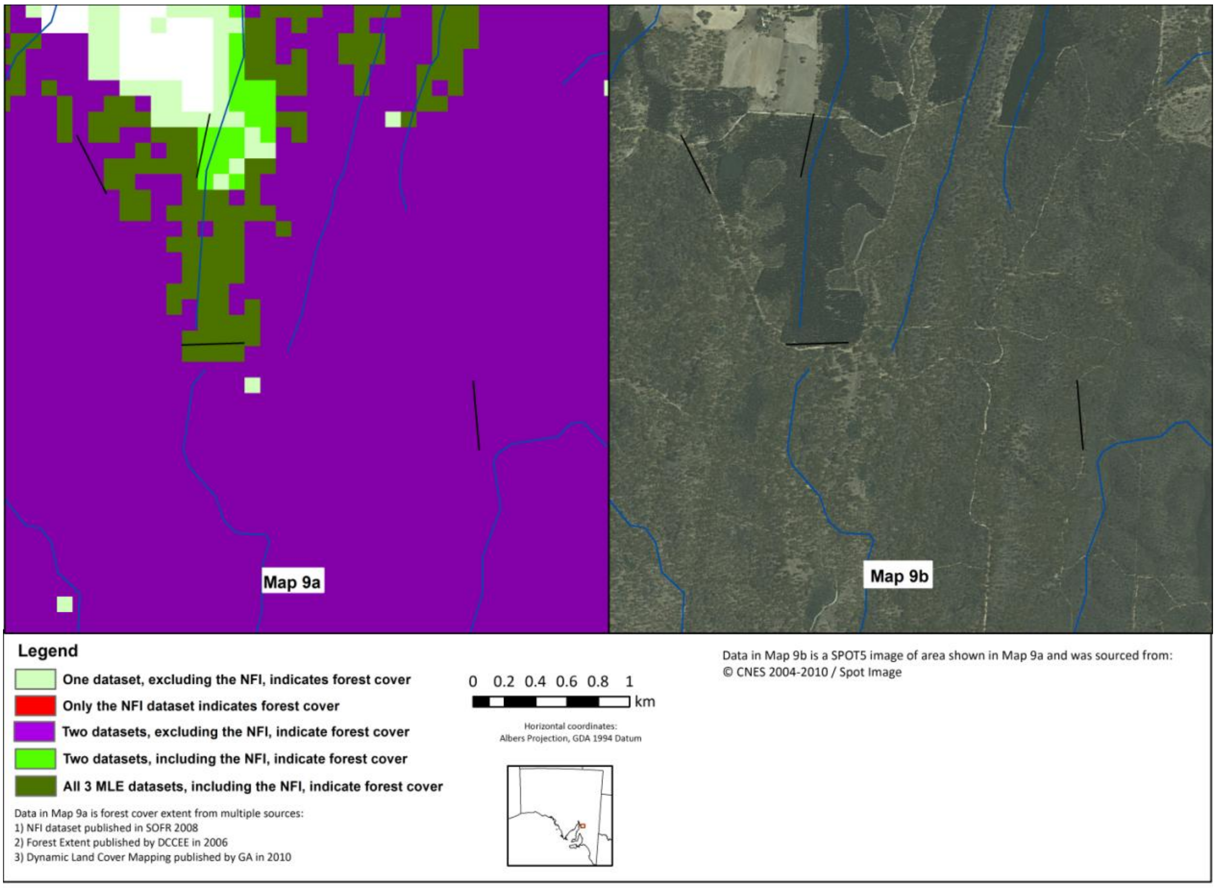
Map 8 Location and distribution of MLE analysis output for South Australia



Map document file name: Multiple_lines_of_evidence_SA_Map_extent.mxd

Map 9 Example area from South Australia

Left image (Map 9a) shows an example area in South Australia where 'Two datasets, excluding the NFI, indicate forest cover'; the NFI dataset indicates non-forest. This is a candidate area for re-allocation as forest in the NFI dataset. Right image (Map 9b) shows exactly the same area in a SPOT5 satellite image.



6 Acronyms and abbreviations

ABARE	Australian Bureau of Agricultural and Resource Economics
ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
BRS	Bureau of Rural Sciences
CC	crown cover
CFMF	Continental Forest Monitoring Framework
CNES	Space Agency of France
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DCCEE	Former Australian Government Department of Climate Change and Energy Efficiency now Department of the Environment
DSITIA	Queensland Government Department of Science, Information, Technology, Innovation and the Arts
DLCM	Dynamic Land Cover Mapping
FFPC	Forests and Forest Products Committee
FPC	Foliage Projective Cover
GA	Geoscience Australia
IceSAT	Ice, Cloud and Land Elevation Satellite
LiDAR	Light Detection And Ranging
MLE	Multiple Lines of Evidence
MODIS	Moderate Resolution Imaging Spectroradiometer
NCAS	National Carbon Accounting System
NFI	National Forest Inventory
NFISC	National Forest Inventory Steering Committee
NSWSF	Former New South Wales State Forests now New South Wales Forestry Corporation
NVIS	National Vegetation Information System
OEH	New South Wales Office of Environment and Heritage
SLATS	Statewide Land Cover And Trees Study
SOFR	*Australia's State of the Forests Report*
SPOT5	Systeme Pour l'Observation de la Terre (System for Earth Observation – Satellite number 5)
TERN	Terrestrial Ecosystem Research Network

7 References and further reading

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