Statewide Landcover and Trees Study

Overview of Methods

Queensland Government

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List of acronyms

DNRME	Department of Natural Resources, Mines and Energy
DES	Department of Environment and Science
ETM+	Enhanced Thematic Mapper Plus
FPC	Foliage Projective Cover
GBR	Great Barrier Reef
NVIS	National Vegetation Information System
OLI	Operational Land Imager
QLUMP	Queensland Land Use Mapping Program
RSC	Remote Sensing Centre
SLC-off	Scan Line Corrector-off
SLATS	Statewide Landcover and Trees Study
TM	Thematic Mapper
USGS	United States Geological Survey
VMA	*Vegetation Management Act 1999*

Glossary of terms used in this document

Albers equal-area projection

A conic map projection which preserves the area of features. This projection is suitable for use when calculating the area of features.

Foliage Projective Cover (FPC)

FPC is defined as the fraction of ground covered by the vertical projection of photosynthetic foliage of all strata (Specht, 1983). FPC is a metric that is used in remote sensing (i.e. satellite-based monitoring) as a direct estimate of the foliage (or leaves) on vegetation when viewed (vertically or near-vertically) from above, as is the perspective of the satellite.

Geometric correction

Also referred to as geo-referencing, is the process used to accurately register satellite images to a ground coordinate system.

Image composite

An image composite refers to the multi-temporal compositing of image scenes. In the SLATS process, image composites are primarily used to replace cloudy areas from one date with clear data from another date so as to maximise the useable data per scene.

Image mosaic

An image mosaic, as referred to in the SLATS process, is produced by combining multiple individual image scenes to produce a single seamless mosaic for the state of Queensland.

Radiometric standardisation

Refers to the process of correcting satellite imagery for atmospheric effects, seasonal differences in reflectance, sensor characteristics and satellite geometry. This standardisation or correction is particularly important for image mosaicking and comparing images over multiple time periods.

Thinning

Thinning refers to the partial removal of trees and/or shrubs.

Woody plants

A plant that produces wood as its primary structural tissue. Woody plants may be trees, shrubs or lianas and are usually perennial.

Woody vegetation

Assemblages of woody plants. This includes stands of native vegetation, regrowth following clearing, plantations of native and exotic species, and woody weeds.

Woody vegetation clearing

The anthropogenic (i.e. human) removal or destruction of woody vegetation.

1 Introduction

1.1 Objectives of the Statewide Landcover and Trees Study

The Statewide Landcover and Trees Study (SLATS) is a vegetation monitoring initiative of the Queensland Government, undertaken by the Remote Sensing Centre (RSC) in the Department of Environment and Science (DES). It supports the *Vegetation Management Act 1999* (VMA), which is administered by the Department of Natural Resources, Mines and Energy (DNRME).

SLATS monitors woody vegetation loss using a combination of automated and manual mapping techniques, primarily based on Landsat satellite imagery and supported by ancillary data sources, including higher resolution satellite imagery such as the European Space Agency's Sentinel 2A and 2B.

The primary objective of the study is to map the location and extent of woody vegetation clearing that is the result of anthropogenic (i.e. human) removal of vegetation across the entire state of Queensland.

The woody vegetation clearing data produced by SLATS are used to update regional ecosystem mapping and to assess compliance of land management activities with the vegetation management framework under the VMA. These data are also used to inform a range of other land management policies and reporting initiatives in Queensland such as protection and management of the Great Barrier Reef (GBR), State of Environment reporting, and biodiversity conservation and planning.

1.2 Purpose of this document

The purpose of this document is to provide an overview of the methods used by SLATS to map woody vegetation clearing and calculate annualised woody vegetation clearing rates. This document is intended to accompany the *Land cover change in Queensland 2016-17 and 2017-18: Statewide Landcover and Trees Study (SLATS) Summary Report* (DES, 2018). This document does not provide details about annual reporting requirements, data summaries, or other contextual information that has been the subject of previous SLATS reporting. For information regarding these, refer to previous SLATS reports (e.g. DSITI, 2017).

It is important to note that SLATS uses a range of methods for its methodology. Key components of the SLATS methodology such as the imagery processing and the woody vegetation clearing index have been subject to international peer-review and publication in journal articles or conference proceedings. References are provided to these published methods in this document, where relevant.

2 Overview of SLATS Methods

2.1 Scope

SLATS detects woody vegetation clearing in Queensland that can be reliably mapped, using Landsat satellite imagery and all available ancillary information. Vegetation and land cover changes that are not included in the scope of SLATS are outlined below.

2.1.1 Woody vegetation clearing

SLATS maps woody vegetation clearing that is the result of anthropogenic (i.e. human) removal of vegetation. SLATS mapping is limited to those areas that can be reliably identified and mapped using Landsat satellite imagery and other ancillary information. This includes high resolution satellite imagery and other spatial data sets (refer to Section 2.5.4 for information about ancillary data sources).

SLATS maps woody vegetation clearing in the National Vegetation Information System (NVIS) structural formation classes of 'Open woodland'/'Sparse shrubland' to 'Closed forest'/'Closed shrubland' (ESCAVI, 2003) provided the tree/shrub density is sufficient to reliably determine that an observed change was due to woody plant removal (Table 1). Woody vegetation height is not considered in SLATS mapping, as vegetation height is not possible to reliably estimate from optical satellite imagery such as Landsat.

Table 1: Extract from National Vegetation Information System (NVIS) Framework Structural Formation Standards used to classify Australian vegetation by cover and height classes (ESCAVI, 2003). Scarth et al. (2008a) was used to estimate the FPC equivalent of the crown cover classes described by NVIS. SLATS maps woody vegetation clearing in 'Open woodland'/'Sparse shrubland' and denser.

FPC Equivalent	> 0	0 – 3	< 11	11 – 27	27 – 45	> 45
Tree	Isolated trees	Isolated clumps of trees	Open woodland	Woodland	Open forest	Closed forest
Shrub	Isolated shrubs	Isolated clumps of shrubs	Sparse shrubland	Open shrubland	Shrubland	Closed shrubland

2.1.2 Land use and land use change

Land use and land use change are not mapped by SLATS. Comprehensive mapping of land use and land use change in Queensland is undertaken by the Queensland Land Use Mapping Program (QLUMP) (https://www.qld.gov.au/environment/land/vegetation/mapping/qlump/). SLATS does report on the replacement land cover where woody vegetation clearing has been mapped (refer to Section 2.5.5).

2.1.3 Fire

SLATS does not map areas directly affected by fire. For the purposes of woody vegetation clearing mapping, fire-affected areas are assumed to be temporary, non-anthropogenic changes in woody vegetation

2.1.4 Natural tree death and natural disaster damage

SLATS does not include any vegetation loss caused by natural tree death or natural disasters (e.g. cyclone) when calculating woody vegetation clearing rates.

2.1.5 Woody vegetation thinning

SLATS maps a category of clearing called ‘thinning’ that refers to the partial removal of woody vegetation from a stand of trees and/or shrubs. It is important to note that this does not necessarily align with the VMA definition of thinning. The VMA defines thinning as the selective clearing of vegetation at a locality to restore a regional ecosystem to the floristic composition and range of densities typical of the regional ecosystem surrounding that locality. It does not include clearing using a chain or cable linked between two tractors, bulldozers or other vehicles. SLATS mapping of thinning may differ from this definition as areas may be mapped where there is of partial removal of trees or shrubs where machinery such as that referred to by the VMA has been used.

2.2 SLATS woody vegetation clearing mapping process

A schematic representation of the SLATS methodology is shown in Figure 1. The methodology involves a number of automated and manual processing steps, with quality control checking and review stages, summarised as follows:

1. Landsat imagery is acquired, corrected for topographic effects and sun and sensor viewing angles, and the most cloud-free images from the dry season period are selected. Refer to Section 2.4 for further details.
2. A woody vegetation clearing index is calculated to detect areas of change that represent possible clearing of woody vegetation. This model has been calibrated using historic mapping of cleared areas, and highlights most of the possible clearing and omits areas that are almost certain not to represent clearing. Refer to Section 2.5.1 for further details.
3. This initial clearing index is visually inspected, and manually edited by trained remote sensing scientists to confirm areas that are clearing, and ignore areas that are not. This manual process makes use of any additional information available to aid decisions. Refer to Section 2.5.2 for further details.
4. Senior SLATS remote sensing scientists review the manual editing, so that mapped clearing has generally been visually checked and verified by a minimum of two staff. Refer to Section 2.5.2 for further details.
5. Further edits and quality control checks are undertaken to finalise the woody vegetation clearing mapping. Refer to Section 2.5.2 for further details.
6. The mapping is compiled, and a statewide mosaic created (i.e. a single statewide map of woody vegetation clearing). Refer to Section 2.6.1 for further details.
7. The mapping is converted to an annualised clearing rate. Refer to Section 2.6.2 and Appendix 1 for further details.

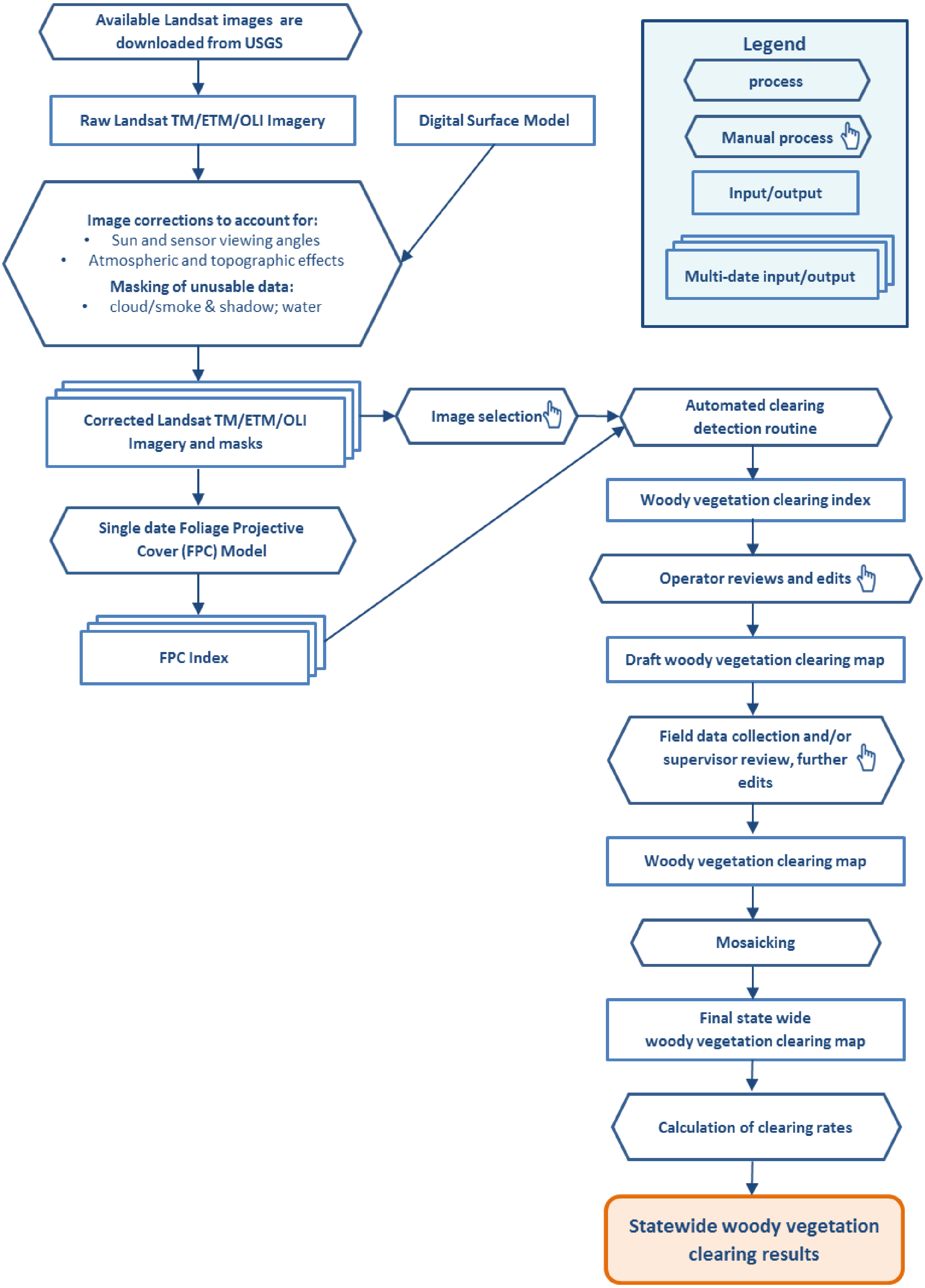


Figure 1: Flowchart of SLATS woody vegetation clearing mapping processes

2.3 Data

2.3.1 Landsat satellite imagery

All reporting is based on analysis of imagery acquired by Landsat satellites. Since 1972, the United States Geological Survey's (USGS) Landsat program has launched eight satellites, seven of which were successfully put into orbit – the Landsat program provides the longest record of earth observation data in history. Landsat data used in SLATS dates from 1988 to present, and has a spatial resolution of approximately 30 metres (note Landsat satellites prior to Landsat 4 were of lower spatial resolution). Landsat satellites have a systematic acquisition strategy: the same place is revisited at least once in its 16-day cycle, meaning the entire state of Queensland is imaged every 16 days. The satellites acquire land surface reflectance data at a range of wavelengths including visible and infrared, some of which are useful for distinguishing different land cover features, including woody vegetation. Landsat data are therefore well-suited to statewide and regional monitoring and reporting of land cover change.

Landsat data used in SLATS includes imagery captured by the Landsat 5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper Plus (ETM+) and Landsat 8 Operational Land Imager (OLI). Landsat 5 TM was launched in 1984 and ceased operation in 2011, while Landsat 7 ETM+ and Landsat 8 OLI remain operational, with the latter launched in 2013. Since 2003, Landsat 7 ETM+ has been capturing imagery in Scan Line Corrector-off (SLC-off) mode when its scan line corrector failed – resulting in strips of lost data along the eastern and western scene margins. While radiometric and geometric quality of the captured Landsat 7 images are maintained, approximately 22% of each image is lost due to the SLC-off gaps, with only a 22 kilometre wide strip in the centre of the image being completely unaffected. For this reason, when Landsat 7 ETM+ was used for SLATS reporting in 2012, a compositing method was developed to infill the missing data in the SLC-off gaps.

2.3.2 SLATS mapping period

A range of satellite overpass dates are acquired in order to capture suitable cloud-free Landsat satellite images for the entire state. The images are typically obtained in the dry winter months between June and October.

Approximately 99 satellite scenes, or footprints, are incorporated in each SLATS mapping period. Theoretically, in any one year, acquisition dates can differ for each of the 99 satellite scenes. However, every attempt is made to acquire imagery within the dry season period, as close as possible to the same time of year.

2.4 Landsat imagery acquisition and pre-processing

2.4.1 Imagery acquisition and scene selection

Landsat satellite imagery is downloaded from the USGS website (earthexplorer.usgs.gov). For each SLATS mapping period, Landsat scenes are manually selected with preference is given to single date, cloud-free, dry season images to align with previous SLATS mapping periods. In cases where a single acquisition date that is cloud-free within the dry season (i.e. June to October) is not available, selected images are composited to produce a single cloud-free image. The compositing process involves selecting a primary image date and infilling cloud-affected areas, or areas affected by the Landsat 7 SLC-off mode, with pixels that are selected from scenes which are as close as possible to the primary date, generally within one to two months. The source image date for each pixel in the composite is recorded in a separate raster image, thus enabling the calculation of the analysis period and woody vegetation clearing rates with the appropriate weighting applied for each pixel (i.e. 30m x 30m area).

2.4.2 Geometric correction of imagery

All Landsat imagery is geometrically corrected by the USGS. Analyses by the USGS suggest that the locational error is below a single pixel (Storey *et al*, 2014). SLATS uses the USGS geometric correction, without modification.

2.4.3 Analysis of sensor differences

An analysis of the impact of the sensor differences between Landsat 7 ETM+ and Landsat 8 OLI on reflectance and FPC models has previously been undertaken by Flood (2014). Flood (2014) determined that with appropriate adjustments made to the models it is possible to ensure imagery from the two sensors is comparable. SLATS applies these adjustments to its Landsat data to ensure comparability between the two sensors, where data is used from each sensor in each mapping period (e.g. in composite images). It also helps to ensure comparability between mapping periods where different Landsat sensors have been used.

2.4.4 Radiometric standardisation

Radiometric standardisation is applied to the Landsat images based on Danaher (2002). Radiometric standardisation allows scene-to-scene matching over space and time. This improves mosaicking and classification. It helps to improve the accuracy of the satellite imagery and provides greater certainty in the comparison of the changes in annual rates of woody vegetation clearing. Top-of-atmosphere reflectance is calculated, to correct for solar incidence angle and earth-sun distance, and an empirical radiometric correction was applied to correct for variation in solar azimuth, viewing angle, systematic atmospheric effects, and the effect of bi-directional reflectance distribution function of the surface measured (Danaher, 2002).

2.4.5 Topographic corrections

A simple topographic correction to the top-of-atmosphere reflectance imagery was also applied to remove artefacts due to variation in illumination angle on sloping terrain (Dymond and Shepherd, 1999). This correction has the effect of ‘flattening’ the terrain, by estimating the reflectance as if the surface had been horizontal. This correction reduces the effect of hill slope to provide more uniform estimates of top-of-atmosphere reflectance. Classification based on this corrected imagery is therefore more accurate in areas of high slope. This increased accuracy reduces the amount of manual editing required to correct initial misclassification of topographic effects.

2.4.6 Other corrections

Cloud, smoke and shadow contamination in the imagery was masked out, to avoid impacts on the woody vegetation clearing index. To ensure accuracy, these models rely on automatic masks generated using the methods of Zhu & Woodcock (2012), combined with manual editing.

2.5 Mapping woody vegetation clearing

This section outlines the processes undertaken to identify and map woody vegetation clearing for a given mapping period.

2.5.1 Detection of woody vegetation clearing: the woody vegetation clearing index

The SLATS method detects change in woody vegetation through an automated process that calculates a multi-component ‘probability of woody vegetation clearing’ index that is then edited by DES remote sensing scientists. This method was first developed for the 2003–04 period (DNR&M, 2006; Scarth *et al*., 2008b).

This woody clearing probability measure is calculated from three components. The most important component is a spectral clearing index, which uses the spectral information from the visible and short wave infra-red bands of the pair of Landsat images selected by SLATS (separated by approximately one year). It is similar in principle to creating a difference map, showing the changes in each spectral band. However, this index transforms all of the differences through a model that was fitted to historical mapped clearing data. The model highlights the sorts of changes that are likely to correspond to removal of woody vegetation (i.e. trees and shrubs), and minimizes the differences that tend to be associated with other sorts of land surface change (e.g. cropping, inundation, pasture response to rainfall).

The second component uses a separate model index that is correlated with the density of tree foliage. This provides a measure of how much foliage cover is present in each pixel, and relates to both the density of the foliage of individual trees, and also the separation between trees within the pixel. While this is not sufficient to perfectly map all tree cover, it does provide a useful indicator. Technically, this is correlated with the foliage projective cover (FPC), and is known as the FPC index (Armston *et al.*, 2009). The change in this index between the two image dates forms the second component of the clearing probability measure.

The third component is also reliant on the FPC index model, but uses the behaviour of the FPC index over the historic time-series of dry season Landsat imagery (1988–present, one dry season image per year) to obtain a measure of the variability over time. This is used to assist in distinguishing grass (which generally varies a lot) from trees and shrubs (which are much less variable). This component tries to reduce the amount of false changes identified by the index that are caused by fluctuations in herbaceous or non-woody vegetation cover and are not due to changes in woody vegetation.

These three components are then combined in a single index, the ‘clearing index’, to give a probability measure that a detected change corresponds to clearing of tree/shrub vegetation (Scarth *et al*., 2008b). This is a useful tool for providing an initial detection of areas that may have been cleared, which, relative to the land surface area of the state, are very small. However, the results of the clearing index requires manual inspection to distinguish the areas that really do correspond to removal of trees and shrubs.

The use of dry season imagery is important, because imagery captured during the dry season typically shows the greatest contrast between woody vegetation and grass. Dense green grass in the wet season can become quite similar (spectrally) to sparse tree foliage, making the distinction between open woodland and dense grass more difficult.

2.5.2 Mapping woody vegetation clearing

The clearing index described above provides a good starting point for the classification, helping to focus the manual mapping effort to those areas where clearing is most likely to have occurred. However, considerable time is spent by a team of remote sensing scientists checking and manually editing the output to ensure that a high quality map of woody vegetation clearing is produced. This manual stage forms the majority of the effort for the SLATS mapping process, and can take up to 8-10 months to complete for the state.

The reason for the extensive manual editing is because naturally occurring events can affect vegetation in ways that appear similar to woody vegetation clearing in terms of the spectral and temporal responses observed by the satellite sensor (and used to calculate the clearing index). For example, damage by storms, fire and drought can all cause a reduction in canopy health or cover that can appear similar to a clearing event, and are often detected by the automated clearing index as possible clearing.

Systematic visual inspection and manual editing is undertaken to distinguish these cases from anthropogenic clearing. Remote sensing scientists inspect the clearing index, and refer to other ancillary image/data sources (refer to Section 2.5.4) to assist in confirming whether an area detected as possible clearing is actually woody vegetation clearing. Additionally, when visually inspecting the clearing index, the scientists may identify and map clearing that has not been detected by the clearing index.

Upon completion of the initial stage of visual interpretation and manual editing, the process is repeated by a senior DES remote sensing scientist to provide an independent check and ensure a high level of accuracy and consistency in the final map. In this step, the senior scientist highlights areas which may require additional investigation by the scientist who undertook the initial mapping. These areas are then further assessed using any additional ancillary data or by cross-calibration with other scientists in the team.

Figure 2 below, shows an example of woody vegetation clearing where Landsat 8 OLI imagery is used for the visual inspection of the clearing index to create the clearing map.

2.5.3 Mapping woody vegetation thinning

SLATS remote sensing scientists are sometimes able to map partial removal of trees or shrubs from within a stand of woody vegetation. This is coded to a ‘thinning’ class, noting that this is distinct from the VMA definition of thinning (refer to Section 2.1.5). Areas of thinning may be detected by the woody vegetation clearing index, or identified by SLATS scientists during systematic mapping. Ancillary high resolution imagery, where available, can be particularly important in confirming this class. Examples of the SLATS mapping of thinning are given in Figure 3 and Figure 4.

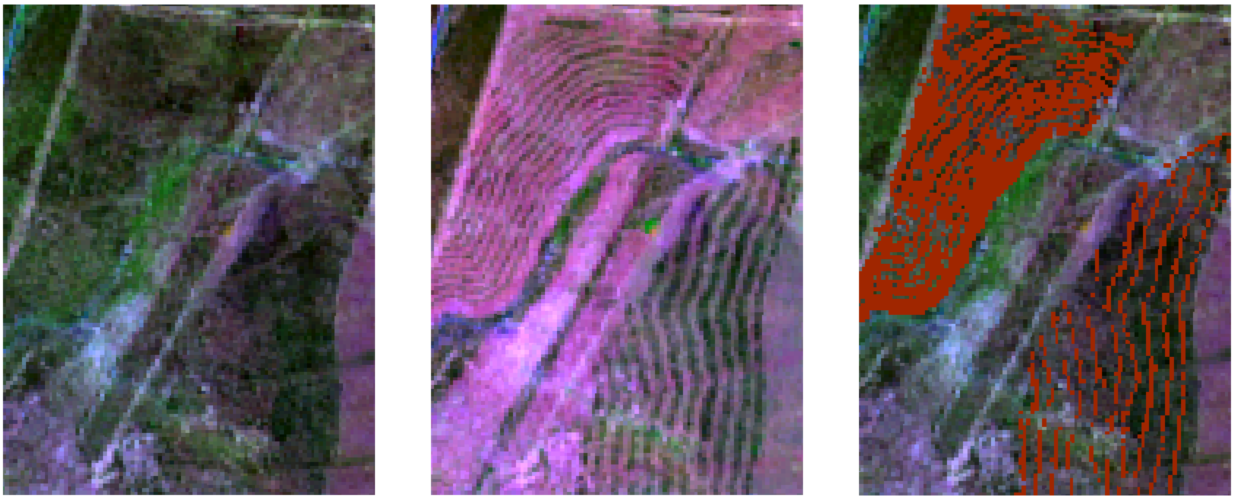
a) Landsat 8 OLI captured in 2013

b) Landsat 8 OLI captured in 2014

c) Woody Vegetation Clearing Index

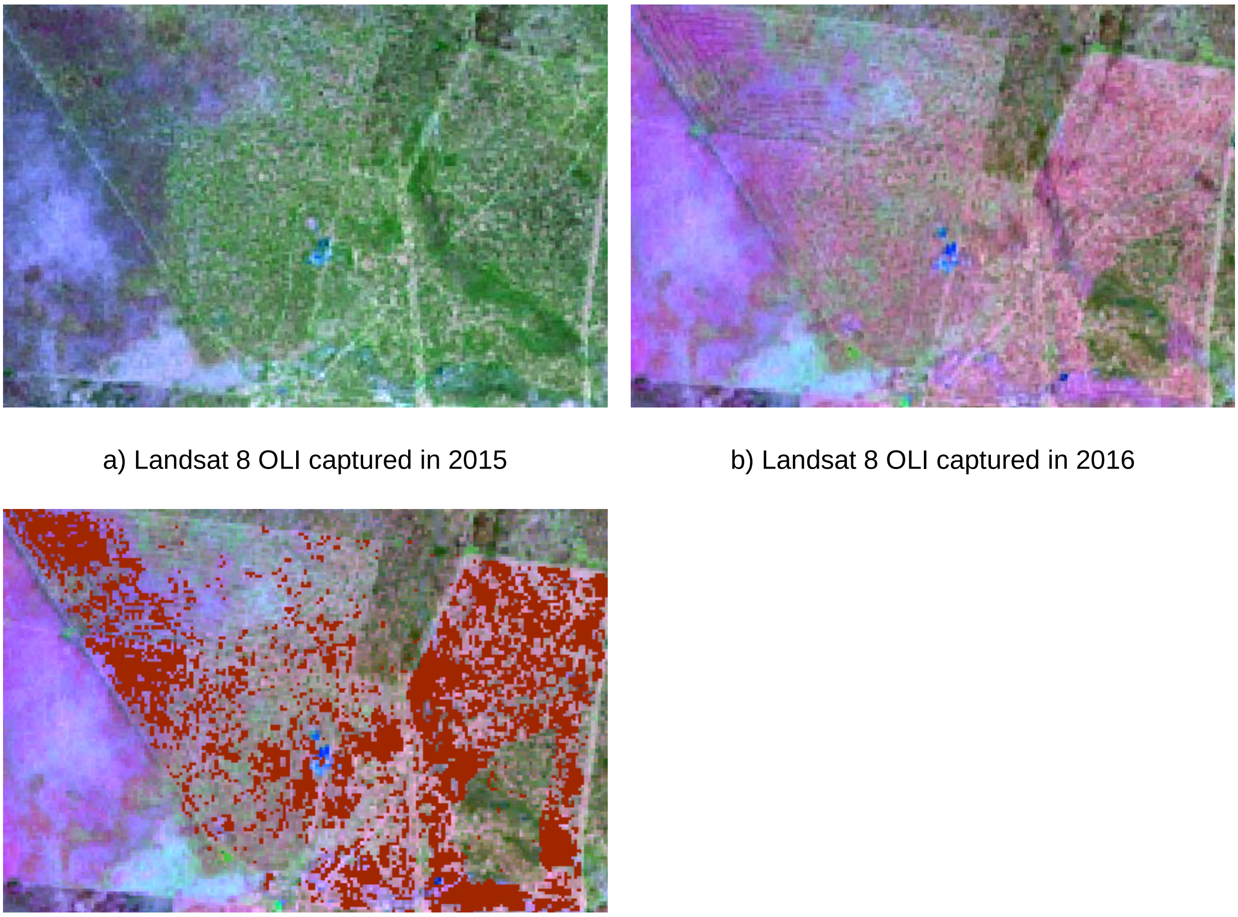
d) Woody Vegetation Clearing Map

Figure 2: An example of a clearing event in south western Queensland as seen in Landsat 8 OLI imagery. a) Landsat 8 OLI captured on 30 August 2013, before the clearing occurred. b) Landsat 8 OLI captured on 1 August 2014 after the clearing occurred. In a) and b), the same black outline is shown to highlight areas of clearing. c) Woody vegetation clearing index overlaid on image in a). Pixels with high probability of being woody vegetation clearing are shown in red, and lower probabilities shown in shades of grey. d) Woody vegetation clearing map edited by a remote sensing scientist overlaid on image in a). Mapped clearing is shown as dark red. The area in all panels is the same, and is approximately 15 kilometres east to west and 12 kilometres north to south.



a) Landsat 8 OLI captured in 2015   b) Landsat 8 OLI captured in 2016   c) Woody Vegetation Thinning Map

Figure 3: An example of a strip thinning event in south western Queensland as seen in Landsat 8 OLI imagery. a) Landsat 8 OLI captured on 19 July 2015 before the thinning event. b) Landsat 8 OLI captured on 9 October 2016 after the thinning event. c) Woody vegetation thinning map edited by a remote sensing scientist overlaid on imagery in a). Mapped thinning is shown as dark red. This example shows some of the diversity in the areas mapped as strip thinning. Less thinning has occurred in the southern section compared to the northern section. The area in all panels is the same, and is approximately 3 kilometres east to west and 4 kilometres north to south.



a) Landsat 8 OLI captured in 2015

b) Landsat 8 OLI captured in 2016

c) Woody Vegetation Thinning Map

Figure 4: An example of a thinning event in south western Queensland as seen in Landsat 8 OLI imagery. a) Landsat 8 OLI captured on 19 July 2015 before the thinning event. b) Landsat 8 OLI captured on 9 October 2016 after the thinning event. c) Woody vegetation thinning map edited by a remote sensing scientist overlaid on imagery in a). Mapped thinning is shown as dark red. This example shows the partial removal of trees and shrubs across the area, as indicated in the woody vegetation thinning map. The area in all panels is the same, and is approximately 6 kilometres east to west and 4 kilometres north to south.

2.5.4 Ancillary data

Ancillary data sources are used to provide additional lines of evidence to assist the remote sensing scientists with their decisions as to whether the vegetation cover that has been cleared is: (i) sufficiently woody to be mapped as woody vegetation clearing; and, (ii) removal of woody vegetation that is the result of anthropogenic activity. In general, woody vegetation clearing in areas with a crown cover less than 20% (approximately 11% FPC) has a lower reliability of detection, and woody vegetation clearing in these areas is only included if the ancillary data are unambiguous.

Ancillary data sources include, but are not limited to:

- Landsat imagery, both the start and end dates for the mapping period as well as additional images captured before, during and after the mapping period.
- Queensland Government's archive of satellite imagery including Sentinel 2A and 2B MultiSpectral Instrument (MSI) (since 2015), Earth-i/DMC-3 (for 2016 and 2017), and SPOT4, SPOT5 and SPOTMaps from a number of previous periods (e.g. 2005-6, 2009, 2012-13).
- High resolution satellite imagery and aerial photography available through online image services such as Planet (QSat), Google Earth, TerraServer and the Queensland Government's Queensland Globe.
- Complementary remote sensing products, for example DES's fire scar data, and the Northern Australia Fire Information's fire hotspots and fire scar maps (https://www.firenorth.org.au/nafi3/).

2.5.5 Replacement land cover

During the manual editing stage, each area of woody vegetation clearing is assigned to a replacement land cover class. This provides an *indication* of the purpose for which the vegetation was cleared. The replacement land cover classes are described in Table 2. The assignment or coding of these classes is primarily based on visual interpretation, with reference to ancillary data sources. In areas where there are many different forms of land use, it can be difficult to interpret the final replacement class and therefore this classification is indicative only. For example, land assigned to the class *pasture* may later be converted to *settlement*.

To ensure that clearing activity related to timber harvesting is not confused with other replacement land cover classes in the final clearing data set, clearing mapped in areas which are designated in official government data sets as known forestry areas is recoded into the *forestry* replacement land cover class.

Table 2: Replacement land cover classes for woody vegetation clearing

Replacement land cover	Description
Pasture	Grazing and other general land management practices (e.g. this class includes clearing for internal property tracks, fence lines or fire breaks). Areas mapped as thinning are also included in this class.
Crops	Cropping or horticultural purposes.
Forestry	Timber harvesting in state or privately owned native or exotic (e.g. pine) forests or plantations.
Mining	Mining activities (including coal seam gas infrastructure).
Infrastructure	Roads, railways, water storage, pipelines, powerlines etc.
Settlement	Imminent urban development.

2.5.6 Field verification

DES maintains a database containing field observations of vegetation cover, gathered over the time that the Landsat satellites that SLATS uses have been operating. These field data are used to calibrate and validate the remote sensing products that DES produces, including those that are inputs to the SLATS clearing index.

Earlier SLATS mapping periods undertook an extensive field program to inform the mapping of woody vegetation clearing, and in particular to clarify areas of uncertainty. In recent mapping periods, high resolution satellite imagery and other ancillary data sources have become more readily available, and have provided a valuable image interpretation resource. It is especially useful for interpreting and verifying areas that are not physically accessible.

2.5.7 Limitations to mapping woody vegetation clearing

The 30 metre pixel size of Landsat imagery is the main limitation for mapping woody vegetation. The pixel size limits the size of landscape features that can reliably be detected, this includes woody vegetation clearing. For example, clearing of narrow riparian strips of woody vegetation cover less than 30 metres wide may sometimes be missed.

The pixel size of Landsat also limits the ability to distinguish open woodland from open grassland, as scattered trees and interspersed grass cover within a pixel are averaged for the whole pixel. DES remote sensing scientists must decide, using all available information including ancillary data, whether a change represents removal of all or most of the trees, or is a change in herbaceous or non-woody cover due to seasonal or other land management impacts.

2.6 Statewide woody vegetation clearing data

2.6.1 Data compilation

A large, seamless mosaic of woody vegetation clearing is created by joining all scenes covering the state. Each scene is trimmed to a standard Landsat scene template to minimise overlap, and remove areas outside the Queensland state border. When producing the mosaic, the scenes are overlapped in paths from north to south and paths are joined from east to west. The full resolution of these data (30 metre pixel) is preserved.

In recognition of the limited ability to detect clearing at the level of one or two Landsat pixels, a filter is applied to the final mosaic to remove clearing of two pixels or less.

In order to calculate annual woody vegetation clearing rates (refer to Section 2.6.2 and Appendix 1), each pixel identified as woody vegetation clearing is attributed with the image dates from the scene selection and compositing process.

Finally, the data are transformed to an Albers equal-area projection, thus allowing woody vegetation clearing rates for different regions to be comparable.

2.6.2 Calculation of woody vegetation clearing rates

Due to the range of satellite overpass dates, the SLATS mapping period is not a precise 365-day period. This also varies from scene to scene. This means that the area of clearing mapped in a given period is not necessarily comparable to the area mapped in another period; variations in the satellite overpass dates mean that reporting periods can be longer or shorter than a year. Therefore, for reporting, the total area of mapped clearing (hectares) is converted to an annual clearing rate (hectares/year) based on a 1st August–1st August period. This conversion makes the results comparable by re-weighting shorter or longer periods, based on the assumption that clearing occurs at a uniform rate throughout the year. A slight adjustment of the woody vegetation clearing rates for the previous period may occur as a result of this rate calculation method. Detail of how this calculation is performed is given in Appendix A.

2.7 Quality Control

SLATS methods are based on extensive literature review, expert knowledge and peer-reviewed processes and approaches. Procedural consistency throughout the SLATS mapping methodology is maximised through a number of measures. With the exception of the manual editing phase, many of the steps involved have been completely automated with purpose-built programs, ensuring repeatability and efficiency. Throughout the image processing and mapping processes, file and program histories are recorded. This not only maximises procedural consistency across many satellite scenes, multiple mapping periods, and remote sensing scientists, but it also enables issues to be reliably traced and rectified.

During the manual editing phase, remote sensing scientists consult regularly with each other, and this combined with a checking process and other quality assurance checks, is intended to maximise consistency.

Data and programs used and produced by SLATS are subject to quality control systems and standard operating procedures used by DES's RSC for image and field data processing, storage and management. The systems and processes used by RSC are fully documented in a WIKI-based system and include a number of peer-reviewed processes. All image processing follows or exceeds internationally-accepted standards. Data sourced from external parties is not incorporated into the workflow without appropriate metadata, including lineage statements. All programs written for SLATS are maintained in the RSC code repository. All data processing is undertaken on the high performance computing facility at the Ecosciences Precinct, Brisbane, supported by systems administrators from the DNRME.

2.8 Continuous scientific improvement

The Queensland Government is committed to the continuous scientific improvement of SLATS and vegetation information to make efficient use of new and emerging science to support evidence-based decision-making. New earth observation technologies such as the European Space Agency's Sentinel 2A and 2B satellite sensors, and significant advances in computing technologies, including computer vision approaches, are being incorporated into the continuous development of SLATS. These technologies are presently being investigated to enhance woody vegetation extent mapping, improve the woody vegetation clearing index, and to develop new regrowth and vegetation condition monitoring methods for the state. This will inform a more comprehensive monitoring and reporting framework for the management of Queensland's vegetation.

Bibliography

Accad A, Neldner VJ, Kelley JAR and Li J (2017), '*Remnant regional ecosystem vegetation in Queensland: analysis 1997–2015'*, Queensland Department of Science, Information Technology and Innovation, Brisbane.

Armston JD, Denham RJ, Danaher TJ, Scarth PF and Moffiet T (2009), 'Prediction and validation of foliage projective cover from Landsat 5 TM and Landsat 7 ETM+ imagery', *Journal of Applied Remote Sensing*, 3: 033540.

Danaher TJ (2002), 'An empirical BRDF correction for Landsat TM and ETM+ imagery',*Proceedings of the 11th Australasian Remote Sensing and Photogrammetry Conference*, Brisbane, Australia, 2–6 September, pp. 966–977.

Department of Environment and Science (2018), *Landcover change in Queensland 2016-17 and 2017-18: a Statewide Landcover and Trees Study (SLATS) Summary Report,* Department of Environment and Science, Brisbane.

Department of Natural Resources and Mines [DNR&M] (2006), *Land cover change in Queensland 2003–04: a Statewide Landcover and Trees Study (SLATS) report*, Department of Natural Resources and Mines, Brisbane.

Department of Science, Information Technology, Innovation and the Arts (2014), *Land cover change in Queensland 2011–12: a Statewide Landcover and Trees Study (SLATS) report*, Department of Science, Information Technology, Innovation and the Arts, Brisbane.

Queensland Department of Science, Information Technology and Innovation. 2017. Land cover change in Queensland 2015–16: a Statewide Landcover and Trees Study (SLATS) report. DSITI, Brisbane.

Dymond JR, Shepherd JD (1999), 'Correction of topographic effect in remote sensing', *IEEE Transactions on Geoscience and Remote Sensing*, 37, 2618–2620.

ESCAVI (2003), *Australian vegetation attribute manual: National Vegetation Information System, Version 6.0*. Executive Steering Committee for Australian Vegetation Information, Department of the Environment and Heritage, Canberra.

Flood N (2014), 'Continuity of Reflectance Data between Landsat-7 ETM+ and Landsat-8 OLI, for Both Top-of-Atmosphere and Surface Reflectance: A Study in the Australian Landscape', *Remote Sensing*, 6, 7952-7970.

Kitchen J, Armston J, Clark A, Danaher T, Scarth P (2010), 'Operational use of annual Landsat 5 TM and Landsat 7 ETM+ image time-series for mapping wooded extent and foliage projective cover in north-eastern Australia', in *Proceedings of the 15th Australasian Remote Sensing and Photogrammetry Conference*, Alice Springs, Australia, 13–17 September, 2010.

Queensland Herbarium (2018), *2017 Remnant Vegetation Cover of Queensland,* Version 11.0 (December 2018), Department of Environment and Science, Brisbane.

Scarth P, Armston J, Danaher T (2008a), 'On the Relationship between Crown Cover, Foliage Cover and Leaf Area Index' *Proceedings of the 14th Australasian Remote Sensing and*

Photogrammetry Conference, Darwin, Australia, October 2008.

Scarth P, Gillingham S, Muir J (2008b), 'Assimilation of spectral information and temporal history into a statewide woody cover change classification', *Proceedings of the 14th Australasian Remote Sensing and Photogrammetry Conference'*, Darwin, Australia, October 2008.

Specht (1983), 'Foliage projective covers of overstorey and understorey strata of mature vegetation in Australia', *Australian Ecology,* 8, 433-439.

Storey J, Choate M, and Lee K, (2014), 'Landsat 8 Operational Land Imager On-Orbit Geometric Calibration and Performance' *Remote Sensing*, *6*(11), pp. 11127–11152.

Zhu Z, and Woodcock C (2012), 'Object-based cloud and cloud shadow detection in Landsat imagery', *Remote Sensing of Environment*, vol. 118, pp 83-94.

Appendix A: Calculation of Woody Vegetation Clearing Rates

i. Woody vegetation clearing rates in SLATS

The Statewide Landcover and Trees Study (SLATS) was established in the mid–1990s and has been mapping the amount of woody vegetation clearing in Queensland back to 1988 using Landsat satellite imagery. This work has been described in a series of reports, available from the Queensland Government website. The mapping has been based on annual or multi-annual snapshots of the state, which are compared in order to map the areas where woody vegetation cover has been removed, i.e. cleared. One of the main products of this study is an estimation of the area cleared on an annual basis. The earliest versions of this study operated on more limited data, with one snapshot every few years, but since 1999 comparison between pairs of images separated by approximately one year has been possible. These dates are always chosen to be in the dry season (most commonly in the months of August and September). Imagery from these drier months has greater likelihood of being cloud-free, and there is usually greater contrast between tree cover and grass cover under these conditions.

The Landsat satellite passes over any given area in Queensland once every 16 days, scanning a path 185 kilometres wide. Sometimes the resulting images are cloud-affected–at times the images can be completely covered by cloud. In these cases, the imagery is of little value for the detection of land cover change features, including woody vegetation clearing. Therefore, it is not always possible to monitor at exactly the desired date. In some years, the occurrence of two or more cloud-affected images in a row can result in a significant time lag between acquisition of a useful image and the desired monitoring date.

For SLATS, woody vegetation clearing is mapped directly from these available images. However, this means that the total amount of clearing mapped can correspond to a shorter or longer period than one year. If the figures are to be compared between years, this discrepancy must be accounted for. For example, if this is not taken into account, an apparent increase in the mapped area of woody vegetation clearing could be evident, partially due to mapping over a longer period in some areas.

To date, the area of mapped woody vegetation clearing has been used to estimate a woody vegetation clearing rate, in hectares/year, for the region under study. This figure is an estimate of the amount of woody vegetation clearing which would take place in the region during one ideal year (i.e. 365.25 days). These woody vegetation clearing rate figures have been calculated in this manner to enable direct comparison from one year to another. This was particularly important in the earlier years of the SLATS study, when the study periods covered multiple years. Even for the later periods (up until 2013–14), which were nominally annual, the variation could be significant, and so conversion to an annual rate was still necessary to enable comparisons between years.

This document describes the methodology used since the 2014–15 period to estimate the annual clearing rate from the area mapped by SLATS, detailing the assumptions and limitations of this estimate. Section ii defines what we mean by a woody vegetation clearing rate, and the assumptions required. Section iii discusses in detail the sources of variation in period length, and how it has been distributed historically. Sections iv and v discuss the spatial and temporal calculations needed to estimate the annual woody vegetation clearing rate as robustly as possible. Finally, section vi discusses the previous rates calculation method (version 1.0) used prior to the 2014–15 period, and the reasons for changing to the current (version 2.0) methodology.

ii. Clearing rates

Woody vegetation clearing is mapped by comparing imagery from two dates. Thus, the exact date of a clearing event is not known, only that it occurred at some time between the two imagery dates. To estimate the amount of woody vegetation clearing in exactly one year, an assumption must be made about the rate at which woody vegetation clearing is occurring. The simplest assumption is that woody vegetation clearing occurs at a constant rate during the period monitored, and use that constant rate to estimate the area of clearing for exactly one year. For example, if there are two dates which are 1½ years apart, it seems reasonable to assume that the woody vegetation clearing occurred at a constant rate over that period, and that therefore 2/3 of that woody vegetation clearing would have occurred in 1 year (1 year is 2/3 of 1½ years). As discussed in the following sections, there are reasons for making this calculation slightly more complicated, but this is the general idea.

It is important to note that this assumption is only valid when making estimates of the amount of woody vegetation clearing which would occur over one year in a given region. It is not possible to derive exactly which locations would be cleared, only that within a given region, it is likely that a certain amount of clearing would occur in any 365 day period. In addition, it should be noted that the smaller the region in question, the less valid the assumption. For example, if the region were the size of a single small property, it is likely that a landholder might clear a certain stand of woody vegetation in a single event, perhaps over a few days, and it is therefore not valid to assume that the woody vegetation clearing would occur at the same rate throughout the year. It is only when aggregating over much larger regions that is can be assumed that clearing is occurring at a fairly constant rate in that region. Furthermore, it is also not valid to assume that woody vegetation clearing occurs at a constant rate over the whole of Queensland, because different amounts of woody vegetation cover are available for clearing in different regions and there are different imperatives that would drive activity in different regions. For example, woody vegetation clearing occurs at a much lower rate in the Mitchell Grass Downs, where there are very few trees, than in the Mulga Lands, where there are many more trees and shrubs, and other land management requirements.

The size of the region in question should be large enough such that the area being cleared is very small compared to the total size of the region, but small enough to assume that there are the same drivers for woody vegetation clearing, and thus the same rate of woody vegetation clearing occurring over the region. Therefore, larger regions should be disaggregated, and smaller regions aggregated. For reporting since 2014–15, SLATS has disaggregated larger regions to the Landsat scene size (approximately 160km x 160km, or 2.5 million ha, after removing overlaps between scenes), and the smallest regions are sub-catchments on the order of 10000 ha. The Landsat scene is also a suitable unit because this is how the imagery is acquired, and so dates are notionally constant over a single scene (although in some cases images are composited together from multiple dates – see Section iii).

Currently, there are little or no data on how the rate of woody vegetation clearing might vary throughout the year. As outlined above, an assumption is made that woody vegetation clearing occurs at a constant rate through the year, given that SLATS only monitors woody vegetation clearing once per year. It is possible that woody vegetation clearing follows seasonal patterns, and is more common at certain times of year, but to date there are little data available to substantiate this.

iii. Variation in period length

The first SLATS period mapped was from 1988 to 1991, approximately three years, with imagery only available for the start and end dates of the period. The next period mapped was a nominal four year period, from 1991 to 1995. After that, mapping was carried out in two year periods 1995–97 and 1997–99, and from then on, annual imagery was acquired, so mapping was notionally performed on an annual basis.

For the periods from 1999 onwards, Figure i summarizes how the period length has varied over time, across Queensland. The solid line is the median length for each period (in days). This is generally around 365 days. The other lines show how much variability there is in period length across Queensland, for each period. The dashed lines show the upper and lower quartiles, which means that the period length of 50% of pixels lies between these two lines. The dot-dashed lines show the 10th and 90th percentile of the period length, which means that the period lengths of 80% of pixels lie between those two lines. The outer lines are the extremes, and probably represent only a small percentage of these data.

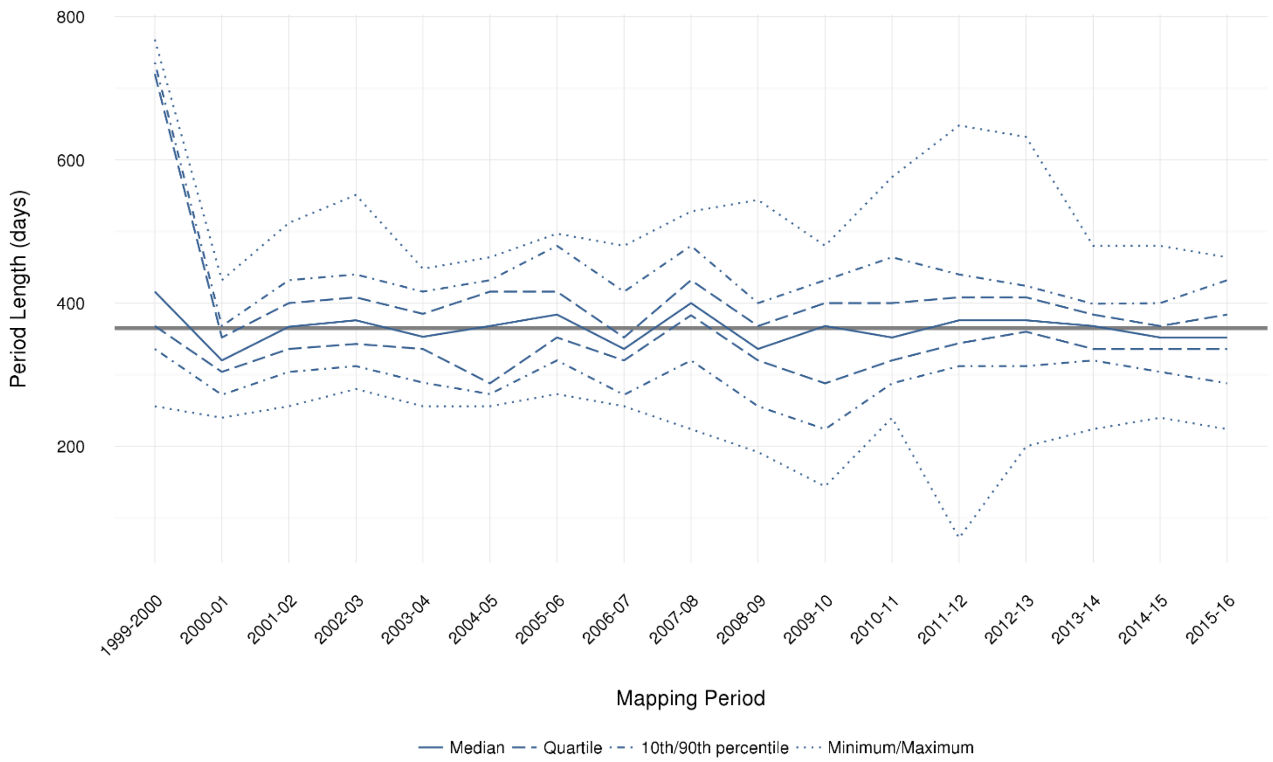


Figure i: Variation in SLATS period length since 1999. Solid blue line is the median period length, over all pixels, for each period. Solid grey line is 365 days, i.e. 1 standard year. For each period, 50% of pixels have a period length between the two quartile lines (blue dashes).

The 2011–12 and 2012–13 periods, both of which include the imagery for 2012, show wider variation in the extremes. This is due to the fact that the 2012 imagery was composited from multiple images, as a result of the use of Landsat-7 SLC-off imagery. The Landsat 7 SLC-off is a result of a partial failure on board the satellite and results in gaps (i.e. no data) in the imagery. Further details of this are explained in the 2011–12 SLATS report (DSITIA, 2014). It resulted in a much larger range of dates being required to allow coverage of all pixels.

The 1999–2000 period shows a small percentage of very long periods. This is due to the fact that for a number of scenes, no cloud-free imagery was available for the year 2000, and so in effect those scenes were mapped as two year periods, from 1999 to 2001.

After 2012, imagery was also composited in some cases (about 25% of scenes), to create a cloud-free image where none was available during the target period. This resulted in a narrower range of dates for most locations, because, for example, two consecutive partly cloudy images could be used to produce a single cloud-free image. This shows up in Figure i as a narrowing of the 10th/90th percentile lines for 2013–14 and 2014–15 periods, with a greater proportion of pixels having a period length closer to 365 days.

The use of image compositing from 2012 onwards has required systems to track the dates of every pixel, instead of just the dates of each scene, as was done previously. While this is somewhat more complex, the general principles are the same when considering the calculation of the woody vegetation clearing rate. However, when calculating the annual woody vegetation clearing rate across any group of pixels which do not all have the same start and end dates, some allowance must be made for this. The current method of accounting for this is described in Section iv.

iv. Summarising clearing area and period length over a polygon

In order to calculate the annual woody vegetation clearing rate over a given polygon (e.g. a bioregion or a drainage division), we need to know the area of woody vegetation clearing actually detected in that polygon, and the length of time for which that polygon was monitored, i.e. the period length for that polygon.

The actual area mapped is given by the total area of all pixels which were mapped as woody vegetation clearing for the period. However, given that the period length varies spatially (i.e. from pixel to pixel), there may be no single value for period length for a given polygon. To account for this, the period length for the polygon is approximated by the average value of the period lengths for each pixel contained within the polygon (based on pixel centre coordinates). All pixels in the polygon are considered, carrying equal weight. This provides an appropriate weighting for different parts of the polygon and different period lengths for pixels within the polygon.

Note that both of these computations are carried out with pixels projected in Albers Equal Area projection, so that areas carry their correct relative weighting, regardless of location.

v. Estimating clearing rate over time

When estimating the woody vegetation clearing rate for a single period, the only information available is the area cleared in that period, and the period length. However, when there is a time series of clearing areas and image dates over a number of years, there is more information available about how the rate of clearing has varied over time. If the assumption is made that we are estimating the annual woody vegetation clearing rate for a specific 12 month period, explicit use can be made of the clearing area and image dates from the adjacent periods to refine the estimate of clearing rates in any given period.

This can be illustrated by considering the accumulated area cleared over time, for a single Landsat scene which has not been composited. Using a single Landsat scene means the spatial distribution considerations discussed in Section iv can be ignored, as the period length is constant over the scene. Woody vegetation clearing actually occurs as a series of small events, throughout the year. However, the totals are only observed at the selected imagery dates, once per year. By plotting these once-per-year observations as cumulative values, it can be shown how these single snapshots are representative of an ongoing process. Figure ii is an illustrative example of this for a single Landsat scene. The solid blue line shows the actual area of woody vegetation clearing mapped, as it accumulates over multiple years. This accumulation has been observed on two dates, 31 October 2000 and 20 June 2001. An estimate of the annual woody vegetation clearing in this period is based on not only the clearing which occurred between these two dates, but also our knowledge of how much clearing was occurring in the periods prior to, and following those dates. The solid red line shows how we would estimate the cumulative woody vegetation clearing rate on 1 August of 2000 and 2001. The annual woody vegetation clearing rate is thus the difference between these two estimates.

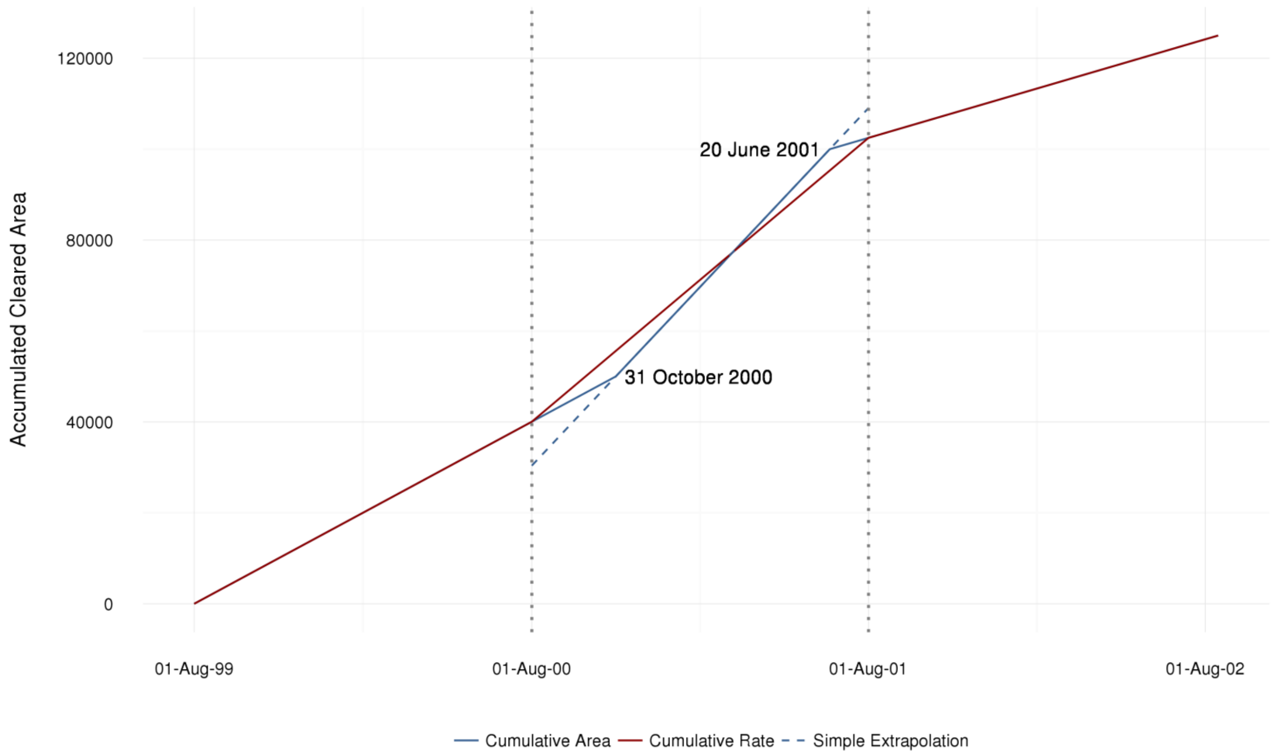


Figure ii: Example calculation of clearing rate from clearing area, for a single Landsat scene. The solid blue line shows the cumulative area cleared, over time. The area of clearing is observed on 31 October 2000 and 20 June 2001. Solid red line shows accumulated annual clearing rate, observed on 1 August each year. Dashed blue line uses a simple extrapolation to estimate change in cumulative clearing, without using known clearing area from preceding and following periods. Annual clearing rate is the difference between the cumulative values on 1 August, and this shows the benefit of using the surrounding periods (red line), instead of just the period in question (dashed blue line).

The dashed blue line demonstrates what would happen if the clearing from the previous and following periods was not taken into account. The measured clearing rate for the period would simply be extrapolated between the two observation dates, extending it out to occupy a full year. In this particular case, this would result in a slightly higher estimate of the annual clearing rate. It should be noted however, that a different set of numbers and dates could give a lower estimate. This is discussed further in Section vi. From the 2014–15 reporting period onwards, the estimation of rates from the areas and dates is carried out after the spatial averaging described in Section iv, i.e. it happens for each polygon of interest.

vi. Comparison with version 1.0 method

Prior to the 2014–15 period, a different method was used for calculating annual woody vegetation clearing rate. This method (version 1.0) was initially used at the start of the SLATS program, and was suitable for the computing hardware and software of the time. It was preserved over subsequent reporting periods in order to maintain comparability with previous reporting. However, the methodology has been improved and used since the 2014–15 reporting to better account for the spatial and temporal distribution of woody vegetation clearing and period length variation, resulting in the method described in Sections iv and v (version 2.0). This has also been made possible by a significant improvement in computational hardware and software in recent years.

Version 1.0 differed in two ways. Firstly, the period lengths were only attached to the clearing pixels, rather than to all pixels, and so pixels which were not mapped as clearing were not explicitly weighted. This relied on the implicit assumption that the distribution of period lengths over "non-clearing" pixels was the same as over "clearing". In principle this is a reasonable assumption, as there are no systematic reasons to the contrary, however, it may be less valid in smaller regions where random chance can have more impact. By changing to the newer method, the period length of pixels which are not mapped as woody vegetation clearing is explicitly taken into account, and therefore the period length estimation for each polygon will be more robust against random chance. Version 1.0 was originally chosen as it was more feasible with the available software and hardware, but these limitations no longer apply.

Secondly, version 1.0 estimated the annual rate using only the dates of each period, and without taking account of the clearing mapped in a prior period. This corresponds to the dashed blue line shown in Figure ii. During the first SLATS period, this was the only method available, since there were no prior mapped periods. In subsequent periods, the same methodology was retained for consistency. However, given that there are now many years of woody vegetation clearing data available, as well as improved computational capacity, it is now possible to provide a more robust estimate of the rate of clearing using the multi-date method of version 2.0, as outlined in Section v. This method also has the advantage that it preserves the cumulative total area cleared, whereas the previous, simpler method relied on the assumption that the over-estimates and under-estimates will, on average, cancel out. It should be noted however, that for completeness, the adoption of this new method implies that when the next period is mapped, the clearing rate estimate for the previous period should be revised, in light of the newly available data. This is the technique used in the 2014–15 and 2015–16 reports, and so all figures in the whole historic time series have been re-calculated on a consistent basis to allow for comparisons between periods.

In practice, these changes in woody vegetation clearing rate estimation methods make only small differences to the final figures. To demonstrate this, Figure iii shows the whole time series of annual woody vegetation clearing rates for Queensland, from 1988 until 2014, calculated using the old and new methodologies.

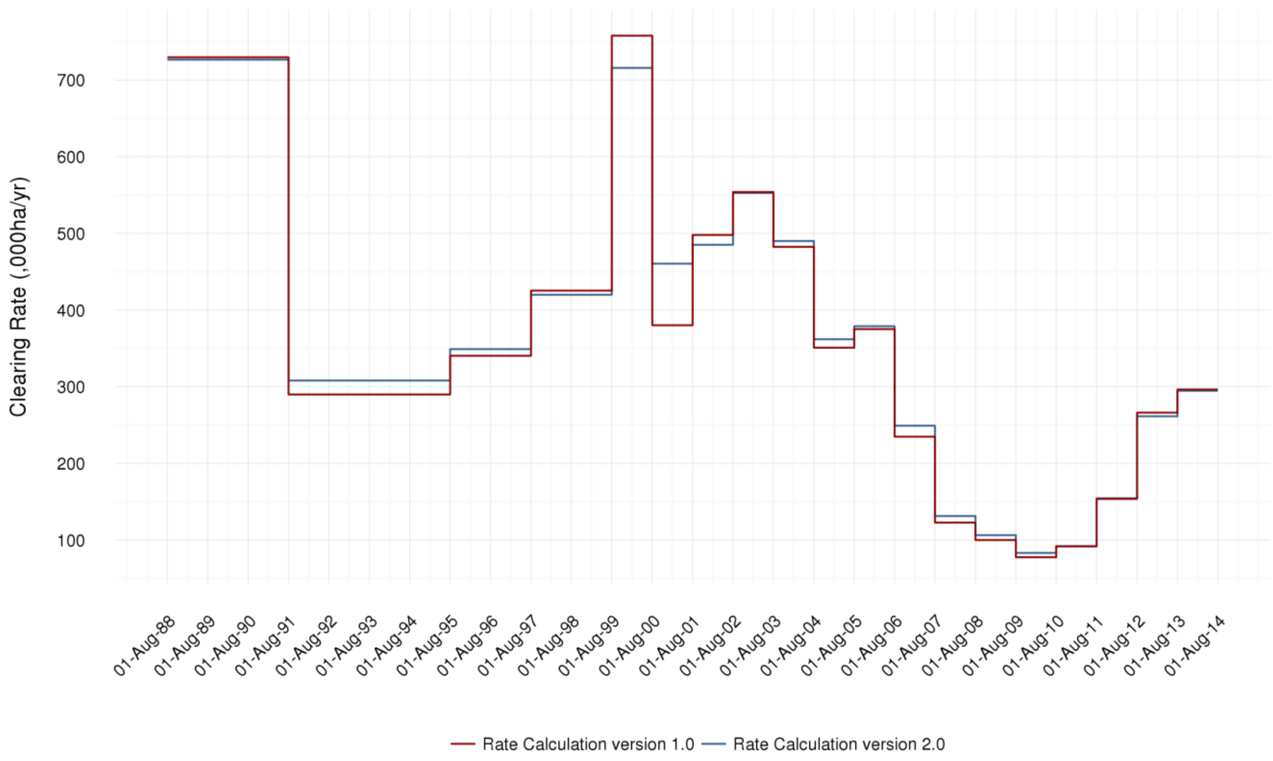


Figure iii: Annual clearing rates using the version 1.0 (red line) and version 2.0 (blue line) methodologies.

The red line is the annual woody vegetation clearing rate estimates as they have been given in past SLATS reports. The blue line is the estimates calculated using the version 2.0 methods described in this appendix. In almost all periods the difference is very small. The main exception is in the periods 1999–2000 and 2000–01. The reason for this is that the 1999–2000 period included a number of scenes for which cloud-free imagery was unavailable in 2000, and so they are, in effect, mapped as a two year period followed by a period of zero length. This point is discussed in Section iii. By taking account of the known clearing area in the prior and following periods, the estimate of the annual woody vegetation clearing rates are now more robust against these variations in actual period length.