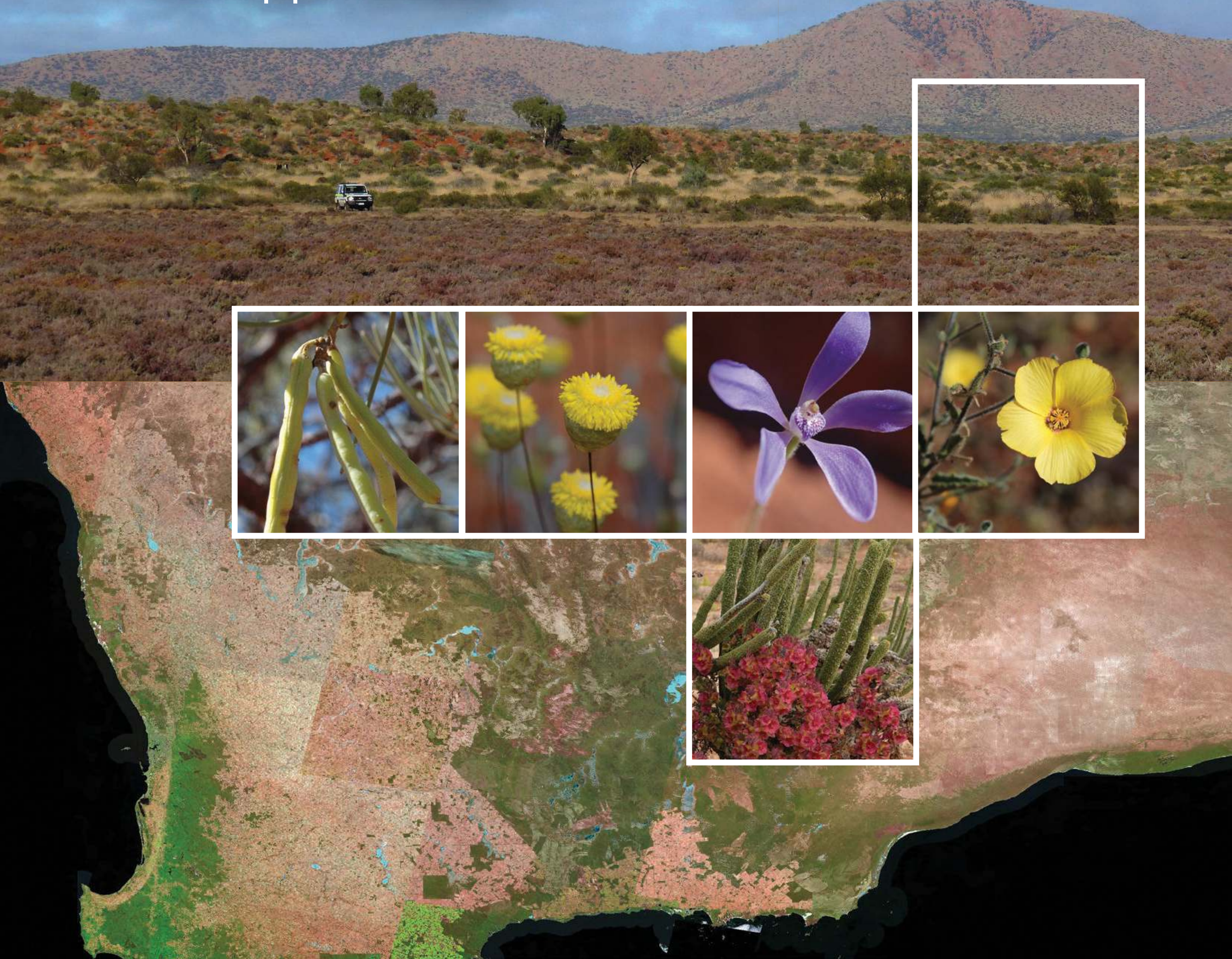
The Western Australian Biodiversity Science Institute

Measuring native vegetation extent and condition using remote sensing technologies

A review and identification of opportunities



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Contents

List of Figures

List of Tables

Acronyms

ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
ADS40	Airborne Digital Sensor 40. The first commercial digital airborne camera designed to fulfil both photogrammetric and remote sensing requirements
ALOS	Advanced Land Observing Satellite. From the Japan Aerospace Exploration Agency (JAXA) Earth Observation Research Center
ANU	Australian National University
ARD	Analysis Ready Data. Data processed to standards and to a level required for direct use in monitoring and assessing landscape change
AusCover	TERN AusCover is a national data delivery service and expert network providing a range of remote sensing information about Australian environments. It includes time-series of key environmental variables, continental-scale map products, high-resolution datasets for sites, and essential ground calibration and validation datasets for airborne and satellite image data
AVHRR	Advanced very-high-resolution radiometer measure reflectance in five spectral bands: red (0.6 µm), near-infrared (0.9 and 3.5 µm) and thermal infrared (11 and 12 µm). Pixel resolution is 1.1km
BIO	Biodiversity Information Office – a WABSI-led proposal
Bionet	The repository for biodiversity data products managed by the Office of Environment and Heritage (OEH) in NSW
CPN	Conditional Probability Network
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DAF	Department of Agriculture and Fisheries (Queensland Government)
DBCA	Department of Biodiversity, Conservation and Attractions (Western Australian Government)
DoEE	Department of the Environment and Energy (Australian Government)
DENR	Department of the Environment and Natural Resources (Northern Territory Government)
DFES	Department of Fire and Emergency Services (Western Australian Government)
DPIRD	Department of Primary Industries and Regional Development (Western Australian Government)

DMIRS	Department of Mines, Industry Regulation and Safety (Western Australian Government)
DEA	Digital Earth Australia. A digital infrastructure within Geoscience Australia that uses satellite data to detect physical changes across Australia
DEM	Digital Elevation Model – maps of the elevation of the earth's surface. Also called digital terrain model (DTM) as distinct from digital surface models (DSM) which record the highest elevations (tops of trees, buildings etc.)
DEW	Department of Environment and Water (South Australian Government)
DELWP	Department of Environment, Land, Water and Planning (Victorian Government)
DPIF	Department of Primary Industries and Fisheries (Queensland Government)
DPI	Department of Primary Industries (NSW Government)
DPIPWE	Department of Primary Industries, Parks, Water and Environment (Tasmanian Government)
DPLH	Department of Planning, Lands and Heritage (Western Australian Government)
DSITI	Department of Science, Information Technology and Innovation (past Queensland Government Department). Science is now with the Department of Environment and Science. Information Technology is with the Department of Housing and Public Works. Innovation is with the Department of Innovation and Tourism Industry Development and the Commonwealth Games
DSM	Digital surface model. Maps the elevation of the highest surface (trees, buildings, open ground etc.)
DWER	Department of Water and Environmental Regulation (Western Australian Government)
EPA	Environmental Protection Authority (Western Australian Government)
EROS	Earth Resources Observation and Science. A USGS centre which studies land change and produces land change data products
ESA	European Space Agency. An international organisation with 22 Member States. Responsible for the Sentinel 1 and 2 platforms
EVI	Enhanced Vegetation Index enhances the vegetation signal in high biomass regions. Compared with NDVI it is more responsive to canopy structural variations, including leaf area index (LAI), canopy type, plant physiognomy, and canopy architecture. Is complementary to NDVI

Fractional cover	The fraction of an area (usually a pixel for the purposes of remote sensing) that is covered by a specific cover type such as green or photosynthetic vegetation, non-photosynthetic vegetation (e.g. stubble, senescent herbage, leaf litter) or bare soil/rock
GA	Geoscience Australia (Australian Government)
GEOGLAM	GEO Global Agricultural Monitoring initiative. A Group of 20 initiative to strengthen global agricultural monitoring by improving the use of remote sensing tools for crop production projections and weather forecasting
GFOI	Global Forest Observation Initiative
GHG	Greenhouse gas
GIS	Geographic Information System
GLADIS	Global Land Degradation Information System (established by the Food and Agriculture Organisation) is a global tool that contains low resolution information on the status of land and ecosystem resources and the processes acting on them
Ground cover	Vegetation (living and dead), biological crusts and stone that is in contact with the soil surface. The non-woody ground cover such as crops, grass, forbs and chenopod-type shrubs may change monthly, making this component a good indicator of land management performance. Ground cover is a sub-component of land cover and (from a remote sensing perspective) is the fractional cover of the non-woody understorey
HCAS	Habitat Condition Assessment System
IBSA	Index of Biodiversity Surveys for Assessments
IPCC	Inter-governmental Panel on Climate Change
Land cover	The physical surface of the earth, including combinations of vegetation types, soils, exposed rocks and water bodies. Land cover classes may be discriminated by characteristic patterns using remote sensing. Land cover is distinct from land use. Land use is how humans use the land, e.g. for urban, forestry and agricultural land uses
Landgate	The Western Australian Land Information Authority operates under the business name of Landgate. It is the guardian of property ownership and custodian of WA's location information asset. It contains a unit responsible for aerial photography and satellite remote sensing acquisitions on behalf of government agencies
MODIS	Moderate Resolution Imaging Spectroradiometer
MSS	Multi-Spectral Scanner, the first phase of Landsat with 80x80m pixel sizes

NAFI	Northern Australia Fire Index
NASA	National Aeronautics and Space Administration
NCAS	National Carbon Accounting System, now part of the National Inventory
NCI	National Computing Infrastructure – a supercomputer network housed at ANU
NCRIS	National Collaborative Research Infrastructure Strategy. A national network of research infrastructure projects to drive greater innovation
NDVI	Normalised Difference Vegetation Index - the ratio between the near infrared and the visible red light reflected from vegetation. NDVI = (NIR – R)/(NIR + R)
NPP	Net primary productivity
NVIS	Native Vegetation Information System – a program of the DoEE which assembles the best native vegetation maps from each state and territory
NVR	Native Vegetation Regulatory map. A NSW Government map which categorises land where management of native vegetation can occur without approval or where management of native vegetation may be carried out in accordance with an act of parliament
ODC	Open Data Cube. An open source geospatial data management and analysis software project managed by GA to help harness the power of satellite data. It has a set of Python libraries and a PostgreSQL database that helps clients work with geospatial raster data
OEH	Office of Environment and Heritage (NSW Government)
OGC	Open Geospatial Consortium. An international not for profit organisation committed to making quality open standards through a consensus process
PAR	Photosynthetically active radiation
PCT	Plant community type
PFC	Projected foliar cover
PLB	Pastoral Lands Board
Polygon	A figure with three or more sides all lying on one plane
PWS	Parks and Wildlife Service. A section within DBCA (Western Australian Government)

QGIS	A free and open-source cross-platform desktop GIS application that supports viewing, editing and analysis of geospatial data
Raster model	A representation of the world as a surface divided into a regular grid of cells. Raster models are used to store data that varies continuously such as aerial photographs, satellite images and elevation surfaces
RCM – NVI	Resource Condition Monitoring – Native Vegetation Integrity. A 2008 project managed by the Department of Environment and Conservation (Western Australian Government)
RSII	Remote Sensing and Image Integration. A program within CSIRO's Data 61
RUE	Rain use efficiency – the ratio of Net Primary Productivity (NPP) to Precipitation - a measure of degradation. 'Water use efficiency' includes irrigation as well as rainfall
SCDI	Seasonal cover disturbance image – an index used to identify and map non-woody vegetation change beyond established land use data classifications by identifying the pattern of change in vegetation cover over multiple seasons and across multiple years
Sensor change effect	Extending a record of observations across more than one sensor can result in discontinuities because of different spatial and/or spectral resolutions. The discontinuities represent a sensor change effect which need to be taken into account
SLATS	State-wide Landcover and Trees Study (Queensland Government)
SLICP	State Land Information Capture Program – aerial photography capture program
SOG	Senior Officers Group within natural resource management agencies (Western Australian Government).
SPOT	Satellite Pour l'Observation de la Terre. A French satellite
TERN	Terrestrial Ecosystem Research Network. Australia's land-based ecosystem observatory delivering data streams to enable environmental research and management
TLS	Terrestrial Laser Scanning for vegetation biomass monitoring
USGS	United States Geological Survey. Part of the US Department of Interior
Vector models	Polygons, points and lines constitute vector models useful for storing one-dimensional data with discrete boundaries
WABSI	The Western Australian Biodiversity Science Institute

WALIS	Western Australian Land Information System. Established in 1981 to coordinate the discovery of, and access to, location-based or geographic data generated by WA Government agencies
WOfS	Water Observations from Space. A Geoscience Australia product showing when, and the proportion of the time between 1987 and 2014, an area had surface water

Summary

The Western Australian Biodiversity Science Institute commissioned this study to review and report on the use of remote sensing technology nationally and globally for mapping the extent of native vegetation, and monitoring change in extent and condition.

The review analysed existing remote sensing technologies and data providers including consideration of the limitations and opportunities of each. It also examined the extent to which the various existing technologies and products could contribute to a state-wide native vegetation measurement and monitoring program.

Its main conclusion is that Western Australia has long experience and capacity in remote sensing of native vegetation, but its potential is yet to be fully utilised.

Like other states, Western Australia's main use of vegetation remote sensing is in response to defined legislative needs relating to management of condition of leasehold land in the rangelands and to regulating clearing. There is use of remote sensing of vegetation in nature conservation areas aimed at management interventions but very limited analysis of loss in extent and condition on freehold land caused by chronic issues such as overgrazing, land degradation (including the salinisation of low-lying areas), plant diseases, pests, inappropriate fire regimes and climate change. This deficiency appears to be the result of a lack of resources and expertise to examining existing imagery rather than a lack of suitable data. The supply of imagery and the ease of access have increased rapidly in recent years, but the capacity and expertise to use these products to their potential within state agencies is limited.

The best example of coordinated use of remote sensing in Western Australia has been the Land Monitor project that has provided perennial vegetation extent (and indicators of condition change) mapping for the entire south west to a consortium of state Natural Resource Management (NRM) agencies since the late 1990s. This monitoring was extended to the rest of the State in late 2018 but is yet to be used to estimate state-wide statistics. Land Monitor provides annually-updated raster maps of woody vegetation extent, clearing and regrowth. The Land Monitor Trends product provides indicators for the south west of cover change within this woody vegetation, which are spatially and temporally detailed. Automated recognition of non-native vegetation is not part of the system and would require additional research and inputs. Further investment is required to develop value-added vegetation cover products from this state-wide dataset. A proposal to develop native vegetation extent and change products for Land Monitor operational processing was put by the Land Monitor consortium to the Department of Water and Environmental Regulation for consideration last year.

The gap between potential and use is widening as analysis-ready data and finer-scale resolution remote sensing data (from satellite and digital aerial photography) become increasingly available, some for free. Monitoring is a long-term activity requiring specialist expertise. A cross-state commitment and clear institutional arrangements are important to ensure that monitoring is continuous and to a high standard.

As shown in the table below, early optical monitoring had a low spatial resolution. MODIS and its predecessor have a high frequency and longevity but a low spatial resolution making it only suitable for coarse analyses. High spatial resolutions greatly increase usefulness (e.g. the detection of small areas of illegal clearing, targeting of ground data collection, carbon accounting) but the data size makes analysis more challenging. For example, digital aerial photography contains about 40,000 times more observations than MODIS for the same area, and so requires high performance computation when extensive areas are analysed. Landsat imagery has much higher volumes than MODIS.

In spite of this, the need to meet demanding information requirements has seen the development of national and state Landsat-based vegetation monitoring programs since the late 1990's (Section 4 of this report). Modern computational methods and recent developments in data access have significantly reduced the cost of processing large volumes of data.

Platform	Spatial resolution (m)	Frequency of acquisition	Length of record	Approximate Data size (kB/km^2)
Aerial photography	0.2 - 0.3	Biannually Perth-Peel; every 5-10 years in other populated areas; every 20 years in remote areas	Digitised analogue film since the 1930s. Digital photography (including near infra-red) in some areas since about 2010	4000 Urban Monitor including a near infra-red band
MODIS, AVHRR	250 - 500	Daily	Since 1970s	0.1
Landsat series of satellites	30 - 80	Every 16 days subject to cloud	80m resolution 1972-88 30m resolution since 1987	2 20 (calibrated 6 bands)
Sentinel 2	10	Every 5 days subject to cloud	Since 2015 (Sentinel A) or 2017 (Sentinel B)	120-200 (depending on # bands)

There is little 'technology risk' in implementing state-wide vegetation monitoring at Landsat scale or better, and multiple agencies would benefit. However, apart from the Land Monitor initiative, there is little coordination of state remote sensing needs at a high or strategic level. At present in Western Australia, it is mainly project-specific issues that are being addressed, often to meet a single agency need.

Throughout Australia, regulatory requirements drive the monitoring of native vegetation extent and condition. This is the case for clearing control regulation in the Department of Water and Environmental Regulation and for rangeland monitoring by the Department of Primary Industries and Regional Development, the Department of Planning, Lands and Heritage and the Pastoral Lands Board.

The extent of clearing approved under Part V (Environmental Regulation) of the Environmental Protection Act 1986 is well known but it is less well known for approvals under Part IV (Environmental Impact Assessment). The former includes delegated clearing for urbanisation and capital works programs. Sentinel imagery is currently used to identify changes in vegetated areas and Land Monitor (Landsat series) provides annual checks and consistent historical information. The current approach is not sufficient to produce accurate estimates of cleared areas as a result of legal and illegal activities, nor does it account for revegetation for example, after mining).

Legacy arrangements underlie current vegetation extent mapping efforts (for example, past funding by the National Land and Water Resources Audit, Natural Heritage Trust). However, there has been a loss of momentum since federal funding ceased. As an example, the current vector data for native vegetation extent based on aerial photographs has resourcing and quality limitations but is used extensively by agencies for planning and prioritisation.

There is a growing gap between data availability and user awareness and capacity to use current remote sensing products. In most state agencies, and all local governments, there is limited capacity to use raster maps produced from remote sensing and limited ability to combine these with vector data. Arrangements to overcome this need to be addressed before existing remote sensing products can be fully used. Modern computational approaches can help bridge the user access gap by enabling access to centralised data and products, but investment is needed to produce both the delivery and access systems.

Remote sensing products are rarely the complete answer because they need to be used with other data and knowledge in relation to differing policy questions. State-wide vegetation association maps (Beard et al. 2013) are coarse in scale and the vegetation may have changed since the maps were produced. Remote sensing now can deliver information state-wide on physical difference and changes in vegetation at a scale which is far more detailed than the vegetation mapping. Improved underlying mapping would enable remote sensing products to be targeted to vegetation types. Accurate stratification on vegetation types would greatly assist in monitoring products and interpretation of changes in terms of cause and condition. It would also identify associations that are highly cleared or poorly represented under secure land tenure to decide whether clearing applications over such vegetation should be approved.

A proposal to improve state vegetation mapping ten years ago was deferred due to a lack of resources. New and improved remote sensing products, including higher-resolution images, radar, 3D photogrammetry and thermal infra-red bands, may allow vegetation maps to be upgraded more efficiently than in the past. This would require an investment in new analysis techniques but would provide superior products able to be regularly updated as digital data and analytical methods improve.

Information on plant species collected in biological surveys associated with environmental impact assessments are currently being captured in the Index of Biodiversity Surveys for Assessments by the Department of Water and Environmental Regulation. A proposal to house this data and additional biodiversity survey data in a Biodiversity Information Office is currently in development by The Western Australian Biodiversity Science Institute. Plot-based vegetation information is critical for updating the current vegetation maps of the State and such a facility could contribute to enabling this function.

An objective assessment of which factors are causing losses of vegetation extent and condition would enable better targeting of management interventions. More than 30 years of remote sensing products show vegetation changes at fine scale on freehold land in the south west. Remote sensing and GIS data, combined with ground-truthing, could be used to estimate the relative contributions of clearing, grazing, land degradation, pests-weeds-disease, fire, climate change and combinations of these processes. Such vegetation-landscape models have been used in the past to map salinity extent and potential in the south west.

There is an opportunity, building on current dispersed expertise and Western Australia's computing infrastructure, to create a specialist remote sensing group to provide the State with improved vegetation information. Such a group would require an institutional home, strategic goals, cross-agency commitment as well as specific funding allocation.

The Land Monitor project continues to use very modest state agency contributions ($10,000 per agency per annum) which limits the Consortium's ability to develop new products. It also relies on the continued contribution of CSIRO (WA) to provide the products at a reasonable rate. This partnership has enabled the State to develop innovative satellite and digital aerial photography map products.

It is recommended that the Senior Officer's Group within NRM agencies develop a cross-government set of needs for mapping and monitoring native vegetation and identify the best means of resourcing the initiative in the long term. While this will require some new resources, current resources could be used more strategically. The group could also decide how the State should respond to opportunities offered by the proposed Biodiversity Information Office, Digital Earth Australia, new platform sensors, the Pawsey Supercomputing Centre, data analysis technologies, and the Joint Remote Sensing Research Program, amongst other initiatives. Until a decision has been made on how best to manage NRM remote sensing demands and supply are decided, the Land Monitor Consortium could continue to provide technical coordination under guidance from the NRM Senior Officer's Group.

1. Introduction

The Western Australian Biodiversity Science Institute (WABSI) is an unincorporated joint venture partnership between research organisations which acts as a research broker to address Western Australia's strategic biodiversity priorities through collaborative research. WABSI enables and supports high quality and end-user driven research to address critical research gaps. It ensures that information is made available in a form that is relevant and accessible to policy makers, industry, land managers and other stakeholders.

It is in this regard that WABSI commissioned this review of the use of remote sensing technology, nationally and globally, for mapping the extent of native vegetation, and monitoring change in extent and condition.

The review includes an analysis of existing remote sensing technologies and data providers including:

1. Limitations and opportunities of each; and
2. The extent to which the various existing technologies and products could contribute to a state-wide native vegetation measurement and monitoring program in Western Australia (WA).

This report also examines options for utilising remote sensing data in WA to develop spatial information products. It is confined to perennial native vegetation within WA, excluding introduced plants such as plantations and woody weeds except where they impact on native vegetation extent and quality.

When added to other datasets, an assessment of extent, condition and change in condition of native vegetation could be used to help answer the following questions:

1. How much native vegetation is directly cleared each year in WA, and where?
2. How much native vegetation remains in WA, and what associations do they represent?
3. How is the area changing over time, especially for important or rare associations; and are these changes cyclical or directional?
4. What are the trends in vegetation condition and what factors are affecting these changes; climate, grazing, fire regimes, weeds, pests and diseases, clearing, land degradation (especially dryland salinity), droughts, floods etc.?
5. Are conservation programs effective and achieving their set goals and outcomes?
6. Where should management and policy interventions be targeted to have most impact?

To be able to be combined with other datasets, maps of presence and of changes in condition have needed in the past to be in vector form to be overlain with maps of ground condition monitoring, fire scars, known pest occurrences, grazing pressures etc. Remote sensing images are raster data, and the products derived from them by digital processing are in raster format. While thematic raster products can be 'vectorized' over small areas, vector formats are not suitable for recording or analysing products from medium- and high-resolution remote sensing. This report examines the need to combine vector and raster data so that large remote sensing datasets can be best utilised by agencies and individual operators. The project involved consultation with providers and users of remote sensing products throughout Australia, as shown in the acknowledgements section.

2. Measuring native vegetation extent and condition

Native vegetation in Western Australia (WA) varies from isolated chenopods growing on salt-affected soils to dense karri and tingle forests in areas receiving more than 1200 mm of annual rainfall. Therefore, vegetation in arid areas may be in excellent condition but have very low leaf area indices and reflectance in those parts of the electromagnetic spectrum known to detect actively photosynthesising vegetation.

An economic way of routinely assessing native vegetation extent and change over time for an area of almost 2.65 million km^2 requires repeated observations and other datasets. Suitable remote sensing data and methods are increasingly feasible with advances in data access and computation. Cloud cover is not a major issue in collecting optical remotely-sensed data from WA given about three-quarters of the State receives less than 400mm of rainfall per annum. Rainfall is strongly seasonal; winter in the south and summer in the north.

Remote sensing provides unique capacities for monitoring vegetation extent and change but is less suited to mapping of vegetation types based on species.

Two essentially different types of information products can be generated from remote sensing imagery. Both are relevant to vegetation monitoring. The first is a 'classification map' where the image data is processed to assign a label to each pixel analogous to conventional mapping; one relevant example is a 2-class map of 'woody vegetation' and 'not-woody-vegetation'. Maps of change over time (e.g. clearing) can be generated by differencing two independent maps, or by more sophisticated schemes. Classification maps can be summarised to produce statistical area summaries of thematic classes.

The second type of product is a raster 'image' of a continuous variable or index derived from the pixel data. Examples are 'cover indices' and greenness indices including the well-known Normalised Difference Vegetation Index (NDVI). Spectral indices may be linked by empirical means or theoretical modelling to biophysical measurements (such as biomass or cover percent) and these indices may be used as surrogates or estimates of the true values. Spatial variation in the index, and particularly temporal changes, are used to indicate changes in the associated physical variable. Numerous studies in WA and elsewhere have shown that optical remote sensing can detect vegetation changes within native vegetation at the scale of management (e.g. grazing, removal of understorey) and ecological processes (e.g. fire, drought, weed invasion).

Remote sensing alone is not suited to identify species or composition, nor to differentiating native from non-native vegetation. Some perennial tree and horticultural crops may be spectrally separable from native vegetation, but in general other data are required to identify non-native vegetation. Remote sensing records the integrated signal from physical components within a pixel – including soil, living vegetation and cover/litter. It can be used to map broad variations in vegetation associated with physical differences at the pixel scale which may correspond to broad vegetation types in undisturbed systems. It is not suited to mapping of vegetation types based on presence of particular species. Disturbance (e.g. from fire) and degradation of vegetation vary the physical signals from vegetation but may not alter the 'vegetation type' from a botanical or land system view.

Plants reflect light in different parts of the electromagnetic spectrum and satellite sensor bands have been chosen to discriminate between vegetated and non-vegetated areas, mainly in the visible and infra-red frequencies. Combinations of optical bands are used to monitor vegetation through cover or greenness indices; the most common being NDVI. This is calculated by (NIR – R)/(NIR + R) where NIR is the near infra-red and R is the red part of the spectrum. NDVI is theoretically related to the proportion of photosynthetically active radiation (PAR) intercepted by green leaves. It is particularly sensitive to variations in green growing crops. Cover indices are often more relevant than NDVI to most Australian perennial vegetation as explained in Section 5.2.

The concept of vegetation condition has multiple and evolving definitions and nomenclature (ecological condition, biodiversity condition, rangeland condition etc.). Condition is thus problematic for direct measurement, mapping or monitoring. Lawley *et al*. (2016) reviewed site-based and remote sensing methods of monitoring indicators of vegetation condition in Australia. This paper illustrates that the lack of clear definition of 'condition' over large areas and vegetation types remains a major problem for any measurement scheme for condition itself.

Most states have protocols and manuals for ground-based recording of condition at sites; the summarised data taken as a measure of condition at the site. Implicitly or explicitly, the site recordings are referenced to some 'ideal' state of the structure, cover and composition of the vegetation group. These site recordings are most often used at specific locations of high value or may be required where development proposals are being assessed. Site data collection schemes are limited in space and time and are often not suited to informing landscape processes, nor to the detection of disturbance or change.

There are measurable spatial and temporal aspects to 'condition', such as fragmentation and recovery/decline under external forces such as rainfall, fire or grazing. Remote sensing data are well suited to inform such processes, and to provide updates for vegetation response models. National research projects are underway to develop and define metrics for condition incorporating time-series remote sensing. Estimates of condition usually need to be specific to vegetation associations because the same reflectance change could result from different vegetation responses, and changes may not reflect what is happening at the species level. An international review of remote sensing of vegetation by Xie (2008) similarly concluded that "a well-fit vegetation classification system should be carefully designed according to the objective of studies in order to better represent actual vegetation community compositions".

The 'Resource Condition Monitoring – Native Vegetation Integrity Project' (RCM-NVI;(Department of Environment and Conservation 2008) concluded that the appropriate management questions need to be asked when defining vegetation condition. The definition of vegetation condition used in this project was:

> *"A measure, for the purpose of biodiversity conservation, of indicators of vegetation composition, structure and function relative to a reference state (i.e. within the context of the presence or absence of threatening processes) at a patch or landscape (community or ecosystem) scale".*

The RCM-NVI project aimed to develop a long-term, large-scale, strategic approach to assess and monitor and evaluate native vegetation condition in Western Australia, with an overarching goal to conserve the State's biodiversity. The project was not progressed given resource constraints, and vegetation association maps remain at a coarse scale over much of the State.

Monitoring of cover and greenness changes using optical remote sensing is an established and operational technology in Australia. Cover changes from remote sensing have been shown to be sensitive to management impacts and other disturbances in rangelands, woodlands and forests in Australia. Cover changes in the context of rainfall events, fire, and other disturbances provide indicators of condition, and condition change. Where accurate vegetation maps are available, stratification to vegetation type enables comparison with known reference areas and detection of outlying change pixels. Condition may be inferred where conceptual models of condition relate to responses of the vegetation type and to climate or disturbance.

Remote sensing can provide some assessment of structure; indeed, stereo photography may be processed to provide direct estimates of vegetation height. Radar imagery also provides information on vegetation structural variations. Some functions (e.g. density and response to environmental conditions) may be inferred. However, on-ground survey measurements and validation are required to assess composition. Native vegetation also grows on soils with very different colours and spectral reflectance, and there is often dead vegetation and vegetation recovering from past fire events to confuse the signal.

As noted above, remote sensing can monitor vegetation cover changes over time in most environments. In general, a decline in perennial cover would be associated with declines in vegetation condition, while perennial cover increases or long-term stability would be associated with good condition. However, fire and weed invasion complicate simple interpretations. Fire is an extreme case – a burnt area with very low cover may in fact be judged to be in 'good' condition depending on the recovering plant species. Over time, introduced or native species may invade areas of native vegetation providing indicators of increased cover which can be detected by remote sensing. Weed invasion most often occurs on degraded areas. Numerous examples show that this process can be detected using Landsat 'Trends' products or similar. It is difficult to determine from remote sensing alone whether the increasing species are native or weeds. Further, the interpretation of 'condition change' following such events requires additional data or conceptual models.

Vegetation may be unable to grow in areas if the soil required for it to grow on is irreversibly degraded. The loss of native vegetation can result in severe land degradation such as the erosion of soil to a hardpan in parts of the rangelands. The annual loss of land to dryland salinity in Southwestern Australia has been determined using multi-temporal Landsat TM images and landscape (water-accumulation) models to be about 14,000 ha per annum (McFarlane *et al*. 2004).

Cover trends are effective at monitoring changes in sparse areas. Determining whether sparse areas have been cleared, or cover is declining for other reasons, is difficult without validation or other knowledge. Cover trends can detect changes over long time periods and draw attention to areas of low or no cover response. Rainfall is the most common limitation on vegetation growth in much of WA. Other limitations can be light, temperature, inundation, waterlogging, erosion, salt, sodicity, pH, boron toxicity, water repellence and nutrient deficiencies.

Aspects of condition status may entail assessing how vegetation cover responds (or does not) to rainfall; examples are annual-dominated versus perennial responses. In combination with stratification maps, time series remote sensing can provide indicators of such different responses. The work of Gary Bastin and colleagues provides well documented examples (e.g. Bastin *et al*. 1993, 2014). For arid vegetation in central Australia, they proposed a conceptual model of condition where failure of an area to increase its cover after significant rain was equated with degradation. Degraded areas were mapped from Landsat using temporal responses of cover indices from dates chosen with respect to major rainfall events. Accurate vegetation stratification maps were required to assess recovery against relevant ungrazed benchmarks. The cover trends approach to rangeland monitoring, developed initially in WA and since applied successfully over many areas of Australia (Wallace and Thomas 1998, Karfs *et al*. 2004; Section 7.2), is less prescriptive. It displays 'trend maps' showing areas of differing change in cover index over a chosen period; i.e. areas of stability, decline or increase. Stratification on vegetation type is used, so that a pixel's response can be compared with similar vegetation. Dry season imagery is chosen to focus on the perennial components of cover, and the period (typically a decade or more) is chosen with knowledge of the system and major weather events.

The 'VegMachine®' software package was developed to deliver the information to regional users. Expert knowledge and targeted on-ground validation are required to associate changes with condition change or other causes. As noted above, finer-scale vegetation maps for stratification would assist in producing best products and in interpretation.

Associations of dry season Landsat cover indices and WA site recordings of rangeland condition were examined in a study conducted by DAFWA (Robinson et al. 2012). In this case, the 'condition' measure was defined from historic traverse site data. Condition ratings, recorded on a 1-5 scale, were dichotomized to good and poor prior to analysis. After stratifying on vegetation type and property, a strong association of the condition rating and particular cover indices was demonstrated for almost all vegetation types. The study also implemented a version of the cover trends approach.

The main factors that need to be considered when choosing suitable satellite or aerial remote sensing data for assessing native vegetation in an area as large as WA are:

1. The number and location of the reflectance (and for radar, emission) bands being measured;
2. The spatial resolution of each pixel;
3. The frequency with which images are collected;
4. The cost of acquiring and storing data from the images;
5. The length of the historic archive, so that past conditions can be assessed;
6. Whether the data, or compatible data, will be continued to be archived in future; and
7. Whether the data has been or can be geometrically and radiometrically corrected to make it consistent over space and time?

Increasingly it is possible to fuse images from satellites with different spatial resolutions and frequency of overpass to develop a better overall product. It is also possible to extend time records by correlating past data from defunct satellites with new satellite imagery. The next section examines possible options for Western Australia.

3. Satellite and airborne platforms

There are currently three optical satellite systems providing data that can be used to monitor changes in native vegetation extent and condition over the entire state of WA at a relatively low cost (because the data are freely available):

- MODIS which is already used in the rangelands;
- Landsat MSS & TM and later versions which have been used for the past 20 years by the Land Monitor Consortium in the South West[1] which was extended state-wide in 2018; Landsat is also extensively used in Australia for rangeland monitoring and in the national forest monitoring system; and
- Sentinel-2, a relatively recent optical platform from the European Space Agency. Sentinel-1 has radar data that appears suited to assessing vegetation structure.

Data from these systems are archived in Australia and there are commitments to continuity of data from these systems. Access has been made easier to Landsat and Sentinel data through Geoscience Australia's (GA) open data cube within Digital Earth Australia[2].

In addition to satellite systems, there is historical aerial photography that shows the extent of perennial vegetation throughout the State on an irregular basis.

Each system is summarised below.

3.1 MODIS

NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) imaging sensor is on the Terra (since 1999) and Aqua (since 2002) satellites. Terra passes over Western Australia between 9:00am and noon, and between 9:00pm and midnight Western Standard Time (WST). The Aqua satellite passes over between 0:30am and 2:30am, and between 12:30pm and 2:30pm WST. The revisit frequency is one to two days. With the need for data without cloud cover, the 500m bands can be viewed as 8- and 32-day ('monthly') composites. Data is received at Murdoch University.

While the satellites have 36 bands, only daytime passes for the first seven bands are used for monitoring vegetation (see Table 3-1 in Appendices). MODIS NDVI and fractional cover indices are used for vegetation trend analyses and average vegetation cover calculations for rangeland areas in Western Australia as detailed in Section 8.5.2.

3.2 Landsat series MSS, TM, ETM

Landsat imagery has been collected by the US in a continuous program since the early 1970s. Australia constructed a reception facility for Landsat in Alice Springs in 1980 which is now operated by Geoscience Australia. A full national archive of Landsat imagery has been collected since that time. The US Geological Survey now makes available for free download the full global archive of Landsat imagery. The Australian archive includes some images of Australia that were not archived by NASA.

Landsat imagery has formed the basis of significant Australian and international monitoring programs. Details on the various Landsat sensors are provided below while the radiometric and spatial resolutions of each of the Landsat bands are shown in Table 13-2 to Table 13-5 in Appendix 1.

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[1] https://landmonitor.landgate.wa.gov.au/home.php

[2] http://www.ga.gov.au/about/projects/geographic/digital-earth-australia

Landsat 1-5 Multispectral Scanner (MSS) operated continuously from July 1972 to January 1999. MSS data were also collected from June 2012 until January 2013 after Landsat 5 failed. MSS was used in numerous early studies in Australia, particularly in rangeland cover and condition studies. Its resolution was too coarse to detect small changes in vegetation extent in the south west and for mapping dryland salinity. MSS had 4 spectral bands: two visible (green and red) and two near infrared bands. MSS data can be very valuable in long-term studies because they are the only data for early periods. The original MSS pixel size was 79 x 57m but it is generally resampled to 60m pixel resolution.

Landsat 4-5 Thematic Mapper (TM) images with a 30m pixel size are available from July 1982 to May 2012 (but are only available for Australia from late 1987) with a 16-day repeat cycle. Very few images were acquired from November 2011 to May 2012. The data have seven spectral bands with a resolution of 30m for bands 1 to 7. The thermal infrared band 6 was collected at 120m.

Landsat 7 Enhanced Thematic Mapper Plus (ETM+) consists of seven spectral bands with a spatial resolution of 30m for Bands 1-5, and 7 (Table 13-4). The resolution for panchromatic Band 8 is 15m. All bands can collect one of two gain settings (low or high) for increased radiometric sensitivity and dynamic range, while Band 6 collects both low and high gain (Bands 61 and 62, respectively) for all scenes. Images have been collected since August 1999. The Scan Line Corrector failed on May 31, 2003 so all images since then have areas of missing data. Both Landsat 7 and 8 have a 16-day revisit cycle, and their orbits are offset to provide 8-day repeat coverage.

Landsat 8 Operational Land Imager (OLI) / Thermal Infrared Sensor (TIRS) consist of nine spectral bands with a spatial resolution of 30m for Bands 1 to 7 and 9 (Table 13-5). The resolution for Band 8 (panchromatic) is 15m. Thermal bands 10 and 11 provide surface temperatures at 100m resolution. It has been in operation since 2013.

Landsat TM/ETM optical imagery is the basis for several major operational land monitoring projects in Australia as described in Chapter 6. In these projects, the pixels are generally resampled to 25m to enable consistency of raster products with traditional mapping scales. The full archive of Landsat imagery is housed and processed at GA (Section 6.1).

3.3 Sentinel

The European Space Agency (ESA) has developed the Copernicus Program which has seven satellites in orbit. As such it is purported to be the biggest provider of Earth observation data in the world. Importantly ESA has committed to continuation of the program and open data access.

3.3.1 Sentinel-2 Optical

Sentinel-2 is a polar-orbiting, multispectral high-resolution imaging mission for land monitoring to provide, for example, imagery of vegetation, soil and water cover, inland waterways and coastal areas. The revisit frequency is every 5 days. Sentinel-2A was launched on 23 June 2015 and Sentinel-2B followed on 7 March 2017. The radiometric and spatial resolutions of Sentinel-1 and -2 bands are shown in Tables 13.6, 13.7 and 13.8. ESA has committed to free availability of Sentinel data and GA has plans to continuously store the data in its 'Open Data Cube' (Section 6.1). In comparison with Landsat, Sentinel-2 has greater spatial resolution (e.g. 10, 20 and 60m), temporal resolution (5-day pass) and bands (13). The higher resolution of Sentinel-2 is attractive for specific applications such as monitoring vegetation in narrow roadside or riverine locations; and for mapping sparse woody systems using texture (Section 4.3). As storage and computational analysis capacity increases it is becoming more feasible to process higher-resolution Sentinel-2 data over large areas – eventually state-wide.

3.3.2 Sentinel-1 Radar imagery

Sentinel-1 is a polar-orbiting, all-weather, day-and-night radar imaging mission for land and ocean services. The revisit frequency is every 12 days. Sentinel-1A was launched on 3 April 2014 and Sentinel-1B on 25 April 2016. It is a C-Band Radar sensing system (central frequency 5.404 GHz).

Radar imagery has unique properties which may complement optical imagery for detection and mapping of vegetation characteristics. Radar responds to variations in surface orientation and roughness and so may provide information on structural variations in vegetation.

In past decades, satellite radar systems have been short-lived, and data have been difficult to access. Numerous research studies have examined the use of radar, or radar combined with optical for the mapping of landcover including forest and crop cover. Studies have applied radar imagery to estimate or characterise above ground biomass (e.g. Lehman *et al*. 2015, TERN 2018, CSIRO 2018a).

Sentinel-1 is the first radar system which is providing open access data with full coverage, making it feasible for applications including native vegetation over WA. It currently assists crop mapping projects through CSIRO's Graincast project[3]. This project uses multiple satellite inputs and other datasets and growth models to 'map' land uses in addition to crop areas and their yields. It could therefore offer another monitoring option for both perennial vegetation and land use changes in future (Roger Lawes, pers. comm. 7th December 2018).

3.4 Analogue and Digital Aerial Photography

Aerial photography provides unique capabilities because of its high resolution and 3-D capabilities. There is an existing photo archive and ongoing acquisition program for the entire state, though the coverage is not systematic.

For the past decade, digital air photography (DAP) systems have been used to capture the State's aerial photography. This imagery records visible and (in an increasing number of cases) near-infrared (NIR) data. It is collected at a resolution of 50cm in rural areas, and higher resolution (10-20cm) over towns and the Perth-Peel region. The full historic archive of analogue photography is being scanned and stored in digital form by Landgate.

While photography has been used for decades for traditional mapping, including extraction of contours, digital data and modern computational power now make it feasible to conduct fine-scale monitoring and the extraction of new metrics which are directly relevant to native vegetation. Monitoring is limited by the sparse and varied capture program for areas outside the Perth-Peel region.

Automated methods can extract accurate digital elevation models (DEM) and digital surface models (DSM). Classifications of vegetation, and maps of vegetation height at fine scale can be produced. These data provide capacity to measure vegetation structure, per cent cover and connectedness at a fine scale. Because DAP is collected to photogrammetric standards, it can be processed and radiometrically calibrated to enable digital change detection and monitoring.

[3] https://research.csiro.au/graincast/

One of the leading examples of such processing is the Urban Monitor project, which has acquired annual DAP coverages over the Perth-Peel area (about 10,000 km^2) since 2007 (Caccetta *et al*. 2015; Figure 3-1). Processing of these data is carried out as resources allow, often only every second year. Being 3-D, both DSM and DEM maps allow the heights of individual trees to be estimated and changes in canopy extent and heights can be monitored (Figure 3-2, Figure 3-3). The group has recently been contracted to process and produce similar products for the greater Melbourne and Sydney areas (CSIRO 2018b).

The data volumes and processing required for these photo-derived products are very large – for example 40 TB for 0.1m resolution data for the 9,600 km^2 Perth-Peel area (Figure 3-1). It is not suggested that state-wide coverages should be routinely processed; the Urban Monitor coverage is only 0.4% of the State. However, for priority areas (e.g. National Parks, disease or pest outbreaks), these products can provide direct measures of vegetation height and spatial arrangement which may assist in rapid appraisal or ground survey for biodiversity and mapping purposes. As an example of such use, the Urban Monitor extent was extended south of Mandurah to assess the extent of Tuart dieback, into the Wungong Catchment to assess tree-thinning practices in a drinking water supply catchment, and across the Gnangara Groundwater Mound to assess the impacts of fire, climate and groundwater extraction on vegetation health.

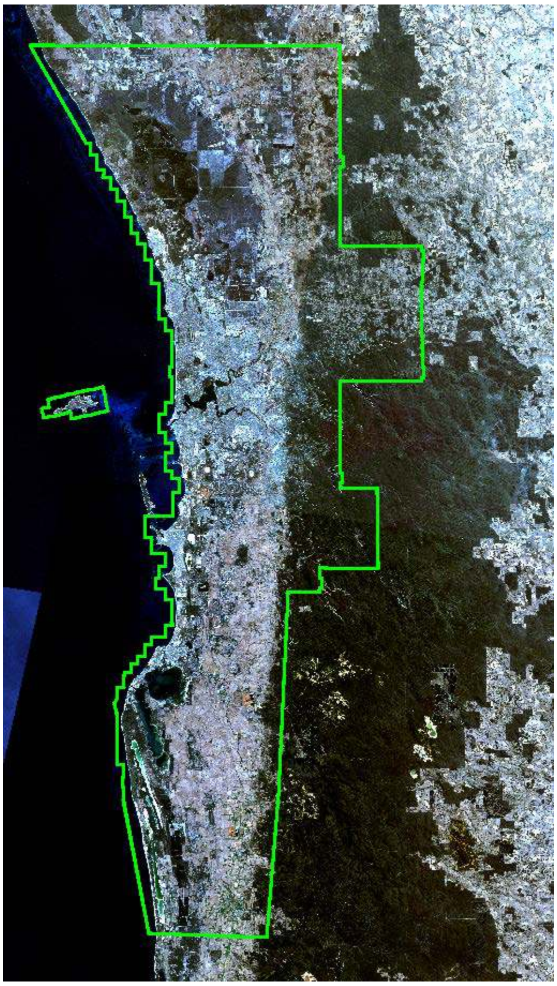

FIGURE 3-1: Extent of Urban Monitor capture 2007 to present

FIGURE 3-2: Urban Monitor example – height of greenspace with hot colours = greatest heights above ground surface

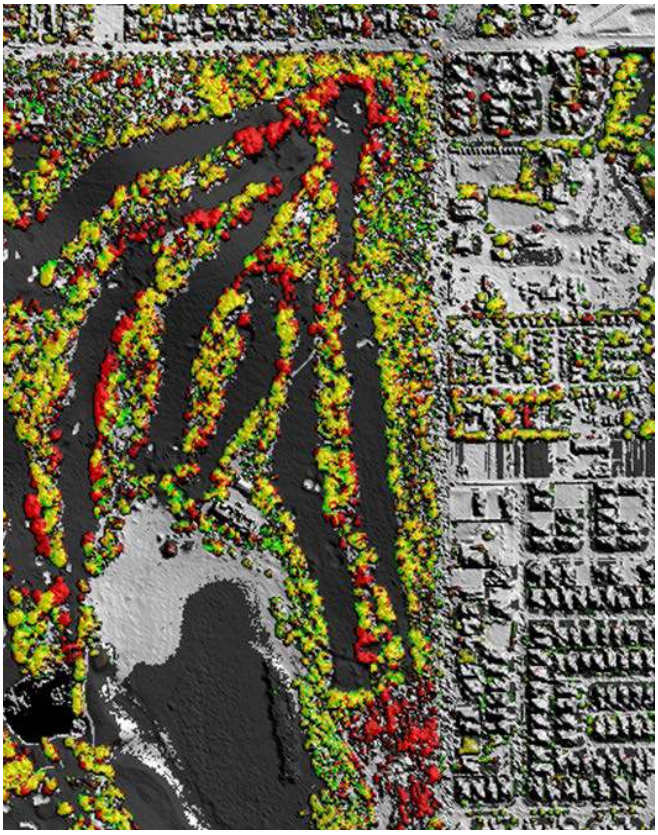

FIGURE 3-3: Urban Monitor example – change in tree cover between two dates – red = loss, green = gains, yellow = no change

4. Three operational Australian vegetation monitoring systems

This section briefly describes three long-running operational programs monitoring vegetation cover in Australia; the Queensland Government's State-wide Landcover and Trees Study (SLATS); Western Australia's Land Monitor Project; and the Department of Environment and Energy's forest monitoring part of the National Greenhouse Gas Inventory (formerly known as the National Carbon Accounting System - Land Cover Change Program or NCAS-LCCP). These programs were designed, and continue to be resourced, to meet specific policy priorities.

These systems share some common elements, but also notable variations in methods, objectives, products and resourcing. All were built using Landsat imagery based on its spatial resolution and its (until recently) unique archive with comprehensive coverage. These systems originated in the 1990's during the phase when Landsat data was 'commercial' (i.e. expensive) and computational systems were much inferior to those of today. In addition, processing and calibration standards were in their infancy at that time, and all programs were required to test and develop suitable and efficient methods within their operating environment. There was considerable information exchange between these programs during the first development phases. Initially all systems set out to produce 'classification' maps of 'woody' or 'forest' vegetation and clearing using time series imagery. They have in common a definition of 'woody vegetation' as a nominal 20% crown cover. Additional products are now produced.

All three systems invested in improvement and research and are linked to active research capability. Within their ~20 years of operation these programs have implemented improvements in efficiency, computation and evolution of products. Product development is partly driven by technology and new data, but also by new policy or information requirements.

Elements of these systems are highlighted here. More information is available from websites and publications relating to these systems.

4.1. Queensland's State-wide Landcover and Trees Study (SLATS)

The SLATS program commenced in the late 1990's to monitor woody vegetation clearing of Queensland's native vegetation in support of the *Vegetation Management Act 1999.* Extensive areas of Queensland's native vegetation are dominated by woody vegetation; clearing of trees to enhance grass growth for grazing is widespread and an important issue for the State. The SLATS program was housed (until recently) within Queensland Government's Department of Science, Information Technology and Innovation (DSITI) and has been well-resourced and staffed by the State since its inception.

The SLATS program covers the entire state to produce woody extent and clearing maps. The program developed rigorous pre-processing standards to ensure consistency across such a large area. The classification of clearing is 'semi-automated'. SLATS generates a 'probability of change' raster map from Landsat imagery. These areas are then checked visually against the images and manually digitized to produce the final clearing products. At the present time SLATS does not produce maps of woody 'regrowth' or reforestation but is in the process of developing regrowth products. It is also moving to annual updates from previous biennial updates and is setting up to use higher-resolution Sentinel-2 imagery. A summary of SLATS reporting products can be found at:

https://www.qld.gov.au/environment/land/management/mapping/statewide-monitoring/slats/slats-reports#most-recent-reports.

The SLATS program and DSITI have a large-scale ground measurement program recording site data on ground cover, tree-layer projected foliar cover (PFC) and other physical measures. These data have supported the development of indices for cover and PFC which are used to track trends and changes within 'woody' and 'non-woody' areas. In recent years SLATS has produced cover proportion images (green, dry, bare) using a version of unmixing (Scarth *et al*. 2010). Changes in these proportions over time are used for woodland and rangeland monitoring. SLATS processing methods are shared by NSW. SLATS provides specified products to NSW, Tasmania and the Northern Territory (see also Section 7.2).

SLATS is heavily involved in research into new sensors and improved estimation of biophysical parameters using remote sensing. The vehicle for much of this research is the Joint Remote Sensing Research Program (JRSRP) outlined in Section 5. A review of the research activities is found in Tindall *et al*. (2015); see also Gill *et al*. (2017). Currently there is limited use of SLATS products in managing biodiversity in Queensland.

4.2. Land Monitor – Southwestern Australia

The Land Monitor Project commenced in 1998 as a finite 3-year project to produce mapping and monitoring data for dryland salinity (using spring images) and woody vegetation (using summer images) for the south-west agricultural area of WA. The area covered is about 13% of Western Australia. Again, Landsat TM was the chosen data source, and the initial project aimed to cover the decade 1990-2000. For vegetation, two standard products were envisaged: classification maps of woody vegetation extent and change (clearing and revegetation); and 'vegetation trends' showing temporal changes in vegetation cover indices within the woody vegetation areas. The cover index used in the project had been identified in prior research: ground sites where native vegetation condition assessments had been recorded were used to guide discriminant analysis to identify indices which separated good and poor condition sites (Furby and Wallace 1998, Wallace *et al*. 2006). The vegetation trends analysis is a statistical approach (Wallace and Thomas 1998, Lehmann *et al*. 2012) developed in the WA rangelands. It was applied to an annual sequence of indices derived from summer (dry season) Landsat imagery. See Section 8.2 for examples of Land Monitor vegetation products.

The methods and workflow were produced by the CSIRO WA remote sensing group. The project was managed by Department of Agriculture (now DPIRD) with a guidance committee of representatives from relevant government departments.

Land Monitor now covers the entire state. The 2018 data and vegetation classification products (Woody, Sparse-woody and Non-woody) are now identical with and form part of the National Forest Monitoring system (Section 4.3). At present, vegetation trend products are produced only for the south-west region.

The project was innovative in several ways. A key technology was developed to control errors in classification, and to derive accurate change maps. Rather than differencing individual maps, the approach uses full time series processing in a probabilistic model framework known as a Conditional Probability Network (CPN). The effect minimises errors in vegetation extent, clearing and revegetation areas without the need for manual intervention.

Following the completion of the original project in 2001, a collaborative arrangement (Land Monitor II) was set up to continue updating the perennial vegetation extent and trend products, and to produce new products for state users. Ground truthing is required to interpret trends and to separate native from non-native vegetation. Plantation forestry occupies a very small percentage of WA so this is not a significant source of error, especially if plantation masks are used.

In fact, the Land Monitor change products have been used to check and update plantation vectors in the southwest. The annual time series of image-derived vegetation products now covers the period 1988-2018. Land Monitor has also produced a ‘one-off’ woody vegetation extent map using high resolution (4.5m) imagery from the Chinese ZY-3 satellite from the period 2012-2015. The product covers most of the south west but some data strips are missing.

The Land Monitor process continues to produce products for its consortium members. Land Monitor has no dedicated employees and a small operating budget contributed by the partners. Annual product updates are produced by CSIRO WA, distributed to State agencies through the committee (currently chaired by DBCA), while an (out-of-date) website is maintained for non-consortium members by Landgate. The project now uses Landsat data sourced from Geoscience Australia’s ‘open data cube’ (Section 6.1). The Land Monitor committee recently committed to using Landsat imagery to cover the whole state, and to developing and producing an extended set of products. The first set of state-wide vegetation products was produced in 2018. More details on this are provided in Section 10.2.

In some respects, Land Monitor’s classification technologies are superior to those operated by SLATS. Notable advantages are the systematic and automated detection of regrowth and reforestation areas, as well as clearing. The lack of human interpretation and digitising removes the element of human judgement and variability. Both features were critical to adoption of the Land Monitor approach in the National Forest Monitoring System (Section 4.3).

Land Monitor products now provide a spatially-detailed history of woody vegetation extent, and areas of woody vegetation loss and gain for the whole state. These products are consistent with the DoEE national program. These standard remote sensing extent-and-change products are not attributed for vegetation type or cause of change. The data can be summarised statistically and attributed using GIS. However, unlike Queensland, Western Australia lacks detailed vegetation mapping which allows identification of areas where clearing would compromise a vegetation association that is not well represented in secure holdings or is subject to multiple or cumulative impacts. WA lacks a legislative basis to make this check which reduces the requirement to have accurate vegetation association maps.

An example of maps and statistics currently able to be generated by Land Monitor are shown for map sheet SI-50 (Figure 4-1).

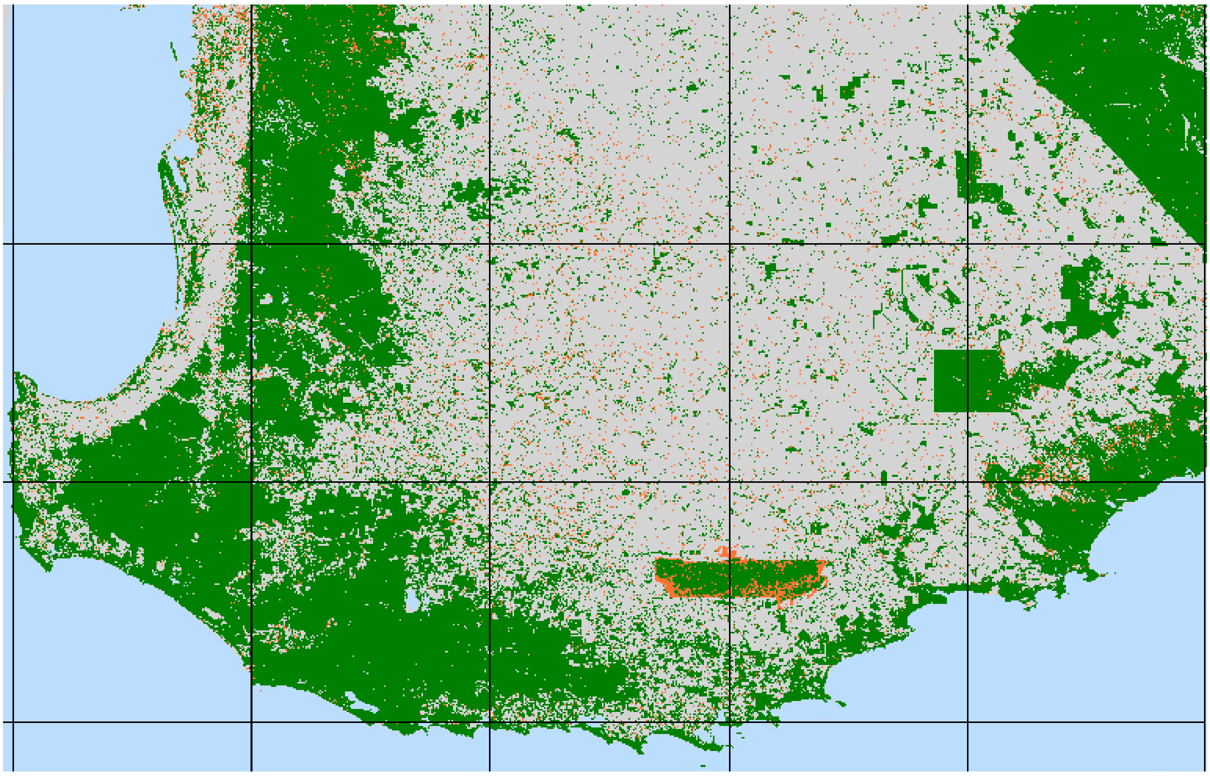

FIGURE 4-1: 2017 Land Monitor/National Inventory forest vegetation (green) and sparse woody vegetation (orange) for the 1:1m map sheet SI-50.
Area shown is approximately 500 km by 320 km. Grid is latitude/longitude whole degrees.

There is no clear long-term trend in areas that have been classified as Forest and Sparse-woody between 2004 and 2018 for the SI-50 map sheet (Figure 4-2). Changes are a combination of clearing, fire, revegetation, and fire- and drought-recovery of both native and introduced species. The reduction in forest and increase in sparsely-forested area in 2010 (and the subsequent recovery) may coincide with tree canopy losses as a result of the extreme drought in that year. Without ground truthing this is just a hypothesis that could however be tested, as the change data is spatially detailed. The land area of the SI-50 map sheet is 12,764,631 ha so a 5 million ha forested area represents 39.2%.

Areas that were previously classified as Forested and then as Non-woody are shown as 'loss' in the bar chart in Figure 4-3. Reasons for the change include passive and active clearing, logging as well as fire and seasonal condition (especially drought). Areas that were Non-woody and then classified as Forested are shown as 'gains'. This includes recovery from fire, drought and active and passive revegetation including timber plantations. Given the large impact of fire and seasonal conditions on vegetation statistics there is change on a year-to-year basis. To separate causes of change, and to enable tracking of long-term trends associated with different causes, a GIS attribution program is required to label change areas.

TABLE 4-1: Annual vegetation and change area statistics.

Year	Woody (forest) area (ha)	Sparse area (ha)	Annual change interval	'Loss' area (ha) Forest => Non-woody	'Gain' area (ha) Non-woody => Forest
2000	4741150	410677	2000-01	*89726	*37466
			2001-02	*89726	*37466
2002	4884089	389442	2002-03	*61491	*36740
			2003-04	*61491	*36740
2004	4939547	386233	2004-05	52660	51896
2005	4931106	401628	2005-06	34507	48946
2006	4898096	431784	2006-07	38911	59264
2007	4874889	457273	2007-08	47558	89491
2008	4823348	493168	2008-09	30062	45587
2009	4791041	521646	2009-10	47296	45860
2010	4756641	610460	2010-11	23316	53468
2011	4708766	652650	2011-12	67702	38555
2012	4762027	656395	2012-13	32147	31314
2013	4789806	638915	2013-14	50446	43835
2014	4879856	574859	2014-15	37231	38616
2015	4934701	537356	2015-16	31774	74423
2016	4932852	483209	2016-17	27429	40484
2017	4942799	459634	2017-18	34651	54651
2018	4948130	444192			

* = total change over the two-year periods 2000/02-04 have been equally divided

Note: Extent of forest and sparse woody vegetation for 1:1m Map sheet SI-50 The SI-50 map sheet covers the SW of WA from 32 Deg S to 120 Deg E (i.e. approx. from Fremantle in the North to Ravensthorpe in East, Figure 4-1). These raw change and area statistics include native and non-native vegetation and changes from multiple causes including seasonal conditions, clearing, fire loss, revegetation and fire recovery. Source: Land Monitor.

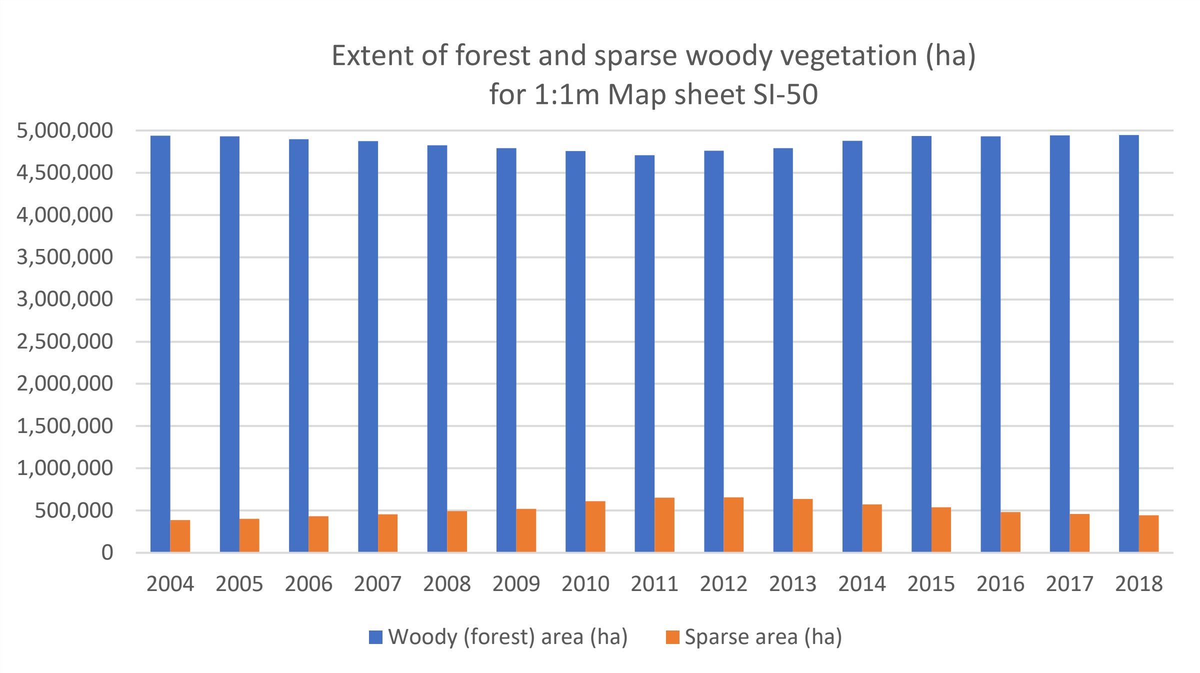

FIGURE 4-2: Extent of Forest and Sparse woody vegetation for the SI-50 map sheet estimated by Land Monitor between 2004 and 2018

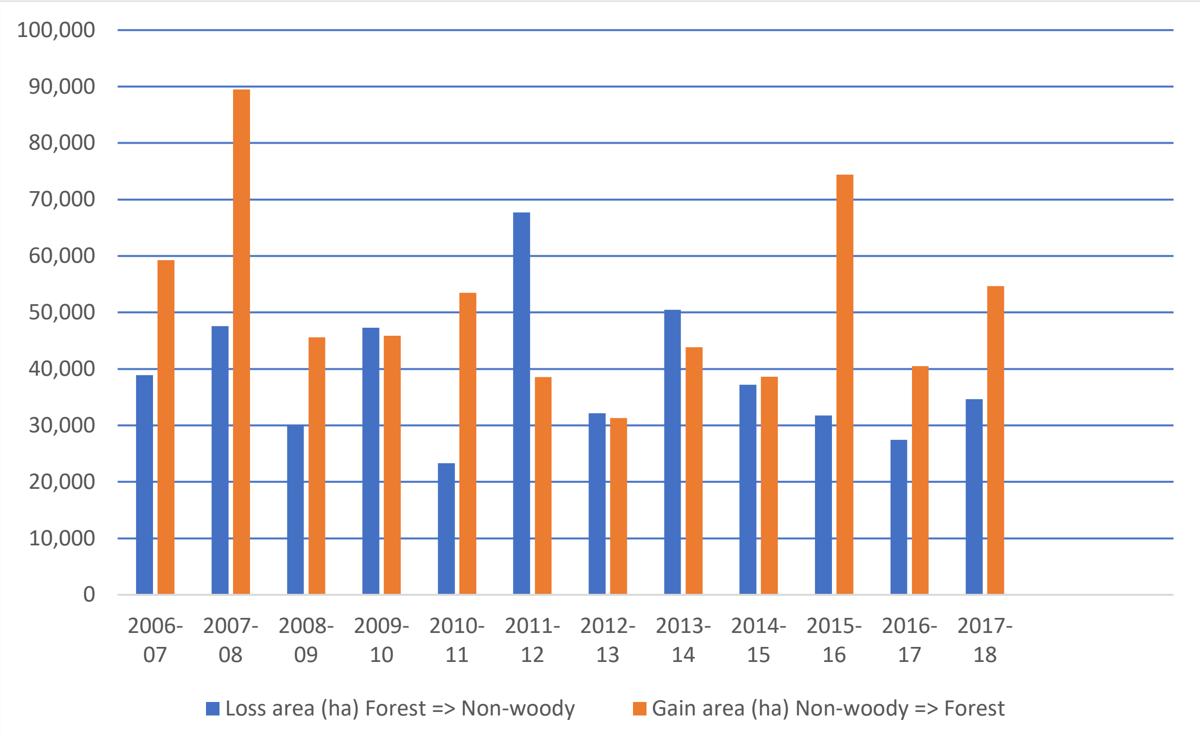

FIGURE 4-3: Vegetation loss areas (i.e. Forest to Non-woody classification change) and gain areas (Non-woody to Forest) for the SI-50 map sheet estimated by Land Monitor between 2004 and 2018.
Note: A high proportion of the vegetation canopy losses and gains are due to fire and seasonal conditions.

4.3 The national forest monitoring program component of DoEE's National Greenhouse Gas Inventory

This program began under the Australian Greenhouse Office (AGO) as the NCAS-LCCP. It was created to provide critical 'audit quality' information for the entire country on forest change to enable reporting of Australia's land-based greenhouse gas (GHG) accounts. Australia, in signing the Kyoto protocol in 1998, had argued for a special clause to include land-based emissions, and was required to produce a national system which would be subject to review by the IPCC. The AGO was charged and funded to develop the system. An example product from it is shown in Figure 4-4.

The specifications required 'sub-hectare' monitoring and required national data for the longest possible period prior to the 1990 baseline. The rules at that time related specifically to forest areas and Australia's forest definition was based on woody vegetation with canopy cover above 20%. The system was designed to be ongoing to support GHG accounting through the 'commitment period' and beyond.

Landsat (MSS and TM) was the only data source suitable to meet these requirements, but the continental scale of the project (~370 Landsat scenes cover Australia) was unprecedented at that time. The project remains one of the largest and most rigorous vegetation monitoring projects on the planet and has been influential in providing a model for subsequent international activities (See Section 5).

The system needed to map forest extent and detect timing and areas of deforestation and reforestation with minimal error. It was critical that the processing within the system should be nationally consistent, based on repeatable and automated methods with minimal human interpretation/judgement. The approach developed in WA for Land Monitor, with the CPN processing, met these requirements and was selected. The initial implementation was managed at the Australian Greenhouse Office via a CSIRO secondment with production outsourced to industry. Subsequent updates used CSIRO (WA) for technical management with production outsourced as needed, but this need has declined with increasing automation. The outsourcing is contracted by the Department of the Environment and Energy (DoEE). Major revisions and technical improvements have been implemented in subsequent updates. The CSIRO group now uses access-ready data from Geoscience Australia's open data cube, which removes major pre-processing steps, and continues to update the system and products. A summary of the technical components can be found in Caccetta *et al*. (2017).

Based on evolving policy needs in GHG accounting, the system has added new products. One is the national 'Sparse Woody' product, which produces maps of woody vegetation in the nominal 5 - 20% canopy cover range. Below 20% tree cover, classification using Landsat bands becomes highly inaccurate. 'Sparse Woody' mapping was initially attempted under a forestry accounting scheme, as a response to the large areas of Australia having woody vegetation below the 20% forest definition threshold. To produce an acceptable 'Sparse' accuracy, texture metrics were derived from Landsat and used in addition to the optical bands.

The underlying research conducted analysed multi-scale texture metrics from aerial photography in several rural areas. The results showed that texture metrics at approximately 10-15m resolution contained the most relevant information for separating sparse woody from cleared land, but there was still information at 20-40m resolution (Furby *et al*. 2007, Caccetta *et al*. 2013).

Hence, Landsat TM (but not MSS) textures were combined with optical data to produce the national sparse woody product (Figure 4-4). Combined with time series Conditional Probability Network processing, this process produced results of acceptable accuracy for sparse extent and change under the original aim.

Now that the accounting system has moved to full landcover, the sparse and forest products are combined as a standard three-class national product. A National Forest Trends product modelled on the Land Monitor trends product (Section 8.2) was also produced until 2012 (Lehmann *et al*. 2013) after which Geoscience Australia changed the geometric and radiometric calibrations. Once cloud cover masking is incorporated into GA's open data cube they will be updated.

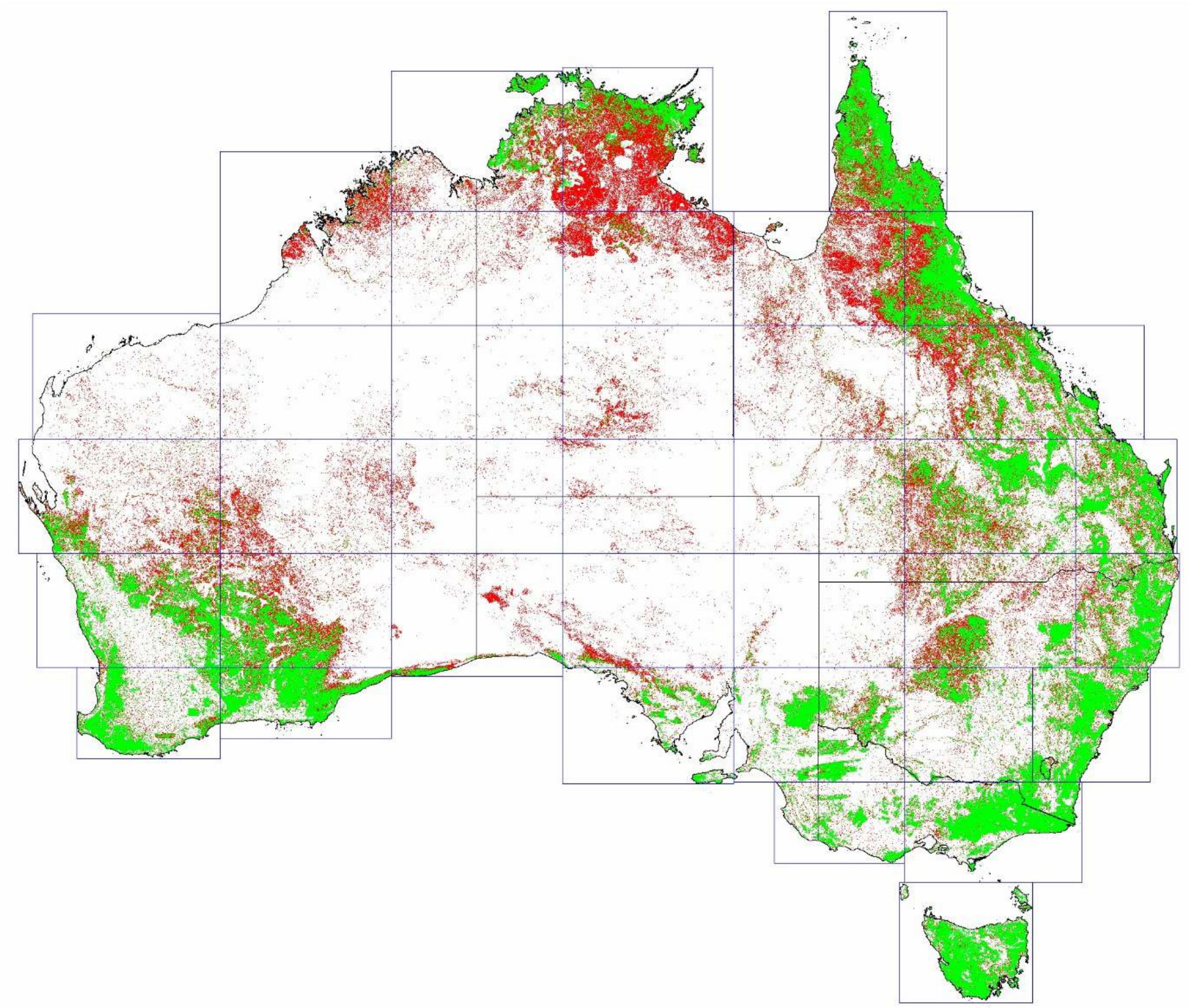

FIGURE 4-4: National Forest (green) and Sparse woody (red) extent product from DoEE's National Greenhouse Gas Inventory.
Note: These maps are produced from Landsat at 25m resolution and updated annually. Definition of 'Forest' is nominal > 20% crown cover and for 'Sparse woody' 5-20% woody cover.

As noted above, the 2018 Land Monitor state-wide vegetation products are now identical to those of the national system. Land Monitor produces the WA products for the national coverage. The original (south west) Land Monitor perennial vegetation maps were not identical to the national forest maps as they contained some areas of vegetation beyond the NCAS forest definition. With the formal inclusion of the sparse category in the DoEE products, and state-wide coverage of Land Monitor, these products are now identical.

It is relevant to note that, for GHG accounting purposes, DoEE applies a post-classification 'Attribution' process to forest and change areas. This is achieved through a vector database containing records including forest plantation (and type), dated fire impacts and other natural disturbances, and tenure.

5. International programs in vegetation monitoring using remote sensing

A brief overview of some international and national programs is presented in this section.

Australia's capacity in developing operational remote sensing programs is highly regarded internationally. In Australia relatively recent large-scale clearing of natural vegetation post European settlement has continued into the satellite era. It is difficult to find direct parallels with Australia's environmental changes, land ownership and regulatory regimes. However, there are significant national and international programs using remote sensing for monitoring land and vegetation.

International monitoring of vegetation using satellite imagery is not a new idea. A major focus of data analysis in the early Landsat Multi-Spectral Scanner (MSS) missions was predicting the Soviet wheat crop. Experiments in the early years of MSS produced more accurate estimates of Russia's 1977 crop than either the USA or the USSR itself. Agricultural crop monitoring using remote sensing continues in many forms today.

In terms of 'native' vegetation monitoring, two relevant areas where remote sensing is used are:

- Forests, especially tropical forests; and
- Rangeland systems at national or larger scales.

Recent developments in national forest monitoring are particularly relevant. This area has developed enormously in the past two decades in response to drivers which require accurate time series detection of extent and change.

5.1. Forest Monitoring

The global importance of forests as carbon stores and of deforestation as a source of greenhouse gas emissions has focussed international programs to develop incentives and technical approaches to conserve and enhance forests. Program such as Reduced Emissions from Deforestation and Degradation (REDD+) offer incentives to tropical countries which can demonstrate compliance with program conditions, all of which are subject to review (UN-REDD, 2018 and Forest Carbon Partnership Facility 2018). One essential element for participation is a rigorous, nationwide system for monitoring forest extent and changes. Time series imagery (usually Landsat) has been directed to construct these 'audit quality' forest monitoring systems (Achard and Hansen, 2017).

In the last 10 years, a large international scientific and technical effort has developed to support national forest monitoring initiatives. Indeed, the importance of forest monitoring has been a significant driver to improve international data systems and access. Major initiatives include the US-led SilvaCarbon (2018) and the Global Forest Observations Initiative (GFOI)[4]. SilvaCarbon describes itself as "...an interagency technical cooperation program of the US Government to enhance the capacity of selected tropical countries to measure, monitor, and report on carbon in their forests and other lands". GFOI (2018) "…supports REDD+ countries to develop their national forest monitoring systems and associated emissions measurement, reporting and verification (MRV) procedures". Among other activities GFOI produces 'Methods and Guidance' documentation to assist countries in building monitoring systems.

Australia was an early leader in establishing a rigorous national remote sensing program for forest monitoring. The NCAS system (now part of DoEE's National Greenhouse Gas Inventory) was described

[4] http://www.fao.org/gfoi

in Section 4.3. Because of the experience in creating this system, the CSIRO WA group has participated in international technical groups such as GFOI and has been involved in technical transfers to create Indonesia's INCAS remote sensing program, Kenya's SLEEK monitoring program and a World Bank program in Fiji. CSIRO remote sensing and forest scientists are co-authors of the GFOI Methods and Guidance document.

The other large country to operationalise forest monitoring at that time was Brazil, because of the national and international importance of deforestation of the Amazonian rainforest and the need to detect illegal logging. Brazil's INRA developed an optical-based system (PRODES) to monitor the entire Brazilian rainforest. With the international drivers and incentives for greenhouse gas abatement, the system has continued to be improved.

Landsat imagery was used for both these large-scale programs despite the cost and technical challenges. At that time Landsat was 'commercial' – the data cost for continental coverage of Australia (approx. 370 Landsat scenes per time epoch) was high but the freely available coarse-resolution imagery (AVHRR, MODIS) was not suited to the task. Global forest monitoring maps are now produced from Landsat (Hansen *et al*. 2013), while earlier work by the same research group had used AVHRR and MODIS (Hansen and DeFries 2004).

Numerous countries have now implemented or are in the process of building forest monitoring systems to enable participation in REDD+. These include Indonesia, Kenya (noted above), Vietnam, Laos, Colombia and Fiji. More Information can be found on the websites above or on the REDD websites of the individual countries.

Forest monitoring thus provides many examples of rigorous, spatially explicit remote sensing monitoring systems which deliver into a complex policy environment. The policy requirements for monitoring (e.g. time series and spatial reporting units) have directed focus to Landsat or finer resolution imagery (e.g. Sentinel-2) and consistent processing methods. By reason of its historic archive, Landsat has provided the main input to forest monitoring. Other complementary activities are required for such a system to be accurate including ground-based survey, calibration of forest models, and possible use of 'one-off' remote sensing data such as LiDAR for biomass or carbon stock estimation.

5.2. Rangeland Monitoring using Remote Sensing

Rangelands monitoring has been an area of remote sensing research and applications for many years for national, regional and international programs. Rangelands are extensive, sparsely populated and generally have low cloud cover. The motivation to examine optical remote sensing to provide rangeland information is obvious.

A 2016 summary of the satellites used to monitor rangelands up until 2014 was reported by Reeves *et al*. (2016) and reproduced in Figure 5-1. The authors concluded that "*it is unclear, however, whether improved spatial, spectral, and temporal resolution of satellite remote sensing will provide the greatest advancements in the evaluations of rangelands on a global scale*"; and "*characteristics such as soil background, leaf anatomy and physiology, and relatively low biomass conspire to hinder remote sensing of rangelands. Very little can be done to change these situations, and as a result, future pathways should include a focus on data continuity, increased data availability, better computer processing systems, and global campaigns for collecting field-referenced data*".

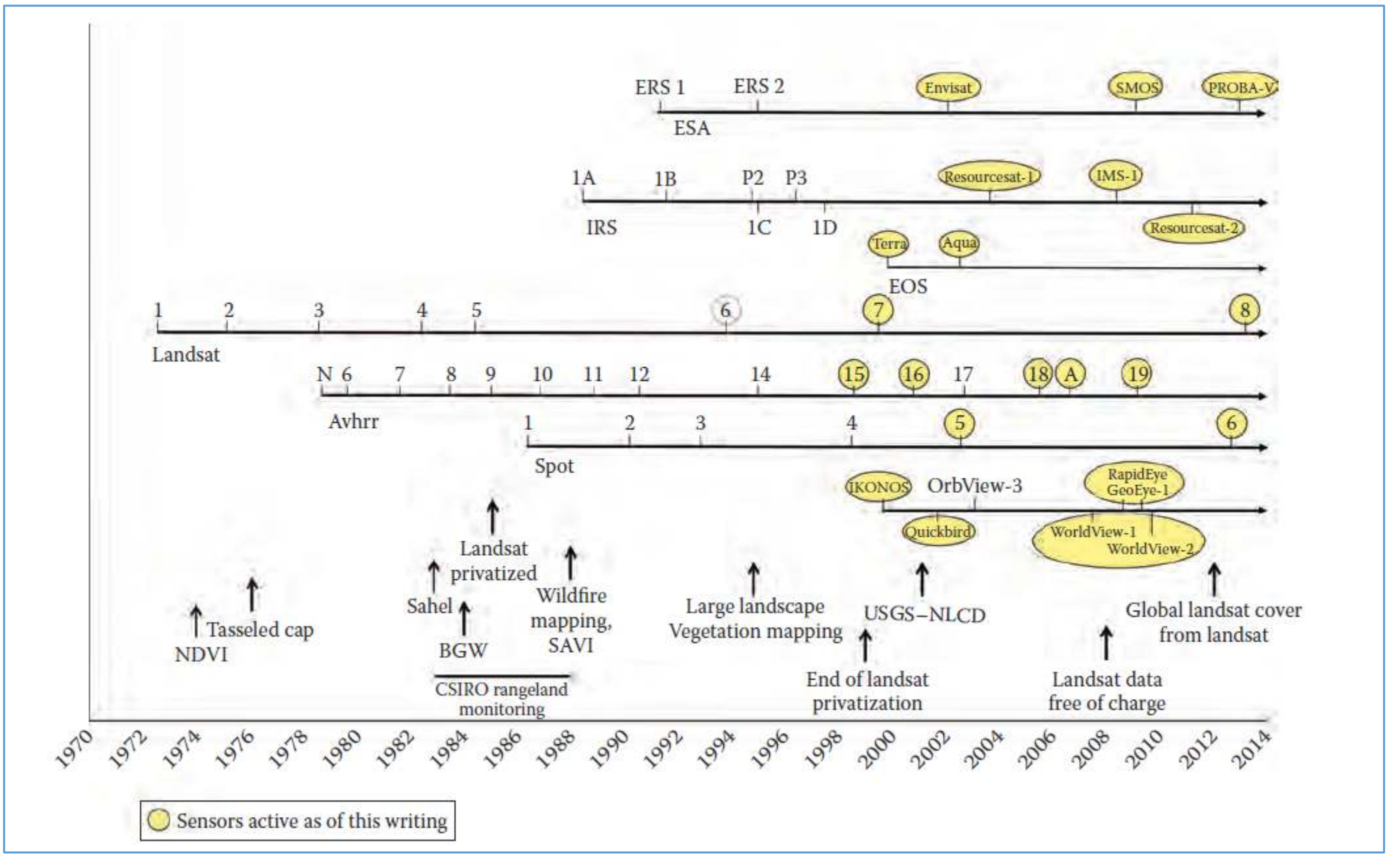

FIGURE 5-1: History of digital remote sensing sensors used in research and monitoring of rangelands since the advent of the technology in the early 1970's until 2014 (prior to Sentinel).
Specific research milestones and policy changes are also noted (Reeves et al. 2016)

The most relevant models for this report are provided by Australian-developed management-relevant examples of rangeland monitoring. Examples were noted in Section 2 and comments on the methods are contained in Sections 7 ('Other states') and 8 ('WA state agency') activities. It is important to note that definitions of condition and degradation are often based on local understanding of vegetation systems and grazing impact and that Australia's land tenure, pastoral practices and regulatory conditions provide the framework for the models and systems developed and used in this country.

Probably the best-known early example was the use of AVHRR NDVI time series to record seasonal changes in the greening response of the Sahel in Africa (Tucker 1979), later followed up with long-term trends related to drought (Anyamba and Tucker 1985; Tucker and Nicholson 1999).

The initial inferences made from such summaries have been subject to some dispute, but coarse-scale NDVI time series is used to detect and quantify 'anomalies' in seasonal responses including drought.

Rangeland remote sensing research and operational programs have been driven by two objectives:

1. Estimating or monitoring productivity 'surrogates' (e.g. using time series NDVI); and
2. Mapping or monitoring areas of degradation, overgrazing or poor 'condition'.

These may be further subdivided by scale: whether the aim is to provide coarse-scale indicators for regional/national reporting, or to provide 'management-relevant' scale maps for ground validation and action. The coarse-scale frequent imagery (AVHRR, MODIS) is suited to the first.

These data are also used nationally and internationally to provide inputs to regional models for pasture growth, net pasture production, soil moisture and drought. The two objectives are not totally separate, but the second, applied at the finer management-relevant scale is most relevant for this report.

Australian researchers, particularly in CSIRO, were active early in applications of remote sensing to rangeland systems. They developed cover indices from Landsat MSS and related cover dynamics to models of degradation. Australian scientists made a large contribution to the rangeland literature and especially to the remote sensing of rangeland literature. CSIRO's Alice Springs group was an early leader in this field and has produced a huge legacy of publications relating to condition and remote sensing. Among other things, this group's research showed that, in Australia's shrubland systems, 'greenness' as detected by NDVI, was a poor indicator of condition (Bastin *et al*. 1995). Perennial vegetation in arid systems (indeed in much of Australia) has low photosynthetic activity and low NDVI. NDVI responds dramatically to the green herbage component which, except for short periods after rain, is a minor component of vegetation cover. Rainfall in these regions is highly variable in space and time and a high NDVI response is more likely to be the result of a local thunderstorm than a signal of underlying condition. Further, the green herbage growth after rain provides an ambiguous indicator of long-term condition – it can be a signal of poor condition (dominance of annual plants) in former perennial systems. As a result, the Alice Springs group focussed on cover indices and cover changes over time to produce indicators of condition or degradation.

Similar 'unexpected' findings were found in woodland remnants in the SW of WA in the early work of Land Monitor. Strong greening responses in spring were associated with poor woodland condition where the understory vegetation had been removed. It was inferred that the loss of perennial understorey allowed green grasses and weeds to flourish after rain. Land Monitor focussed on dry period (summer) images to derive cover trends to provide more robust and interpretable changes. Despite these experiences, NDVI has often been used as a surrogate or input for condition with varied results. Greenness indices do provide indicators of productivity after rain, relevant to grazing, and are used to model pasture growth, Net Primary Productivity (NPP) and Rain Use Efficiency (RUE).

South Africa's CSIR operates in a comparable environment to Australia, but with very different drivers for information. It has an impressive program of research and operational outputs using remote sensing at a range of scales – including very high-resolution airborne instruments.

International programs have focussed on providing indicators of degradation or desertification, driven by processes such as the UN Convention to Combat Desertification. One example is FAO's Land Degradation and Assessment (LADA) project (FAO, 2013), which produced global products and implemented methods at a range of scales. It has an associated online system called Global Land Degradation Information System (GLADIS) which is described as a 'global tool that contains low resolution information'. However, the information provided by the global products may not accord with local interpretation and knowledge (Konrad Wessels, CSIR, pers.comm.). It is unclear if these products are used or validated in Australia.

GEO Global Agricultural Monitoring (GEOGLAM) was launched by GEO in 2011. It aims to provide global updates on growth and expected production with a view to improve food security. An Australian-led sub-program, GEOGLAM RAPP (Rangeland and Pasture Productivity) is focussed on rangeland areas of the world. It provides a data portal, hosted on the National Computing Infrastructure (NCI), which serves updated global indicators of rangeland cover and productivity derived from MODIS composites at 500m resolution. The content includes fractional cover, calculated using the approach of Guerschman *et al*. (2009; 2015) and other indices.

Fractional cover estimates the fractions of photosynthetic and non-photosynthetic vegetation (PV and NPV, respectively) and the remaining fraction of bare soil (BS) using unmixing techniques. The method is reliant on high-quality field data to calibrate and validate the algorithms. The method may not work as well in red soils which are common in many northern rangeland areas including the Pilbara. Trend analyses where sites are compared with themselves over time can overcome some of these issues.

6. National data infrastructure and research alliances

This section describes three major programs which have been developed to improve data access and knowledge to enable more efficient access to remote sensing data, to distribute standard derived products and indices, and to develop new methods to derive information from remote sensing data for multiple purposes. It is not a comprehensive review of remote sensing research in Australia. Several universities and CSIRO participate directly in these programs, but also conduct other project activities.

6.1. Digital Earth Australia – Geoscience Australia

Geoscience Australia (GA) is the national government agency responsible for reception and archiving of satellite imagery. GA received $15.3 million over two years in the 2017-18 federal budget to build an Open Data Cube (ODC) to store and make remotely-sensed data available to government and industry. Allied to this initiative, Digital Earth Australia (DEA) received an additional $36.9 million over the following four years to make it available to government and industry as Analysis Ready Data (ARD). The stated aims are to improve understanding of environmental change across Australia, including soil and coastal erosion, crop growth, water quality and the growth of cities and regions. Worldwide Landsat imagery has been available for some years for download from the USGS but this does not offer terrain-illuminated correction as part of their ARD. The ODC architecture offers this feature and the promise of integration with other datasets for Australian users.

National data sets (including DEA) are housed on the web in NationalMap which was built by CSIRO[5]. Past satellite data, and products such as Normalised Difference Vegetation Indices, are provided to users free of charge either through NationalMap or the ODC[6]. There are three options: view, access (download) and analyse.

DEA has access to a wide array of analysis ready data (ARD) from satellites planned for the cube (Table 6-1). Because the data are very large (ca. 300,000 images, about 1 petabyte) considerable computing power is needed to analyse large areas. The National Computing Infrastructure (NCI) at the Australian National University (ANU) provides this capability for large users.

The full Australian Landsat TM archive was the first dataset to be processed and stored in the ODC. Importantly, imagery stored in the ODC has been rectified and radiometrically calibrated. Terrain-illumination corrected versions are also available.

Automated cloud masks are generated for each scene but are far from perfect. Nevertheless, as noted above, the availability of ARD has largely removed the need for pre-processing in existing time series monitoring programs, and opened opportunities to new applications.

[5] http://www.nationalmap.gov.au/
[6] https://www.opendatacube.org/

The planned storage of Sentinel optical and radar data in comparable 'cubes' makes it feasible to develop applications based on these sensors. Very recently, Sentinel-2 ARD data has been made available using automatically-derived cloud masks. At the time of writing, operational experience with these data is limited.

TABLE 6-1: When satellite data will be added to the DEA's open data cube (Source: DEA webinar 13th October 2018)

Satellite	Availability (from September 2018)
Landsat (1987- today)	Now
Sentinel-2 ARD	ca. 3 months
Near-real time Sentinel-2	Now (beta)
Near-real time Landsat	ca. 3 months
Sentinel-1 Radar	ca. 1 year
Landsat Surface Temperature	ca. 1 year

DEA have produced several automated derived products available through web services:

- Water Observations from Space (WOfS) show historical areas of surface water as measured using Landsat 5, 7 and 8 between 1987 and 2014;
- Landsat 5, 7 and 8 surface reflectance as 16-day rolling composites; and
- Sentinel-2 Near Real Time Data (rolling 30-day archive).

6.2. TERN Auscover

The Terrestrial Ecosystem Research Network (TERN) is a multi-party consortium established in 2009 under the Australian Government's National Collaborative Research Infrastructure Strategy (NCRIS). It is based at the University of Queensland and funds grants for research infrastructure to develop a national terrestrial ecosystem observatory using standardised and integrated measures of changes in land-based ecosystems. It supports data, tools and infrastructure under three themes: biodiversity, carbon and water, and land and terrain.

One TERN product is AusCover - a national data delivery service and expert network hosted by CSIRO which provides remote sensing information including time-series of environmental variables, continental-scale map products, high-resolution datasets, and ground calibration and validation datasets for airborne and satellite image data. The ground data collated by TERN, and the calibration of remote sensing measurement, is increasingly valuable with the recent developments in medium-resolution data access, and derived indicators, through Digital Earth Australia. National maps produced by AusCover are described in: http://www.auscover.org.au/dataset_categories/land-cover-dynamics-and-phenology/ .

They include:

i. Australian Ground Cover Reference Sites Database includes site descriptions and field measurements of cover fractions at 486 one-hectare sites collected between July 2010 and June 2014. The data are used to calibrate, validate and improve vegetation fractional cover products mainly derived from MODIS and Landsat;

ii. Normalised Difference Vegetation Index (NDVI) using the Advanced Very-High-Resolution Radiometer (AVHRR) at 1 and 5km resolution;

iii. Enhanced Vegetation Index (EVI) and Land Surface Temperature (LST) – MODIS, spatially and temporally interpolated;

iv. Enhanced Vegetation Index (EVI) – MODIS, MOD13Q1(c5) mosaic de-spiked;

v. Normalised Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI) – MODIS, MOD13Q1(c5) mosaic;

vi. Fractional Cover Metrics using MODIS;

vii. Ecosystem Disturbance Index using MODIS. Identifies the timing, location and magnitude of major ecosystem disturbances such as wildfire, flooding, climate change and human-triggered land use;

viii. Phenology – MODIS, derived from MOD13C1 EVI – cycles of greening and browning and quantification of the cycles' inter- and intra-annual variability from 2000; and

ix. Land Cover Dynamics – MODIS, MCD12Q2(c5) mosaic – identifies the vegetation growth, maturity, and senescence that mark seasonal cycles.

6.3. The Joint Remote Sensing Research Program (JRSRP)

The JRSRP is a collaboration between the Remote Sensing Research Centre in the University of Queensland, the Queensland Government's Department of Environment and Science, the New South Wales Office of Environment and Heritage, the Victoria Department of Environment Land Water and Planning, the University of New South Wales, TERN AusCover and the University of New England. The Tasmanian and Northern Territory governments are also involved in projects with JRSRP. It has been operating since 2007, adding new members over the past 11 years.

The JRSRP aims to increase Australia's capacity to conduct pure and applied remote sensing research to implement and assess effective environmental management policies at local, state and national scales[7].

Tindall *et al*. (2015) detailed their applications for mapping and monitoring rangeland conditions to be:

a) Processing systems and data storage/management in the Queensland, NSW and Australian Government computing systems. Images from about ten remote sensing platforms and aerial photography can be accessed through this system. This includes corrections and calibrations of the imagery. The JRSRP produce seasonal compositing Landsat images at the conclusion of each 3-month period;

b) Field monitoring techniques for calibrating and validating satellite imagery. As at 2005 over 2500 sites were included in the system, some of which are in WA. Terrestrial Laser Scanning (TLS) and hemispherical photography are also used to collect field data;

[7] https://www.jrsrp.org.au/

c) Woody vegetation mapping and monitoring. Includes Foliar Projected Cover (FPC) and land cover change estimates. Fractional cover methods (Scarth et al. 2010) are used to analyse trends in the green signal to monitor changes in woody vegetation caused by climate variability, land management, fire regimes, increased atmospheric CO_2 and woody weed invasion. Radar is also used to assess vegetation structure;

d) Ground cover and pasture biomass mapping and modelling. Methods used include AussieGRASS, fractional cover and separating reflectance from different strata woodlands. As well as Landsat (16-day coverage), MODIS is used to increase temporal coverage; and

e) Landsat-based fire scar mapping. This is automated detection and mapping using Landsat data which complements MODIS and AVHRR data. This method has been extended into WA.

In addition to the above infrastructure and research alliances outlined above, the Australian Government's Department of the Environment and Energy has established the National Vegetation Information (NVIS) System which has collated and regularly updates, detailed maps of vegetation associations from each state. As would be expected, there are large differences across Australia given the intensity of land use and availability of resources for mapping.

7. Other states' approaches to monitoring native vegetation

Land and vegetation management are state responsibilities under the Australian Constitution. This has resulted in each state considering different ways of mapping and monitoring native vegetation conditions according to their individual needs and level of resources. Each state has a regulatory need to control clearing and legislation differences have had a major effect on monitoring.

Native vegetation is only one of many layers in Geographic Information Systems (GIS) established to manage natural resources in states and territories. The characteristics of the native vegetation maps therefore need to be concordant with this larger information system.

This section provides a brief summary of the key vegetation datasets used by different states in biodiversity processes, and of the approach to update those data. Current uses of remote sensing are described. Some current research work and future ideas were provided by different state contacts. The federal system has disadvantages in that effort is dissipated across multiple jurisdictions, but it also provides for different approaches and the ability of states to learn from each other as is indicated below.

7.1.Overview

Vegetation type and extent. To underpin native vegetation and biodiversity management and regulation, all states have a working map of spatial floristic or community type and in regions subject to clearing, their extent. The quality and currency of state-wide vegetation maps varies considerably between states, as does the approach to updating the extent maps, and to improving floristic maps. All states have some version of a 'pre-European' or '1750' vegetation map. The National Vegetation Information System (NVIS) map is based on an amalgam of these state products, which is updated as states provide improved information. The current version (5.1) is described as 'appropriate for use at a regional scale' (DoEE 2018). All states have more detailed maps of areas with a 'high value' vegetation status and for threatened communities and species.

Remote sensing. There is considerable variation between states in capacity and scale of operational uses of remote sensing for resource management. This appears to be driven by differing policy priorities, and by historic investment (or lack of it) in developing and disseminating remotely-sensed data. States with significant operational capacity in remote sensing of land cover are Queensland, NSW (which largely employs a common technology with Queensland under the Joint Remote Sensing Research Program) and WA.

Even in states with an established program for monitoring vegetation, the overlap of remote sensing products with biodiversity reporting and regulatory actions is at present limited to updating woody vegetation extent maps in some jurisdictions (Queensland, NSW, Tasmania) and to supporting clearing surveillance in NSW. This is despite several established national, state and regional monitoring programs using remote sensing to provide vegetation monitoring information as detailed in previous sections. Remote sensing provides inputs to vegetation and land cover modelling products. It is also used to provide rangeland monitoring information in those states with rangelands. The main findings from this review of states other than WA are summarised in Table 7-1. Section 8 looks at what WA agencies are collectively and individually doing.

TABLE 7-1: Summary of state and territory approaches to managing native vegetation

Note: uses are approximate as this review concentrated on state-wide uses and was not comprehensive

State / Territory	Status of state-wide vegetation maps	Remote sensing use for clearing surveillance or mapping	Remote sensing use for vegetation management (including rangelands)
Queensland	Fine-scale mapping state-wide. Ongoing update program	Yes, woody vegetation clearing and Trend products	Yes, state-wide clearing linked to biodiversity regulation. Cover and greenness products
New South Wales	Coarse-scale mapping Fine-scale remapping in progress	Yes	Yes, woody cover and clearing at fine-scale, limited time steps. Inputs to models
Victoria	Coarse-scale only. Not updated	No	Limited to modelling of broad cover types
South Australia	Coarse-scale only. Not quite complete and not updated	No	Limited use for modelling broad cover types
Tasmania	Fine-scale mapping 'TasVeg' state-wide; updated by priority	No, except for forest reports. Clearing	Yes, for specific purposes including State of Forests
Northern Territory	Coarse-scale only state-wide. Not updated	No	Rangeland monitoring products are available NAFI fire products used
Western Australia	Coarse-scale only state-wide. Not updated	Yes, for surveillance Annual woody clearing maps are produced	Coarse-scale regional rangeland products Yes, for DBCA estate Fire products
National	Coarse-scale approx. 1:1m amalgam of above	No, except for the DoEE National forest monitoring	Yes, broad-scale information, reporting and modelling Specific fine-scale reporting (Section 6.3)

7.2. Queensland

Queensland has resourced remote sensing capacity for over 20 years within the former Department of Science, Information Technology and Innovation (DSITI). The program is known widely by its acronym, SLATS which stands for State-wide Landcover and Trees Study. A summary of the program is given in Section 4.1. The SLATS program also provides Landsat products to some other states (e.g. Landsat-derived Projected Foliar Cover (PFC) and ground cover proportion estimates). NSW's program is strongly linked, but some key differences exist because of state legislation (see Section 7.3). The SLATS group has research capacity and is linked with TERN and the Joint Remote Sensing Research Program (Section 6.3).

Queensland has also had a long-running and well-resourced state-wide vegetation mapping program called the Regional Ecosystem Mapping Framework undertaken by the Queensland Herbarium. The map data is produced by conventional mapping and is explicitly linked to biodiversity legislation.

Queensland is currently expanding its capacity for research and development in both remote sensing and mapping. One aim is to develop methods for measuring 'biodiversity condition' at sites using remote sensing.

Key current datasets. The key vegetation dataset for biodiversity actions is the Regional Ecosystem Map described above. It is at a 1:100,000 scale for most of the State; but also 1:50,000 or even 1:25,000 in parts of south-east Queensland. By comparison with other states, this mapping is at a fine scale, and associated descriptors to the data are detailed. They include biodiversity attributes. The data underpins much of the biodiversity planning and policy and is a regulatory requirement to support vegetation management legislation in Queensland as outlined in the box below and on the website:
https://www.qld.gov.au/environment/plants-animals/plants/ecosystems.

The maps are produced by air photo interpretation plus field visits. Production and update of the maps has required a large effort over many years. There is a hierarchy of attribute descriptions from Bioregion > Land zone > vegetation composition. As such, it is much more detailed than WA's land system/land unit maps, or WA's Beard vegetation maps.
There are two versions of the maps; a 'Pre-Clearing Vegetation Ecosystem Map' and a current version. For biodiversity purposes, the remaining extent (as a percentage) of each ecosystem is a key value linked to legislation, which triggers status (e.g. 'endangered').

> The Regional Ecosystem Description Database lists the biodiversity status (BD Status) and the vegetation management class (VM class) of each regional ecosystem.
>
> The biodiversity status is based on an assessment of the condition of remnant vegetation in addition to the criteria used to determine the class under the *Vegetation Management Act 1999* (the Act). The VM class is listed in the Vegetation Management Regulation under the Act.
>
> The biodiversity status is used for a range of planning and management applications including the Biodiversity Planning Assessments and to determine environmentally sensitive areas that are used for regulation of the mining industry through provisions in the *(Queensland) Environmental Protection Act 1994.*

Current use of remote sensing in vegetation mapping (extent, condition) and updates. For biodiversity purposes, remotely-sensed woody vegetation clearing data from SLATS is used to update woody vegetation extent in the regional ecosystem mapping database. The Herbarium then produces new reports on ecosystem biodiversity conservation status based on updated vectors and areas. Condition is not attempted at present but is an area of current research and development.

SLATS does not currently report regrowth of woody vegetation, but is working to develop a regrowth mapping methodology. However, regrowth areas (where recognised) are given a value in the ecosystem assessment according to rules about cover, height and age since clearing, e.g. "Regrowth which has reached 50% of original cover and 70% of original height is valued at 50% compared to remnant vegetation." If regrowth is over 15 years old it is valued higher.

Remote sensing rangeland monitoring. Cover Trends VegMachine Approach. Since 2000, Queensland's Department of Agriculture and Fisheries (DAF) has been a lead user of the 'VegMachine' software and the Landsat cover trends approach described later (Beutel *et al*. 2015). SLATS-generated cover indices are used within the system for agricultural extension and use by NRM groups. These groups raised funding to support a software upgrade and training manual (Beutel *et al*. 2010) and more recently to support development of an online version at the University of Queensland.

A dedicated departmental extension officer has been key to the uptake of this monitoring technology in the regions. Queensland DAF also uses remote sensing in other spatial products focussed at the grazing industry.

Current research and development. At the time of preparation of this report, the Queensland Government had advertised several new scientific positions in their remote sensing and biodiversity groups. This investment is focussed to deliver into gaps and information requirements for vegetation condition and biodiversity. A specific goal of the new program in biodiversity is to define and develop methods for measuring, or modelling, 'biodiversity condition' at the site level. Linking the to-be-developed work to remote sensing is in scope. There is a goal to develop and evaluate new remote sensing approaches to speed up and improve vegetation mapping and to produce biodiversity condition metrics.

7.3. New South Wales

NSW's Office of Environment and Heritage (OEH) is the agency responsible for care and protection of the state's environment and heritage, with a considerable capacity in biodiversity science, data collection and remote sensing. OEH maintains the Bionet Database which includes all site-based data, species data and vegetation maps. NSW's Department of Primary Industries (DPI) has an interest in biodiversity and condition within forested areas.

OEH has an established remote sensing group which works very closely with Queensland's SLATS group. Under the Joint Remote Sensing Research Program (JRSRP) research team arrangement, NSW and Queensland use common underlying analyses to produce similar products. NSW legislative requirements on clearing of native vegetation have necessitated the acquisition and use of high-resolution data. A Native Vegetation Regulatory (NVR) map (described below) has recently been produced in response to legislative changes.

NSW remote sensing map products are generally provided and used in raster form. Simple products such as the extent of woody vegetation are provided as vector products if required. The NVR map is raster-based because the level of detail is more than vector-based systems can handle.

OEH also has an active group developing and applying models for vegetation type, land use and condition across the state.

Current datasets – vegetation type. A State Vegetation Type Map (SVTM) is being produced by OEH and is near completion (80% of the State has been published). Information, including a link to a detailed methods document, can be found at:
https://www.environment.nsw.gov.au/vegetation/state-vegetation-type-map.htm

A broad structural class map and a more detailed plant community type (PCT) map are being produced. Both use remote sensing data, mainly aerial photography, as inputs. There is an underlying coarse scale 'pre-European' Vegetation Map with approximately 100 classes.

The methodology for the PCT mapping includes processing of historic and new species survey data from across the state to allow allocation to a PCT. Stratification on soil, environmental variables and tenure data is used. High resolution imagery is used as an input to segmentation routines which define 'homogeneous' spatial units to which PCT labels are assigned. Digital Air Photography (ADS40, 50cm resolution) is the preferred source of data; SPOT 5 is used where ADS40 is not available. This segmentation process essentially replaces the line work produced from the manual interpretation of units from aerial photography.

The assignment of a PCT label to an image-defined polygon unit includes visual interpretation. In particular, the interpreter must decide if the unit is composed of native vegetation. The methods document states:

> "*A polygon with greater than 10% native vegetation by area is tagged as native and attributed a vegetation photo pattern (VPP). The interpretation is based on digital aerial photography, time-series remote sensing data, landscape position, survey records, environmental layers, existing mapping and personal knowledge.*
>
> *Native vegetation polygons can include other coincident features such as rock outcrops, small farm dams, watercourses and wetlands, and isolated buildings. Recent fire scarring is classified as native and interpreted relative to the adjoining land cover or by referencing earlier imagery.*
>
> *Native grasslands are the most difficult to characterise due to the lack of distinctive spatial signatures or VPP in the available imagery and the paucity of survey records."*

Current datasets – extent and clearing. Remote sensing data is used to provide working vegetation extent (woody vegetation) using an approach like SLATS. However, NSW legislation requires mapping of vegetation at a finer scale than the Department of Industries (responsible for Crown Lands) can provide. NSW has purchased SPOT 5 imagery for the State. The available coverages lag by some years but, as explained in the next section, that is expected to change soon. Currently NSW has a woody vegetation extent map for 2008 (from Landsat) and 2011 (from SPOT); both based on time series analyses. This essentially provided a single-period clearing history (from mixed sensors). Photography is used in priority areas to update clearing data. Going forward, NSW and Queensland will be using Sentinel-2 data (10m resolution in visible-NIR) for this purpose. Woody regrowth is not mapped at present.

OEH's remote sensing group produces and uses other products including time series summaries of cover fractions (SLATS approach) which provide indicators of disturbance and has the potential to map non-woody vegetation types.

Remotely sensed image data is also an input to the NSW Native Vegetation Regulatory (NVR) map which was developed after a change in vegetation management legislation in NSW. It is based on most of the data sets mentioned above, modified by rules relating to legislative changes. Its production also included use of high-resolution aerial imagery to update some satellite data sets such as woody extent. Links to the NVR map method and appendices can be found at:
https://www.environment.nsw.gov.au/biodiversity/regulatorymap.htm

Current data – condition. Modelling of vegetation and habitat condition is an active research and development area in the OEH, with several model products in development or refinement. The main purpose is prioritising conservation actions and assessing biodiversity outcomes. Legislation has driven the investment in this area. The *Native Vegetation Act 2003* required OEH to monitor *Biodiversity Condition* and *Ecological Condition*. This modelling is not yet in operation. The *Native Vegetation Act 2003* has recently been repealed and it is uncertain whether the new legislation will similarly drive investment.

The information below was supplied by OEH:

> "*A model of habitat condition (Drielsma et al. 2012, Love et al. 2018 unpublished), applicable state-wide, has been developed to support biodiversity assessment, which incorporates FPC estimates from SPOT scaled relative to benchmarks for expected vegetation type (i.e. overall condition of grassland or woodland doesn't get downgraded due to observed FPC), and dynamics of 10-year fractional cover. Habitat condition is also used to develop measures of habitat connectivity and spatial context/fragmentation as well as to perform biodiversity evaluations*

under future climate models (Office of Environment and Heritage 2016) or different management scenarios.

A new state-wide model for predicting habitat condition from on-ground assessments is in the early stages of development and has been prototyped at regional scales (McNellie et al. (2014)".

For ground-based site recording of condition, a new system (protocol) has been developed like 'Habitat Hectares' in Victoria. It has been designed to be 'backward compatible' with earlier protocols so consistent metrics can be generated from historic data in Bionet.

This relies on a new site-based biodiversity assessment method[8] and newly developed dynamic vegetation integrity benchmarks[9]. These benchmarks are being applied retrospectively to historic (Biometric) site assessment data stored in Bionet.

Relevant research and development driven by State priorities. The modelling exercises described above are in development phases and driven by legislative requirements. It is not clear how these models can be assessed. Validation and refinement are the next steps. It is not clear how (and with what sensitivity) monitoring requirements can be met by models. While relevant remote sensing inputs can be regularly updated state-wide, it is unlikely that ground assessments will be updated. The wish was expressed that more frequent on-ground data would be available to produce model updates.

In terms of remote sensing, there is active research and development (within the JRSRP) to produce frequent and timely updates of woody vegetation extent for NSW using Sentinel-2 imagery.

"Monitoring increasing woody vegetation cover including regrowth, new plantings, encroachment etc. is a very high priority for NSW and Queensland as current vegetation change reports are unbalanced without information on increasing vegetation. We have attempted to map increasing vegetation using SPOT 5 imagery but there was a high level of false positives. We are currently investigating the use of ALOS radar imagery for monitoring change in biomass from 2009-2016." (Tim Daniher, pers. comm.)

There is also current research into quantifying the 'sensor change effect' in derived woody vegetation maps and an investigation into improvements to the seasonal cover disturbance index (SCDI) which was used in the NVR map via visual interpretation. This summarises multi-temporal seasonal responses of estimated cover fractions (from Landsat time series) and is prospective to provide information on non-woody vegetation as well as disturbance relating to condition.

7.4. Victoria

The Department of Environment, Land, Water and Planning (DELWP) is the responsible agency for vegetation and biodiversity in Victoria. The Arthur Rylah Institute for Environmental Research within DEWLP has a focus on applied ecological research including biodiversity. Victoria does not have an operational remote sensing capacity comparable to SLATS or WA's Department of Biodiversity, Conservation and Attractions.

Victoria – current vegetation type, extent and update. Victoria's state-wide vegetation type mapping datasets are essentially static. Floristic maps are described as old and coarse scale. Some maps were updated in the Regional Forest Agreement era, but there is no program to update this mapping state-wide. There is a 'pre-1750' modelled vegetation map. Specific high-valued vegetation types are mapped in greater detail (e.g. wetlands, threatened communities). For development proposals, regulations require detailed Environmental Impact Statements (EISs) including ground-based vegetation condition measures as described below.

[8] https://www.environment.nsw.gov.au/biodiversity/assessmentmethod.htm

[9] https://www.environment.nsw.gov.au/resources/bionet/native-vegetation-integrity-benchmarks-170440.pdf

With the era of widespread clearing over in Victoria, clearing or conversion of fringes, open paddock trees and native grasslands are concerns for biodiversity. There is no state-wide program for monitoring clearing or updating woody vegetation extent. Non-woody vegetation (grasslands, <20% tree cover) are also important in Victoria.

Condition is measured at site level using the 'Habitat Hectares' protocol[10]. This is a ground-based assessment method developed in Victoria by DELWP. It is widely known, and variants have been adopted by Tasmania and NSW for site recording. In Victoria, Habitat Hectares recordings are mandatory for EIS involving native vegetation, including for development and clearing proposals. In effect the protocol provides a definition of condition. The need for consistency in ground recording is emphasised in supporting material. There is an accreditation process for natural vegetation condition recorders. There is no systematic state-wide program for recording Habitat Hectares data, and no program for monitoring condition change.

Products from remote sensing used now. DELWP (Arthur Rylah Institute) produces a multi-epoch modelled Landcover dataset (in raster form) using multiple inputs including optical and radar remote sensing layers. It produces state-wide maps of 19 landcover classes in 5-yearly epochs. Thus, modelled change layers and statistics are produced. The approach has been implemented collaboratively with South Australia. Details on the approach, its applications and limitations are provided in White *et al*. (2018). There is no state-wide remote sensing program for monitoring woody or native vegetation changes per se.

Research and development, and future plans*.* As noted above, native grasslands and open woodlands are considered important and vulnerable. Better maps and monitoring of these vegetation types is thought to be desirable. The land cover modelling process described above addresses this in part. Seasonal Landsat data and radar inputs are helpful to map different grasslands and trees in open paddocks. The outputs provide a 'probability' of landcover at each location along with a measure of confidence for each class. There is considerable error and uncertainty in distinguishing non-woody native communities from agricultural land covers. The general modelling approach is new, and will be developed with new data and longer time series to reduce uncertainties in land cover and changes

7.5.South Australia

The Department of Environment and Water's (DEW) responsibilities include administration of the *Native Vegetation Act 1991*. Among other things DEW produces public information including 'report cards' and provide a viewing portal[11]. A range of map products can be viewed at this site, along with metadata.

Current vegetation type, extent and change. South Australia's vegetation type mapping covers about 90% of the state. It is coarse scale and derived from traditional methods; species from sample quadrats plus air photo interpretation (API) for boundaries. It has been produced by a series of separate programs over many years and is not routinely updated. The mapping is in vector form and comprises floristic associations. Condition ratings are not included. There are some communities mapped at finer scales (e.g. mangroves) and local areas have been mapped at finer scales.

Clearing. There is no comprehensive program to monitor or record clearing. Under South Australia's regulatory framework, compliance and clearing are dealt with by separate processes, essentially 'event driven' rather than relying on routine state-wide or regional monitoring. Landsat images are

[10] https://www.environment.vic.gov.au/__data/assets/pdf_file/0016/91150/Vegetation-Quality-Assessment-Manual-Version-1.3.pdf
[11] https://data.environment.sa.gov.au/NatureMaps/Pages/default.aspx

inspected for evidence of woody vegetation loss but not in a systematic temporal program. Detected areas of change will trigger inspection and appropriate actions.

Condition. In general, the South Australian Government does not record condition data, even at sites. ‘Condition’ is regarded as a problematic concept due to a lack of definition and a consensus on what it constitutes. The state report card on woody vegetation reports trends (in area) but, regarding condition states: *“The condition of woody native vegetation percentage cover is rated as unknown because there are no agreed state-wide benchmarks”.*

South Australian landcover layers. The land cover layers analysis detailed above is recent (Willoughby *et al*., 2018). It provides state-wide products of modelled land covers layers at several time points and is a key input to the ‘trend’ component in the state report cards[12].

South Australia collaborated in a multi-epoch modelled Landcover dataset with DELWP (Arthur Rylah Institute) whom built a similar dataset for Victoria. These products use multiple data layers as inputs, including multi-season optical remote sensing. The output layers are raster data, presented as ‘most likely’ cover at each pixel. The process provides measures of confidence, and uncertainty is acknowledged at individual locations, so modelled change at each location has an uncertainty. Aggregate statistics (e.g. for trends in area) are reported with high confidence, though confusion between non-woody native vegetation and agricultural cover is acknowledged. Output layer labels include native vegetation of various types (e.g. woody, non-woody, natural low cover, wetland vegetation).

The following report on the landcover layers provides detail and useful examples:
http://data.environment.sa.gov.au/Land/Data-Systems/SA-Land-Cover

Current research and development, and future plans. The modelled landcover layers form a new approach to informing some of DEW’s reporting on native vegetation. There is anticipation that more consistent data and products from national monitoring systems could update and improve these products.

Regarding condition, it was emphasized that there is a need for consistency and definition of ‘condition’, before South Australia could consider investment in recording condition. There is interest in CSIRO’s HCAS/HCAT program and The Australian Ecosystems Models Framework. It is hoped that these projects may provide a consistent way to describe and record ecosystem dynamics applicable to South Australia’s native vegetation.

DEW is aware of Geoscience Australia’s Digital Earth Australia program to produce national dynamic land cover layers. There is optimism that this may provide relevant and consistent products across jurisdictions, including the extent and change in native vegetation for WA.

[12] https://data.environment.sa.gov.au/Content/Publications/Booklet_22_RC401_WoodyVeg.pdf

7.6. Tasmania

The Department of Primary Industries, Parks, Water and Environment (DPIPWE) is the main agency responsible for native vegetation information and regulation in Tasmania. Sustainable Timber Tasmania (STT) is a business enterprise wholly owned by the Government of Tasmania with interests in production forest areas. DPIPWE is responsible for mapping vegetation – its website contains useful information on this and related activities. It produces and updates the detailed TASVEG community mapping, which is the primary biodiversity information.

Tasmania does not have a strong capacity in remote sensing or image processing. It conducts only limited activities in monitoring vegetation change and extent at state scale. This has similarities with the South Australian and Victorian situations, and contrasts with the legislative drivers and consequent activities in Queensland and NSW. The State-of-the-Forests and Regional Forest Agreement (RFA) processes (both 5-yearly) are exceptions.

Current vegetation type, extent and updates. The TASVEG mapping is the native vegetation dataset which underpins biodiversity values. It is produced by conventional mapping using photography and has been revised and improved since its initial release. Over 150 vegetation communities are recognised. It is detailed and fine scale. From the website[13]*:*

> *"TASVEG is a resource that underpins legislated native vegetation conservation provisions, policy, vegetation management agreements and monitoring at both State and Commonwealth levels. TASVEG is a vital tool for biodiversity research and monitoring, land use planning and sustainable management of Tasmania's unique natural resources".*

Aerial photography interpretation (API) for mapping and monitoring. DPIPWE value digital air photography highly to update and improve TASVEG. The photography program is not regular over the state but is flown according to priorities. Remapping is not automatic - priorities for remapping are areas where change is occurring, where past mapping is considered 'poor', or where particular high value assets exist or are known to be threatened. An example of fire damage and threat to alpine pencil pines was noted as a driver for photo acquisition to enable improved mapping of these communities, and of fire-damaged stands. Mapping is done essentially by photo-interpretation at the 'desktop' by digitizing over standard image displays of the photography. A 3-D terminal is used to assist with height interpretation. An infra-red band has been archived since digital photography has been collected.

Change monitoring is done only by differencing the old and new TASVEG maps as part of the API mapping process. The State-of-the-Forest mapping detailed below is the exception. Reference was made to the change in fragmentation in rural areas as a surrogate for condition.

Condition monitoring is referred to on the DPIPWE website. It is essentially a guide to site-based assessment modelled on the Victorian 'Habitat Hectares' site system. There is a strategy document[14] for assessment principally referring to site-based floristics etc. There is not a systematic program for locating and recording sites. Condition assessments are driven by individual project needs.

Current use of remote sensing data/products. Landsat time series data are used to monitor forest (woody) area changes - the driver for this is the *Forest Practices Act 1985* arising from the Regional Forest Agreement for 'State-of-the-Forest' (SoF) reporting.

[13] https://dpipwe.tas.gov.au/conservation/development-planning-conservation-assessment/planning-tools/monitoring-and-mapping-tasmanias-vegetation-(tasveg)/tasveg-the-digital-vegetation-map-of-tasmania
[14] https://dpipwe.tas.gov.au/Documents/Native-Vegetation-Monitoring-Strategy.pdf

While this is a driver for monitoring, there is a lack of other drivers to motivate regular, state-wide remote sensing uses. DPIPWE must report changes under SoF reporting but has no compliance role.

For SoF, DPIPWE sources Landsat images and woody vegetation extent and change products from Queensland's SLATS team with whom they have an agreement and paid arrangement. Products are based on SLATS methods. This arrangement meets SoF reporting requirements. They are currently considering either renewing the arrangement with SLATS or using GA/DEA as an alternative supplier. SLATS processes throughout Tasmania provide updates of woody vegetation extent and 'probabilities of change' raster maps. Indicated change areas are checked and digitised manually to prepare the reports.

In the past, the temporal update interval for SoF has been 5-yearly, most recent 2010-2015. They are moving to annual changes at present, though reporting for SoF and RFA will remain 5-yearly.

Woody extent changes on public land are assumed to be rotational forestry and are not updated. Forestry records changes on public land but there are very few conversions from forest to non-forest uses at present. Changes on private land are monitored, as they may be clearing. Known tree plantation vectors are taken as 'true' and changes are not recorded or tracked.

DPIPWE use Landsat and Sentinel data for other tactical project purposes; one example was detection of flowering leatherwood for honey producers. Landsat and Sentinel data are also used to update the fire history database.

Significant areas of LiDAR data have been collected over Tasmania by Sustainable Timber Tasmania and others. Lidar can provide Digital Elevation Models, estimates of height and information on density. This data is relevant to vegetation yield mapping and fuel load reporting. Geodata Services[15] are working to release mosaics from LiDAR of these derived data products. More LiDAR acquisitions are anticipated.

Research and development, and future plans. More frequent, complete and higher-resolution updates of the woody cover map using Sentinel data are planned. There is interest in fractional cover, woody change and water observations. DPIPWE intends to move from SLATS products to GA/DEA updates using Sentinel for such products as they become available.

DPIPWE would like to see increased access to LiDAR-derived products as processed mosaics.

Land type or land zone mapping would be useful to use as fundamental landscape units for comparison and reporting changes. The mapping would incorporate geology, geomorphology, vegetation and hydrography to help delineate zones of differing ecosystem function. These would be useful for benchmarking changes in woody growth and fractional cover through time and space.

7.7. Northern Territory

There is considerable expertise in biodiversity science and conservation in the Northern Territory (NT). Only a small proportion of land has been cleared and converted for settlements and agriculture, so clearing is a relatively minor issue. Large areas are modified by grazing, fire regimes and weed invasions. There are also extensive conservation and aboriginal lands.

The NT regulatory framework includes a *Planning Act 2009* and a *Pastoral Land Act 1992* which require clearing applications. There are no specific regulations about native vegetation extent, and no legislation which requires or dictates monitoring of vegetation extent.

For development proposals, there are land clearing guidelines and the proponent is required to assess regional impacts. NT does not have a standard tool or approach to this for biodiversity and is searching ('struggling') to come up with one.

[15] https://www.geodataservicesinc.com/

Current data on vegetation type extent and updates. The NT-wide vegetation type mapping is coarse scale (approx. 1:1million); this is provided to the federal National Vegetation Information System (NVIS) dataset. It is not being updated. There are a range of areas mapped at finer scales (1:10,000 - 1:100,000) such as the Macarthur River and Daly River catchments, primarily by conventional mapping (air photo interpretation) with some use of satellite image classification (as described below). In addition, a few 'high value' vegetation types (e.g. Lancewood, *Melaleuca*) are mapped at finer scale for specific purposes, including development assessments.

The NT-wide vegetation and extent maps are not updated. The NT Government is not actively working on biodiversity condition maps or condition changes.

Current uses of remote sensing. Satellite imagery has been used for finer-scale vegetation mapping for specific areas (e.g. Macarthur River). Landsat digital classifications were used along with a 'post classification' correction/addition of line work based on air photo interpretation. Sentinel data was used similarly for mapping of Groote Eylandt.

Rangeland monitoring products based on Queensland-produced Fractional Cover time series (Landsat) are used. This is a collaborative arrangement with the University of Queensland whereby access to imagery and cover products is provided on an annual fee basis.

Models of habitats and species presence have been built for specific areas. Landsat-derived fractional cover is one input, along with terrain and other environmental variables.

Fires are extensive, frequent, and important for many reasons in the NT. MODIS fire mapping products for all northern Australia (hot-spots and burnt extent) are updated daily in the Northern Australia Fire Index (NAFI) program housed at Charles Darwin University and distributed on a website. The NAFI data are simple raster maps which do not require high bandwidth. The products are widely used and are an example of the effective distribution of raster products. While fire frequency and timing are known to affect landcover, land function and emissions, it is not clear if fire history data forms any part of the operational mapping or biodiversity management of the Department of Environment and Natural Resources.

Future improvement/plans. Tools for assessing development are lacking but a desire was expressed for such tools, with a capacity to update both maps and modelled outputs.

8. What WA state agencies are currently doing and require in future

8.1. Approach taken

Nominated staff from each agency were interviewed to provide a better understanding of what each agency required in mapping the extent of native vegetation over time and gaining an understanding on how its condition may be changing. Key references were also examined, some of which were not public documents.

This work was somewhat broader than the terms of reference, but it was felt important to understand the needs of agencies with different areas of responsibility (conservation, grazing impacts, fire risks etc.) and to get a cross-agency appreciation of what each agency needed and was doing to look for synergies and efficiencies.

8.2. Land Monitor

The Land Monitor project (see Section 4), established in the 1990's, used remote sensing to provide detailed mapping and monitoring of dryland salinity and native vegetation over the south-west agricultural region. Sequences of spring Landsat TM images were processed and analysed, in conjunction with DEM derivatives, for monitoring dryland salinity while summer image sequences were used to produce vegetation extent and change products (Wheaton *et al*. 1992, 1994; McFarlane *et al*. 2004; Caccetta *et al*. 2009).

The extent and change in extent (clearing, revegetation) products are produced using a Conditional Probability Network (CPN) time series processing approach (Section 4). The 'Trends' product summarises changes in density within vegetation for each pixel, based on the time series of cover indices over a chosen period. Vegetation trends are formed from a multi-date image file of cover index values from summer dates of Landsat TM data. The period can be adjusted but standard Land Monitor trend products cover the most recent decade, and the full time series from the project; i.e. 2008-2018, and 1998-2018 in the most recent update (e.g. the images shown on the cover of this report).

The trends approach, which had earlier been developed for rangeland cover monitoring, was later adopted in the DoEE National Inventory program to produce the 'National Forest Trends' product (Section 4.3). The index used is an 'inverted' sum of Band 3 and Band 5 as described in Lehmann *et al*. (2013). The 2018 results are outlined in Furby (2018) and Furby *et al*. (2018a; 2018b; 2018c; 2018d). The most easily interpretable summary is the 'linear trend' or slope (rate of change per year) of the pixel's cover index over the period. Wallace *et al*. (2006) provides examples of trend products in different vegetation systems. Summaries of change are produced for each pixel as six band image files as per Table 8-1.

TABLE 8-1: Land Monitor Trend Products Bands used to summarise vegetation over time

Band	Measure
1	Mean index brightness over all dates
2	Linear trend (slope) in brightness over time (scaled)
3	Quadratic trend (slope) in brightness over time (scaled)
4	Standard deviation about the mean (scaled)
5	Residual standard deviation after fitting linear trend (scaled)
6	Residual standard deviation after fitting linear and quadratic trends (scaled)

In trend products for the south-west, areas which were never classified as having perennial vegetation cover are masked out and given a null value in all bands. These will include areas of very sparse native vegetation. The bands can be displayed separately or together to summarise trends and stability of vegetation over time as measured by the index, and to highlight areas with different patterns of change. One display shows positive and negative linear trends in different colours; while other bands can be used to examine deviations from these trends.

Trend class is a simplified one-band summary of the linear trend over the whole period broken into five classes chosen from inspection only (Furby *et al*. 2018c). The thresholds for classes have been determined statistically, based on the distribution of linear trend values for the area. They are not referenced to on-ground changes or ecological interpretation, but results and prior experience in rangeland environments clearly show that the approach is sensitive to subtle changes as well as 'extreme events' such as fire and logging. Trend class products may be interpreted as shown in Table 8-2.

TABLE 8-2: Classification of trend classes over long periods used in Land Monitor

Trend class number	Trend
1	Major positive trend in vegetation density over the entire period
2	Positive trend
3	No major change
4	Negative trend
5	Major negative trend

Examples of long-term (28-year) vegetation extent and change are shown in Figure 8-1 and Figure 8-2[16]. Area statistics and connectivity models can be readily calculated from the underlying classification data. In the high rainfall area of Figure 8-1, the large areas of increase (blue colour) are plantings of Tasmanian Bluegums (*Eucalyptus globulus*) on former agricultural land; some smaller areas were revegetated as part of Landcare projects. Losses are likely to be due to sheep grazing and the spread of dryland salinity, especially along drainage lines.

[16] http://landmonitor-beta.landgate.wa.gov.au/home.php

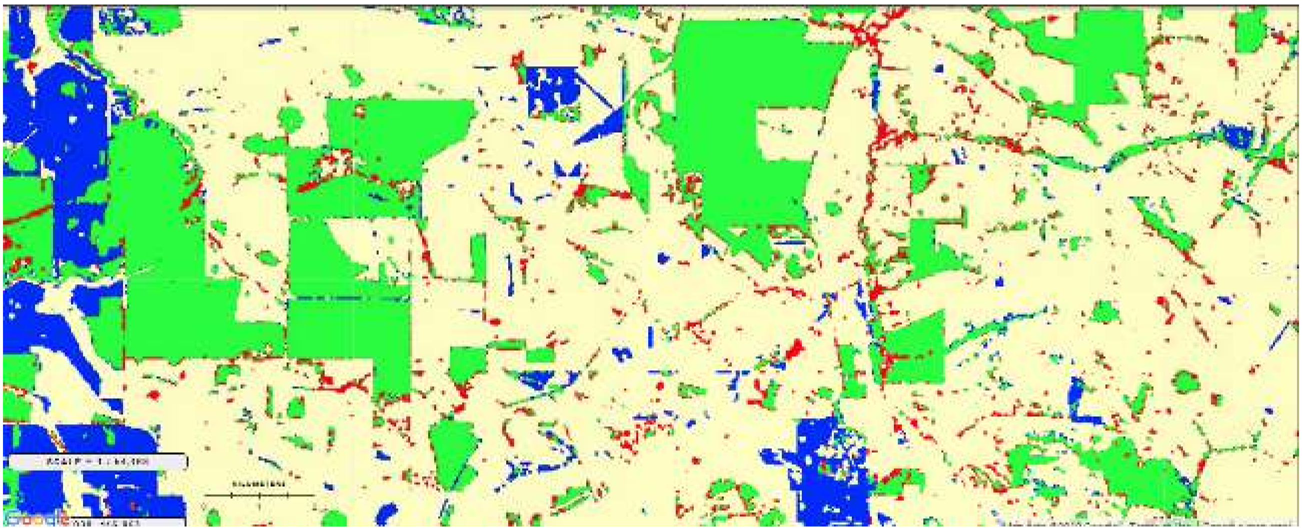

FIGURE 8-1: Woody vegetation extent and change map 1990-2017.
Losses (red), gains (blue) and no change (green). Area shown is in the upper Tone River area; the South Jingalup Nature Reserve is upper centre. Yellow areas are cleared agricultural land

Figure 8-2 shows a similar extent and change map from the central Wheatbelt. It shows long-term perennial vegetation losses associated with bush reserves and remnants within paddocks. Small areas may recover because of fire and revegetation, but the predominant change has been loss over this 28-year period. Uncontrolled stock access was a significant cause of remnant decline in the early part of this period, but remnants are now being affected by the use of wide boom sprays and remotely-operated farm machinery.

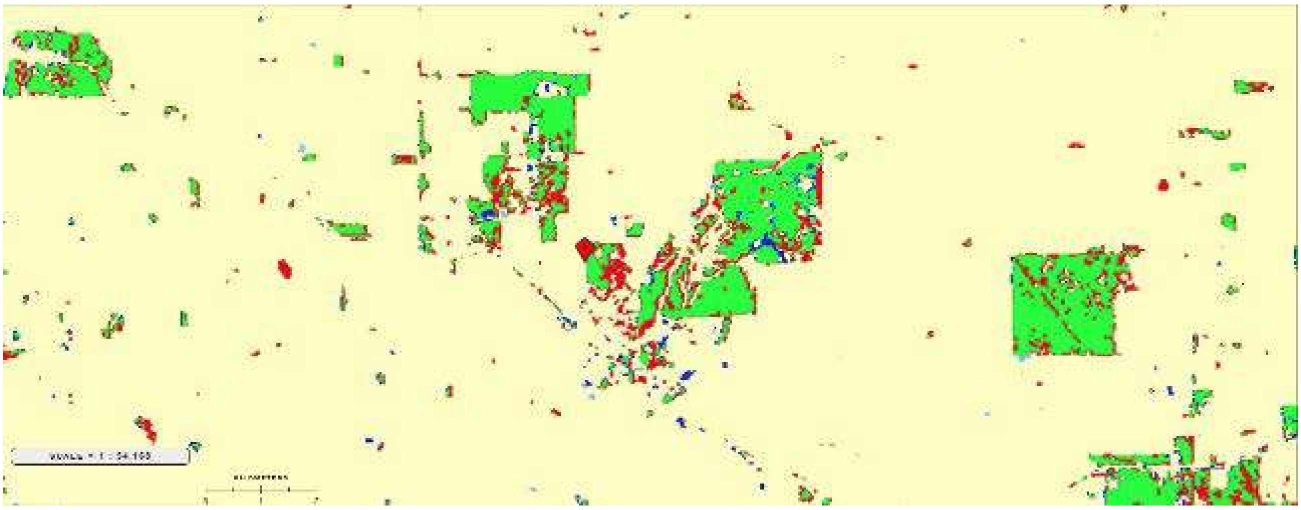

FIGURE 8-2: Vegetation extent and change 1990-2017. Area shown is near Wyalkatchem in the Wheatbelt.
Losses (red), gains (blue) and no change (green) in perennial vegetation between 1990 and 2017. Yellow areas are cleared agricultural land throughout the period.

Vegetation trend products provide more information on the timing and extent of changes (decline, recovery) within perennial vegetation. A vegetation trend map for the Jingalup area is shown in Figure 8-3. The new plantations and revegetation show clearly in blue colours. Within native vegetation remnants, stable, declining and recovering areas are highlighted, indicating where and when processes are affecting the vegetation. Figure 8.4 is the simplified 'Trend Class' product for the same area.

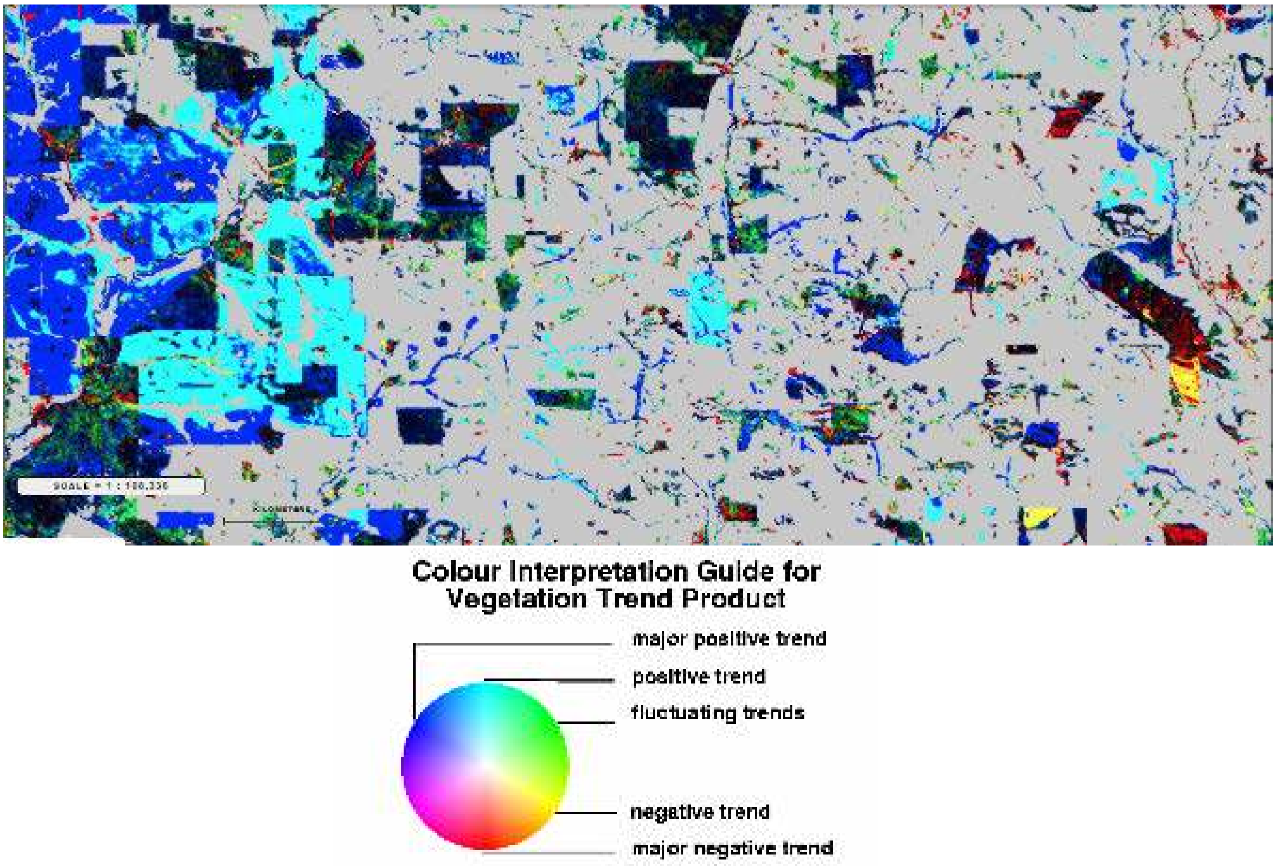

FIGURE 8-3: Vegetation trend product between 1990 and 2017 in the upper Tone River area.

The area of Figure 8.1 is within the area shown. The South Jingalup Nature Reserve is upper centre. Grey background is cleared land throughout the period. Blue and Light Blue areas indicate the different timing of revegetated areas (light blue is younger). For the remnants, black indicates stable cover throughout the period, while hot colours indicate decline in cover. Green indicates disturbance and recovery within the period. Source: Land Monitor website.

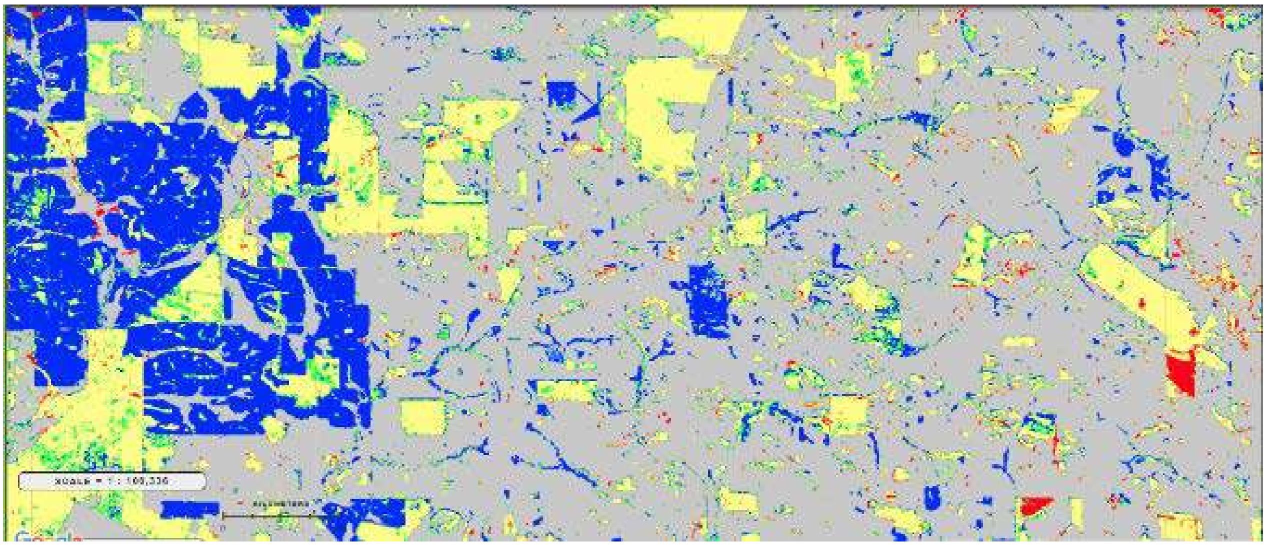

FIGURE 8-4: Vegetation trend class map in perennial vegetation between 1990 and 2017 in the upper Tone River area.

Background cleared areas are shown in grey. Trend Class (Table 8.2) colours shown are; Blue: major positive trend over the period; Green: positive trend; Yellow: stable; Orange: negative trend; Red: major negative trend.

A technical consortium was formed in the late-1990s to continue the vegetation monitoring after the initial mapping had been completed. Currently it contains the Department of Biodiversity, Conservation and Attractions (Chair); Landgate (Secretary); Department of Planning, Lands and Heritage; Department of Primary Industry and Regional Development; Department of Water and Environmental Regulation; Water Corporation; CSIRO and the Department of Fire and Emergency Services. The Department of Mines, Industry Regulation and Safety has indicated an interest in joining the consortium.

Each member contributes $10,000 per annum and gets full resolution digital data delivered via the Pawsey data portal. CSIRO uploads the data and the members download when they require it for their area of responsibility. Integrating large datasets into their own systems is a challenge for some members. A Landgate website[17] allows non-members and the general public to view picture products derived from that data.

In June 2018 the consortium agreed to extend coverage to the whole-of-the-state. CSIRO subsequently delivered products to the Pawsey Supercomputing Centre in November 2018. The new state-wide products span 30 years (since 1988) and are now consistent with the DoEE national products for greenhouse accounting. The national products for WA are already produced at CSIRO Floreat.

The extended Land Monitor products released in 2018 cover the whole state with multi-temporal 3-class Forest (>20% woody cover), Sparse (nominal 5-20% woody cover) and Non-Woody maps. These products do not yet replace the DPIRD Native Vegetation Extent dataset as the basis for the state-wide vegetation statistics data produced by DBCA each year and which inform DWER's assessments. The current suite of products requires significant further work; in particular, attribution of the extent data to native and non-native categories, and attribution of change data to various causes (fire, clearing, native revegetation, forestry, climate etc.).

Land Monitor has recognised the need for improved vegetation information across all vegetation types in WA, and the opportunity presented by new data sources and computational methods. The Consortium also recognised in 2018 the need to set up an outreach program to make Consortium members more aware of Land Monitor at both a management and technical/user level. It is working towards a native vegetation cover product within the limited resources it has available. Further investment is required for the State to develop a vegetation cover product.

In 2018, CSIRO prepared a proposal based on Land Monitor experience for DWER aimed at improving vegetation products for the whole state including grasslands and non-woody vegetation (Appendix 13.2). The project aims to produce state-wide 'cover proportions' for both wet and dry season Landsat time series using unmixing, calibrated where possible to vegetation information; and to evaluate summaries of these against relevant products as metrics of vegetation and change. It also aims to evaluate the information content of Sentinel-1 (radar) and Sentinel-2 (optical) for vegetation cover and structural information in priority vegetation areas where ground data can be collected, and to develop methods for processing. The findings of these studies would provide guidance to the methods and value of scaling up the use of these data or integration of data sources for WA vegetation. The proposal set out to focus on 'measurable' properties of vegetation rather than the difficult concept of condition.

[17] http://landmonitor.landgate.wa.gov.au/

8.3. Landgate

Landgate used to develop remote sensing products and manage the Western Australian Satellite Technology Application Consortium (WASTAC) whose role was to provide AVHRR and MODIS satellite imagery to clients. The data distribution role has since been taken over by Geoscience Australia although some users obtain images directly from satellite source companies. All data (Landsat TM, Sentinel) are now provided free on the internet so there is no longer any possibility of funding Landgate work through providing this traditional service. Few web services are supported except for Land Monitor images (but not the underlying data) as explained above.

The Pawsey Supercomputing Centre is used for image storage (e.g. Land Monitor) but not image analysis. Urban Monitor data has been moved from the Pawsey Centre to the National Computational Infrastructure (NCI) in Canberra.

Programs that have been developed or supported by Landgate staff, mainly in conjunction with CSIRO and/or state or national partners include:

- FireWatch (historical map of fire scars) and My FireWatch (public version available on mobile phones);
- Aurora (simulates the spread of fires once ignited);
- Northern Australia Fire Information (NAFI) www.firenorth.org.au provides information on the timing of fires, their spatial extent and, by comparison across years, the frequency with which a given area is burnt across northern Australia;
- FloodWatch (MODIS, radar) for tracking the extent of inundation during events for DFES and the Bureau of Meteorology;
- Pastures from Space estimated pasture growth rates (PGR) on a weekly basis across the agricultural areas of Australia. PGR was calculated through an algorithm that utilises the NDVI number, rainfall, soil moisture, temperature, evaporation and solar radiation. It was closed in late September 2018;
- RangeWatch – Pastures from Space for rangelands, is an estimate of pasture growth rates and total green biomass at a 250 x 250m (MODIS) or 30 x 30m (Landsat 8) resolution on a weekly basis. It can track trends since 2004. It is in beta version; and
- CarbonWatch was developed in 2009 to estimate carbon sequestration levels for individual afforestation projects but has recently ended.

The West Australian Land Information System (WALIS) is still supported by Landgate but is not staffed. It has a Board composed of mid-level managers and coordinates state government custodial data entries onto the www.data.wa.gov.au website.

8.4. Department of Biodiversity, Conservation and Attractions

The DBCA has as a mission "to manage Western Australia's parks, forests and reserves to conserve wildlife, provide sustainable recreation and tourism opportunities, protect communities and assets from bushfire and achieve other land, forest and wildlife management objectives".

At 30 June 2017, the total terrestrial area under DBCA's (formerly Department of Parks and Wildlife) direct care was over 20 million ha; it is also responsible for fire preparedness and pest animal and weed control over about 66m ha of Vacant Crown land and unmanaged reserves (Table 10, Department of Parks and Wildlife 2016-17 Annual Report). Given these large areas, satellite remote sensing has been a significant tool in its management program.

DBCA interest is mainly on the conservation estate and Vacant Crown Land, with some work on roadside vegetation and other areas where threatened species and communities occur off the formal conservation estate.

DBCA has an active remote sensing GIS group. This group has worked closely with CSIRO staff based in the Leeuwin Centre and through the Land Monitor Consortium. It has developed its own capacity to provide new indices and products in response to the Department's management, scientific and reporting needs. It routinely deploys and modifies the cover trends approach to vegetation monitoring over DBCA's areas of interest in response to specific management or science questions. Standard Land Monitor Trend Products cover fixed periods and apply a common cover index over the entire area. Typically, the DBCA modifications involve careful selection of image dates in the context of the question, use of vegetation stratification information, and (often) use of alternative cover indices most appropriate to the soil and vegetation. The capacity of the DBCA group to deploy and adapt established methods for purpose is a good example for the generation of flexible and relevant products for State purposes from the image databases and from standard product suites.

DBCA has developed effective methods for mapping and monitoring selected communities in WA and currently carries out the following remote sensing activities, in many cases using Land Monitor products, as the basis for policy focussed products and reports:

- Forest Management Plan reporting;
- Forest extent change detection;
- Monitoring of vegetation change;
- Explanations for vegetation change;
- Observing temporal trends for reporting on Natural Diversity Recovery Catchments; and
- Developing a wetland inundation classification.

At national level DBCA are collaborating with:

- CSIRO – vegetation condition mapping across Australia to which they provide best-on-offer ('pristine') sites; and the development of ecosystem models;
- TERN – Auscover mapping and National Ecosystem Surveillance Monitoring; and
- TERN AusPlots network – currently 70 in WA; may grow to 500 – the program operates from the University of Adelaide.

The European Space Agency's Sentinel-1 imagery is of likely interest to DBCA as it may be able to assess vegetation volume, while Sentinel-2 has greater spatial resolution (e.g. 10, 20 and 60 m), temporal (5-day pass) and bands (13) resolution than Landsat TM. As such, Sentinel-2 data could also be used for monitoring narrow pieces of vegetation such as roadside vegetation, remnant corridors and riparian zones, modelling species distribution, and identifying small areas of patch burning (e.g. in the Kimberley) where Landsat resolution is insufficient. At present, DBCA would see Sentinel products mainly used in specific applications. The availability of Landsat analysis-ready data and standard products through Land Monitor will continue to be used for state-wide information.

Identifying long-unburnt land is a useful application of image time series, which would require access to digitised aerial photography that pre-dates Landsat TM (i.e. before 1987). Whilst old nitrate-based aerial photographs are being digitised, there is a concern some may be lost due to deterioration.

National environmental economic accounts are being adopted to understand the condition of Australia's environment, and its relationship with its economy. The states and territory have evaluated methods to integrate environmental and economic information into decision making including the piloting of accounts at different scales and timeframes[18]. In time, these accounts may influence the need for specific satellite remote sensing products.

In 2014, DBCA and CSIRO carried out Landsat and GIS processing to assist the then Department of Planning and Lands (DPL) in successful trials of rangeland monitoring using the cover-trends 'VegMachine®' approach in the Goldfields and Pilbara regions. VegMachine is software that provides a user interface for linking imagery, trends products and ground data in pictorial displays. The actual trend data is created offline and imported into the software's database. VegMachine can use any cover index as input (CSIRO, GA, SLATS PFC). Property-scale and detailed summary products were produced in 2014 (Figure 8-5).

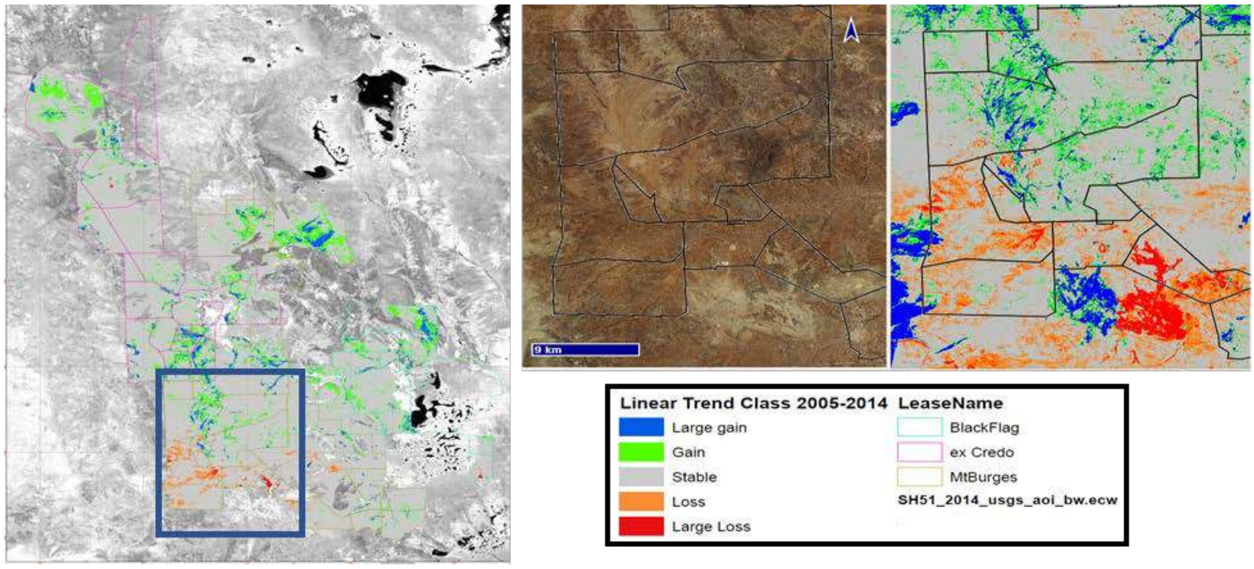

FIGURE 8-5: Landsat cover trend class map 2005-2014 for three pastoral stations near Coolgardie WA.

Left: masked to the woodland and chenopod vegetation type; green and blue areas show cover increase and major cover increase over the period. Area shown is approx. 75km by 90km.

Right: Detail area of the map shown alongside an aerial photograph mosaic; black lines are paddock boundaries. Recovering areas within this vegetation type are mainly chenopod systems impacted by historic grazing. Red areas indicate decline including fire scars in the south; most decline areas are in shrublands which are not grazed by domestic stock. Source: DPL/DBCA range monitoring pilot study 2014, Credo Workshop Presentation.

8.5. Department of Primary Industries and Regional Development

Native vegetation plays several important functions in DPIRD's role of growing and protecting Western Australia's agriculture and food sector:

- As food for cattle, sheep and goats in active pastoral stations which occupy over 40% (857,833 km^2) of the State;
- Managing remnant vegetation on freehold land for natural resource management purposes;
- Regulation control through support of the Commissioner for Soil and Land Conservation; and

[18] http://www.environment.gov.au/science/environmental-economic-accounting

- Direct economic use such as firewood, carbon farming, sandalwood and grazing, mainly in times of drought.
- DPIRD currently carries out several activities related to monitoring native vegetation. The remote sensing activities are mainly carried out through the Land Monitor Consortium:
- Assesses the likely impact of clearing applications, mainly on dryland salinity;
- Administers drainage and soil conservation regulations and ensuring compliance and covenanting conditions are met under the *Soil and Land Conservation Act 1945*;
- Preparing land condition reports for the Department of Planning, Lands and Heritage and the Pastoral Board;
- Soil-landscape mapping and rapid catchment appraisals. Many soil maps are based on the native vegetation that act as a 'bioassay' of what lies beneath; and
- Flood, flood and dry season responses.

Trend products could be used to assess the invasion of woody weeds such as Bellyache Bush (*Jatropha gossypiifolia*), Parkinsonia or Jerusalem Thorn (*Parkinsonia aculeata*), Bardi Bush (*Acacia victoriae*) and Mesquite (*Prosopis* spp.), but no active program is in place.

The Office of the Auditor General (2017) found the State's knowledge of land condition at the pastoral lease level had declined since 2009 as a result of *"Reductions in lease inspections, limited use of remote sensing technology, agency preference to replace compliance activities with a cooperative approach to work with lessees to fulfil requirements of the LA Act, and inadequate records of the work conducted.."* (Office of the Auditor General 2017). It was recommended that better use could be made of remote sensing technology to monitor land condition and to inform management decisions.

Products produced by DPIRD that relate to native vegetation monitoring include:

- Land system maps for most of Western Australia's rangeland pastoral leases, except for pastoral leases in the Southern Goldfields and to the north-east of Wiluna-Meekatharra. The Southern Goldfields region, covering the area known as the Great Western Woodlands is expected to be completed soon. These maps are at a finer scale than the Beard vegetation maps but are not updated.
- The West Australian Rangeland Monitoring System (WARMS) which is a representative network of point-based rangeland monitoring sites on which soil surface and vegetation attributes are recorded and regularly re-assessed. Site installation began in 1993 and was completed in 1999. There are 1608 WARMS sites; 625 are 'grassland' sites and 983 'shrubland' sites. Grassland sites are monitored every 3 years and shrubland sites every 6 years. The seventh assessment of the grassland sites was completed in 2014 and the fourth assessment of shrubland sites was completed in 2015.
- GIS (vector) maps of remnant vegetation (explained in more detail below). The data for the intensive land-use zone (ILZ) in south-western Australia was originally derived from 1995 Landsat TM satellite imagery and has been corrected using digitised aerial photography acquired between 1996 and 2006. This is a continuation of work commenced under the National Land and Water Resources Audit and is done when resources allow. The recent availability of digital aerial photography and high-resolution satellite imagery is likely to replace this dataset although the vector format is attractive for users unfamiliar with raster data analysis software. The data are available on www.data.wa.gov.au

8.5.1 State-wide vector data set of native vegetation

As mentioned in iii) above, a state-wide vector data set of native vegetation extent has been created and is maintained by DPIRD. Photo interpretation and manual digitizing has been used to create and update this data. In recent years, this has been carried out by a single officer at DPIRD on an irregular basis. The notional threshold for inclusion of vegetation is 20% cover, like the threshold for operational Landsat programs (Section 4).

The Perth-Peel data has been described as accurate in Gaia Resources (2018) but the manual interpretation approach has limitations in terms of timeliness and consistency. Updates are limited by the photo capture program. Aerial photography is acquired very rarely over the rangelands, infrequently over the agricultural area and frequently over Perth-Peel and large towns. The scale (resolution) of the imagery also varies. For much of the Wheatbelt, the latest photography is over ten years old (Figure 8-6). Updates to the vector data are not immediately produced. Thus, there is no consistent date for the existing dataset. Vectors are tagged with the date of photography and the date of creation. Further, there is an element of 'operator judgement' in which scale of an 'object' is included and in the detail of the line work. This leads to the possibility of inconsistency; the fact that there is a single officer charged with this work minimises the problem. As updates are created the underlying previous vector data is often 'improved' by the operator. Examples of an aerial photograph and the current linework are shown in Figure 8-8 to Figure 8-10.

This dataset is intersected with pre-European vegetation mapping and used as the basis for the annual analyses of the conservation status of vegetation produced by DBCA, which informs conservation status rankings under the *Biodiversity Conservation Act 2016* and clearing decisions under the *Environment Protection Act 1986*.

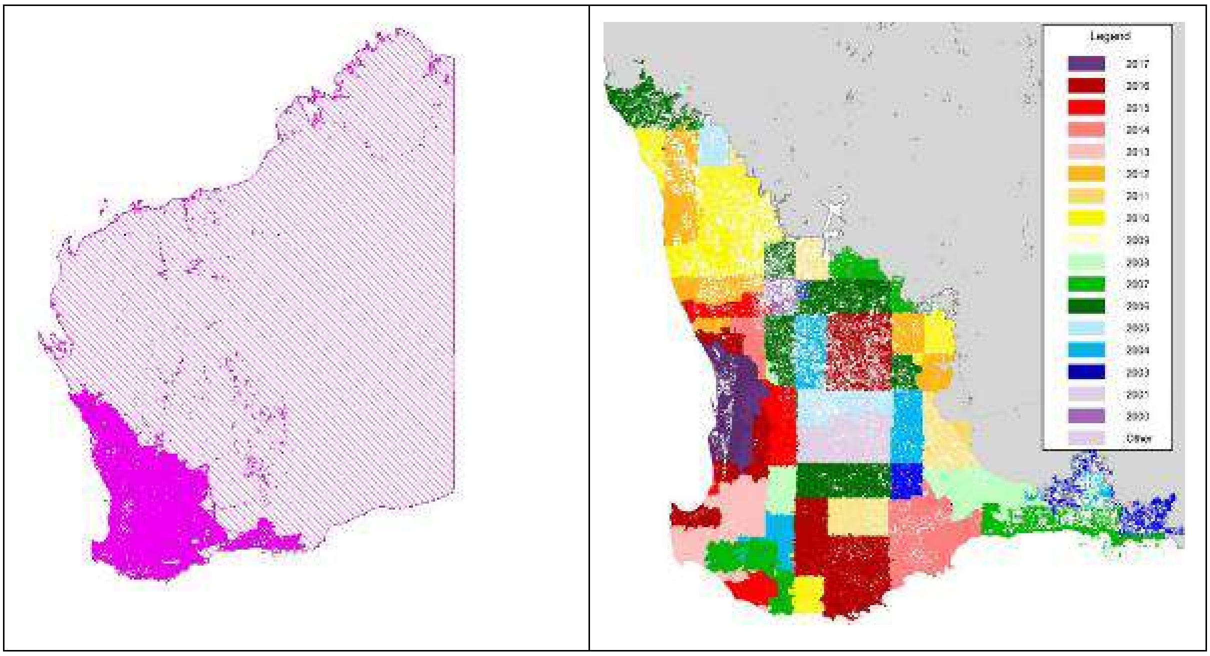

FIGURE 8-6: Left. State-wide vector dataset – density of linework covers the South-west at this scale. Right: Current orthophotography capture dates for SW coloured by year (Source: E. Wise, DPIRD)

FIGURE 8-7: Latest aerial photograph (2018) image detail. Location approx.118:32:40E, 34:07:35S in the Fitzgerald corridor region.

FIGURE 8-8: Native vegetation extent vectors (digitised 2016 on 2014 photography) overlaid on 2018 photography.

Note: Same area as Figure 8-7. Some narrow features are omitted, and some low cover areas are included in this example.

FIGURE 8-9: Native vegetation extent vectors (pink lines) on photography on Perth's northern fringe.

Yellow lines are part of Agricultural landuse dataset. Approximate location 115:55:10E, 31:52:42S.

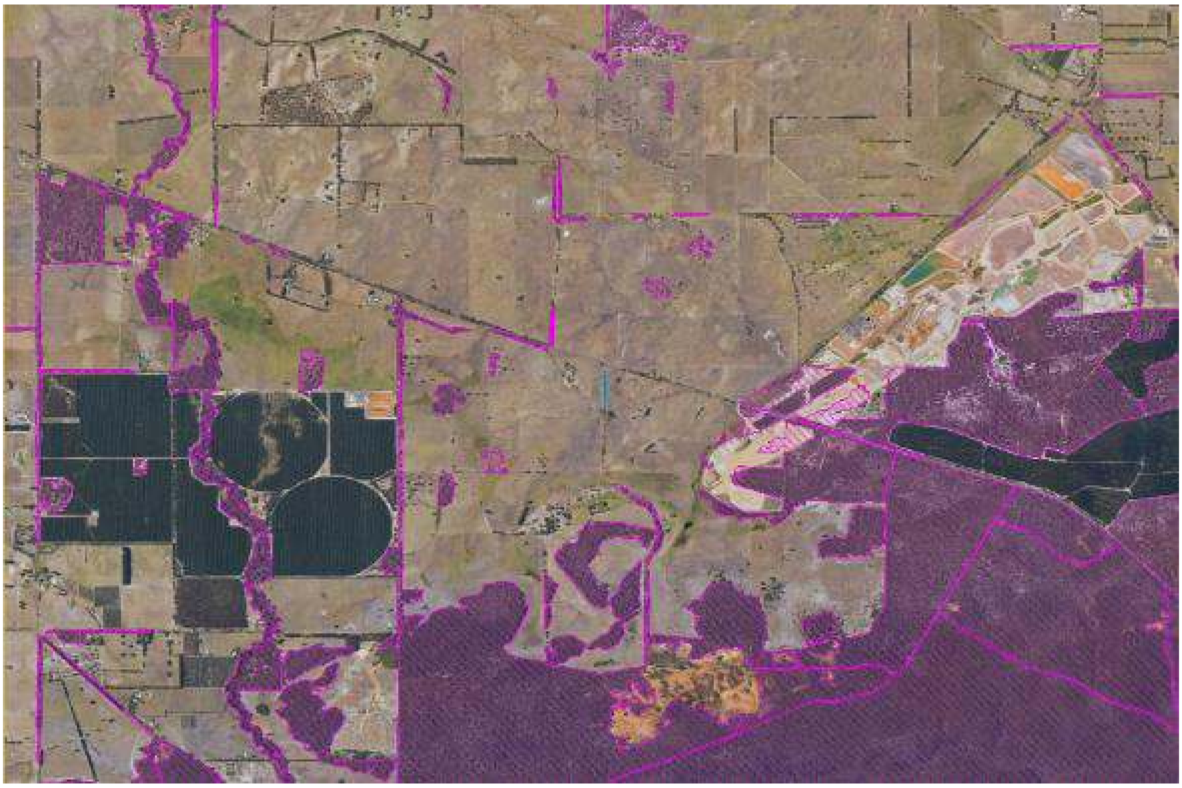

FIGURE 8-10: Detail from the Geographe region.

Here photography is more recent that the vector update, so the expansion of the mining area at right has not yet been incorporated. Operator decisions have affected the inclusion or not of linear connections. Note: Forest plantations are not included; other areas to the south-west of this photo are interpreted as non-native and have not been included.

8.5.2 Rangeland monitoring

DPIRD does not use remote sensing for lease-scale reporting but has recently conducted a trial of the VegMachine cover-trends approach using Landsat imagery for this purpose (report in preparation). Regional vegetation cover trend analysis and average vegetation cover calculations for the rangelands areas of Western Australia are based on the MODIS fractional cover and NDVI products produced by CSIRO (Guerschman *et al*. 2009). These were reported in Department of Agriculture and Food, Western Australia (2017) and detailed below.

Fractional cover for each 500 x 500m pixel refers to the cover estimate provided by photosynthetic vegetation (green, growing plants), non-photosynthetic vegetation (dead plants, sticks, logs) and bare soil. A cover trend analysis is derived by DPIRD from the photosynthetic vegetation component of the fractional cover dataset. Using multiple images and changes avoids some of the issues of red soils and calibration against vegetation standards.

In the Northern Rangelands, July (day 185) imagery is used to minimise the influence of fire, which is based on analyses of the Northern Australia Fire Index (NAFI) data. The incidence and extent of fire increases after this date. It is also the earliest month when the influence of annual plants on total vegetation cover is reduced.

In the Southern Rangelands, October imagery (day 289) is most suitable for perennial cover because the influence of annual plants is reduced. Fire in the Southern Rangelands is far less frequent than in the Northern Rangelands, so all years can usually be analysed (Department of Agriculture and Food, Western Australia 2017).

Using land system descriptions and expert knowledge, the 554 land systems in the rangelands have been grouped into 10 vegetation functional groups in the Kimberley, 14 in the Pilbara and 36 in the Southern Rangelands (Robinson *et al*. 2012).

The slope of the vegetation cover line over time is used to estimate the vegetation cover trend (Table 8.1). A linear regression is fitted for each vegetation functional group within the regions. An uncorrected vegetation cover trend is calculated which is the slope for each pixel relative to zero (i.e. no trend). Trend classes are defined by zero plus or minus one standard deviation. This uncorrected vegetation cover trend is used in State of the Environment reporting (Wallace and Thomas 1998) and at MODIS scales, indicates gross changes in vegetation cover across the specific landscape.

The corrected vegetation cover trend shows areas where the cover trend differs from the mean cover trend for the specific vegetation functional group. As above, trend classes are calculated as the mean slope for the group plus or minus one standard deviation. This trend shows areas in which cover has substantially (greater than one standard deviation) increased or decreased relative to the mean slope for the respective vegetation (Department of Agriculture and Food, Western Australia 2017).

The Pilbara is shown as an example of vegetation cover trend analysis in Figure 8-11.

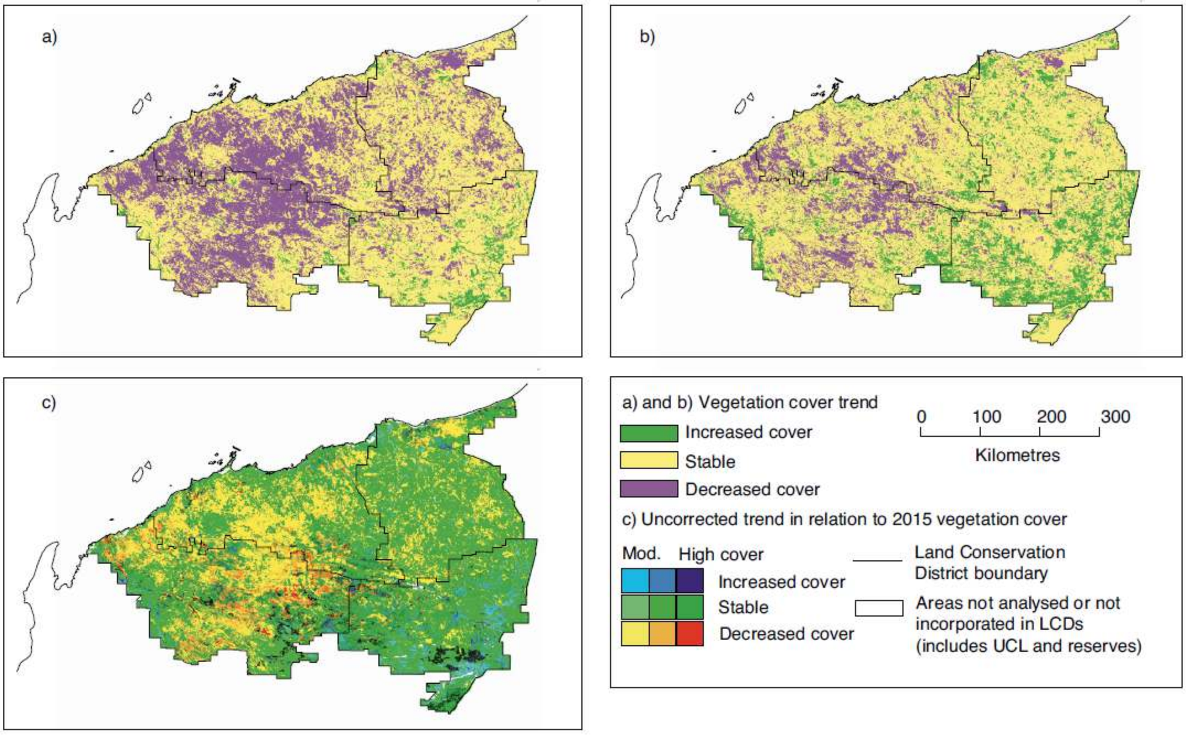

FIGURE 8-11: Vegetation cover trend in the Pilbara, 2006–15.
a) uncorrected trend, which shows the gross changes in vegetation cover across the landscape; b) corrected trend, which better accounts for trends related to seasonality, management[19] or fire; c) uncorrected trend (gross change in vegetation cover) in relation to vegetation cover in 2015. Source: Department of Agriculture and Food, Western Australia (2017).

Because the vegetation cover varies with vegetation type, soil characteristics and climatic conditions, numerical comparisons of vegetation cover levels for the same vegetation functional group in different climatic zones may be misleading.

In future it is expected that Landsat will replace MODIS fractional cover (but maybe not MODIS NDVI) for monitoring change in the rangelands (Phil Thomas pers. comm. 14th November 2018). Public reports on rangeland conditions such as State of the Environment may remain at the broad Land Conservation District (LCD) scale while leasehold inspection and advice to the Soil and Land Conservation Commissioner (and Pastoral Lands Board) will be at paddock- or station-scale, which require Landsat-type resolution. As mentioned above, DPIRD conducted a trial of the VegMachine rangeland monitoring approach in the Murchison region during 2018 and a report is in preparation. It is not yet clear how the expansion of Land Monitor to the rest of WA – data availability and potential national analyses by Digital Earth Australia, the appointment of new staff or the availability of computational storage and capacity at the Pawsey Supercomputing Centre – may assist with the monitoring of the WA rangelands but these developments are all promising.

8.6. Department of Water and Environmental Regulation

The main direct use of remote sensing data of native vegetation in DWER is for detecting illegal clearing. For clearing detection and compliance, DWER mostly use Sentinel-2 in surveillance mode, performing weekly automated change detection on every cloud-free image within the south-west (and some areas in the north) to identify clearing (Craig Jacques pers. comm. 12th October 2018).

[19] An average management effect is removed, highlighting above or below 'expected' responses that could be related to particularly good or particularly poor management impacts

The DWER Native Vegetation Branch uses information derived from remotely-sensed data such as salt-affected areas (Land Monitor) and vegetation statistics (the DBCA analyses referred to in the DPIRD section) in assessing clearing permit applications. Aerial photography is also used to assess vegetation condition and extent.

Clearing permits are required unless an exemption applies as described in Schedule 6 of the *Environmental Protection Act 1986* or for low impact routine land management practices (outside of Environmentally Sensitive Areas) detailed in the *Environmental Protection (Clearing of Native Vegetation) Regulations 2004*. DWER has delegated authority to DMIRS to assess and determine applications for clearing permits for the purposes of:

- An activity authorised by or required by the *Mining Act 1978*, the *Petroleum and Geothermal Energy Resources Act 1967*, the *Petroleum Pipelines Act 1969*, or the *Petroleum (Submerged Lands) Act 1982*; or
- An activity under a government agreement administered by the Department of Jobs, Tourism, Science and Innovation (DWER 2018).

The methods used to detect clearing of native vegetation are outlined in DER (2014a) and on the web at: https://www.der.wa.gov.au/our-work/clearing-permits. Given its timeliness (every 5 days) and spatial resolution (10m pixel size), Sentinel-2 is used to inspect suspected illegal clearing sites. Cloud-free images of Sentinel-2 for the south west are automatically downloaded from Google Cloud (faster than from the European Space Agency), vegetation loss is mapped and intersected with the DWER Clearing Permit System database with the results sent to a Power BI report. An officer manually reviews vegetation change data in cases where DWER have no spatial record of a permit application or offset. This is essentially a surveillance process and therefore does not answer the question “how much vegetation is cleared in WA each year?”

If there is not an exemption or approval, the area is assessed, and risk rated to guide the appropriate compliance response. DWER can require unlawfully cleared areas to be revegetated through a Vegetation Conservation Notice. All clearing must be done in accordance with the *Environmental Protection Act 1986*, i.e. in accordance with a clearing permit or exemption. There is no reporting by the Department of Planning, Lands and Heritage (DPLH) on areas cleared for residential purposes because it is an exemption from the clearing regulations, not a delegation. As well as the DPLH, local government and the WA Planning Commission can issue Development Approvals. DWER review some areas if they suspect the clearing was not done in accordance with the exemption for planning and subdivision approvals.

It is important to identify and respond to illegal clearing as soon as possible to get the best environmental outcome. Downloading only cloud-free images reduces the amount of data being captured. The annual change detection from the Land Monitor project is also very useful, but the time delay from when clearing happens to when it is detected is its main limitation (Craig Jacques, pers. comm. 19th November 2018). DWER do not collate figures on illegal clearing. It is possible to clear up to 5ha per year for certain purposes without obtaining a clearing permit (DER 2014b).

Granted clearing applications have increased over time while refused applications have been more varied (Figure 8-12). This is just clearing approved under Part V (Environmental Regulation) of the *Environmental Protection Act 1986*. The amount of clearing approved under Part IV of the EP Act is not collated and published, and so cannot be reported upon. The average approved clearing area of Part IV approvals is significantly greater than that of Part V approvals (Gaia 2018).

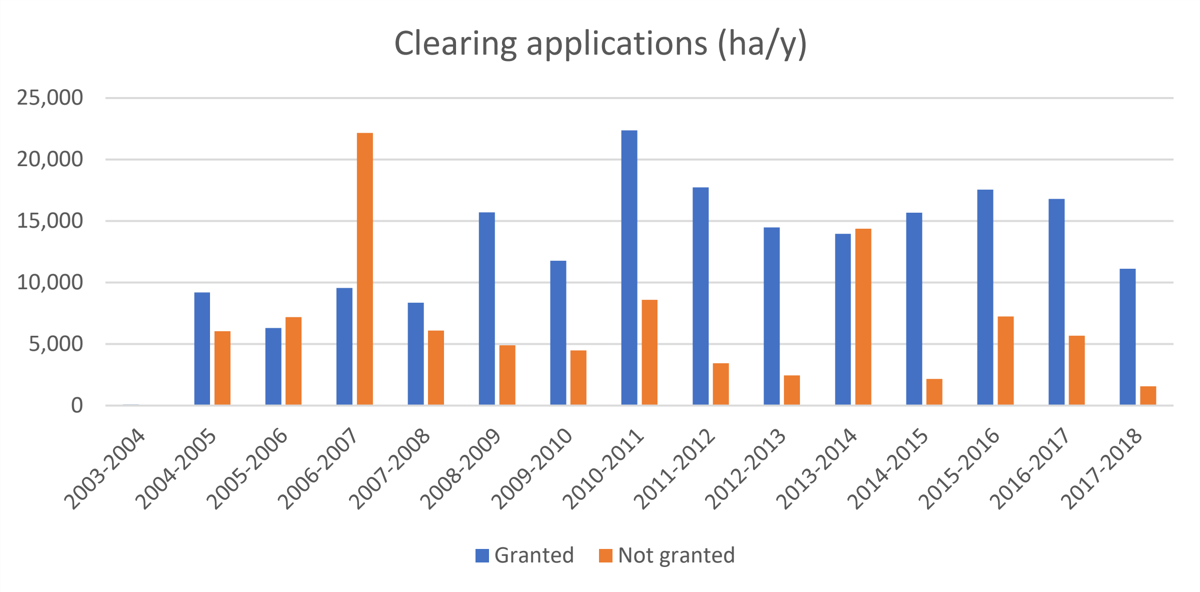

FIGURE 8-12: Approved and refused clearing applications under Part V of the EP Act between 2003-04 and 2017-18 (Source: DWER)

Under the delegation, DMIRS applies the same principles and policies as DWER when undertaking assessments of clearing applications for mining and petroleum-related activities. DMIRS generally uses satellite imagery from Landgate for their assessments. However, DMIRS also have a procedure to use small Remote Piloted Aircraft or drones to collect information, although this is focussed mainly for use during compliance activities. The amount of clearing that has been approved each year is not readily available from DMIRS because DWER administers the system which captures all clearing permit information for the State. All mining disturbances subject to the *Mining Act 1978* are captured via the Mining Rehabilitation Fund. The area affected by mining is much smaller than that for which clearing is approved because a substantial proportion of new mining areas will have been, or will be, rehabilitated.

Therefore, the area of native vegetation that is cleared each year includes:

- Areas approved under a clearing permit by DWER or DMIRS;
- Areas cleared in accordance with an exemption (which are not measured). This includes Part IV approvals and clearing for subdivisions which are not recorded; and
- Unlawful clearing (also not measured).

There are also some increased vegetated areas through revegetation under various instruments (Vegetation Conservation Notices, Mining Act requirements, EPA Offsets etc.).

An examination of Land Monitor images (e.g. Figure 8-3 and Figure 8-4) indicates that clearing application areas are probably small when compared with losses caused by factors such as unrestricted grazing, land degradation (e.g. salinisation of valleys), removal of trees in the use of GPS-controlled farming machinery, and clearing for which a permit is not required (e.g. urban developments). No agency has the responsibility for assessing overall trends in native vegetation extent and condition on private and public lands. Any such assessment would need to consider long-term trends because of the considerable impacts of seasonal conditions and fires.

8.7. Department of Planning, Lands and Heritage

The DPLH do not undertake satellite image analyses themselves but, as outlined in Section 8.5, fund DPIRD staff to monitor the condition of rangelands as part of reporting to the Pastoral Lands Board. DPLH are a member of the Land Monitor Consortium and have supported its extension beyond the south west to cover the whole of WA. DLPH initiated the rangeland monitoring trials conducted with CSIRO and DBCA in 2014 referred to in Section 8.4.

With regard to clearing for residential purposes, there is no reporting by DPLH on areas, because it is an exemption from the EP Act, not a delegation. Local government and the WA Planning Commission can also issue Development Approvals. Were this data to be required, digital aerial photography (e.g. Urban Monitor) or Sentinel-2 satellite imagery could be used. DPLH has funded CSIRO to analyse Urban Monitor digital aerial photography coverage for the Perth-Peel region (Figure 3-1) for 2009, 2014 and 2016 as part of their Urban Forest project (DPLH 2018).

8.8. Water Corporation

Water Corporation have been long-standing consortium members of both Land Monitor and Urban Monitor projects. Their main interest is in their surface water and groundwater catchments, especially land use changes, vegetation condition and fire history as these changes can significantly affect both drinking water yields and quality.

8.9. Department of Fire and Emergency Services

DFES became a member of the Land Monitor Consortium in 2017. They currently use, or intend using, remote sensing in several ways:

- Monitoring of greenness and rates of curing of dry grass to assess fire risks;
- Planning prescribed burns, and monitoring the area affected after such burns;
- Managing fire outbreaks by mapping extent and surrounding vegetation (including dry annuals, crops etc.); and
- Collating other datasets that can assist understand risks and fire behaviours (e.g. land use, digital terrain models, vegetation type).

DFES use several satellites (e.g. Sentinel, Himawari, MODIS, Landsat) including ones that are real time and able to penetrate smoke and cloud when monitoring and predicting fire progress. DFES has a need for more accurate vegetation association maps because (for example) spinifex and shrublands can change over time into grasslands with very different fire risks. While only joining the Urban Monitor Consortium relatively recently, DFES are likely to be a very active user of remote sensing with other agencies and independently in future.

9. Discussion

Remote sensing of native vegetation is being done at a national level for reporting of overall trends using coarse-scale platforms such as MODIS and at a finer scale using Landsat for regulatory purposes (e.g. greenhouse gas emissions under the National Inventory). Each state and territory have developed their own systems of monitoring their native vegetation (with some notable examples of collaboration) with the most rigorous methods being used for regulatory purposes, principally clearing and rangeland management. All states have partnerships with universities and/or CSIRO to help refine monitoring tools. The development of national environmental account standards may lead to more convergence on what is measured and the remote sensing methods to help monitor these attributes.

While there is a good case for standardisation, vegetation condition monitoring using remote sensing requires considerable process understanding of the vegetation association being monitored because signals need expert interpretation. The good news is that there are increasingly fine scale and varied remote sensing signals becoming available (e.g. optical reflectance, thermal emission, radar, 3-D through photogrammetric overlays) and statistical tools to interpret the various data. The weakest elements appear to be recent high-quality ground truthing and a good understanding of the ecology of key vegetation associations and their responses to climate, fire, grazing, pests, diseases and weed invasion. This would require resourcing of a multi-disciplinary team for data acquisition, interpretation and data delivery. Agencies such as DBCA use remote sensing in this manner but cover relatively small areas of the state.

While there are understandable legislative differences, Western Australia can, and has learnt from these other experiences. The free availability of analysis-ready data from both the Landsat and Sentinel platforms from Digital Earth Australia, or directly from the platform providers, removes the cost of basic processing. Centralising and standardising remotely sensed data can help with the storage and retrieval of large and consistent datasets, but their analysis requires skills and analysis that not all agencies have or want to acquire. Analysis and production of generic datasets for multi-agency use e.g. native vegetation extent and change, requires investment in a program. In Western Australia the availability of supercomputing facilities at the Pawsey Centre provides a significant opportunity.

The expansion of Land Monitor to the whole of WA represents a major improvement to native vegetation monitoring data in the rangelands including non-agricultural land in the interior. Effective use of this information requires Land Monitor Consortium members to be more aware of its capabilities; this is being addressed through meetings with individual agencies. It also requires better training of key operatives within some agencies, especially the handling of large raster datasets. Products that can explicitly give native vegetation extent statistics and where feasible, condition change (not just a trend) would be valuable to NRM agencies. The interpretation of data on non-woody vegetation needs much further analysis.

For clearing information, Land Monitor now provides annual state-wide woody vegetation change products. Attribution (in GIS) of change areas to clearing/other causes would create a state-wide clearing update each year for woody vegetation. This product is essentially like the SLATS state-wide woody clearing and could be coordinated with DWER surveillance activities. The clearing data is likely to be timelier and more consistent than the photo-based vector updates. The Land Monitor products span more than 30 years of change for the state. If the attribution program was applied to the historic sequence, a comprehensive database of cumulative clearing could be established.

However, this attribution of historic change requires an additional 'once-off' GIS input to identify areas of non-native vegetation (e.g. plantations, orchards, introduced grazing shrubs and perennial grasses, gardens) as well as areas that have been actively revegetated using either native or non-native plants (e.g. under Landcare programs).

While technical developments are promising, the institutional arrangements which support it appear to be weak. For example, Land Monitor requires each consortium member to find $10k per annum in a largely informal arrangement that could be impacted by the loss of key personnel or a change in commitment by agencies. This amount does not allow for the development of new tools suited for specific applications regarding West Australian vegetation. There is also a high dependency on CSIRO (WA) to process and generate the products and if CSIRO were to focus its efforts elsewhere, the entire initiative could fail. Continuing to capture a near infra-red band and to retain all the information (~12-bit full dynamic range) in digital aerial photography is also currently a state commitment that could suffer under budgetary pressures on the State Land Information Capture Program (SLICP).

The State has benefited from collaboration with CSIRO since the mid-1980s, which maintains a strong research and development capacity in optical and radar remote sensing. The group has added a nationally-leading capacity in processing digital aerial photography for high resolution and 3-D mapping and monitoring; delivered in a small area of WA through the Urban Monitor project.

Strong institutional support of remote sensing would help to ensure that there are synergies achieved by producing a common set of high-quality datasets. A coordinated response to new initiatives also helps to ensure that there is a sustained capacity and skills base. Current capacity in WA is heavily underpinned by collaborations with CSIRO either on a project-by-project basis, or through the Land and Urban-Monitor initiatives. Externally-funded projects have a clear but short-term focus and are unlikely to retain key staff nor build awareness and capacity.

Currently the Department of Biodiversity, Conservation and Attractions (DBCA) has strong capacity and experience in NRM-related remote sensing, but its focus is on DBCA-managed estate. DBCA currently chairs the Land Monitor Consortium after Landgate did so for many years and the (then) WA Department of Agriculture before that. The succession appears to reflect different levels of historical involvement in remote sensing within the state. The DBCA group has the technical capability to combine remote sensing data with other data, and to apply RS/GIS processes and products to the Department's science and management questions. As such, it provides a good example of how the delivery of remote sensing information can meet wider needs across state agencies.

The Department of Agriculture played a key role in mapping remnant vegetation and dryland salinity in the south-west in the 1990s, and in the rangelands (for longer) using external providers. DPIRD have an incentive to develop improved tools to address a recommendation from the Auditor General's report (2017) on rangeland monitoring and has recently recruited to develop its capability. Formerly, Landgate was WA's lead agency for managing satellite remote sensing data and worked with partners to develop products such as fire histories and along with CSIRO, the Pastures from Space product. It coordinates GIS datasets and access through its websites[20]. While it retains a remote sensing data management role, this is being subsumed by others, especially Geoscience Australia. It is apparent that a cross-agency body to examine roles and responsibilities would help to facilitate an agreed state-wide policy and program.

The major remote sensing policy driver at present is monitoring native vegetation and land use changes. This emphasis may assist to clarify state roles and responsibilities. One possibility is that the Senior Officers Group across NRM agencies provide strategic oversight and where agreed, collaborative funding of key state government priorities. The establishment of a remote sensing group to service WA's needs seems timely with an initial emphasis on vegetation based on:

[20] www.data.wa.gov.au and Land Monitor data through http://landmonitor.landgate.wa.gov.au/home.php

- WA's current established remote-sensing expertise;
- The computational and data storage facilities at the Pawsey Supercomputing Centre;
- A history of sharing spatial data established over almost 40 years through the Western Australia Land Information System (WALIS); and
- The increasing availability of analysis-ready remote sensing data.

Committed support will also help to retain the current level of expertise in WA. A remote sensing group could promote both the provision and dissemination of products to end users. They could also decide how WA wants to respond to opportunities such as Digital Earth Australia, and the possible involvement in the Joint Remote Sensing Research Program to benefit from research efforts at the national scale. This is especially important as Sentinel-1 and -2 become used more frequently to better define condition (and potentially biodiversity) for specific vegetation associations.

The fusion of imagery that makes the best of spatial and temporal strengths looks likely as more platforms become available. The Senior Officers Group could investigate whether super-computer capacity at the Pawsey Centre could be better used to manipulate and store large datasets and products.

The operational programs described in Section 4 provide models for effective delivery of information from remote sensing. The common elements are a dedicated group able to deliver products that can be adjusted over time and which are able to be quickly and accurately interpreted to meet clearly identified client needs. The potential of remote sensing to improve land management is large compared with current uptake by state agencies and land managers.

The Land Monitor Consortium has survived multiple government and agency changes in the past 20 years, but its role is more at the technical level than strategic. The role could be enhanced through a Memorandum of Understanding (or similar) developed through the Senior Officers Group. This may also clarify intellectual property and data ownership issues (e.g. the Urban Monitor images which were collected using both Consortium and Landgate funds, and subsequent products developed using DPLH funding).

Digital Earth Australia are funded to make available Landsat and Sentinel remote sensing data (and potentially other datasets such as aerial photography) to users and have been conducting workshops to encourage commercial use of these data. This is a major advantage for national data users, but specialist skills are required to access and process the data. At present most of the intellectual property and knowledge associated with interpreting remotely sensed data are located in state NRM agencies, research agencies such as CSIRO and universities, and with land managers who are often the only ones able to correctly interpret the images. While it is attractive to develop consistent nation-wide methods for interpreting native vegetation images, local expertise is required to deliver to State policy and information requirements. As mentioned previously, the complexities of vegetation associations on different soil backgrounds responding differently to climate and management practices makes the need to develop locally-calibrated products essential.

The current approach in WA to detection of all clearing appears to be fragile based on scarce resources. Maintenance of the current vector dataset on native vegetation extent is reliant on a single individual in DPIRD, based on a legacy arrangement, and the dataset has limitations for reporting and regulation.

Additional effort therefore seems warranted so that the annual area being lost due to clearing can be stated with some confidence. However, there are multiple issues affecting vegetation aside from clearing. The Land Monitor images of the south west of the state since 1987 show that the loss of native vegetation from all causes is much larger than that which is cleared. However, there appears to have been no systematic attempt to quantify the causes of these losses despite these maps being available for over 20 years. These causes need to be correctly identified so that management responses are well targeted.

The state-wide (Beard) vegetation map is coarse scale. A more detailed and comprehensive map of native vegetation associations would assist in interpretations from monitoring data for biodiversity purposes. One opportunity for the rangelands is improving the linkage between land system mapping and the state-wide vegetation association map.

The proposed Biodiversity Information Office (BIO) could assist the update of vegetation maps by, for example, providing access to centralised plot-based vegetation data to inform the mapping. This new initiative, led by the Western Australian Biodiversity Science Institute (WABSI), aims to aggregate, curate and make accessible biodiversity information collected as part of biological surveys, including those carried out for environmental approvals. This represents an opportunity to combine vegetation data with remote sensing data to revise state vegetation association maps.

The methodology employed to assess the growth of commercial crops in CSIRO's Graincast project may also be applicable for improving land use mapping, native vegetation association mapping and monitoring change over time. This method assembles multiple datasets (remote sensing, soil, climate) and would require growth models for key native vegetation associations and associated training data. Currently both annual- and tree-crops use the Agricultural Production Systems Simulator (APSIM) model for this purpose. Graincast uses information provided by landholders and this same approach may help for vegetation monitoring if trained observers were able to be coordinated.

It is not clear whether the land cover modelling approach used in Victoria (White *et al*. 2018) and South Australia (Willoughby *et al*. 2017; 2018) would be useful for conservation or regulatory purposes. The relevant NRM agencies (DBCA, DWER, DPIRD) could identify what additional value such maps would provide and assess the cost (including opportunity costs) of doing this mapping.

Fine-scale mapping and monitoring of vegetation in areas of high value or interest are becoming more available and provide relevant data for intensive management purposes while not being relevant for state-wide assessments. Examples may be special habitats requiring direct measurements of structure. In addition, Urban Monitor coverage in Perth-Peel have been available since 2007. All digital aerial photography can be used for monitoring if the data are collected in a standardised manner. The full dataset can also be stored until future capabilities are able to cheaply process such large datasets.

The reviews in Sections 7 (Other states approaches to vegetation monitoring) and 8 (WA state agency approaches) in this report show that there is a complex legislative framework that dictate roles and responsibilities. This naturally fragments levels of interest and focus in how (or if) remote sensing has been applied to native vegetation mapping, monitoring and management.

Each state and agency also has different levels of resources and geographical areas of responsibility. WA has the disadvantage of a large state but the advantage of a lower population pressure to impact on vegetation. At the national level there has been an emphasis on relatively coarse-scale imagery such as MODIS (to produce nation-wide figures) or an emphasis on compliance with greenhouse gas inventories. Duplication and abrupt changes in compatibility, effort and detail can occur across state boundaries, and can result in the development of multiple 'competing' systems. WA would benefit by learning from the other states, and national and international systems and seek collaboration when warranted.

10. Conclusions

WABSI commissioned this study to review and report on the use of remote sensing technology nationally and globally for mapping the extent of native vegetation, and monitoring change in extent and condition. This report has reviewed existing remote sensing technologies and data providers including limitations and opportunities of each, and the extent to which the various existing technologies and products could contribute to a state-wide native vegetation measurement and monitoring program. Specifically, the report required information on the ability to monitor the extent of clearing over the entire state.

It can be concluded that remote sensing is eminently suitable for monitoring native vegetation and to detect trends which are probably related to its condition but requires more information to be correctly interpreted. Remote sensing is the only feasible approach to assessment in a state the size of Western Australia. Because over 90% of the State is Crown Land there is also a public need to monitor its extent and condition.

With respect to native vegetation extent and clearing, the state-wide vector data set of native vegetation extent (Section 8.5.1) is inadequate for providing state-wide summaries and updates. Remote sensing products combined with a GIS attribution program are best suited to provide this information.

The latest Land Monitor products provide state-wide raster coverages of woody and sparse-woody vegetation at 25m resolution spanning 30 years from 1998. Raster maps of change in these vegetation classes have been produced annually since 2004. Losses include clearing but also many other factors, especially fire, grazing and poor seasonal conditions. Similarly, mapped gains can be active revegetation as well as recovery from fire or low rainfall. These products are consistent with the national program run by the Department of the Environment and Energy (DoEE). This department has a documented process for attribution (see below) of its vegetation products for purposes of greenhouse gas accounting.

To provide state-wide data for specific purposes, such as native vegetation extent or loss, an 'attribution' program is required to label the datasets. Such a program could be commenced now. Attribution refers to the use of GIS tools to assign labels to the raster maps, using existing data or data collected for the purpose. A minimum goal of an attribution program should be the labelling of the vegetation extent maps as being either native or non-native vegetation. Various datasets exist to assist this process, including maps of exotic timber plantations and the 'state-wide vector data set' which has excluded fruit trees, vineyards and other introduced exotics. Using these data, a 'non-native' attribution layer can be constructed, and the standard raster vegetation products can be labelled as 'native' or 'non-native'.

For attributing losses, the vegetation loss maps for a particular year can similarly be attributed to cause (including fire, timber harvesting, clearing, and vegetation decline below a threshold due to grazing, disease, pests, climate etc.). This will require additional datasets (e.g. DTMs, mapped salinity hazard areas) and training rules (e.g. fire areas will recover from the loss; small remnants in regularly cropped paddocks may be cleared; gradual losses in long-grazed paddocks may lack protection from stock). A research project like the dryland salinity identification work in Land Monitor may be required to properly attribute losses to likely causes (with an associated probability). Coordination of this exercise with the DWER clearing surveillance exercise (using Sentinel) would be efficient. The application of this approach through the historic time series would create a comprehensive 30-year history of overall loss and gains, and specifically clearing. This would require additional investment and effort.

There are vast areas of ‘non-woody’ vegetation outside the south-west region especially grasslands and chenopods which are subject to change from multiple causes. Management-induced and natural processes, including grazing (by domestic and feral animals), fire, climate, and pests currently affect far greater areas in WA than mechanical clearing. Remote sensing cover change products could identify areas of annual cover loss, including mechanical clearing. Improved methods and new data sources are likely to improve the interpretability and resolution of non-woody change products, but an inspection and attribution effort is likely to be required to identify clearing from other changes.

Vegetation condition, as discussed in Section 2, has multiple definitions. Measurement is problematic even for site-based assessment schemes, in part because multiple observations are integrated into a linear scoring system. To provide data relevant to condition, or biodiversity condition, over broad areas, a pragmatic and useful approach to provide measures of the components of condition are structure, function and composition. For management, indicators of stability or change are particularly relevant. As discussed in this report, remote sensing is not suited to provide species composition information beyond broad vegetation groups. It is suited to provide some information on structure and function and uniquely suited to provide monitoring of changes.

In well-understood systems, changes in condition may be inferred from cover/greenness changes over time. Targeted ground validation in both changed and stable areas is required to assess both condition and the processes that are affecting the vegetation. The existence of remote sensing change information greatly increases the efficiency and relevance of ground sampling efforts for understanding landscape processes and management impacts. Fragmentation and ‘representativeness’ metrics can be derived and updated using Land Monitor vegetation cover maps, in combination with vegetation maps and digital elevation model data. If higher spatial resolution is required for specific purposes or areas, Sentinel-2 imagery is now available.

Integration of Sentinel-2 data into Land Monitor woody cover products is technically feasible now but would require additional effort. A one-off 6.5m dataset covering the south-west is available to test resolution effects on such derived metrics. Structural information at the pixel or patch level may be provided from Sentinel-1 radar imagery – research is required to evaluate this for WA native vegetation. Processed digital (or digitised) photography can provide direct measurements of vegetation canopy height, and other parameters. The processing involves large data volumes and is computationally intensive but is operational in WA (Urban Monitor). The State’s historic photo archive is being digitized which can provide information that pre-dates satellite imagery.

Producing vegetation change products at management-relevant scales (i.e. 10-30m) has become much easier and cheaper with the free and ready availability of Landsat TM+ and Sentinel data. Calibrated analysis-ready Landsat and Sentinel-2 data is provided through Geoscience Australia and other sources.

A research proposal described in the next section aims to develop new state-wide cover products from Landsat, and to evaluate Sentinel-1 and Sentinel-2 data for additional vegetation information. This availability has placed an emphasis on the development of vegetation response models and indices that are relevant to Western Australian conditions to interpret vegetation change maps.

Western Australia has a remote sensing capacity which is technically strong, but institutionally weak. Some areas of remote sensing in the State are fragile in that they rely on a single individual and their skills and commitment. WA has a long history of innovation and product delivery relevant to land and vegetation inquiry. The collaborative Land Monitor arrangement continues to operate after more than fifteen years. Despite this longevity and ability to produce products suited to NRM agencies, there is limited evidence that the products are widely used and merged with other datasets. There is therefore a need to improve awareness and capability, especially in the use of raster data, and a need to improve ease of access to data and products.

A dedicated remote sensing group would strengthen WA's remote sensing capacity and ensure ongoing delivery of policy-relevant vegetation products to WA agencies. Such a group would require analytical and computational skills, as well as strong links to user natural resource management agencies and a secure funding base. A WA-based group would help ensure that policy-relevant products are produced that meet changing state needs. This group could also provide a technical and policy basis for state interactions and collaborations with national and international programs including Geoscience Australia's Digital Earth Australia and the Joint Remote Sensing Research Program. The Land Monitor Consortium acts in this way now and has benefited in terms of efficiency through sourcing analysis-ready data from GA's Open Data Cube, and from collaboration with DoEE's national monitoring program. Individual agencies could use their in-house capability and skills to 'value-add' to standard products for their particular purposes or could interact with a dedicated specialist group.

This availability of user-ready remote sensing data now places an emphasis on the development of vegetation response models and indices that are relevant to Western Australian conditions to interpret vegetation change maps. This could become an area of strategic research involving state agencies, CSIRO and universities to progressively build up within-state capabilities and expertise. Advances such as new platform sensors, mixed data methods and machine learning offer yet more technical promises but they require an understanding of state strategic priorities and clear policy drivers. Strategic guidance from state NRM agencies to make the most of these developing opportunities would help here.

Finally, despite a limited level of resourcing applied to monitoring native vegetation in recent decades, the State has a surprisingly good and nationally-consistent basis for monitoring native vegetation extent and changes in 'condition'. Intelligent interventions and strategic investments would both enhance the capability and ensure that the current system is more secure.

11. Recommendations

The following recommendations are made based on the material in the previous sections.

11.1. Strategic Coordination

The Senior Officers Group (SOG) for NRM agencies consider undertaking a state-wide coordination role for remote sensing and for updating vegetation information of WA. A key role would be to address arrangements to strengthen WA's remote sensing capacity to meet state requirements. This will provide a more secure base for investments, improve investments in products that benefit multiple agencies and allow the State to respond in a coordinated manner to national opportunities. The SOG should consider the proposal from Land Monitor to develop and evaluate new vegetation products (Appendix 13.2). It would be strengthened if extra effort targeted to priority vegetation, could be added to collect additional ground data for methods testing and validation of structural and cover metrics.

The SOG should also consider mechanisms to establish and support a centralised remote sensing specialist group within the WA Government to provide and develop products for state clients, and mechanisms to strengthen the capacity within agencies to use and value-add to remote sensing products for their specific requirements.

11.2. Technical Coordination

A formal Memorandum of Understanding (or similar) be developed by the Senior Officers Group for the current member agencies of the Land Monitor Consortium to act as a technical advisory body for NRM remote sensing needs in WA. This would provide this group with a more secure and strategic role in the future.

11.3. State-wide responses to opportunities

The SOG and Land Monitor Consortium consider the opportunities arising from coordinated responses to Digital Earth Australia and to investigate the benefits and costs of becoming a member of the Joint Remote Sensing Research Program as well as the research and development opportunities listed below.

11.4. Use of digital data to improve vegetation association maps

Updating the accuracy and scale of the current vegetation association maps for Western Australia is important for management and clearing control reasons but the cost is large if traditional methods are used. The existence of multi-temporal optical and radar imagery, collated biodiversity data and three-dimensional landscape models may enable statistical methods to be developed that reduce costs while producing updated maps of improved accuracy. Linking remotely sensed data with vegetation plot information captured in the proposed Biodiversity Information Office is a further opportunity to be investigated. A related approach was used to map areas that were affected by, and at risk of being affected by dryland salinity (e.g. McFarlane *et al.* 2004; Caccetta *et al*. 2009). This opportunity could be investigated through a state-supported research project. Resourcing would need to be identified, potentially via a collaborative arrangement nationally.

11.5. Identifying native vegetation and the factors responsible for native vegetation loss

Raster maps of vegetation extent (Forest, Sparse, Non-woody) need to have GIS attribution labels to separate known non-native areas (e.g. plantations, orchards, tagasaste, gardens) from native vegetation areas.

Multi-temporal Land Monitor images show distinctive patterns of loss that lend themselves to estimating the main cause. Areas where the cause of loss is known or can be strongly inferred could be used as training areas. Landscape, hydrology and vegetation response models could be used to infer causes of loss elsewhere in nearby areas. Ideally a probability of the cause could be assigned (e.g. 90% probability of fire). Such an attribution process would enable better targeting of management responses by landholders, Landcare groups, regional NRM councils and the State. Cross linking the attributed losses with vegetation associations could also improve the protection of poorly protected and rare vegetation types.

11.6. Training

Training of relevant state and local government GIS staff in the handling of raster datasets (e.g. using free software such as QGIS) and the merging of vector and digital data is urgently needed so that remote sensing products can be used more widely. Non-GIS staff may also be trained in how to manipulate and interpret simpler raster data products.

The ability to manipulate large datasets may require some upgrading to processing capabilities within agencies, or an agreement to use centralised services for complex or large data manipulation tasks.

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13. Appendices

13.1. Radiometric and spatial resolution characteristics of satellite remote sensing platforms suitable for mapping and monitoring native vegetation in the whole of Western Australia

TABLE 13-1: Radiometric characteristics of MODIS Bands 1 to 7

Band	Wavelength (µm)	Name	Resolution (m)
1	0.62 - 0.67	Red	250
2	0.841 - 0.876	Near infra-red	250
3	0.459 – 0.479	Blue	500
4	0.545 – 0.565	Green	500
5	1.230 – 1.250	Short wave infra-red	500
6	1.628 – 1.652	Short wave infrared (like Landsat band 5)	500
7	2.105 – 2.155	Short wave infrared (like Landsat band 7)	500

TABLE 13-2: Spectral and spatial resolution of Landsat MSS 1-5 bands

Band number	Wavelength (µm)	Name	Resampled resolution (m)
Landsat MSS 1-3			
4	0.5-0.6	Green	60
5	0.6-0.7	Red	60
6	0.7-0.8	Near Infrared (NIR)	60
7	0.8-1.1	Near Infrared (NIR)	60
Landsat MSS 4-5			
1	0.5-0.6	Green	60
2	0.6-0.7	Red	60
3	0.7-0.8	Near Infrared (NIR)	60
4	0.8-1.1	Near Infrared (NIR)	60

TABLE 13-3: Spectral and spatial resolution of Landsat 4-5 TM bands

Band number	Wavelength (µm)	Name	Resolution (m)
1	0.45-0.52	Blue	30
2	0.52-0.60	Green	30
3	0.63-0.69	Red	30
4	0.76-0.90	Near Infrared (NIR)	30
5	1.55-1.75	Shortwave Infrared (SWIR) 1	30
6	10.40-12.50	Thermal	120 (resampled to 30)
7	2.08-2.35	Shortwave Infrared (SWIR) 2	30

TABLE 13-4: Spectral and spatial resolution of Enhanced Landsat TM bands

Band Number	Wavelength (µm)	Name	Resolution (m)
1	0.45-0.515	Blue	30
2	0.525-0.605	Green	30
3	0.63-0.69	Red	30
4	0.775-0.90	Near infra-red	30
5	1.55-1.75	Mid infra-red	30
6	10.4-12.5	Thermal infra-red	60 (resampled to 30)
7	2.08-2.35	Mid infra-red	30
8	0.52-0.9	Panchromatic	15

TABLE 13-5: Spectral and spatial resolution of Landsat 8 Operational Land Imager (OLI) / Thermal Infrared Sensor (TIRS)

Band number	Wavelength (µm)	Name	Resolution (m)
1	0.435 - 0.451	Ultra-Blue (coastal/aerosol)	30
2	0.452 - 0.512	Blue	30
3	0.533 - 0.590	Green	30
4	0.636 - 0.673	Red	30
5	0.851 - 0.879	Near Infrared (NIR)	30
6	1.566 - 1.651	Shortwave Infrared (SWIR) 1	30
7	2.107 - 2.294	Shortwave Infrared (SWIR) 2	30
8	0.503 - 0.676	Panchromatic	15
9	1.363 - 1.384	Cirrus	30
10	10.60 - 11.19	Thermal Infrared (TIRS) 1	100 (resampled to 30)
11	11.50 - 12.51	Thermal Infrared (TIRS) 2	100 (resampled to 30)

TABLE 13-6: Ten metre spatial resolution bands on Sentinel-2

Band number	Sentinel-2A		Sentinel-2B	
	Wavelength (µm)	Name	Wavelength (µm)	Name
2	0.448 – 0.546	Blue	0.444 – 0.541	Blue
3	0.538 – 0.582	Green	0.536 – 0.582	Green
4	0.646 – 0.684	Red	0.645 – 0.685	Red
8	0.762 – 0.907	Near Infra-Red	0.766 – 0.900	Near Infra-Red

TABLE 13-7: Twenty metre Spatial Resolution Bands on Sentinel-2

Band number	Sentinel-2A		Sentinel-2B	
	Wavelength (µm)	Name	Wavelength (µm)	Name
5	0.694 - 0.713	Red	0.694 – 0.714	Red
6	0.731 – 0.749	Red	0.730 – 0.748	Red
7	0.768 – 0.797	Near Infra-Red	0.766 – 0.794	Near Infra-Red
8a	0.848 – 0.881	Near Infra-Red	0.848 – 0.880	Near Infra-Red
11	1.542 – 1.685	Shortwave Infra-Red	1.560 – 1.681	Shortwave Infra-Red
12	2.081 – 2.323	Shortwave Infra-Red	2.067 – 2.305	Shortwave Infra-Red

TABLE 13-8: Sixty metre Spatial Resolution Bands on Sentinel-2

Band number	Sentinel-2A		Sentinel-2B	
	Wavelength (µm)	Name	Wavelength (µm)	Name
1	0.430 – 0.457	Ultra-Blue	0.429 - 0.456	Ultra-Blue
9	0.932 – 0.958	Near Infra-Red	0.930 – 0.956	Near Infra-Red
10	1.336 – 1.410	Cirrus	1.340 – 1.414	Cirrus

13.2. Proposal from CSIRO to Develop Native Vegetation Extent and Change Products for Land Monitor III Operational Processing

The Western Australian Department of Water and Environment Regulation (DWER) have requirements for vegetation monitoring information that are not met by currently available products.

Specifically, they want to monitor native vegetation extent and change as follows:

- Location and extent of change at a local compliance level relative to specific legalisation and clearing permits. Attribution as mechanical (human) versus wildfire versus other natural causes would be beneficial. Locations of change would be highlighted for further detailed review / documentation.
- For summaries of vegetation change versus extent at regional scales (shire, land use zone, …)
- For strategic assessment and planning. Cumulative amount of clearing and its effect on the remaining vegetation extent and its status / condition. How much vegetation is left? Is it OK?

There is an acceptance that change in status / cover trend is a more achievable goal than direct condition classes.

Native vegetation includes grasslands, heath, shrublands, trees and mixtures of these vegetation communities. Aquatic vegetation is also included in the definition but has been set outside the scope of this activity. The main human induced impacts are (irrigation) cropping, roads, mining and grazing. The particular regions of interest are outside the south-west agricultural zone covered by the existing Land Monitor woody extent and change products. Simply extending these products omits significant proportions of the total vegetation cover.

A four-component strategy to address these needs is proposed, with CSIRO co-investing in methodology and product development. The first component uses existing well-characterised data sources to develop a sensor-scalable operational product. The other three components investigate using emerging data sources to improve and/or supplement the operational products and can be considered optional depending on funding availability.

The components are:

Component	Description
1	Develop and evaluate a multi-temporal fractional cover component product using Landsat data sources (annual or twice yearly), with recommendations and costings for ongoing operational products to be included in the Land Monitor III program.
2	Evaluate the information content of Sentinel-2 (optical) imagery for understanding vegetation communities / structure at known sites and time series for the detection of change in extent and structure (increased spatial and some spectral resolution).
3	Evaluate the information content of Sentinel-1 (radar) imagery for understanding vegetation communities / structure at known sites and time series for the detection of change in extent and structure.
4	Evaluate the information content of dense time series imagery (every available image) for understanding vegetation communities / structure at known sites and time series for the detection of change in extent and structure.

Activities proposed within each of these components are listed below.

Component 1: Multi-temporal unmixing for fractional cover components (annual or twice yearly)

- Create annual, cloud-free dry season and wet season Landsat image composites over 1:1,000,000 map sheet tiles (14 over MGA zones 50, 51 and 52). Many of the composites needed are available from companion projects, but not all have had manual cloud screening applied.
- Collect and collate available cover assessment data for evaluation of products in collaboration with DWER (agreed), DBCA (informally agreed) and DPIRD (for discussion).
- Unmix the Landsat time series data to estimate fractional cover components to provide extent and change in extent between key cover components, including woody vegetation, green vegetation and bare ground assessment.
- Compare wet and dry season products for annuals versus perennials.
- Extract areas of irrigation cropping (if not already a by-product of above analyses).
- Compare to other vegetation mapping / monitoring products available nationally.
- Evaluate broad-scale products against cover assessment data and engage stakeholders in a review through the Land Monitor consortium.
- Discuss (evaluate / prototype?) product display tools.
- Continuous improvement based on feedback and outcomes of other modules.
- Recommendations and costings for ongoing operational products to be included in the Land Monitor III program.

Component 2: Incorporating Sentinel-2 (optical) imagery

- Assess ortho-rectification and calibration comparability for integration into time series with Landsat data.
- Development of methodology to address the different spatial resolutions of Landsat and Sentinel-2 data to separate on-ground change from sensor change issues.
- Evaluate the information content for understanding vegetation communities / structure at known sites (increased spatial and some spectral resolution).
- Evaluate time series imagery for detection of change in vegetation cover and structure at known sites.
- Provide recommendations and evaluation products as appropriate.

Component 3: Evaluation of Sentinel-1 (radar) imagery over test sites

- Evaluate the information content for understanding vegetation communities / structure at known sites.
- Evaluate time series imagery for detection of change in vegetation cover and structure at known sites.
- Integrate as a complementary data source to the optical imagery.
- Form sample products and recommendations as appropriate.

Component 4: Evaluation of dense optical time series imagery (every available image, mixed sensors)

- Evaluate the information content for understanding vegetation communities / structure at known sites.
- Evaluate time series imagery for detection of change in vegetation cover and structure at known sites.
- Inform optimal selection of imagery for annual or semi-annual monitoring.
- Form sample products and recommendations as appropriate.

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