Meelup Regional Park Vegetation Monitoring using Multi-spectral Imagery

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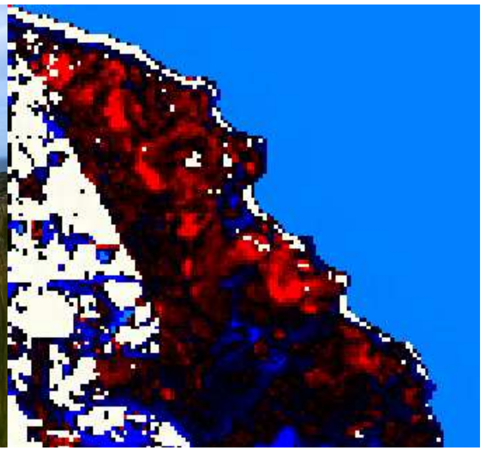

Department of Parks and Wildlife

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Glossary

Calibration	A process of making image data values (pixel values) comparable through time.
ETM+	Enhanced Thematic Mapper Plus, a sensor in the Landsat 7 satellite.
Geolink	A link of two or more image windows in geographic coordinate space.
GIS	A system of hardware and software used for storage, retrieval, mapping and analysis of geographic data.
Homogeneous Site	An area that has the same cover type and consistent spatial arrangement.
Landsat	Various satellites operated by U.S. government organisations, used to gather data for images of the earth's land surface and coastal regions. These satellites are equipped with sensors that respond to earth-reflected sunlight and infrared radiation.
Land Monitor	A coordinated initiative set up by the National Dryland Salinity Program and supported by the CSIRO, Landgate, Department of Environment and Conservation, Department of Agriculture and Food Western Australia, Department of Water, Water Corporation, and the Department of Planning and Infrastructure. The project originally aimed to systematically monitor salt-affected land and remnant vegetation change over the agricultural area of south west of Western Australia. In 2001, seven government agencies agreed to continue to acquire and process satellite imagery for Land Monitor II with the aim of providing annual mapping of remnant perennial woody vegetation in the agricultural area of south west western Australia.
Monitoring	The process of repeatedly observing and measuring using a consistent method at regular intervals.
NDVI	Normalised Difference Vegetation Index, a mathematical combination of spectral bands in imagery based on normalised ratios, used to measure the amount of green vegetation cover over soil.
OLI	Operational Land Imager, a sensor in the Landsat 8 satellite.
Orthogonal rectification	Also known as ortho-rectification, a process of making corrections within a photograph so that the scale is uniform throughout the resulting image.

Pixel	The smallest single component of a digital image. Indicator of spatial resolution e.g./ 30m pixel.
Reflectance Value	A measure of the light reflectance characteristics of a surface.
Remote Sensing	The science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation.
Spatial Resolution	An indicator of how well a sensor can record spatial detail. Often referred to as pixel size.
Spectral Band	An interval in the electromagnetic spectrum defined by two wavelengths, frequencies, or wave numbers, for example the red spectral band in the Visible Spectrum has a range of wavelengths between 0.6µm to 0.69µm.
Temporal Resolution	How often a satellite records imagery of a particular area.
Time series	A sequence of data gathered at spaced intervals of time.
Trend	A generalisation of the direction of variation in a quantity over time or space.
TM	Thematic Mapper, a sensor in Landsat 4 & Landsat 5 Satellites.
Vegetation Index	A mathematical combination of spectral bands in satellite imagery, which is sensitive indicators of the presence and condition of living vegetation, eg NDVI.
VegMachine	A software package and an extension program which enable land managers to interactively view and interrogate many dates (time series) of imagery, informing on management actions and assisting reporting.

Introduction

Remote Sensing is a useful tool for monitoring changes in vegetation cover including vegetation and tree declines (Wallace et al., 2006; Zdunic and Behn, 2009; Lehmann et al., 2013). The Landsat satellite series has provided consistently captured imagery at 30m ground resolution for the last 27 years. Landsat imagery is available for download from the United State Geological Survey (USGS) (

http://landsat.usgs.gov/). In collaboration with CSIRO at the Leeuwin Centre for Earth Sensing Technologies, methods for using this imagery in a calibrated, rectified and consistently processed time series have been developed (Furby and Campbell, 2001; Wu et al., 2001; Caccetta et al., 2007).

Meelup Regional Park has many pressures on its vegetation health and remote sensing can help in understanding changes in vegetation cover over the last 27 years. Monitoring and quantifying the spatial distribution of vegetation cover change, an investigation into how vegetation recovers after known impacts can be achieved.

This analysis will produce vegetation change products for the period February 1988 to January 2015. The selection of imagery will prioritise February captures, but due to cloud cover and availability other dates may be selected.

Data

Satellite Imagery

Landsat satellite imagery is utilised in this study due to its long history, appropriate spatial resolution (30m pixel) and established techniques in time series analysis. Landsat imagery used in this analysis will include imagery from Landsat satellites 5, 7 and 8. The dates selected for use are predominately February imagery as dry season imagery reduces the amount of annuals present and the perennial vegetation can be assessed (Table 1). Cloud free imagery is more likely to be captured at this time of year and where there is no suitable February imagery available January and March image dates are utilised.

In 2003 Landsat 7 acquired a scan line corrector failure, this results in missing data in strips of the imagery (http://landsat.usgs.gov/products_slcoffbackground.php). This data is still useful and in the years of 2012 and 2013 this is the only data available. Filling the gaps with a close image date has been successfully employed in the Land Monitor Project and in the National Carbon Accounting System Land Cover Change Project (Caccetta et al., 2007). Table 1 shows the fill in dates used when required in the secondary and tertiary image date columns.

Pre-processing of imagery is required to make it appropriate for use in time series analysis. This requires the position of the imagery to be co registered and differences due to sun angle and atmosphere resolved. Imagery sourced from USGS has systematic processing applied to ensure rectification is appropriate for time series analysis http://landsat.usgs.gov/Landsat_Processing_Details.php). Variations due to differing illumination angles are resolved using software provided by CSIRO using methods developed by Wu et al.(2001).

As part of the product suite supplied, false colour enhancements of each image date are supplied in ECW format. This format is suitable for use in all major GIS packages. The false colour enhancement uses bands 5, 4 and 3 in a red, green and blue display as these bands show variation in vegetation cover and vigour more distinctly than the true colour bands of the Landsat satellites (see Data Delivery).

Table 1: Landsat scene 113/083 image capture dates.

Year	Satellite	Primary Image Date	Secondary Image Date	Tertiary Image Date
1988	Landsat 5	27/02/88		
1989	Landsat 5	13/02/89		
1990	Landsat 5	31/01/90		
1991	Landsat 5	19/02/91		
1992	Landsat 5	05/01/92		
1993	Landsat 5	08/02/93		
1994	Landsat 5	27/02/94		
1995	Landsat 5	18/03/95		
1996	Landsat 5	01/02/96		
1997	Landsat 5	02/01/97		
1998	Landsat 5	22/02/98		
1999	Landsat 5	29/03/99		
2000	Landsat 7	20/02/00		
2001	Landsat 7	22/02/01		
2002	Landsat 7	29/03/02		
2003	Landsat 7	28/02/03		
2004	Landsat 5	23/02/04		
2005	Landsat 5	25/02/05		
2006	Landsat 5	28/02/06		
2007	Landsat 5	14/01/07		
2008	Landsat 7	26/02/08	10/02/08	
2009	Landsat 5	20/02/09		
2010	Landsat 5	23/02/10		
2011	Landsat 5	26/02/11		
2012	Landsat 7	21/02/12	08/03/12	
2013	Landsat 7	22/01/13	21/12/12	07/02/13
2014	Landsat 8	18/02/14		
2015	Landsat 8	20/01/15		

Field data capture

Field data of vegetation cover can be used to calibrate a Landsat vegetation index to values related to projected foliage cover (PFC; Behn et al., 2000). This transforms the index values from digital numbers to a scale more relatable on the ground. This data is also used to develop and determine the strength of the relationship of a Landsat vegetation index to the field observed vegetation.

Field data was captured on the 18th and 19th February 2015 as this time of year aligns with the dry season capture of the satellite imagery (Figure 1). Field sites were planned to cover a range of vegetation densities and represent homogenously patterned sites of 90m by 90m. In order to represent all of the vegetation types and densities in Meelup Regional Park some smaller plots were established. The November 2013 digital orthophotos were used to aid field site selection of a variety of vegetation cover densities.

The field data collected included estimates of canopy cover, site photographs and digital photographs of canopy (upward) and low/ground cover (downward). Through the use of established automated methods, the digital photographs were converted to canopy metrics (Macfarlane, 2001) and low/ground cover metrics (Macfarlane and Ogden, 2011).. These photographs were taken in a three by three grid format with 30m spacing to produce nine points covering the centre of each plot. General site descriptions and tree species were also recorded (Table 2); the full field data collected is supplied in ESRI file geodatabase format (see Data Delivery).

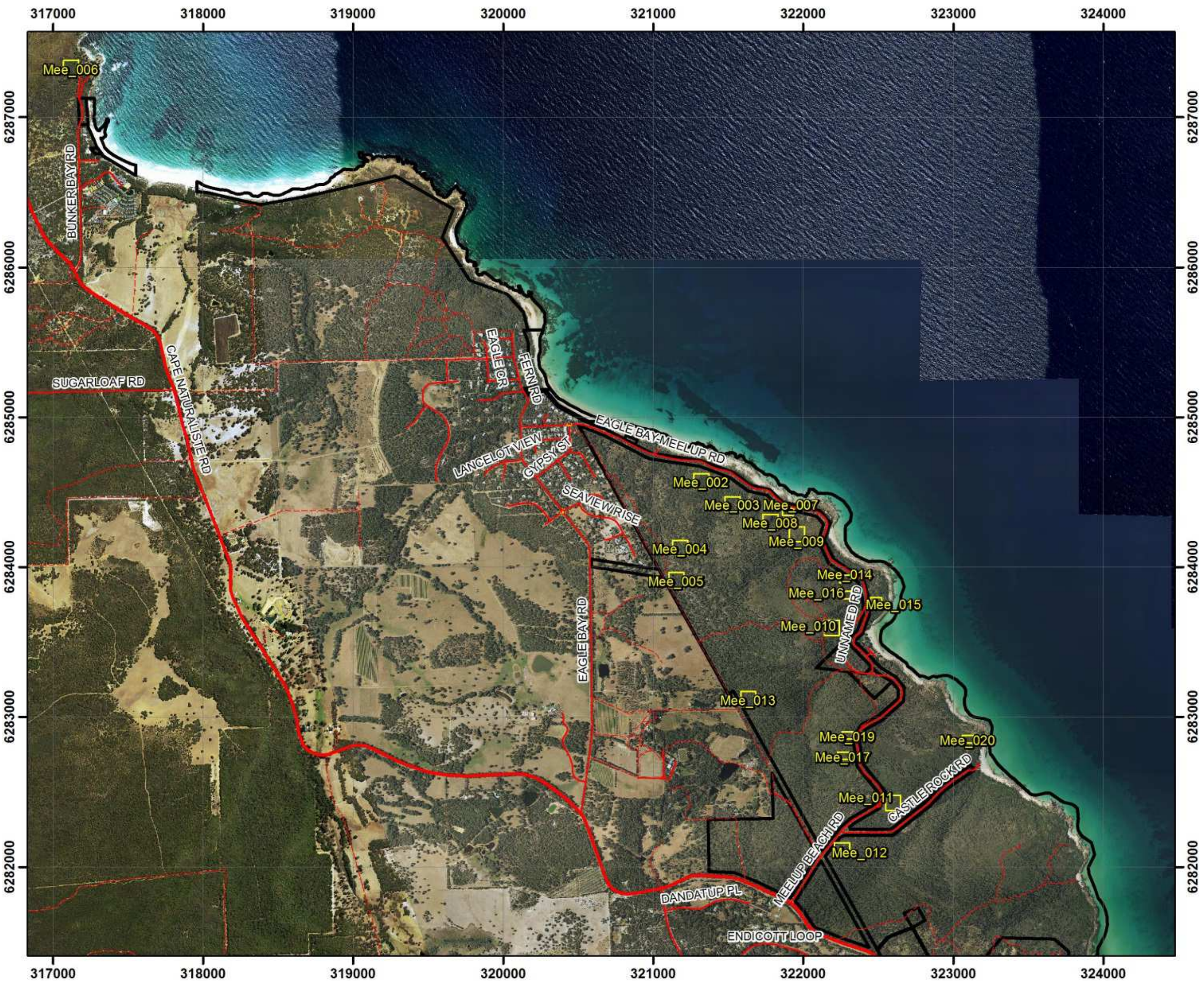


Figure 1: Field plots captured on 18-19/02/2015, shown on aerial photograph from November 2013.

Table 2: 2015 Field site descriptors, for full data see ESRI geodatabase Meelup_FieldData_150218.gdb.

SiteID	Description	Muir Vegetation Class	Canopy Cover	Mid Cover	Ground Cover	Litter	Exposed Soil	Shadow	Aspect	Slope
Mee_002	Shrubs on granite hill near peak.Some grasstrees. Loose small rocks, some dead standing bushes.	Heathland	0	0	40	10	20	5	NE	10
Mee_003	Marri over grass tree + tall shrubs, thick understorey g/cover. Some open gravel/rock areas. Numerous dead shrubs + breakaway of laterite	Low Open Forest	35	0	40	15	10	20	NE	4
Mee_004	Open forest, pred Marri with some Jarrah, over numerous grasstrees. Evidence of fire, some patches of bare granite.	Open Forest	35	0	35	10	20	20	NNW	2
Mee_005	Mixed Marri, Agonis forest over grasstrees + healthy macrozamia. Much forest litter + large fallen logs. Evidence of fire. Some Banksia grandis.	Closed Forest	70	0	5	20	5	0	N	1
Mee_006	Dense Melaleuca forest on side of hill. Lots of dead debri. Ground cover of moss. Estimated locations as too dense for GPS.	Closed Forest	80	0	0	15	5	40	SE	10
Mee_007	Dense Agonis with many Casuarina, some shrubs + occasional Marri. Drainage line (man made?) through site.	Dense Low Forest A	80	0	0	15	5	50	NE	1
Mee_008	Low shrubs+ grasstrees + Melaleuca. Old evidence of fire. Exposed granite outcrops. Near top of hill.	Heathland	0	5	50	10	35	5	E	15
Mee_009	Low shrub/heath with Nuytsia, grasstree, Banksia + others. Exposed granite hillside towards bottom 2m of slope.	Low Heath C	5	0	40	0	5	5	E	5
Mee_010	Nuytsia over low shrubs and grasstrees, exposed rocky outcrops near top of hill, steep.	Dwarf Shrub C	2	0	28	10	10	0	E	7
Mee_011	Heath with exposed granite outcrops. Hakea sp, Accacia sp, some grasstrees, canopy of a few emergent Jarrah.	Dense Heath A	11	80	0	0	4	0	E	3
Mee_012	On top of hill, Jarrah with grasstree + shrub understorey, organic soil with duricrust and lateritic soil patches. Debri, evidence of intense fire. Lots epicormic regrowth.	Low Forest A	50	5	35	10	0	20	W	5
Mee_013	Jarrah + Marri over grasstree + sml shrubs. New tree recruits, lots leaf litter + debri. Evidence of fire. Some flagging in canopies (both sp). Dead/dying macrozamias.	Open Forest	40	10	20	15	15	0	NW	3
Mee_014	Low shrubland with occasional grasstree, Marri, tall Accacia on exposed granite hillside. Few macrozamia, evidence of fire, lots of standing dead shrubs mid slope.	Dwarf Shrub C	5	5	20	5	5	0	NE	10
Mee_015	Agonis, Nuytsia, Marri over shrubs, rocky soil adjacent to shore, lots of debris, maybe Agonis death.	Low Woodland A	25	30	0	20	25	15	E	1
Mee_016	Nuytsia, Hakea?, Accacia?, Banksia grandis over low shrubland on exposed granite hillside, near top, lots of debris.	Dwarf Shrub C	5	0	25	10	5	2	E	15
Mee_017	Jarrah + Marri with tall 3m grasstrees over shrubs, top of hill, fire 3/4 up trunks, epicormic recovery, sand with lateritic gravel, dense clumps of trees with patches between.	Open Tree Mallee	25	5	35	25	10	10	W	1
Mee_019	Jarrah + Marri with Banksia grandis (2m) + tall shrubs. Lateritic soil, lots of gravel, near top of hill, lots of 1m ant/termite mounds.	Low Woodland A	20	15	30	10	25	20	E	6
Mee_020	Shrub dominated Melaleuca, Accacia, grasstree, rocky slope with exposed granite, evidence of old fire.	Heath B	65	0	0	20	15	0	E	3

Methodology and Results

The approach applied in this study is to use time series trend analysis on a sequence on satellite imagery to detect changes in vegetation cover. Field data is collected to verify vegetation identification and cover density. The field data is then used to refine the analysis of the sequence of satellite imagery and produce a reliable series of images through time representing the vegetation cover.

Field data processing

In order to relate the field data to the Landsat 30m pixel data the field measures of vegetation cover are combined and averaged per site. Projective foliage cover (PFC) combines canopy cover, which assumes canopies are opaque, and canopy openness to derive a percentage of foliage cover (Hnatiuk et al., 2009). In previous studies PFC values have been found to have a high correlation to vegetation cover sensed by Landsat satellites (Behn et al., 2000; Peter et al., 2003). Canopy cover was recorded using three methods; aerial photograph interpretation (Aitken and Hall, 1951); Bitterlicht field measurement (Bitterlich, 1947) and visual field estimation using a top down view of the vegetation cover. Canopy openness was recorded using two methods; by classifying vegetation cover in the upward and downward photographs (Macfarlane, 2001; Macfarlane and Ogden, 2011); and visually estimated using templates (Hnatiuk et al., 2009). Several methods are employed as different measures perform better in varying environments. Various combinations of the canopy cover and canopy openness measures were combined to produce PFC values. These were then tested against vegetation indices to determine the strongest relationship between the field measures of vegetation cover and the Landsat vegetation index.

Index development

To determine the most appropriate Landsat vegetation index to apply to Meelup Regional Park statistical analysis was carried out. The technique utilised is Canonical Variate Analysis (CVA; Campbell and Atchley, 1981), this approach has been applied in the National Carbon Accounting System Land Cover Change Project (Caccetta et al., 2007). This technique summarises the separation between sites, in this case the planned field plots, using the 6 band (dimension) Landsat data. Routines to determine indices have been developed (McKay and Campbell, 1982), in this case sparse and dense sites of vegetation cover were contrasted to establish a band combination (index) that best represents the variation in vegetation cover. Figure 2 displays the spread of the field plots in the first and second canonical directions and the dense and sparse sites used to develop a vegetation index. The developed index is –band 2 + band 3 + band 5, this combination describes 79.625% of the variation between the dense and sparse vegetated sites.

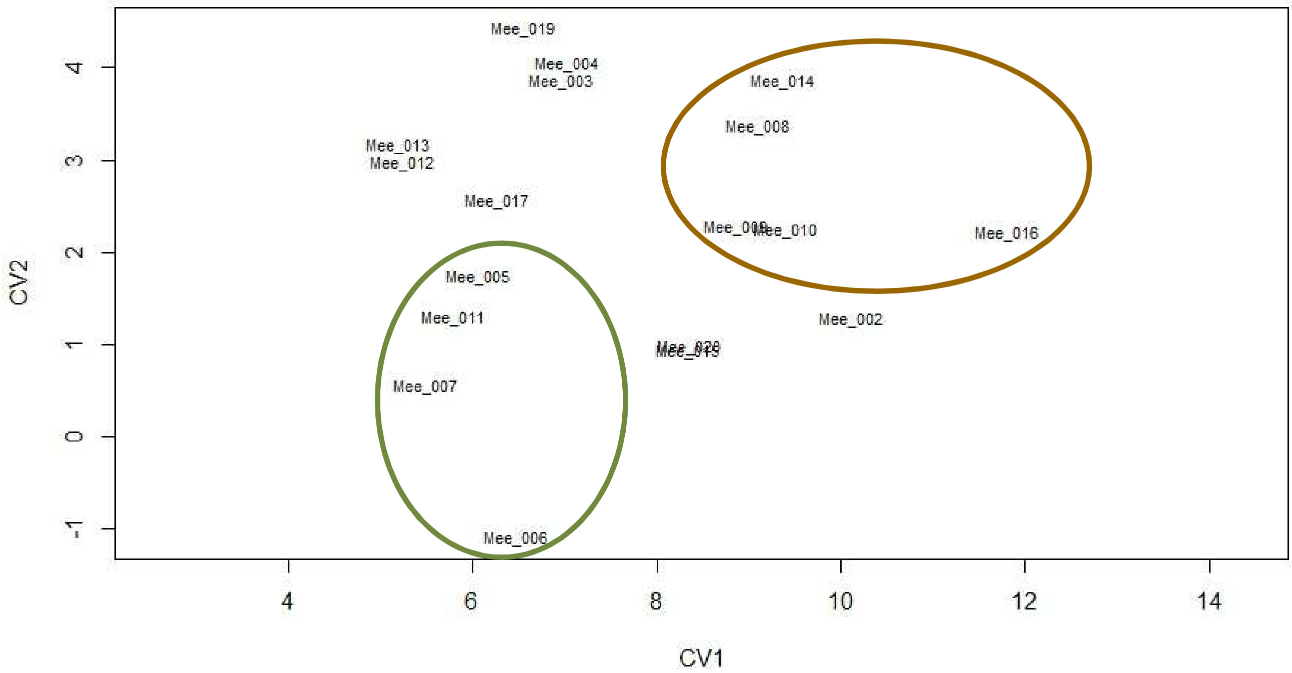


Figure 2: Plot of canonical variate one and two of the field plot locations using Landsat 8 image from the 20/01/2015. The green oval indicates sites with dense vegetation cover and the brown oval indicates sites with sparse vegetation cover.

Linear model selection

The relationships between the developed Landsat vegetation index and field derived measures of PFC were examined using linear regression. The previously applied Landsat vegetation index used in the Land Monitor Project (Band 3 + Band 5; Caccetta et al., 2000) was also tested. In all ten linear regression models were calculated. Five separate measures of canopy cover or PFC were regressed against the two Landsat vegetation indices, resulting in ten separate models. All the models produced significant p values (Table 3).

Table 3 Model summary statistics for Meelup Regional Park. The table presents adjusted r squared values, p values and Akaike's "An Information Criterion" scores (AIC) for ten models. AIC can be used as a criteria to choose between competing models, with lower values indicating a better model than the alternatives. Model m4 has the lowest of the AIC scores (highlighted in yellow).

Models	Adjusted r squared	P value	Akaike's AIC
m1	0.842	5.091E-08	132.34
m2	0.797	3.892E-07	128.94
m3	0.792	4.593E-07	129.15
m4	0.812	2.084E-07	127.91
m5	0.831	8.624E-08	130.55
m6	0.833	7.810E-08	133.30
m7	0.786	5.943E-07	129.88
m8	0.781	6.990E-07	130.09
m9	0.796	4.037E-07	129.38
m10	0.814	1.886E-07	132.29

Model m4 used the developed Landsat vegetation index –Band 2 + Band 3 + Band 5 and a PFC derived from canopy cover from visual field estimation using a top down view of the vegetation cover and canopy openness from a combination of upward and downward photography. A scatterplot of the field derived PFC and the developed Landsat vegetation index with the linear fitted model and equation is shown in Figure 3.

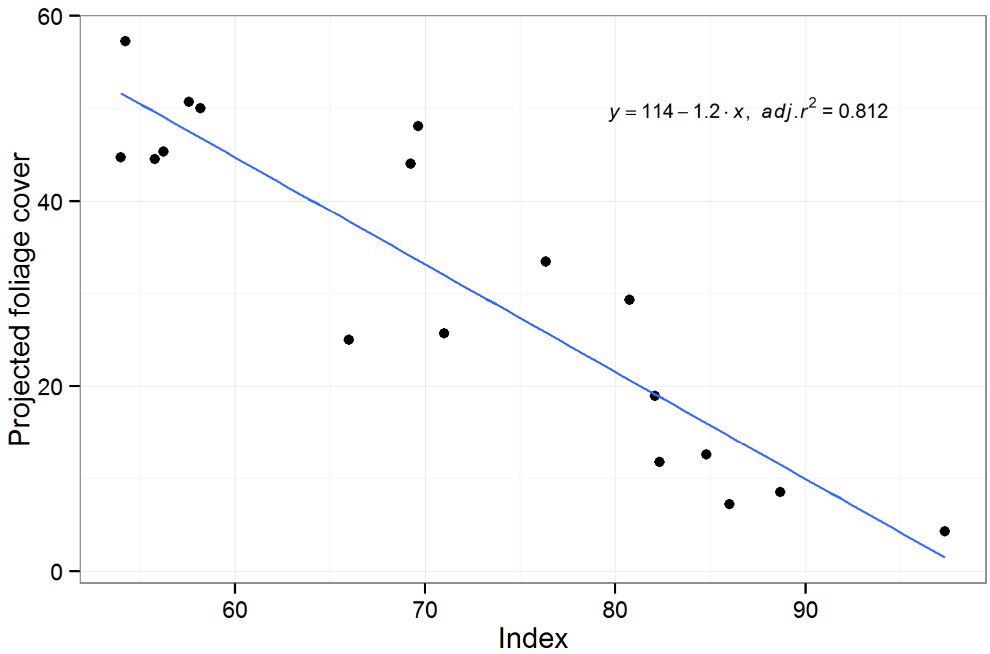


Figure 3: Scatterplot of projected foliage cover and a specially developed vegetation index for Meelup, Western Australia. The blue line is the least squares regression, and the line equation and adjusted r squared are displayed on the plot.

Trend analysis

In order to view changes in vegetation cover from several image dates in a single view a method of summarising the changes is required. Trend imagery is one method of summarising the changes using linear regression (Furby et al., 2008). A line can be fitted to the different values of vegetation cover over time for a single point (or pixel). The slope of this line indicates whether the general trend of the vegetation cover is increasing or decreasing. This can then be shown in an image display where red is assigned to the slopes showing vegetation loss, and the brighter the red the greater the loss and blue is assigned to slopes showing gain.

The trend can be calculated for different time periods, for example pre and post a management action to assess the impact of the change. This has been successfully previously to assess the impact of feral goat removal on Dirk Hartog Island (van Dongen et al., 2013). Depending on the ancillary information provided different trend periods may be applied to Meelup Regional Park. The trends can further be summarised using vegetation mapping and comparing vegetation community cover changes. In this analysis the time period has been arbitrarily broken into three equal time periods of 9 years each as well as the whole time period trend. Figure 4 displays the four trend periods calculated. The area between Eagle bay and Bunker bay has not been shown in Figure 4 as the detail would not be visible at the printed scale, and the area of vegetation is very small, however the full extent images have been supplied in digital ECW format (see Data Delivery).

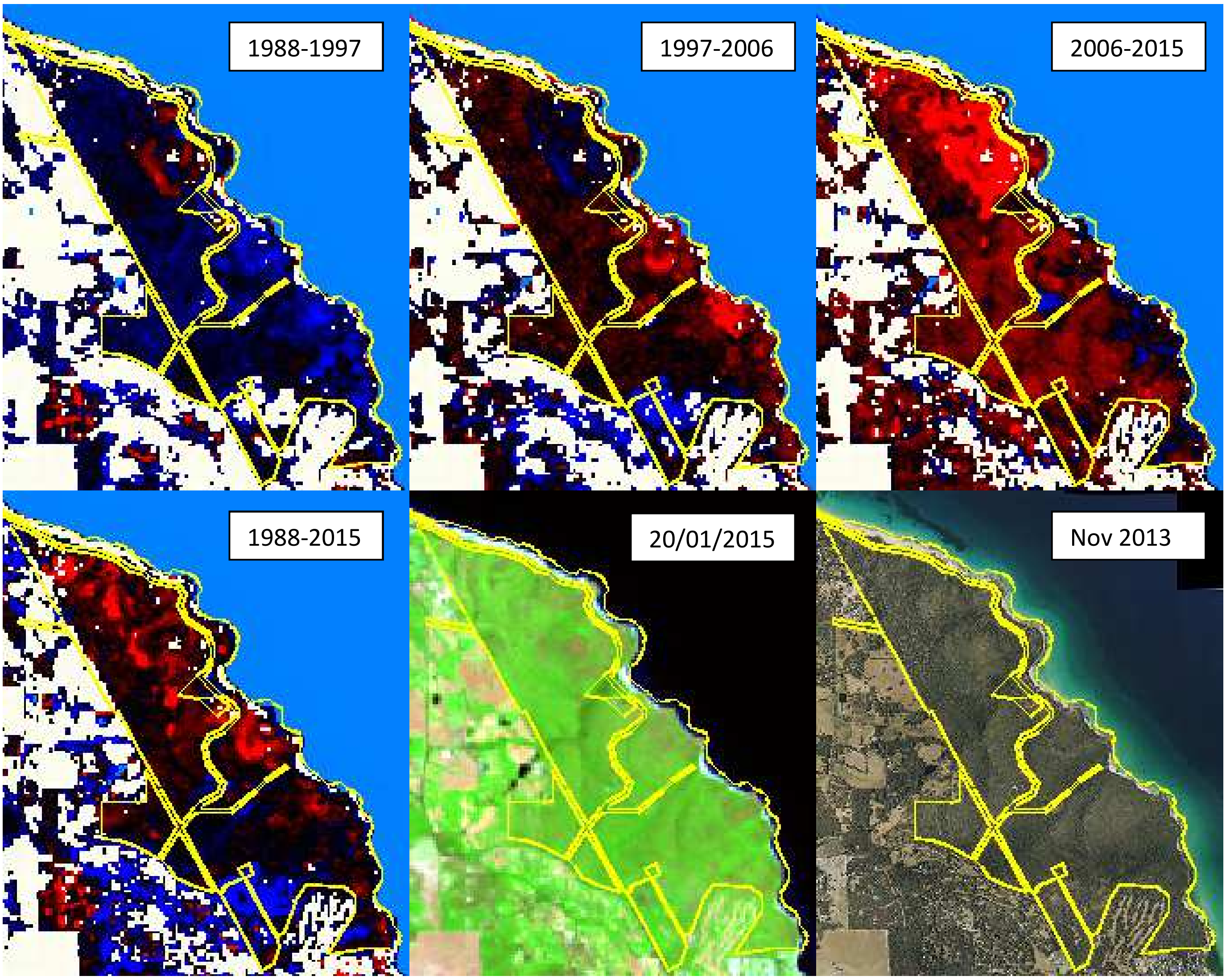


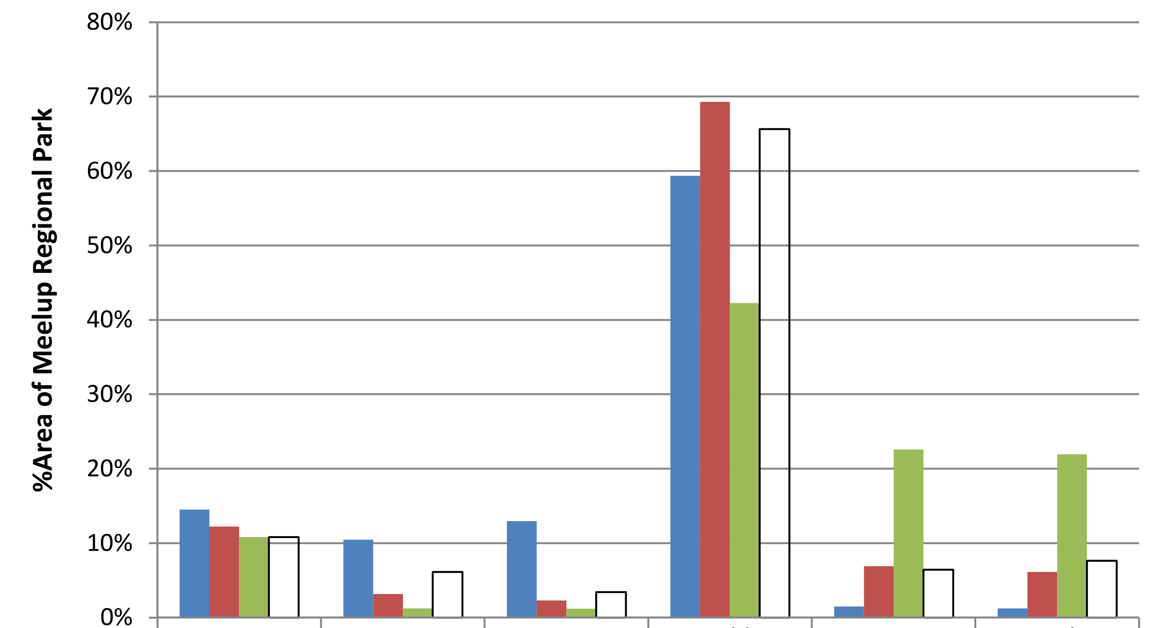
Figure 4: Trend displays for varying time periods, red indicates vegetation cover loss, blue vegetation gain and black areas are stable, white are masked non perennial vegetation areas and light blue is masked water, Meelup Regional Park boundary is indicated in yellow. Clockwise from top left: trend display 1988-1997, trend display 1997-2006, trend display 2006-2015, aerial photograph from November 2013, Landsat false colour display from 20/01/2015, trend display 1988-2015. For full park extent images see ECW images described in the Data delivery section.

To enable calculation of areas of change the linear slopes of loss and gain are classified into five classes of large loss, loss, stable, gain and large gain. The boundaries of these classes have been arbitrarily set at 10 and 15 counts of PFC over the time period assessed. For the 9 year time periods the linear slopes are the same, but for the whole 27 year time period the slope are much less for the same change. For example for a 10 count change in PFC over a 27 year time period this is a change of 0.37 PFC per year, whereas over a 9 year period this is a more dramatic variation and results in change of 1.11 PFC per year. Table 4 shows the classification boundaries for each time period and class.

Table 4: Trend class boundaries based on total change in PFC values over the time period.

Class	9 year time period	27 year time period
Large gain: +15 PFC or more	+1.67 PFC/year or more	+0.55 PFC/year or more
Gain: +10 to 15 PFC	+1.11 to +1.67 PFC/year	+0.37 to +0.55 PFC/year
Stable ± 10 PFC	-1.11 to +1.11 PFC/year	-0.37 to +0.37 PFC/year
Loss : -10 to 15 PFC	-1.11 to -1.67 PFC/year	-0.37 to -0.55 PFC/year
Large loss: -15 PFC or more	-1.67 PFC/year or more	-0.55 PFC/year or more

The trend class images were converted to vector format and the areas calculated, these have been supplied in ESRI shapefile format. To look at how Meelup Regional Park has changed in each of these time periods the areas were summarised and displayed in a graph (Figure 5). The areas could also be summarised by vegetation type or other boundary such as fenced versus unfenced, or disease free and infected.



	Bare areas	Large gain	Gain	Stable	Loss	Large loss
1988-1997	14.52%	10.45%	12.95%	59.34%	1.50%	1.24%
1997-2006	12.21%	3.17%	2.31%	69.30%	6.89%	6.13%
2006-2015	10.79%	1.23%	1.20%	42.26%	22.57%	21.94%
1988-2015	10.80%	6.14%	3.42%	65.61%	6.41%	7.62%

Figure 5: Trend class areas in three 9 year time periods and over the entire time period.

Complementary data analysis

Complementary data such as rainfall, fire scars, vegetation association mapping, dieback mapping and known areas of decline can be used with the trend data and the time series image data to aid in understanding the drivers of vegetation change. The information in the following section needs to be used in a local context and local understanding of ecological processes applied.

Rainfall

Rainfall is a key driver of vegetation cover. Examination of the annual rainfall at the Cape Naturaliste station and calculation of the average rainfall for each trend time period yields interesting results (Figure 6, Table 5). The downward trend observed in the 2006-2015 may be due in part to the substantially lower rainfall in that time period. There was also a large fire in this time period causing a large area to have a downward trend. The ability of vegetation cover to return to pre fire levels could be impaired by lower rainfall and the return of too frequent fire can result in the future vegetation community composition being permanently altered (Roadside Conservation Committee, 2011).

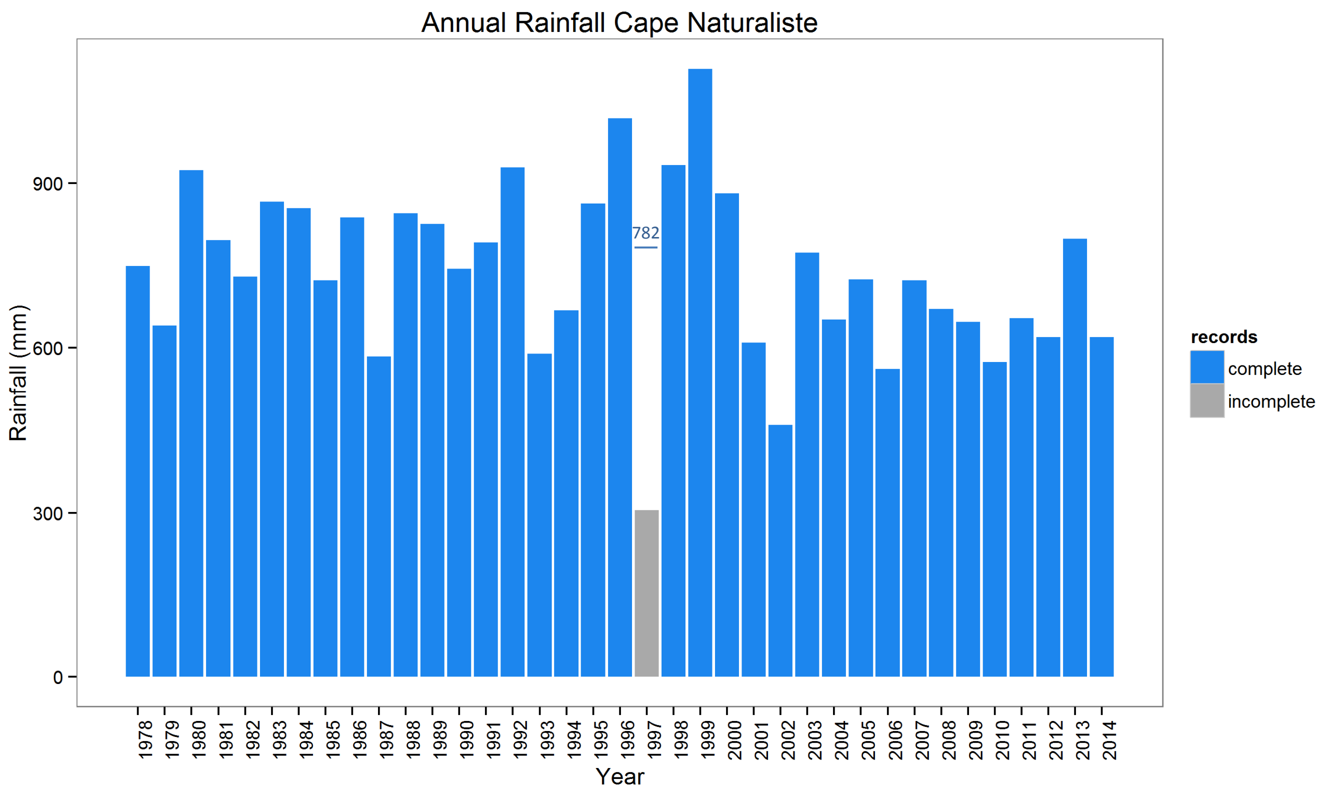


Figure 6: Bureau of Meteorology annual rainfall data recorded at Cape Naturaliste, 1997 was incomplete and the total indicated is from local Eagle Bay records.

Table 5: Annual rainfall averages for trend class periods and 10 years previous, brackets indicate actual year's annual rainfall used in averages as image capture is in February of each year.

Average annual rainfall	mm
1978-1988 (78-87)	770.09
1988-1997 (87-96)	785.63
1997-2006 (96-05)	793.78
2006-2015 (05-14)	**659.24**
1988-2015 (87-14)	737.31
1978-2015 (78-14)	750.32

Fire

Fire is a source of one of the major impacts on vegetation cover in Meelup Regional Park and affects the vegetation trends accordingly. Due to a lack of fire history mapping available over Meelup Regional Park examination of the impact of fire is not comprehensive. The Landsat satellite images for each year have been examined and obvious fires have been identified with an outline, see Figure 7. Non burnt areas within fire outlines have not been identified. A vector file in ESRI shapefile format has been provided attributed with the date of imagery the fire was identified in (see Data Delivery). Each of the three trend periods will be examined with the fires identified within that time period. Areas that display declines will be interrogated to display the vegetation history in graph form. These graphs show the vegetation cover levels prior to the fire impact and the recovery over time.

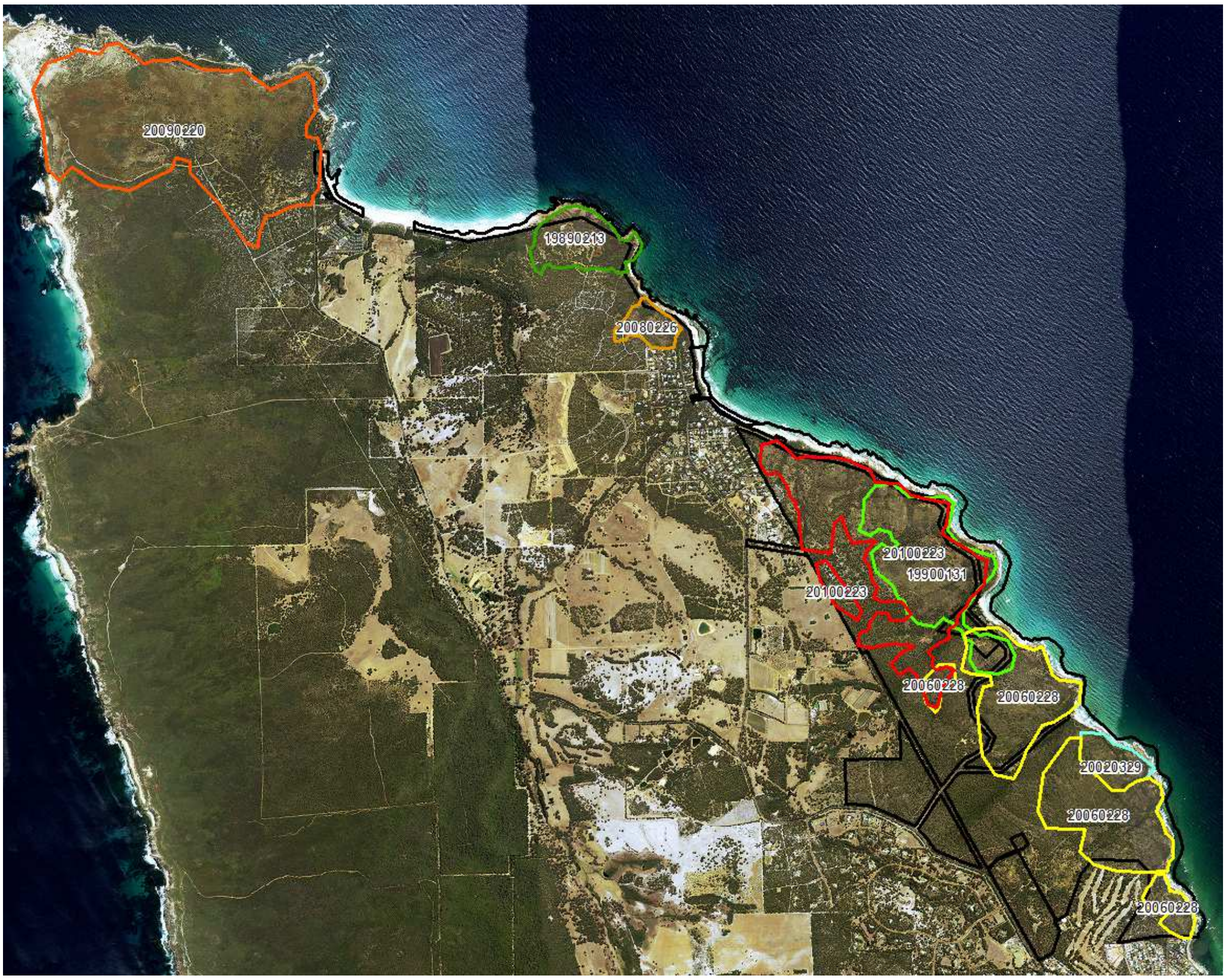


Figure 7: Fire scars identified in Landsat annual sequence of imagery. Various colours indicate image date fire was identified in with older fires shown in cooler colours and more recent fires in warm colours. Meelup Regional Park boundary is indicated in black and the background image is an aerial photograph captured in March 2012.

Two fires were identified in the period 1988 to 1997, one in the 1989 annual image and other in the 1990 annual image (Figure 8). The 1990 fire shows the greatest lasting impact on the trend image and examination of the vegetation cover history of an area of declining vegetation cover shows the area did not start to recover from the vegetation cover loss until 1996. The same area is then impacted again from fire in 2010 from which it is slowly recovering. In the provided vegetation association mapping (Meelup vegetation assoc mapping Sept2013_region.shp) this area is Jarrah, Marri low woodland to open tree mallee.

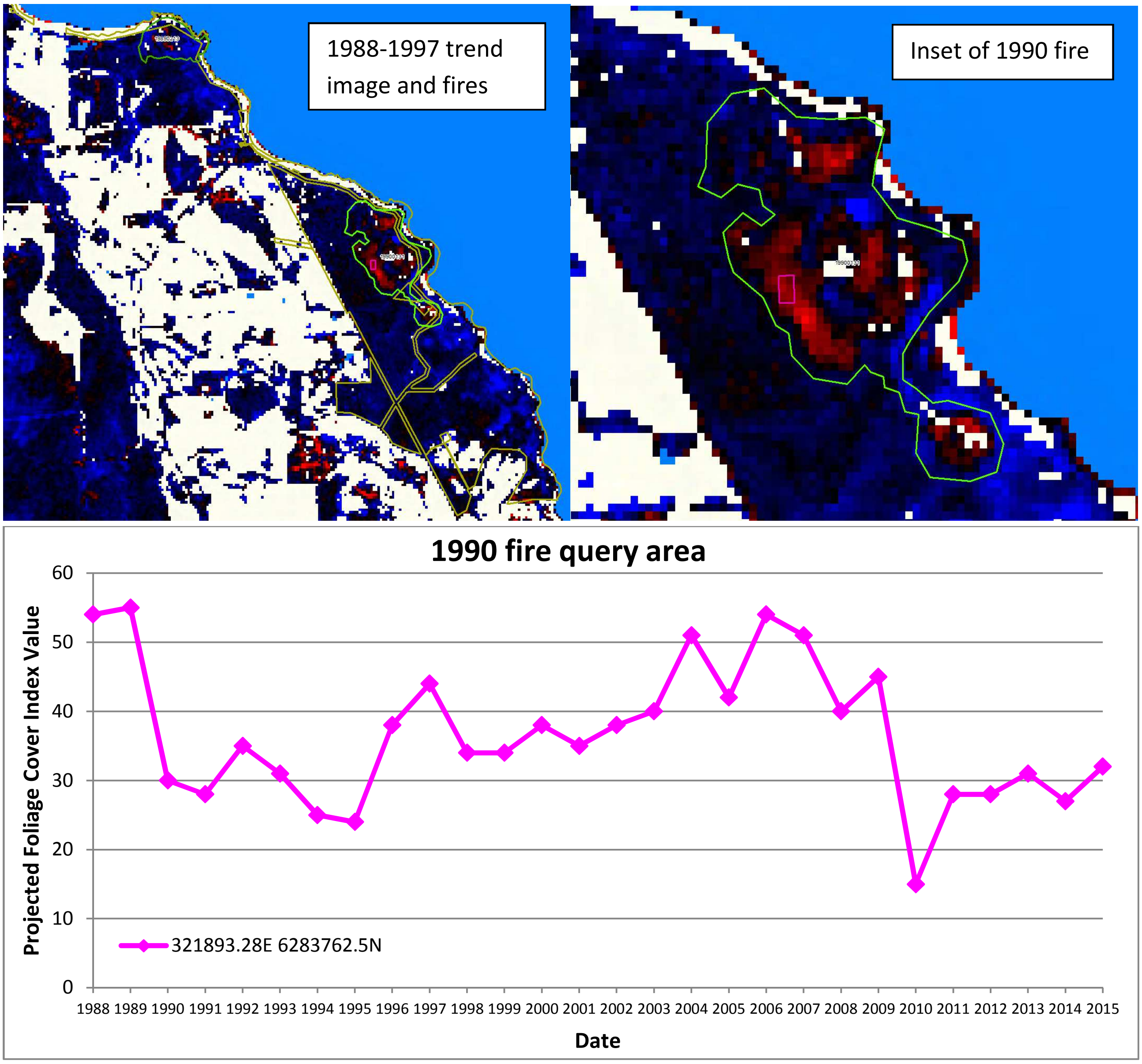


Figure 8: Fires in the 1988 to 1997 time period displayed on 1988-1997 trend image with graph of loss area identified in 1990 fire inset shown in pink. Meelup Regional Park boundary is shown in dark yellow on the top left image.

Four fires were identified in the period 1997 to 2006, one in the 2002 annual image and others in the 2006 annual image (Figure 9). Examination of areas showing declines in these fire impact areas shows vegetation that can vary in cover from year to year substantially, but were showing an increasing trend in vegetation cover throughout the 1990’s before stabilising in the late 1990’s. The fire impacts have had an enduring effect on vegetation cover levels with the 2002 site appearing to start to gain vegetation cover in the last few years. In the provided vegetation association mapping the 2002 site is within *Calothamnus graniticus* closed heath and the 2006 site is within Jarrah, Marri low open forest with *Allocasuarina fraseriana* on loam soils.

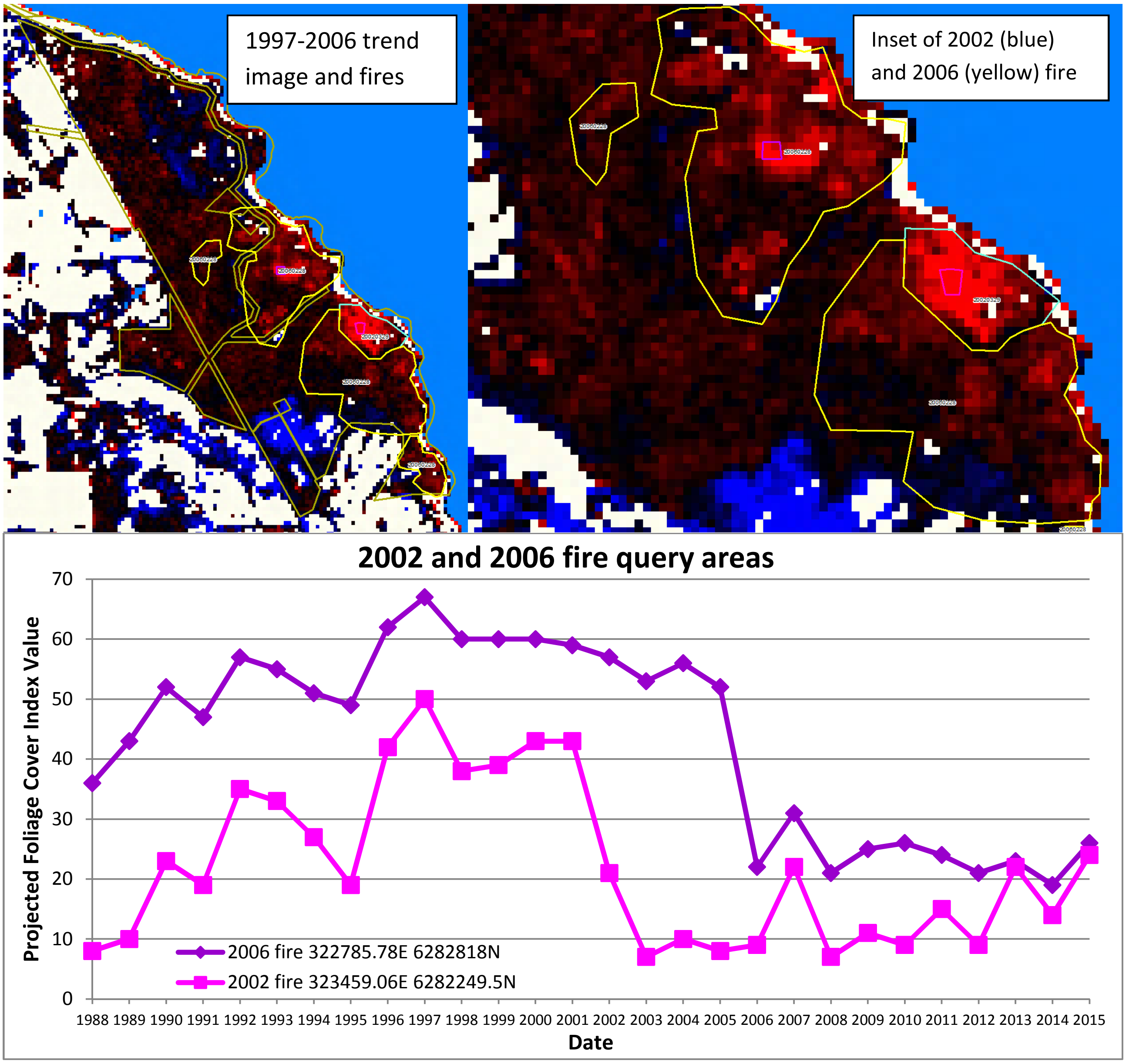


Figure 9: Fires in the 1997 to 2006 time period displayed on 1997-2006 trend image with graph of fire impact decline identified in 2002 fire inset shown in pink and 2006 fire shown in purple. Meelup Regional Park boundary is shown in dark yellow on the top left image.

Two fires were identified in the period 2006 to 2015, one in the 2008 annual image and the other in the 2010 annual image (Figure 10Figure 9). The 2008 site in declining vegetation was increasing in vegetation cover during the 1990's before stabilising in the late 1990's and maintaining cover levels until the file impact in 2008. Since the fire impact a small amount of recovery has taken place, but the cover levels are still approximately half of the pre fire levels. The 2010 site in declining vegetation was impacted by fire in 1990 and took 7 years to return to pre fire impact levels. Since the fire impact in 2010 the area does not show a recovery of vegetation levels and is currently approximately half of pre fire cover. The 2008 site is outside the Meelup vegetation association mapping, however in the state wide pre-European vegetation mapping it has a vegetation association of a mosaic of medium forest; Jarrah-Marri low woodland (Shepard 2003). The 2010 site is in a mixture of mixed granitic closed low heath and Jarrah, Marri low open forest on lateritic soil with a potential creek line through the middle.

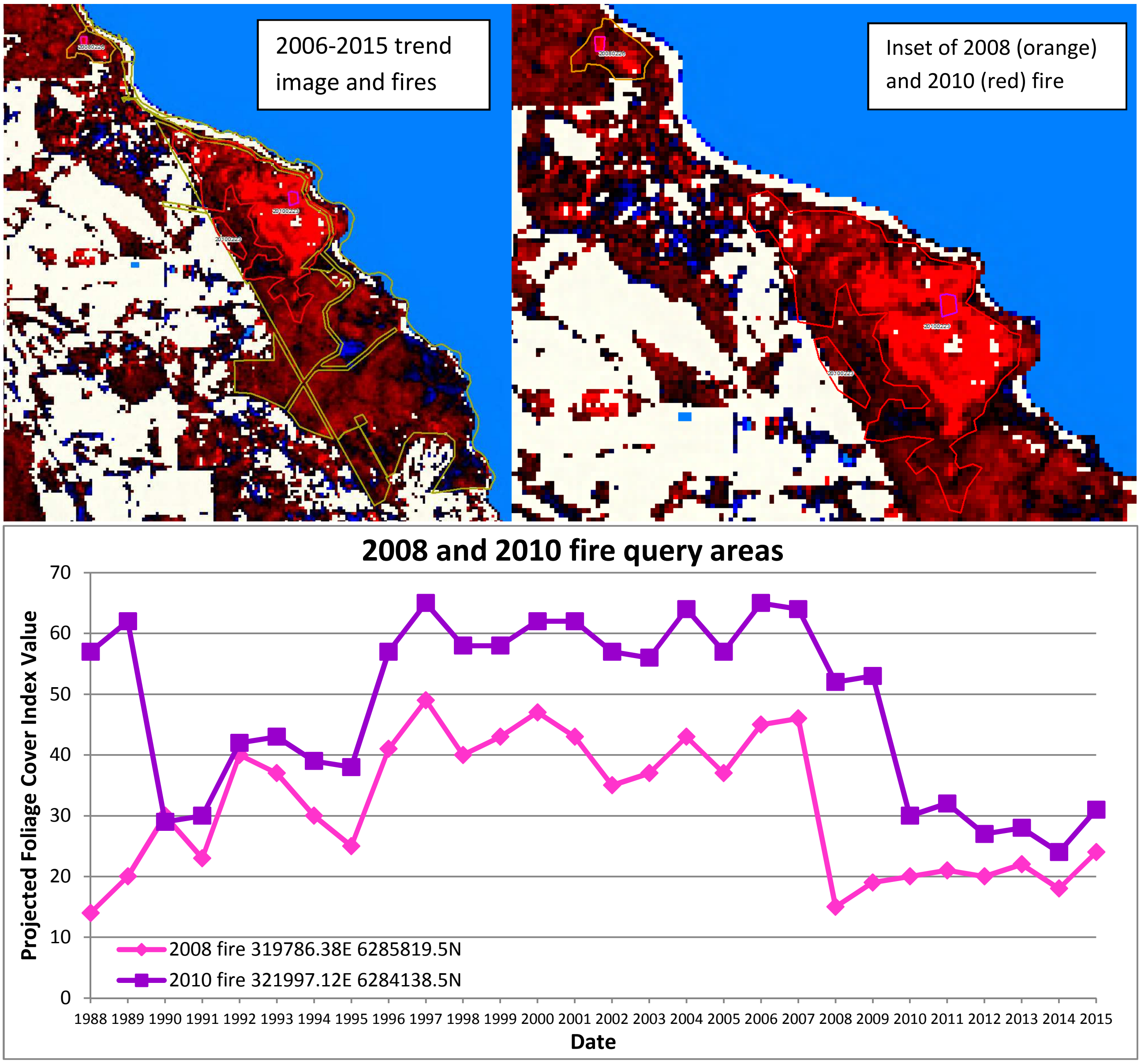
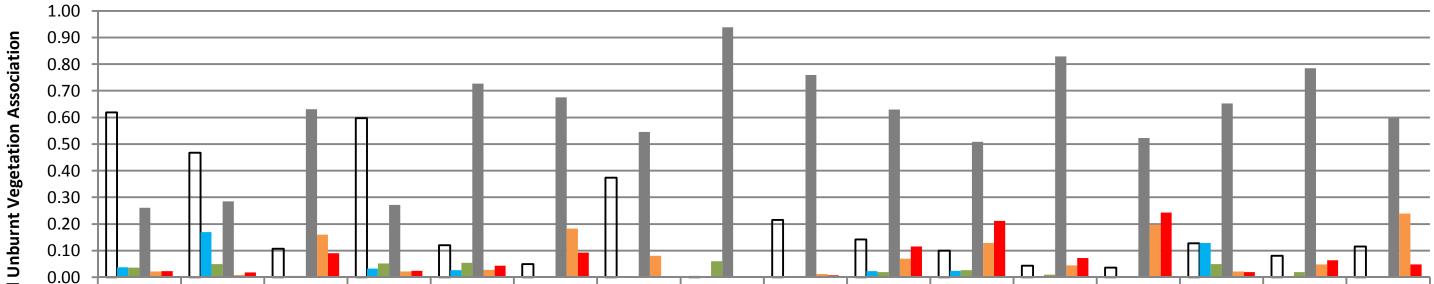


Figure 10: Fires in the 2006 to 2015 time period displayed on 2006-2015 trend image with graph of fire impact decline identified in 2008 fire inset shown in pink and 2010 fire shown in purple. Meelup Regional Park boundary is shown in dark yellow on the top left image.

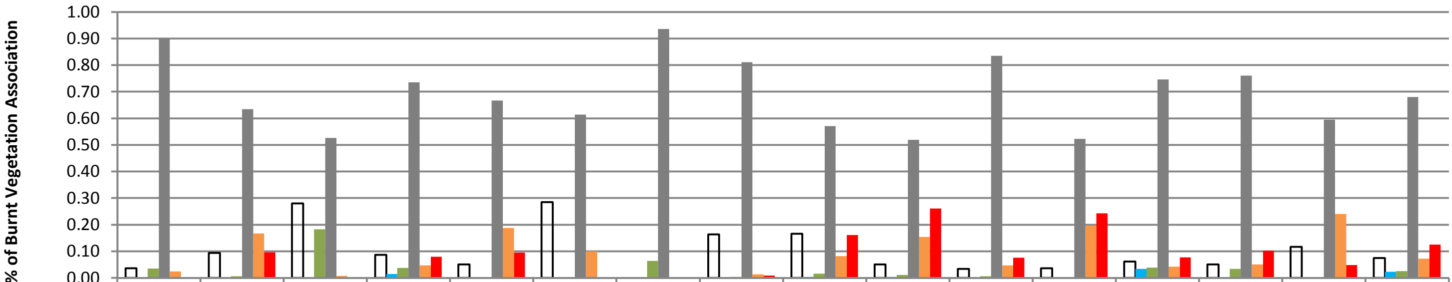
The slow recovery of fire impacts in the 2000's as opposed to the fire impacts in the early 1990's may be due to lower rainfall in this time period or higher intensity fire. The sites selected in each of the graphs are located in dieback free areas. This has implications for managing fire risk in the park to ensure the fire return intervals allow for recovery of vegetation levels and avoiding high intensity fires. Planned low intensity fire appear not to have the same enduring effects on vegetation cover as many of these types of fires indicated on the supplied Meelup fire history (MRP FMP 1 – Fire History A3 v3.pdf) are not obvious on the annual Landsat imagery and trends.

Vegetation Association

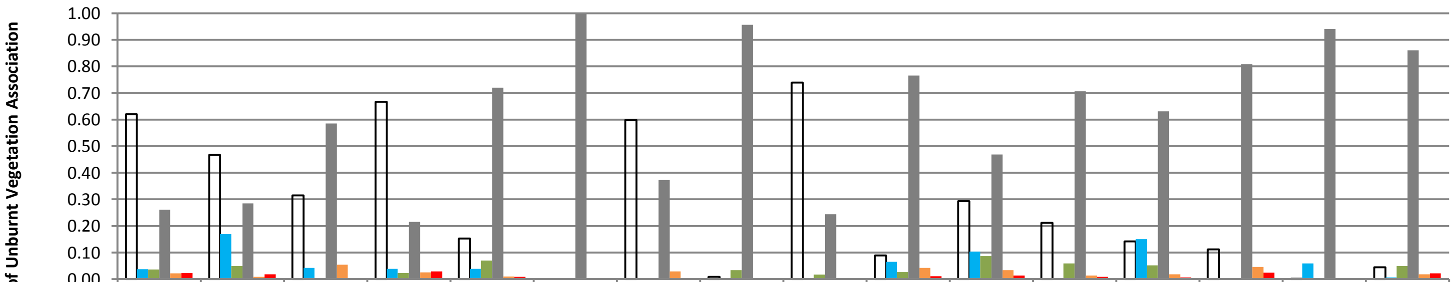
Vegetation mapping to association level has been provided for this project (Meelup vegetation assoc mapping Sept2013_region.shp). To examine the long term trends in the vegetation mapping fire impacts need to be taken into account. Figure 11 displays the trend classes for each vegetation association across the whole of Meelup Regional Park, and then separately for burnt and unburnt areas. By separating out the burnt and unburnt areas the long term trends show a small amounts of decline in unburnt areas, and some vegetation associations show areas of gain over 10 percent. The declines observed in burnt vegetation could be due to the initial impact of the fire; however some areas display an enduring effect as seen in the Fire section of this report. Field visits of fire impacted vegetation associations could be useful in determining recovery.



	Unattributed	Banksia low open forest	C.graniticus closed heath	Coastal	Creekline	Creekline ? need to check	Granite apron	Granitic apron	J/M open forest to woodland	Jarrah, Marri low open forest. Lateritic soil.	Jarrah, Marri low open forest. Loam soils.	Jarrah, Marri low woodland to open tree mallee	Jarrah, Marri low woodland to open tree mallee.	Jarrah, Marri open forest. Lateritic soil.	Jarrah, Marri open forest. Loam soils.	Mixed granitic closed low heath
Bare	0.62	0.47	0.11	0.60	0.12	0.05	0.37	0.00	0.22	0.14	0.10	0.04	0.04	0.13	0.08	0.12
Large gain	0.04	0.17	0.00	0.03	0.03	0.00	0.00	0.00	0.00	0.02	0.02	0.00	0.00	0.13	0.00	0.00
Gain	0.04	0.05	0.01	0.05	0.05	0.00	0.00	0.06	0.00	0.02	0.03	0.01	0.00	0.05	0.02	0.00
Stable	0.26	0.29	0.63	0.27	0.73	0.68	0.55	0.94	0.76	0.63	0.51	0.83	0.52	0.65	0.78	0.60
Loss	0.02	0.01	0.16	0.02	0.03	0.18	0.08	0.00	0.01	0.07	0.13	0.05	0.20	0.02	0.05	0.24
Large loss	0.02	0.02	0.09	0.02	0.04	0.09	0.00	0.00	0.01	0.12	0.21	0.07	0.24	0.02	0.06	0.05



	Unattributed	C.graniticus closed heath	Coastal	Creekline	Creekline ? need to check	Granite apron	Granitic apron	J/M open forest to woodland	Jarrah, Marri low open forest. Lateritic soil.	Jarrah, Marri low open forest. Loam soils.	Jarrah, Marri low woodland to open tree mallee	Jarrah, Marri low woodland to open tree mallee.	Jarrah, Marri open forest. Lateritic soil.	Jarrah, Marri open forest. Loam soils.	Mixed granitic closed low heath	Mixed granitic closed low heath.
Bare	0.04	0.09	0.28	0.09	0.05	0.29	0.00	0.16	0.17	0.05	0.03	0.04	0.06	0.05	0.12	0.07
Large gain	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.02
Gain	0.04	0.01	0.18	0.04	0.00	0.00	0.06	0.00	0.02	0.01	0.01	0.00	0.04	0.03	0.00	0.03
Stable	0.90	0.63	0.53	0.74	0.67	0.61	0.94	0.81	0.57	0.52	0.84	0.52	0.75	0.76	0.59	0.68
Loss	0.02	0.17	0.01	0.05	0.19	0.10	0.00	0.01	0.08	0.15	0.05	0.20	0.04	0.05	0.24	0.07
Large loss	0.00	0.10	0.00	0.08	0.09	0.00	0.00	0.01	0.16	0.26	0.08	0.24	0.08	0.10	0.05	0.12



	Unattributed	Banksia low open forest	C.graniticus closed heath	Coastal	Creekline	Creekline ? need to check	Granite apron	Granitic apron	J/M open forest to woodland	Jarrah, Marri low open forest. Lateritic soil.	Jarrah, Marri low open forest. Loam soils.	Jarrah, Marri low woodland to open tree mallee	Jarrah, Marri open forest. Lateritic soil.	Jarrah, Marri open forest. Loam soils.	Mixed granitic closed low heath	Mixed granitic closed low heath.
Bare	0.62	0.47	0.31	0.67	0.15	0.00	0.60	0.01	0.74	0.09	0.29	0.21	0.14	0.11	0.00	0.05
Large gain	0.04	0.17	0.04	0.04	0.04	0.00	0.00	0.00	0.00	0.07	0.10	0.00	0.15	0.00	0.06	0.01
Gain	0.04	0.05	0.00	0.02	0.07	0.00	0.00	0.03	0.02	0.03	0.09	0.06	0.05	0.00	0.00	0.05
Stable	0.26	0.29	0.59	0.22	0.72	1.00	0.37	0.96	0.24	0.77	0.47	0.71	0.63	0.81	0.94	0.86
Loss	0.02	0.01	0.05	0.03	0.01	0.00	0.03	0.00	0.00	0.04	0.03	0.01	0.02	0.05	0.00	0.02
Large loss	0.02	0.02	0.00	0.03	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.02	0.00	0.02

Figure 11: Vegetation associations and trend classes 1988-2015. Top: burnt and unburnt vegetation included, middle: burnt vegetation only, bottom: unburnt vegetation only. Note the vegetation association descriptions are exactly as they appear in the provided mapping.

Phytophthora dieback

Phytophthora dieback is known to occur in Meelup Regional Park and boundaries of the dieback infested and non-dieback infested areas have been supplied. In long unburnt areas of Banksia woodland on the Gnangara mound Landsat imagery has effectively shown vegetation loss due to phytophthora dieback (Wilson et al., 2012). However due to the relatively slow spread of phytophthora dieback of metres per year compared to impacts such as fire or weed invasion the time series of Landsat 30m pixels is too large to distinguish this variety of impacts on vegetation cover. Figure 12 displays the long term trends 1988 to 2015 over Meelup Regional Park in the dieback infested areas only. When a fire has occurred in the time series these areas cannot be assessed for dieback impacts, in Figure 12 fire affected areas are indicated with an orange outline, yellow outlines indicate areas not mapped as burnt from the annual Landsat time series.

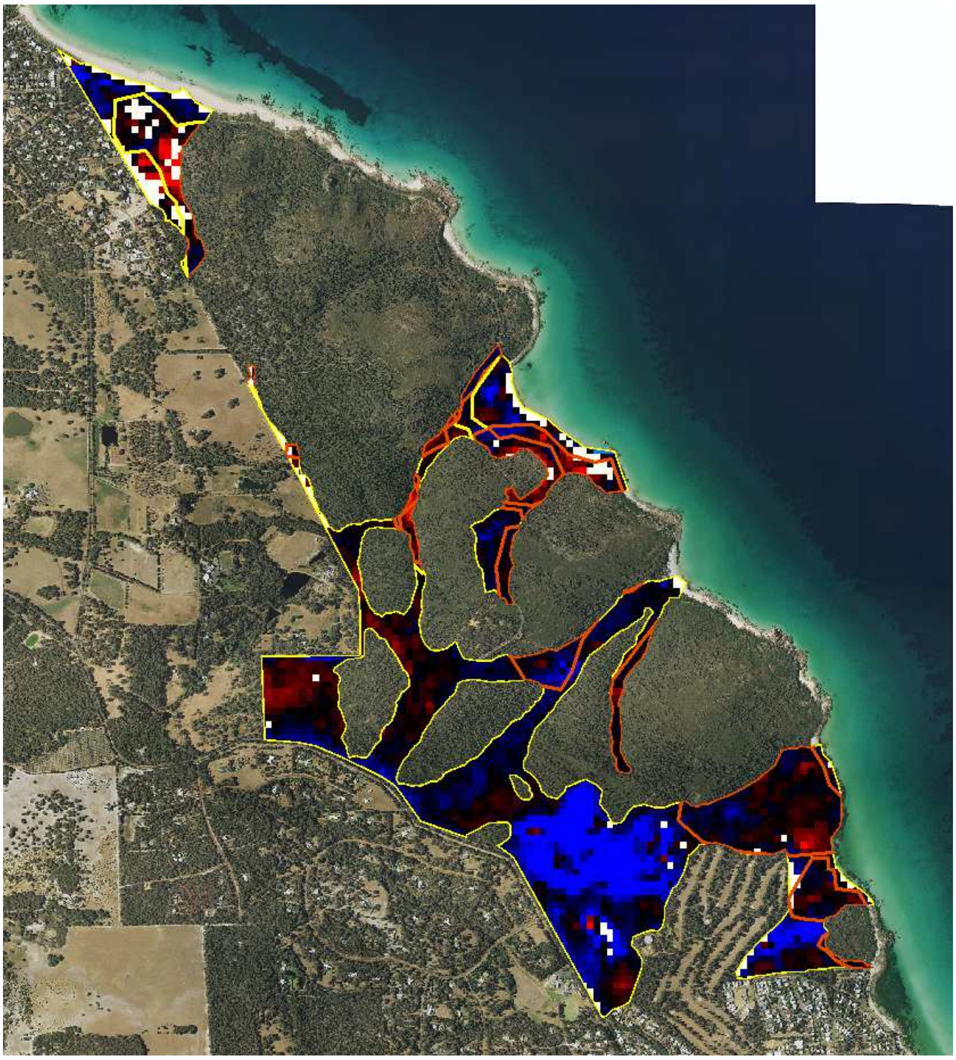
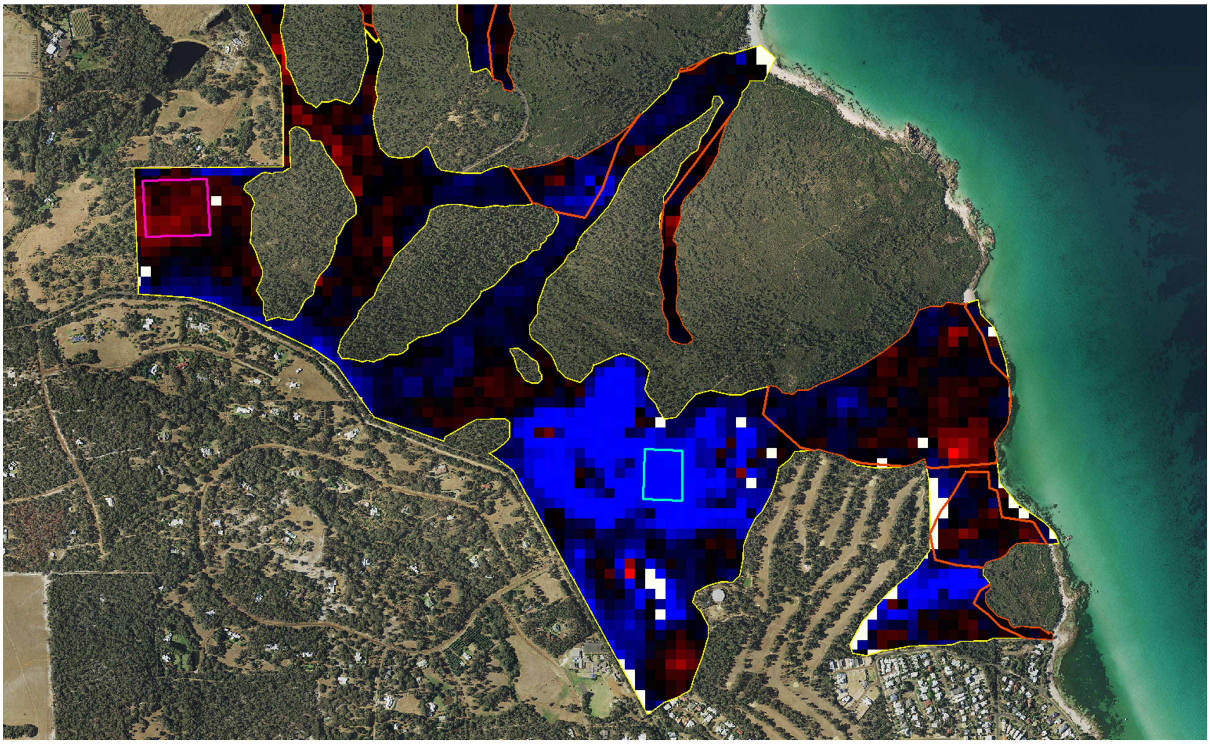


Figure 12: Phytophthora infested areas in Meelup Regional Park shown with the 1988-2015 trend image, red areas have declining vegetation cover, blue areas increasing vegetation cover, black areas and stable and white areas are non-vegetated areas. Locations with a yellow outline have not been burnt in the time period and locations in the orange outline have been burnt.

Only a few areas are unburnt and have a distinctive vegetation cover trend to investigate, in Figure 13 two areas have been queried for their vegetation history. The area showing a large increasing trend (blue outline) is a former tip area that now has substantial vegetation cover. The other area (pink outline) is in a location of Jarrah Marri open forest on lateritic soil. This location appears to have large variations in vegetation cover but since 1998 has not reached higher levels of cover previously obtained.



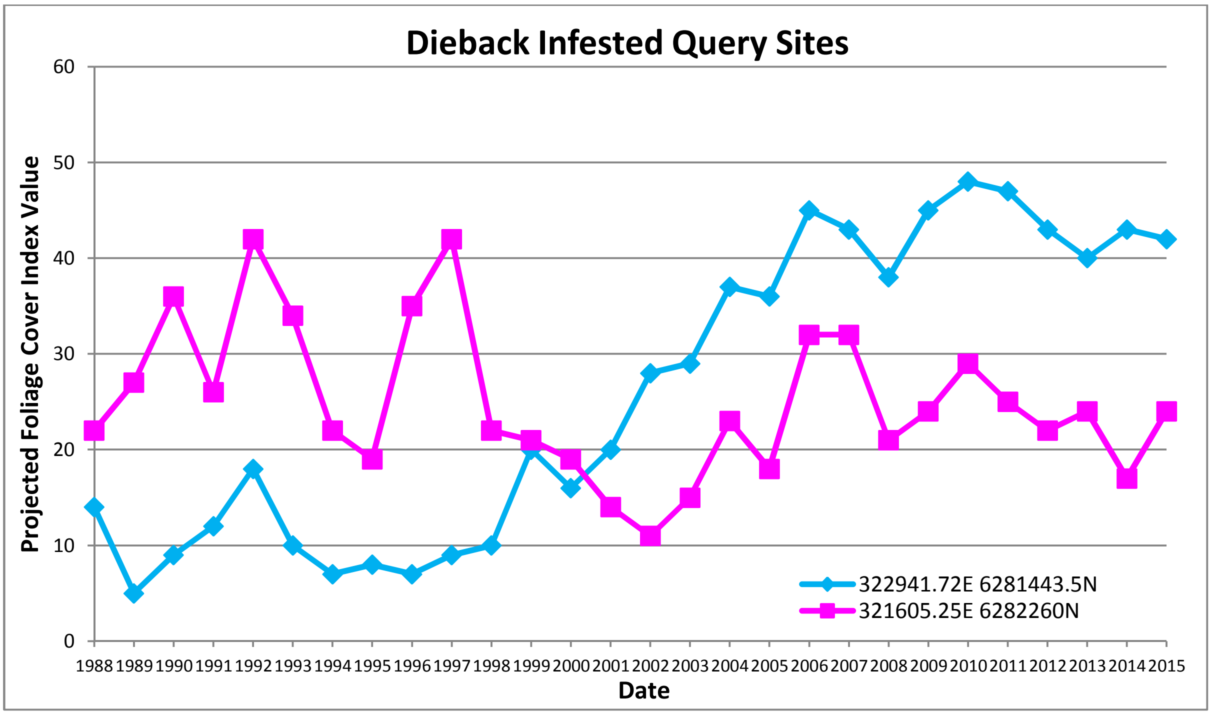


Figure 13: Phytophthora dieback infested areas with query locations and vegetation cover time series graph. Top image displays the query locations in pink and blue on the 1988-2015 trend image, red areas have declining vegetation cover, blue areas increasing vegetation cover, black areas and stable and white areas are non-vegetated areas. Locations with a yellow outline have not been burnt in the time period and locations in the orange outline have been burnt.

Small area changes

Observations of declines in *Agonis flexuosa* have been observed along the coast of Meelup Regional Park (Mandy Polley 2015 pers. comm. 18 May) and locations of observations provided. The areas are too small to confidently attribute changes to the vegetation using the Landsat 30m pixels, however the Landsat data can provide the landscape context. The provided ECW's of the various trend images and each image date enable investigation of these areas, these are especially useful in the field when used with a GPS mapping program e.g. OziExplorer, QGIS. The locations surrounding the observed areas of decline are shown on the November 2004 (0.5m pixel, 1:25 000 scale) and November 2013 (0.1m pixel, 1:16 000 scale) aerial photography (Figure 14). These images demonstrate what is detectable at different pixel resolutions and enables examination of these locations over the intervening time period.

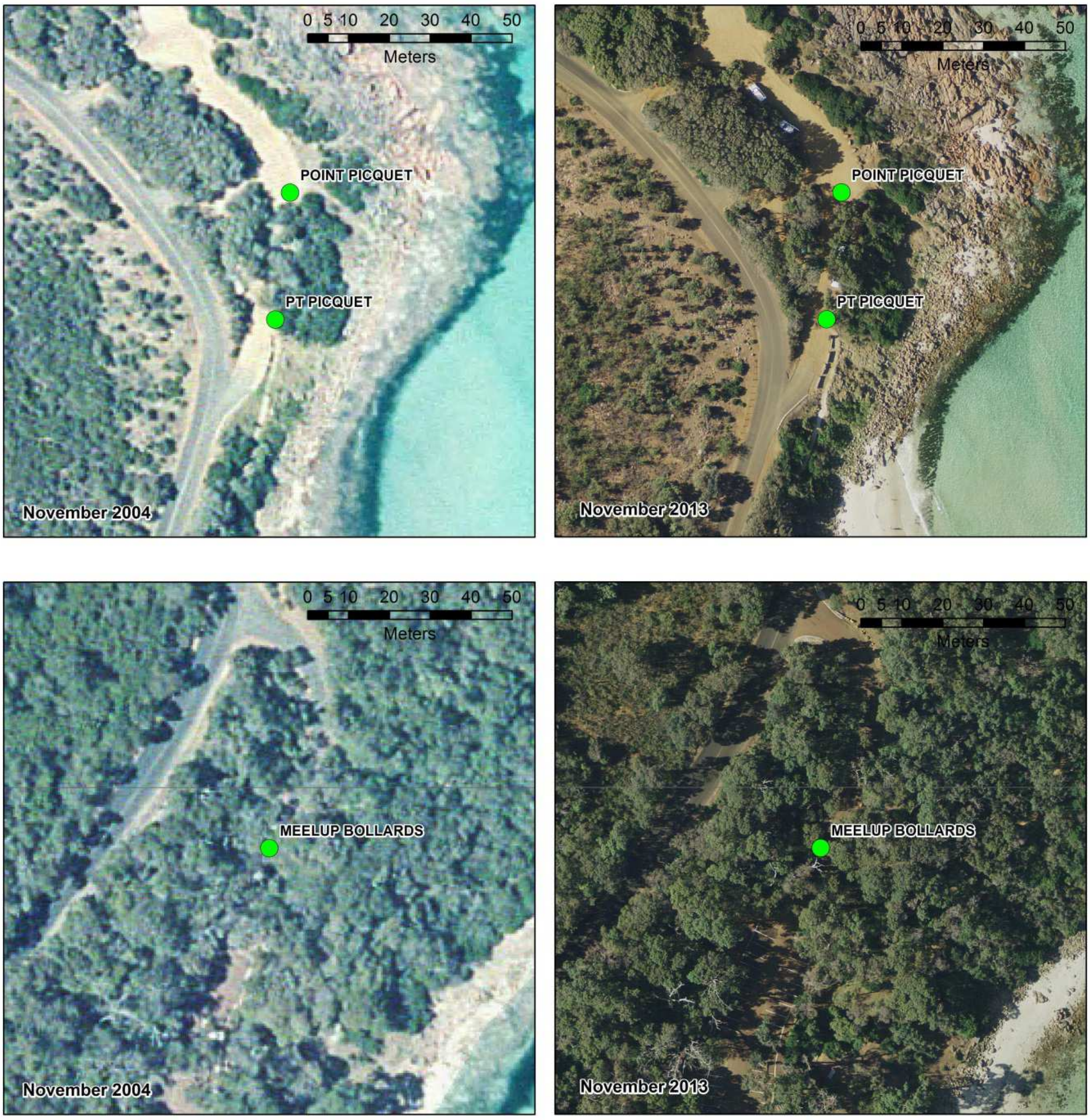


Figure 14: Locations of *Agonis flexuosa* observed declines displayed on November 2004 (0.5m, 1:25 000) and November 2013 (0.1m, 1:16 000) aerial photography.

Higher resolution imagery is required to identify individual canopy loss. This requires strict controls on the time of day the imagery is captured, ideally two hours either side of midday, and then applying the same controls to the repeat capture. This avoids issues with different shadows and capture angles.

The declared rare flora Meelup Mallee (*Eucalyptus phylacis*) occurs in Meelup Regional Park. One of the locations of this species was provided by the local DPaW flora conservation officer. The location is confidential and thus only the graph of the vegetation cover over time is provided (Figure 15). The graph shows the effects of a fire visible in the 2006 imagery and subsequent recovery. Comparison of the 2004 and 2013 aerial photography in this area appears to show that previously bare areas now have been populated with vegetation possibly from the adjacent low heath. It is unclear whether the fire enabled post fire colonisers to germinate in this area. This may be an example where increasing vegetation cover does not indicate recovery of the previously occurring vegetation species.

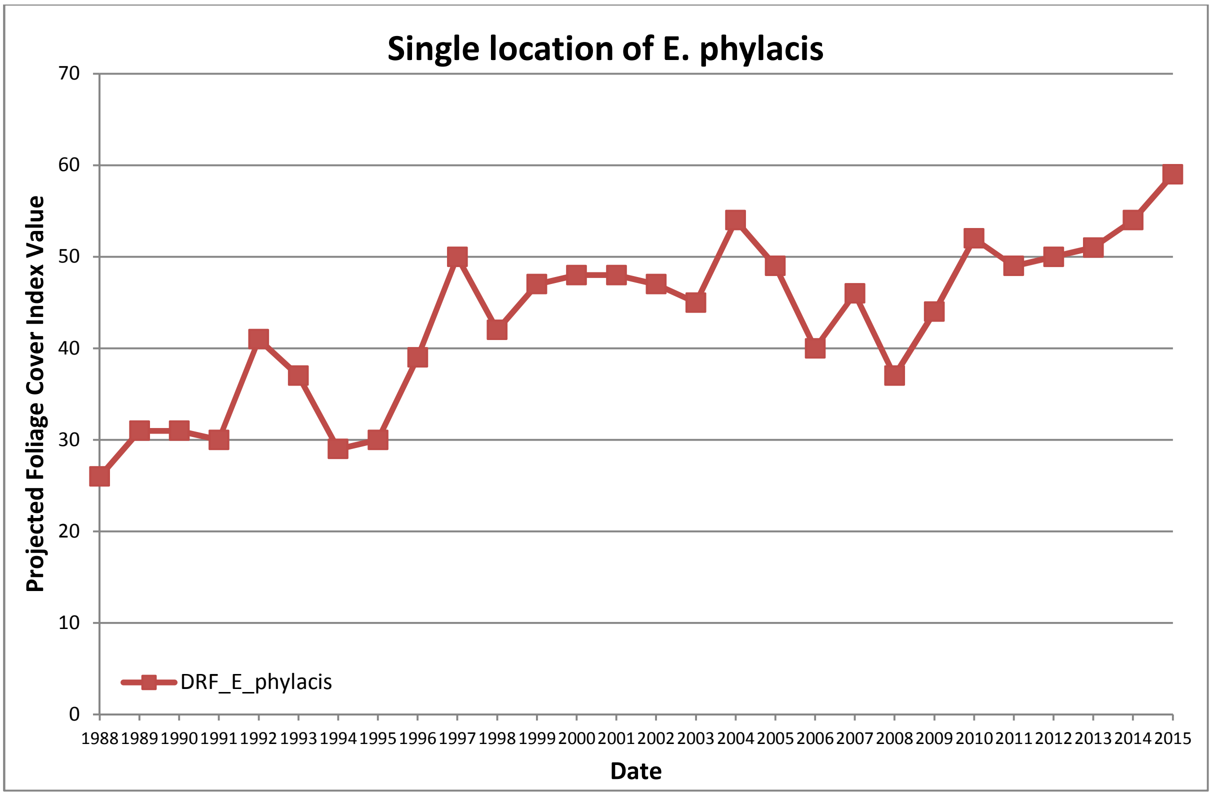


Figure 15: Vegetation cover time series graph of a single location of Meelup mallee (*E. phylacis*).

Possible future image analysis

The following section identifies some applications and extended analysis of using imagery. This includes Landsat imagery and airborne high resolution imagery. This section provides suggestions that would require more complete scoping to develop.

High resolution imagery for the capture of high value assets: If the detection of individual canopy loss is a high priority then high resolution digital imagery is needed. This imagery would need at a minimum, four spectral bands including the blue, green, red and near infrared bands. A benchmark date image is required for change analysis and the State government captures of aerial photography may be suitable for further processing to enable its use for canopy loss detection. However these images are not captured with ideal controls on capture dates and time of day. The technology to process this type of imagery does exist but rigorous capture and pre-processing protocols need to be followed to get the best quality result. Figure 16 displays and example of high resolution imagery used to examine vegetation change over three dates in a ten year period.

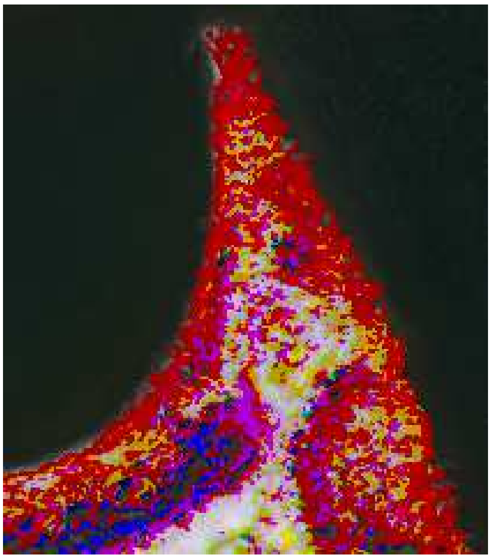


Figure 16: Example of 1m resolution imagery three date change detection. Red are areas with vegetation present in date 1 and gone by date 2, yellow areas have vegetation in date 1 and date 2 but lost in date 3, magenta areas have vegetation in date 1 and date 3 and not date 2 (this was due to flooding), blue areas are new vegetation in date 3 and white areas are stable vegetation.

Fire planning: Understanding the historical vegetation cover and recovery from high intensity fires can aid in planning fire management actions. Some areas burnt in the 2000's are still at half pre fire vegetation cover levels. The planned returned fire interval for these areas may need to be extended in this case. Also areas that show a large increase in vegetation cover require investigation may indicate a need for earlier planned fire management. Any fire planning should use field visits to determine fuel levels as this analysis does not provide any information regarding fuel loads.

Dense Landsat time series analysis: The presented analysis looked at annual changes in vegetation cover. This approach is useful in that dry season imagery reduces the inclusion of annuals in the vegetation cover and trend analysis showing changes in perennial vegetation can be applied. However to examine the changes within a year, at different times of year or seasons, then more dates of imagery are required. Obtaining every cloud free Landsat image during the year and extracting the vegetation cover requires different tools to find changes. A methodology can be applied to monitor vegetation cover at monitoring point plots adapted from Zhu et al., (2012), who used all available Landsat imagery to detect forest disturbance at high temporal frequency. Statistical analysis can be applied to find time periods when the vegetation cover varies from the previous dynamic and can be useful to compare changes before and after management actions such as feral removal and fencing. This does not give the landscape context of the annual trend imagery but gives insight into the vegetation dynamics throughout the year and how these have changed over time in areas of interest.

VegMachine install and training: VegMachine is an easy to use program developed for pastoralists to examine time series Landsat data (Karfs et al., 2004). It can easily be adapted to show the data produced by this analysis and enable interactive use. Locations can be queried and the vegetation cover history shown in a graph display. Figure 17 shows a trend image calculated using image dates between 1988 and 2015 displayed in the program VegMachine. The graph in Figure 17 shows two inquiry areas corresponding to a red area and a blue area in the image. The timing and nature of the vegetation change is different at each site. The fire in the orange site appears to have occurred in

2006 and has continued to slowly decline, this can be confirmed by looking at the image sequence. The blue site appears to have been increasing in vegetation cover in the period 1997-2003 before stabilising in cover.

If there is interest in using this program then installation on an appropriate computer, training and support will be required. This cost has been included as an extra cost in the Schedule of Rates section in the original tender.

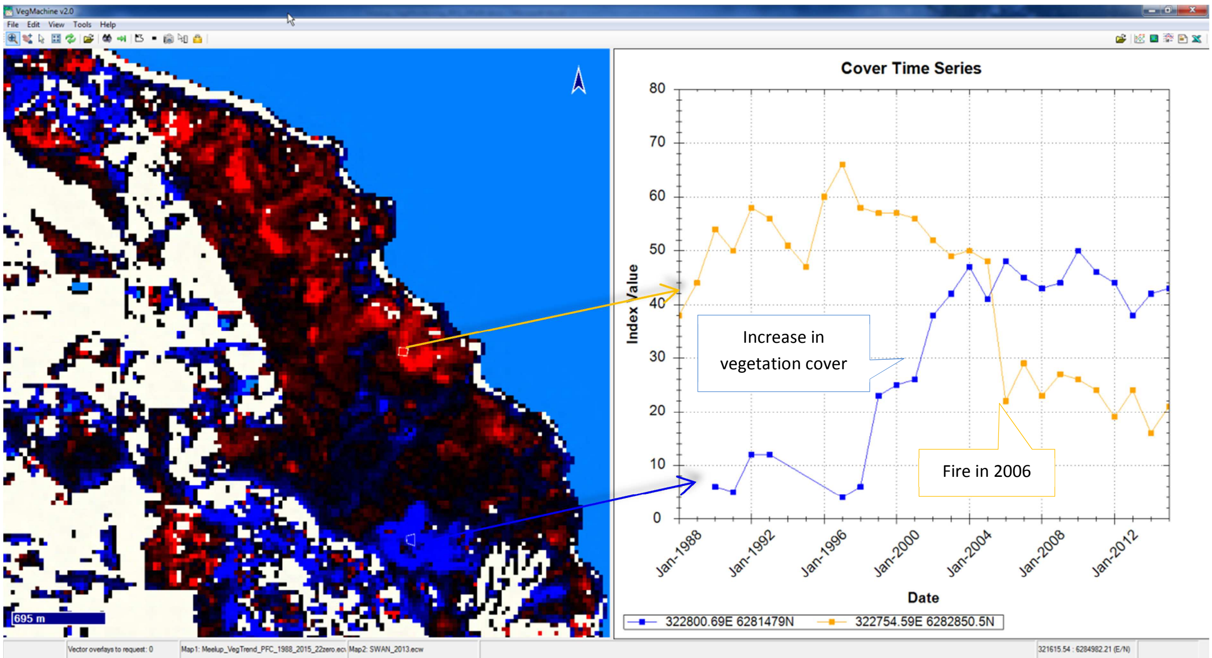


Figure 17: VegMachine display of trend image and graph. Trend image uses all image dates between 1988 and 2015; red indicates loss of vegetation cover, blue indicates a gain in vegetation cover. The light blue is a water mask and the cream colour a non-perennial vegetation mask. The graph shows variations in vegetation cover using image dates from 1988 to 2015.

Conclusion

The historical analysis of vegetation cover in Meelup Regional Park has shown how the vegetation responds to different rainfall and fire regimes. In the years prior to 2000 the average annual rainfall was higher and it appears that there were less intense fires (2) covering a smaller area. In the post 2000 period the rainfall is significantly lower and greater number of fires (6) covering the majority of the park.

The current rainfall and fire regime has implications for fire management planning and phytophthora dieback mitigation efforts. In theory phytophthora dieback should be slowed in a lower rainfall regime and lower vegetation density as movement via water and root to root contact is reduced. However this supposition would need to be verified with field measurements of phytophthora dieback front movements, and may not hold along drainage lines. Fire management planning can take into the vegetation association and the time since last burn to aid in ensure fire return intervals are appropriate, this should always take into account current fuel levels. The current fire and rainfall regime may impact weed management as different weed species may thrive in these conditions, or the increased bare ground provides greater opportunity for growth.

The trend and annual images provide an interactive tool to investigate different locations in the park and give a landscape view of Meelup Regional Park vegetation cover over the last 27 years. This context is invaluable when analysing point location information or more recent high resolution aerial imagery.

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Data Delivery

Datum and projection: GDA 94 MGA50

Date delivered: 17/06/2015

Contact: Katherine Zdunic/Bart Huntley, Remote Sensing and Spatial Analysis Section, GIS Branch, Department of Parks and Wildlife Western Australia, 17 Dick Perry Avenue, Kensington. Katherine.Zdunic@dpaw.wa.gov.au, Ricky.VanDongen@dpaw.wa.gov.au

Dataset Delivered	**Format**	**Description**
FireScars_from_AnnualLandsatImagery_1988_2015_polygons.shp	ESRI shapefile	Fire scar outlines 1988-2015 identified from annual Landsat imagery used in the vegetation monitoring. The date attribute refers to the date of imagery the fire scar was identified in and not the date of the fire ignition.
LandsatImages (folder)	ECW	False colour display enhancements of each Landsat image date used in the time series analysis. Landsat bands 5, 4, 3 in a red, green, blue display.
Photos_150218 (folder)	JPEG	Field photos divided into sites, downward (nadir), upward (zenith) and site photos. These are referenced in the ESRI geodatabase Meelup_FieldData_150218.gdb.
Meelup_FieldData_150218.gdb	ESRI file geodatabase	Contains field data collected on each plot and at each point within the plots.
Meelup_FieldData_150218_MetaData.docx	Word 2010	Metadata document describing fields in the ESRI geodatabase Meelup_FieldData_150218.gdb.
TrendDisplay (Folder)	ECW	Displays of vegetation trends over different time periods, red indicates loss, blue areas gain and black stable. Cream and light blue areas are non-vegetated and water areas respectively.
TrendClass (Folder)	ESRI shapefile	Trend class boundaries within Meelup Regional Park for four time periods. Gridcode field indicates trend class category indicated below: 0 – Bare/masked areas 1 – Large gain 2 – Gain 3 – Stable 4- Loss 5 – Large loss
MeelupRegionalPark_RSAnalysis_Jun2015.pdf	PDF	This report document