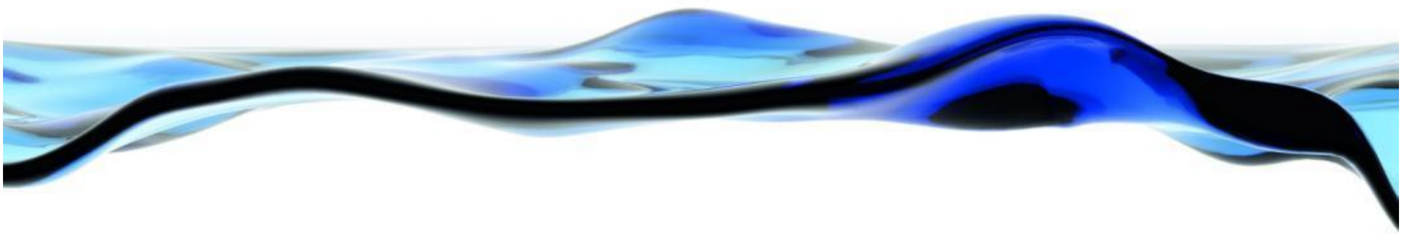
Developing ecological response models and determining water requirements for wetlands in the South-East of South Australia

Temporal Wetland Phenology, Inundation and Vegetation Communities

Ken Clarke, Megan Lewis and Michelle Clark



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Section 1: Executive summary

1.1 Background

This report is part of the report series arising from Goyder project E.2.5, Water requirements for wetlands in the South East of South Australia. The aim of the overall project was to provide insight into wetland temporal behaviour, to support water management and resource allocation planning in the South East.

1.2 Aims

The aim of this project component, Task 3, was to improve our understanding of the historic temporal behaviour of wetland vegetation and inundation, and to determine whether there have been changes in wetlands in the south east. All components of this task utilise either remotely sensed data, either satellite imagery or aerial photography.

This task was broken in to the following objectives:

- 3.1 **Characterise wetland phenology** (greenness) and trends in phenology and inundation at a landscape scale (from MODIS imagery for the period 2000 to end 2013)
  - **3.1.1 Trends and breaks in temporal greenness and inundation**
  - **3.1.2 Temporal greenness clustering**
- 3.2 **Map the temporal inundation extent for 20 case study wetlands** (from Landsat imagery for the period 1991 to 2012), and
- **3.3 Map the changes in vegetation communities from 1969 to 2013 for four case study wetlands**

1.3 Outcomes

1.3.1 Characterise trends and breaks in wetland temporal greenness and inundation

Temporal greenness and inundation profiles were extracted for 20 case study wetlands and average seasons, long-term trends, and any significant breaks in those trends were quantified. This component revealed that most wetlands in the South East experienced reductions in greenness and inundation from 2003/04 to 2006/07, and then an increase in greenness and inundation until 2011, and then another decrease in greenness and inundation from 2011 to the end of 2013. This component has also provided more detailed insight into the inter- and intra-annual pattern of inundation and greenness for the case study wetlands and the region as a whole.

1.3.2 Temporal greenness clustering

A data-driven clustering of the landscape into areas of similar temporal greenness behaviour was conducted. This allowed examination of the average seasonal greenness of wetlands and other major land cover types in the south east; and allowed identification of areas of the landscape with similar temporal greenness behaviour to known wetlands. This analysis revealed that, when looking at the landscape as a whole, the case study wetlands had a similar temporal greenness signal to the suburban areas of Mt Gambier, much of the vineyards in the Coonawarra area, some swale areas throughout the south east, and large areas of relatively exposed soils in north east of the study area, east of Padthaway. Examination of average seasonal greenness profiles revealed that the wetlands class was amongst the lowest; greener than coastal dune vegetation, but lower greenness than forestry, native woody vegetation, irrigated pasture, and non-irrigated agriculture (except in summer, where non-irrigated agriculture is lower greenness).

1.3.3 Map temporal inundation extent for 20 case study wetlands

This component aimed to map temporal inundation extent across the whole of the south east once every summer and winter from 1990 to present. However, cloud cover presented clear image acquisitions in some summers, and many winters. This component illustrated the large range of natural intra- and inter-annual variation in inundation extent over the whole South East; and revealed how much inundation can occur in wet years (e.g., 2054 ha in 1992) and comparatively how little inundation there was in the Millennium Drought (e.g., 155 ha in 2006).

1.3.4 Map changes in vegetation communities from 1969 to 2013 for four case study wetlands

Vegetation community extent was mapped in 1969 and 2013 for three case study wetlands, and for 1969, 1982, 2008 and 2013 for another case study wetland. Vegetation communities were then given a wetness ranking, and the area and type (wetting, drying or static) of all mapped changes were documented. This component revealed that there was a significant change from wetter vegetation communities in 1969 to dryer vegetation communities in 2013, and a significant increase agroforestry in the immediate vicinity of all four wetlands. This increase is likely to indirectly reduce water availability for vegetation in these wetlands through increased evapotranspiration and interception.

Section 2: Introduction

The overall aim of Task 3 of the Goyder Institute research project E.2.5 was to improve our understanding of the historic temporal behaviour of wetland vegetation and inundation, and to determine whether there have been changes in wetlands in the south east. All components of this task utilise either remotely sensed data, either satellite imagery or aerial photography.

The specific objectives of Task 3 were to

3.1 Characterise wetland phenology (greenness) and trends in phenology and inundation at a landscape scale
3.2 Map the temporal inundation extent for 20 case study wetlands, and
3.3 Map the changes in vegetation communities from 1969 to 2013 for four case study wetlands

Task 3.1 was further broken down into

Analysis 1 Trends and breaks in temporal greenness and inundation
Analysis 2 Temporal greenness clustering

The first component of objective 3.1, Analysis 1, extracts temporal greenness and inundation profiles for 20 case study wetlands and then quantifies the average seasons, long-term trends, and any significant breaks in those trends. This provides insight into past temporal greenness and inundation behaviour across the region as a whole, and for individual wetlands.

The second component of objective 3.1, Analysis 2, is a data-driven clustering of the landscape into areas of similar temporal greenness behaviour. This allows examination of the average seasonal greenness of wetlands and other major land cover types in the south east; and allows identification of areas of the landscape with similar temporal greenness behaviour to known wetlands.

Objective 3.2 aimed to map temporal inundation extent across the whole of the south east once every summer and winter from 1990 to present. However, cloud cover prevented clear image acquisitions in some summers, and many winters.

Finally, objective 3.3 maps vegetation community extent in 1969 and 2013 for three case study wetlands, and for 1969, 1982, 2008 and 2013 for one more case study wetland. Vegetation communities are then given a wetness ranking, and the area and type (wetting, drying or static) of all mapped changes were documented.

Section 3: Methods

3.1 Task 3.1 – Wetland phenology

The goal of this task was to characterise wetland temporal greenness and inundation response at a landscape scale. We have employed hyper-temporal MODIS imagery (319 image dates) to allow examination of intra- and inter-annual patterns. The MODSI NDVI was used to examine greenness, and MODIS band 5 (mid-infrared reflectance) was used as a surrogate of inundation.

Outputs include graphs of variation of greenness and inundation over time, including identification of any trends and major breaks from trends; and a classification of the landscape into areas or land covers which have exhibited similar historical temporal greenness (NDVI) pattern, and characterisation of the "average season" of each of these land covers.

3.1.1 Data: MODIS satellite imagery

The Moderate Resolution Imaging Spectroradiometer (MODIS) is a satellite remote sensing instrument operated by NASA. The MODIS sensor records reflectance in 36 spectral bands ranging from 0.4 µm to 14.4 µm, and in spatial resolutions ranging from 250 m to 1000 m. Two copies of the instrument are operational at the time of writing, onboard the Terra and Aqua polar-orbiting satellites, and each images the entire Earth surface every 1 to 2 days. In addition to supplying raw MODIS reflectance data, NASA produces several highly validated MODIS image products, including the MOD13Q1 vegetation indices product used in this project.

This project used two MODIS products, the MOD13Q1 Normalised Difference Vegetation Index (NDVI) product, and the MCD43A4 Nadir Bidirectional Reflectance Distribution Function (NBAR) product.

The NDVI product is produced at 250 m resolution, and is a cloud-free composite image product available every 16 days. The NDVI is based on the contrast between red and near infra-red reflectance, and the differential reflectance in these two regions of green vegetation versus other land cover types. The index is formulated so that strongly growing vegetation produces high NDVI values, up to 0.8 index value, while dead vegetation or exposed soil produce low NDVI values of approximately 0.2, and open water can result in NDVI values of 0 or lower.

The NDVI product is a composite product, produced from multiple images rather than a single image acquisition. The compositing process evaluates all MODIS imagery of a given area within a 16 day period and assigns each image element (pixel) a quality value, with higher values given to cloud free pixels and pixels near to nadir (looking directly down) view angle. The final composite MODIS image is made up of a weighted average of the best quality pixels over the 16 day period

The Nadir Bidirectional reflectance distribution function Adjusted Reflectance (NBAR) product is also a composite product based on 16 days of MODIS imagery. The product is an estimate of nadir reflectance (looking straight down), and is modelled using a bidirectional reflectance distribution function (BRDF), a method that reduces geometric effects on reflectance. This method minimises geometric effects on reflectance that result from incorporating imagery acquired at a range of view angles over the 16 day compositing period. The NBAR product was obtained for Band 5, which records mid infra-red reflectance, and was used as a surrogate for degree of inundation. Radiation in the mid infra-red portion of the spectrum is strongly absorbed by water, and moderately to strongly reflected by other land surface covers.

Complete temporal coverage of both the NDVI and NBAR products were acquired for the study area from the start of the MODIS archive (18 February 2000) to the end of 2013. In total 319 NDVI and 319 NBAR images were acquired and analysed in this project.

3.1.2 Analysis 1: Temporal greenness and inundation

For the 20 case study wetlands mean NDVI (as an indicator of greenness) and mean NBAR Band 5 reflectance (as an indicator of magnitude of inundation) were extracted for every image date. The South Australian Wetland Inventory Database (SAWID) extent for each wetland was used to delineate wetland extent, and NDVI and Band 5 values within each SAWID polygon were extracted. This produced a temporal series of NDVI and Band 5 describing the temporal pattern of greenness and inundation, respectively, for each case study wetland.

These temporal profiles were then decomposed into time series of season, trend and remainder with the Breaks For Additive Season and Trend (BFAST) method (Verbesselt et al. 2010). This method identifies the average season in the time series, calculates cumulative deviation from average season (trend), and allows identification of significant breaks in trend that may be indicative of significant climatic or management changes.

3.1.3 Analysis 2: Temporal greenness clustering

All 319 MODIS NDVI images from 2000 to 2013 were combined into one multi-band image file, and subsetted to cover just the lower South East of South Australia. An ISOCLASS unsupervised classification was then used to classify pixels into groups of similar temporal greenness (NDVI) pattern over the 2000 to 2013 period. We found that 20 classes captured all major temporal greenness patterns within the study area. Each class was then examined in relation to historical and current Landsat and Google Earth imagery, and its land cover type described.

Next, the “average season” NDVI profile was calculated for all classes. This was accomplished by vectorising each class then extracting mean NDVI for each class from each image date. Next, the mean NDVI for each class was calculated for each image-day across all image years (e.g., mean NDVI for the January 1st image, or image day 001, was calculated as the class mean NDVI for image 2001-001, 2002-001, 2003-001… 2013-001; mean NDVI for the January 17th image was calculated as the class mean NDVI for image 2001-017, 2002-017, 2003-017… 2013-017; and so on for all 23 annual image days). Finally, the “average season” NDVI per-class profiles were plotted to allow visualisation of the onset of greenness, magnitude of greenness, and end of senescence for each land cover class.

3.2 Task 3.2 – Wetland temporal inundation extent

The goal of this task was to map the temporal inundation extent for wetlands selected in Task 1. To accomplish this, we have analysed Landsat 5 and 7 imagery. Specifically, the following method utilised band 5 (mid-infrared reflectance) which is particularly sensitive to water absorption. Outputs included inundation extent images and maps.

3.2.1 Data: Landsat 5 and 7 imagery

The Landsat 5 and 7 satellites carry the Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) sensors. Both the TM and ETM+ sensors have seven identical spectral bands with the same numeric designation which record reflectance from the blue (Band 1), through green (Band 2), red (Band 3), near-infrared (Band 4), mid-infrared (Bands 5 and 7), and the far-infrared, or thermal infrared (Band 6) parts of the electromagnetic spectrum. Spatial resolution is 30 m for Bands 1-5 and 7, and 60 m for Band 6.

This project used georectified Level 1 GEOTIFF Landsat imagery downloaded from the USGS Global Visualisation Viewer (GLOVIS) data portal[1]. Three Landsat scenes were required to cover the study area, Path 95 Row 86, Path 96 Row 85, and Path 96 Row 86. We aimed to acquire one wet season and one dry season image for each year covered by the USGS image catalogue (1991 - 2012). However, cloud cover sometimes prevented acquisition of one or more scenes for either the wet or dry season, or both seasons within a given year. In total 126 images were acquired and analysed. The matrix of covered year and season is presented in Table 1.

3.2.2 Analysis: Temporal inundation extent from Landsat satellite imagery

Inundation extent was mapped by density slice classification of Landsat Band 5 (mid infra-red)(*e.g.* Thomas et al. 2011). This method exploits the spectral characteristics of water which absorbs mid infra-red radiation very strongly. In contrast, other land cover types all reflect moderately to strongly in the mid infra-red.

On each image date Band 5 was examined and a threshold value was chosen such that known inundated areas (Lakes Eliza and George in the study region) and known non-inundated areas (nearby coastal dunes) had reflectance values below and above the threshold respectively. A threshold classification was then performed on the whole image with the result that areas with reflectance values below the threshold were mapped as inundated, and areas with reflectance values above the threshold were mapped as dry.

[1] http://glovis.usgs.gov/

Table 1. Year and rainfall season covered by acquired Landsat imagery for inundation extent mapping.

Year	Season	Image month
1991	Dry	Feb
1992	Wet	Aug
1992/1993	Dry	Dec/Jan
1993	Wet	July
1994	Dry	Jan/Feb
1995	Dry	Feb/Mar
1997	Dry	Feb
1999	Dry	Jan
1999	Dry	Dec
2000	Wet	Jun
2001	Wet	Jul
2002	Dry	Dec
2003	Dry	Apr
2005	Dry	Jan
2005	Wet	Jul
2006/2007	Dry	Dec/Jan
2007	Wet	Aug
2008	Wet	Jul
2009	Dry	Jan
2009	Dry	Dec
2010	Dry	Apr/May
2011	Wet	Jun/Jul
2012	Dry	Feb
2012	Wet	Jul/Aug

3.3 Task 3.3 – Change in vegetation community over time

The goal of this task was to map changes in vegetation communities from 1960 to 2013 for four selected case study wetlands, Deadmans Swamp, The Marshes, Topperwein and Trail Waterhole. These wetlands were chosen because they were known to have experienced significant increases in depth to groundwater in the 1980s. It was unknown whether the increase in depth to groundwater had resulted in a reduction in water available for wetland vegetation, and a consequent change in vegetation community.

Vegetation was mapped to a community scale by visual interpretation of historical aerial photography, supported by field data. The mapped vegetation communities for each wetland and mapping date were then assessed by ecologists Jason Nicol and Susan Gehrig and given a relative 'wetness' ranking. Finally, the mapped vegetation communities were compared across time, and combined with the wetness ranking information to allow tabulation of change in vegetation community wetness over time.

Outputs include the vegetation community classification spatial layers and the tabulated change in vegetation community/wetness across time.

3.3.1 Data: Aerial photography

Archival aerial photography coverage of the four focal wetlands, The Marshes, Deadmans Swamp, Trail and Topperwein from the Department of Environment, Water and Natural Resources (DEWNR) to enable mapping of change in vegetation communities. Imagery from 1969 and 1980 was scanned at 800 dpi by DEWNR staff and delivered as un-geocoded digital files. Imagery from 2008 and 2013 was already in digital ortho-rectified image format, and was delivered as is. The spatial and spectral characteristics of the imagery varied by year and location (Table 2).

The un-geocoded 1969 and 1980 imagery was georectified to the 2008 ortho-rectified aereal imagery in ERDAS Imagine. Where possible hard-edged right angled temporally invariant features where chosen as ground control points. When these features were not available less ideal features were chosen. All georectifications were of a high quality, and achieved a RMSE of better than 2 pixels.

Table 2. Spatial and spectral characteristics of aerial photography by wetland and year.

Location	Year	Spatial resolution	Spectral characteristics
Deadmans Swamp	1969	2.00 m	B&W
	1982	3.35 m*	RGB
	2008	0.90 m	RGB
	2013	0.50 m	False colour IR
The Marshes	1969	3.35 m*	B&W
	2013	0.50 m	False colour IR
Topperwein	1969	3.35 m*	B&W
	2013	0.50 m	False colour IR
Trail Waterhole	1969	3.35 m*	B&W
	2013	0.50 m	False colour IR

* Approximate ground resolution, calculated from a nominal photography scale of 1:67,000.

3.3.2 Analysis 1: Vegetation community classification from aerial photography

On each aerial photography date and for each focal wetland vegetation community extents were digitised by expert interpretation. The interpreter started with the 2013 imagery and defined visually interpretable vegetation cover classes based on colour, intensity, texture and pattern. These classes were linked to specific vegetation communities through a combination of consultation with field ecologists with good on-ground knowledge of the focal wetlands, by consulting existing vegetation community maps (where available) and field vegetation survey records, and a field visit to the focal wetlands. Visual keys for major cover types were created from the 2013 imagery, and were used throughout the mapping process to ensure consistency (Appendix 1).

Once the 2013 vegetation mapping was complete, the earlier dates (Table 2) were mapped using the same process (identification of visually distinct blocks, and consulting existing vegetation community maps and field vegetation survey records). For all four wetlands, pre 2013 imagery was lower fidelity (spatial and spectral resolution), and independent validating information was extremely limited or non-existent. Hence, mapped vegetation categories in these earlier epochs tend to be broader and should be interpreted with lower confidence.

All vegetation community mapping was conducted at a display scale of 1:6,000. Mapping was conducted over the extent of the wetland as defined by the SAWID database, and including a 1 km buffer outside this boundary to provide some landscape context.

3.3.3 Analysis 2: Quantifying change in vegetation community over time

Mapping of change in vegetation community over time required two major elements: that the area of each vegetation community on a first date was compared to the mapped vegetation communities on a second date, and the change (if any) be quantified. These comparisons were done for all mapped vegetation communities for Deadmans Swamp 1969 vs 1984, Deadmans Swamp 1984 vs 2008, Deadmans Swamp 2008 vs 2013, The Marshes 1969 vs 2013, Topperwein 1969 vs 2013, and Trail Waterhole 1969 vs 2013.

Additionally, for each wetland and image date ecologists Jason Nicol and Susan Gehrig provided interpretation of the relative ‘wetness’ of each mapped vegetation community, ranging from 0 (not wetland at all) to 10 (vegetation standing in permanent water).

Finally, matrices of change in vegetation community area (in m^2) were produced for each wetland date-pair, with vegetation communities sorted by wetness order to aid interpretation of any drying or wetting trend.

Section 4: Results

4.1 Task 3.1 – Wetland phenology

This section presents results which provide insight into the way vegetation vigour has varied over the 2000 to 2013 period for wetlands, and across the south east as a whole. Two major results are presented here: Analysis 1, an analysis of trends and breaks from these trends for vegetation vigour (as measured by MODIS NDVI) and inundation (as indicated by MODIS Band 5 reflectance), for 20 case study wetlands; and Analysis 2, a statistical clustering of MODIS NDVI over the whole of the south east into groups with similar temporal greenness pattern over the 2000 to 2013 period.

However, interpretation of Analysis 1 results (trend and breaks in vegetation vigour and inundation) requires an understanding of the limits of the method, and the specific responses of NDVI and Band 5 to vegetation and inundation. Hence, "caveats" and "interpretation" sections precede the Analysis 1 results proper.

4.1.1 Analysis 1: Temporal greenness and inundation, caveats

In performing these analyses we found that it was not possible to produce valid results for some wetlands, due to their proximity to the coast or their small size. A summary of Band 5 and NDVI pixel count, as well as notes on limits to interpretation is presented in Table 3.

Due to confounding effects of water, including sea-spray, coastal areas are masked out of the MODIS NDVI product. Temporal profiles were not produced for affected coastal wetlands (noted in Table 3 with a single asterisk (*)).

Due to small size (and hence few covering pixels) and periods of persistent cloud cover, there were some image dates for which NDVI or Band 5 reflectance was not recorded for some wetlands. We have still included the temporal profiles for these wetlands, and the zero-data dates can be seen in the data component (Yt) as zero values. However caution should be exercised in the interpretation of profiles for these wetlands, as especially the trend and break components may be skewed.

Results for small wetlands with very few covering pixels should be treated with some caution. There are inherent limits to the horizontal accuracy of image products, which at best limit the linking of recorded reflectance to specific ground features with approximately +/- 1 pixel width uncertainty. Therefore, temporal profiles for wetlands with very few covering pixels should be interpreted with caution, as the observed reflectance values may sometimes or always correspond to areas partially or wholly outside the wetland area.

Finally, for Band 5, Cress Creek was too small to record any reflectance value with any confidence, so no profile is presented.

Table 3. Number of Band 5 and NDVI pixels, and notes on limits to interpretation of derived temporal profiles for all case study wetlands.

Wetland	Pixel count: Band 5 (500 m pixels)	Pixel count: NDVI (250 m pixels)
Big Dip Lake	1**, ***	*
Bimbimbi Swamp	3**, ***	10
Bool and Hacks Lagoon	**137****	**545**
Butchers Lake	3**, ***	*
Cress Creek	****	3***
Deadmans Swamp	4**, ***	23
Ewens Ponds	1**, ***	3**, ***
Freshwater Lake	1**, ***	*
Honans	8**	46
Kangaroo Flat	5**	13
Lake Frome	**139**	**566**
Lake Hawdon South	**152**	**622**
Lake Robe	17**	*
Middlepoint Swamp	9**	11**
Pick Swamp and Pic Ponds	18	58**
The Marshes	18**	63
Topperwein	3**, ***	12
Trail Waterhole	4**, ***	9
West Avenue Complex	**112**	**441**
Willalooka Wetlands	6	25

Wetlands in bold are those covering the most pixels, and hence in which we have the greatest confidence in results.

*NDVI temporal profile not presented, data not available due to coastal masking.

**temporal profile presented but caution should be exercised in interpreting the result, zero-data image dates may seriously impact the trend and break component.

***temporal profile presented but caution should be exercised in interpreting the result, low number of pixels and inherent locational uncertainty of all image products mean pixels may not all/always relate to the target wetland area.

****Temporal profile not presented, wetland was too small to reliably sample any pixel.

4.1.2 Analysis 1: Temporal greenness and inundation, interpretation

Interpretation of the results in this section requires an understanding of BFAST components and the remote sensing products.

Firstly, the BFAST analysis of both Band 5 and NDVI temporal profiles presented here has four components, with symbols defined by the BFAST method: the data profile (Yt); the average season component (St); the trend and break component (Tt); and the residual component (et). The data profile(Yt) is the mean image values for that wetland, for each image date throughout the entire temporal series. The average season component (St) presents the average annual profile, calculated by averaging all observed years. The trend and break component (Tt) is the long-term trend as determined by comparison of the observed current data (Yt) and the expected value as represented by the season component (St), and significant breaks from the long-term trend, as determined by a sensitivity threshold, which is a unitless variable set by the user (here set to 0.175). Finally, the residual component (et) is a graphical representation of the difference between the observed (Yt) and expected (St) data.

Band 5 reflectance is presented as an indicator of the magnitude of inundation, and to aid in the interpretation of NDVI profiles. This is not to say that Band 5 reflectance is a direct measure of inundation, and is only influenced by inundation. Radiation in the portion of the spectrum covered by Band 5 is strongly absorbed by water, and moderately to strongly reflected by all other land covers. Hence, very low Band 5 reflectance values are indicative of extensive inundation, while moderate or high values suggest minimal inundation.

The NDVI is an index that strongly correlates with vegetation density and vigour. Interpretation of NDVI is relatively straightforward: high NDVI values (around 0.8) correspond to extremely dense, very strongly growing vegetation (e.g., temperate or tropical forest, or full crop canopy), and low values (around 0.15) indicate dead vegetation or bare soil. However, one complication to interpreting NDVI is that water produces a negative NDVI value. When interpreting temporal mean NDVI for wetlands, it is important to keep in mind that two conflicting signals may be present: high NDVI due to strongly growing vegetation, and negative NDVI due to open water.

Interpretation may be aided by considering a typical seasonal NDVI profile for a wetland in the South East. Mean NDVI will increase over autumn and winter as rainfall increases and causes an increase in vegetation density and vigour. However, once rainfall accumulation results in significant areas of open water the observed mean NDVI signal may level off, or even begin to decrease. This is due to the strong negative NDVI signal produced by open water counteracting the strong positive signal produced by the dense and vigorous vegetation. Toward the end of the year open water area will decrease well before vegetation vigour decreases, and mean NDVI will increase again. Finally, NDVI will decrease to a minimum as vegetation dries off over summer.Thus, the NDVI and Band 5 temporal profiles should be interpreted together wherever possible. If Band 5 values are high, and NDVI low, inundation is likely to be extensive; whereas, if Band 5 values are low and NDVI low, there is unlikely to be any inundation, and vegetation is likely sparse or senescent.

Inundation and greenness profiles for Lake Hawden South are presented below with interpretation as an example. The remaining temporal profiles are presented in Appendix 2.

4.1.2.1 Example interpretation, Lake Hawden South, inundation and greenness

This section provides an example of the kind of interpretation that may be made by examining the Band 5 reflectance and NDVI temporal profiles.

Starting with the NDVI average season component (St) for Lake Hawden South (Figure 2), we see that the lowest values (minimum greenness) are recorded in approximately January, that greenness values increase to a maximum in approximately May as rain and surface runoff promote vegetation growth. NDVI values then decline until about August, probably as a result of inundation increasing and the strong negative inundation NDVI signal overcoming the positive greenness NDVI signal. Then in September as inundation extent decreases and vegetation remains green NDVI values increase briefly, before vegetation senescence leads to minimum NDVI again in January.

Comparing this to the Band 5 average season component, we see that the minimum Band 5 reflectance values occur in approximately August, and coincide with the centre of the mid-year dip in NDVI values. This is indicative of maximum inundation, since water very strongly absorbs radiation of the wavelength recorded by this band. Thus, taken together the average season component of NDVI and Band 5 reflectance tell a clear story of the average seasonal pattern of vegetation growth and inundation extent.

Looking now at the NDVI data profile (Yt) for the period corresponding to January 2007 we see the lowest minimum greenness in the temporal record. This suggests that very little vegetation is present, and that what vegetation is present is not photosynthesising strongly. Put more simply, during the summer of January 2007 Lake Hawdon South contained the least green vegetation of any other time between 2000 and 2015. Additionally, the maximum greenness for the growing season before and after this minimum (June 2006 and June 2007) was amongst the lowest in the temporal record. Thus, even in these winters there was minimal vegetation growth. This period corresponds to the height of the Millennium Drought, and is the closest Lake Hawden South has come in the 2000 to 2015 period to completely drying out.

Examining the Band 5 data profile for January 2007 (corresponding to minimum greenness), very high values are recorded, which suggests minimal or no respiring vegetation or open water. Similarly, the minimum Band 5 reflectance in the winter of 2006 is the highest minimum in the record, which suggests that even over this winter there was minimal vegetation respiration and inundation. The minimum Band 5 reflectance in the winter of 2007 is a little lower than that in 2006, but still among the highest (and hence driest) winters in the dataset.

To examine a counterpoint the period January 2011 to January 2012 was an unusually wet period. Over this period very high over-summer NDVI values are recorded indicating extensive green vegetation was maintained through summer. Likewise, very high maximum NDVI values are recorded, with a very strong mid-winter dip indicating extensive inundation. Conversely, the lowest over-summer peak Band 5 reflectance were recorded, providing further evidence for the presence of either open water or significant vegetation respiration.

Finally, looking at the NDVI trend component (Tt), we see that there was a stable trend until 2004, when overall vegetation greenness declined during the driest years of the Millennium Drought. Greenness then increased with several years of average or above average rain until mid-2011, before declining again slightly.

The Band 5 trend is essentially the reverse of this trend, due to the relationship between water availability and vegetation growth.

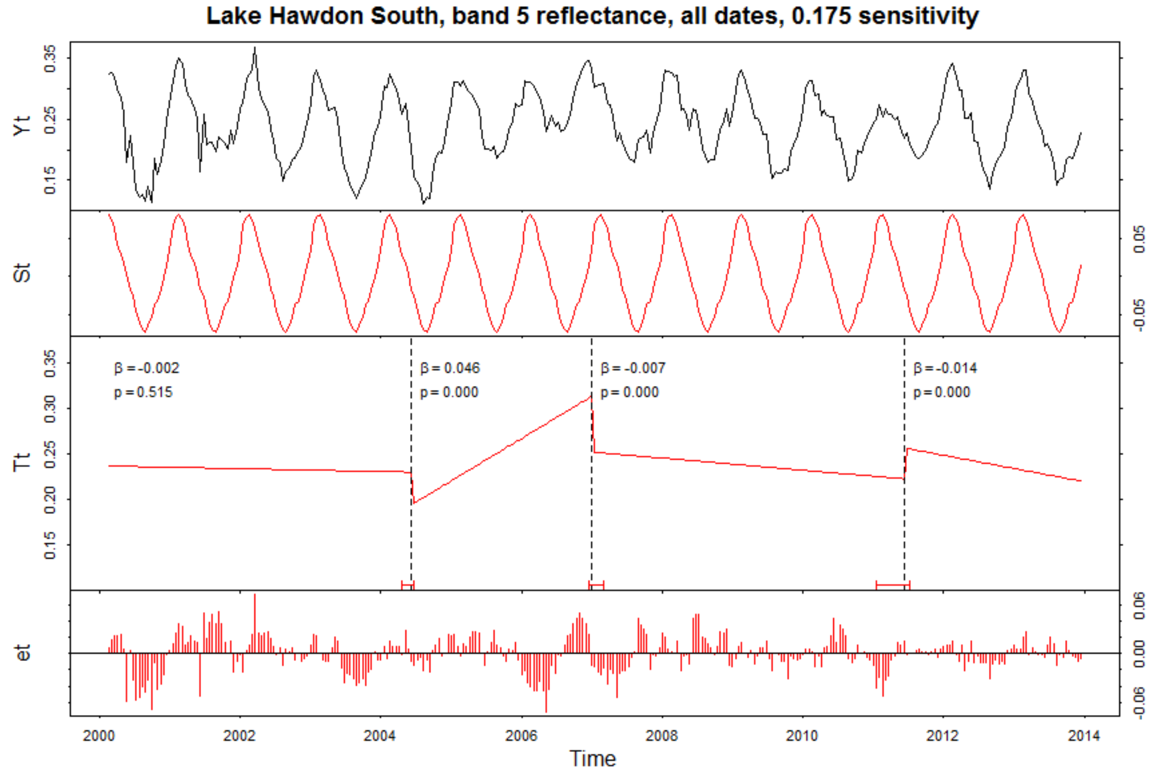

Figure 1. Lake Hawden South Band 5 reflectance, as an indicator of inundation. Data profile (Yt); average season component (St); trend and break component (Tt)); and the residual component (et). Low values indicate more extensive inundation, high values indicate less inundation.

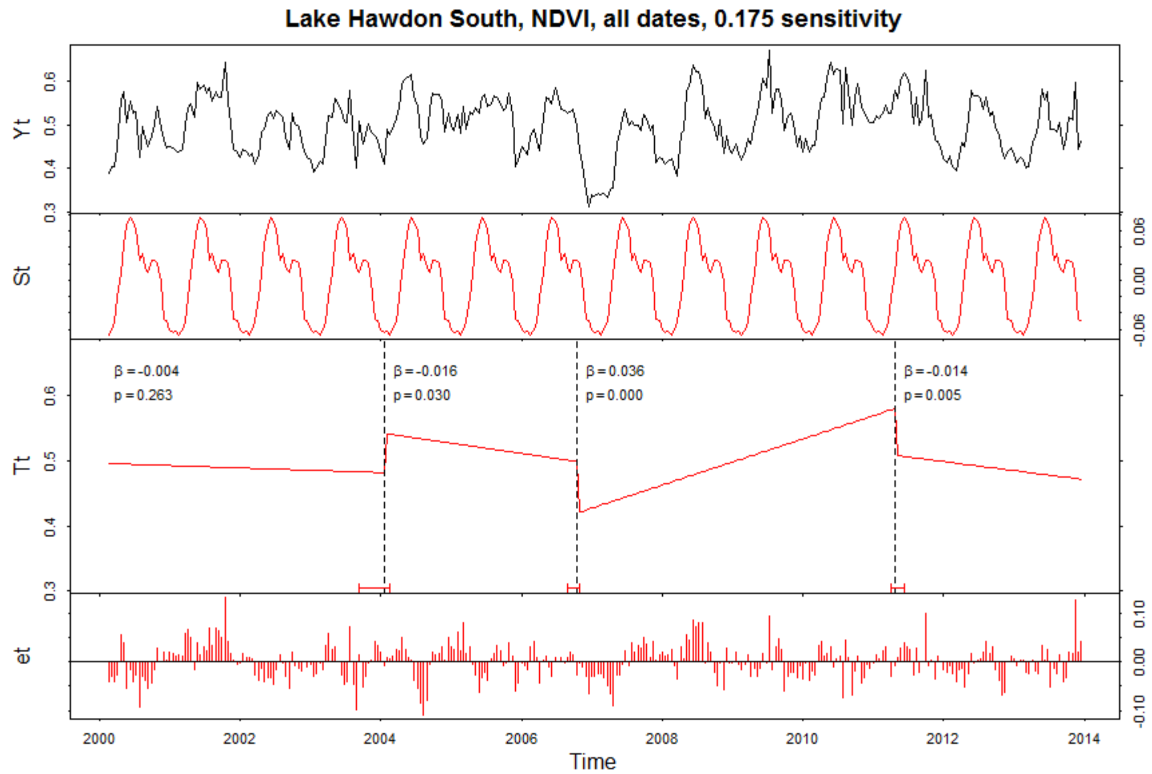

Figure 2. Lake Hawden South NDVI, an indicator of vegetation greenness. High values indicate dense or strongly growing vegetation.

4.1.3 Analysis 2: Temporal greenness clustering

This section presents the results of the ISOCLASS unsupervised classification of all MODIS NDVI images from 2000 to 2013, which clustered pixels into groups of similar temporal greenness (NDVI) pattern over that period. We found that twenty classes captured the major temporal greenness patterns within the study area, and that clustering into more classes resulted in meaningful classes being split into multiple sub-classes with no discernible differences.

The 20 classes were examined in relation to historical and current Landsat and Google Earth imagery, and their land cover type described (Table 4). These classes were then grouped thematically, and mapped (Figure 3).

Unsurprisingly, the majority of classes and the majority of area correspond to agricultural (covering 68 % of the terrestrial area) or agro-forestry (17 % of the terrestrial area) landscape utilisation (Table 5). However, it is interesting to note that forestry has increased significantly over the study period. Class 19 (5.4 % of the area) captures areas that were either continuously forestry, or changed from agriculture to forestry, and class 16 (6.6 % of the area) corresponds to areas that changed from agriculture to forestry over the imagery period (2000 to 2013). Contrast this with the area that remained continuously utilised by forestry over the study period (class 20, 4.7 % of the area). Class 1 corresponds to areas that were continuously inundated by deep water (sea), and classes 2 to 7 correspond to various combinations of coastal land covers including exposed sand, intertidal zone (which is temporally a mixture of water and exposed sand), shallow coastal wetlands and some terrestrial vegetation (3.7 % of the area). Class 9 was a very small class (0.09 % of the terrestrial area) which seemed to correspond to an agriculturally utilised area that was frequently inundated.

The class that included the largest number of the 20 case-study SAWID wetlands was class 18 (11 % of the area). However, this class also included the urban and suburban areas of Mt Gambier, much of the vineyards in the Coonawarra area, some swale areas throughout the south east, and large areas of relatively exposed soils in north east of the study area, east of Padthaway. Finally, many of the case-study wetlands fell into classes that were predominantly characterised by non-wetland land cover.

To illustrate the similarity and differences of temporal greenness pattern between classes, the average season NDVI profile was calculated and graphed for all classes (Figure 4). This visualises the temporal greenness profile for an average calendar year for each class.

The highest overall NDVI is observed in the three forestry classes which retain high NDVI over summer, and then increase further to very high values around June, before decreasing back to high values in early December. By contrast, the agricultural classes maintain low NDVI over summer, before increasing steeply in mid-March as crops germinate and grow. Agricultural classes then reach high to very high peak NDVI levels, rivalling those observed for forestry, around early spring before decreasing back to summer levels as crops ripen, and senesce or are harvested.

The coastal classes are generally very low over summer, increasing in early March to moderate-to-high peak NDVI values in winter, and then decreasing over spring back to minimum NDVI values by the early December. The overall low NDVI signal of this class is probably due to these classes containing areas of water and exposed soil, both of which produce low or negative NDVI values. The increase in NDVI over winter is probably due to the presence of some terrestrial vegetation in these classes.

The mixed wetland, lakes and swales and Mt Gambier class temporal profile follows a similar temporal pattern to the coastal and agricultural classes, with lower NDVI over summer and higher NDVI over winter, but with maximum NDVI values only moderately higher than the coastal classes. This may initially appear surprising, as one might naïvely expect wetlands and suburban areas to support high levels of essentially irrigated vegetation, resulting in very high NDVI levels. Indeed, we believe that the vegetated component of wetlands and suburban areas is responsible for the observed winter greening. However, there are two other land cover types in wetlands and suburbs which make up a significant proportion of their area and hence reflectance signal. In wetlands, small to moderate amounts of visible inundation (which produces negative NDVI values) will reduce the mean NDVI signal. In suburban areas, roof-tops, roads and paving all produce very low NDVI values, and will likewise reduce the mean NDVI signal.

Thus, we believe that the modest winter increase in NDVI observed for this class is a result of a significant NDVI increase from strong vegetation growth being counterbalanced by very low and negative NDVI from built surfaces and water respectively. Put another way, we believe that temporal profile resulting from high NDVI suburban garden and parkland being moderated by low NDVI built surfaces is similar to the temporal profile that results from high NDVI wetland vegetation being moderated by negative NDVI inundation.

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Table 4. Class numbers, detailed descriptions and thematic class (as presented in the map, Figure 3) for ISOCLASS clustering of MODIS temporal NDVI from 2000 to 2013.

Class number	Detailed description	Thematic class (map legend)	Area (km^2)
1	Sea	Sea	18718
2	Coast 1, mixed beach-sand and intertidal zone	Coastal	197
3	Coast 2, mostly exposed sand with some coastal wetlands	Coastal	167
4	Coast 3, exposed sand	Coastal	94
5	Coast 4, coastal sand and terrestrial vegetation	Coastal	111
6	Coast 5, water and terrestrial vegetation	Coastal	33
7	Coast 6, inundated coastal wetlands and terrestrial vegetation	Coastal	84
8	Mixed: pasture and cropping	Predominantly agriculture	95
9	Mixed: water and agriculture	Mixed water and agriculture	16
10	Mixed: forestry and agriculture	Predominantly agriculture	45
11	Mixed: native woody vegetation and agriculture	Predominantly agriculture	45
12	Agriculture	Predominantly agriculture	45
13	Mostly non-irrigated agriculture, some smaller wetlands	Predominantly agriculture	7393
14	Non-irrigated agriculture 1	Predominantly agriculture	2526
15	Non-irrigated agriculture 2	Predominantly agriculture	1693
16	Conversion to forestry (over 2000 - 2013)	Forestry, new	1231
17	Mixed: woody vegetation and pasture	Predominantly agriculture	999
18	Mixed: Wetlands, lakes and swales, and Mt Gambier	Mixed wetlands, lakes and swales, and Mt Gambier	2132
19	Mixed: continuous and conversion to forestry (over 2000 - 2013)	Forestry, continuous and new	1006
20	Continuous forestry	Forestry, continuous	876

Table 5. Area and percent of total terrestrial area by thematic class / map legend

Map legend / class theme	Total area (km2)	Percent of total terrestrial area
Sea	18718	NA
Coastal	686	3.7%
Predominantly agriculture	12841	68%
Forestry, continuous	876	4.7%
Forestry, continuous and new	1006	5.4%
Forestry, new	1231	6.6%
Mixed water and agriculture	16	0.09%
Mixed wetlands, lakes and swales, and Mt Gambier	2132	11%

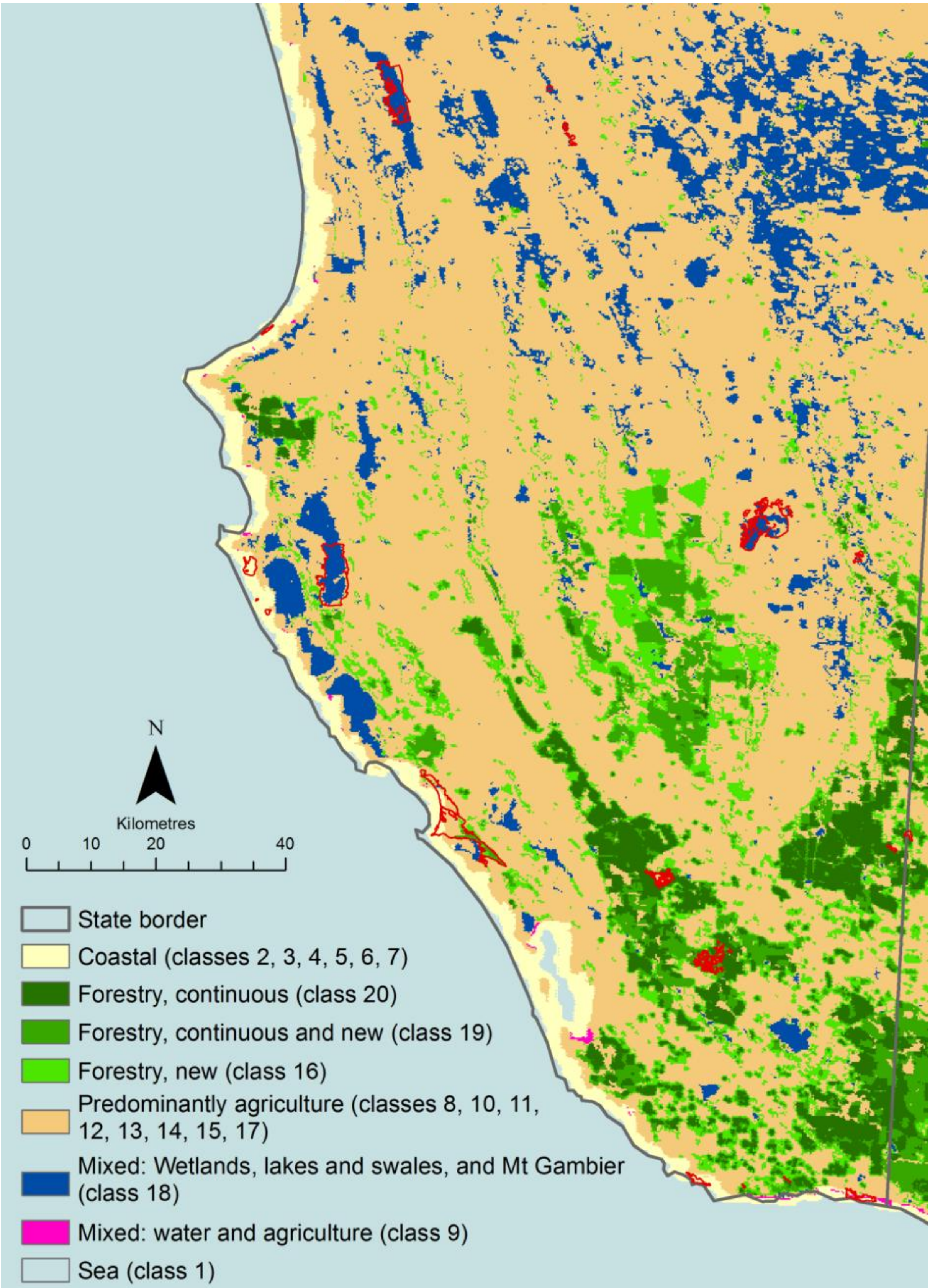


Figure 3. Major thematic classes of the 20 classes of similar temporal greenness pattern (NDVI) over the 2000 to 2013 period. Longer descriptions of each class are presented in Table 4, and average seasons are graphed in Figure 4.

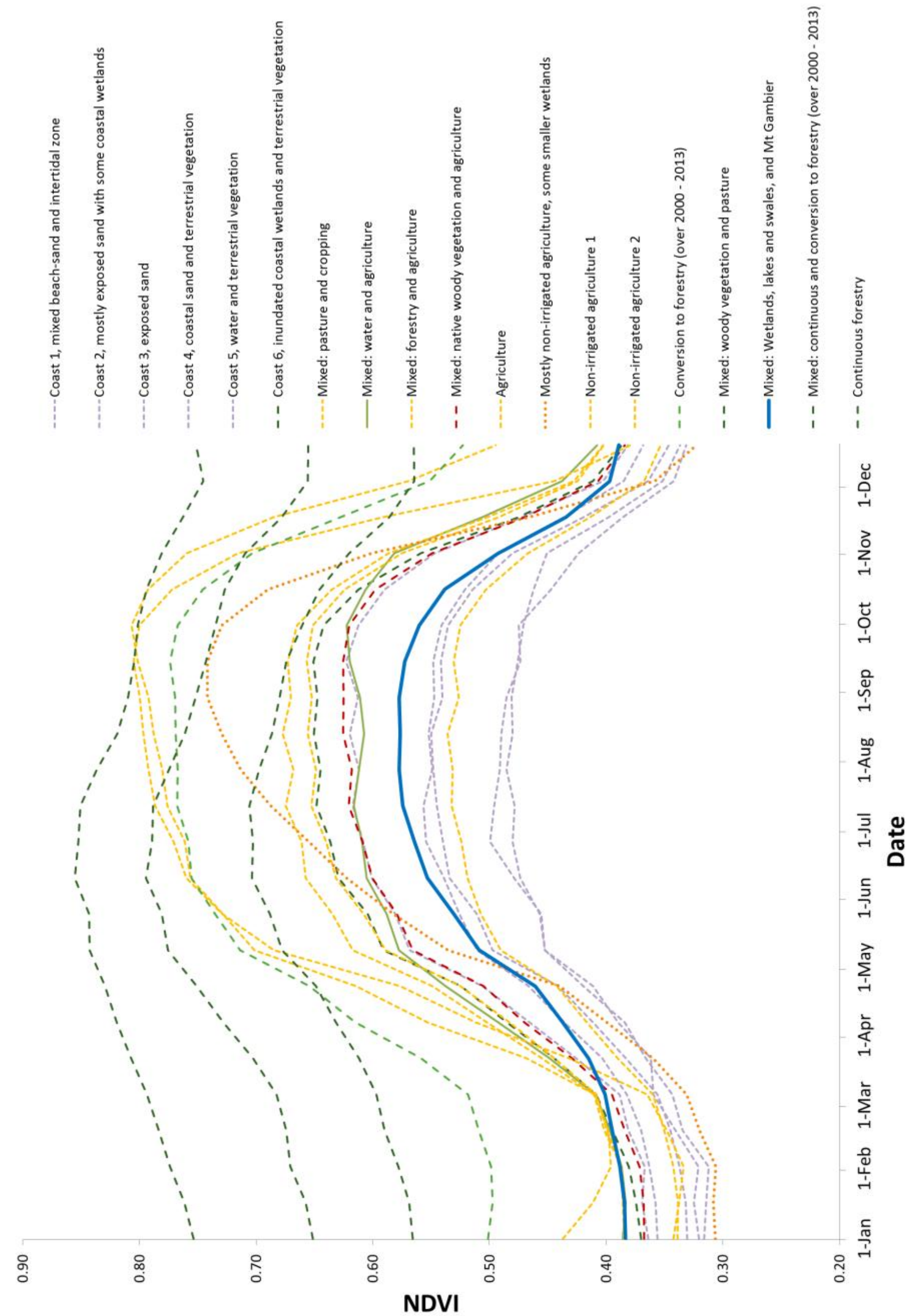


Figure 4. Average season NDVI profile for the 20 classes of similar temporal greenness pattern (NDVI) over the 2000 to 2013 period. Classes are grouped by theme and mapped in Figure 3. Temporal NDVI profile for the Sea class is not presented; a meaningful profile could not be produced for this class due to frequent null values resulting from strong water absorption and error filtering.

4.2 Task 3.2 – Wetland temporal inundation extent

This section presents maps of the extent of inundation over the south east as mapped from Landsat 5 and 7 imagery. Three Landsat scenes were required to cover the study area, and we aimed to acquire one complete set of images for each wet season and each dry season for the period covered by the USGS Landsat catalogue (1991 – 2012). However cloud cover sometimes prevented acquisition of one or more scenes for either the wet or dry season. In total nine wet season and fifteen dry season inundation maps were produced. Three of the twenty four maps are presented below with some interpretation, to provide an example of the information that can be extracted from the maps. The remaining 21 maps are presented in Appendix 3.

The example maps below show a 'wet' and 'dry' scene from a wet period, and two 'dry' scenes from average and dry period (respectively, August 1992 (Figure 5), December/January 1992/93 (Figure 6), January/February 1994 (Figure 7), and April 2003 (Figure 8)). Together these scenes illustrate the range of natural inter- and intra-annual variation within the South East due to natural seasonal and climatic variability. The period 1992 to 1993 (inclusive) is one of the wettest in South Australia in the last three decades, and Figure 5 and Figure 6 show that under very wet conditions both wet and dry season inundation can be extensive in the South East. In these figures, not only are most wetlands completely inundated, but many non-wetland areas are also inundated. Careful examination of Figure 6 even reveals that inundation in some areas can be more extensive in the nominally dryer December/January than in the nominally wetter August (Figure 5).

The dry image from 1994 (Figure 7) shows inundation in summer following an fairly average rainfall winter, and by comparison with Figure 5 illustrates the range of inundation extent experienced by wetlands from wet winters to (average) dry summers. Finally, the dry image from 2003 (Figure 8) shows summer inundation following a dry winter, and by comparison with Figure 7 shows that in dry periods many wetlands that often retain some water over summer may completely dry out over summer.

4.2.1 Example maps

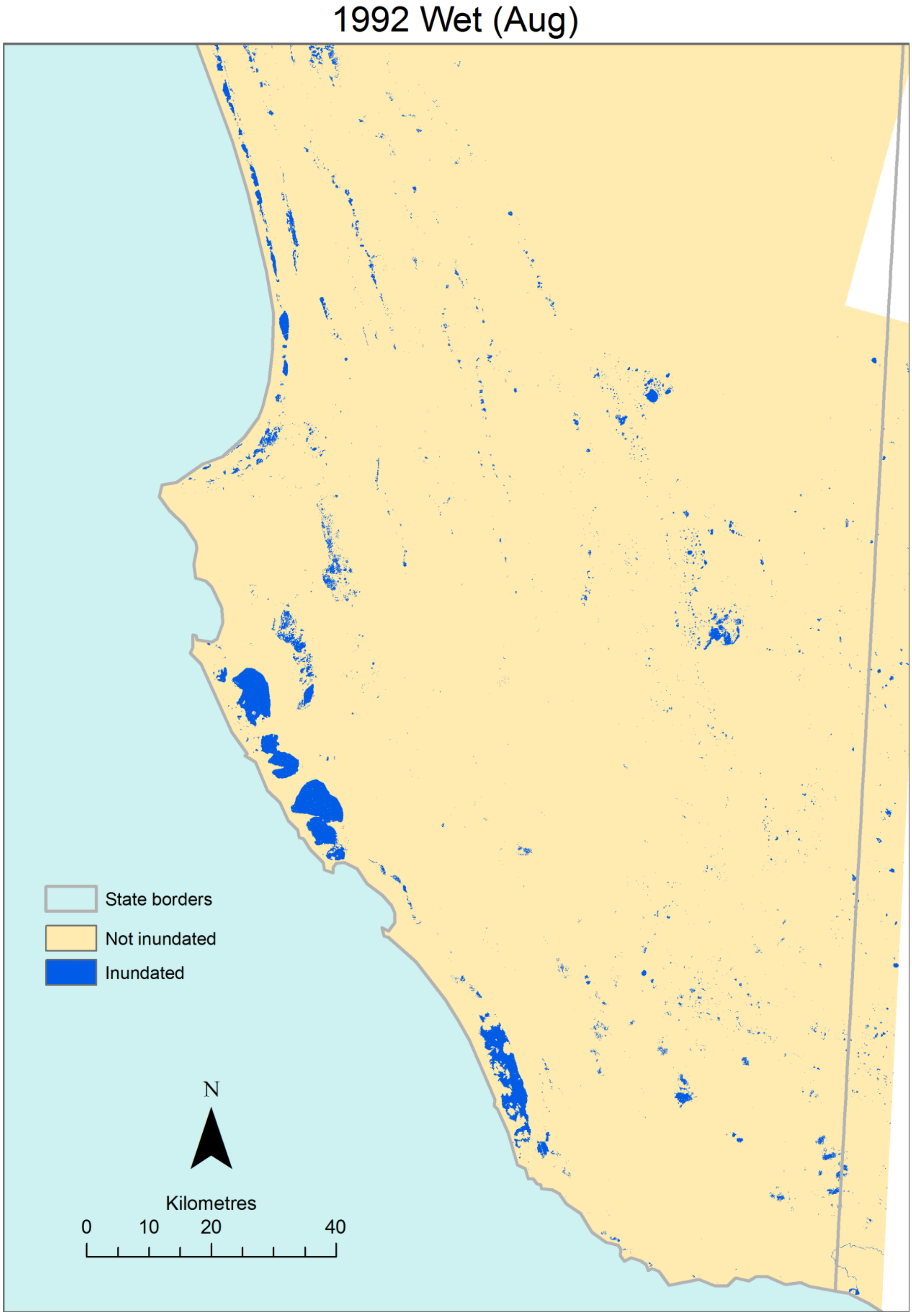


Figure 5. Inundation extent mapped from Landsat imagery 1992 wet season. Imagery was acquired in August 1992.

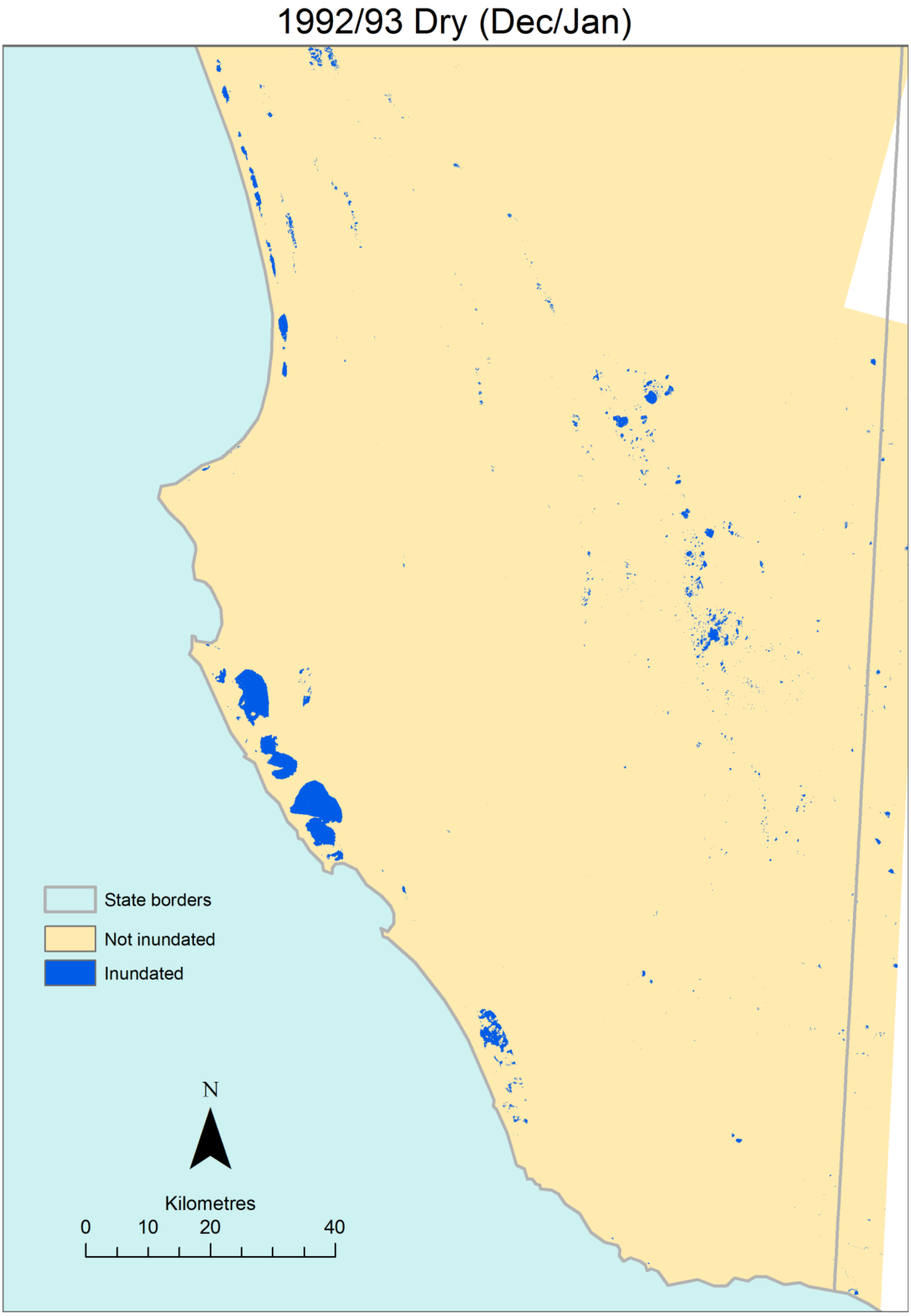


Figure 6. Inundation extent mapped from Landsat imagery; 1992/93 dry season. Imagery was acquired in December 1992 and January 1993.

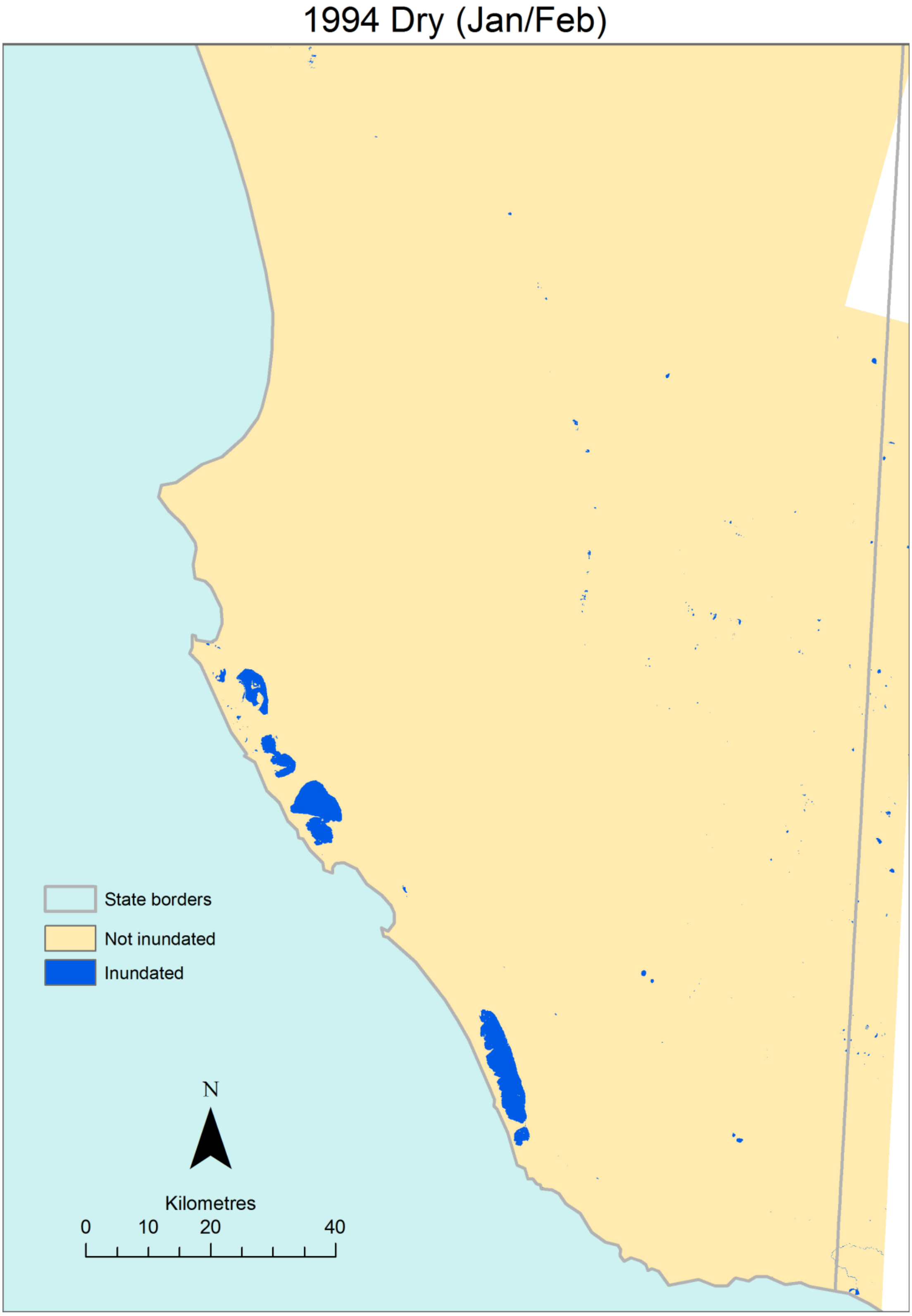


Figure 7. Inundation extent mapped from Landsat imagery; 1994 dry season. Imagery was acquired in January and February 1994.

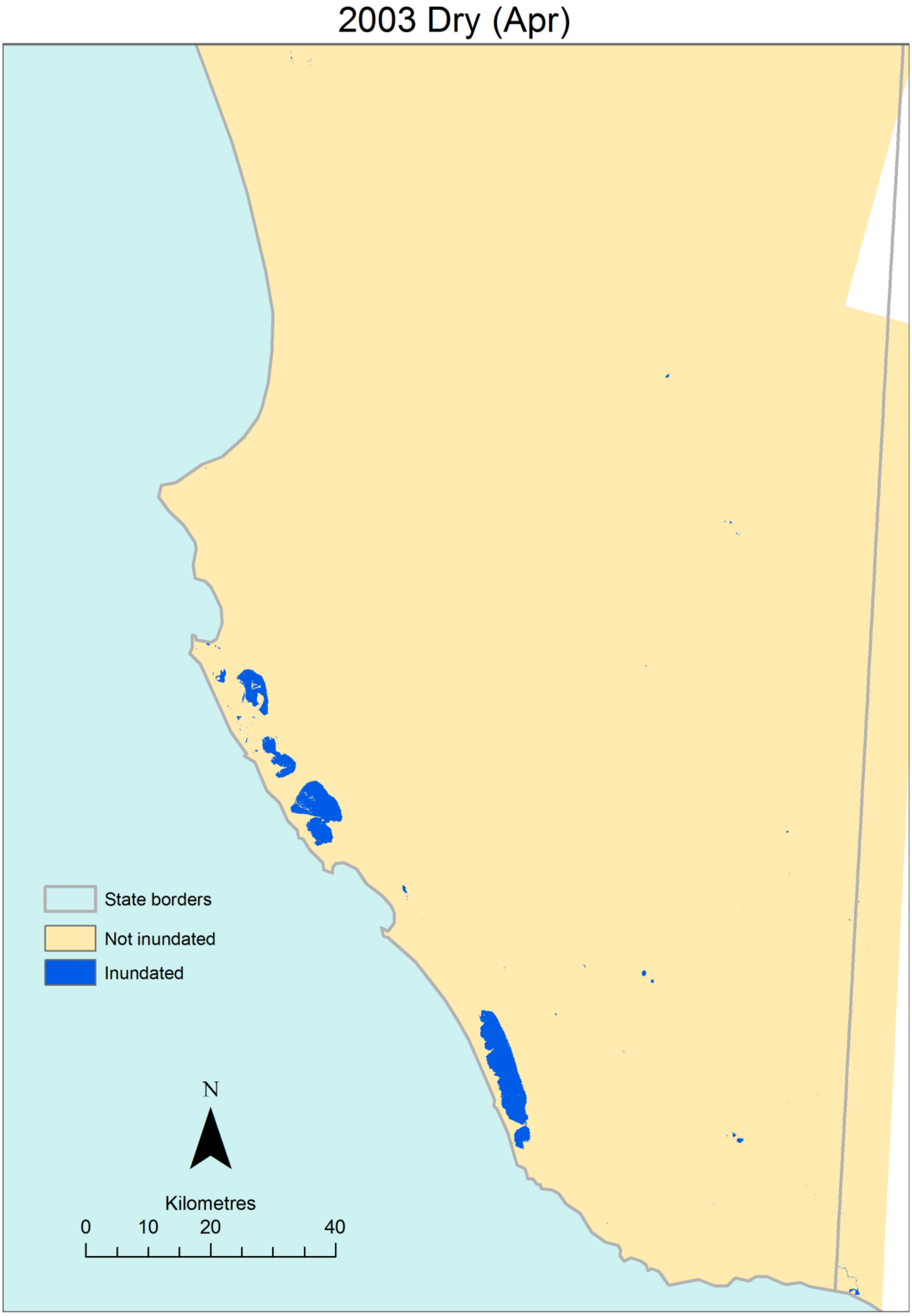


Figure 8. Inundation extent mapped from Landsat imagery; 2003 dry season. Imagery was acquired in April 2003.

4.3 Task 3.3 – Change in vegetation community over time

This section presents the tabulated change in vegetation community area over time, ranked by community wetness. Results are presented for 1969 and 2013 for The Marshes, Topperwein and Trail Waterhole for 1969 and 2013, and for 1969, 1982, 2008 and 2013 for Deadmans Swamp.

Maps of all the vegetation communities on each date are not presented here, but an example map for Baumea vegetation classes is presented for Deadmans Swamp (Figure 9), and the vector data files will be made available. It was not possible to use one unified legend across all mapping dates, due to the different levels of community detail discernible in the 1969 and 2013 imagery.

4.3.1 Interpretation and caveats

Interpretation of the matrices presented in this section is relatively straightforward, although there are some caveats to this. The change matrices present the vegetation classes mapped on the earlier date (rows) against the classes mapped on the later date (columns), with area (in hectares) presented in the cell. For each vegetation class mapped on the earlier date (row), shaded bars represent the proportionate change from the earlier class to the later class. Wetness score ranges from high (wetter) to low (drier).

Finally, while we have made every effort to be exacting and use supporting data wherever possible, all mapped vegetation classes are interpretations of aerial photography, which in the case of 1969 imagery is low resolution black and white imagery. Hence some classes are more easily distinguished in the 1969 imagery than others. For instance, Baumea and Eucalypt woodland are easily distinguished, so mapped change from one to the other is likely to be accurate. However, Agroforestry and some native woodlands look very similar in the 1969 aerial photography, so some confusion between these classes is to be expected.

We suggest the following as guidelines for estimating the confidence of results in the vegetation community change matrices:

- a change from one major community type to another (sedgeland or grassland/shrubland/woodland) is high confidence
- a change within a community type is lower confidence
- a change in density within the same vegetation class is high confidence
- changes from pure to mixed classes are moderately high confidence
- changes from mixed classes to other classes are low confidence

4.3.2Deadmans Swamp, map of change in Baumea from 1969 to 2013

Here we present an example map of one of the most significant vegetation community changes mapped for any of the four case study wetlands; change from areas originally mapped as Baumea in 1969 to drier vegetation communities in later dates (Figure 9). This example is presented to illustrate the nature of the mapping, and the kind of insight it can provide when specific questions are investigated. However, we do not present for all vegetation communities in all case study wetlands, due to the number of communities mapped and the difficulty of creating meaningful symbology for more or less similar communities on different dates.

Baumea is indicative of the wettest parts of Deadmans Swamp, and is at its densest in the wettest of these areas. This map shows that areas mapped as dense, medium and light Baumea in 1969 become less dense shifting from dense to medium, or medium to light; and that areas of formerly pure Baumea become mixed communities by 2013. Both of these changes are indicative of a decrease in access to water, either surface inundation or soil water.

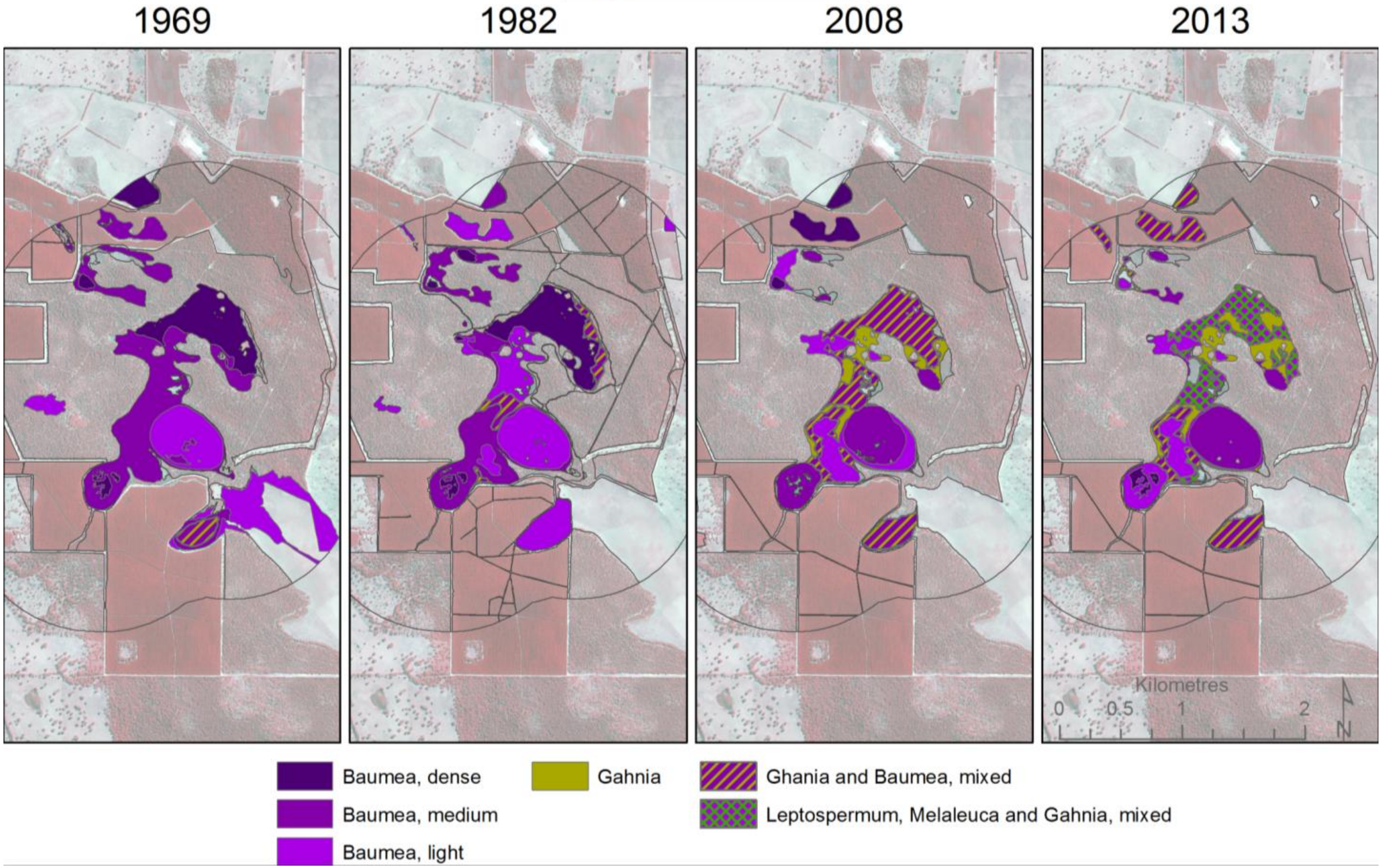


Figure 9. Map of change in Baumea vegetation communities in Deadmans Swamp from 1969, through 1982 and 2008 to 2013.

4.3.3 Deadmans Swamp vegetation community change from 1969, through 1982 and 2008 to 2013

For the 1969 to 1982 matrix (Figure 10), and considering the wetter 1969 vegetation classes (wetness 8 to 4), there is some small indication of change from wetter to drier vegetation communities from 1969 to 1982. Change from ‘Baumea, medium’ to ‘Baumea, light’, ‘Cladium procerum sedgeland’ to ‘Baumea, dense’ and ‘Baumea, light’ to ‘Grassland, some large eucalypts’ are all indicative of drying that we have high confidence in. In terms of area or magnitude of change, these changes were moderate proportions of the original class. The dryer 1969 classes do not appear to change significantly.

For the 1982 to 2008 matrix (Figure 11) the changes from ‘Dry aquatics’ to ‘Baumea, dense’, ‘Typha’ to ‘Baumea, medium’, ‘Baumea, light’ to ‘Ghania and Baumea, mixed’ and ‘Baumea, dense’ to ‘Ghania and Baumea, mixed’ are all indicative of wetter classes drying, and we have reasonable confidence that these are real changes. Additionally, these were relatively large changes in the area of these classes. Conversely, the change from ‘Baumea, light’ to ‘Baumea, medium’ is a change we have high confidence in, but which suggests an increase in wetness. The dryer 1982 classes did not change significantly.

Finally, for the 2008 to 2013 matrix (Figure 12) the changes from ‘Baumea, medium’ to ‘Baumea, light’, ‘Baumea, dense’ to ‘Ghania and Baumea, mixed’, and ‘Ghania and Baumea, mixed’ to ‘Leptospermum, Melaleuca and Ghania, mixed’ are moderate to large changes, in terms of area, are indicative of drying and we have confidence in the accuracy of the mapped change. Conversely, the changes from ‘Exposed soil with Baumea’ to ‘Baumea, medium’, and ‘Baumea, light’ to ‘Baumea, medium’ are indicative of wetting and we have high confidence in the accuracy of the change.

Taken together, we are confident in concluding that there has been significant change from wetter to dryer vegetation communities in Deadmans Swamp over the 1969 to 2013 period. While there have been some recent small expansion in wetter vegetation communities between 2008 and 2013, there were larger changes indicative of drying over the same period; meaning that even in this period the overall trend was towards drying.

1969		Vegetation cover description	Exposed soil	Dry aquatics	Typha	Baumea, medium	Cladium procerum sedgeland	Melaleuca brevifolia and Baumea, mixed	Baumea, light	Baumea, dense	Ghania and Baumea, mixed	Gahnia, and Leptospermum	Grassland, some large Eucalypts	Euc., Melaleuca, Acacia and Leptospermum woodland	Track	Agroforestry	Vineyards	Total area (ha)
		1982																
Wetness score			NA	7	7	6	6	5	5	4	3	2	1	1	1	1	1	
	Mean height above sea level (m)		61.4	59.8	60.5	61.4	63.8	61.6	62.3	62.6	62.6	63.2	68.8	71.3	71.6	72.1	79.0	
NA	61.8	Exposed soil	0.39	0.00		1.21		0.03	1.37	0.02	0.08		1.17	0.71	0.09	0.19		5.26
8	NA	Typha			0.01				0.00									0.01
7	61.0	Ghania and Baumea, mixed							5.01									5.01
7	61.8	Baumea, medium	0.28	0.05	0.05	34.85	0.03	0.44	26.21	3.76	4.36	0.93	0.44	5.64	0.29	1.52		78.84
6	61.8	Melaleuca brevifolia and Baumea, mixed	0.01	0.10		0.65		0.53	0.01	0.89				0.72				2.92
6	63.8	Cladium procerum sedgeland					0.47			0.49								0.96
5	62.9	Baumea, dense	0.00	0.49		3.05	0.23		0.14	26.10	2.92	0.07	3.46	0.50				36.97
4	63.4	Baumea, light	0.05		0.04	1.14			23.46		0.10		19.43	5.53	1.35			51.10
3	64.3	Leptospermum over Gahnia and Baumea sp.								0.01	0.93			0.87	0.00			1.81
2	65.0	Leptospermum, Melaleuca and Gahnia, mixed												0.56	0.00			0.57
1	66.8	Grassland, some large Eucalypts				0.12			0.76				67.33	0.45	1.69		9.14	79.50
1	71.7	Euc., Melaleuca, Acacia and Leptospermum woodland	0.00	0.00		2.17		0.05	2.96	0.34	0.03		75.08	364.69	10.28	2.41	0.02	458.03
1	72.1	Agroforestry				1.01			0.41		0.54		0.02	1.29	9.32	249.76		262.35
1	73.3	Track	0.00			0.41							0.50	3.26	25.42	10.31		39.90
		Total area (ha)	0.75	0.65	0.10	44.62	0.73	1.04	60.33	31.60	8.96	1.00	167.44	384.23	48.44	264.19	9.16	

Figure 10. Tabulated change in vegetation community area for Deadmans Swamp from 1969 to 1982. Figures are hectares; for each row, shaded bars represent the proportionate change from the 1969 class to 1982 classes. Wetness score ranges from high (wetter) to low (drier); NA indicates that it was not possible to rank the relative wetness.

4.3.4 Deadmans Swamp vegetation community change from 1982 to 2008

			2008																
Wetness score			NA	8	8	7	7	6	6	5	4	3	2	1	1	1	1	1	
	Mean height above sea level (m)		64.3	60.4	60.5	60.8	63.7	61.0	63.6	62.1	61.9	62.4	63.8	68.7	69.3	71.1	72.2	72.3	
1982		Vegetation cover description	Exposed soil	Exposed soil with Baumea	Typha	Baumea, medium	Cladium procerum sedgeland	Baumea, light	Baumea, dense	Ghania and Baumea, mixed	Melaleuca brevifolia and Gahnia, mixed	Gahnia	Leptospermum, Melaleuca and Gahnia, mixed	Vineyards	Grassland, some large Eucalypts	Euc., Melaleuca, Acacia and Leptospermum woodland	Track	Agroforestry	Total area (ha)
NA	61.4	Exposed soil	0.36			0.18				0.06	0.03	0.06				0.05			0.75
7	59.8	Dry aquatics						0.13	0.41		0.11								0.65
7	60.5	Typha		0.02	0.03	0.05													0.10
6	61.4	Baumea, medium	0.03			9.20		14.10	2.44	7.84	3.21	1.91			0.00	5.77	0.12	0.00	44.61
6	63.8	Cladium procerum sedgeland				0.01	0.61			0.04		0.06				0.01			0.73
5	61.6	Melaleuca brevifolia and Baumea, mixed								0.05	0.75					0.23			1.04
5	62.3	Baumea, light	0.72	0.36	0.02	17.06		9.07	6.45	13.64	0.36	5.02		0.76	1.62	5.11	0.12	0.00	60.33
4	62.6	Baumea, dense	0.68			4.78	0.16	0.22	0.42	22.73	0.19	2.01	0.14			0.28			31.60
3	62.6	Ghania and Baumea, mixed				0.18		0.15		3.58		1.76	2.65			0.64			8.96
2	63.2	Gahnia, and leptospermum								0.03		0.96				0.01			1.00
1	68.8	Grassland, some large Eucalypts							0.01					16.09	148.18	1.50	1.66	0.00	167.44
1	71.3	Euc., Melaleuca, Acacia and Leptospermum woodland				0.05		0.30		0.77	0.46	0.68	0.22	0.02	2.85	377.94	0.93		384.22
1	71.6	Track	0.03			0.03			0.00	0.07	0.00			0.11	0.17	14.01	28.96	5.09	48.47
1	72.1	Agroforestry	0.41						1.93							1.43	3.47	256.94	264.18
1	79.0	Vineyards												7.46	1.70		0.00		9.16
		Total area (ha)	2.25	0.38	0.05	31.55	0.77	23.96	11.66	48.82	5.11	12.46	3.01	24.43	154.52	406.98	35.26	262.03	

Figure 11. Tabulated change in vegetation community area for Deadmans Swamp from 1982 to 2008. Figures are hectares; for each row, shaded bars represent the proportionate change from the 1982 class to 2008 classes. Wetness score ranges from high (wetter) to low (drier); NA indicates that it was not possible to rank the relative wetness.

4.3.5Deadmans Swamp vegetation community change from 2008 to 2013

			2013																	
Wetness score			NA	8	8	8	7	7	6	5	4	3	2	2	1	1	1	1	1	
	Mean height above sea level (m)		68.4	60.1	60.3	60.5	60.9	63.7	60.9	61.7	62.2	62.2	62.6	62.7	68.7	69.3	71.1	71.9	72.3	
2008		Vegetation cover description	Exposed soil	Baumea, dense	Dry aquatics	Typha	Baumea, medium	Cladium procerum sedgeland	Baumea, light	Melaleuca brevifolia and Baumea, mixed	Ghania and Baumea, mixed	Leptospermum, Melaleuca and Baumea, mixed	Leptospermum, Melaleuca and Gahnia, mixed	Gahnia	Vineyards	Grassland, some large Eucalypts	Euc., Melaleuca, Acacia and Leptospermum woodland	Track	Agroforestry	Total area (ha)
NA	64.3	Exposed soil	0.99	0.70					0.00				0.55	0.00						2.25
8	60.4	Exposed soil with Baumea				0.04	0.34													0.38
8	60.5	Typha				0.04	0.00													0.05
7	60.8	Baumea, medium		1.79		0.06	21.52		8.18											31.55
7	63.7	Cladium procerum sedgeland						0.77												0.77
6	61.0	Baumea, light			1.34		4.76		13.83	1.13	1.09		1.17				0.63			23.96
6	63.6	Baumea, dense			0.22				0.65		10.78									11.66
5	62.1	Ghania and Baumea, mixed	0.00				0.03		0.38		15.42		26.60	6.39						48.82
4	61.9	Melaleuca brevifolia and Gahnia, mixed					1.51			3.60										5.11
3	62.4	Gahnia	0.03									1.81		10.62						12.46
2	63.8	Leptospermum, Melaleuca and Gahnia, mixed											3.01							3.01
1	68.7	Vineyards													24.43					24.43
1	69.3	Grassland, some large Eucalypts														154.52				154.52
1	71.1	Euc., Melaleuca, Acacia and Leptospermum woodland									1.59						405.39			406.98
1	72.2	Track															0.08	35.18		35.26
1	72.3	Agroforestry																1.71	260.32	262.03
		Total area (ha)	1.03	2.48	1.56	0.15	28.15	0.77	23.04	4.73	28.88	1.81	31.34	17.01	24.43	154.52	406.10	36.90	260.32	

Figure 12. Tabulated change in vegetation community area for Deadmans Swamp from 2008 to 2013. Figures are hectares; for each row, shaded bars represent the proportionate change from the 2008 class to 2013 classes. Wetness score ranges from high (wetter) to low (drier); NA indicates that it was not possible to rank the relative wetness.

4.3.6 The Marshes vegetation community change from 1969 to 2013

There are more vegetation cover classes, and hence many more changes for The Marshes (Figure 13) than for any of the other case study wetlands, so interpretation is more time consuming. However, the changes can be divided into drying, wetting, uncertain and land use change.

The changes from 'Baumea, dense' to 'Baumea, sparse dry and mixed dry acquatics' and 'Grassland, some large eucalypts', from 'Carex, grassy aquatics and sparse Baumea sp.' to 'Grassland, some large eucalypts', from 'Baumea and Leptospermum, mixed' to 'Baumea, sparse dry, and mixed dry aquatics', and from 'Carex' to 'Baumea, dense wet' and 'Carex' to 'Carex, grassy aquatics and sparse Baumea sp.' are all changes from wetter to dryer vegetation covers in which we have medium to high confidence in the mapping. The change from 'Leptospermum' to 'Eucalypt woodland with Leptospermum, Melaleuca and Acacia understory' would be indicative of drying, but is possibly not genuine change, as those two classes appeared very similar in the 1969 imagery. Finally, the change from 'Leptospermum' to 'Eucalypt woodland…' and from 'Leptospermum and Melaleuca, mixed' to 'Eucalypt woodland…' is an increase in tall woody vegetation, which may indicate a decrease in inundation frequency, or an increase in depth to groundwater.

The change from 'Baumea, medium' to 'Baumea, dense, wet' would suggest an increase in wetness, and we have moderate confidence in this mapping. However, while the change from 'Baumea, medium' to 'Carex, grassy aquatics and sparse Baumea sp.' might also suggest an increase in wetness, we are not certain that the 1969 'Baumea, medium' class did not also contain carex and other acquatics, and so this change should be consider low confidence.

We are uncertain how to interpret the changes from 'Baumea, medium' to 'Baumea, dense dry'. The increase in density might suggest an increase in water availability, while the note that the vegetation appeared dry would suggest a decrease in water availability.

There were some significant land use changes from 'Baumea, sparse, and mixed dry aquatics' to 'Grassland, some large Eucalypts' and 'Agroforestry', and significant expansions of 'Agroforestry' which mostly came from land that was 'Grassland, some large Eucalypts', but from the conversion of the majority of the class 'Leptospermum, with some Melaleuca and Eucalyptus'. Additionally, the 1969 'Unknown aquatics' class was almost completely subsumed into the 'Grassland, some large Eucalypts' and 'Agroforestry' classes by 2013. As these changes were a result of anthropogenic land use change, they not a result of increase or decrease in surface or groundwater availability. However, they may be drivers of change in water availability in the area, by reducing runoff through interception, and by utilising rainfall and groundwater for respiration.

2013

1969		Vegetation cover description	Irrigated agriculture	Dry waterhole	Unknown acquatics	Open water	Typha	Phragmites sp.	Baumea, dense wet	Grassland, sparse Baumea and some Large eucalypts	Carex, grassy aquatics and sparse Baumea sp.	Sedges	Baumea, sparse dry, and mixed dry acquatics	Baumea, medium dry	Baumea, dense dry	Baumea, sparse dry	Baumea and Leptospermum, mixed	Baumea, dense wet, and Carex, mixed	Baloskion and Leptospermum, mixed	Baumea, Baloskion, acquatics, mixed	Baloskion	Baumea sparse, and mixed dry acquatics	Leptospermum, with some Melaleuca and Eucalyptus	Leptospermum	Baloskion, Leptospermum and blackberry, mixed	Grassland, some large Eucalypts	Melaleuca	Leptospermum and Melaleuca, mixed	Eucalypt woodland with Leptospermum, Melaleuca and Acacia understory	Track	Quarry	Agroforestry	Total area (ha)
Wetness score			NA	NA	NA	11	10	9	9	8	8	7	7	7	7	7	7	7	6	6	5	5	4	4	4	3	3	3	2	1	1	1	
	Mean height above sea level (m)		74.0	76.8	80.9	77.3	79.0	79.0	79.2	76.9	78.9	77.4	78.4	78.9	79.0	79.4	79.4	79.5	79.3	79.7	79.5	79.9	79.6	79.8	80.6	79.0	79.6	80.0	79.9	88.3	92.0	98.8	
NA	79.0	Exposed soil											0.03													1.04				0.06		0.17	1.29
9	76.1	Grassland, sparse Baumea and some large Eucalypts								0.29																							0.29
9	78.0	Baumea, sparse, and mixed dry acquatics		0.02		1.18			0.38	0.13		0.65	47.27	0.27	0.05							3.46				9.92			1.93	0.43	1.34	11.99	79.03
9	78.3	Baumea, dense			0.54	0.18	0.03		10.30		0.06		40.07	0.15	4.62		0.09		0.77					0.36		37.31		0.06	0.50	0.10		1.36	96.50
8	79.0	Baumea, medium			1.56			0.16	14.81		23.44		5.17	2.83	14.84		0.50	0.73	0.80	0.08	0.12			0.44		3.77		0.27	8.69	0.36		3.19	81.78
7	79.3	Carex						0.00	0.22		0.12				0.01						0.00												0.36
7	79.6	Carex, grassy aquatics and sparse Baumea sp.			0.78						0.50		0.92								0.18					1.68			0.51				4.57
7	80.0	Aquatics with Carex									1.67			0.76															0.07				2.50
6	79.2	Baloskion							0.05		0.07										1.22			0.04					0.04				1.43
5	78.7	Baumea and Leptospermum, mixed			0.00	0.00							3.81	0.68	0.58	0.51										3.83		0.34	0.17	0.35		2.82	13.08
5	79.7	Baloskion and Leptospermum, mixed			0.02								0.02	0.66					1.50		0.18			0.13	0.94	0.03	0.04		0.78	0.01			4.32
5	79.8	Leptospermum											0.03											1.12					1.64	0.00			2.79
4	81.0	Baloskion, Leptospermum and blackberry, mixed																							3.68				0.80	0.00			4.48
4	81.3	Baumea, sparse											1.40		2.10											0.69			0.40			0.69	5.27
3	78.7	Leptospermum, with some Melaleuca and Eucalyptus			0.29				0.45		0.57		1.63		1.00		1.30			0.32	0.13					1.41			3.67	0.55		34.24	45.55
3	80.2	Leptospermum and Melaleuca, mixed									0.31		0.07		0.72		0.58		0.43	0.11	0.10			0.42				3.20	8.89	0.44		1.22	16.49
3	80.4	Grassland, some large Eucalypts	39.29		0.21	0.23				43.47			34.87	0.14	0.03				0.31							532.57			17.93	28.52	1.56	322.37	1,021.51
2	80.1	Eucalypt woodland with Leptospermum, Melaleuca and Acacia understory			0.21		0.01	0.01	5.25	0.02	0.43		5.37	0.71	26.68		12.20		16.91	0.37	6.30	0.26	0.85	34.38	1.35	32.45	0.07	16.94	359.61	8.50	1.63	82.35	612.85
1	94.1	Track			0.11				0.00		0.06	0.06	0.42		0.08		0.12	0.01	0.24	0.01	0.15		0.01	0.20	0.00	2.90		0.10	14.14	73.91		43.65	136.17
1	106.4	Agroforestry	0.00		0.85						0.09	0.19	1.85											0.90		2.74			2.07	25.22		917.85	951.76
0	82.4	Unknown acquatics			2.14				0.01	0.86	0.23		5.92		0.15			0.41	0.41	0.29	0.57		0.15	0.23		56.71		1.33	3.93	2.46	0.64	47.07	123.51
		Total area (ha)	39.29	0.02	6.72	1.59	0.05	0.17	31.47	44.78	27.54	0.90	148.85	6.21	50.86	0.51	14.80	1.15	21.37	1.18	8.96	3.71	1.02	38.22	5.97	687.06	0.10	22.23	425.79	140.90	5.16	1,468.96	

Figure 13. Tabulated change in vegetation community area for The Marshes from 1969 to 2013. Figures are hectares; for each row, shaded bars represent the proportionate change from the 1969 class to 2013 classes. Wetness score ranges from high (wetter) to low (drier); NA indicates that it was not possible to rank the relative wetness.

4.3.7Topperwein vegetation community change from 1969 to 2013

There is relatively little change in vegetation communities in the Topperwein wetland from 1969 to 2013 (Figure 14), but the mapped changes are all indicative of drying. The changes from ‘Open water’ to ‘Grassland, some large Eucalypts’ and ‘Exposed soil’ are indicative of significant drying that we have very high confidence in. The change from ‘Baumea, dense’ to ‘Baumea, Chorizandra sp and dry acquatics’ if accurate is probably a change to a dryer class. However, the ‘Baumea, Chorizandra sp and dry acquatics’ class could be confused with the ‘Baumea, dense’ class, so we only have moderate confidence in the accuracy of this change. Finally, the changes from ‘Grassland, some large Eucalypts’, ‘Eucalypt woodland with Leptospermum and Acacia’ and ‘Unknown open woodland’ to ‘Agroforrestry’ are all anthropogenically driven changes likely to indirectly reduce water availability for wetland vegetation in the region through increased evapotranspiration and interception. We have very high confidence in the mapping of these last changes.

2013

1969 Wetness score	Mean height above sea level (m)	Vegetation cover description	Exposed soil	Unknown wetland vegetation	Agriculturally utilised wetland	Irrigated pasture	Open water	Baumea, Chorizandra sp and dry aquatics	Elocharis sp	Baumea articulata	Leptospermum, Melaleuca and Baumea, mixed	Baumea, sparse dry	Baumea, dense dry	Baumea and other sedges, with sparse Leptospermum & red gums	Baumea arthrophylla	Leptospemum, Eucalyptus and red gum, sparse	Grassland, some large Eucalypts	Baumea, medium dry	Agroforestry	Eucalypt woodland with Leptospermum and Acaia	Total area (ha)
Wetness score			NA	NA	NA	NA	8	7	7	6	5	5	5	4	4	3	2	2	1	1	
	Mean height above sea level (m)		67.2	67.4	68.3	69.3	66.8	67.0	67.0	68.0	67.2	67.2	67.2	68.5	68.8	67.9	69.2	69.4	70.6	70.7	
NA	67.1	Unidentified wetland fringing vegetation						1.46						0.70		0.06					2.22
NA	67.2	Exposed soil	0.18											0.12		0.07					0.38
NA	68.3	Unknown wetland vegetation		11.01	11.63		1.19							0.86			23.61		10.59	4.73	63.63
NA	70.1	Track	0.04										0.02	0.82		0.77	24.20		5.83	2.78	34.46
8	68.0	Open water	0.13														0.20		0.00	0.01	0.34
7	67.0	Baumea, dense						6.85						0.06		0.01					6.92
7	67.0	Baumea, Chorizandra sp and dry aquatics						7.03	0.03			0.35		1.80		0.10	1.18	0.38	0.00	0.13	11.00
6	68.0	Baumea arthrophylla		0.05											0.53		0.09				0.67
5	68.8	Baumea, medium		0.42				0.01				0.71		2.41		6.06	2.17	13.48		0.05	25.30
4	67.2	Leptospermum, Melaleuca and Baumea, mixed									3.31						0.38		0.08	0.32	4.09
3	68.3	Baumea and other sedges, with sparse Leptospermum & red gums	0.71	0.25				0.18		0.23		0.01		45.99	0.31	16.22	0.35			3.77	68.01
3	68.4	Leptospemum, Eucalyptus and red gum, sparse												0.32		4.29	0.31			3.03	7.95
2	69.3	Grassland, some large Eucalypts		4.74	2.48	4.58		0.55						0.88	0.27	0.10	424.22		157.74	1.80	597.35
2	70.4	Eucalypt woodland with Leptospermum and Acaia				0.09		0.08			0.79					0.03	58.73		70.52	116.81	247.04
1	71.0	Agroforestry											1.93	2.11	0.91	0.31	9.89		388.46	0.07	403.70
1	71.3	Unknown open woodland															1.50		9.95	1.75	13.21
		Total area (ha)	1.06	16.47	14.11	4.67	1.19	16.14	0.03	0.23	4.10	1.06	1.95	56.07	2.02	28.02	546.83	13.87	643.19	135.26	

Figure 14. Tabulated change in vegetation community area for Topperwein from 1969 to 2013. Figures are hectares; for each row, shaded bars represent the proportionate change from the 1969 class to 2013 classes. Wetness score ranges from high (wetter) to low (drier); NA indicates that it was not possible to rank the relative wetness.

4.3.8 Trail Waterhole vegetation community change from 1969 to 2013

As with the Topperwein wetland, there are relatively few changes in vegetation communities in the Trail Waterhole from 1969 to 2013 (Figure 15), but the mapped changes are all indicative of drying. The change from ‘Baumea, sedges and dry aquatics’ to ‘Baumea and other sedges, with sparse Leptospemum & red gums’ is indicative of woody invasion of a formerly quite wet class, and we have high confidence in the mapping of this change. The change from ‘Dry aquatics with sparse Baumea’ to ‘Baumea and other sedges, with sparse Leptospermum & red gums’, ‘Leptospermum and Baumea, mixed’ and ‘Eucalypt woodland with Leptospermum and Acacia’ is a relatively small total area of change, but we have high confidence in the change mapping, and the changes are all indicative of drying. Finally, the change from ‘Grassland, some large Eucalypts’ to ‘Agroforrestry’ is an anthropogenically driven change, in which we have high confidence, that is likely to indirectly reduce water availability for wetland vegetation in the region through increased evapotranspiration and interception.

4.3.9 Summary of overall vegetation community change

In the four wetlands examined our mapping shows a significant change from wetter vegetation communities in 1969 to dryer vegetation communities in 2013. Our mapping also shows a significant increase agroforestry in the immediate vicinity of all four wetlands. This increase is likely to indirectly reduce water availability for vegetation in these wetlands through increased evapotranspiration and interception.

Finally, in some of the mapped changes were from dryer to wetter vegetation communities. However, in all cases these changes were much smaller in area than the concurrent drying changes.

Wetness score	Mean height above sea level (m)	Vegetation cover description (1969 \ 2013)	Agriculturally utilised wetland	Unknown wetland vegetation	Baumea articulata	Dry aquatics with sparse Baumea	Baumea, sedges and dry aquatics	Baumea and other sedges, with sparse Leptospermum & red gums	Leptospermum and Baumea, mixed	Eucalypt woodland with Leptospermum and Acaia	Grassland, some large Eucalypts	Track	Agroforestry	Vineyards	Total area (ha)
		Wetness score (2013)	NA	NA	5	4	4	3	3	2	1	1	1	1	
		Mean height above sea level (m) (2013)	67.6	68.8	67.6	67.5	67.5	67.9	68.0	68.6	69.5	69.7	69.9	70.8	
NA	68.1	Unknown shurbland					0.01	2.54	0.12		0.21		3.69		6.58
NA	68.2	Unknown wetland vegetation		1.42									0.04		1.47
NA	68.5	Agriculturally utilised wetland	9.27	0.69							2.06	0.36	2.65		15.02
4	67.8	Baumea, sedges and dry aquatics			1.66	2.51	7.76	18.78	2.86	3.46	0.47	0.07	1.11		38.67
3	67.9	Dry aquatics with sparse Baumea				0.10		0.25	0.12	0.16					0.63
2	68.6	Eucalypt woodland with Leptospermum and Acaia				0.12		0.71	0.22	23.07		0.30			24.42
1	69.5	Track		0.16				0.32	0.09	2.70	3.94	11.98	4.92		24.12
1	69.6	Agroforestry		1.26		0.00	0.28	0.85	0.43	0.19	0.25	9.50	425.47		438.22
1	70.2	Grassland, some large Eucalypts	2.67	0.64						1.05	74.99	5.37	152.30	1.64	238.66
		Total area (ha)	11.94	4.17	1.66	2.73	8.05	23.45	3.84	30.63	81.92	27.58	590.19	1.64	

Figure 15. Tabulated change in vegetation community area for Trail Waterhole from 1969 to 2013. Figures are hectares; for each row, shaded bars represent the proportionate change from the 1969 class to 2013 classes. Wetness score ranges from high (wetter) to low (drier); NA indicates that it was not possible to rank the relative wetness.

Section 5: Summary

This task had the following objectives:

3.1 Characterise wetland phenology (greenness) and trends in phenology and inundation at a landscape scale (from MODIS imagery for the period 2000 to end 2013)

3.1, Analysis 1 Trends and breaks in temporal greenness and inundation

3.1, Analysis 2 Temporal greenness clustering

3.2 Map the temporal inundation extent for 20 case study wetlands (from Landsat imagery for the period 1991 to 2012), and

3.3 Map the changes in vegetation communities from 1969 to 2013 for four case study wetlands

For component 3.1, Analysis 1 we extract temporal greenness and inundation profiles for 20 case study wetlands and then quantify the average seasons, long-term trends, and any significant breaks in those trends. Overall, this component reveals that most wetlands in the South East experienced reductions in greenness and inundation from 2003/04 to 2006/07, and then an increase in greenness and inundation until 2011, and then have again experienced a reduction in greenness and inundation from 2011 to the end of 2013. This component also provides more detailed insight into the inter- and intra-annual pattern of inundation and greenness for the case study wetlands and the region as a whole.

Component 3.1, Analysis 2 is a data-driven clustering of the landscape into areas of similar temporal greenness behaviour. This allows examination of the average seasonal greenness of wetlands and other major land cover types in the south east; and allows identification of areas of the landscape with similar temporal greenness behaviour to known wetlands. This analysis revealed that, when looking at the landscape as a whole, the case study wetlands had a similar temporal greenness signal to the suburban areas of Mt Gambier, much of the vineyards in the Coonawarra area, some swale areas throughout the south east, and large areas of relatively exposed soils in north east of the study area, east of Padthaway. Examination of average seasonal greenness profiles reveals that the wetlands class is amongst the lowest; greener than coastal dune vegetation, but lower greenness than forestry, native woody vegetation, irrigated pasture, and non-irrigated agriculture (except in summer, where non-irrigated agriculture is lower greenness).

Objective 3.2 aimed to map temporal inundation extent across the whole of the south east once every summer and winter from 1990 to present. However, cloud cover presented clear image acquisitions in some summers, and many winters. This component illustrates the large range of natural intra- and inter-annual variation in inundation extent over the whole South East; and reveals how much inundation can occur in wet years (e.g., 1992/93) and comparatively little inundation there was in the Millennium Drought (2002 – 2008).

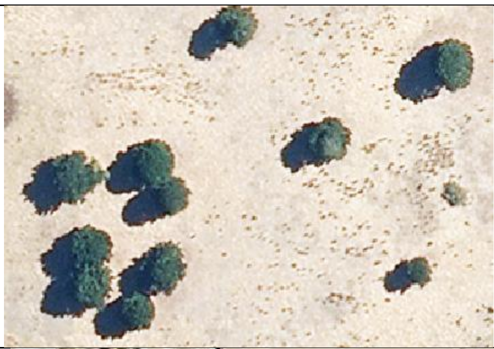
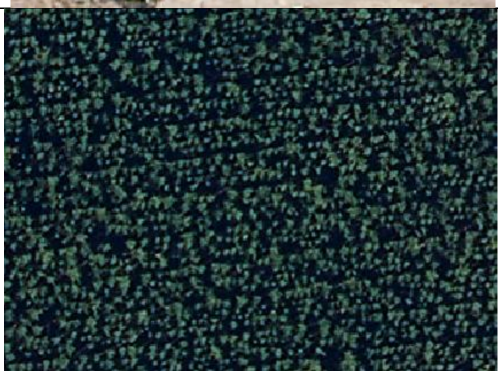
Finally, objective 3.3 mapped vegetation community extent in 1969 and 2013 for three case study wetlands, and for 1969, 1982, 2008 and 2013 for one more case study wetland. Vegetation communities were then given a wetness ranking, and the area and type (wetting, drying or static) of all mapped changes were documented. This component revealed that there was a significant change from wetter vegetation communities in 1969 to dryer vegetation communities in 2013, and a significant increase agroforestry in the immediate vicinity of all four wetlands. This increase is likely to indirectly reduce water availability for vegetation in these wetlands through increased evapotranspiration and interception.

Section 6: References

Thomas, R.F., Kingsford, R.T., Lu, Y., & Hunter, S.J. (2011). Landsat mapping of annual inundation (1979–2006) of the macquarie marshes in semi-arid australia. *International Journal of Remote Sensing, 32*, 4545-4569

Verbesselt, J., Hyndman, R., Newnham, G., & Culvenor, D. (2010). Detecting trend and seasonal changes in satellite image time series. *Remote Sensing of Environment, 114*, 106-115

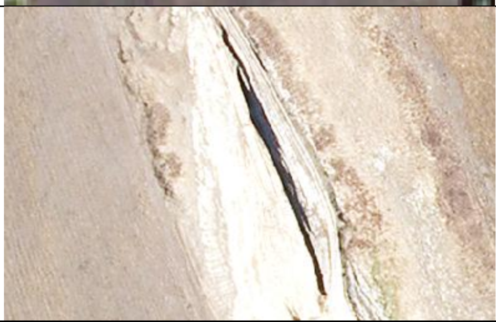
Section 7: Appendix 1. Vegetation digitisation visual key.

Vegetation Class	Visual Key	Colour and intensity	Texture
Acacia		Dark green.	Rough, circular shaped, closed canopy trees.
Agricultural property		Variable.	Angular, smooth roof tops surrounded by smooth pastures.
Agroforestry		Dark green.	Rough, linear plantings.
Aquatics		Pale brown, grey to green.	Mostly smooth, ground level, with slight patchiness.

Baloskion		Dark green to black.	Mottled, small clumps.
Baumea arthrophylla		Dark brown to black with a purple hue.	Mostly smooth with slight patchiness.
Baumea sp.		Light to dark brown.	Smooth with small mottled clumps.
Carex		Light green.	Smooth, large clumps.
Cladium procerum		Yellow green to pale green.	Slightly rough and clumped.

Cleared grassland		Pale beige to pale brown	Smooth.
Degraded wetland		Light to dark brown	Smooth to slightly patchy. Some may have remnant vegetation.
Dry aquatics		Light brown	Mostly smooth, low lying with slight roughness.
Elocharis sp.		Red brown to dark brown	Smooth, small, low lying and clumped
Eucalyptus sp.		Pale green.	Tall, open canopied tree with slightly rough texture.

Exposed soil		Pale to light beige.	Smooth.
Gahnia sp.		Light brown.	Slightly rough and very patchy.
Irrigated pasture		Green.	Smooth.
Leptospermum		Pale grey/green.	Patchy and uneven.
Melaleuca		Light green.	Medium height, open canopy trees with some roughness.

Open water		Dark blue/green to black.	Very smooth.
Phragmites sp.		Dark green to brown.	Very rough and clumped.
Quarry		White to pale beige.	Smooth with multiple levels.
Sedges		Light to dark green.	Rough and clumped.

Track		White, pale beige or light grey.	Linear and smooth.
Trackside vegetation		Light brown to dark green.	Variable clumped and patchy, mixed vegetation.
Typha		Pale green/brown.	Slightly rough and clumped.
Vineyards		Green to brown.	Linear.

Section 8: Appendix 2. Wetland Phenology Analysis 1: Temporal greenness and inundation, results

8.1.1.1 All wetlands combined, inundation and greenness

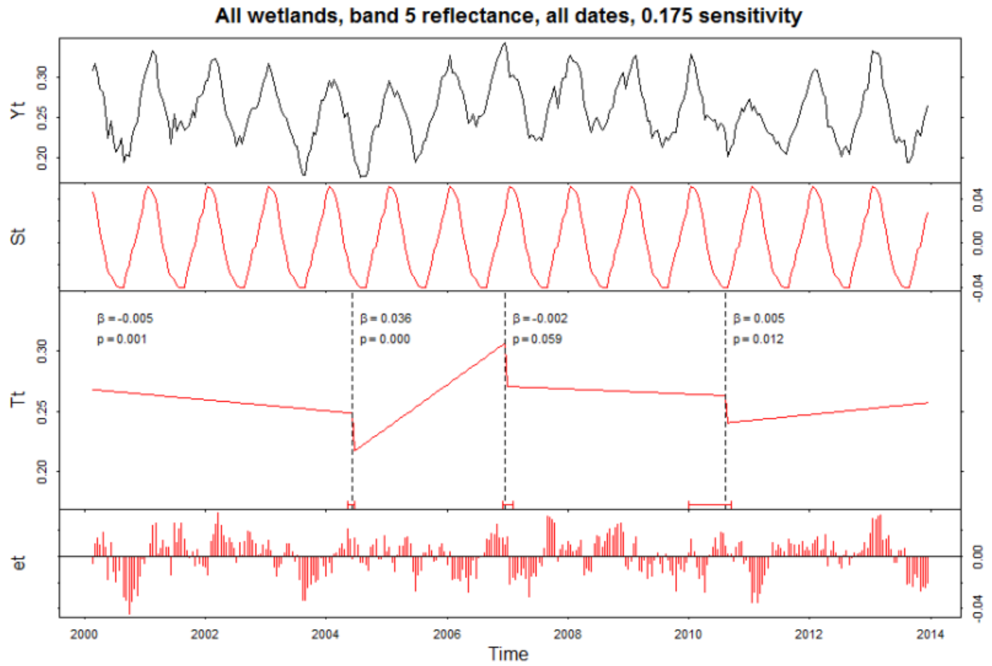


Figure 16. All wetlands combined Band 5 reflectance, as an indicator of inundation. Data profile (Yt); average season component (St); trend and break component (Tt); and the residual component (et). Low values indicate more extensive inundation, high values indicate less inundation.

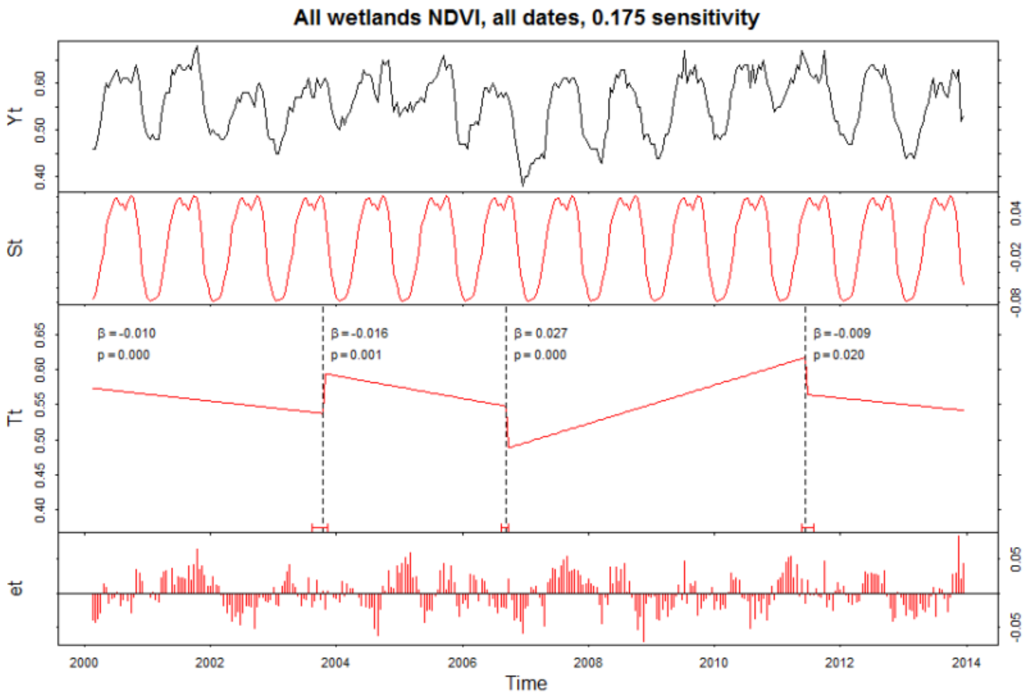


Figure 17. All wetlands combined NDVI, an indicator of vegetation greenness. High values indicate dense or strongly growing vegetation.

8.1.1.2 Big Dip Lake, inundation

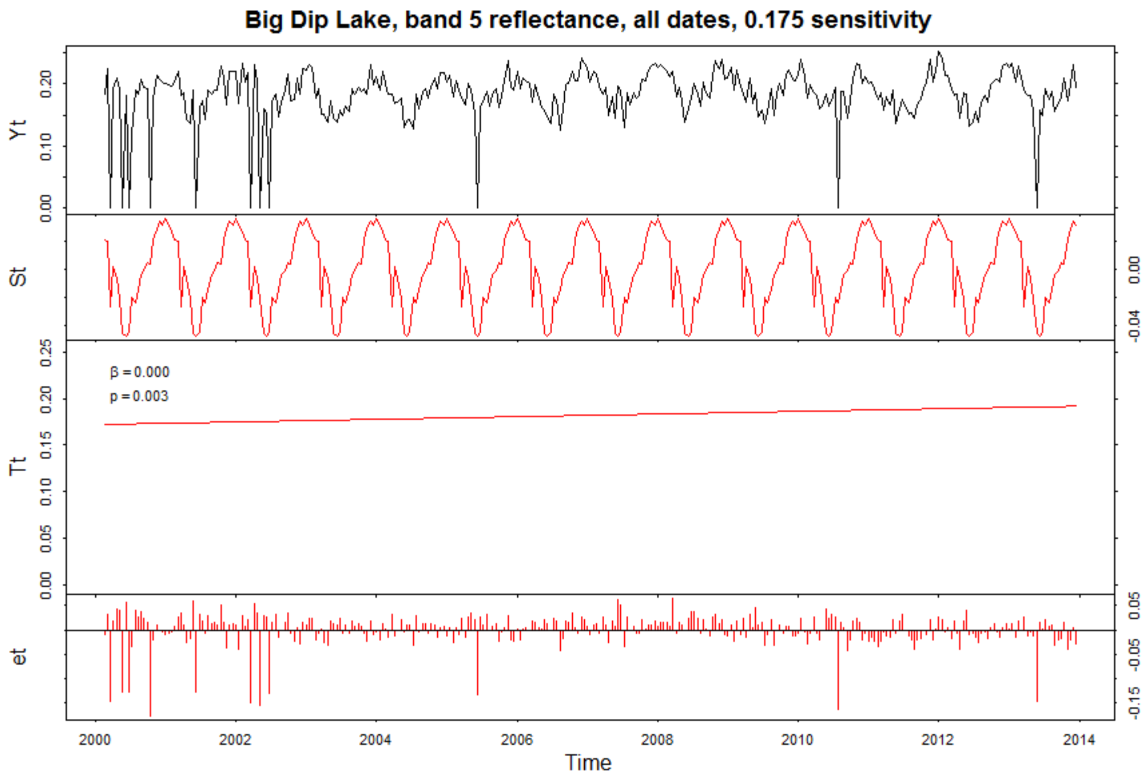


Figure 18. Big Dip Lake Band 5 reflectance, as an indicator of inundation. Data profile (Yt); average season component (St); trend and break component (Tt)); and the residual component (et). Low values indicate more extensive inundation, high values indicate less inundation.

8.1.1.3 Bimbimbi Swamp, inundation and greenness

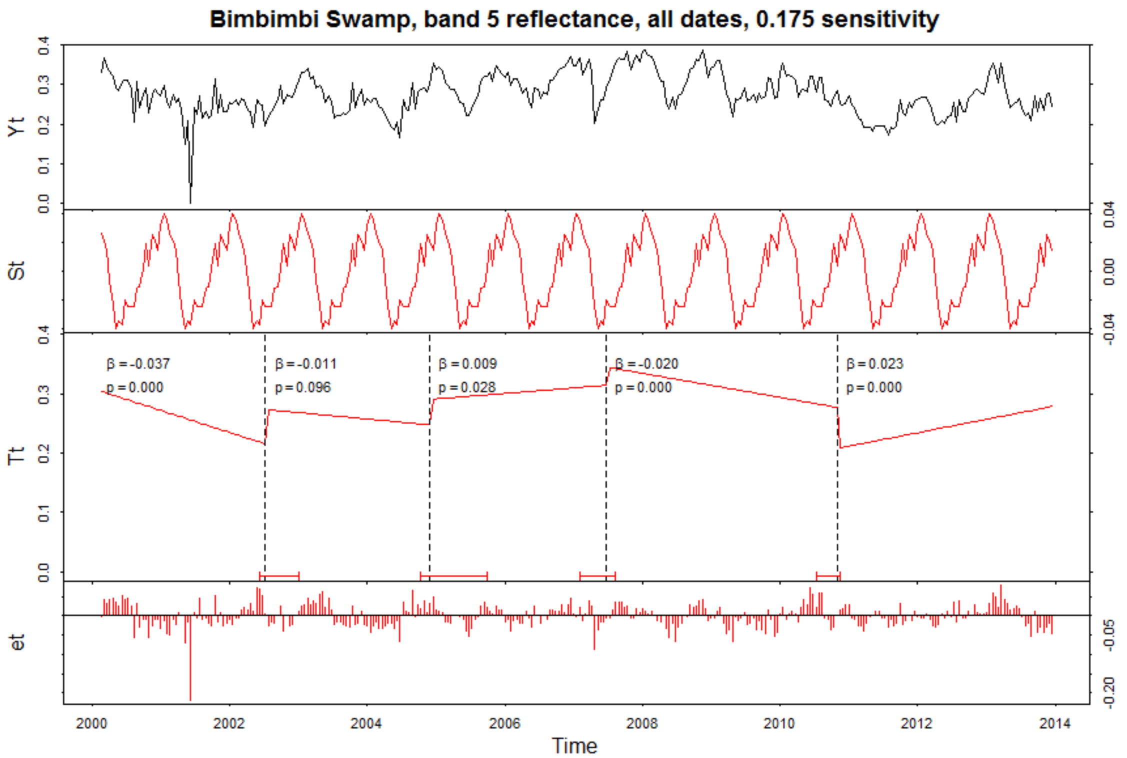


Figure 19. Bimbimbi Swamp Band 5 reflectance, as an indicator of inundation. Data profile (Yt); average season component (St); trend and break component (Tt)); and the residual component (et). Low values indicate more extensive inundation, high values indicate less inundation.

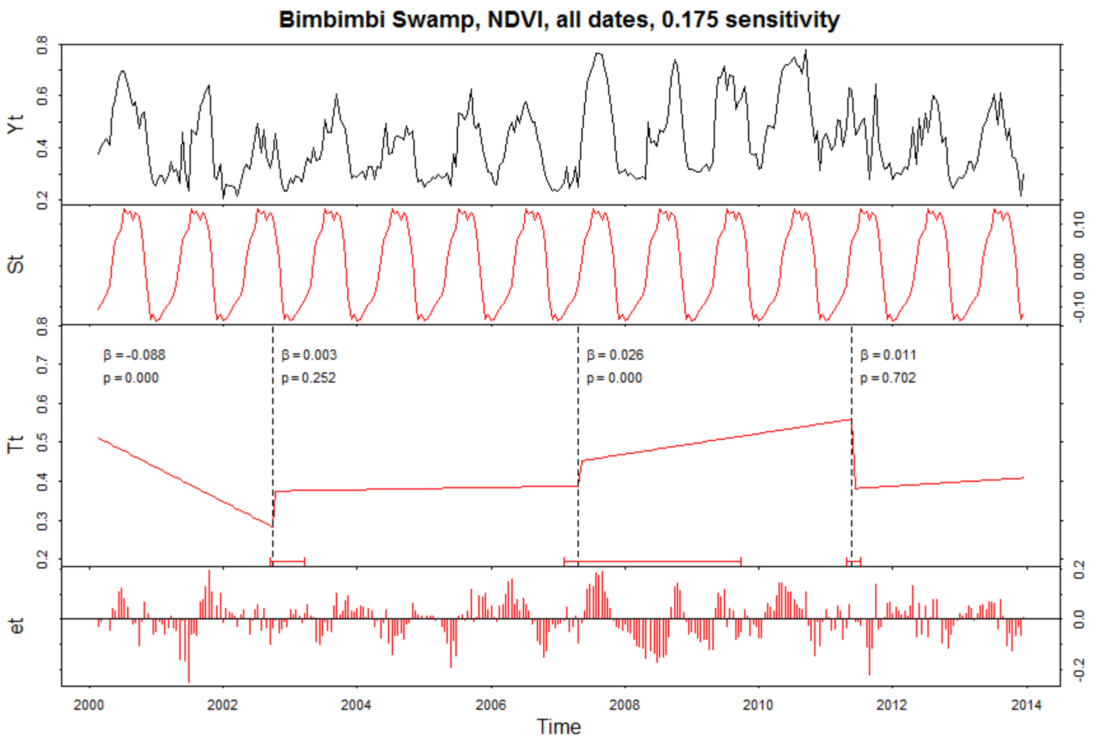


Figure 20. Bimbimbi Swamp NDVI, an indicator of vegetation greenness. High values indicate dense or strongly growing vegetation.

8.1.1.4 Bool and Hacks Lagoon, inundation and greenness

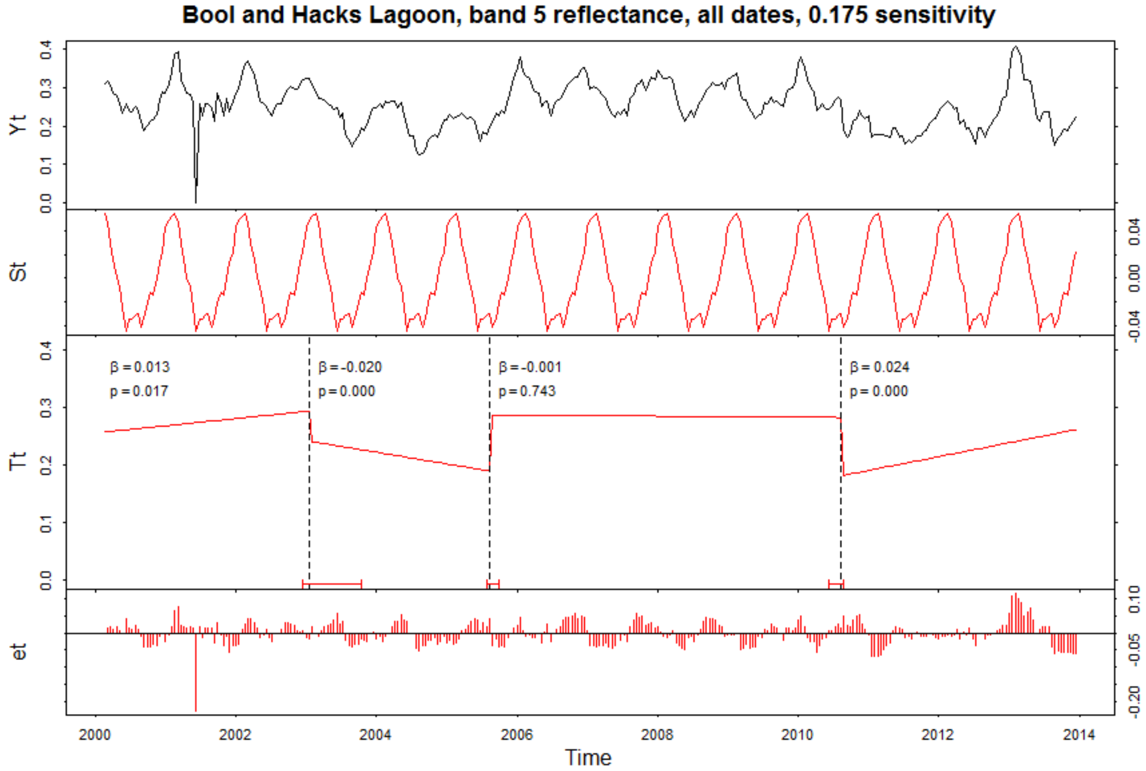


Figure 21. Bool and Hacks Lagoon Band 5 reflectance, as an indicator of inundation. Data profile (Yt); average season component (St); trend and break component (Tt)); and the residual component (et). Low values indicate more extensive inundation, high values indicate less inundation.

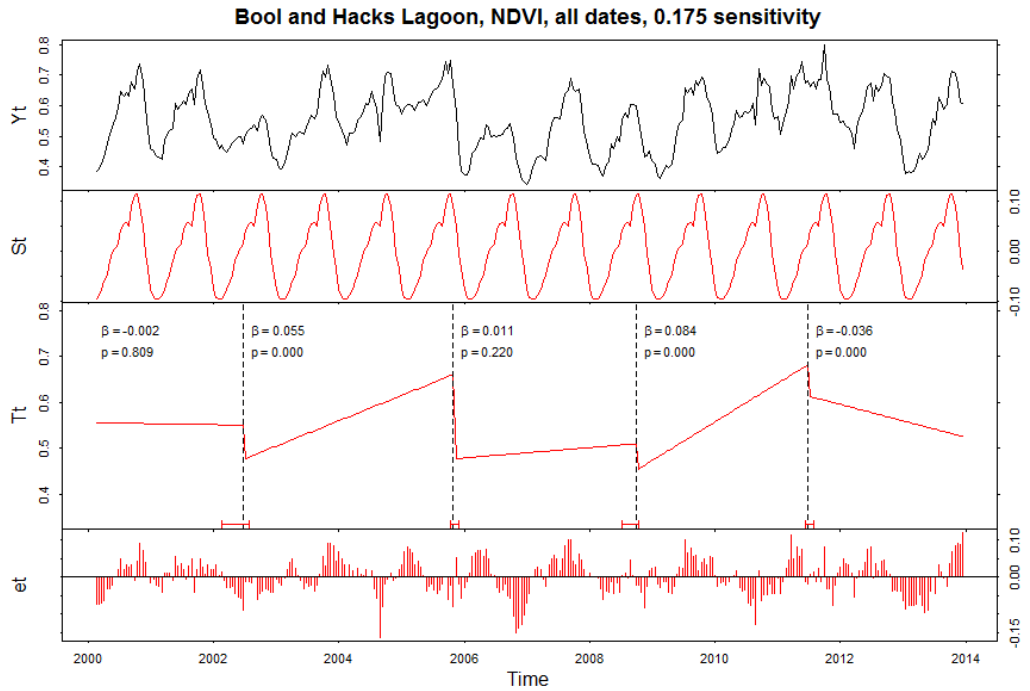


Figure 22. Bool and Hacks Lagoon NDVI, an indicator of vegetation greenness. High values indicate dense or strongly growing vegetation.

8.1.1.5 Butchers Lake, inundation

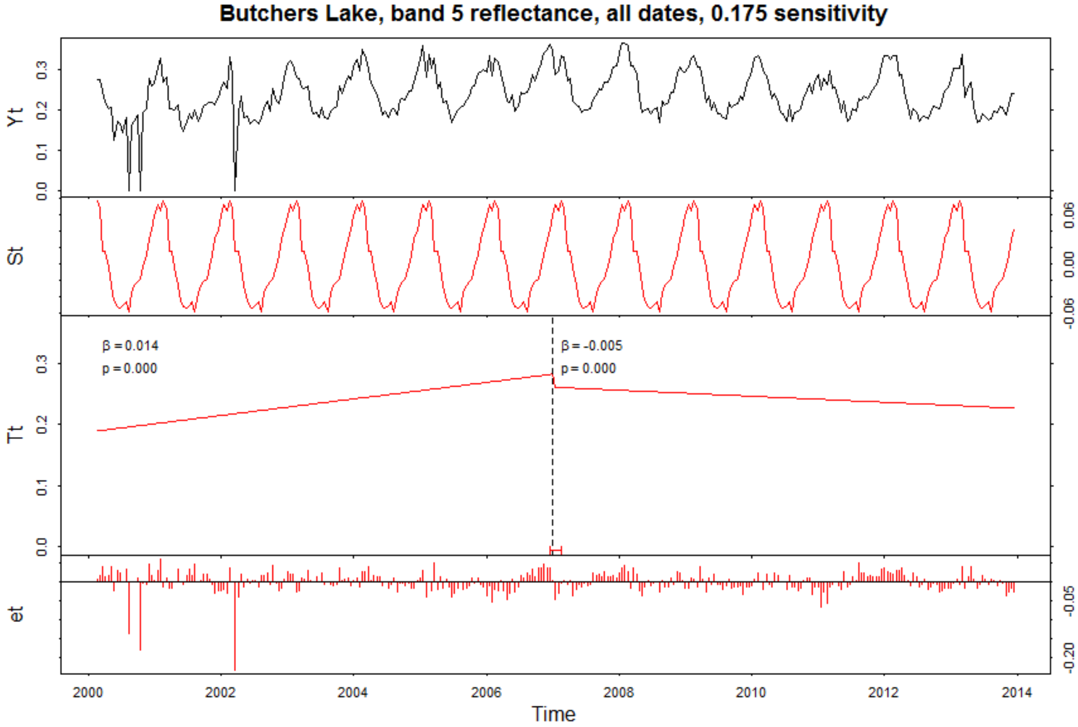


Figure 23. Butchers Lake Band 5 reflectance, as an indicator of inundation. Data profile (Yt); average season component (St); trend and break component (Tt)); and the residual component (et). Low values indicate more extensive inundation, high values indicate less inundation.

8.1.1.6 Cress Creek, greenness

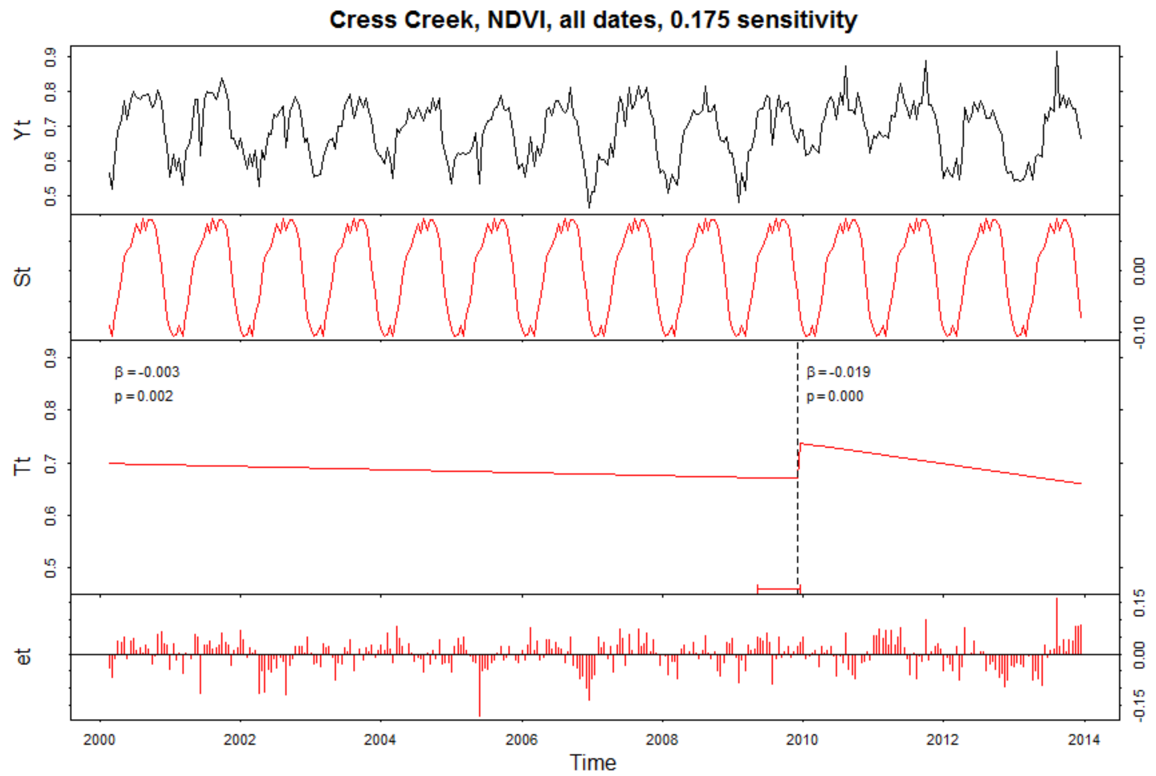


Figure 24. Cress Creek NDVI, an indicator of vegetation greenness. High values indicate dense or strongly growing vegetation.

8.1.1.7 Deadmans Swamp, , inundation and greenness

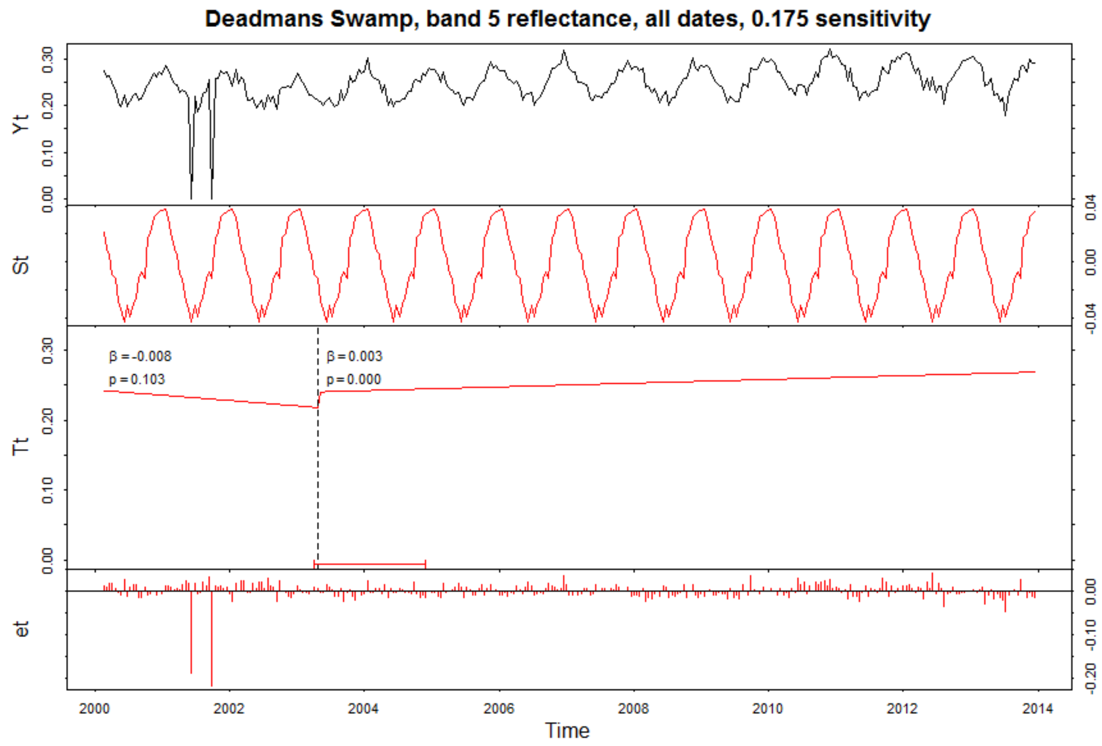


Figure 25. Deadmans Swamp Band 5 reflectance, as an indicator of inundation. Data profile (Yt); average season component (St); trend and break component (Tt)); and the residual component (et). Low values indicate more extensive inundation, high values indicate less inundation.

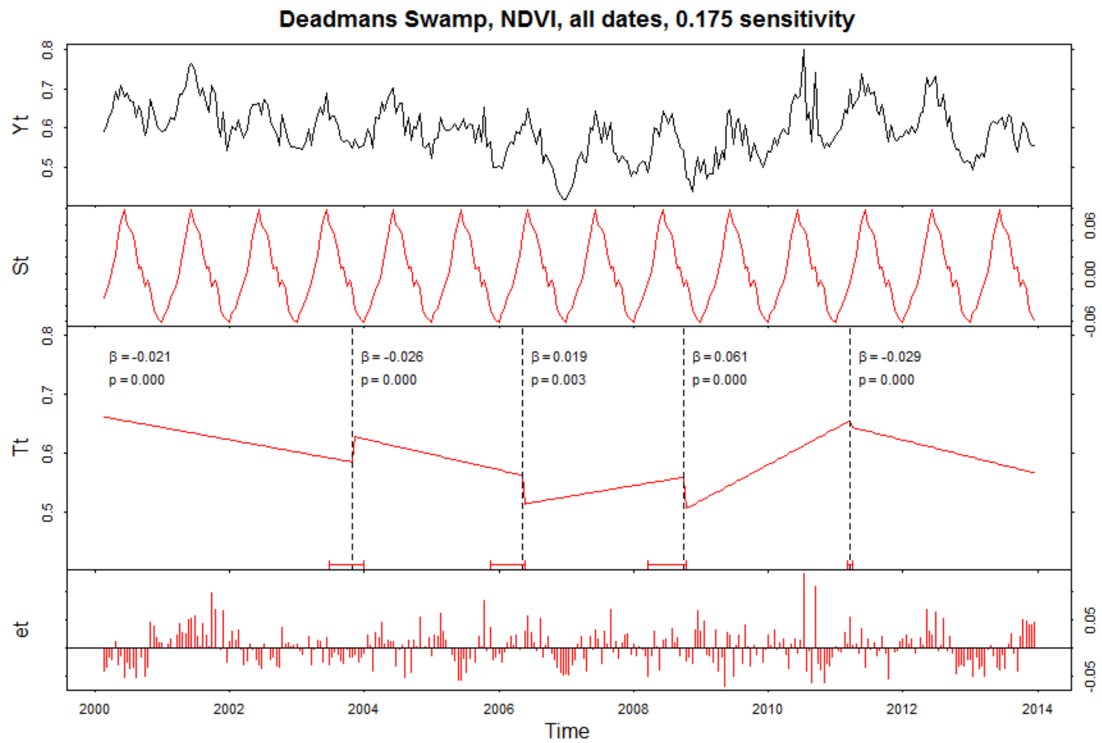


Figure 26. Deadmans Swamp NDVI, an indicator of vegetation greenness. High values indicate dense or strongly growing vegetation.

8.1.1.8 Ewens Ponds, inundation and greenness

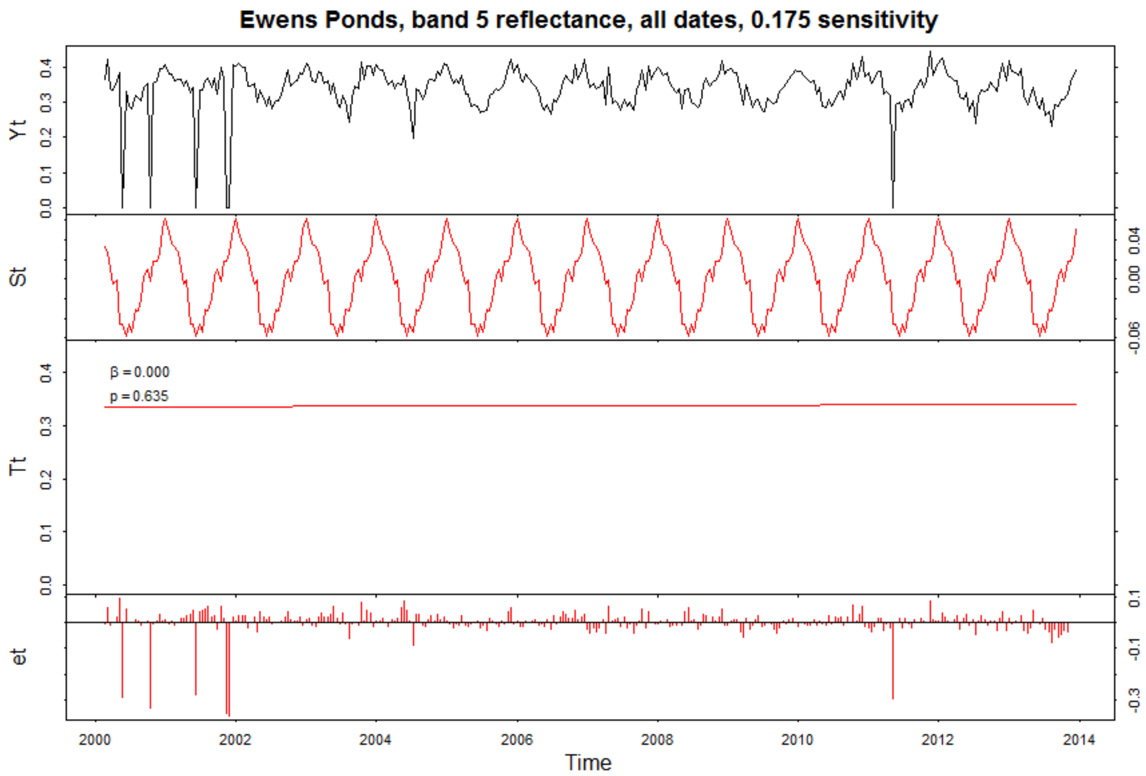


Figure 27. Ewens Ponds Band 5 reflectance, as an indicator of inundation. Data profile (Yt); average season component (St); trend and break component (Tt)); and the residual component (et). Low values indicate more extensive inundation, high values indicate less inundation.

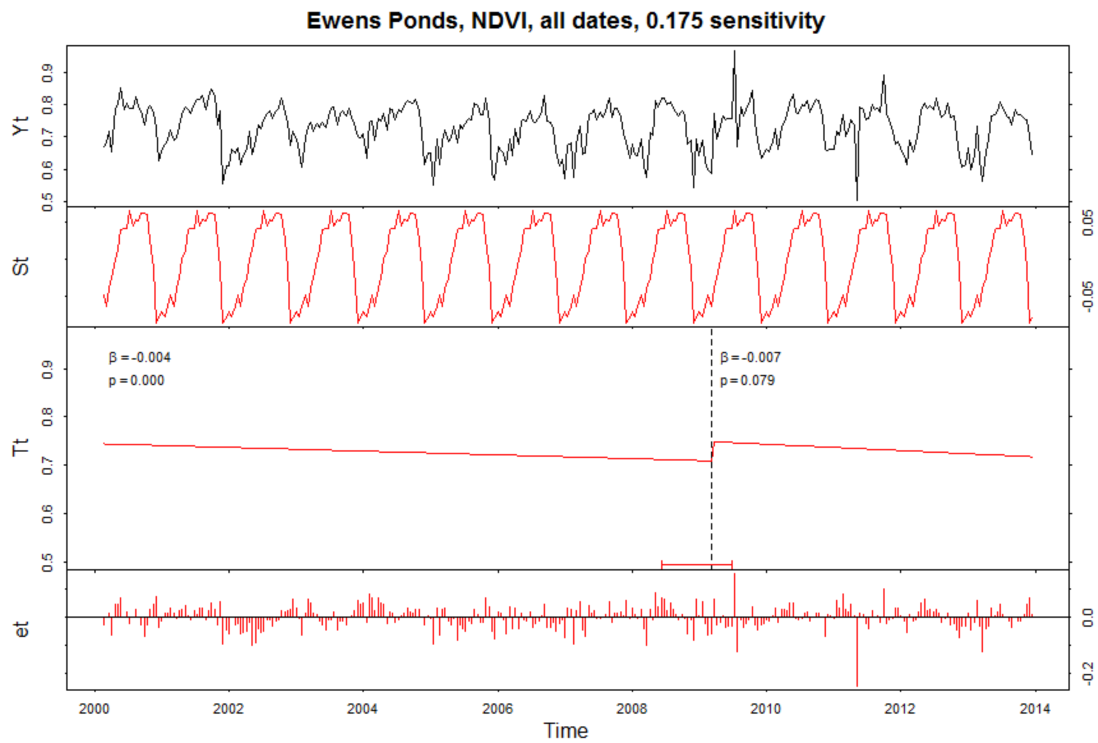


Figure 28. Ewens Ponds NDVI, an indicator of vegetation greenness. High values indicate dense or strongly growing vegetation.

8.1.1.9 Freshwater Lake, inundation

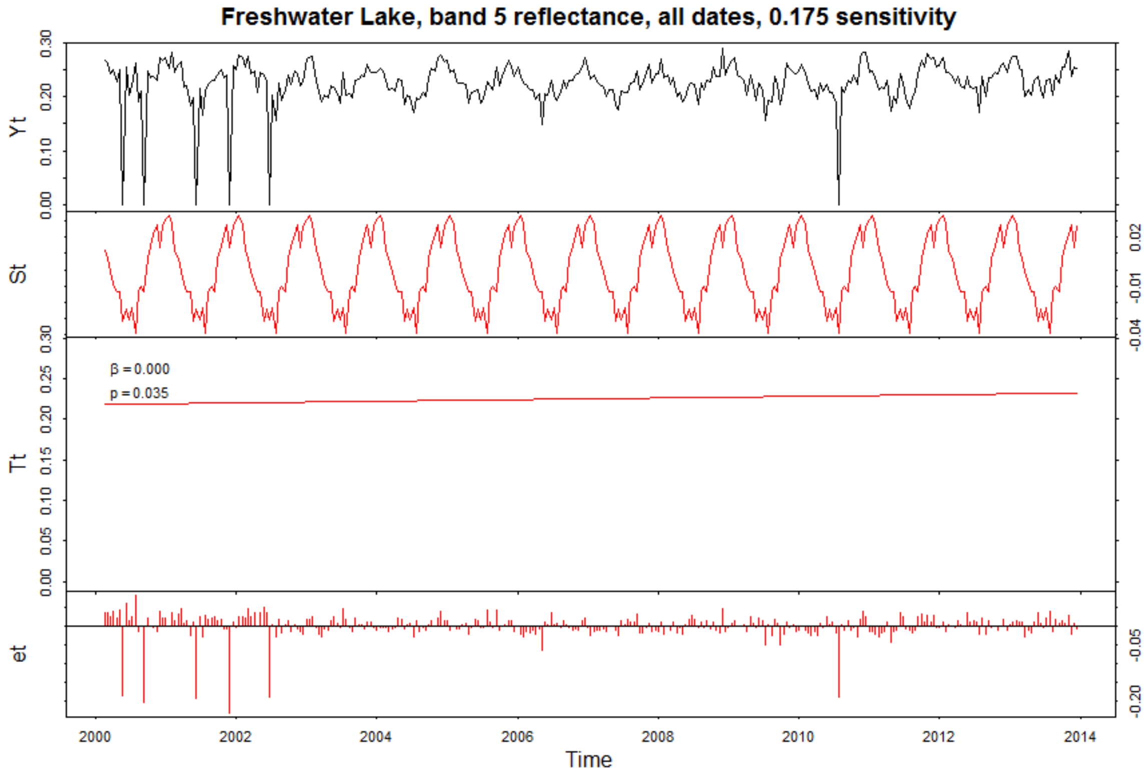


Figure 29. Freshwater Lake Band 5 reflectance, as an indicator of inundation. Data profile (Yt); average season component (St); trend and break component (Tt)); and the residual component (et). Low values indicate more extensive inundation, high values indicate less inundation.

8.1.1.10 Honans, inundation and greenness

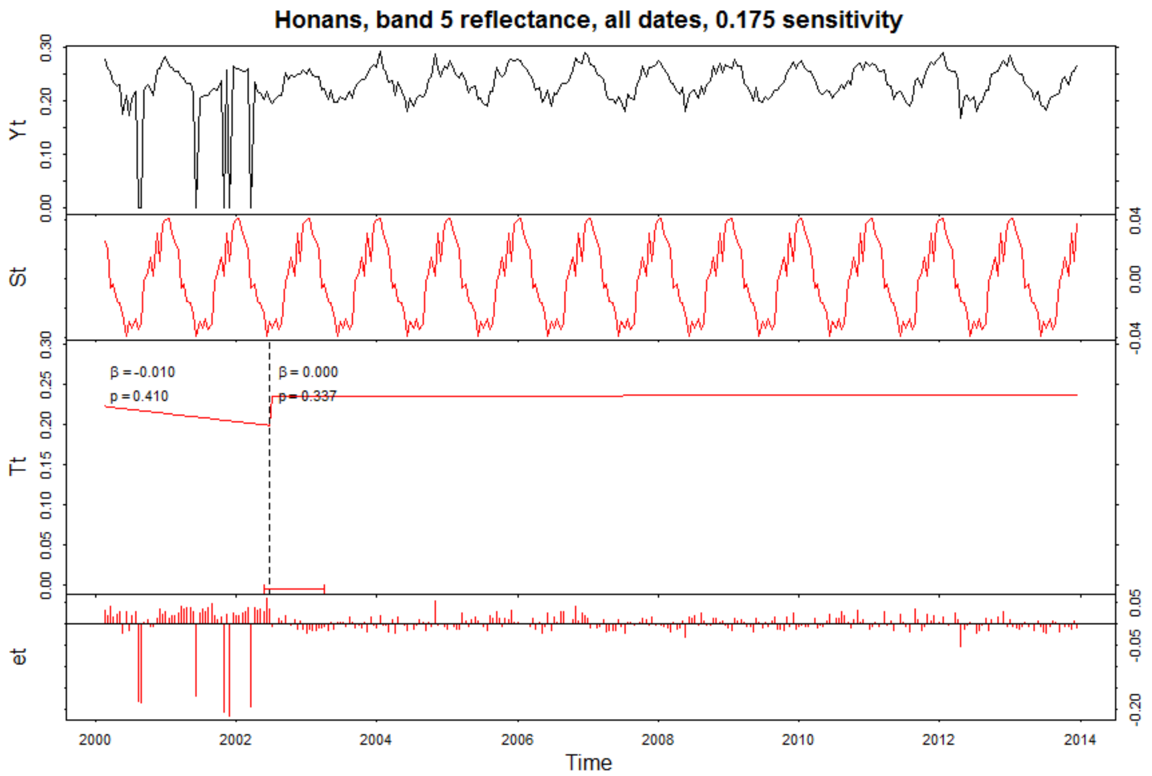


Figure 30. Honans Band 5 reflectance, as an indicator of inundation. Data profile (Yt); average season component (St); trend and break component (Tt)); and the residual component (et). Low values indicate more extensive inundation, high values indicate less inundation.

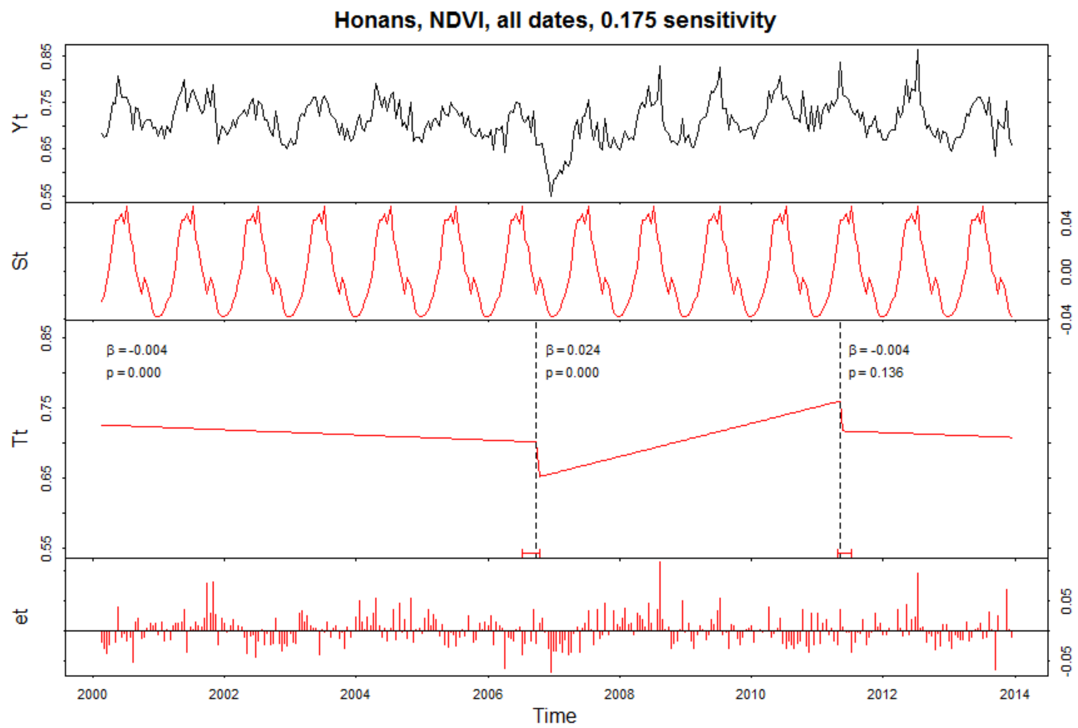


Figure 31. Honans NDVI, an indicator of vegetation greenness. High values indicate dense or strongly growing vegetation.

8.1.1.11 Kangaroo Flat, inundation and greenness

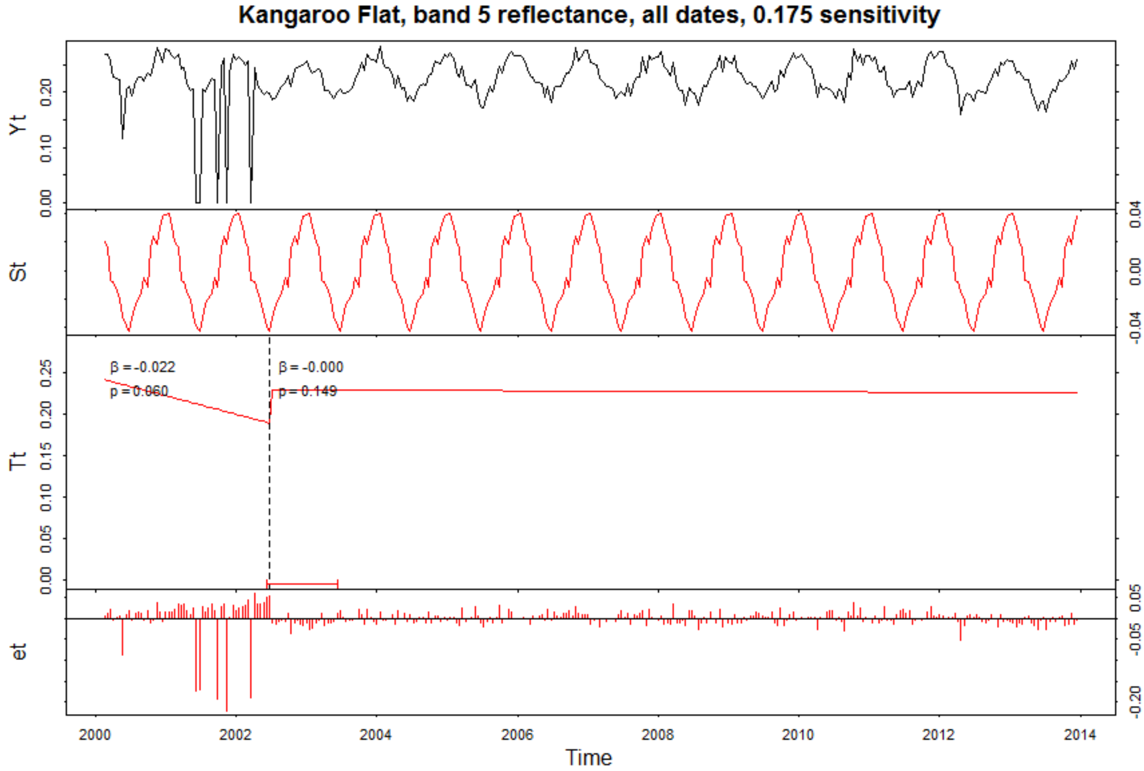


Figure 32. Kangaroo Flat Band 5 reflectance, as an indicator of inundation. Data profile (Yt); average season component (St); trend and break component (Tt)); and the residual component (et). Low values indicate more extensive inundation, high values indicate less inundation.

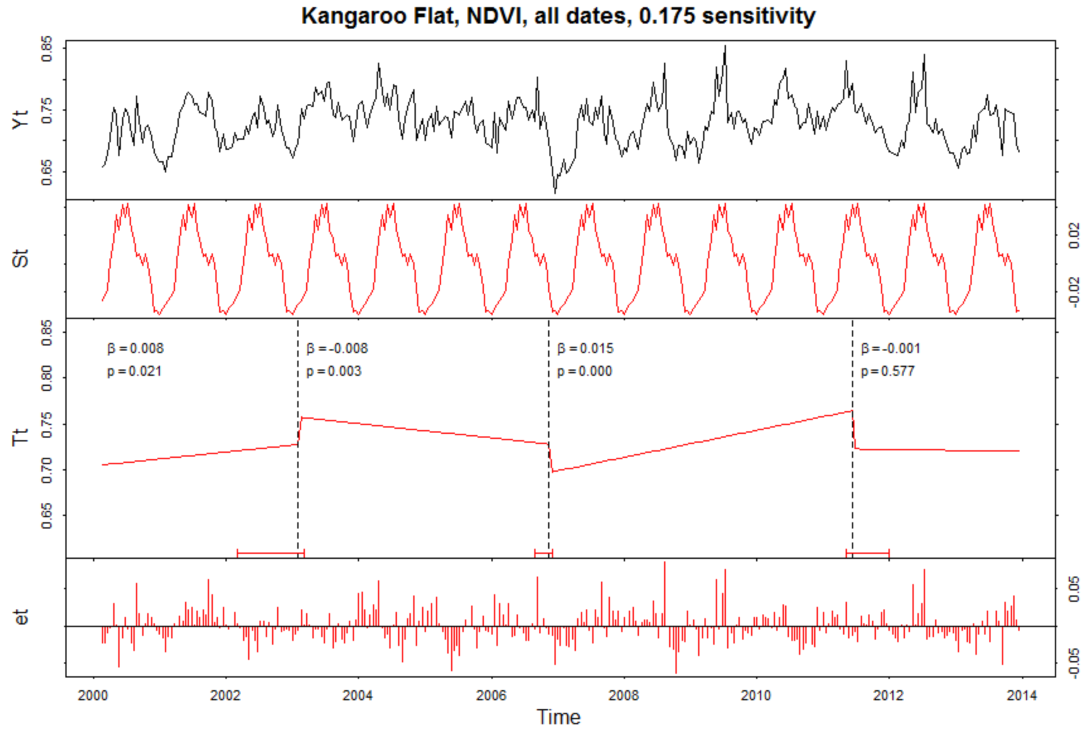


Figure 33. Kangaroo Flat NDVI, an indicator of vegetation greenness. High values indicate dense or strongly growing vegetation.

8.1.1.12 Lake Frome, inundation and greenness

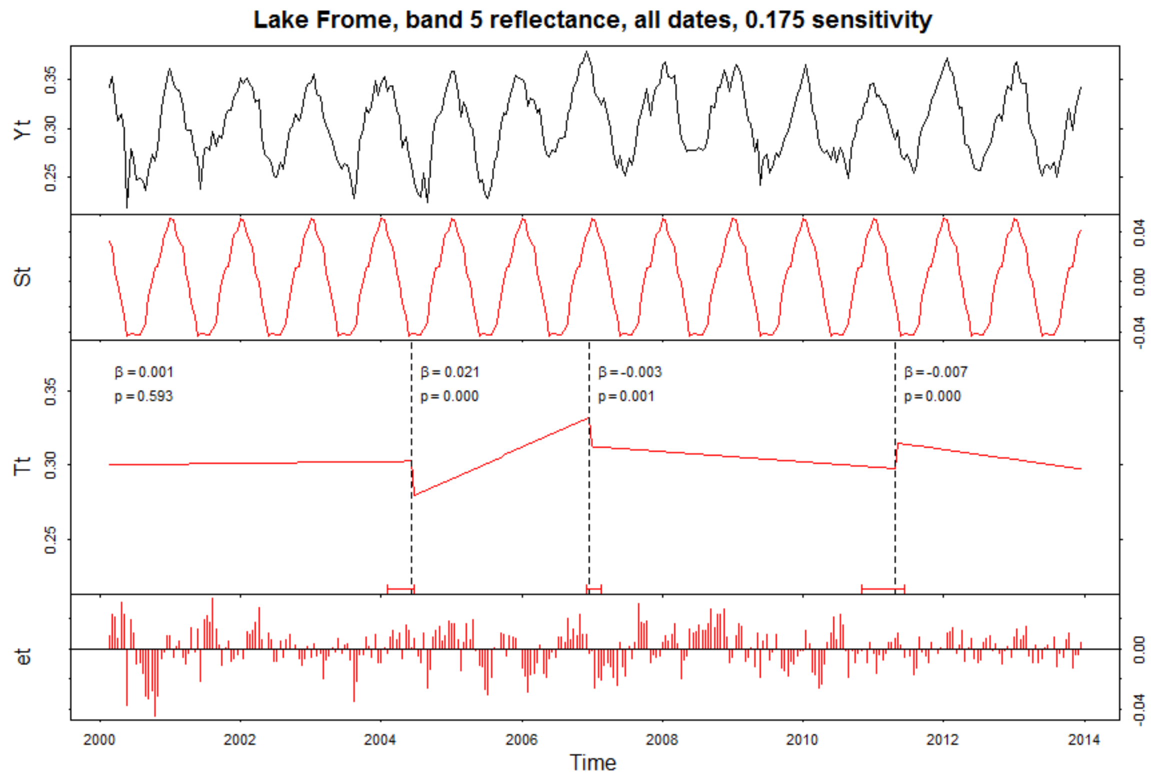


Figure 34. Lake Frome Band 5 reflectance, as an indicator of inundation. Data profile (Yt); average season component (St); trend and break component (Tt)); and the residual component (et). Low values indicate more extensive inundation, high values indicate less inundation.

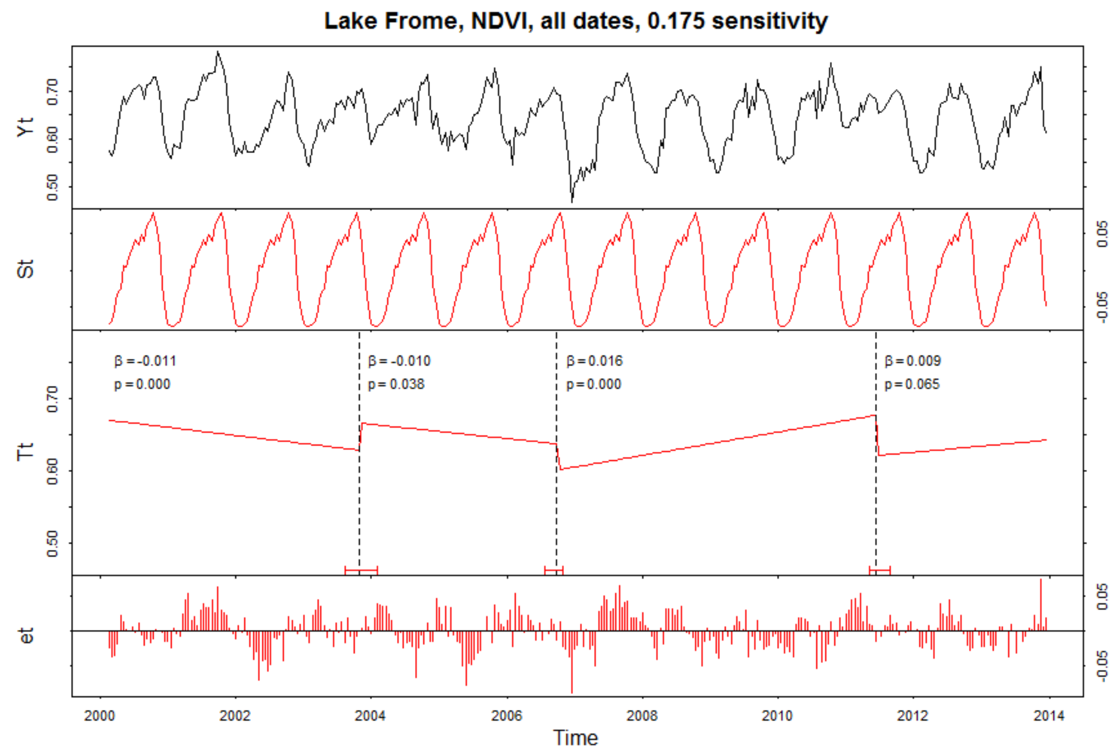


Figure 35. Lake Frome NDVI, an indicator of vegetation greenness. High values indicate dense or strongly growing vegetation.

8.1.1.13 Lake Robe, inundation

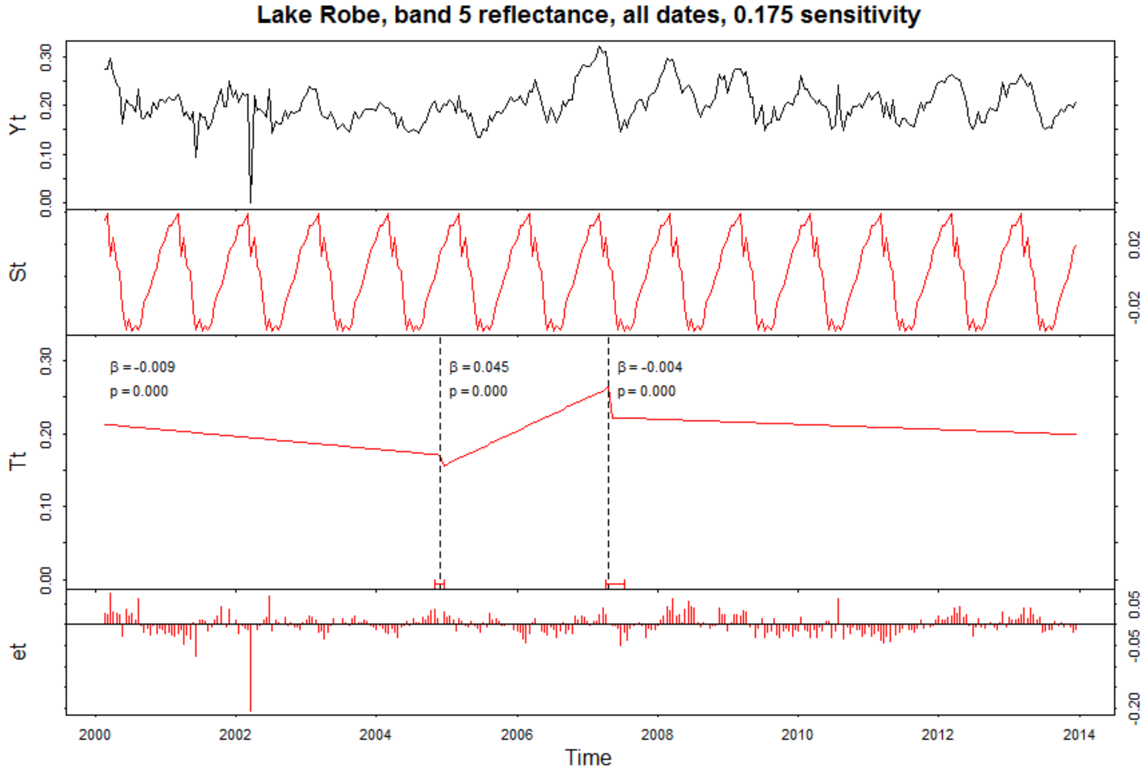


Figure 36. Lake Robe Band 5 reflectance, as an indicator of inundation. Data profile (Yt); average season component (St); trend and break component (Tt)); and the residual component (et). Low values indicate more extensive inundation, high values indicate less inundation.

8.1.1.14 Middlepoint Swamp, inundation and greenness

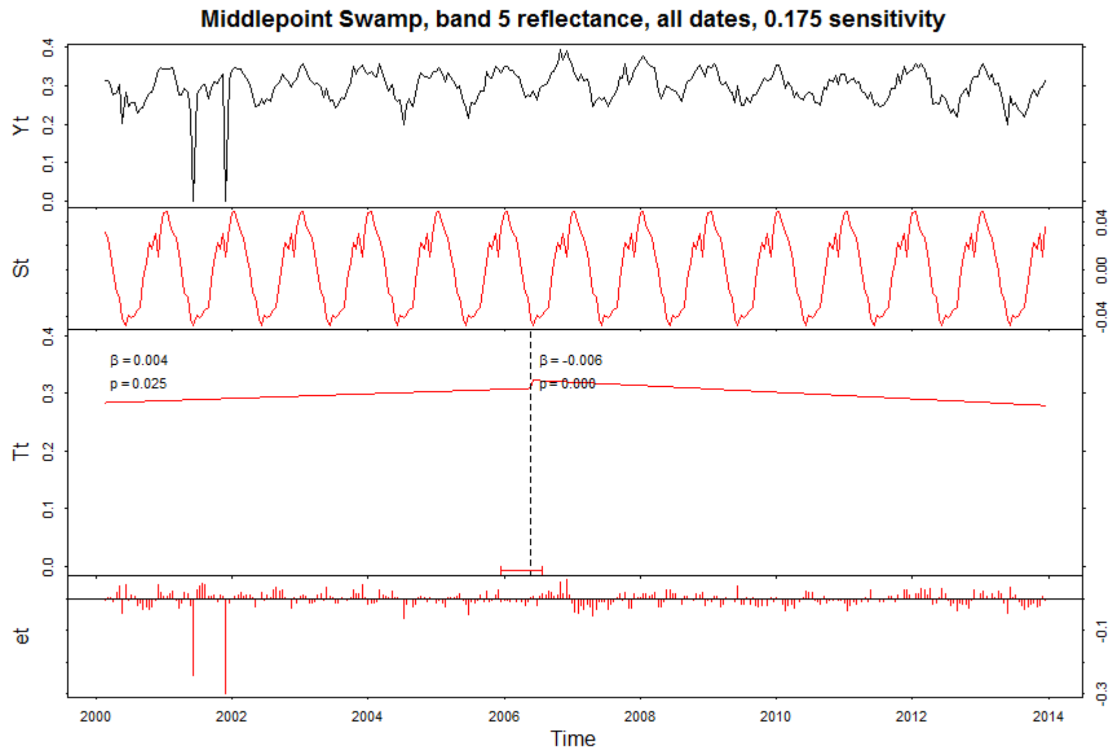


Figure 37. Middlepoint Swamp Band 5 reflectance, as an indicator of inundation. Data profile (Yt); average season component (St); trend and break component (Tt)); and the residual component (et). Low values indicate more extensive inundation, high values indicate less inundation.

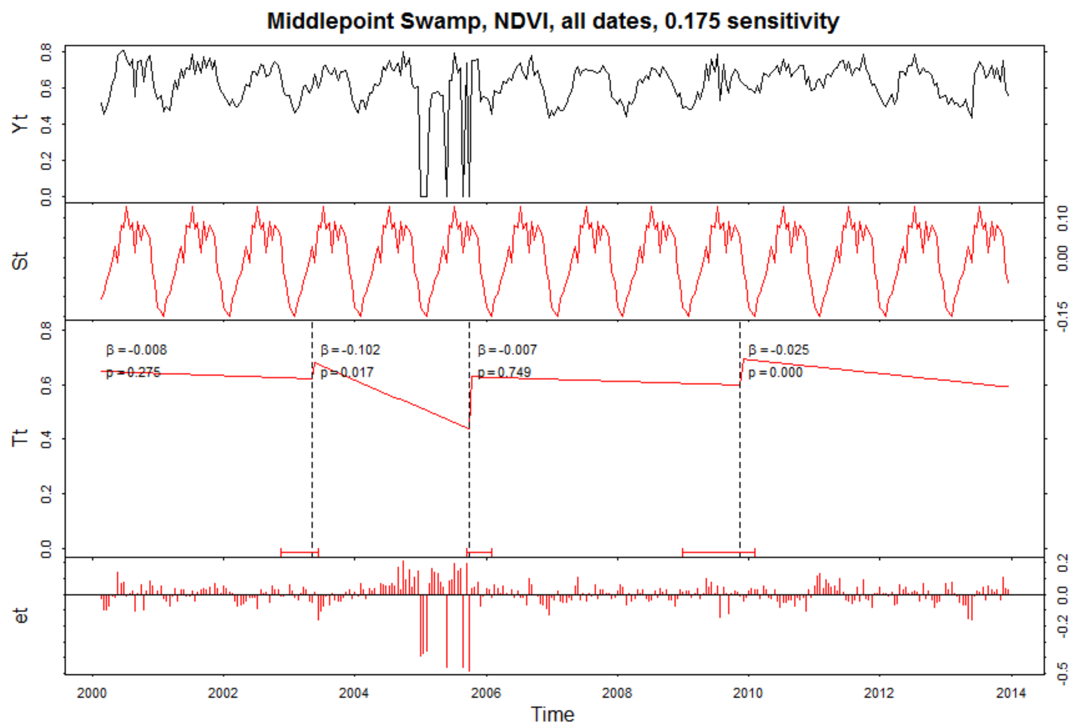


Figure 38. Middlepoint Swamp NDVI, an indicator of vegetation greenness. High values indicate dense or strongly growing vegetation.

8.1.1.15 Pick Swamp and Pic Ponds, inundation and greenness

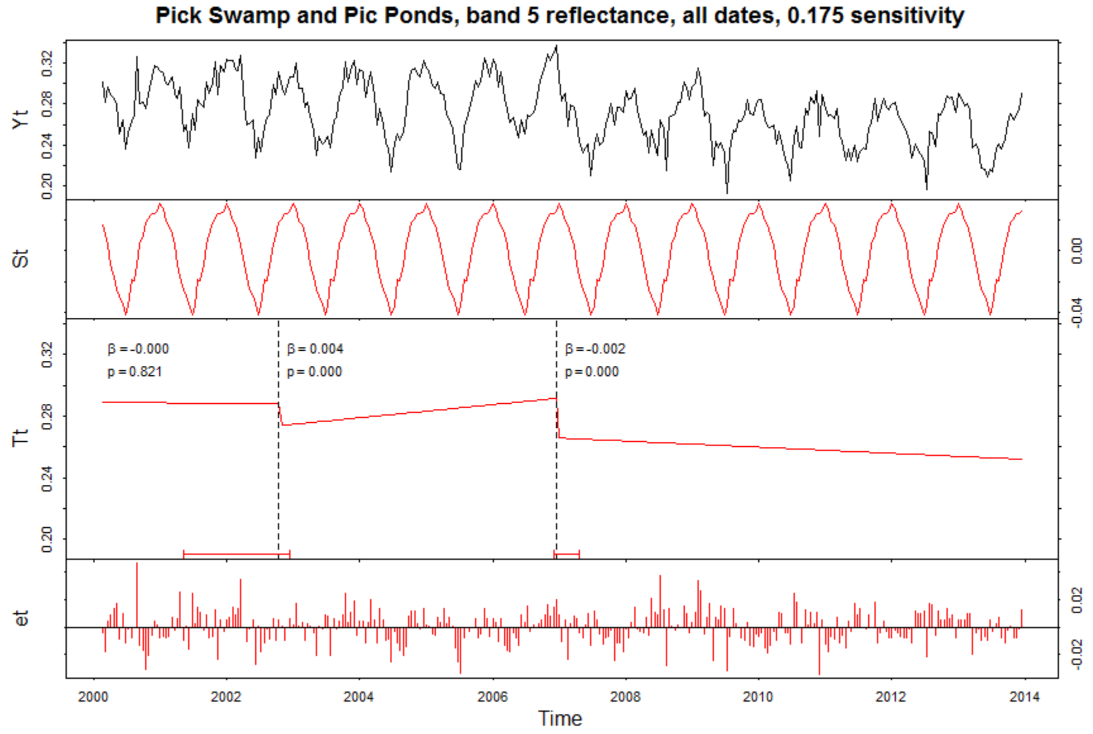


Figure 39. Pick Swamp and Pic Ponds Band 5 reflectance, as an indicator of inundation. Data profile (Yt); average season component (St); trend and break component (Tt)); and the residual component (et). Low values indicate more extensive inundation, high values indicate less inundation.

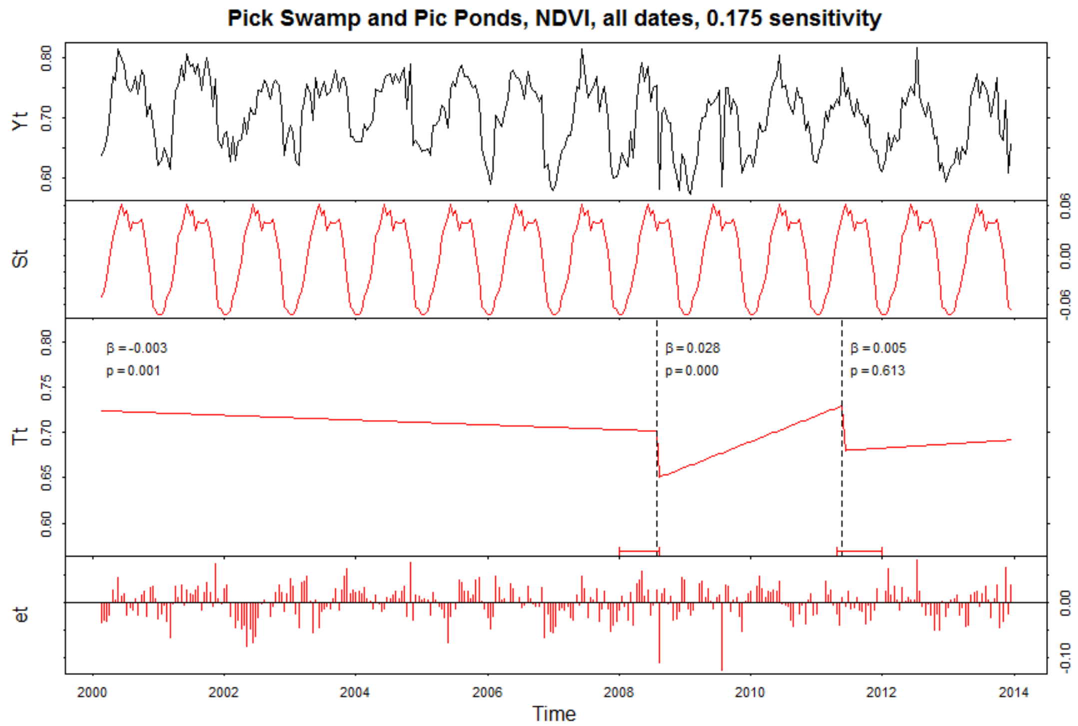


Figure 40. Pick Swamp and Pic Ponds NDVI, an indicator of vegetation greenness. High values indicate dense or strongly growing vegetation.

8.1.1.16 The Marshes, inundation and greenness

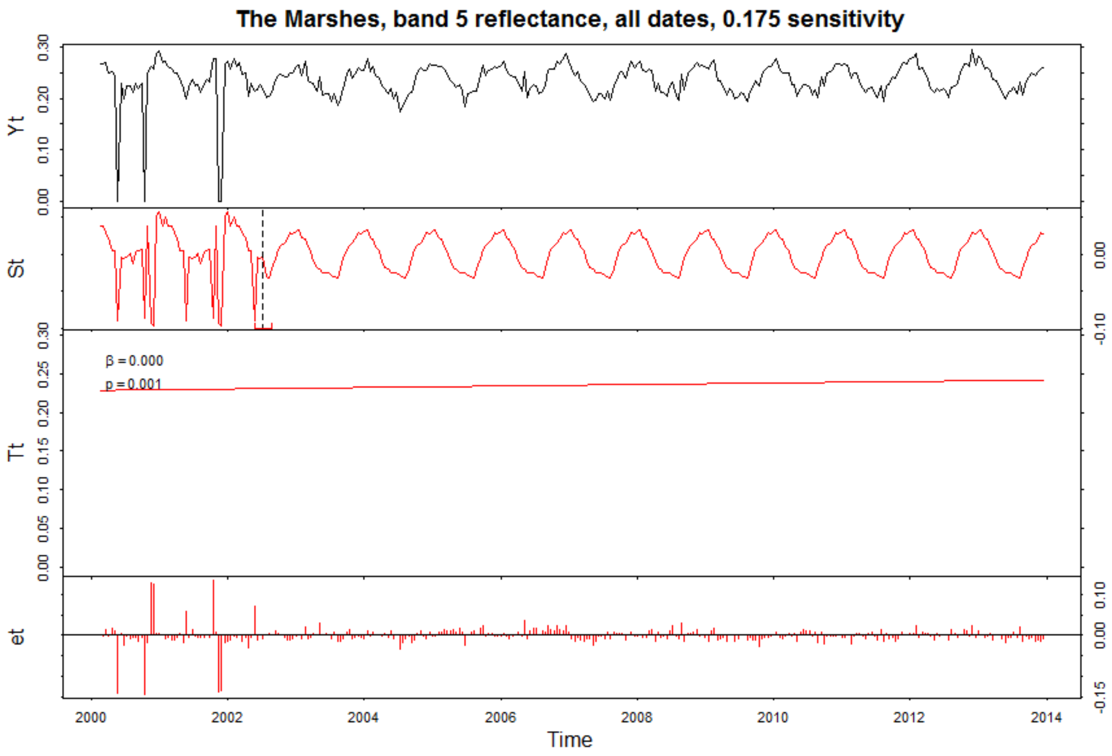


Figure 41. The Marshes Band 5 reflectance, as an indicator of inundation. Data profile (Yt); average season component (St); trend and break component (Tt)); and the residual component (et). Low values indicate more extensive inundation, high values indicate less inundation.

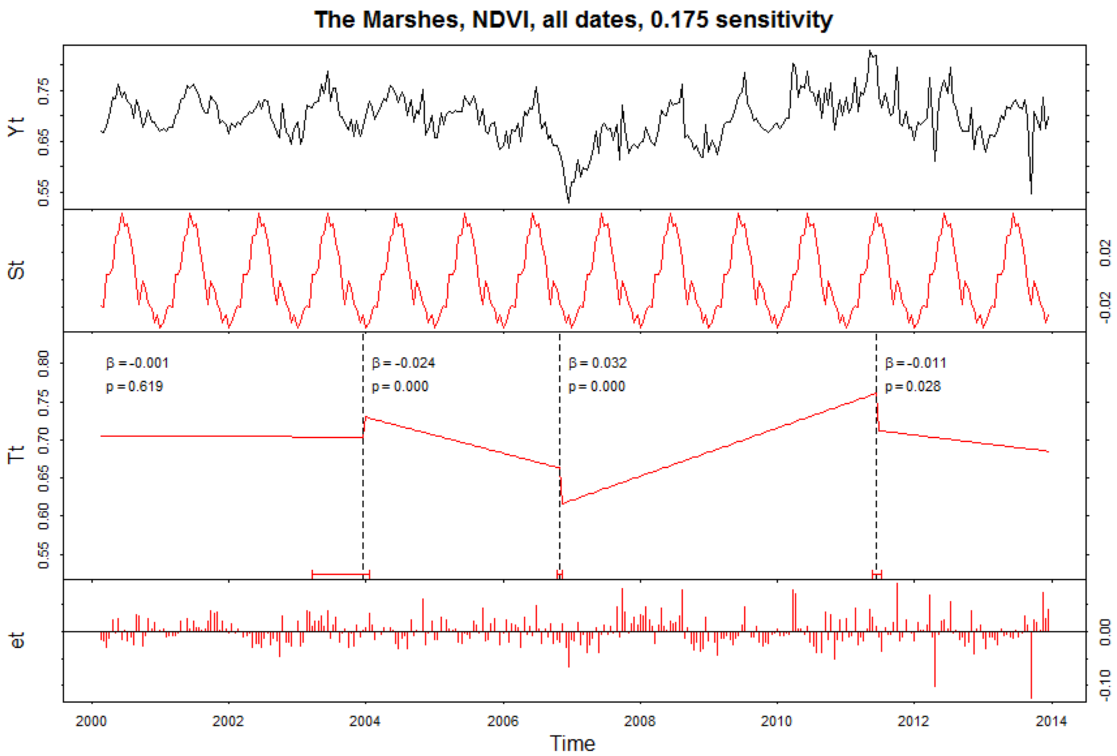


Figure 42. The Marshes NDVI, an indicator of vegetation greenness. High values indicate dense or strongly growing vegetation.

8.1.1.17 Topperwein, inundation and greenness

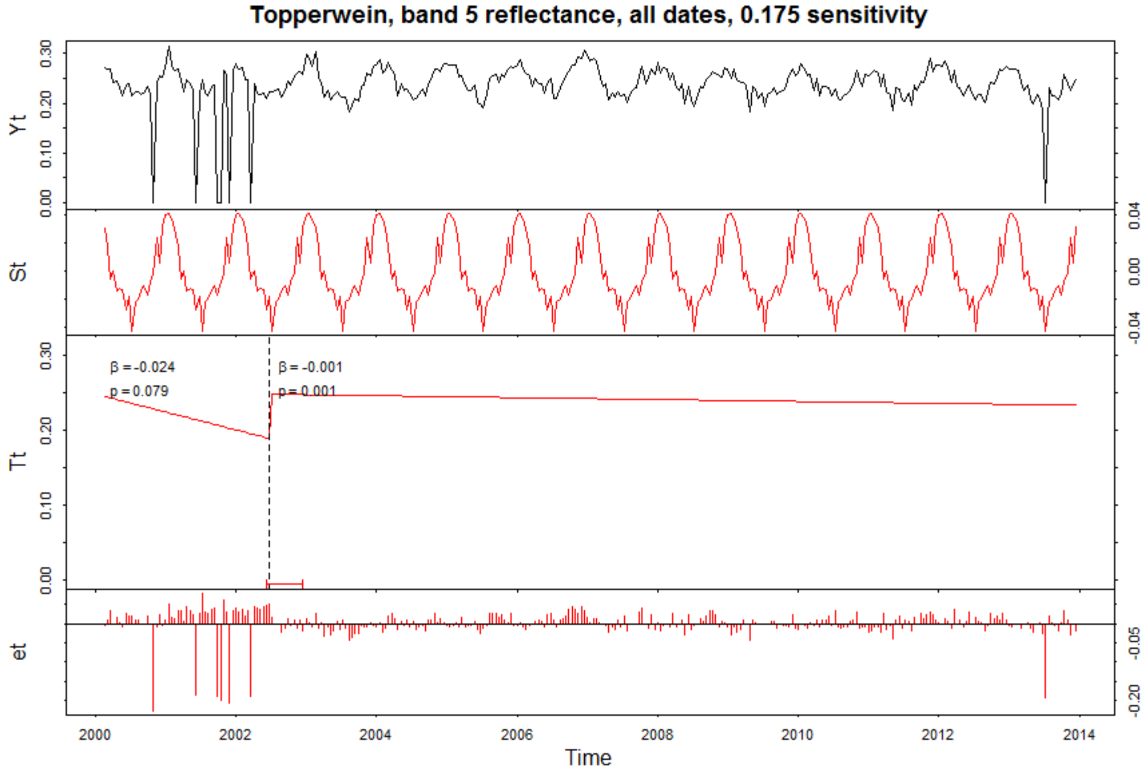


Figure 43. Topperwein Band 5 reflectance, as an indicator of inundation. Data profile (Yt); average season component (St); trend and break component (Tt)); and the residual component (et). Low values indicate more extensive inundation, high values indicate less inundation.

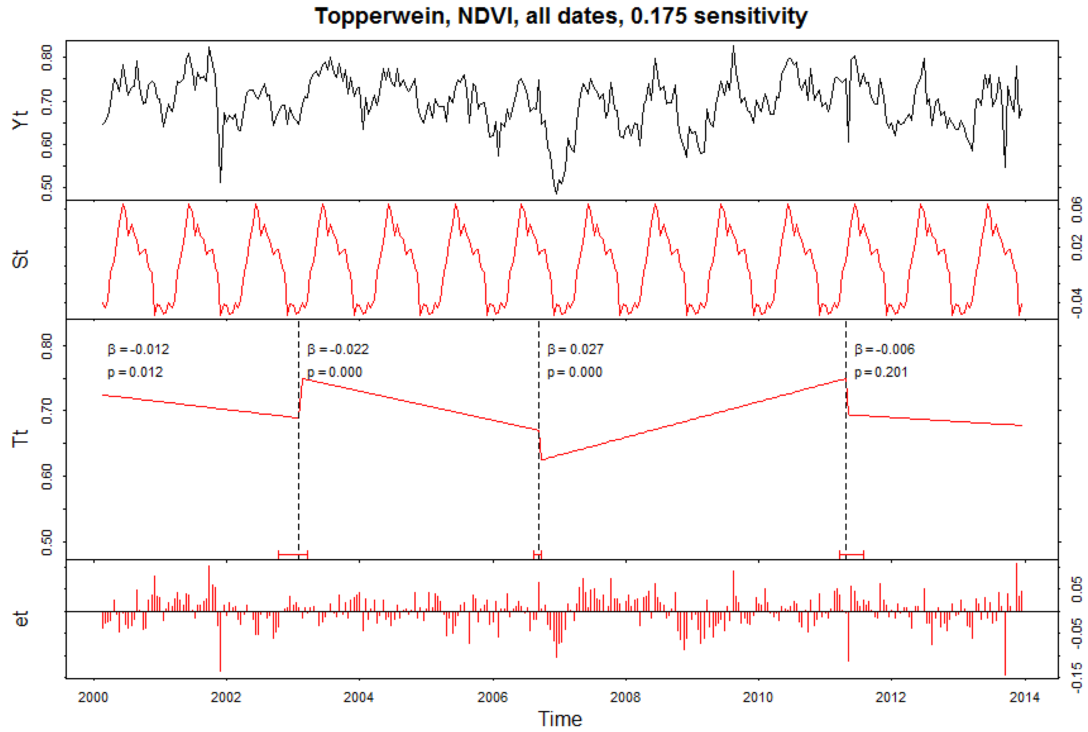


Figure 44. Topperwein NDVI, an indicator of vegetation greenness. High values indicate dense or strongly growing vegetation.

8.1.1.18 Trail Waterhole, inundation and greenness

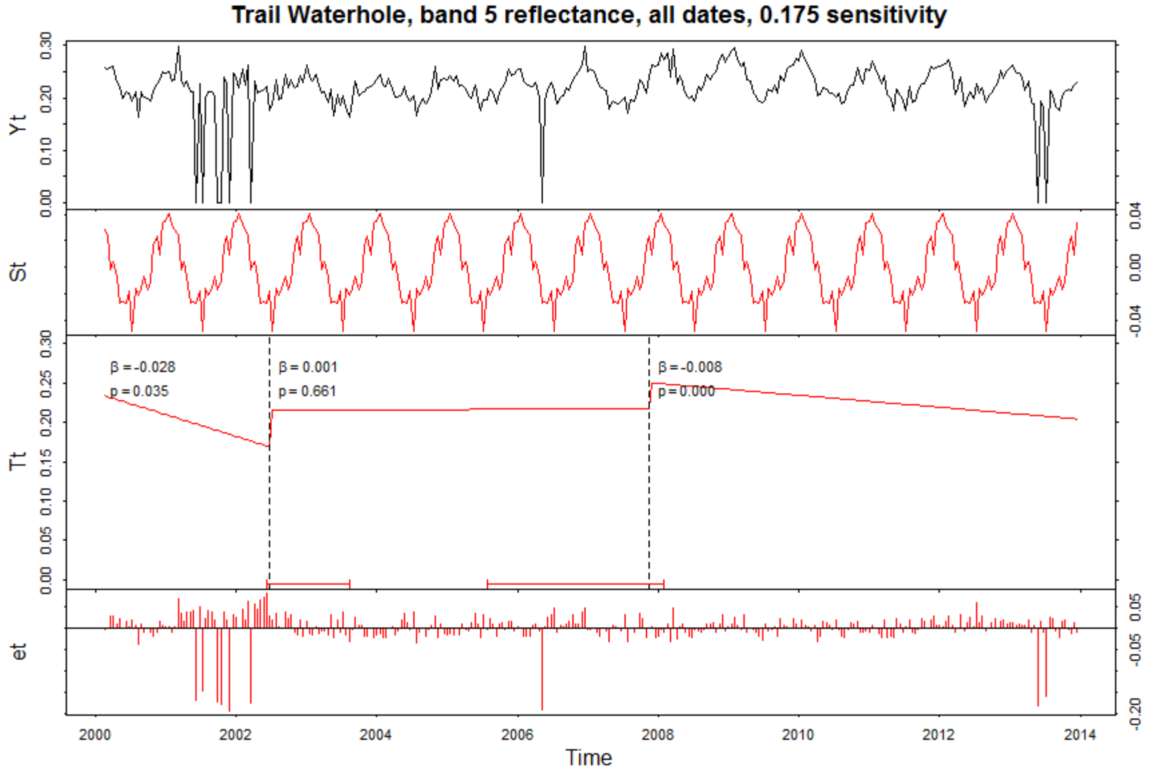


Figure 45. Trail Waterhole Band 5 reflectance, as an indicator of inundation. Data profile (Yt); average season component (St); trend and break component (Tt)); and the residual component (et). Low values indicate more extensive inundation, high values indicate less inundation.

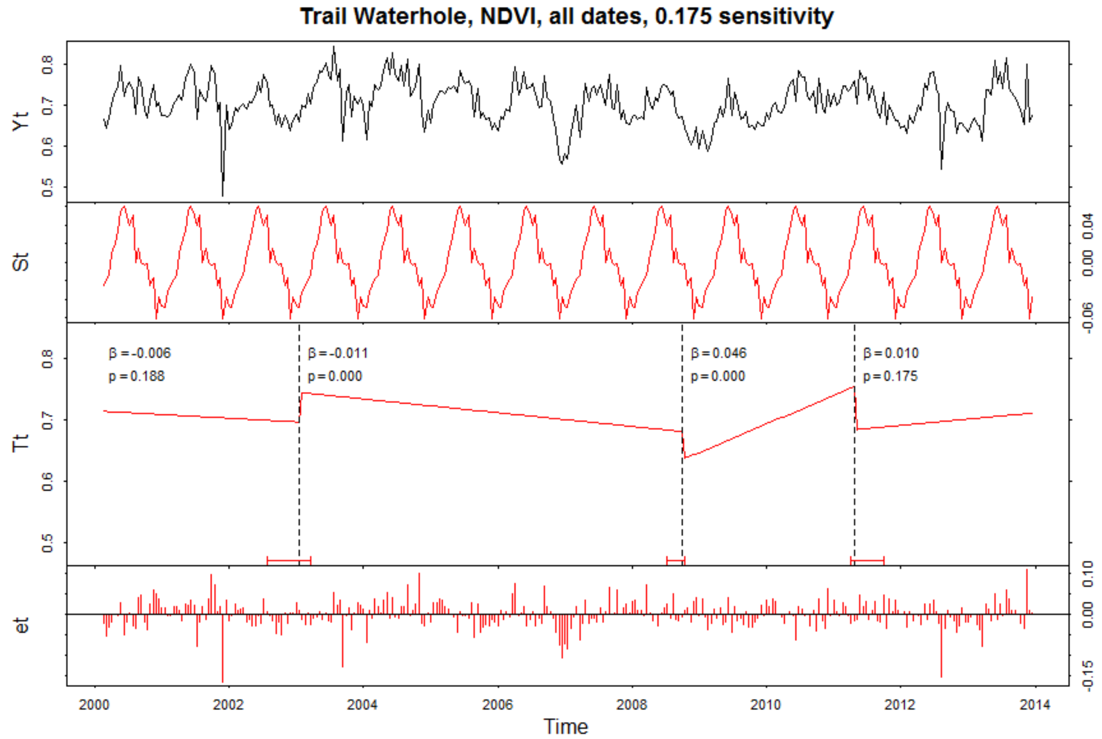


Figure 46. Trail Waterhole NDVI, an indicator of vegetation greenness. High values indicate dense or strongly growing vegetation.

8.1.1.19 West Avenue Complex, inundation and greenness

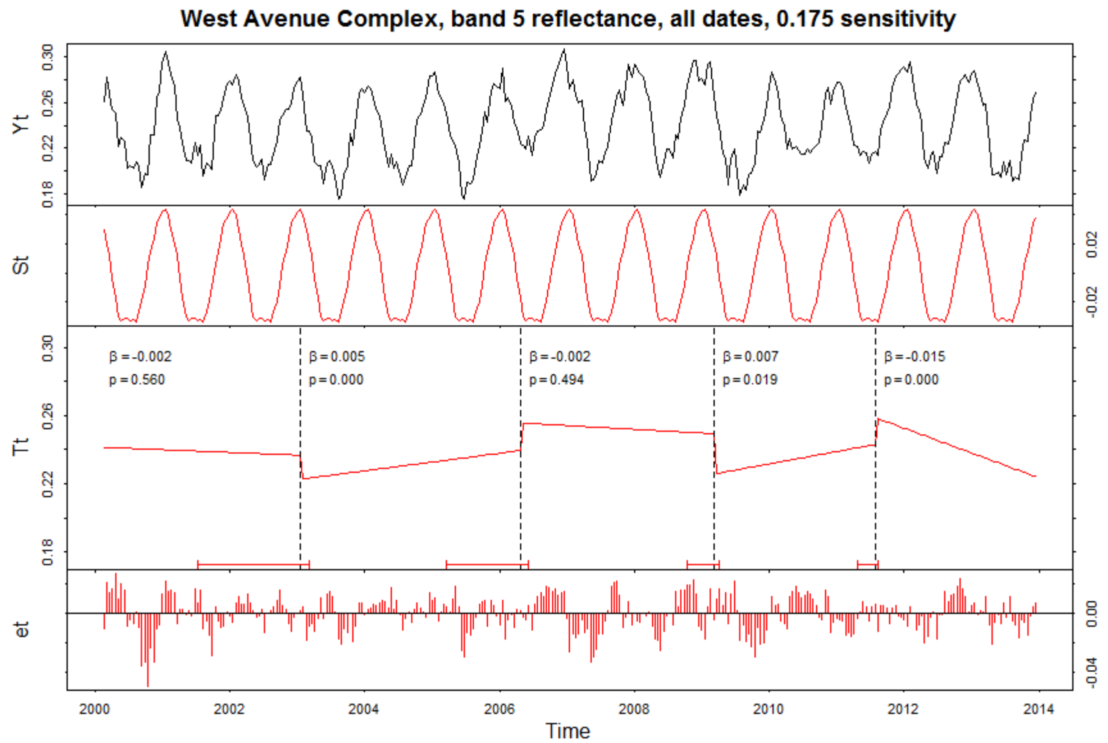


Figure 47. West Avenue Complex Band 5 reflectance, as an indicator of inundation. Data profile (Yt); average season component (St); trend and break component (Tt)); and the residual component (et). Low values indicate more extensive inundation, high values indicate less inundation.

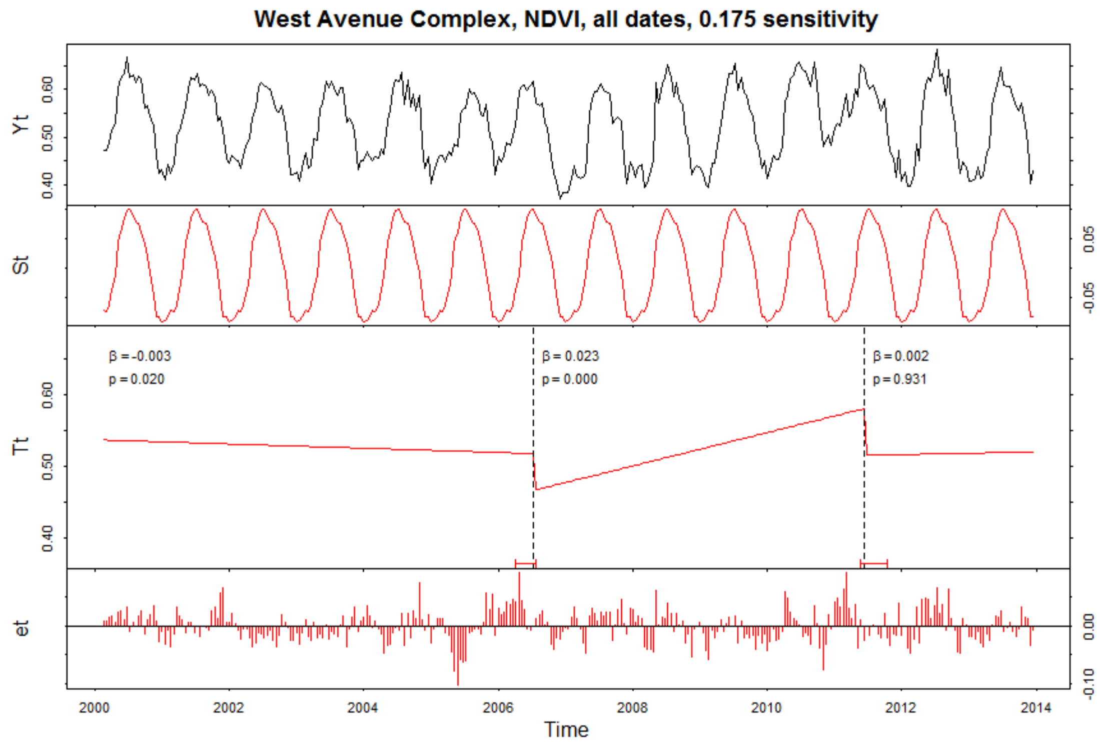


Figure 48. West Avenue Complex NDVI, an indicator of vegetation greenness. High values indicate dense or strongly growing vegetation.

8.1.1.20 Willalooka Wetlands, inundation and greenness

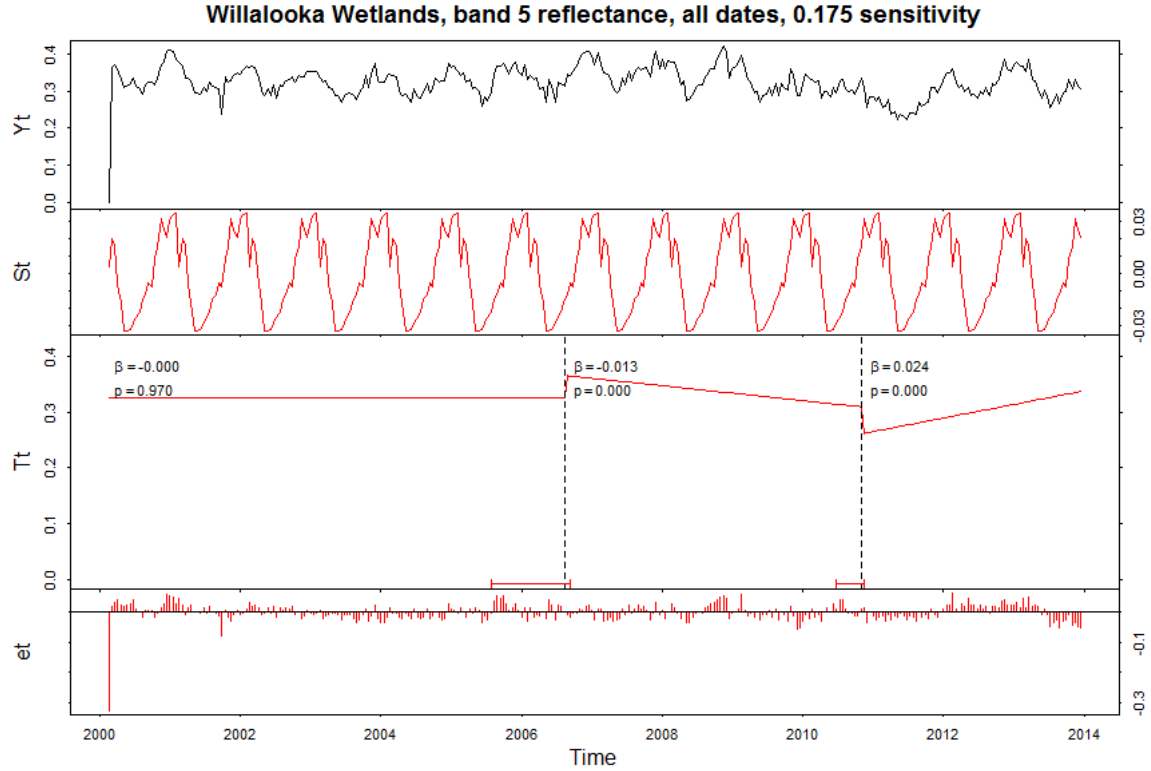


Figure 49. Willalooka Band 5 reflectance, as an indicator of inundation. Data profile (Yt); average season component (St); trend and break component (Tt)); and the residual component (et). Low values indicate more extensive inundation, high values indicate less inundation.

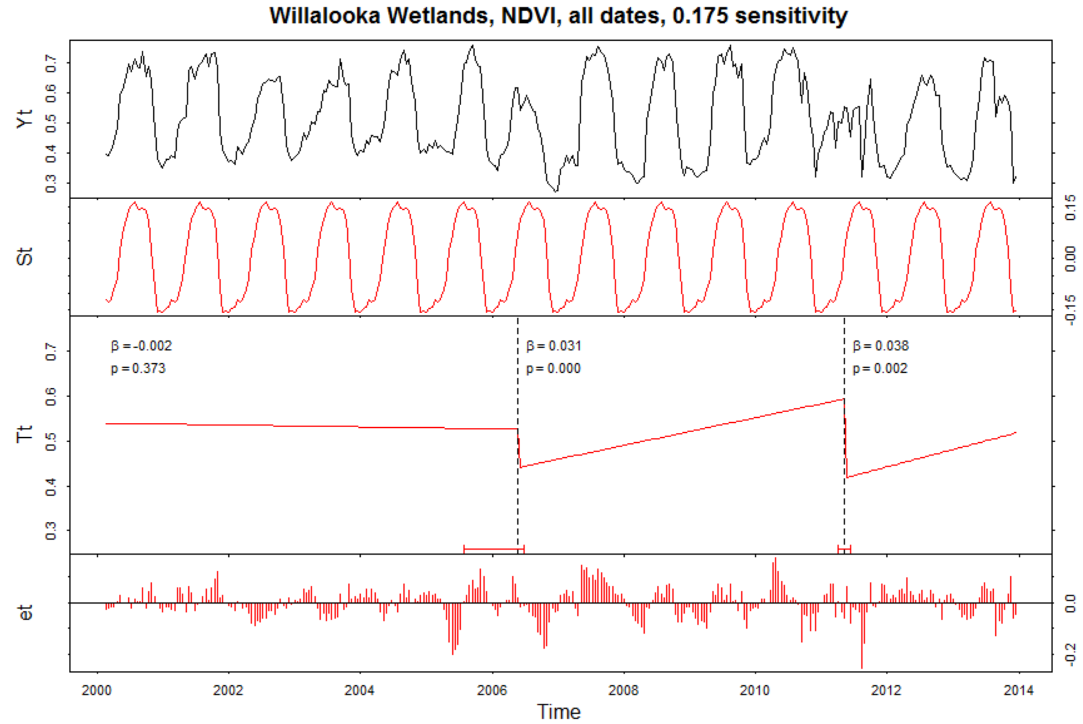


Figure 50. Willalooka NDVI, an indicator of vegetation greenness. High values indicate dense or strongly growing vegetation.

Section 9: Appendix 3. Wetland inundation extent maps

9.1.1 Wet season maps

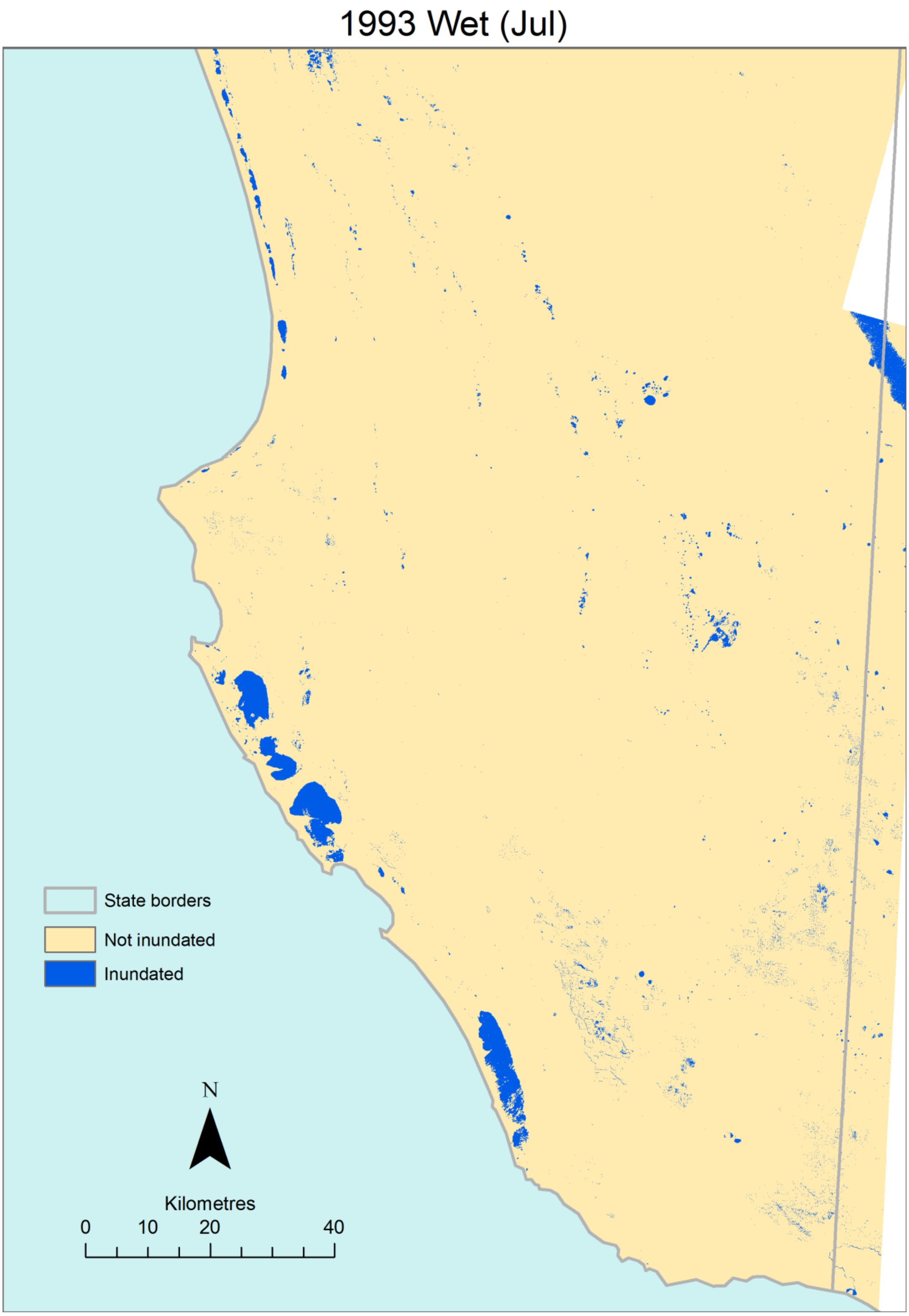


Figure 51. Inundation extent mapped from Landsat imagery; 1993 wet season. Imagery was acquired in July 1993.

2000 Wet (Jun)

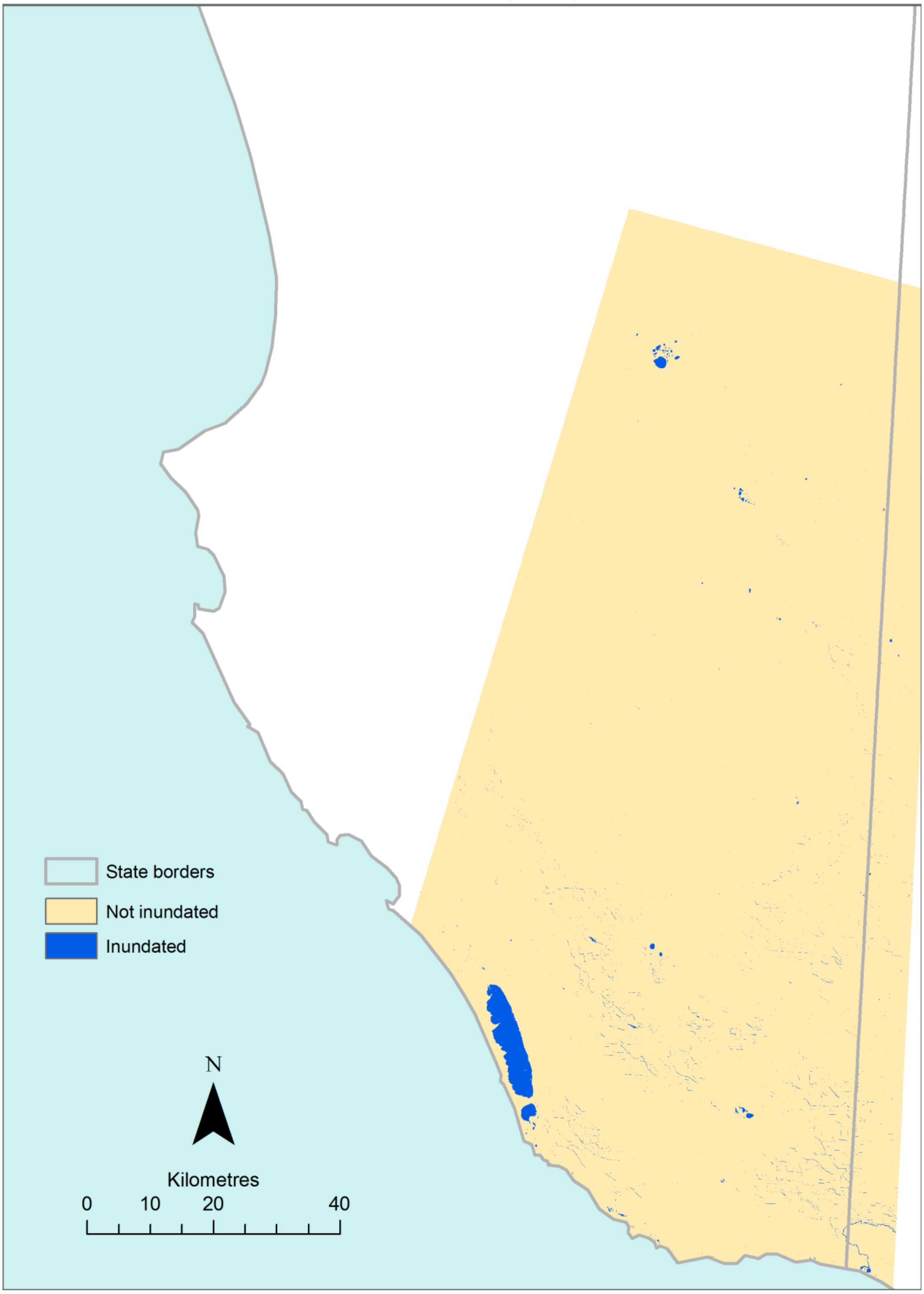


Figure 52. Inundation extent mapped from Landsat imagery; 2000 wet season. Imagery was acquired in June 2000.

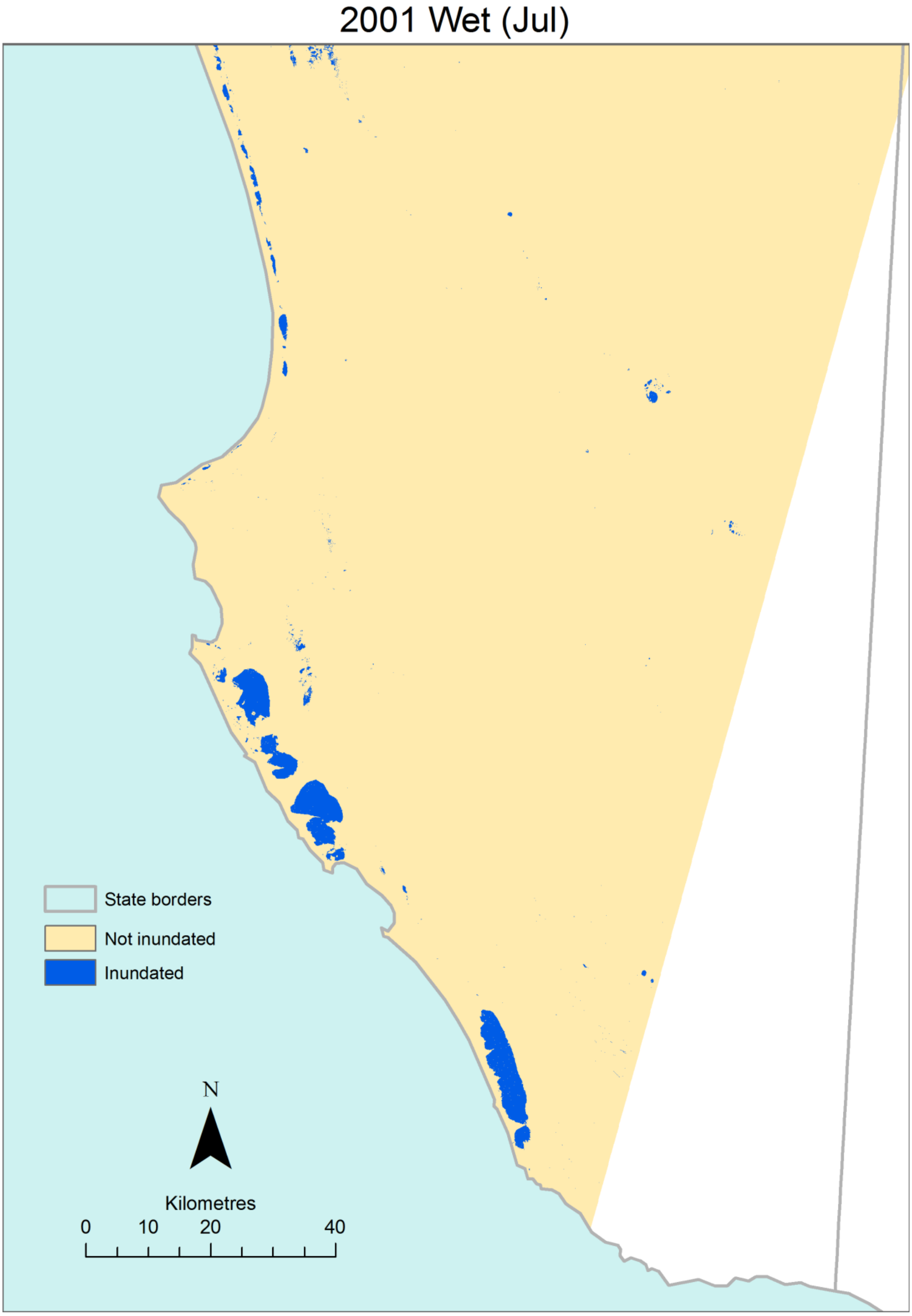


Figure 53. Inundation extent mapped from Landsat imagery; 2001 wet season. Imagery was acquired in July 2001.

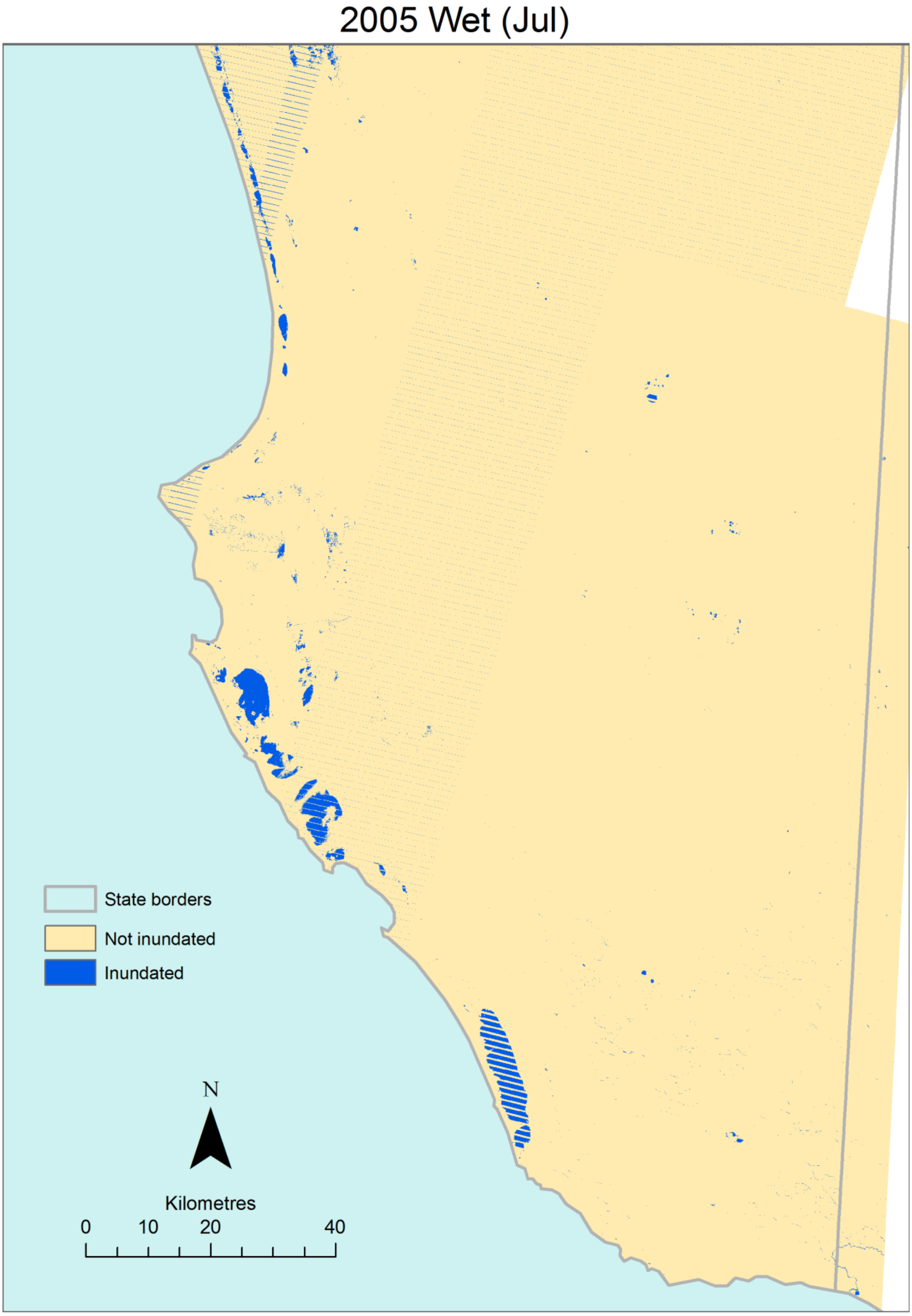


Figure 54. Inundation extent mapped from Landsat imagery; 2005 wet season. Imagery was acquired in July 2005.

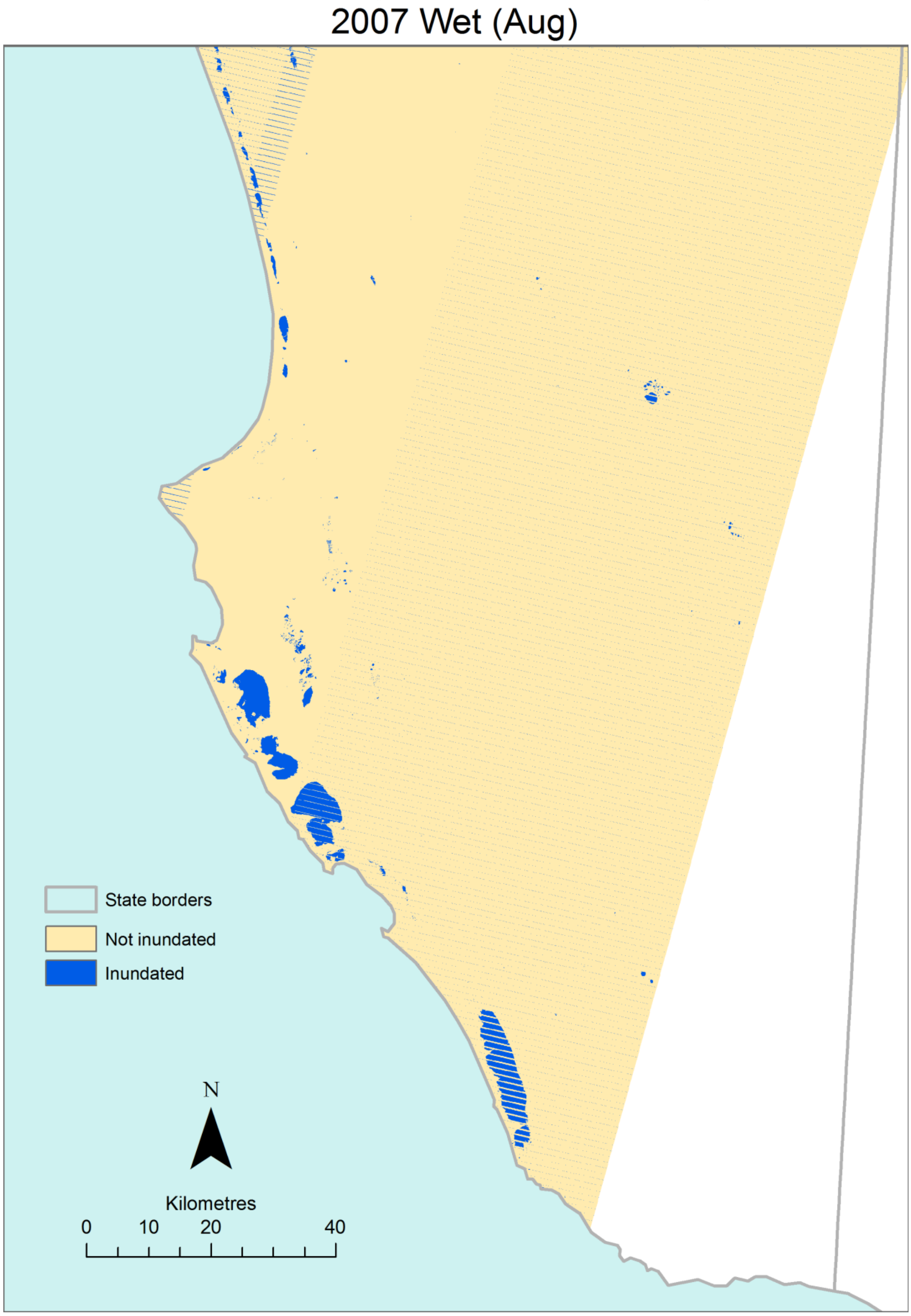


Figure 55. Inundation extent mapped from Landsat imagery; 2007 wet season. Imagery was acquired in August 2007.

2008 Wet (Jul)

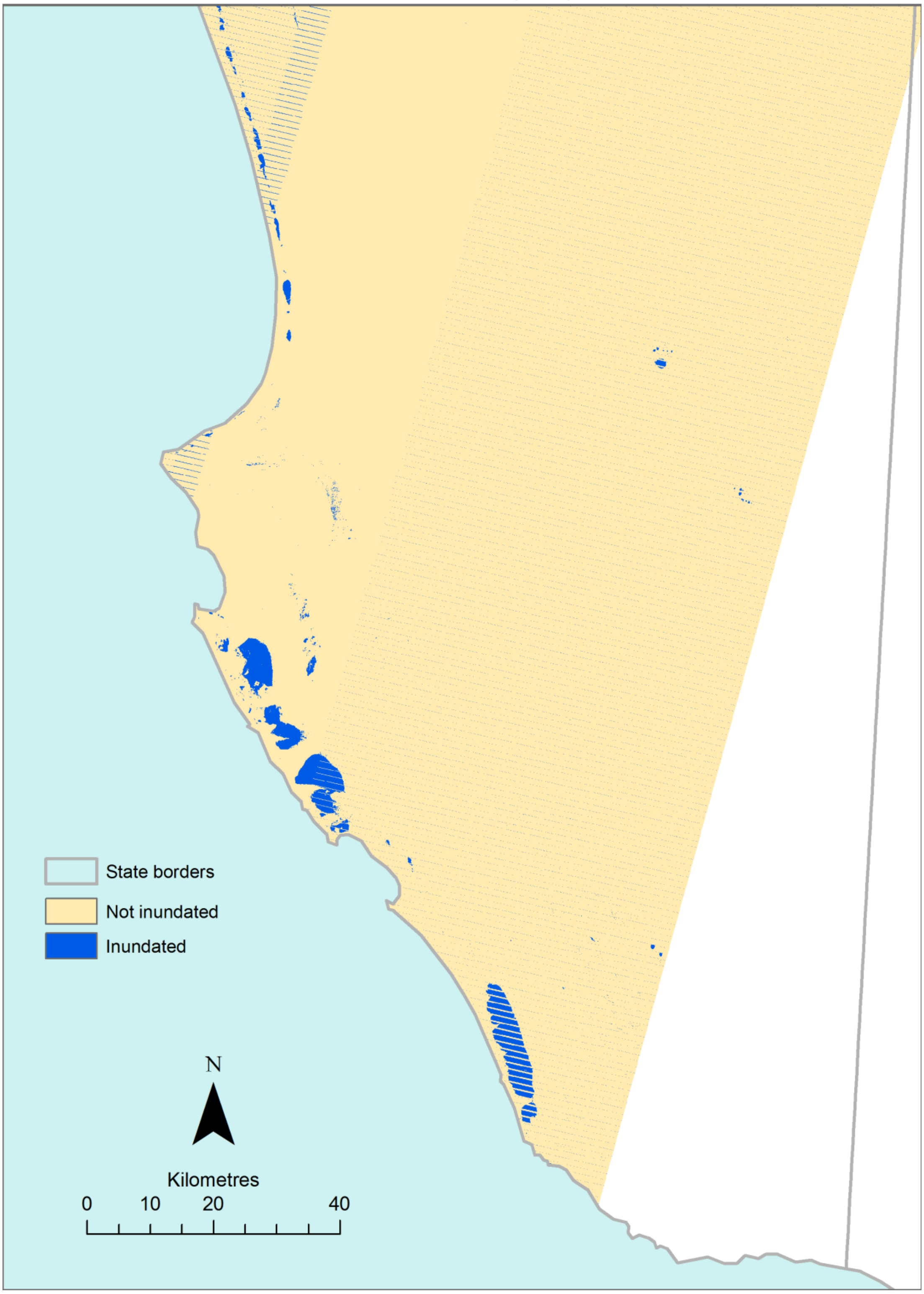


Figure 56. Inundation extent mapped from Landsat imagery; 2008 wet season. Imagery was acquired in July 2008.

2011 Wet (Jun/Jul)

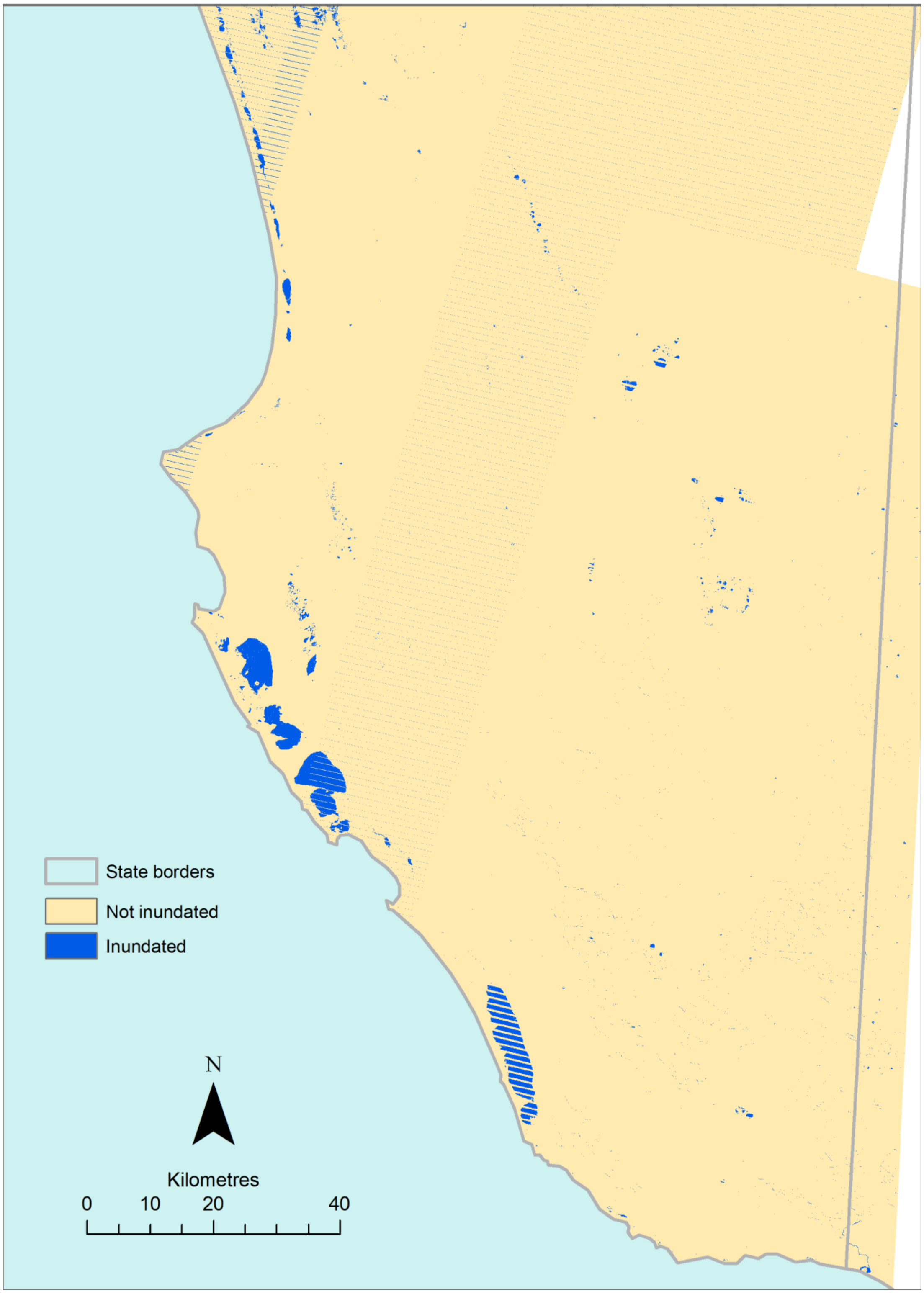


Figure 57. Inundation extent mapped from Landsat imagery; 2011 wet season. Imagery was acquired in June and July 2011.

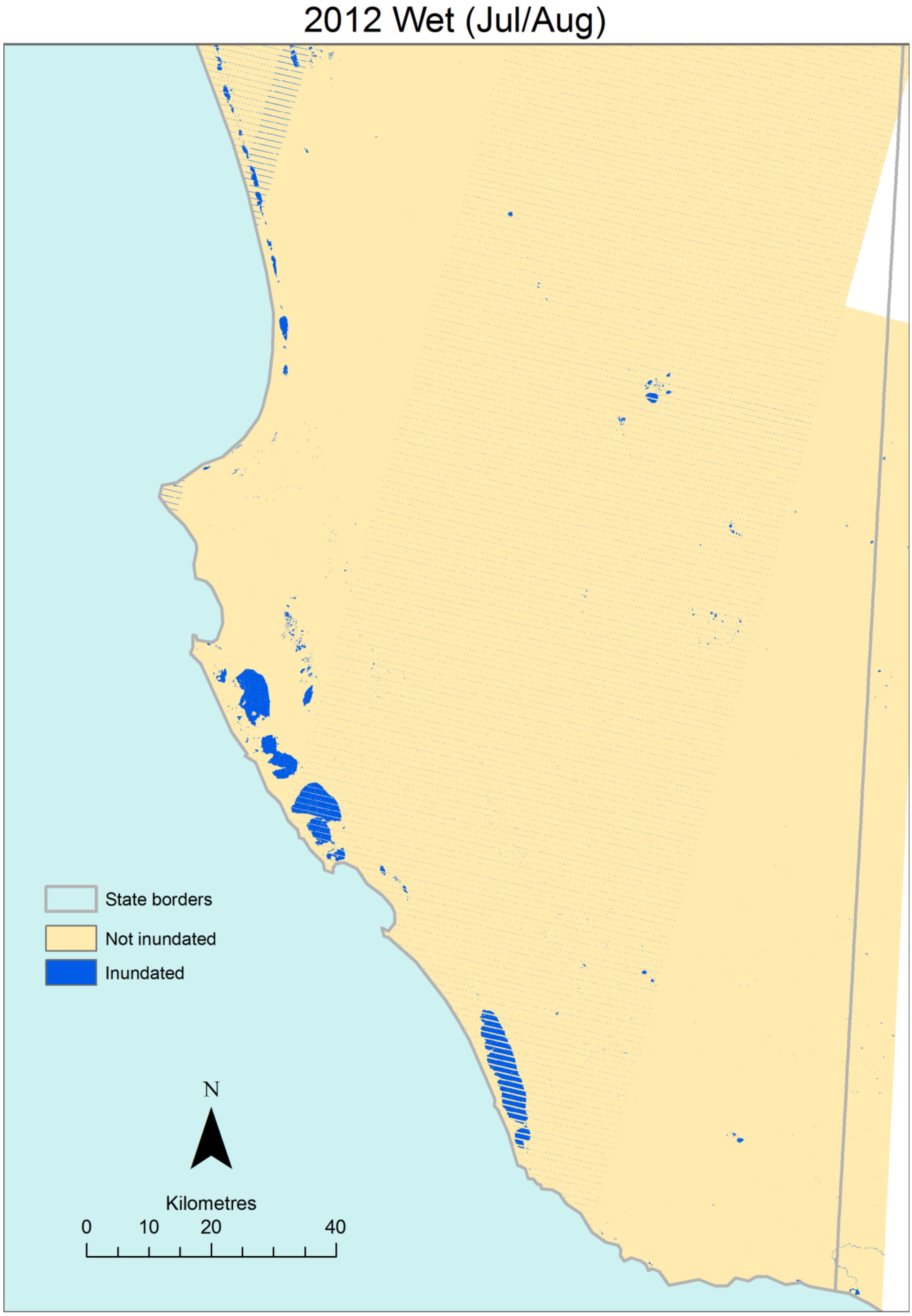


Figure 58. Inundation extent mapped from Landsat imagery; 2012 wet season. Imagery was acquired in July and August 2012.

9.1.2 Dry season maps

1991 Dry (Feb)

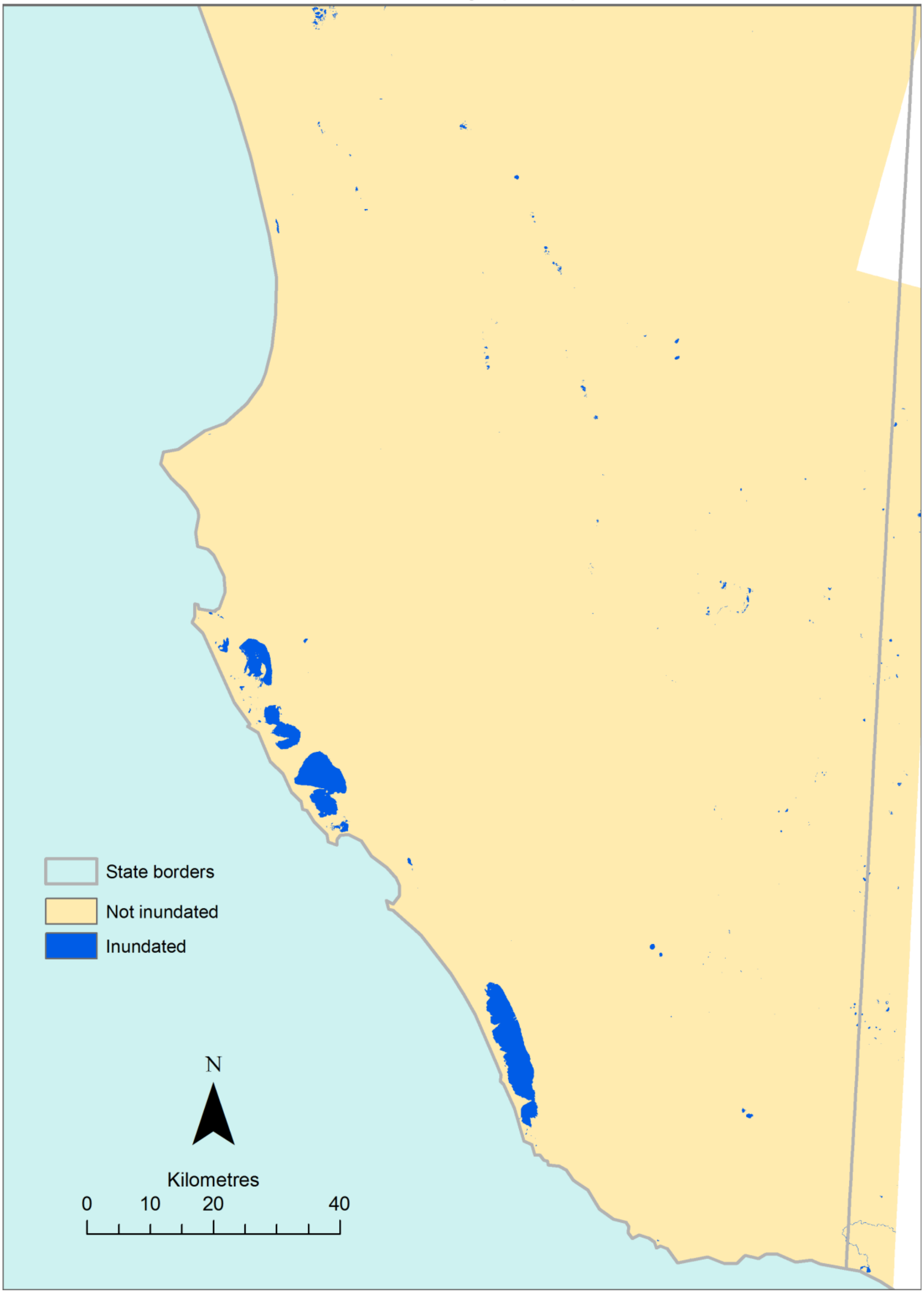


Figure 59. Inundation extent mapped from Landsat imagery; 1991 dry season. Imagery was acquired in February 1991.

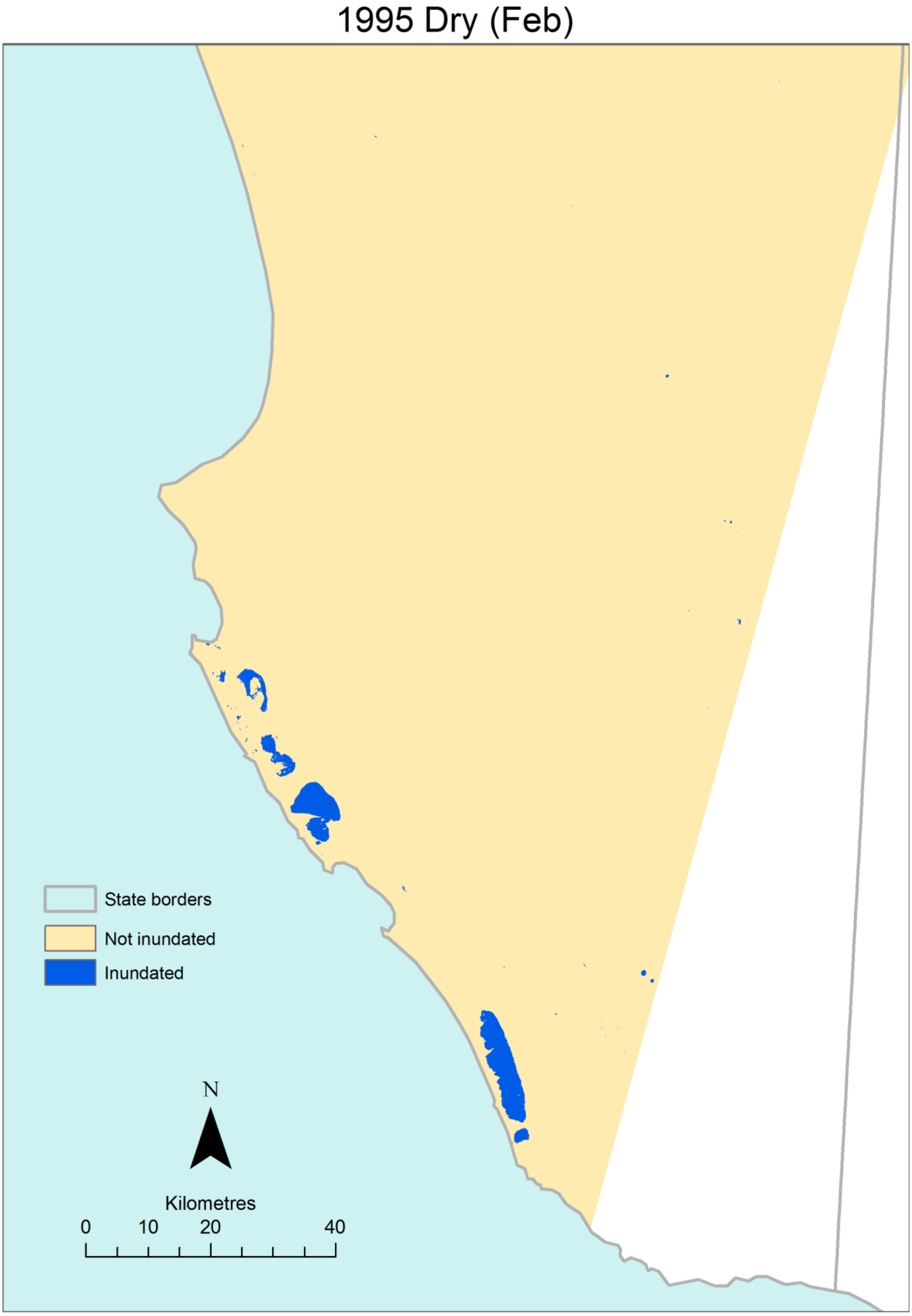


Figure 60. Inundation extent mapped from Landsat imagery; 1995 dry season. Imagery was acquired in February 1995.

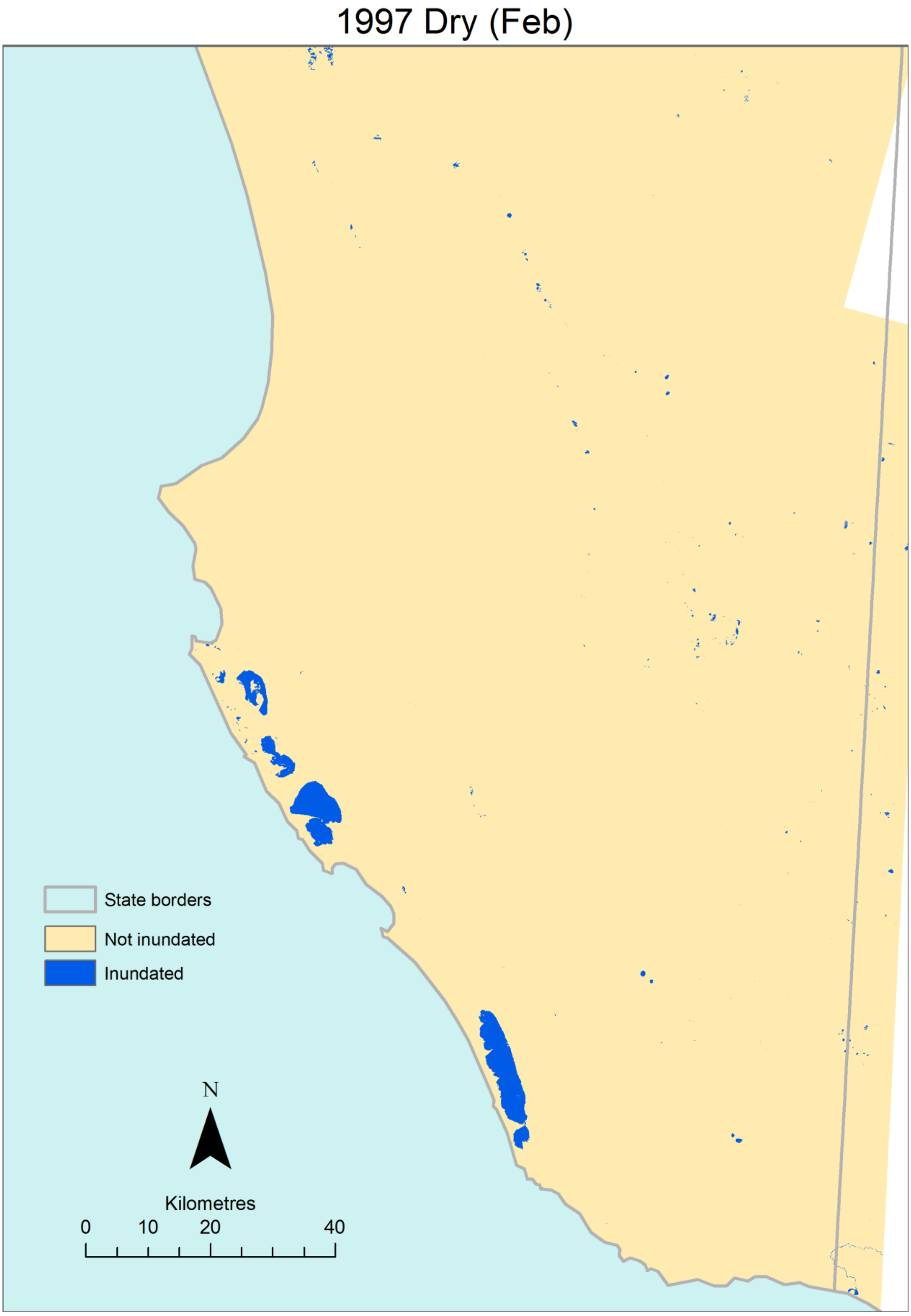


Figure 61. Inundation extent mapped from Landsat imagery; 1997 dry season. Imagery was acquired in February 1997.

1999 Dry (Jan)

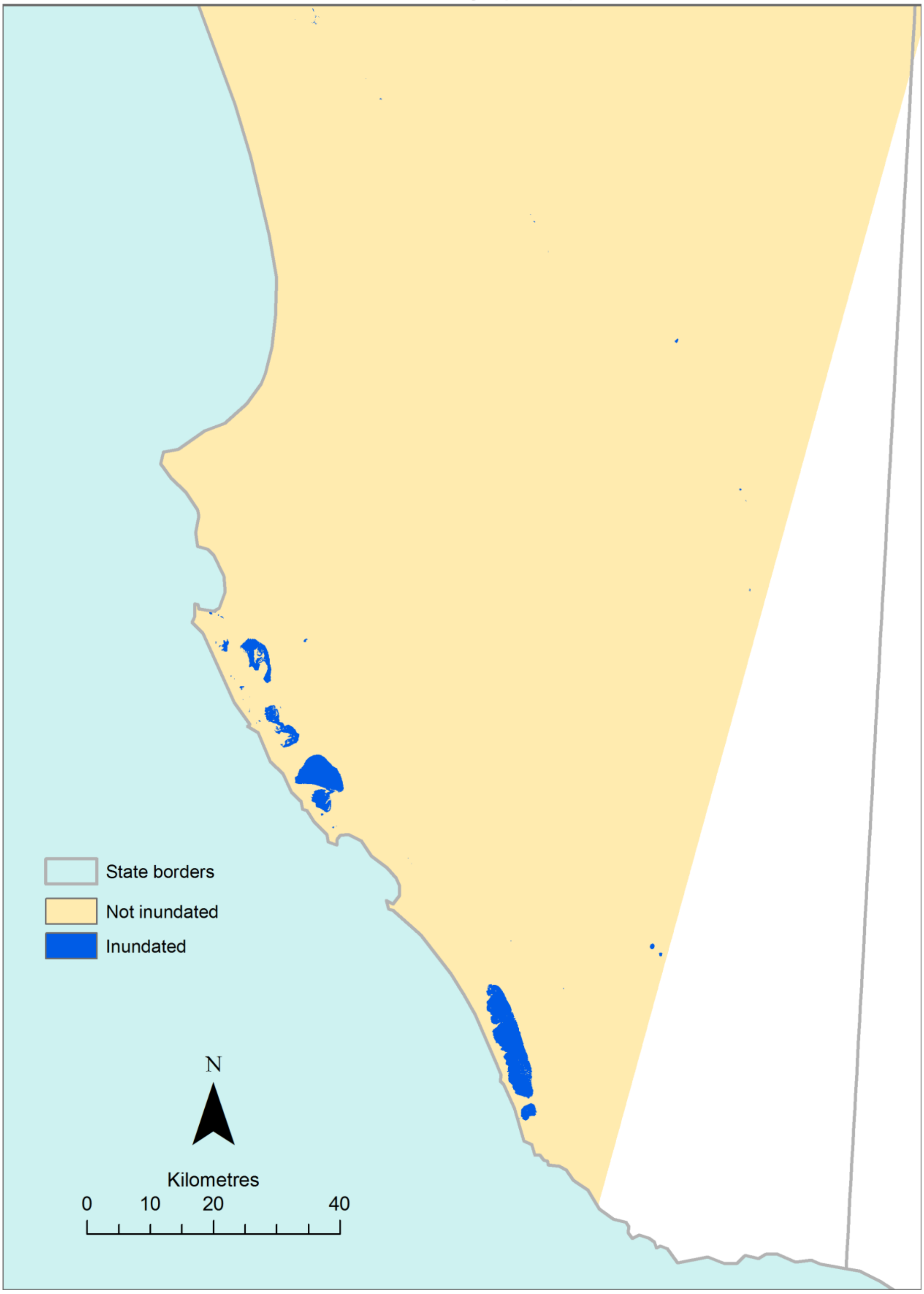


Figure 62. Inundation extent mapped from Landsat imagery; 1999 dry season (January). Imagery was acquired in January 2009.

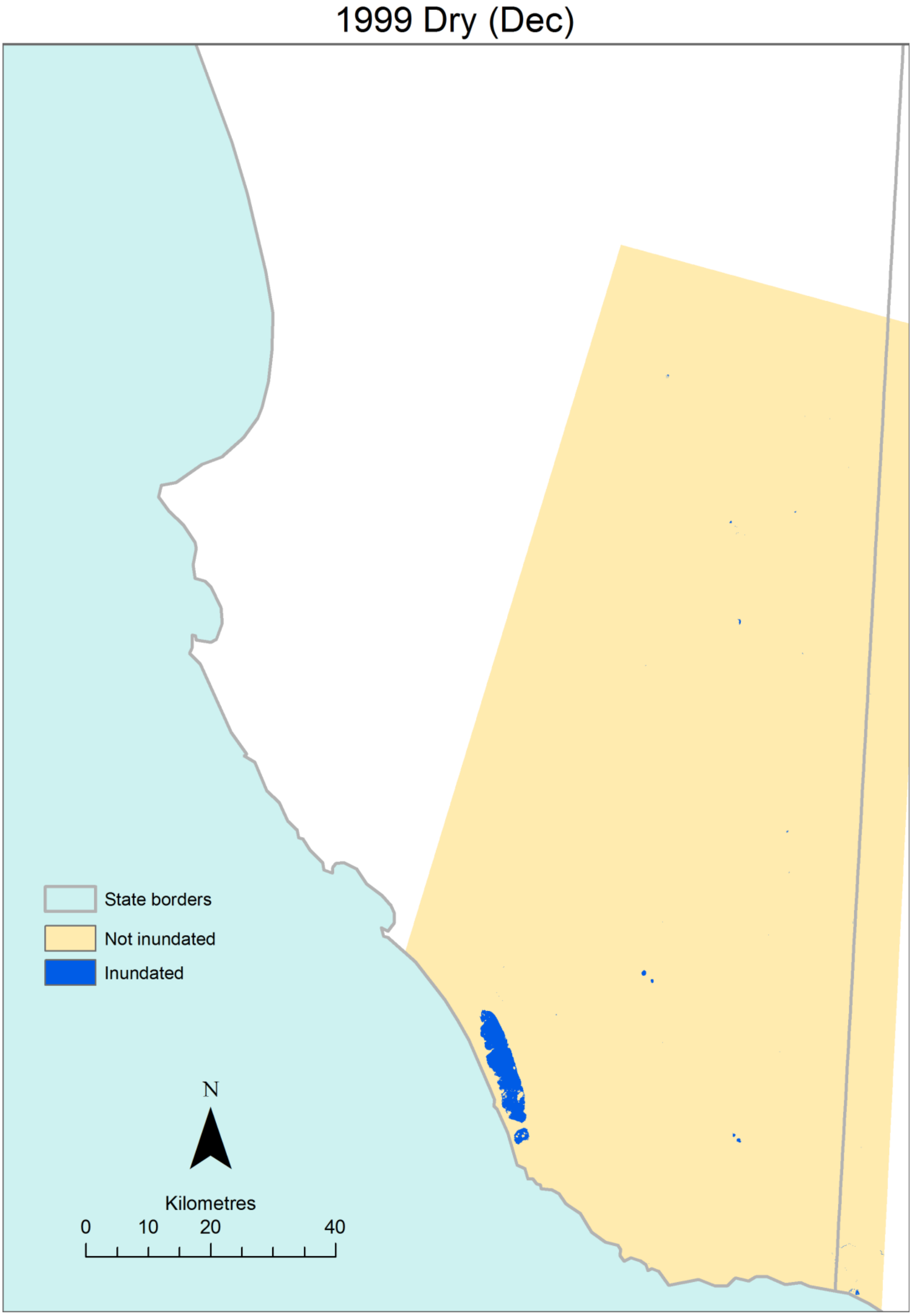


Figure 63. Inundation extent mapped from Landsat imagery; 1999 dry season (December). Imagery was acquired in December 2009.

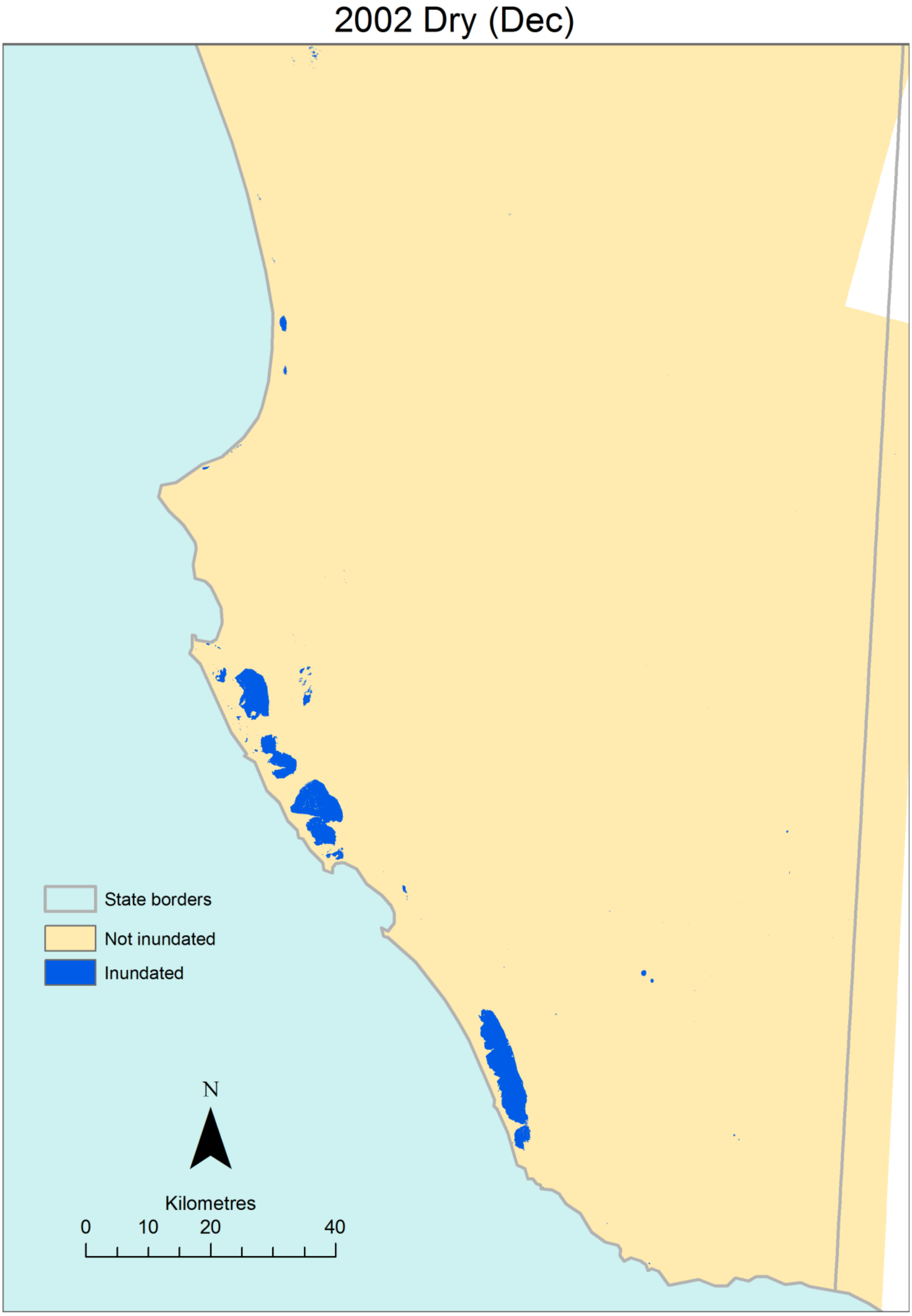


Figure 64. Inundation extent mapped from Landsat imagery; 2002 dry season. Imagery was acquired in December 2002.

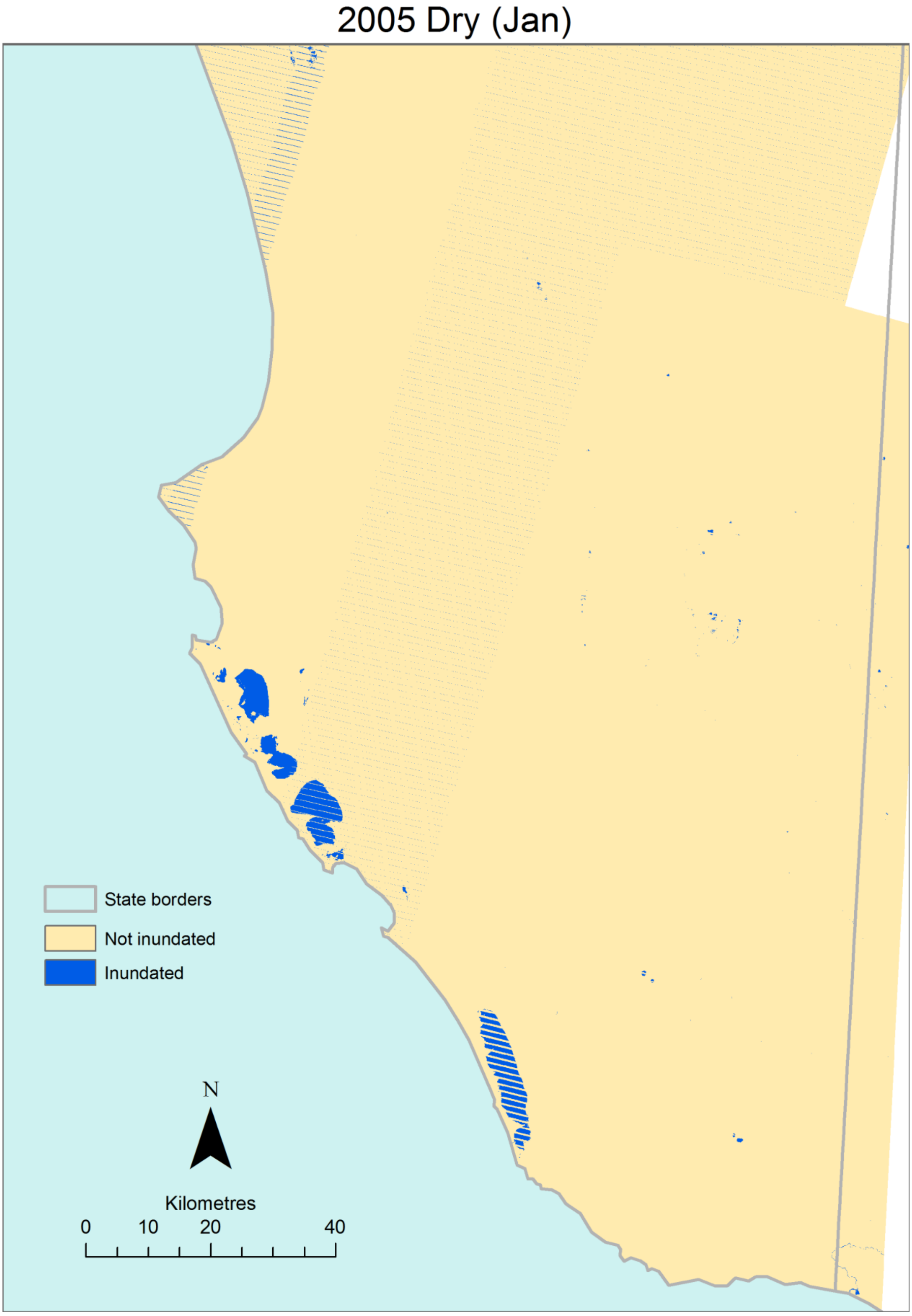


Figure 65. Inundation extent mapped from Landsat imagery; 2005 dry season. Imagery was acquired in January 2005.

Figure 66. Inundation extent mapped from Landsat imagery; 2006/07 dry season. Imagery was acquired in December 2006 and January 2007.

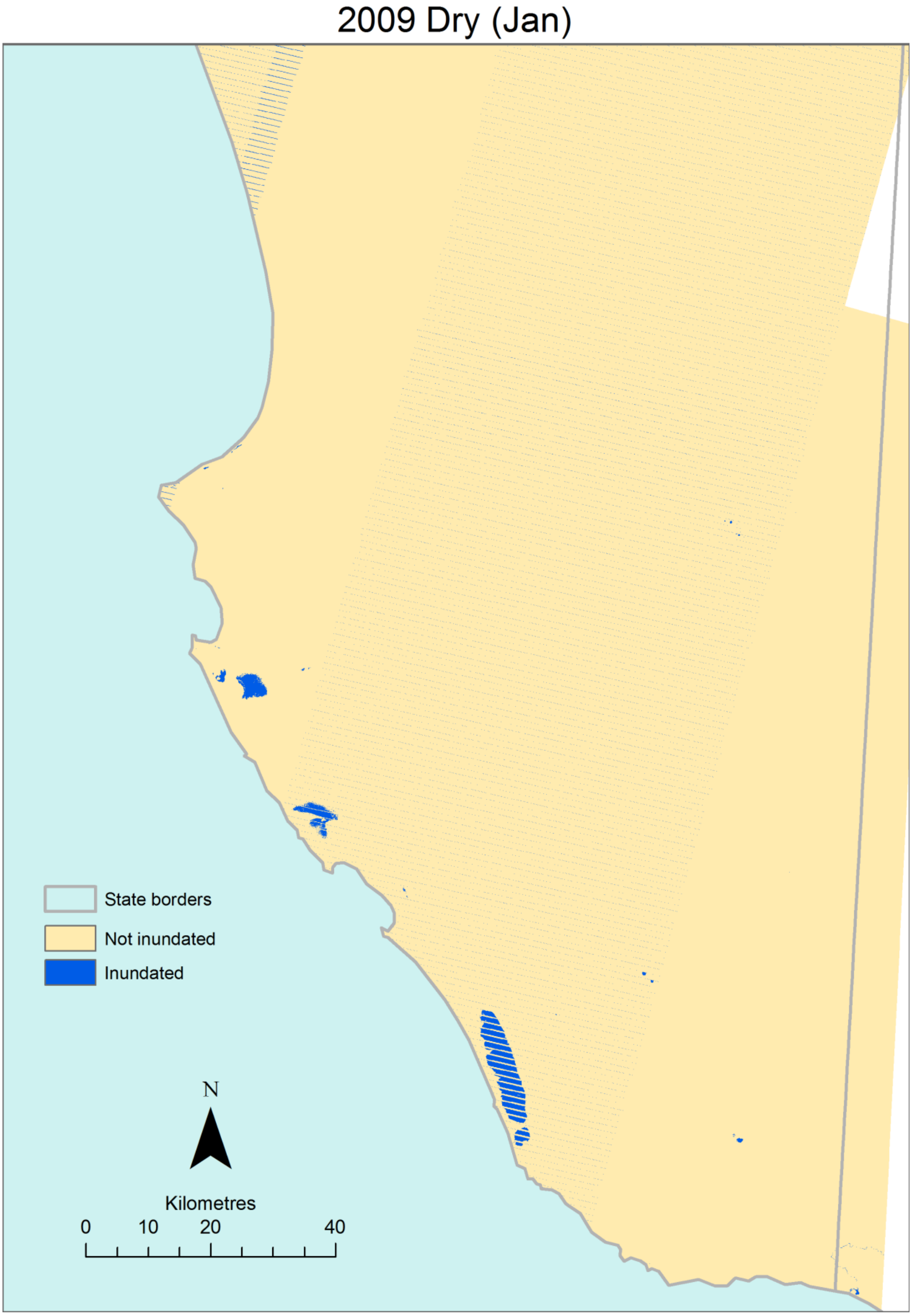


Figure 67. Inundation extent mapped from Landsat imagery; 2009 dry season. Imagery was acquired in January 2009.

2009 Dry (Dec)

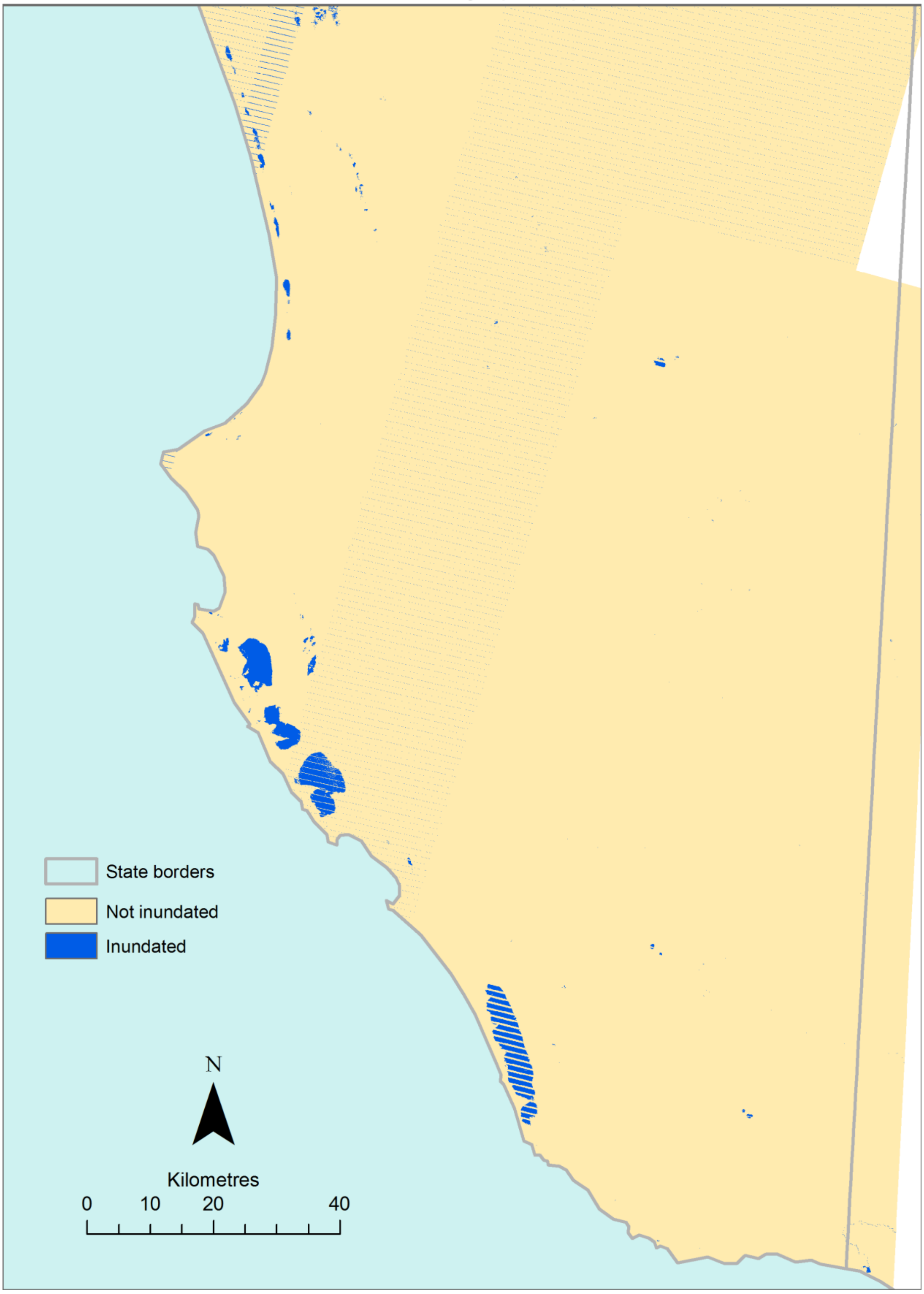


Figure 68. Inundation extent mapped from Landsat imagery; 2009 dry season. Imagery was acquired in December 2009.

2010 Dry (Apr/May)

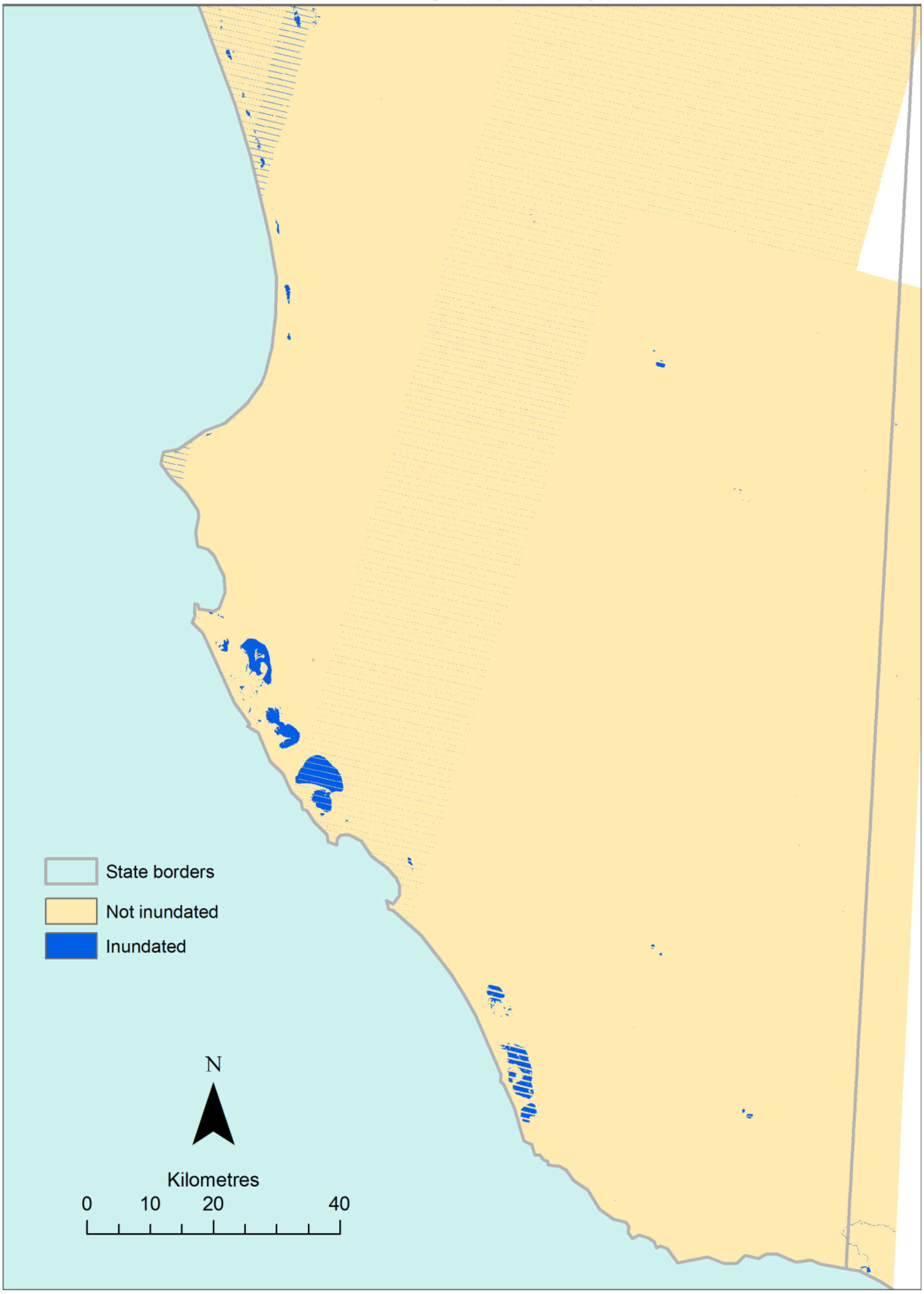


Figure 69. Inundation extent mapped from Landsat imagery; 2010 dry season. Imagery was acquired in April and May 2010.

Figure 70. Inundation extent mapped from Landsat imagery; 2012 dry season. Imagery was acquired in February 2012.

The Goyder Institute for Water Research is a partnership between the South Australian Government through the Department of Environment, Water and Natural Resources, CSIRO, Flinders University, the University of Adelaide and the University of South Australia.