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Mapping salt-affected land in the South-West of Western Australia using satellite remote sensing

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Mapping salt-affected land in the South-West of Western Australia using satellite remote sensing

Salinity extent estimates and methodology

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Executive summary

Background to the Project

Dryland salinity is a pervasive form of land degradation that has resulted from the clearing of about 17 M ha of native vegetation and the introduction of predominately cereal and pasture-based farming systems in the South-West of Western Australia. The change in water balance caused by clearing deep rooted endemic woodlands increased recharge and resulted in rising groundwater levels. After a lag period, the regolith began filling and groundwater approached the soil surface, evaporating and depositing stored salts in the rootzone of salt sensitive crops. Groundwater levels also rise and affect areas of remnant native vegetation, streams, wet-lands and rural and urban infrastructure (Salinity Strategy, 2000).

The area affected was first reported by farmers in the 1955 Australian Bureau of Statistics report as having affected 73,000ha of previously arable land. A further six surveys reported farmers as having estimated the area to have grown to 933,000ha (Trewin, 2002). The area and rate of growth reflected the changed extent and the awareness of farmers as knowledge and extension systems evolved.

To provide an objective and ongoing means to map the extent of dryland salinity, a systematic approach to the acquisition and processing of Landsat satellite images was developed as part of the *Land Monitor Project*. Analysing scenes from 1988 - 1992, and 1996 -2000, two estimates of extent were derived as 860,000ha and 960,000ha (Furby et al 2010, McFarlane et al 2004). Using these estimates and two dates McFarlane et al (2004) extrapolated a rate of increase of 14,000 ha per year.

The *Land Monitor* mapping incurs measurement errors of salt-land *omission* (areas of salt-land, not mapped as salt-land) and salt-land *commission* (areas not saline, mapped as salt-land). As previously reported (Furby et al, 2010), the *Land Monitor* satellite mapping had a tendency to underestimate the extent of salinity in the wheatbelt, particularly moderately affected classes. That is, when *Land Monitor* reported an area as being saline, it was mapped as saline with a high accuracy. However, the moderate affected areas were either underestimated or not detected.

Since the publication of the estimates in about 2000, there had been no update to the change in area affected. This gap – nearly 20 years – was noted by the Office of the Auditor General (OAG) in a review of Dryland Salinity undertaken in 2018 (OAG 2018). The OAG requested the State to establish regular monitoring and reporting of the spread, impact, and cost of dryland salinity. This Report updates the estimate of the extent of dryland salinity.

This Report specifies the revised methodology used in the *Land Monitor* approach and provides an accuracy assessment. Statistical analysis of the *Land Monitor* results has enabled an updated estimate of the extent of dryland salinity for the South-West of Western Australia. It is not intended that this Report discusses details of what is causing changes in extent.

Methodology

CSIRO and DPIRD established a project team in 2019 to update the *Land Monitor Project* assessment of salt affected land, modernising and updating the previously developed methodology to enable mapping the current extent of dryland salinity and determine its trends over the last two decades.

A sequence of 484 Landsat scenes from 2009, 2010, 2011 and 2016, 2017, 2018 and 2019 were acquired from Geosciences Australia's (GA) Digital Earth Australia (DEA) image archive Collections 2 to undertake the analysis and provide decadal updates from the mapping. These data, combined with information derived from existing high-resolution elevation data acquired from Landgate, ground information collected by field surveys and community input, were analysed to form updated estimates of the extent of salt-affected land. The methodology used for the assessment was largely consistent to that performed when producing the 1988 - 1992, and 1996 -2000 estimates (Furby *et al*, 2010), with some minor changes that took advantage of higher levels of automation where possible.

To validate the new salinity estimates, a stratified random sample approach was adopted. Validation was performed for each of seven amalgamated Hydro-zones. The amalgamated Hydro-zones (of 20 affected by salinity) were partitioned into seven composites, with each Hydro-zone reflecting the variation in land systems and hydrological response. For each of the seven amalgamated Hydro-zones, more than 200 point locations were randomly selected for interpretation by a DPIRD hydrologist as to whether the location was affected by salinity or not. Their interpretation was supported by interpretation of Landsat satellite data, high-resolution aerial photographic imagery, consultation with DPIRD peers with detailed local knowledge. Imagery was predominantly from the 2018-2019 period, and the interpretation conducted in August 2021. The point locations were roughly equally sampled from the *Land Monitor* "*Salt*" and "*NotSalt*" mapped classes, with the hydrologist not knowing the *Land Monitor* label for a site. In total, 1354 sites were used in the analysis of the errors of omission, commission and overall accuracy. The errors provide quantitative assessment of any bias of the mapping.

In previous reporting (Furby et al 2010, McFarlane et al 2004), the extent of salinity was reported by directly summing the pixel areas labelled as *Salt / Not Salt* areas (image pixels) as mapped by *Land Monitor*, a method referred to as *pixel counting* approach (Stehman, 2013). Here we report the pixel counting estimates (*pc-estimates*) for the current assessment dates: 2009, 2010, 2011, 2016, 2017, 2018, 2019 for consistency with previous reporting. The *pc-estimates* are the only estimates that report the extent of *Salt* over time, noting that these estimates better represent the extent of severely salt affected land. The pc-estimates provide estimates of the change in extent over time.

In addition to the *pc-estimates*, we report for the first time a *bias adjusted* (Stehman, 2013) estimate (*ba-estimate*) of the extent of *Salt / Not Salt* for the year 2018. The *ba-estimate* is derived using the *Land Monitor* 2018 mapping and the 2018 validation data, and is an estimate for a given region of the extent of all the classes of salinity: *severe, high*, *moderate, and*, *revegetated saline.* The *bias-adjusted* estimate was calculated for the year 2018 only, as ground data was not available for the other years.

In addition to the point location validation, experienced hydrologists from DPIRD undertook field mapping of over 70 landscape segments ranging in area from 60ha to 30,700 ha, with an average area of 5,100ha, totalling 365,000 ha of the 17M ha Wheatbelt. Field locations assessed included some known from previous analysis, some where other biophysical data existed (such as monitoring bores), and others to ensure widespread distribution to enable each of the 20 hydro-zones affected by salinity to have been validated. This data was used to provide further ground validation data for the current salinity extent mapping and the *ba-estimate*, as well as for training data for future modelling.

Reporting of results compares the point-locations based independent validation of *Salt* / *NotSalt* to the modelled data. Errors of commission and omission were developed. For the field mapped comparison datasets, in addition to mapped areas of *severe salinity*, areas of *moderate*, *revegetated saline* and "*bare – but not saline"* land were assessed.

Results

Salinity Extent

The *Land Monitor* salinity mapping update classified over 1,082,419 ha (*pc-estimate*) of land as salt affected for the year 2018 within the mapping extent (23,789,250 ha) within the South-West of Western Australia, equating to 4.5% of the mapped area. Between 1990 and 2018, the extent of mapped/modelled salinity has increased by 118,822 ha (12.3%). Overall, this increase in the extent of salt affected land occurred by the 2009-2011 time-period.

Table 4 Extract. *Land Monitor* region salinity** extent, as estimated from Satellite mapping (*pc-estimate*).

	Land Monitor Region* – Agricultural Area			
	Salinity Extent Estimate (ha)			
Year	Salt	Not salt	Mapped Area	**% Salt (of mapped)**
1990	963,597	21,297,902	22,261,499	**4.33**
1998	1,051,605	21,209,892	22,261,497	**4.72**
2010	1,085,298	22,703,951	23,789,249	**4.56**
2018	1,082,419	22,706,831	23,789,250	**4.55**

* Mapped region is the land area of the south-west; *Salt* comprises affected land including *severe salinity*, *moderate salinity* and *revegetated saline.* ***pc-estimate* best represents *severe salinity*, and on average omits 40% of saline lands predominately from the *moderate salinity* and *revegetated saline* classes.

For the year 2018, where the stratified random sample approach for ground truthing was undertaken, we calculated a bias adjusted estimate (*ba-estimate*) of the extent of salinity for the region to be **1,748,366 ha ± 343,692 ha** at the 95% confidence level, compared to the *pc-estimate* of **1,082,419 ha**. This calculation yielded an overall mapping salinity extent omission error of 40.0%, and a relatively low commission error of 3.1%. Similar stratified random samples of field validation data are not available for the earlier 1990, 1998 and 2010 evaluation periods, and *ba-estimates* were not calculated for these dates.

To better understand the omission errors, further comparison of the *Land Monitor* mapping 2018 *pc-estimates* with the 2018 salinity mapping performed by DPIRD hydrologists for 70 study areas covering 340,727 ha identify *severe salinity*, *revegetated saline* and *moderate salinity* areas having omission errors of 25.4%, 51.8% and 76.8% respectively. Commission errors were relatively low for all classes.

For each of the 70 study areas, comparison of the *ba-estimate* with the DPIRD hydrologists estimate yielded a line of best fit with a coefficient very close to one, or in other words, the *ba-estimate* of *Salt* was in good agreement with the DPIRD hydrologists mapping of the total combined extent of the *severe, moderate,* and *revegetated saline* classes*.*

Change in Extent

Change in the *pc-estimate* of saline land needs to be viewed with the understanding that they best represent the extent of severely salt affected areas and that large areas of less severely affected lands have been omitted as being saline until this evaluation. Inclusion of two independent measures in the 2018 evaluation has allowed underestimation to be better understood. Importantly, we now understand that this underestimation was embedded in the previous *Land Monitor* analysis. The *Land Monitor* mapping from 1990-2018 has been produced with as consistent a methodology as possible, driven by comparable satellite observations over time, and provides the only long-term mapping of the extent and change in *Salt / Not Salt* for the entire region.

The area of *Salt* extent mapped by *Land Monitor* were plotted for each of the major regions in the south-west agricultural area at each of the major time periods where satellite data was available (figure 18). From the figure we observed a continuous rate of rise in land affected in the *Esperance-sand plain / mallee* region, and a plateau in most of the other regions. Care needs to be taken in interpreting this for several reasons. First the area of moderately affected land has large omission errors and is not well accounted in this analysis. Secondly, in some areas revegetated saline land has been reclassified as non-saline. Finally, expansion in severe salt land in the period since 2015 when widespread summer rains occurred throughout the Wheatbelt cannot be detected by *Land Monitor* at this stage.

Notwithstanding the likely omissions, there appear to be a weak pattern in the spatial association of the Hydro-zones where mapped salinity has either plateaued or has reduced in its rate of expansion. From the field evaluations, those areas can be observed in Hydro-zones in the dissected northern and western terrain.

A more detailed evaluation of the change observed is being undertaken as part of a separate project where regional hydrologists are reviewing groundwater change to determine if a spatial relationship exists with salinity extent. Partner projects with some grower groups are also planned to better resolve local change.

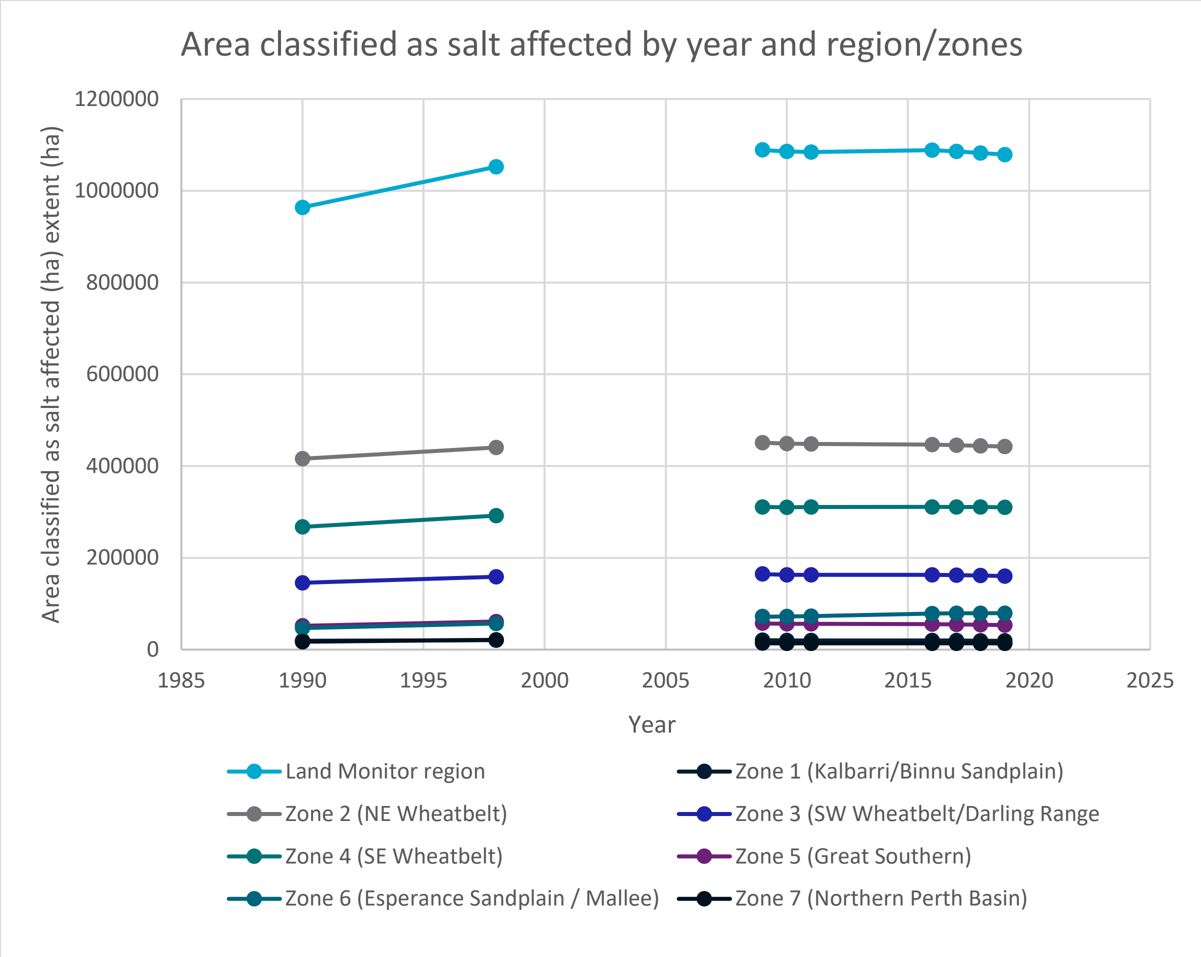


Figure 18. Graph of salinity extent* over time.

Salinity extent* mapped by *Land Monitor* for each of the amalgamated hydro-zones (regions). Taking 1990 and 2018 as reference points, the extent for the *Land Monitor* region has increased by 4400 ha/year from 1990 to 2018. **pc-estimate* best represents *severe salinity*, is the only consistent estimate over the time span, but on average omits 40% of saline lands predominately from the *moderate salinity* and *revegetated saline* classes.

Future work

Results from this analysis indicate *Land Monitor* mapping using Landsat data can detect decametre (satellite resolution) sized areas of *severe salinity* land with low commission error and 25.4% omission error. However, with the use of the optical Landsat sensors, *Land Monitor* has difficulty detecting *revegetated saline (*omission error *51.8%*) and *moderate salinity* (omission error 76.8%), as well as saline land where the extent is relatively small compared to the satellite resolution. Errors were quantified with ground data, and with the ground data and *Land Monitor* mapping, a *ba-estimate* calculated. For a given geographic sub-region, for example the 70 Study sites, the *ba-estimate* provided extents of *Salt* comparable to that mapped by DPIRD hydrologists; for a given random sub-region within the agricultural area (for example another site), the *ba-estimate* may be calculated. Within this random chosen sub-region, *Land Monitor* will likely map the *severe salt*, but not so well the other classes of salt. The *ba-estimate* will provide an area that will include an estimate of what is missing from the *Land Monitor* mapping, but with the limitation that it does not locate where in the sub-region the extra area of *Salt* resides. Further, the *ba-estimate* relies on carefully collected

ground data with its limitations of interpreter variability. Therefore, the narrowing of the *pc-estimate* with *ba-estimate* is desirable, which equates to reducing the omission errors of *Land Monitor* mapping. This could include augmentation of the current mapping with alternative sensing systems with greater sensitivity to those areas currently under-detected, for example sensors with different spectral characteristics and/or improved spatial resolution.

Several research investigations with the aim to better detect under reported salinity will be performed in future works. These investigations will prioritise sensors having features of suitable wavelengths, improved resolution, broad scale availability, and future continuity plans (for example the Sentinel Radar platforms). The data collected during this project and aligned projects will enable these investigations to be performed. Variations (including those with stronger spatial prediction) to the currently used *machine learning* is also being actively pursued as another line of investigation.

Given the integral importance of field observations, future ground data collection should be conducted to at least the effort as applied here.

Work to understand the extent and impact of salinisation of agricultural land, public lands (Reserves, Forest areas), infrastructure and water resources is to be undertaken using the datasets and methodology established in this Report.

1 Introduction

Over two million hectares of broad-acre farmland in Australia is estimated to be currently affected by secondary salinity, with over half (> 1 million ha) occurring in the south-west agricultural region of Western Australia.

The Office of the Auditor General (OAG) Western Australia tabled a report on the 'Management of Salinity' in the Western Australian Parliament in May 2018. The report sought to understand salinity extent and trends and whether management efforts were working to reduce impacts.

The report highlighted that the estimates of the extent of dryland salinity in the south-west of Western Australia were out of date, as the last satellite imagery analysis of salt affected land, which was undertaken by the *Land Monitor* Project, was completed in 2000. At which time, it was calculated that severely salt affected land was increasing by 14,000 hectares per year. It is unknown if this rate of increase has continued, decreased or accelerated (OAG 2018).

One of the report's recommendations (1b) to improve the effectiveness and efficiency of the management of dryland salinity in Western Australia is to establish regular monitoring and reporting of the spread, impact and cost of dryland salinity.

The Western Australian *Land Monitor* project (McFarlane et al. 2004) used satellite imagery, with high-resolution topographic data to map areas of severely salt-affected land based on consecutive spring satellite (Landsat TM) scenes.

The project mapped severely salt affected land over most of the dryland agricultural area of Western Australia (24 million hectares, of which approximately 17 million hectares was cleared) for two- time periods; typically within 1988–1992 and 1996–2000 (figure 1).

The Department of Primary Industries and Regional Development (DPIRD), Western Australia has partnered with the CSIRO's Remote Sensing and Image Integration Team to build the capability to routinely analyse satellite remote sensing imagery data, sourced from Digital Earth Australia (DEA), to periodically map salt affected land in the dryland agricultural region of the south-west of Western Australia.

The objective was to update the *Land Monitor* assessment of salt affected land while modernising and updating the previously developed (Furby et al. 2010) methodology to take advantage of technology developments with the view to improvements in the efficiency and accuracy of the mapping of the current extent of dryland salinity and its change over time. The methodology enabled assessment and results to be available in mapped and database formats.

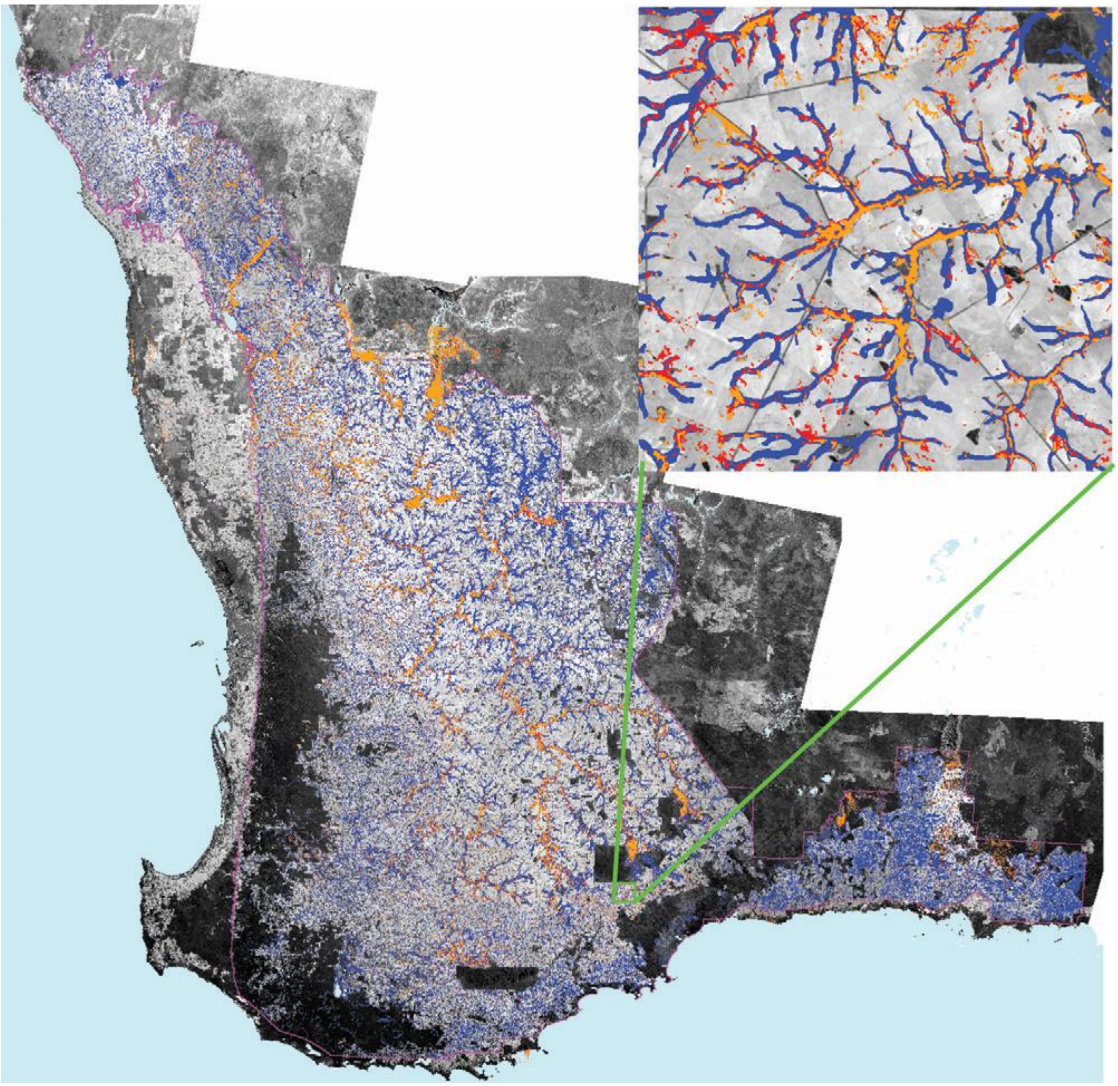


Figure 1. *Land Monitor* historical mapping.

Areas of salt-affected land for the south-west agricultural region determined by *Land Monitor* methodology in 1988 and 1998. Areas mapped as salt affected by 1988 are shown in orange. Areas that *Land Monitor* determined to be salt affected by 1998 are shown in red. The valley hazard areas are shown in blue. The greyscale background is a January 1994 Landsat TM mosaic image. (Source Caccetta et al. 2010).

2 Materials and Methods

The methodology for salinity monitoring relies on an integrated analysis of long-term sequences of optical satellite image data together with variables derived from digital elevation models (Furby *et al*, 2010). The Landsat optical imagery alone cannot distinguish between some salt-affected land and bare ground. Hence a temporal sequence of images and landform was used to assist in the mapping and monitoring. This uses the knowledge that salinity tends to persist from year to year and that salt-affected land is much more likely to be found in valleys than on hilltops or upper slopes (Kiiveri and Caccetta, 1998). The analysis of time-series of data improves accuracies obtained by incorporating land cover transition probabilities, which in combination with annual cropping rotations, reduces commission errors that result should only single images of optical data be applied independently. Similarly, the elevation data provide a physical-based assumption that low lying areas are more prone to dryland salinity than higher areas (Caccetta et al, 2010). Given the large geographic expanse of the wheatbelt, a stratified approach to the analysis was performed. Geographical regions derived from the hydrological zones (Raper et al, 2014) were used as the strata. Here we build on the approach, and incorporate technological improvements with the aim of improving the efficiency of the process whilst maintaining the consistency of the method. Corwin and Scudiero (2019) provide a recent review of methods reported in the international literature, including the use of proximal and remote sensing technologies, for soil salinity assessment.

2.1 Mapping extent and geographic stratification

The mapping extent, depicted in figure 2, encompassed the south-west agricultural region of Western Australia, defined as an area south and west of the 'clearing line'. The 'clearing line' marks the boundary between freehold land that has been substantially cleared for broad-acre dryland agriculture and leasehold land that is used for pastoral grazing of native vegetation (Raper et al 2014). The region is bound to the west by the Indian Ocean, to the south by the Southern Ocean and to the east and north by the 'clearing line'. Large, forested areas that include unallocated Crown land and areas managed for conservation, state forests and water catchment protection and areas which are dominated by urban land use were excluded from the mapping extent (see figure 2).

Further, some regions were excluded based on hydrological properties. Variations in climate, soils, vegetation types, hydrology and farming practices affect the development, location, extent, and severity of salinity. Analysis of data was guided by the regions' *hydro-zones* (depicted in figure 2), which are based on soil-landscape zone mapping units that were defined on geomorphologic or geological criteria and delineate repeating patterns of landscapes and associated soils (Schoknecht et al. 2004). The zones also reflect state-scaled regions with similar climatic and farming system attributes (George et al. 2005). Hydro-zones are therefore defined to coincide with soil-landscape zones, except where hydrogeological boundaries dictate that several soil-landscape zones belong to a contiguous hydrogeological unit (Raper et al 2014). Excluded areas also included the Leeuwin, Donnybrook Sunkland and

Scott Coastal Plain hydrological zones along with parts of the Swan Coastal Plain south of the Shire of Gingin. The southern part of the Swan Coastal Plain (15 in figure 2) is excluded from just north of Perth at the Dandaragan / Gingin Shire boundary.

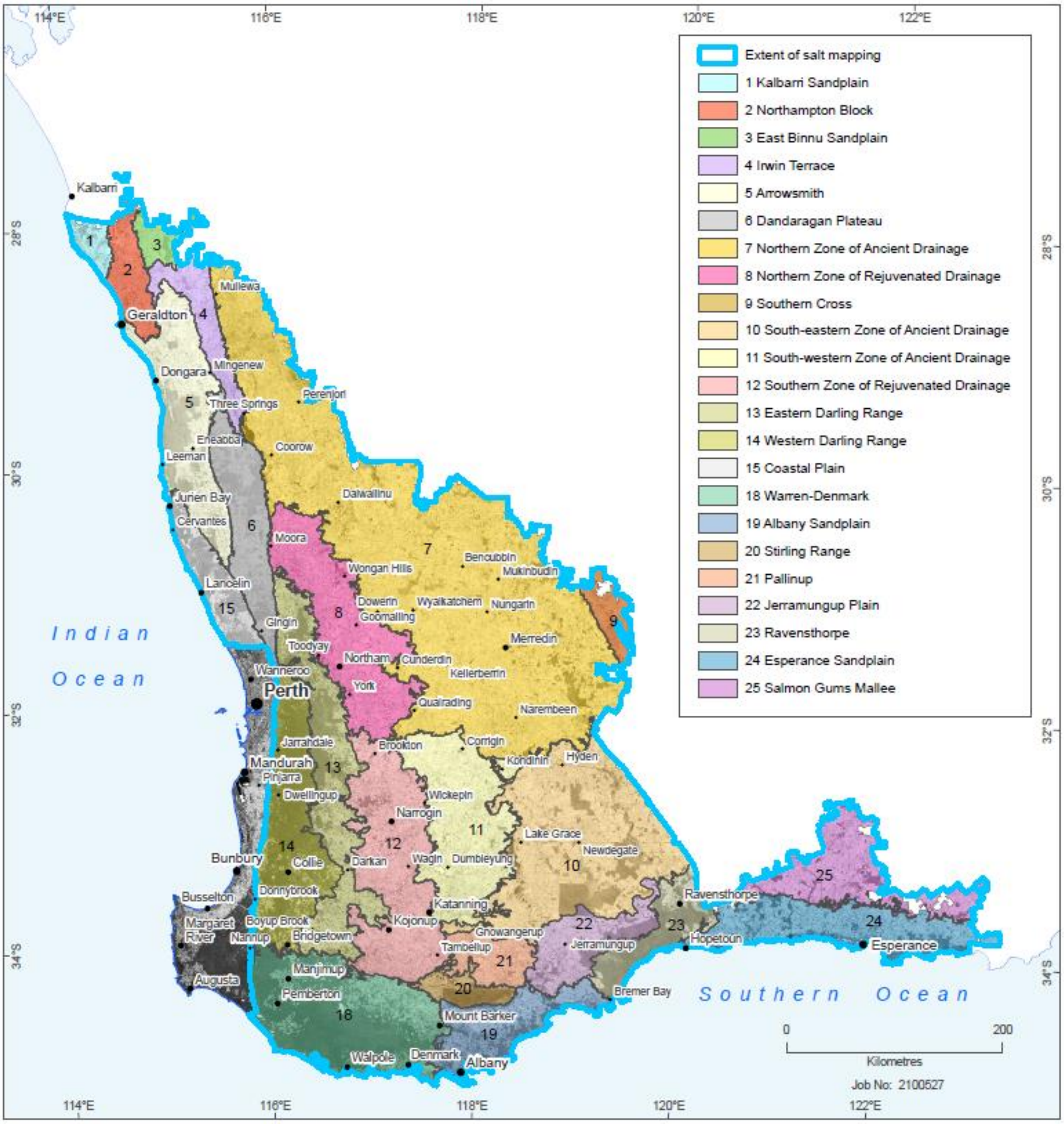


Figure 2. *Land Monitor* mapping extent and Hydrological Zones.

Similar to Furby et al. (2010) we used the varying properties between different hydro-zones, landcovers and salinity expression to guide the stratified analysis of the previous *Land Monitor* salinity extent assessment.

There are slight differences in the current mapping extent and that used in the analyses in the 1990s. Figure 3 shows the comparison. The yellow area shows the mapping extent from the 1990s analyses. In the current mapping the classification has been extended to the full extent

of the hydrological zones in the south-west and to the eastern edge of the agricultural area beyond Esperance – the green areas in figure 3.

The mapping extent is about 24 million hectares and the cleared portion that is used for agricultural production is about 17 million hectares (64%).

Details on the source data used to construct the final mapping boundary may be found in Appendix E.

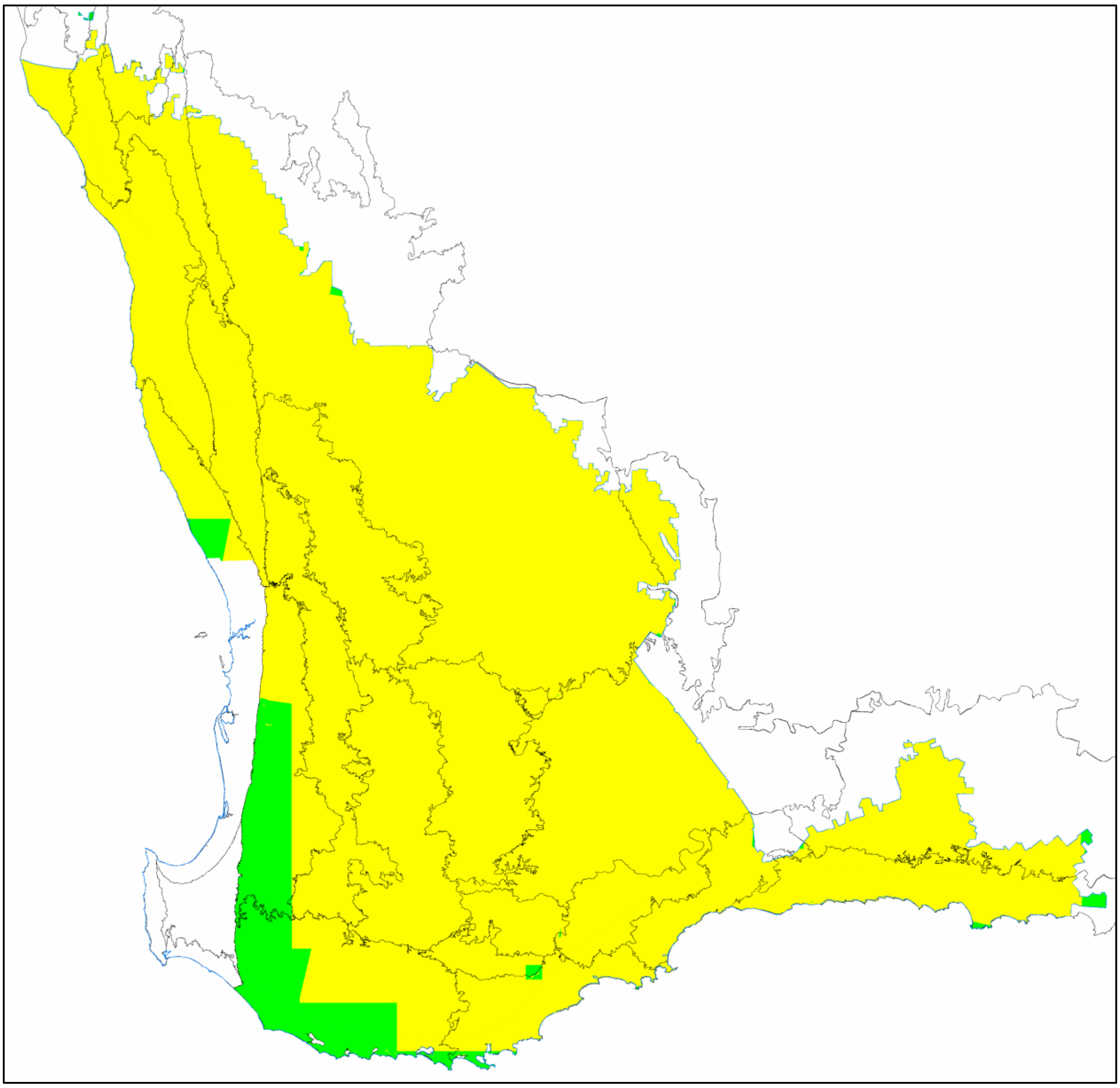


Figure 3. Comparison of current and past mapping extents.

A comparison of the current salinity mapping extents – yellow plus green – and the extents of the original 1990s mapping project – yellow only. The agricultural region boundary is overlaid in blue and the hydro-zone boundaries are overlaid in black.

2.2 Landsat satellite imagery

To map salinity at a given time period, the optical imagery is collected for three or four consecutive years to allow better discrimination of short-term productivity issues associated with weather and management from longer term productivity issues like salinity. 2010 and 2018 were selected as the time periods for analysis at the beginning of this project. Landsat imagery was acquired for 2009, 2010, 2011 and 2016, 2017, 2018 and 2019. This provides approximately decadal updates from the mapping performed using data from the early and late 1990s. Sentinel-2 optical imagery and Sentinel (available from the European Space Agency Copernicus Programme https://www.sentinel-hub.com/) has only been routinely available from 2016, and was not used as no data was available for the 2009-2011 period.

All satellite imagery was sourced from Geosciences Australia's (GA) Digital Earth Australia (DEA) image archive Collections 2 (https://www.dea.ga.gov.au/). The *Analysis Ready Data* has been previously orthorectified and calibrated to surface reflectance (Li et al., 2012). These corrections allow comparison of data from different image dates and geographic regions.

Since the 1988-1998 analysis, CSIRO has developed an automated image compositing methodology that allows the combination of images across a nominated temporal range based on image quality and image desirability scores to produce (almost) cloud-free imagery optimised for specific applications. Candidate images are identified and assigned scores based on cloud cover, image date, sensor type and greenness.

Analyses during the prior salinity mapping program showed that the optimal imagery for discriminating salinity is from the period of peak green vegetation cover during the growing season, typically late August or September for the south-west of Western Australia. Images acquired from May 1 to November 30 were considered within each year. Monthly scores (see table 1) were used to identify the likely time of peak greenness within the growing season. Each score applies to the middle of the month and the scores were interpolated to calculate a score for each specific image date within the month.

Table 1. Monthly image date weights used for salinity mapping in Western Australia

Month	Weight
January	0.0
February	0.0
March	0.0
April	0.0
May	0.1
June	0.6
July	0.7
August	1.0
September	1.0
October	0.6

Month	Weight
November	0.4
December	0.0

Each image received a score based on its sensor type. The sensor type score recognises that all Landsat 7 scenes collected since 30/05/2003 have data gaps due to the Scan Line Corrector (SLC) failure. Landsat 7 scenes acquired after this date are categorized as SLC-off. Landsat 5 or Landsat 8 imagery, when available, are preferred to Landsat 7 SLC-off imagery. Landsat 8 imagery is available from about the middle of 2013 until the present. Landsat 7 imagery is available from the beginning of this time series until the present, but there appeared to be limited availability during the growing season in some more recent years. Landsat 5 imagery is available until late in 2011 when it ceased operation. Landsat 7 SLC-off imagery is assigned a score of 0.05 and Landsat 5, Landsat 7 SLC-off, and Landsat 8 imagery are assigned a score of 1.0.

Both the date and sensor type scores apply to each image as a whole. Cloud and greenness scores are derived on a per-pixel basis within each image.

The image acquisition date is an approximate indication of likely greenness of the vegetation cover. In an early or late season, the actual peak greenness may vary from the assumed August / September time period. A greenness score is used based on the normalised difference vegetation index (NDVI). An NDVI surface is interpolated from a systematic sample of 100 points across each image (water and cloud excluded). A greenness score is then assigned to each pixel based on the NDVI surface with high NDVI giving a high score in this specific application.

The cloud, or pixel quality score, is based on the cloud and data contiguity information provided in the pixel quality image supplied by GA with each image. Pixels determined as having cloud or shadow cover based on this data are given a score of zero (excluded). A distance ramp is used to down-weight pixels near to the excluded pixels, as it is much harder to accurately detect the edges of cloud / shadow. The data contiguity information is used to exclude pixels outside the image, or in the case of Landsat 7 SLC-off imagery, pixels with incomplete information (the gaps are slightly different in each image band). Each pixel within the image gets an individual score, with the distance ramp imposing some smoothing on the scores. A ramp distance of 1000 image pixels (25km) was used.

The outputs from the compositing process are a single composite (or mosaiced) image for each year and a raster image identifying the source image date for each image pixel. Figure 4 shows a sample composite image and corresponding image date information. Each colour represents a different source image acquisition date. A list of all of the image acquisition dates used is provided in appendix D.

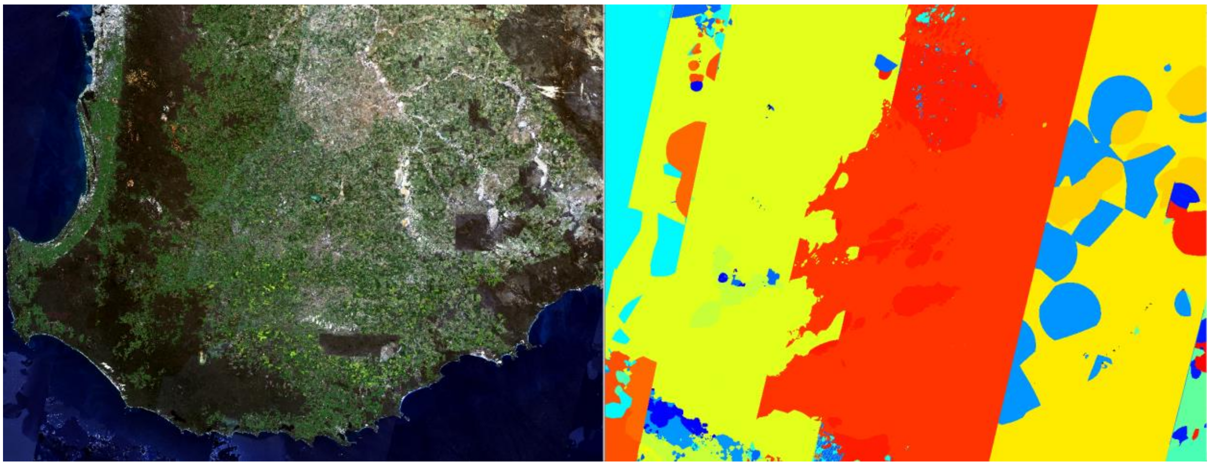


Figure 4. Satellite data compositing example.

2019 Landsat image (left) with the raster date extent image (right). Each colour represents a different source image acquisition date

Unfortunately, the pixel quality information supplied is not perfect. Not all cloud/shadow in every image is accurately detected. Also, the algorithm used is not designed to detect contaminating features such as smoke from fires and image noise. The level of contamination in the final composite is significantly reduced compared to the source imagery, however visual inspection and manual digitising to remove the remaining contaminated pixels has been applied in this instance.

2.3 Historical *Land Monitor* salinity mapping

The Western Australian *Land Monitor* project (McFarlane et al. 2004) mapped severely salt affected land over most of the dryland agricultural area of Western Australia for two time periods in the early and late 1990s. The early 1990s layer, typically derived from data between 1988 and 1992, is referred to as 'old salt'. The late 1990s layer, typically derived from data between 1994 and 2000, is referred to as 'new salt'. Training data was derived from the 'new salt' layer to train the spectral models in the current analyses (section 2.7) and both layers were used as inputs in the multi-temporal classification process (section 2.8).

The source data used here are the original Landsat path/row scene-based products delivered to the *Land Monitor* project partners at the end of the project in 2000. A subsequent mosaiced product combining all the original products was formed by Landgate in 2009 but the process of datum conversion and mosaicking was not well documented and so there are too many uncertainties associated with its use. Only class label products are available. The class membership probabilities that were intermediate products in the processing sequence have not been systematically documented or archived and so cannot be used. The classes are *Not-Mapped*, *Not-Salt*, and *Salt* and identified with value 0, 1, and 2 respectively in the digital files.

The 'new salt' layer includes an extra 'degraded woody cover class label (5)' in the region around Dumbleyung. This label has been ignored (reset to non-saline) as it was not created anywhere else. The woody vegetation extent and south-west trends products from the

continuing *Land Monitor* program provide equivalent and more accurate information on woody cover status from 1988 to the present.

The *Salt* class also includes water bodies. The Landsat image data provides no information on water quality, so products were usually masked with a water layer derived from moderately wet images in the 1990s Landsat image time series. This water mask was also transformed into the current mapping geometry.

The historical salinity mapping was performed in the geographic datum and projection current in Western Australia the 1990s; namely AGD66/TMAMG zones 50 and 51 and used local ground control to rectify the source Landsat imagery to the local map grid. The following steps were applied to convert the historical scene-based data to match the geometry of the current GA Collections 2 datasets:

1. Map-to-map reprojection software within the ERMapper image processing software to convert the data from AGD66/TMAMG5x to GDA94/MGA5x datum and projections.
2. Used the conversion of the local ground control points used in the 1990s to the AGDC v1 geometric base used by GA in 2013 derived as part of the ongoing *Land Monitor* woody vegetation monitoring.
3. Used the conversion derived from AGDC v1 to AGDC v2 (now known as Collections 2) geometric adopted by GA in 2016 derived as part of the ongoing *Land Monitor* woody vegetation monitoring.

The corrections in steps 2 and 3 were combined into a single product resampling as per the CSIRO software developed as part of the ongoing *Land Monitor* woody vegetation monitoring program. Nearest neighbour resampling was applied to the class labels at each stage. The geometrically corrected data for each scene was then mosaiced into 'old' and 'new' salt layers covering the full mapping extent.

2.4 Digital elevation models and derived variables

Elevation data was sourced from Landgate and consisted of Digital Terrain Models (DTM) that had been derived from Capture WA aerial photography by Landgate using digital photogrammetry (Landgate, 2017). The photography is systematically captured using map sheets (commonly 1:100000 series) as the basis for commissioning the aerial surveys. The photography and hence the DTM for each map sheet may then vary by year and date. The DTM was provided as a number of different raster files with extents as depicted in figure 5, where each coloured rectangle represents a DTM. The DTM represented by each coloured region may vary slightly in surface properties, varying with the date the aerial photography was acquired, the survey parameters (adjusted for example to achieve different ground resolutions), the type of camera, and the processing parameters and software version used to generate it. We will refer to these models as LDTM in the following.

For the purposes of estimating the extent of salinity, the individual map sheet DTMs are required to be mosaicked as the monitoring methodology incorporates morphological watershed analysis. Further, the elevation data were extended to the catchment boundaries

using *shuttle* elevation data, having the effect of reducing artefacts at the non-coastal boundary of the aerial survey data. The watershed analysis identifies landform classes such as hilltops and valleys which have a different probability of being affected by salinity. These varying probabilities are used to improve the accuracy of estimating the extent of salinity.

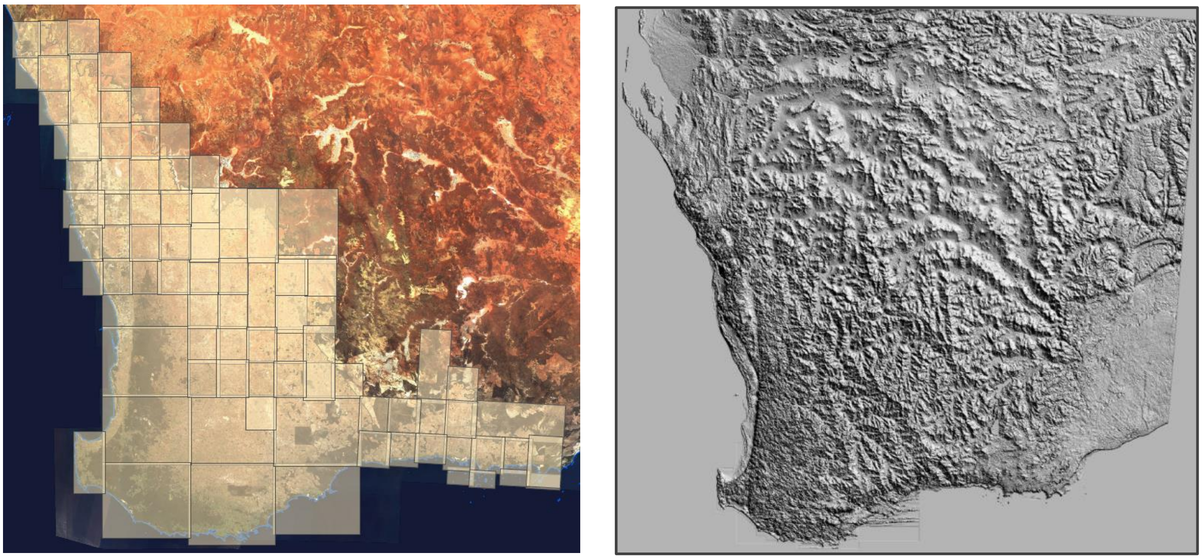


Figure 5. Graphical depiction of the extent of the digital terrain model (DTM).

Left: the DTM was provided by Landgate in approximately map sheet units. The DTM for each unit may vary slightly in surface properties, varying with: date the aerial photography was acquired (image backdrop courtesy WA NOW imagery, Landgate); type of camera used; processing parameters and software version. Right: graphical depiction of the extent of the digital terrain model mosaic. The Landgate elevation data was extended to the watershed boundaries using the *shuttle* elevation model. The data were prepared with a ground sample distance of 10m. The data are displayed with *sun-shading* to emphasise terrain features.

2.4.1 Mosaicking and pre-processing

For modelling purposes, the elevation model mosaic depicted in figure 5-right was created, as described here. This elevation model was created by mosaicing the individual elevation tiles depicted in figure 5-left and a *shuttle* derived elevation model (Gallant et al, 2011), with the latter used to extend the model to the watershed boundaries beyond the *wheatbelt* (intensive land use zone agricultural region). The elevation model surface properties including continuity of slope were an important feature for the final mosaic.

The mosaicking process included the following steps:

1) The supply of individual files was examined for project area completeness. For a given mapsheet, the elevation model may have a 5m or 10m ground sample distance. For a number of mapsheets, two files representing 5m and 10m gridded data were available.
2) The LDTM surface properties were visually examined using displays including *sun-shading* enhancements. Some edge effects (mainly surface fitting extrapolation

beyond data points) were evident in some tiles, indicating that trimming of edge artefacts for some tiles was required. Some differences in surface properties between the 5m and 10m versions were also observed, with the former displaying slightly higher detail than the latter as one would expect.

3) The elevation data were trimmed of edge effects where they were observed by manually creating a mask by digitising a new outer boundary for each affected mapsheet.
4) A crude mosaic was formed by combining all mapsheet files preferencing the 5m data where it existed. A watershed analysis was performed to generate flow paths.
5) The mosaic was visually examined for surface properties as in 2), with spatial continuity within and between mapsheets examined. An inspection of the flowpaths was also performed. Using this criteria, the 10m data were preferenced for select mapsheets and the data re-mosaicked.
6) A mosaic was formed by combining all selected mapsheet files with the Shuttle derived elevation data. The Landgate data was preferenced, with the function of the Shuttle data to extend the model inland.
7) A watershed analysis was performed on the mosaic to generate depressions and flow paths, and the results manually inspected. Importantly, some inconsitencies with the flow paths derived within the Landgate data were observed. Inconsistencies between the results for the Landgate data and *shuttle* data were also observed, though these are of lesser concern as these results are external to the region of mapping.
8) To improve spatial consistency of flow path predictions, the mosaic was resurfaced using an adaptive spatial smoothing algorithm following Caccetta et al (2010). The resurfaced DTM becomes the working model for subsequent analysis.

2.4.2 Derived variables

Landform is a significant factor in groundwater movement and the expression of salinity, with low lowing areas having a higher probability of being saline than higher parts of a catchment. From the elevation model depicted in figure 5, a number of morphological and topographic variables relating to landform were derived. Variable generation and their descriptions follow that described by Caccetta et al (2010). These variables were combined to produce landform strata that were used in subsequent analysis, following that described by Furby et al (2010).

From the elevation model, the following were derived:

- pit filled elevation model: for flow path prediction
- depression layer: morphologically closed depressions where surface water may tend to pond (figure 6)

- flow paths, ridges and hilltops (generated from variable *UpArea*): local topographic features (figure 7, centre)
- height above nearest flow path: regions within a calculated height above the nearest flow path, where nearest is estimated via overland flow

In addition, using the dam mask described in section 2.5.2

- dam upslope distance: this is the catchment area identified as metres from the dam, where distance is calculated as overland flow.

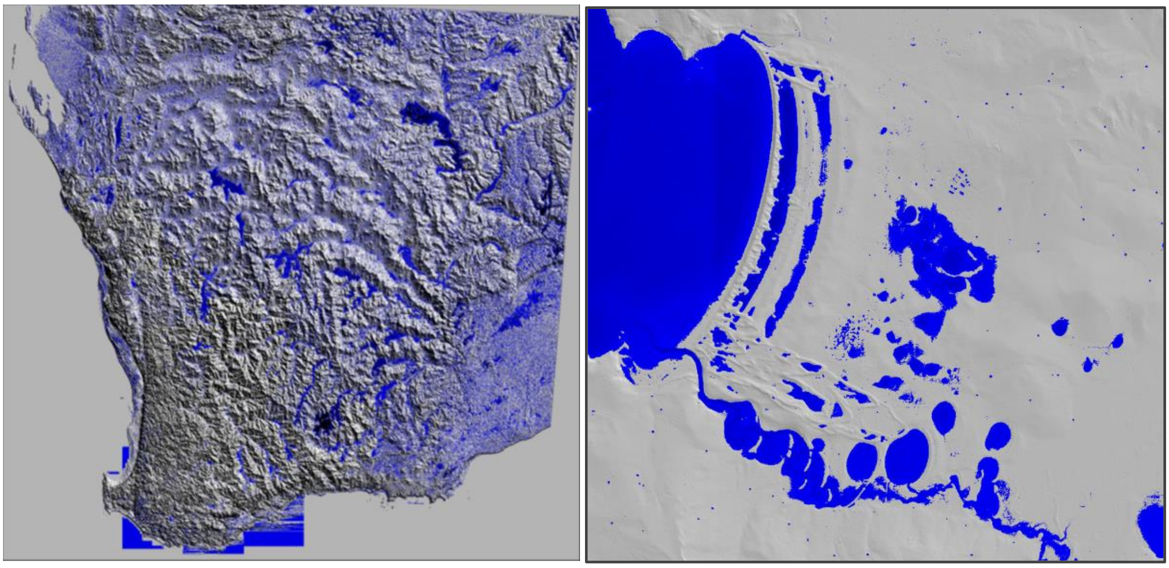


Figure 6. Identification of closed depressions.

Depression layer (blue) overlaid on LM2020_GEM (Ground Elevation Model). Left: total extent calculated. Right: localised example showing detail. State Government elevation models extended north and east with *shuttle* data. A depression layer: this variable identifies all pixels belonging to morphologically closed depressions. These are regions where surface water may naturally pond given enough rainfall. Depressions may include lakes, dams and false depressions due to artefacts or limitations of the elevation model. Each pixel of a depression is labelled with its depth to pour point (the height of water that would need to be added to fill the depression to the top).

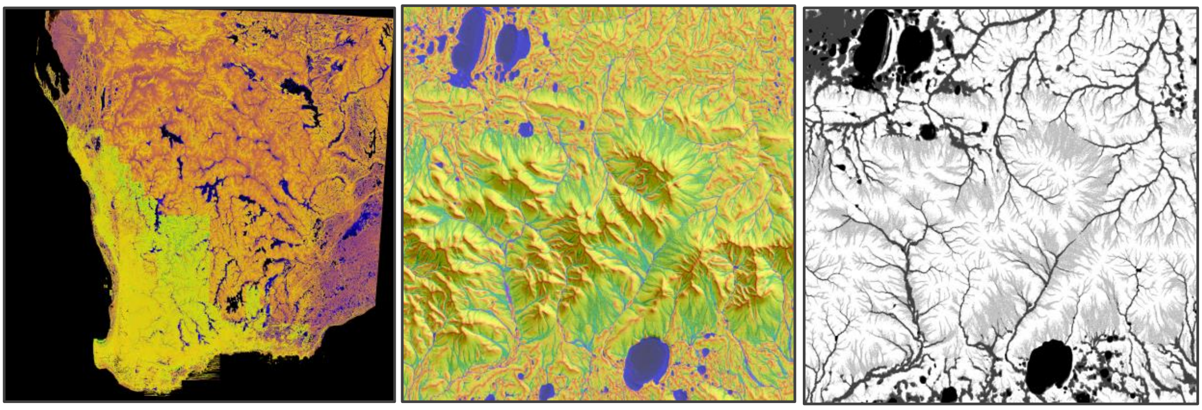


Figure 7. Landform terrain analysis.

Left and middle: Upslope area (coloured) and Depression layer (blue) overlaid on LM2020_GEM. Left is the extent calculated, middle is a localised example showing detail. Right: landform classes: {*depressions, lower_valley, lower_valley_fringe, upper_valley, ridge_hilltop*} shaded black to white successively.

2.5 Geographic masking data

Rules based on ancillary geographic data were applied to the satellite-based mapping to improve the overall accuracy of the mapping. These rules predominately remove commission errors, such as roads and dams being falsely labelled as *salt-affected*. The various masks are described below, and the hectares of masked area summarised in table 3.

2.5.1 Roads, Rail, Buildings, and Airfields

These masks are all used as they were downloaded. The masks described in the next sub-section were further processed prior to use.

Roads were obtained from two sources, downloaded in September 2020:

(i) Roads (LGATE_012) from Landgate via the Data WA catalogue; and

(ii) OpenStreetMap

The links to each of these datasets are below. The datasets have a lot of common elements, but each have a different subset of local roads and tracks. Their union covers all the roads and many of the tracks observed in the imagery. A comparison of the two datasets is shown in figure 8. The Landgate roads are classified as major, minor, local and other. These classifications are used in the masking process.

https://catalogue.data.wa.gov.au/dataset/roads-lgate-012 and
http://download.geofabrik.de/australia-oceania.html

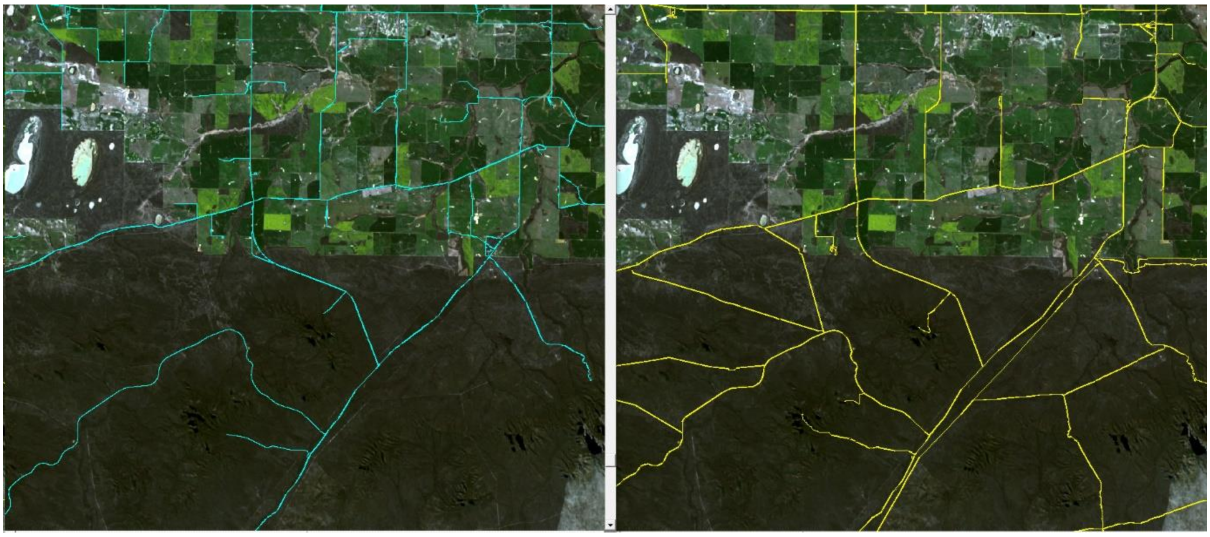


Figure 8. Road vector examples.

The figure depicts the 2019 Landsat image (true colour) with Landgate roads overlaid in light blue (left) and OpenStreetMap roads overlaid in yellow (right). The region shown is the northern edge of the Stirling Range National Park.

Railway lines were identified from the 'Railway Corridor (LGATE-244)' layer downloaded at some time before 2/11/2021 (https://catalogue.data.wa.gov.au/dataset/railway-corridor). This layer delineates the cadastral extent of the Public Transport Authority's Rail Freight Corridors.

The 'Buildings of the South West agricultural region of WA (DPIRD-084)' layer (link below) was used to identify buildings within the study area. This product was created with Deep Learning image segmentation of satellite data (Vivid 2.0), with further filtering of each feature with a Deep Learning binary classifier. The imagery that this data was derived from was mostly captured from 2018 to 2019. The product contains records for 560,000 sheds/houses/silos throughout the south-west agricultural area.

https://catalogue.data.wa.gov.au/dataset/buildings-of-the-south-west-agricultural-region-of-wa

Airfields were identified using the Landgate *Medium Scale Topo General Transport Polygon* layer accessed on 2/11/21 (https://catalogue.data.wa.gov.au/dataset/Medium_Scale_Topo_General_Transport_Polygon_LGATE-035). This dataset includes runways, tarmac areas and airfield buildings within its polygons.

The 'linework' datasets (road and rail) were converted into raster presence / absence layers using gdal_rasterize. Only the 25m pixels directly on the line render path were included in the raster mask.

The 'polygon' datasets (buildings and airstrips) were also converted into raster presence / absence layers using gdal_rasterize. Only the 25m pixels with centres inside the polygons were included in the raster mask.

2.5.2 Dams, reservoirs and estuaries

Three data layers which identified dams and reservoirs were used to create masks.

Firstly, the *Farm dams of the South-West agricultural region of WA (DPIRD-083)* layer was used. This layer was derived from a Deep Learning image segmentation model train to identify farm dams from Vivid 2.0 imagery. This product contains records for 160,000 farm dams throughout the South-West agricultural region.

https://catalogue.data.wa.gov.au/dataset/farm-dams-of-the-south-west-agricultural-region-of-wa

Dam catchment areas with minimal plant cover may also produce false positive detections of saline areas. The region of land within the immediate local catchment area for each dam were identified using the dam location data combined with the elevation data from section 2.4.2 to form a *dam upslope distance* variable, depicted in figure 9.

The *Farm dams of the South-West agricultural region of WA* layer identified most of the farm dams, however did not identify the large valley dams commonly found in higher rainfall areas such as the Shire of Manjimup.

Secondly, large valley dams were identified using a filtered version of the *Digital Earth Australia Waterbodies* layer (ref link below) accessed on the 1/11/21. This layer was filtered using a deep learning convolutional neural network image classifier. This classifier analysed the corresponding Vivid 2.0 imagery for each waterbody polygon and classed each polygon into one of two classes *dam* or *not dam*. This process had a global accuracy of 94% and identified 2847 dams which were masked out of the modelled result.

https://ecat.ga.gov.au/geonetwork/srv/eng/catalog.search#/metadata/132814

Thirdly, reservoirs were identified using the Landgate layer 'Medium Scale Topo Water (Polygon)' (ref link below) accessed on 3/11/21. This layer was filtered to only include polygons attributed as 'Reservoir'. Each reservoir was additionally merged and dissolved with any intersecting polygon from the 'Digital Earth Australia Waterbodies' layer. This process refined the spatial extent of each reservoir.

https://catalogue.data.wa.gov.au/dataset/medium-scale-topo-water-polygon-lgate-016

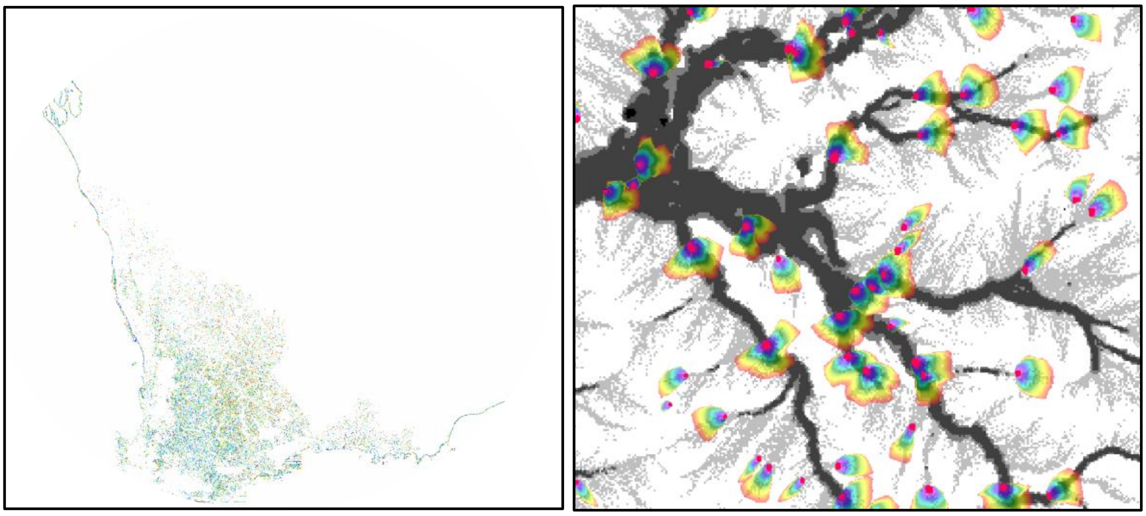


Figure 9. Farm dams and adjacent upslope regions.

Left: synoptic view of extent of *dam upslope distance* calculation. Coloured areas in the agricultural area depict dam catchment areas adjacent to dams. Right: local example of *dam upslope distance*, overlaid on landform. Coloured areas represent upslope distance from dam locations. Dam locations are coloured pink

2.6 Ground Information

Spatially referenced ground information on saline and non-saline cover types was required for several purposes including: for the analysis of the spatial data to form a classification model; for validation of the maps produced from the model; estimating any mapping bias; and for forming a state-wide *bias-adjusted* estimate of salinity extent. Different sets of ground data were used for the different purposes, for example sample locations provided less formally as part of iterative review of mapping and used for model training, compared with data stratified random sampling for validation purposes.

Location of ground sites was aided by high resolution imagery. The first source of data was true-colour satellite Maxar imagery mosaic product labelled *Vivid 2.0* was comprised from acquisitions from 2005 to 2019, with the majority dating from 2018 to 2019. The mosaic had a spatial resolution of 0.5m. The stated positional accuracy (easting, northing) for the imagery is 8.47m. The second source of data was Landgate's WA Now aerial imagery service. This data comprised complete coverage of the *Land Monitor* area with 1:100,000 true-colour imagery. Imagery capture was from 2004 to 2021 with the majority from 2014-2020. The nominal positional accuracy of the pre 2010 imagery is ±2m and ±1m for the post 2010 imagery.

Ground label information was provided by DPIRD hydrologists with local regional knowledge for a number of areas within each stratification zone. Local qualitative and quantitative knowledge includes that obtained from years working with local land-owners and catchment management groups to identify and plan responses to salinity and other related productivity issues. This knowledge was translated into map form using the high-resolution imagery to locate and map boundaries of salt affected land. The resolution and positional accuracy of the photography allowed mapping of saline areas more than sufficient for comparison with the Landsat series of satellites. Interpretation of ground labels was also aided by multiple remote sensed and geographic layers including: 2m elevation contours, Vivid 2.0 satellite imagery, and *WA Now* aerial imagery mosaic, MODIS and Landsat satellite imagery (normalized difference vegetation index) NDVI as well as the historically mapped *Land Monitor* salinity extent. Ground labels thus reflect expert opinion informed from multiple sources of evidence as opposed to direct measurements of salts within the soil.

2.6.1 Training data

An iterative combination of historical *Land Monitor* salinity presence/absence information supplemented with presence/absence data acquired during the course of the project was used to train the models. A sampled version of salinity mapping results from the initial *Land*

Monitor project (McFarlane et al 2004) were used initially as training data and for preliminary salinity mapping update assessment (see example in figure 13). This in part was to reduce the amount of new data that needed to be collected, with the best case being that the data would be sufficient and no extra training data was required.

The first draft of the 2016-2018 Land Monitor salinity map was evaluated by DPIRD hydrologists in early 2020, with the results used to guide where additional training data were required. DPIRD hydrologists subsequently mapped 277 polygons equating to approximately 7000 ha across the study area to delineate known areas of salt affected land and areas with commission or omission errors. DPIRD hydrologists also displayed the draft Land Monitor map at Wagin Woolorama in March 2020 where landholders predominantly from the Great Southern region assisted with mapping 420 polygons covering about 4000 ha which delineated low, moderate and severe salinity, revegetated saline areas, bare or waterlogged soil and infrastructure. These two polygon datasets, which we collectively refer to as *tr-data*, were then used to retrain the model (section 2.7).

2.6.2 Ground reference data and Validation

A number of data were collected during the project for the purpose of validating the accuracy of the satellite mapping. The data were collected either as point data, or mapping region data.

The point data (*p-data*) consisted of a specific location labelled as *Salt* or *Not Salt* according to expert opinion, producing a list having {*Easting, Northing, Label*}, along with possibly some informal site description.

Mapping region data (appendix B) consisted of over 70 local *Study Areas* mapped as *Bare, Revegetated Salt, Severe Salt, Moderate Salt*, and *Not Salt*. We will refer to this data as *sa-data* in the following.

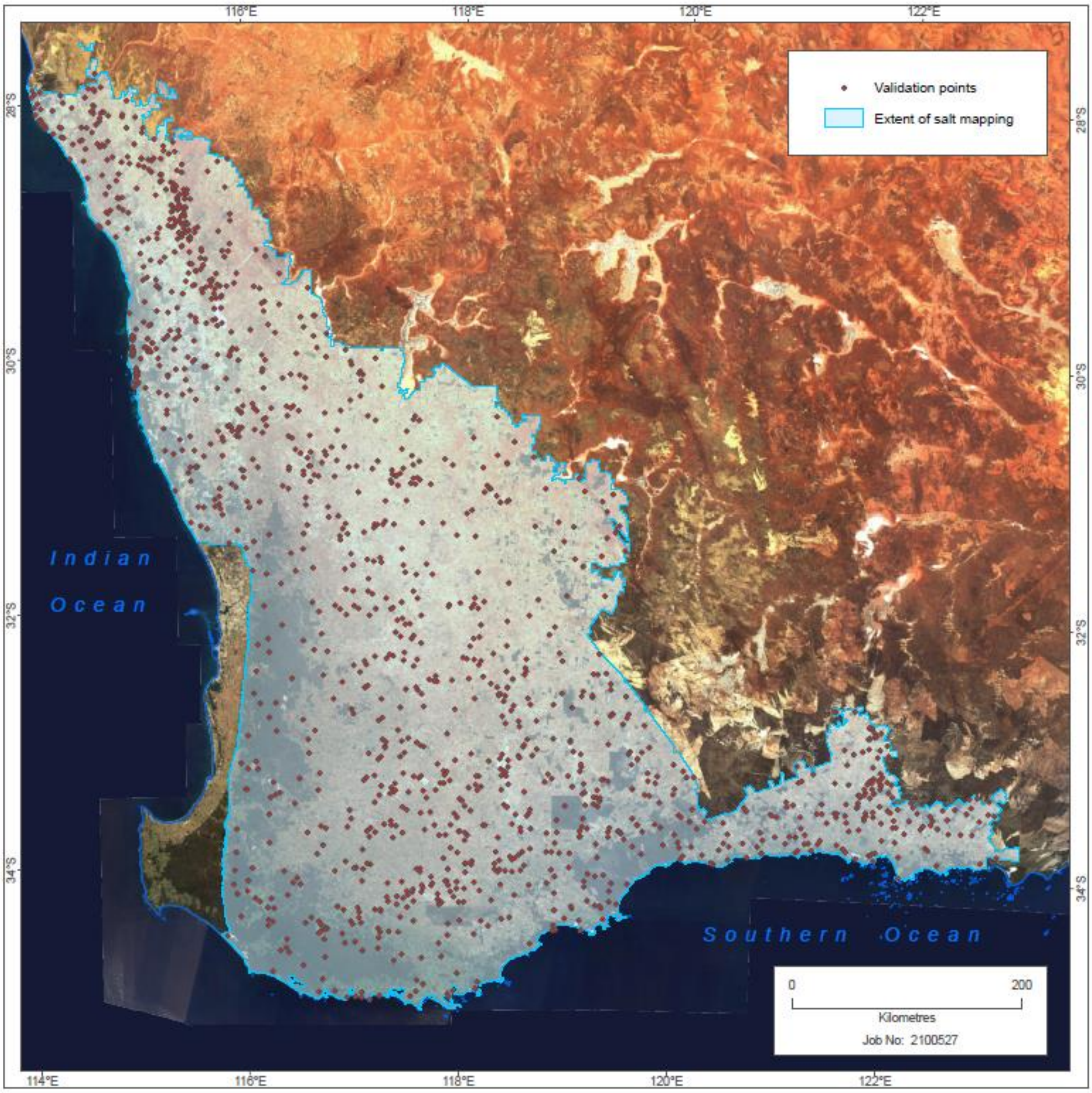


Figure 10. Ground reference site locations.

Image backdrop courtesy WA NOW imagery, Landgate.

p-data: To validate the final model the seven amalgamated hydro-zones (figure 11) were used for the stratified random sample selection. The amalgamated hydro-zones correspond to the six zones identified for salinity prediction (Caccetta et al 2010), with an extra zone representing expansion of mapping into the northern coastal plain. Samples were collected in equal numbers per hydro-zone, allowing error estimates with equal precision for each hydro-zone; and samples were collected by a single senior hydrologist providing uniformity of interpretations. For each amalgamated hydro-zone, 100 pixels from each predicted class, were selected, resulting in 1,400 pixels. Each one of these pixels were manually evaluated for the year 2018 using multiple data layers described above. Figure 10 provides a graphic of the location of the samples.

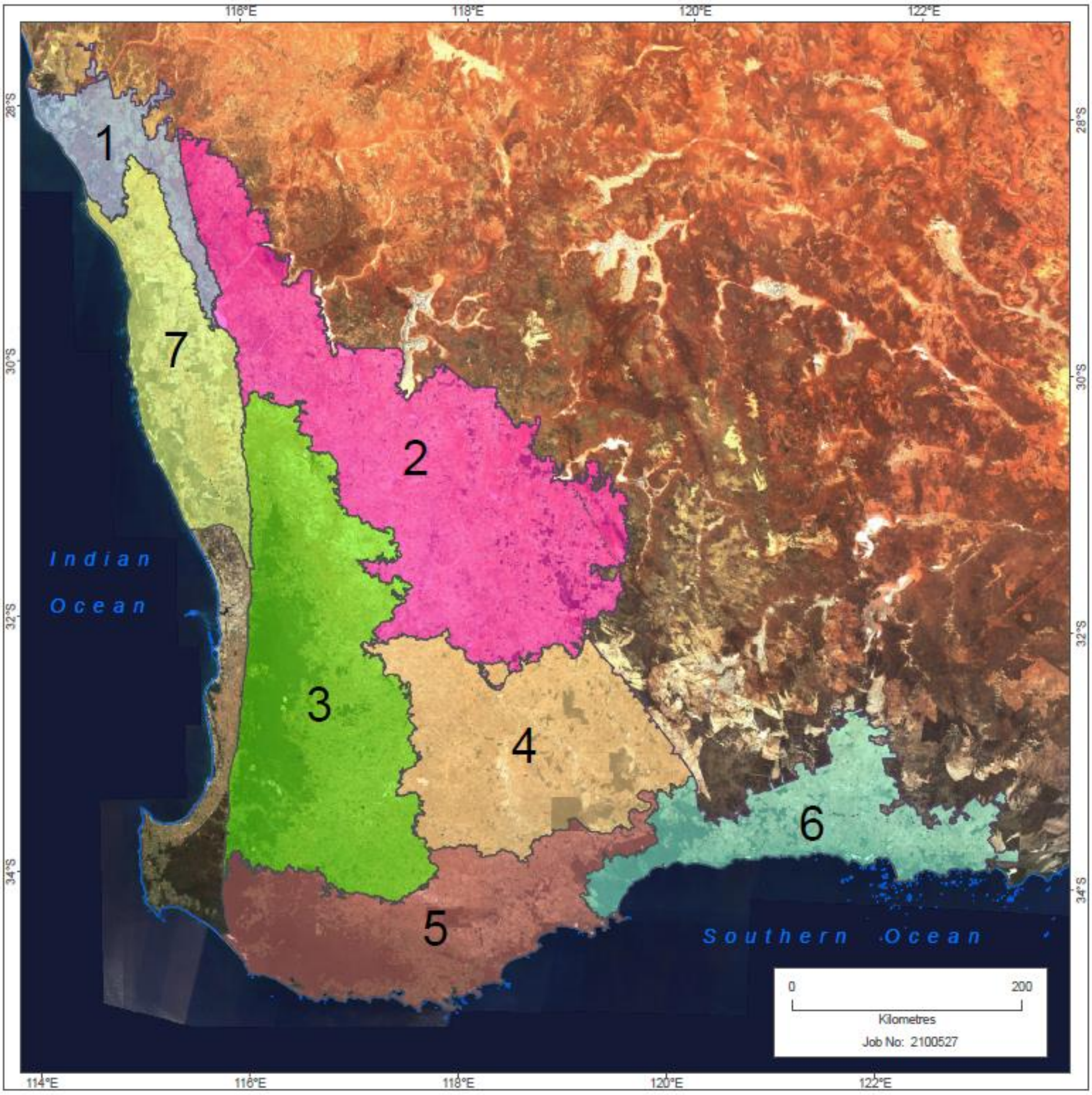


Figure 11. Hydro-zone grouping used for validation.

Image backdrop courtesy WA NOW imagery, Landgate.

sa-data: To provide ground validation data for the current salinity extent mapping and training data for future works, the location and extent of salinity in seventy (70) areas, totalling 354,023ha, situated within twenty (20) hydro-zones across the south-west agricultural region were manually mapped (figure 12). The areas ranged in size from 60ha to 30,700ha, with and mean size of 5,100ha and a median size of 2,300ha. The number of areas mapped within each of the hydro-zones were based on the area of the hydro-zones and ranged from one area in the smaller hydro-zones up to eight areas within the larger hydro-zones of the eastern wheatbelt.

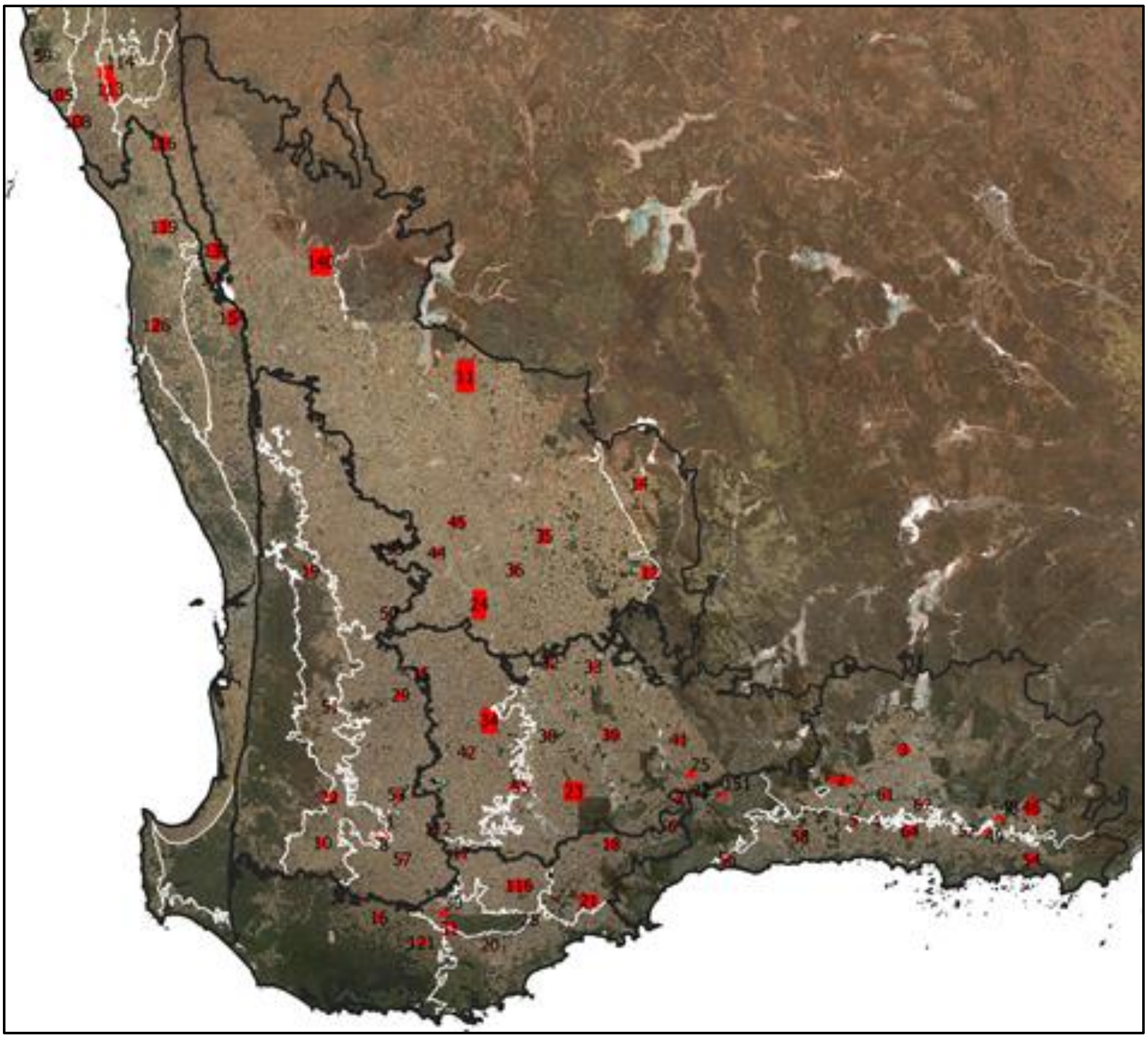


Figure 12. Mapped regions for validation.

Red boxes depict the extent of each mapped region. Numerical labels reference each individual site detail included in appendix B.

Areas were mapped using both field survey and interpretation of the same set of high-resolution imagery used for the initial training and validation. Field surveys used a combination of visual assessments, farmer interview and in some areas a hand-held Electro Magnetic (EM) ground instrument (Geonics EM38) was utilised to measure apparent soil salinity severity at selected sites within the mapped areas. In five mapped areas existing Electro Magnetic (EM) ground-based surveys were available to assist in the mapping. Salinity severity was classified into two classes, severe and a combination of high, moderate and low, based on an amalgamation of the nationally agreed (NCCSI 2009) salinity classes (table 2).

Table 2. Australian land salinity classification

Class	Soil ECe (dS/m)	Description	***Study Area*** **mapping classes**
Non-saline	< 2	land not currently affected by shallow or rising watertable	Not salt
Slightly saline	2 – 4	ground surface seasonally damp after extended periods of rain; gradual change in pasture composition with reduced vegetation diversity and reduced growth and/or yield of crops and pastures often associated with a slight yellowing of the leaves; deep rooted species are affected, especially horticultural species and salt sensitive legumes (eg. white and sub–clover, soybeans, chickpea, etc.); patches of salt tolerant species such as sea barley grass (Hordeum marinum) or Strawberry Clover (Trifolium fragiferum); dieback in some trees; intermittent streams flow for longer periods.	Low to moderate to high salinity
Moderately saline	4 – 8	ground surface damp for very long periods after extended periods of rain; many field crops and pasture species are severely affected; change in pasture composition to dominance by salt-tolerant species including salt tolerant grasses; a reduction in the vigour of less tolerant species such as Strawberry Clover; dieback in most trees; intermittent streams evolve to permanent streams; rising damp in buildings; some deterioration of road conditions.	
Highly saline	8 – 16	ground surface waterlogged or permanently moist too salty for most field crops, as well as lucerne; halophytes are common; salt tolerant species (eg. sea barley grass - Hordeum marinum) may dominate large areas and only salt tolerant plants remain unaffected.; trees dead or dying; areas of bare soil with salt crusts; degradation of soil structure with subsequent soil erosion; rising damp and salt efflorescences in buildings; major deterioration and crumbling of roads.	
Severely saline	16 – 32	Halophytes dominate and only highly salt tolerant plants survive (eg Puccinellia ciliate and Atriplex species). Decreased growth of most halophytes, some may show a reddening of the leaves and at the upper end of the range even highly salt tolerant species may be scattered and in poor condition. Most trees will be dead, except for some highly salt tolerant trees (eg. *Melaleuca spp*). Extensive bare saline areas occur with salt stains and or crystals evident (on some soils a dark organic stain may be visible), topsoil may be flowery or puffy.	Severe salinity
Extremely saline	>32	Bare salt scalds and Samphire (Halosarcia spp.) dominate. Some halophytes die; most have decreased growth	

2.7 Spectral analysis of Landsat observations

A sequence of spring Landsat imagery from 2009, 2010, 2011, 2016, 2017, 2018 and 2019 were used in the analysis, and we note that the methodology is readily extendable for adding future and historical dates, and for incorporating data from new optical and SAR sensors. For each date of imagery, an analysis was performed to produce a class label and class label probabilities image. Three classes were defined: (1) salt, (2) not salt, and (3) water. The class probabilities obtained from the analysis were used as inputs to the multi-temporal model (Section 2.8).

Here we applied a highly automated workflow using a *RandomForest* machine learning algorithm (Breiman, 2001) to predict the class labels and their probabilities from the satellite observations. This approach is computationally feasible with modern computing tools, and offers automation as compared with the canonical variate analysis and multivariate gaussian maximum likelihood classification methodology used in the historical mapping and described by Furby et al, (2010), which is computationally less expensive but requiring specialised human analysts.

As with the historical methodology, the *RandomForest* classifier is a supervised classification, building the classification model from training data. The training data takes the form of sample image spectra with known class labels. An initial set of training data was derived from the historical *Land Monitor* salinity mapping. A preliminary salinity extent map based on averaging the probabilities from these analyses was supplied to DPIRD hydrologists to seek feedback. Subsequent mapping based on a multi-temporal classification of the initial class probabilities was also supplied. Based on the feedback from DPIRD hydrologists the training data were adjusted to produce the final spectral class probabilities.

To create the training data for the first iteration of the *RandomForest* classifier the following steps were applied to the geometrically transformed historical 'new salt' and 'water' layers:

1. Omit all areas of salinity less than 15 connected pixels (just under 1 hectare) in size.
2. Omit all not salt areas within 20 pixels (500m) of the remaining areas mapped as salt.
3. Use the *Land Monitor* woody vegetation monitoring water mask to omit all areas that it labels as water (ocean, inland lakes and many rivers / creeks) thus omitting all the water areas labelled as 'salt' in the historical mapping.
4. Apply the historical salinity mapping water mask to add the pixels for the new water class
5. Retain all *Salt* and *Not Salt* labels from the historical *new salt* layer not otherwise omitted or altered by the above four steps.

Several iterations of testing were performed using the 2016 and 2018 image data to refine the size and distance parameters used. The training layer created from this process was used to create a separate classifier for each of the image years. A sample of the training data is shown in figure 13. In this first iteration of the spectral classification each amalgamated hydro-zone was treated as a separate stratification zone. Twenty percent of training data in each class in each stratification zone, selected randomly, was reserved for a preliminary

accuracy assessment of the fitted model. The accuracy assessments were pooled to generate error rates estimates used in the multi-temporal classification. Given the variability in season and available imagery, the quality and accuracy for the purpose of mapping salinity may vary year to year. These error rates weight the contribution of each year as estimated by the accuracy of the *RandomForest* results, allowing suboptimal/optimal observations to be weighted relative to one another. For example, results obtained from images with some haze present may not be as accurate as obtained from images with clear skies – in this case the results obtained from the hazy images may be less accurate and down weighted accordingly.

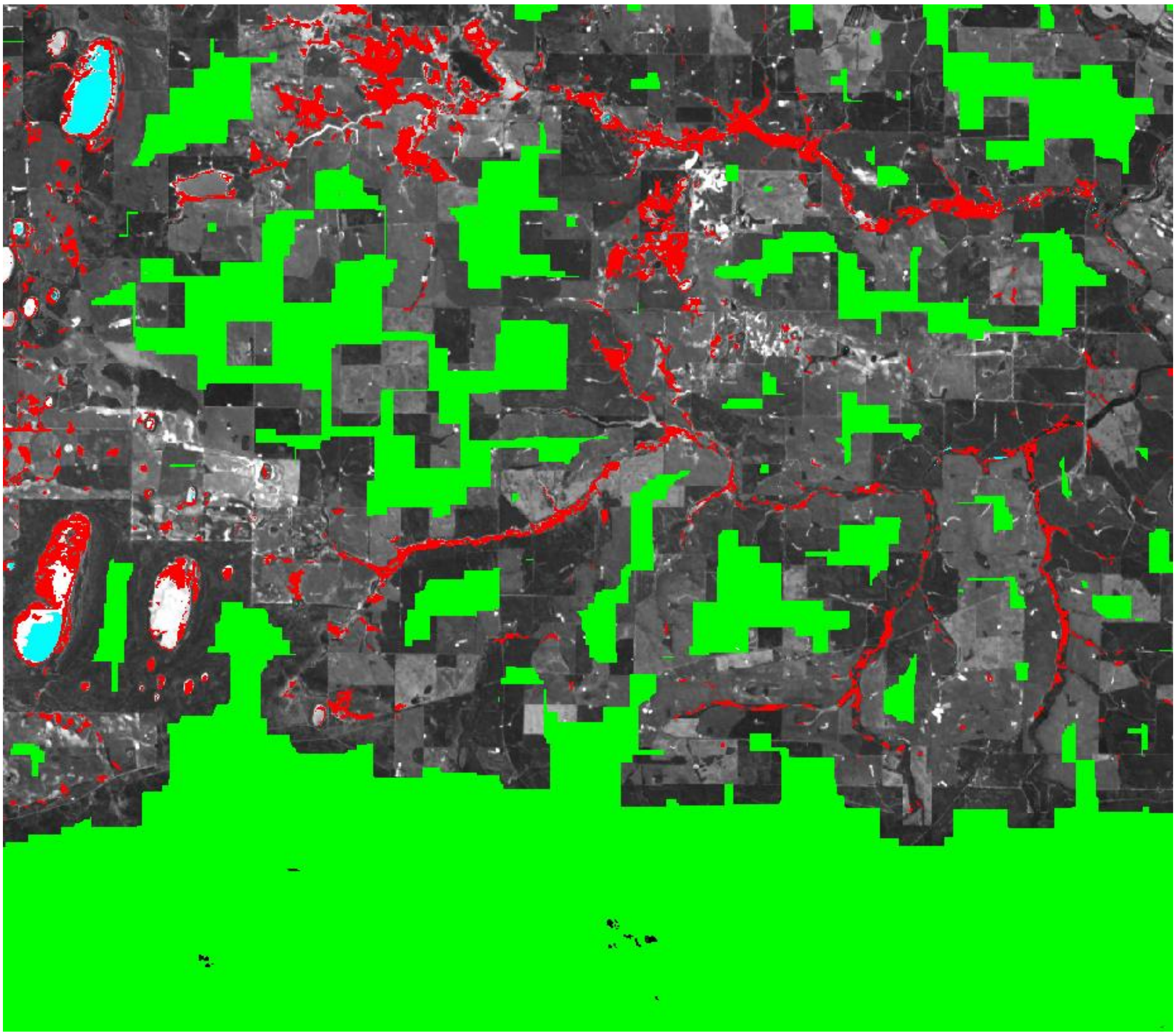


Figure 13. Example of initial training data.

Example of iteration 1 training data overlaid on a greyscale view of the 2019 Landsat image. Green are *Not Salt* training samples, red are *Salt* training samples and light blue are *water* training samples. The region shown is at the northern edge of the Stirling Range National Park.

Following review of the initial product additional training data (*tr-data*) was supplied in the form of several hundred polygons with *Salt* / *Not Salt* labels (Section 2.6.1) and a review of the parameters used to set up the initial training dataset was undertaken. The updated training samples were formed from the initial training sample as follows:

1. The *Salt* sites from the feedback polygons were added to the *Salt* training class. A buffer zone of twenty non-saline and water pixels (500m) surrounding the new sites were omitted.
2. The *Not Salt* sites from the feedback polygons were set to *Not Salt*.
3. Additional polygons on commission errors such as mine sites, rocky outcrop and burnt bush areas were digitised and set to *Not Salt*.
4. A smaller set of polygons on likely, but not certain, commission errors were digitised and omitted from the training sample.
5. Omit all *Not Salt* in low-lying areas (classes 1, 2 and 3 in the landform class map, section 2.4.2).
6. Omit all areas labelled as roads or buildings in the raster versions of these datasets.
7. Omit all areas labelled as dams and all areas within 3 pixels (75m) of in raster version of this dataset.
8. Omit the historical water layer and replace with a year-specific water layer based on thresholding a combination of the SWIR1 and blue image bands in the current imagery.

Figure 14 shows a comparison of the original and revised training samples.

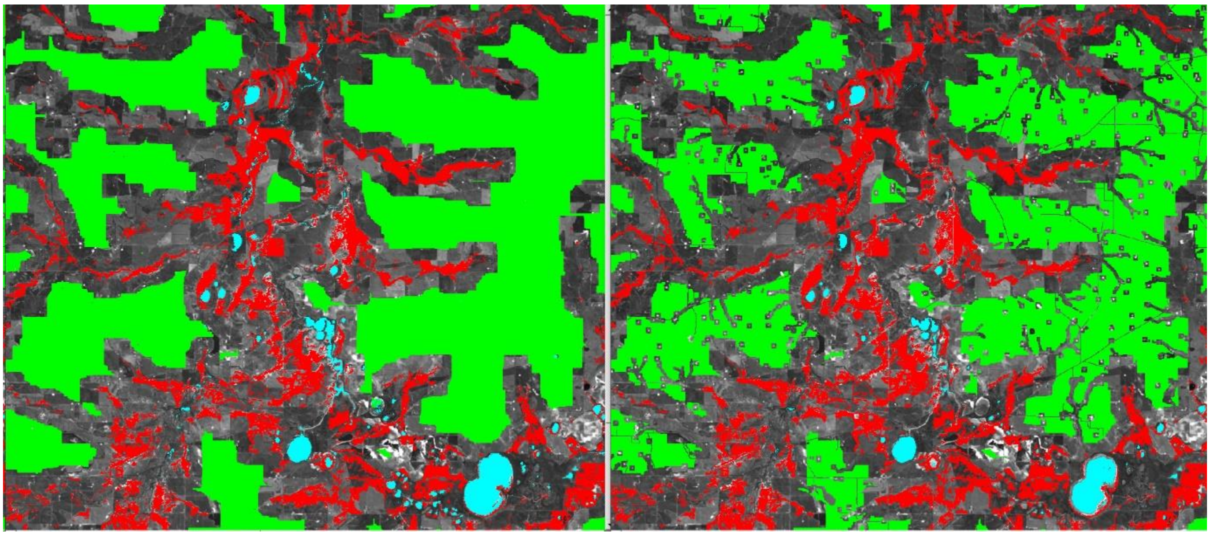


Figure 14. Example of initial and revised training data.

Original (left) and revised (right) training data overlaid on a greyscale view of the 2019 Landsat image. Green are *Not Salt* training samples, red are *Salt* training samples and light blue are *water* training samples.

The effect of revising the training sample was to significantly reduce the training sample size, particularly in some hydro-zones. The local accuracy of both the historical and current salinity layers also appeared to vary across the hydro-zones.

The hydro-zones were also used to stratify the region for analysis both in the direct spectral analysis of the satellite image data and in the multi-temporal modelling. In the first iteration of the spectral analysis each hydro-zone was considered individually. In the second iteration

performed in response to initial feedback the hydro-zones were grouped as shown in figure 15. Each colour represents a combined stratification zone.

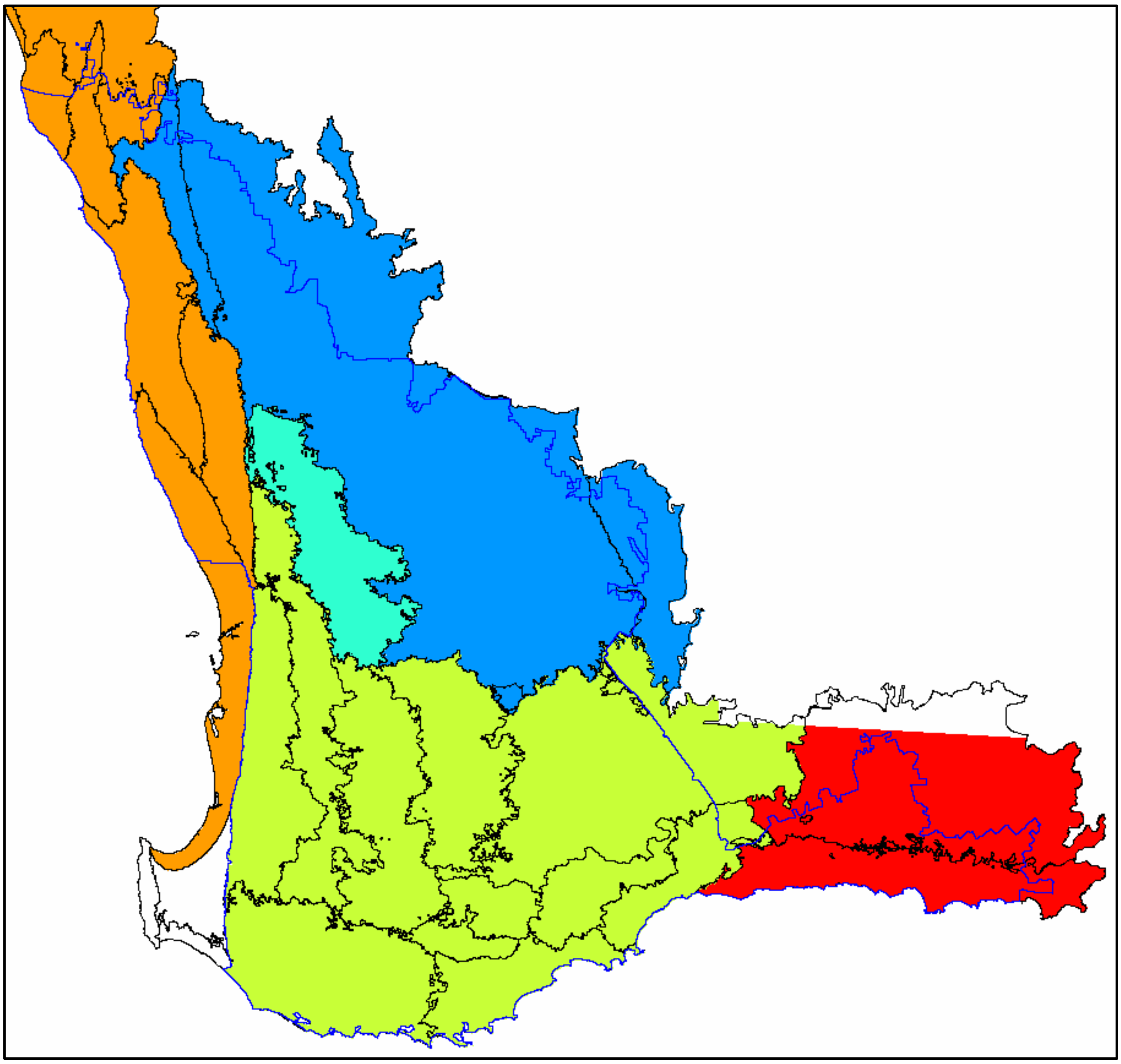


Figure 15. Grouping of hydro-zones for spectral analysis.

This figure depicts the grouping of hydro-zones into the final stratification zones for the second iteration of the spectral analysis of the satellite image data. Each colour denotes a stratification zone. The individual hydro-zones vector is overlaid in black and the mapping extent vector in blue.

2.8 Spatial-temporal classification

Noting that optical Landsat imagery alone cannot distinguish between some salt-affected land and bare ground, we use a temporal sequence of images and landform for mapping and monitoring. The time series is composed of sources of data of varying quality and spectral discrimination. We use joint models which incorporate error rates of the initial interpretations as well as temporal and spatial rules. Here we provide a brief outline of the model, with the

reader referred to (Kiiveri and Caccetta, 1998) for greater detail. To specify the model, we introduce some notation.

Probability distributions will be denoted as $p(.)$, and $q(.)$ used to denote conditional and unconditional potential (unnormalized) distributions. For pixel $i = 1, \ldots, n$ let u_i and z_i represent the stratification zone and landform variables respectively, and in addition for time point $t = 1, \ldots, m$ let w_{it}, y_{it}, and x_{it} represent the satellite observation, class label, and *true* class label respectively. We use the notation $n(i)_t$ to denote the 8 pixels class labels adjacent to i at time t. The joint potential model for the observed and unobserved images can be written as:

$$q(\mathbf{x}_1, .., \mathbf{x}_m, \mathbf{y}_1, .., \mathbf{y}_m, \mathbf{w}_1, .., \mathbf{w}_m, \mathbf{u}, \mathbf{z},)$$
$$= \prod_{i=1}^{n} \prod_{t=1}^{m} q(y_{it}|w_{it}) p(y_{it}|x_{it}) \, p(x_{it} \,|x_{it-1}, u_i, z_i) \, p(x_{it}|\mathbf{x}_{n(i)_{t-1}}) \, p(u_i) \, p(z_i) p(w_i)$$

where we define $p(x_{i1}|x_{i0}, u, z_i) = p(x_{i1}|u_i, z_i)$. In practice for this application the model terms $p(u_i), p(z_i), p(w_i)$ are inactive as these variables are conditioned upon.

The model and data are used to compute the most likely class label for each unobserved variable $\mathbf{x}_t$ by maximizing the marginal distributions

$$q(x_{it} \,|\mathbf{x}_{n(i)1}, \ldots, \mathbf{x}_{n(i)m}, y_{i1}, \ldots, y_{im}, u_i, z_i)$$

for $t = 1, \ldots, m$.

The model terms are estimated and/or calculated as:

$q(y_{it}|w_{it})$: the value for pixel i and for date t is the class probability generated from the *RandomForest* analysis of the previous section.

$p(y_{it}|x_{it})$: the error rate estimated for each classification generated from *RandomForest* analysis of the previous section.

$p(x_{it} \,|x_{it-1}, u_i, z_i)$: estimated using an EM algorithm

$p(x_{it}|\mathbf{x}_{n(i)_{t-1}}) \propto \exp\{\alpha_s + \beta_s N(x_{is})\}$: where $N(x_{is})$ is the number of eight nearest neighbours of pixel *i* with label x_{is}. This value is generated during the calculation from neighbouring pixels class labels.

A graphical depiction of the model is displayed in figure 16, where the nodes in the graph are represented as squares and circles representing discrete and continuous variables

respectively, and the edges in the graph specify the dependences between the variables. Variables depicted as solid or hollow shapes represent observed and unobserved variables respectively. Variables denoted by dotted outlines represent neighbourhood operations. The class label variables depicted as orange are those which we predict.

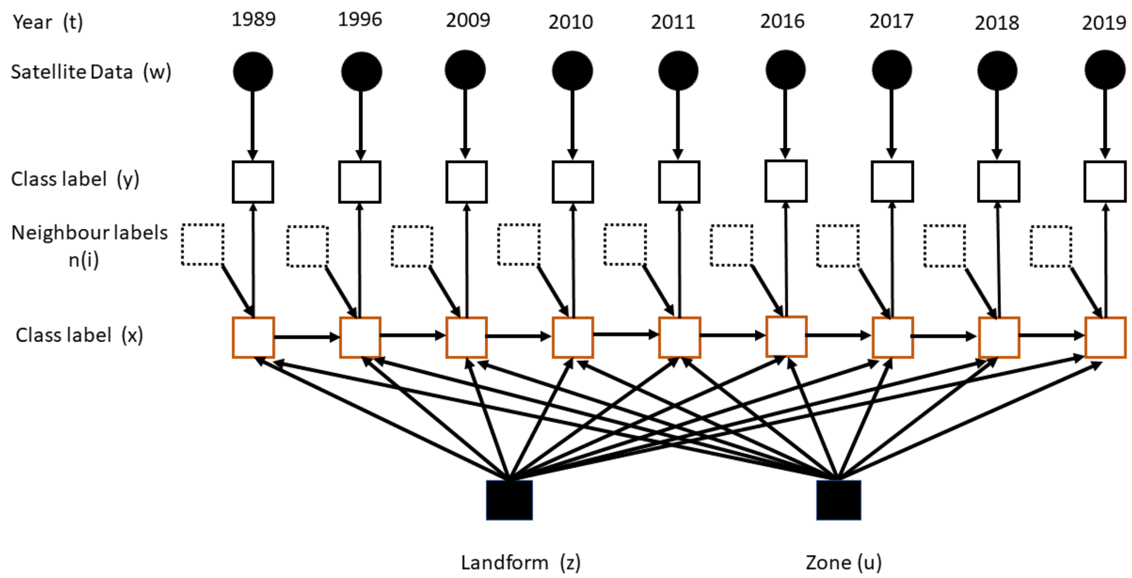


Figure 16. Graphical depiction of the spatial-temporal model.

Squares and circles represent discrete and continuous variables respectively. Variables that are solid and hollow represent observed and unobserved variables respectively. Unobserved class label images represented by the orange squares are predicted using the model and observed data.

The model was fitted using individual hydro-zones. Where the fits were observed to produce poorly fitting maps, typically resulting from small numbers of observed saline areas, parameters from larger neighbouring hydro-zones were applied.

2.9 Post Classification Processing

Some commission errors (false positives in the *Salt* class) remain after spectral, temporal and spatial analysis, typically associated with areas of little vegetation or built structures low in the landscape. Available spatial datasets that correspond to common error types were used to automatically remove the errors. The error masks were coded according to which dataset was used to generate the exclusion. There were several datasets that were used to remove errors.

Roadside verges and the tracks around outer edges of cropped paddocks typically have low vegetation cover and may be spectrally similar to some salt-affected lands. In some cases, the construction of a road can disrupt waterflows and contribute to an outbreak of salinity, but such areas typically extend into the cropped area of a paddock or local blocks of native

vegetation. Pixels classified as salt on or immediately adjacent to roads were masked unless the connected saline area extended more than one pixel (25m) from the road. The masking was a performed separately using all features in the Landgate and OpenStreetMap road layers.

Major roads typically have wider shoulders and road reserve areas than local roads within a region. Further masking was applied to these features without considering the extent of the overlapping saline area using the Landgate roads layer. All roads labelled as 'major' were masked including one pixel (25m) either side of the road. All roads labelled as 'minor' were masked with no additional buffer.

Houses, sheds and yards in rural areas were often labelled as saline because of the lack of vegetation cover in the immediate area. Pixels classified as salt totally within the building polygons were masked. Any salt-affected area that extended beyond a building footprint was retained. The masking was not as successful in townsites because other features like roads, bridges and carparks also contribute the areas labelled as salt-affected but were not within the building polygons. Mines and airstrips were treated in the same manner.

Catchments associated with farm dams may be purposely denuded of vegetation and are within surface water flow regions and so were often mapped as salt affected. The distance from a dam was considered slightly differently than from roads and buildings. Only the upslope direction was considered, and the upslope distance was used. If the area of salinity mapped was completely within 75m upslope distance, then the region was masked. If the salt-affected area extended beyond this distance it was not excluded.

Larger areas of water were also masked in the south-west area. These were identified as larger farm dams, reservoirs and estuaries. Saline pixels inside these areas were masked.

A buffer of 500m around the whole coastline was also masked. This excluded areas with low vegetation cover such as beaches and variations in the coastline over time.

The masking was applied independently to the 'old' and 'new' historical salt layers as well as each of the current years. The water and salt classes were combined for the purpose of the masking. Some pixels were masked by more than one feature. For example, the airstrips polygons include the runways, tarmacs and airport buildings. Most airport buildings were also included in the building data. Similarly, within towns roads and building were adjacent to each other and potentially overlapping when buffer extents were considered. For each of the final salinity data layers there was a corresponding 'clean mask' data layer. The values in the mask correspond to 'the ID value' in table 3 or '0' otherwise (not masked). In the case of a pixel being masked by more than one feature, the value recorded was the first one in the list (lowest ID number). Table 3 also records the hectares of land that was masked.

Table 3. Geographic masking data, total area masked by category.

Total area masked by year (hectares). MGA50 (extended)										
Year	**ID**	**1990**	**1998**	**2009**	**2010**	**2011**	**2016**	**2017**	**2018**	**2019**
Upslope of local dams	1	7154	8471	9445	9119	9122	9326	9243	9075	8812
Inside bigger farm dams	2	6517	6613	10152	10194	10374	10475	10530	10498	10478
Inside reservoirs	3	2220	2220	4021	4051	4076	4101	4126	4162	4163
Inside estuaries	4	3477	3480	3916	3927	3940	3947	3949	3946	3928
Within coast buffer (500m)	5	6595	6842	6708	6748	6705	6846	6811	6619	6567
Inside buildings	6	98	108	574	574	567	564	552	528	499
Inside mines	7	1144	1630	1545	1643	1746	1847	1921	1952	1944
Inside airstrips	8	66	81	87	84	83	81	80	78	76
Roads via distance buffer	9	2152	2605	2973	2894	2897	2935	2899	2862	2800
Imposed major roads (2 pixels)	10	1978	2398	3822	3783	3767	3778	3756	3724	3655
Imposed minor roads (1 pixel)	11	6865	8122	8140	7820	7731	7711	7646	7594	7522
Imposed rail (2 pixels)	12	4039	4669	5685	5623	5596	5574	5520	5459	5388
Inside other	13	6	6	84	87	84	85	65	66	66

2.10 Estimating areas and accuracy assessment

Stehman (2013) reviewed a number of different approaches for estimating area from an accuracy assessment error matrix and a landcover map. The so-called *pixel-counting* approach directly counts the number of pixels of each class in the land cover map, with the number of pixels (converted to say hectares) being the area estimate for each class. We will refer to this widely used approach to estimating area as the *pc-estimator* in the following, and the estimate the *pc-estimate*. The extent of *Salt/NotSalt* reported by Furby et al (2010) and McFarlane et al (2004) used the *pc-estimator*. Stehman further describes the *bias-adjusted estimator* (or *ba-estimator* for short) which uses the error matrix and land cover map to

estimate and then adjust for the bias in the mapping to produce a biased adjusted estimate (*ba-estimate*) of each landcover. Olofsson et al (2014) present good practice recommendations on the key steps and methods that are needed to complete an accuracy assessment of land cover and to estimate the area of land cover classes using the *ba-estimator*. We used these recommendations as a basis for the *ba-estimate* presented in this report.

3 Results

In this section we present: in section 3.1 the results of the extent of *Salt / Not Salt* calculated directly from the satellite mapping (*pc-estimate*); in section 3.2 the accuracy assessment of the mapping as compared with the point location ground truth data (*p-data*), along with the *bias-adjusted* estimate (*ba-estimate*) of the extent of *Salt / Not Salt* based on the accuracy assessment and the *Land Monitor* mapping; in section 3.3 a comparison with other ground truth data (*sa-data*) which provides information on the distribution of errors of the mapped *Salt / Not Salt* for the sub-classes *SevSalt, ModSalt, RevSalt, Bare* and *Not Salt*. In section 3.3 we also provide a comparison of the *ba-estimate* ($U_{LM+p\text{-}data}$) and *pc-estimates* (U_{LM}) to the mapping ground truth data (*sa-data*) provided by DPIRD hydrologists.

3.1 *Land Monitor* Salinity Extent – satellite mapping

The extent of mapped *Salt/NotSalt* is provided in figure 17. The extent (*pc-estimate*) of *Salt / Not Salt* for the agricultural region was recorded in table 4, the results for each of the amalgamated hydro-zones in appendix A.2, and a plot of the results provided in figure 18.

From table 4 we observe that 1,082,419 ha of land was mapped as *Salt* for the year 2018 in the mapping extent (22,706,831 ha) within the south-west of Western Australia, equating to 4.6% of the mapped area. Comparing the year 2018 with 1998, approximately 157,000 ha more salt affected land has been detected since the original assessment presented by McFarlane et al (2004). However, of note is approximately 127,000 ha of land that was classified as *Salt* in 1998 time-step but was not classified as *Salt* for 2018, which is discussed further in Section 4. Therefore, the increase in total extent of salt affected land since the original land monitor mapping and this updated mapping is between 31,000 ha and 37,000 ha (table 4). The increase recorded was predominantly in the first time-period (2009) of this updated mapping (table 4).

From the tables in appendix A.2, we observe that for the year 2018, Zone 4 (South-Eastern Wheatbelt) had the highest percentage (9.0%) of *Salt*, followed by Zone 2 (North-Eastern Wheatbelt) 6.9%, Zone 6 (Esperance Sandplain and Mallee) 3.4%, Zone 3 (South-West Wheatbelt / Darling Range) 3.1%, Zone 1 (Kalbari/Binnu Sandplain) 1.8%, Zone 5 (Great Southern) 1.6% and Zone 7 (Northern Perth Basin) having the lowest percentage (0.6%).

We further observe that between 2010 and 2018 only two amalgamated hydro-zones, Zone 6 and Zone 4 recorded increases in *Salt*. Zones 1 and 7 did not record any increase in *Salt* since 1998. Zones 2, 3 and 5 have not recorded *Salt* increases since the 2009-2011 period. However, these results must be viewed in the context of the accuracy assessments, particularly the omission errors, which are areas that are *Salt* as assessed by the DPIRD hydrologists, but not detected by the *Land Monitor* satellite mapping. The results of the accuracy assessment are presented next.

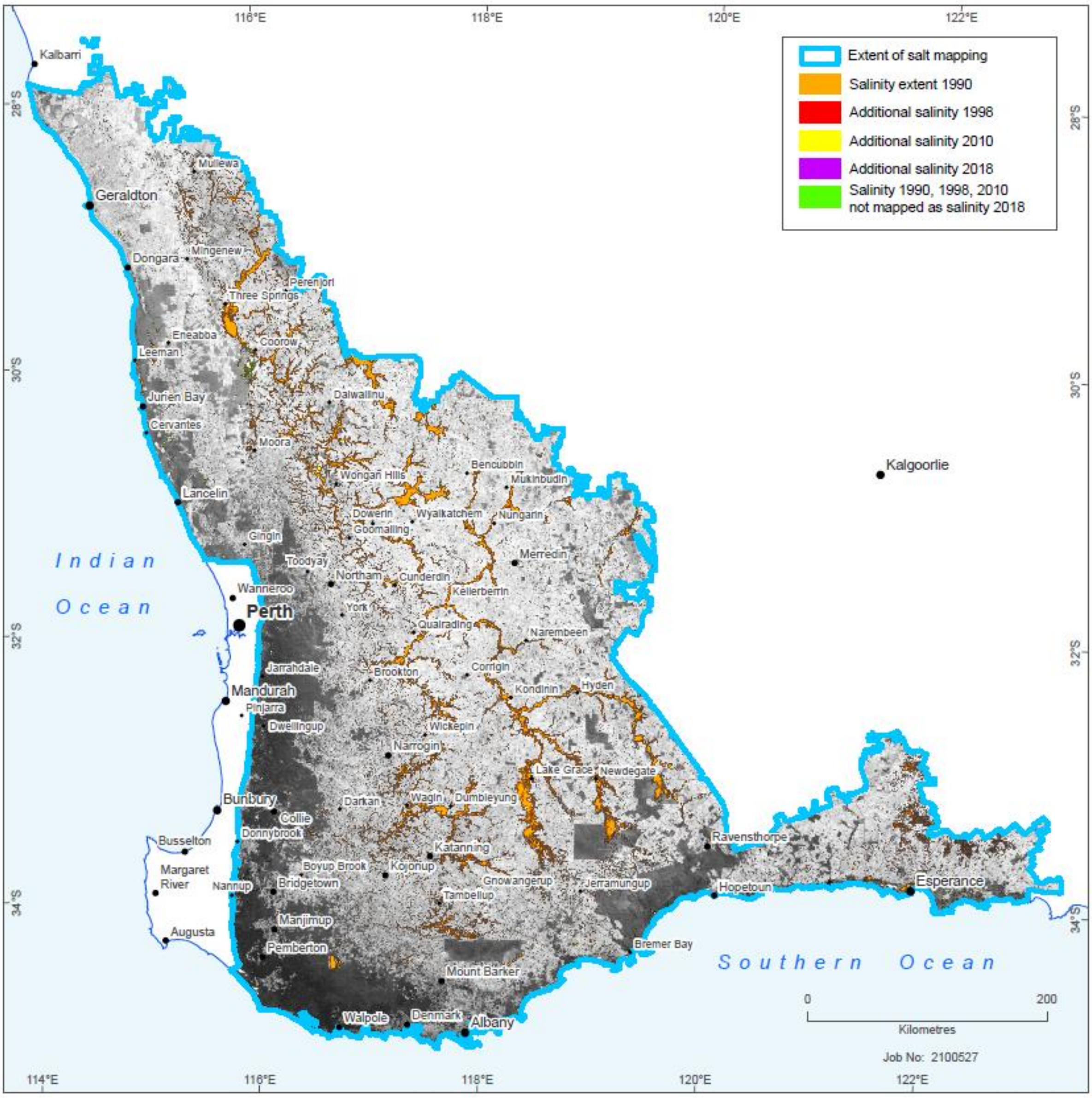


Figure 17. Graphical depiction of the spatial extent of salinity.

Table 4. *Land Monitor* region salinity extent.

Land Monitor Region – Agricultural Area				
Salinity Extent Estimate (ha)				
Year	Salt	Not salt	Not Mapped	**% Salt (of mapped)**
1990*	963,597	21,297,902	123,867,867	4.33
1998*	1,051,605	21,209,892	123,867,867	4.72
2009	1,088,514	22,700,734	122,340,117	4.58
2010	1,085,298	22,703,951	122,340,117	4.56
2011	1,084,026	22,705,224	122,340,117	4.56
2016	1,088,107	22,701,142	122,340,117	4.57

2017	1,085,788	22,703,460	122,340,117	4.56
2018	1,082,419	22,706,831	122,340,117	4.55
2019	1,078,254	22,710,996	122,340,117	4.53

As estimated from satellite mapping and associated modelling.

* Derived from the *Land Monitor* Project salinity mapping estimates presented by McFarlane et al 2004, with the commission error masking (section 2.9) applied as for 2009 onward.

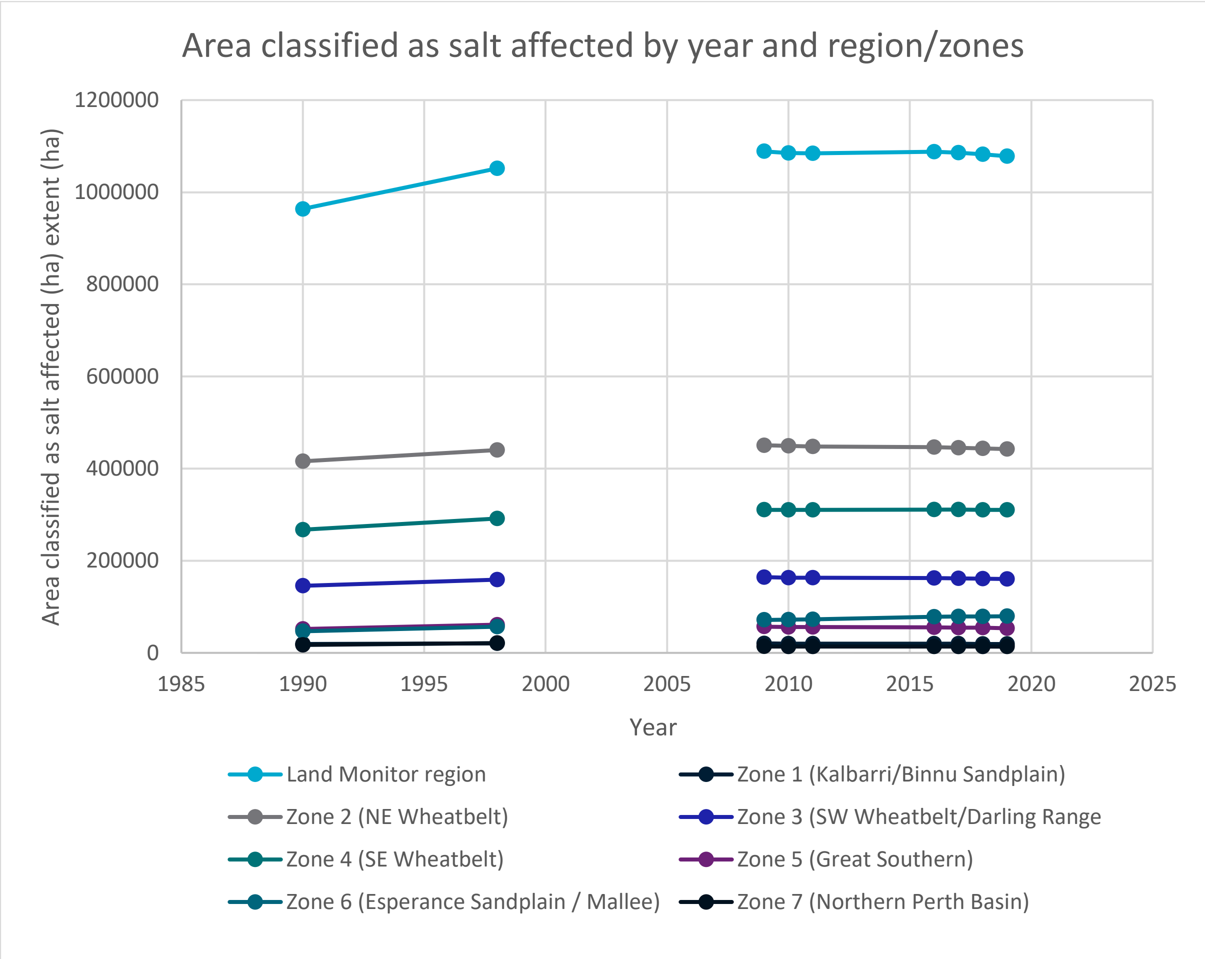


Figure 18. Graph of salinity extent* over time.

Salinity extent* mapped by *Land Monitor* for each of the amalgamated hydro-zones (regions). Taking 1990 and 2018 as reference points, the extent for the *Land Monitor* region has increased by 4400 ha/year from 1990 to 2018. **pc-estimate* best represents *severe salinity*, is the only consistent estimate over the time span, but on average omits 40% of saline lands predominately from the *moderate salinity* and *revegetated saline* classes.

3.2 Accuracy assessment of *Salt / Not Salt* mapping

As previously reported (Furby et al, 2010), the *Land Monitor* satellite mapping had a tendency to underestimate the extent of salinity in the wheatbelt, particularly the *Moderate* and

Revegetated saline classes. The knowledge that *Land Monitor* mapping underestimated the extent of *Salt* was derived from the comparison of the mapping with the validation data collected at the time and summarised as *accuracy assessment error matrices*.

Table 6 (from appendix A). Site label counts of ground truth label (*p-data*) versus mapped labels (LM) for 2018.

Land Monitor region				
	Predicted Label			
		Salt	Not salt	Total count
Ground Truth Label	Salt	599	19	618
	Not-salt	24	654	678
	Unsure	32	27	59
	Invalidated	45	0	45
	Total count	700	700	1400

For the year 2018, where ground truth data coincident with the mapping were available, *error matrices* were formed using the *p-data*. The 1400 ground truthed pixel sites' labels were compared with the *Land Monitor*'s mapping labels (LM) and the results recorded in tables 6-13, appendix A.1. Of the 1400 pixel sites, the DPIRD hydrologist could not determine a label for 59 sites which were recorded as *Unsure*. A further 45 sites were *Invalidated* by a later stage of map masking that occurred post the stratified random sample. *Unsure* and *Invalidated* sites were not used in subsequent accuracy assessment.

As a stratified random sampling scheme was used for the *p-data*, the validation accuracy calculations (*ba-estimator*) require the points to be weighted by the area of the strata from which they were sampled. These calculations also produce a bias-adjusted estimate of the area of *Salt / Not Salt.* Table 14 records the *ba-estimator* summary information for the *Land Monitor* mapping extent, and tables 15-21 (appendix A) the *ba-estimator* summary information for each of the amalgamated hydrozones.

From table 14, we observe the *ba-estimate* of salinity extent (denoted u) to be 1,748,366 ha ± 343,692 ha at the 95% confidence level. The *Land Monitor* mapping had an overall accuracy of 96.9%, a relatively low error of commission (3.1%), and a relatively high error of omission (40.0%). The omission error is perhaps the most interesting of these accuracies. The omission error contributes the underestimate for the *Land Monitor pc-estimate* of *Salt* of 1,082,526 ha compared with the *ba-estimate* of 1,748,366 ha.

Similarly, for each of the amalgamated hydro-zones 1 to 7 (figure 11), we observe (from tables 15-21, appendix A) overall mapping accuracies of 98.9%, 97.0%, 97.9%, 93.8%, 95.9%, 97.9%, and 98.9% respectively. We further observe for each of the amalgamated hydro-zones 1 to 7 commission errors of 2.2%, 1.0%, 3.5%, 5.2%, 6.6%, 3.2% and 6.1% respectively, and omission errors of 38.3%, 30.0%, 29.3%, 29.9%, 72.2%, 37.6%, and 64.3% respectively. For amalgamated hydro-zones 5 and 7, the majority of saline areas are not directly mapped.

Table 14 (from appendix A). *Land Monitor* regional statistics.

Land Monitor – all zones aggregated					
Ground truth	Predicted label				
	Salt	Not Salt	Total	Omission Error %	Area ESTIMATED
Salt	0.04371973	0.0291641	0.07288383	40.0	1,748,366
Not Salt	0.0014073	0.92571	0.9271173	0.2	22,240,023
Total	0.04512703	0.9548741	1.000000		
Commission Error %	3.1	3.1		Overall accuracy = 96.9 %	
Area Mapped	1,082,526	22,905,863	23,988,389		

Land Monitor – all zones aggregated							
	u	SE(u)	u [ha]	95% CI	CI % of tot	Low [ha]	High [ha]
Salt	0.07288383	0.00731	1,748,366	+-343,692	+-19.7%	1,404,673	2,092,058
Not Salt	0.9271173	0.00708	22,240,023	+- 333,015	+- 1.5	21,907,008	22,573,038

3.3 Comparison with other ground truth data

The 70 mapping regions (depicted in figure 20) covering 340,727 ha (table 22) produced by the DPIRD hydrologists provided another source of ground truth information collected by a different process, and also on *Salt / Not Salt* sub-classes *SevSalt, ModSalt, RevSalt, Bare* (but not saline) and *Not Salt*. These sub-classes provide for the distribution of *Land Monitor* omission errors for *Salt/ Not Salt* to be evaluated for these sub-categories.

3.3.1 Further examination of omission errors

A comparison of *Land Monitor* mapped pixel labels {*Salt*, *Not Salt*} with *sa-data* labels {*RevSalt, ModSalt, SevSalt, Bare, Not Salt*} for each of the 70 sites and the results recorded in appendix B. Next, the sites were pooled for each amalgamated hydro-zone and the results recorded in tables 24-31, appendix C. In the tables, *TotalGTSalt* is the sum of *RevSalt, ModSalt, and SevSalt.*

From table 24 we observe that the omission errors for *TotalGTSalt* were 47.5%, commission errors of *Salt* were 15.4% and the overall mapping accuracy was 96.4%. Of the classes mapped by the hydrologists, *Land Monitor* best mapped, as measured by omission errors, the severe (*SevSalt*) salinity class, followed by the revegetated (*RevSalt*) and then high/moderate/slight (*ModSalt*) class having omission errors of 25.4%, 51.8% and 76.8% respectively.

Table 24 (from appendix C). Pixel counts, all mapped regions pooled.

This table provides the overall error rates for the mapped regions (sa-data) versus mapped labels (LM) for 2018.

All Mapped-regions pooled, pixel counts					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total	Omission error %
	RevSalt	45,904	49,395	95,299	51.8
	ModSalt	22,678	75,087	97,765	76.8
	SevSalt	110,421	37,641	148,062	25.4
	Total GT Salt	**179,003**	**162,123**	**341,126**	**47.5**
	Bare	924	52,338	53,262	1.7
	Not-salt	31,751	5,025,502	5,057,253	0.6
	Total	211,678	5,239,963	5,451,641	
	Commission error %	15.4	3.1	Overall accuracy = 96.4 %	

3.3.2 Further examination of *pc-estimates* and *ba-estimates*

The *p-data* provided for the derivation of the error rates used to calculate the overall *Land Monitor ba-estimate* u. From the perspective of consistency in estimates, it was of interest to compare the *pc-estimate* (u_{LM}) and *ba-estimates* ($u_{LM,p\text{-}data}$) directly with the DPIRD hydrologist mapping for each of the 70 Study Regions. For each of the 70 mapping sites, the error rate (tables 7-13, appendix A) for the amalgamated hydro-zone which it was located was used for the calculation. We compared u_{LM} and $u_{LM,p\text{-}data}$ with the DPIRD hydrologist mapping (the *ground truth* - GT). The results of the calculations are recorded in table 5.

Table 5. Comparison of salinity extent estimates for the study regions.

For each of the study sites, this table contains the salinity extent estimates derived from hydrologist mapping (GT), *Land Monitor* satellite mapping *pc-estimates* (u_{LM}) and area estimators (*ba-estimates*) using validation error rates and LM mapping ($u_{LM+p\text{-}data}$). The *Ground truth pixel counts* are the hydrologist mapping of the sites as in appendix B. All estimates are in units of pixel counts.

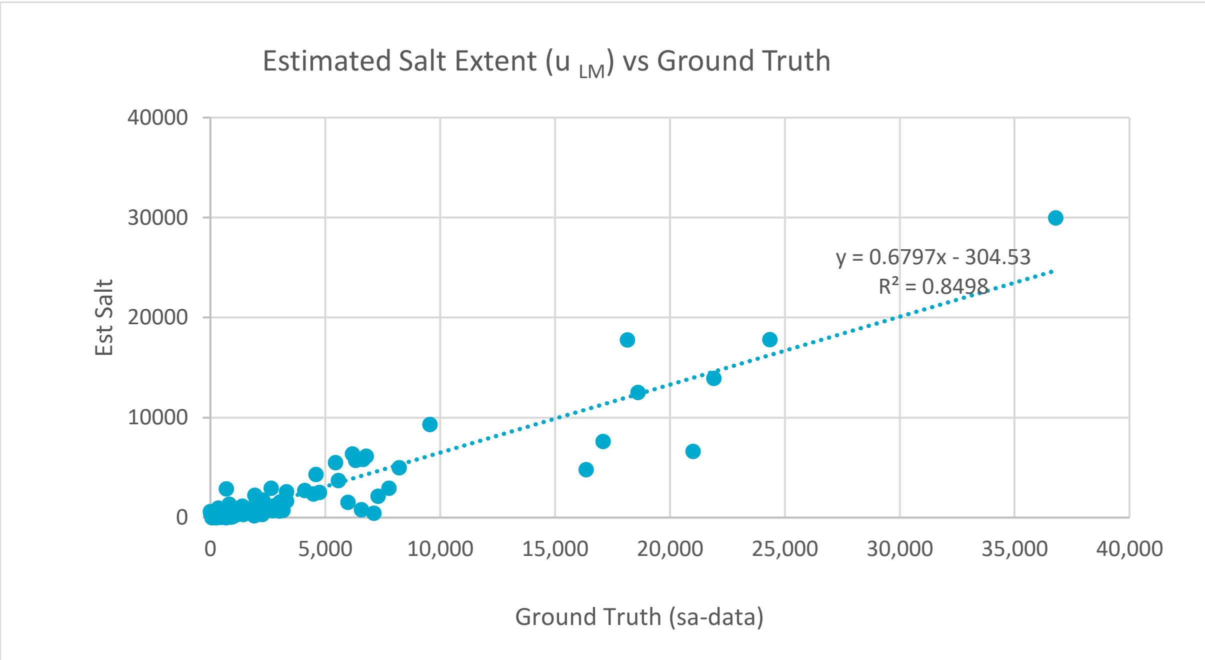
Amalgamated Hydrozone number	Site Name	Site ID	Ground truth pixel counts (GT)	Estimated Salt Extent (*pc-estimate*) u_{LM}	Estimated Salt Extent (*ba-estimate*) $u_{LM+p\text{-}data}$
1	Kulla Kulla	59	197	0	11
1	Mongeragarry Spring	114	7,119	452	1978
1	Hutt River	113	6,574	794	3440
1	Harry Spring	105	256	0	934
1	Woolawar Gully	108	684	0	1254
1	Kockatea Gully	116	7,768	2940	4349
1	Geebulla Creek	131	18,149	17758	19191
1	Wilton Well	37	1,263	418	499
2	East Perenjori	140	21,918	13927	25131
2	Beacon	11	21,010	6636	21752
2	Southern Cross	14	9552	9328	10590
2	Wallatin Creek	45	2,177	443	2888
2	Burracoppin	35	12	394	3489
2	Cunderdin	153	6,784	6139	6435
2	Tammin	44	979	239	1302
2	East Belka	36	223	12	1403
2	Skeleton Rocks	12	1,386	1137	5011
2	Sth Yarding North	24	36,787	29974	38831
3	Yalanbie	19	1,122	287	794
3	Morbinning	50	3,310	2587	2678

3	East Yornanning	29	5,574	3725	4307
3	Dwarda	51	68	0	92
3	Queerfellows	53	4,753	2519	2761
3	Bowelling	22	5,993	1519	3766
3	Kojonup Nth	1	1,917	987	1105
3	Kojonup NW	8	803	393	621
3	Dinninup	10	3,159	734	1367
3	Byenup Hill	57	622	437	554
4	Woodabulling	15	7,296	2146	5978
4	Karlgarin	32	4,598	4304	5376
4	East Hyden	33	6,644	5818	6760
4	Kulin	34	688	2889	24101
4	Dingo Rocks	38	1,931	2242	3219
4	Newdegate	39	18,616	12524	15860
4	Kathleen	41	8,216	4994	6846
4	Moulyinning	42	2,110	725	1449
4	Mt Madden	25	4,104	2720	4191
4	Merilup	55	6,189	6358	10514
4	Pingrup (Lake Bryde)	23	24,354	17813	35935
4	Katanning	112	963	100	1001
5	Frankland	16	894	47	1071
5	Wamballup	121	2,719	697	1764
5	Cranbrook	30	3,004	682	1754
5	Kendenup	31	1,908	184	4890
5	Chillinup	20	347	962	1052
5	Broomhill	17	157	33	740
5	Borden	118	1,607	872	8151

5	Mailalup	28	307	37	195
5	Bremer River	21	17,092	7610	14115
5	Fitzgerald River	18	5,449	5499	7860
5	West River	6	826	1331	1950
5	Upper Phillips River	7	3,306	1663	2439
6	Mooyal Woodenup	151	460	27	330
6	Hopetoun	56	1,434	312	1169
6	Munglinup	58	4,488	2351	2926
6	Upper Lort River	2	2,776	1185	3138
6	Lort River	5	1,544	875	1163
6	West Dalyup	4	3,032	1553	1942
6	Scaddan west	61	689	680	1123
6	Salmon Gums	3	6,316	5740	6821
6	Dalyup West	64	16,355	4798	6726
6	Scaddan east	62	2,288	1769	2067
6	Backmans	52	2,255	302	546
6	Coolinup	49	1,223	679	1228
6	Mt Ney	48	1,951	1257	1477
6	Beaumont	46	343	256	2904
6	Condingup east	54	0	592	1963
7	Irwin River	119	881	192	1525
7	Bindoon Creek	126	2651.00	2956	3508

From table 5, we produced a summary graph (figure 19) of the ground truth (GT) salt extent areas compared with the estimates u_{LM} and $u_{LM+p\text{-}data}$, along with a linear relationship fitted to the variables. If the estimates u_{LM} and/or $u_{LM+p\text{-}data}$ agreed completely with the ground truth, all points would fall on the line mapping a 1:1 relationship (corresponding to an equation *y=mx+b*, with *m=1* and *b=0*).

From figure 19, we observe that the *Land Monitor* mapping *pc-estimate* produce the relationship (y = 0.6797x - 304.53, R^2 = 0.8498) demonstrating that the *Land Monitor* mapping explains approximately 85% of the variance recorded for the mapping regions *Salt* extents (R^2 = 0.8498) though generally underestimates the extent of salinity (m=0.6797) for the 70 study sites (GT). From the figure we further observe that the *ba-estimator* results in a relationship y = 0.9923x + 504, R^2 = 0.7631, demonstrating an excellent general agreement between GT and the *ba-estimate* (m=0.9923), though explaining less of the variance of the estimates (R^2 = 0.7631) compared with the *Land Monitor* mapping. The lower R^2 value is unsurprising given that $u_{LM+p\text{-}data}$ is an adjustment of u_{LM} based on regional expectations, rather than only direct observations of the site itself (u_{LM}).



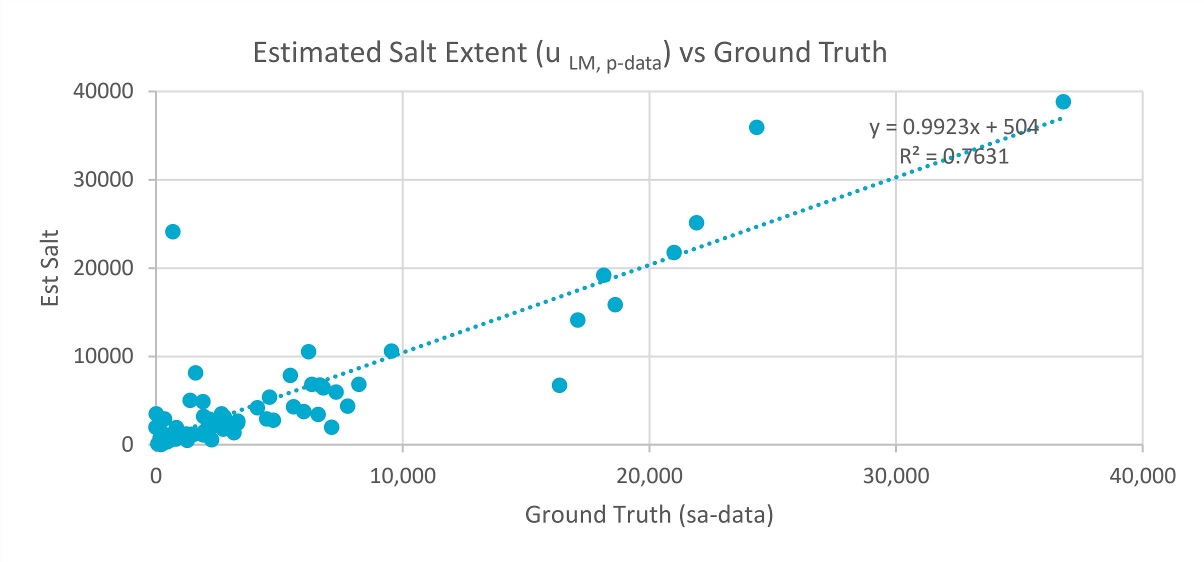


Figure 19. Plots of study site salinity estimates compared with ground truth.

Each data point on the graphs represents the extent of salinity for a study site. Top: *Land Monitor* mapping *pc-estimate*. Bottom: Bias adjusted estimate (*ba-estimate*) using *p-data* derived error rates and *Land Monitor* mapping. If the estimates agreed completely with the ground truth, the chart would have a 1:1 relationship. We observe from the top chart that *Land Monitor* mapping best explains the variation in the site estimates (R^2 = 0.8498), though underestimates the extent (0.6797 coefficient). Similarly, we observe from the bottom chart that the estimates are almost 1:1 with the ground truth (0.9923 coefficient), though with an increase in variance of the estimates compared with the top chart.

4 Summary and discussion

This *Land Monitor* salinity mapping update classified over 1,082,526 ha of land as *Salt* in the mapping extent (23,988,389 ha) within the south-west of Western Australia in 2018, equating to 4.6% of the mapped area. Since the original *Land Monitor* salinity mapping (1998) and this updated mapping, the area of land classified as salt affected increased by 37,000 ha.

The Land Monitor mapping (LM) had a relatively high error of omission (40.0%), a relatively low error of commission (3.1%) and an overall accuracy of approximately 97%. The overall accuracy is the percentage of pixels correctly classified, however it does not assure the reliability of mapping and that the area estimate of a category (*Salt* or *Not Salt*) is accurate to within ± 3% (Shao 2019). Hence the omission error in relation to *Salt*, is perhaps the most interesting of these accuracies.

Validation of regional-scale salinity models with independent data enhances the robustness and reliability of the assessment (Corwin and Scudiero, 2019). The ground truth mapping by the DPIRD hydrologists (GT) was used for this purpose and provided independent validation of the mapping accuracy and errors, along with valuable information on what was being classified as *Salt* by the model in relation to the salinity classes (table 2).

Of the classes mapped by the hydrologists, *Land Monitor* best mapped, as measured by omission errors, the severe (*SevSalt*) salinity class, followed by the revegetated (*RevSalt*) and then high/moderate/slight (*ModSalt*) class having omission errors of 25.4%, 51.8% and 76.8% respectively (table 24). This is consistent with the original *Land Monitor* salinity mapping, where severe salinity was typically well mapped, while marginal salinity (slightly-highly saline) was less accurately mapped (Furby et al 2010). The original mapping in the 1990s mostly detected persistent, 'severely' salt-affected areas with low density vegetative cover that had been degraded for a number of years but had difficulties reliably detecting salt-affected areas that had a dense vegetative cover (Simons et al 2013). Other international studies also found the relationships between soil salinity and reflectance are best for severely salt-affected soils but become weaker for low and moderately salt-affected soils (Wang et al., 2012).

For the year 2018, where validation data coincident with the mapping were available, we calculated (results in appendix A) a *bias adjusted* estimate of the extent of salinity for the region to be **1,748,366 ha ± 343,692 ha** at the 95% confidence level (table 14), compared to the mapping estimate of **1,082,526 ha**. This calculation yielded an overall mapping salinity extent omission error of 40.0%, and a relatively low commission error of 3.1%, with the interpretation that the *Land Monitor* mapping tends not to falsely map areas as *Salt* (3.1%) but does underestimate the extent of *Salt* land as compared with the DPIRD hydrologists' interpretation of coincident ground locations. The good statistical agreement (coefficient 0.9923) between the independently acquired ground truth mapping (*sa-data*) by the DPIRD hydrologists (GT) and the bias adjusted estimate ($u_{\text{LM+p-data}}$) for the 70 mapping study areas

supports the 1,748,366 ha regional estimate derived from the mapping and the separately acquired site point ground truth data (*p-data*).

This project estimated the extent of salinity extending the estimates of the original survey to recent times. The estimates were generated using methods comparable with the original survey, allowing comparisons of the change in the extent of predominantly severe salinity to be made.

Any changes in the extent of salt affected land detected by *Land Monitor* in the updated salinity mapping are most likely within the severe salinity class and may represent either expansions of this class of salinity or improvements in the condition of severely salt affected land or in the reduction of commission errors (compared to the original mapping). However, some of the changes could be attributed to other factors, such as the range of annual growing season conditions and the time of year pixels were sourced from the Landsat satellite images which can affect the mapping accuracy (Furby et al 2010). Also, changes in the Landsat satellite series (Landsat 5, 7 and 8) and associated improvements in the sensitivity of the sensors (8bit vs 16bit) provided improved discrimination abilities.

Also, as Furby et al (2010) earlier identified, underestimates of the extent can be attributed to the size of the surface expression of the salinity relative to the image pixel size. If the extent of the salt-affected area was less than an image pixel (25m for Landsat imagery) or very narrow, then it was unlikely to be detected sufficiently to be mapped as potentially saline (Allbed and Kumar 2013).

Advances in computing power and analytics provided for greater automation for most steps of the project while maintaining a comparable methodology. The strategy for maintaining comparable results was to replace time consuming previously manual steps with automated steps producing functionally equivalent results. For example, spectral analysis was performed by an AI algorithm to produce a probability of salinity for each pixel, compared with the previous manual approach to produce a probability – the interpretation of the data did not radically change from the original survey. However, better data was maintained: data departures from the original survey include better dynamic range of the newer satellite sensors, providing improved discrimination – the newer data was not coarsened to have the lower specifications of the older sensor. Steps made easier by improved computational resources compared to the past include: access to pre-processed satellite imagery from Digital Earth Australia; the provision of high resolution elevation models by Landgate (generated outside of this project); spectral analysis of satellite imagery by AI algorithm as opposed to the former manually intensive supervised approach; whole of region terrain analysis; whole of region time-series analysis; and general data handling.

Like the previous salinity extent assessment, the extent mapped using the Landsat optical satellite sensor under-reported the extent of salinity compared with that mapped by the DPIRD hydrologists. We employed stratified random sampling and statistical area estimators using ground truth and *Land Monitor* mapping to form a *bias adjusted* estimate of salinity extent for the year 2018. The estimate was limited to the year (2018) where coincident ground truth and mapping was available. Given the increased area estimated over that of the

satellite mapping, the quality of the ground data is important to this calculation. We would recommend that ground data collection is adequately resourced and conducted to at least the resourcing as applied here. This would be particularly required should a future survey adopt a substantially different approach, or sensor such as discussed next.

Several research investigations to improve the detection of salinity (through reducing omission errors) will be performed in future works, enabled by the data collected during this project and aligned projects.

Firstly, some saline omission errors were due to the limited spatial resolution (25-30m) of the Landsat sensors, for example detection of scalded creek lines. ESA's (European Space Agency) Sentinel 2 sensor with 10m resolution for some bands may improve on the spatial detection of these regions.

Secondly, newly available free to ground Synthetic Aperture Radar such as the ESA's Sentinel 1 C-band sensor offers data at very different wavelengths and possible detection of some forms of salinity. Some preliminary investigations have been performed (Zhang et al. 2020), where the relationship between radar signal and soil electrical conductivity were reported, though with crop and remnant vegetation residual effects clearly visible in the spatial predictions. Planned future investigations will examine the discrimination potential for the sensor. Similarly, there are proposed L-band sensors which will also be examined for discrimination potential, though they are not yet free to ground. While the forementioned approaches do not offer the ability for comparison and re-exploration of earlier decades, they may offer improvements for future reporting.

Thirdly, noting that underreported highly, moderately, slightly and revegetated saline classes are often adjacent to well reported severely affected classes, another approach will consider the use of classifiers offering better spatial discrimination and prediction. One candidate classifier is the convolution neural network which, with the use of training data, can learn spatial relationships. The DPIRD hydrologists salinity mapping in the 70 study areas will be used for this investigation. A challenge for this approach is the requirement for many accurate spatially mapped training samples. Another more recent candidate modelling approach is the so-called Physics Informed Neural Network, which seeks to combine observations (ground water depths, saline surface expressions) with physical (hydrological) models in order to make predictions.

Appendix A Amalgamated Hydro-zone site-based validation data

The 1400 Round 3 ground truth sites' labels were compared with the *Land Monitor*'s mapping labels and the results recorded in tables 6-13. Of the 1400 sites, the expert could not determine a label for 59 sites which were recorded as *Unsure*. A further 45 sites were *Invalidated* by a later stage of map masking that occurred post the random sample. *Unsure* and *Invalidated* sites were not used in subsequent accuracy assessment.

A.1 Amalgamated Hydro-zone site validation tables

Table 6. All Hydro-zones: Site label counts of ground truth versus mapped labels for 2018.

Land Monitor region - all hydrozones combined				
	Predicted Label			
Ground Truth Label		Salt	Not salt	Total count
	Salt	599	19	618
	Not-salt	24	654	678
	Unsure	32	27	59
	Invalidated	45	0	45
	Total count	700	700	1400

Table 7. Amalgamated Hydro-zone 1 ground truth versus mapped labels.

Entries are site label counts of ground truth versus mapped labels for 2018.

Amalgamated Hydro-zone 1				
	Predicted Label			
Ground Truth Label		Salt	Not salt	Total count
	Salt	91	1	92
	Not-salt	2	89	91
	Unsure	5	10	15
	Invalidated	2	0	2
	Total count	100	100	200

Table 8. Amalgamated Hydro-zone 2 ground truth versus mapped labels.

Entries are site label counts of ground truth versus mapped labels for 2018.

Amalgamated Hydro-zone 2				
	Predicted Label			
Ground Truth Label		Salt	Not salt	Total count
	Salt	96	3	99
	Not-salt	1	92	93
	Unsure	1	5	6
	Invalidated	2	0	2
	Total count	100	100	200

Table 9. Amalgamated Hydro-zone 3 ground truth versus mapped labels.

Entries are site label counts of ground truth versus mapped labels for 2018.

Amalgamated Hydro-zone 3				
	Predicted Label			
Ground Truth Label		Salt	Not salt	Total count
	Salt	83	2	85
	Not-salt	3	95	98
	Unsure	4	3	7
	Invalidated	10	0	10
	Total count	100	100	200

Table 10. Amalgamated Hydro-zone 4 ground truth versus mapped labels.

Entries are site label counts of ground truth versus mapped labels for 2018.

Amalgamated Hydro-zone 4				
	Predicted Label			
Ground Truth Label		Salt	Not salt	Total count
	Salt	91	6	97
	Not-salt	5	90	95
	Unsure	2	4	6
	Invalidated	2	0	2
	Total count	100	100	200

Table 11. Amalgamated Hydro-zone 5 ground truth versus mapped labels.

Entries are site label counts of ground truth versus mapped labels for 2018.

Amalgamated Hydro-zone 5				
	Predicted Label			
Ground Truth Label		Salt	Not salt	Total count
	Salt	71	4	75
	Not-salt	5	95	100
	Unsure	8	1	9
	Invalidated	16	0	16
	Total count	100	100	200

Table 12. Amalgamated Hydro-zone 6 ground truth versus mapped labels.

Entries are site label counts of ground truth versus mapped labels for 2018.

Amalgamated Hydro-zone 6				
	Predicted Label			
Ground Truth Label		Salt	Not salt	Total count
	Salt	90	2	92
	Not-salt	3	96	99
	Unsure	0	2	2
	Invalidated	7	0	7
	Total count	100	100	200

Table 13. Amalgamated Hydro-zone 7 ground truth versus mapped labels.

Entries are site label counts of ground truth versus mapped labels for 2018.

Amalgamated Hydro-zone 7				
	Predicted Label			
Ground Truth Label		Salt	Not salt	Total count
	Salt	77	1	78
	Not-salt	5	97	102
	Unsure	12	2	14
	Invalidated	6	0	6
	Total count	100	100	200

A.2 Amalgamated Hydro-zone satellite mapping estimates (*pc-estimates*)

Hydro-zone 1				
Salinity Extent Estimate (ha)				
Year	Salt	Not salt	Not Mapped	**% Salt (of mapped)**
1990	19205	1060185	2786231	1.78
1998	20629	1058762	2786231	1.91
2009	20355	1062462	2782805	1.88
2010	20225	1062592	2782805	1.87
2011	20098	1062719	2782805	1.86
2016	19933	1062884	2782805	1.84
2017	19738	1063079	2782805	1.82
2018	19479	1063338	2782805	1.80
2019	19195	1063622	2782805	1.77

Hydro-zone 2				
Salinity Extent Estimate (ha)				
Year	Salt	Not salt	Not Mapped	**% Salt (of mapped)**
1990	415897	5989545	2641242	6.49
1998	440631	5964809	2641243	6.88
2009	450757	5965014	2630912	7.03
2010	449143	5966628	2630912	7.00
2011	448070	5967701	2630912	6.98
2016	446925	5968845	2630912	6.97
2017	445521	5970250	2630912	6.94
2018	444101	5971670	2630912	6.92
2019	442295	5973476	2630912	6.89

Hydro-zone 3				
Salinity Extent Estimate (ha)				
Year	Salt	Not salt	Not Mapped	**% Salt (of mapped)**
1990	145591	4388323	601835	3.21
1998	159004	4374910	601835	3.51
2009	164511	4967079	0	3.21
2010	163233	4968357	0	3.18

2011	162920	4968670	0	3.17
2016	162662	4968928	0	3.17
2017	161959	4969630	0	3.16
2018	161171	4970418	0	3.14
2019	160158	4971432	0	3.12

Hydro-zone 4				
Salinity Extent Estimate (ha)				
Year	Salt	Not salt	Not Mapped	**% Salt (of mapped)**
1990	267420	3175487	886430	7.77
1998	291989	3150917	886430	8.48
2009	310565	3132619	886153	9.02
2010	310386	3132797	886153	9.01
2011	310609	3132574	886153	9.02
2016	310973	3132210	886153	9.03
2017	310945	3132238	886153	9.03
2018	310567	3132616	886153	9.02
2019	310086	3133098	886153	9.01

Hydro-zone 5				
Salinity Extent Estimate (ha)				
Year	Salt	Not salt	Not Mapped	**% Salt (of mapped)**
1990	51853	2463422	805941	2.06
1998	61224	2454051	805941	2.43
2009	56922	3261022	0	1.72
2010	56225	3261719	0	1.69
2011	55897	3262047	0	1.68
2016	55619	3262325	0	1.68
2017	55061	3262884	0	1.66
2018	54438	3263507	0	1.64
2019	53670	3264274	0	1.62

Hydro-zone 6				
Salinity Extent Estimate (ha)				
Year	Salt	Not salt	Not Mapped	**% Salt (of mapped)**
1990	46854	2260855	2413573	2.03

1998	57134	2250576	2413573	2.48
2009	71610	2272781	2376891	3.05
2010	72393	2271998	2376891	3.09
2011	72804	2271588	2376891	3.11
2016	78438	2265953	2376891	3.35
2017	79067	2265325	2376891	3.37
2018	79226	2265166	2376891	3.38
2019	79465	2264927	2376891	3.39

Hydro-zone 7				
Salinity Extent Estimate (ha)				
Year	Salt	Not salt	Not Mapped	**% Salt (of mapped)**
1990	17023	2158373	1296323	0.78
1998	21243	2154153	1296323	0.98
2009	13879	2238805	1219036	0.62
2010	13778	2238906	1219036	0.61
2011	13717	2238967	1219036	0.61
2016	13649	2239035	1219036	0.61
2017	13593	2239091	1219036	0.60
2018	13537	2239147	1219036	0.60
2019	13484	2239200	1219036	0.60

A.3 Amalgamated Hydro-zone *bias-adjusted* estimates

Table 14. *Land Monitor* Regional statistics.

Land Monitor – all zones aggregated					
Ground truth	Predicted label				
	Salt	Not Salt	Total	Omission Error %	Area ESTIMATED
Salt	0.04371973	0.0291641	0.07288383	40.0	1,748,366
Not Salt	0.0014073	0.92571	0.9271173	0.2	22,240,023
w	0.04512703	0.9548741	1.000000		
Commission Error %	3.1	3.1		Overall accuracy = 96.9 %	
Area Mapped	1,082,419	22,905,863	23,988,389		

Land Monitor – all zones aggregated							
	u	SE(u)	u [ha]	95% CI	CI % of tot	Low [ha]	High [ha]
Salt	0.07288383	0.00731	1,748,366	+-343,692	+-19.7%	1,404,673	2,092,058
Not Salt	0.9271173	0.00708	22,240,023	+- 333,015	+- 1.5	21,907,008	22,573,038

Table 15. Amalgamated Hydro-zone 1 accuracy assessment and *bias-adjusted* area estimates.

Amalgamated Hydro-zone 1					
Ground truth	Predicted label				
	Salt	Not Salt	Total	Omission Error %	Area ESTIMATED
Salt	0.017602	0.010911	0.028514	38.3	30875
Not Salt	0.000387	0.971099	0.971486	0.0	1051942
w	0.017989	0.982011	1.000000		
Commission Error %	2.2	1.1		Overall accuracy = 98.9 %	
Area Mapped	19479	1063338	1082817		

Amalgamated Hydro-zone 1							
	u	SE(u)	u [ha]	95% CI	CI % of tot	Low [ha]	High [ha]
Salt	0.028514	0.010735	30875	+- 22784	73.8	8091	53659
Not Salt	0.971486	0.010915	1051942	+- 23165	2.2	1028777	1075107

Table 16. Amalgamated Hydro-zone 2 accuracy assessment and *bias-adjusted* area estimates.

Amalgamated Hydro-zone – Area 2					
Ground truth	Predicted label				
	Salt	Not Salt	Total	Omission Error %	Area ESTIMATED
Salt	0.068507	0.029393	0.097900	30.0	628102
Not Salt	0.000714	0.901387	0.902100	0.1	5787669
w	0.069220	0.930780	1.000000		
Commission Error %	1.0	3.2		Overall accuracy = 97.0%	
Area Mapped	444101	5971670	6415771		

Amalgamated Hydro-zone – Area 2

	u	SE(u)	u [ha]	95% CI	CI % of tot	Low [ha]	High [ha]
Salt	0.097900	0.016628	628102	+- 209097	33.3	419005	837199
Not Salt	0.902100	0.016804	5787669	+- 211310	3.7	5576359	5998979

Table 17. Amalgamated Hydro-zone 3 accuracy assessment and *bias-adjusted* area estimates.

Amalgamated Hydro-zone – Area 3					
Ground truth	Predicted label				
	Salt	Not Salt	Total	Omission Error %	Area ESTIMATED
Salt	0.030312	0.019971	0.050283	29.3	258032
Not Salt	0.001096	0.948621	0.949717	0.1	4873558
w	0.031408	0.968592	1.000000		
Commission Error %	3.5	2.1		Overall accuracy = 97.9%	
Area Mapped	161171	4970418	5131589		

Amalgamated Hydro-zone – Area 3							
	u	SE(u)	u [ha]	95% CI	CI % of tot	Low [ha]	High [ha]
Salt	0.050283	0.014942	258032	+- 150288	58.2	107743	408320
Not Salt	0.949717	0.014060	4873558	+- 141416	2.9	4732142	5014973

Table 18. Amalgamated Hydro-zone 4 accuracy assessment and *bias-adjusted* area estimates.

Amalgamated Hydro-zone – Area 4					
Ground truth	Predicted label				
	Salt	Not Salt	Total	Omission Error %	Area ESTIMATED
Salt	0.085500	0.056863	0.142363	29.9	490180
Not Salt	0.004698	0.852940	0.857638	0.5	2953003
w	0.090198	0.909802	1.000000		
Commission Error %	5.2	6.2		Overall accuracy = 93.8%	
Area Mapped	310567	3132616	3443183		

Amalgamated Hydro-zone – Area 4							
	u	SE(u)	u [ha]	95% CI	CI % of tot	Low [ha]	High [ha]
Salt	0.142363	0.022688	490180	+- 153115	31.2	337065	643295

Not Salt	0.857638	0.022688	2953003	+- 153115	5.2	2799888	3106118

Table 19. Amalgamated hydro-zone 5 accuracy assessment and *bias-adjusted* area estimates.

Amalgamated Hydro-zone – Area 5					
Ground truth	Predicted label				
	Salt	Not Salt	Total	Omission Error %	Area ESTIMATED
Salt	0.015328	0.039741	0.055069	72.2	182715
Not Salt	0.001079	0.943852	0.944931	0.1	3135230
w	0.016407	0.983593	1.000000		
Commission Error %	6.6	4.0		Overall accuracy = 95.9%	
Area Mapped	54438	3263507	3317945		

Amalgamated Hydro-zone – Area 5							
	u	SE(u)	u [ha]	95% CI	CI % of tot	Low [ha]	High [ha]
Salt	0.055069	0.022369	182715	+- 145466	79.6	37249	328182
Not Salt	0.944931	0.019568	3135230	+- 127257	4.1	3007973	3262486

Table 20. Amalgamated Hydro-zone 6 accuracy assessment and *bias-adjusted* area estimates.

Amalgamated Hydro-zone – Area 6					
Ground truth	Predicted label				
	Salt	Not Salt	Total	Omission Error %	Area ESTIMATED
Salt	0.032704	0.019718	0.052422	37.6	122898
Not Salt	0.001090	0.946488	0.947578	0.1	2221494
w	0.033794	0.966206	1.000000		
Commission Error %	3.2	2.0		Overall accuracy = 97.9%	
Area Mapped	79226	2265166	2344392		

Amalgamated Hydro-zone – Area 6							
	u	SE(u)	u [ha]	95% CI	CI % of tot	Low [ha]	High [ha]
Salt	0.052422	0.014257	122898	+- 65509	53.3	57389	188407
Not Salt	0.947578	0.013884	2221494	+- 63798	2.9	2157696	2285292

Table 21. Amalgamated Hydro-zone 7 accuracy assessment and *bias-adjusted* area estimates.

Amalgamated Hydro-zone – Area 7					
Ground truth	Predicted label				
	Salt	Not Salt	Total	Omission Error %	Area ESTIMATED
Salt	0.005643	0.010143	0.015786	64.3	35560
Not Salt	0.000366	0.983848	0.984214	0.0	2217124
w	0.006009	0.993991	1.000000		
Commission Error %	6.1	1.0		Overall accuracy = 98.9%	
Area Mapped	13537	2239147	2252684		

Amalgamated Hydro-zone – Area 7							
	u	SE(u)	u [ha]	95% CI	CI % of tot	Low [ha]	High [ha]
Salt	0.015786	0.011101	35560	+- 49012	137.8	-13452	84572
Not Salt	0.984214	0.010144	2217124	+- 44787	2.0	2172337	2261911

Appendix B Mapping-based validation regions

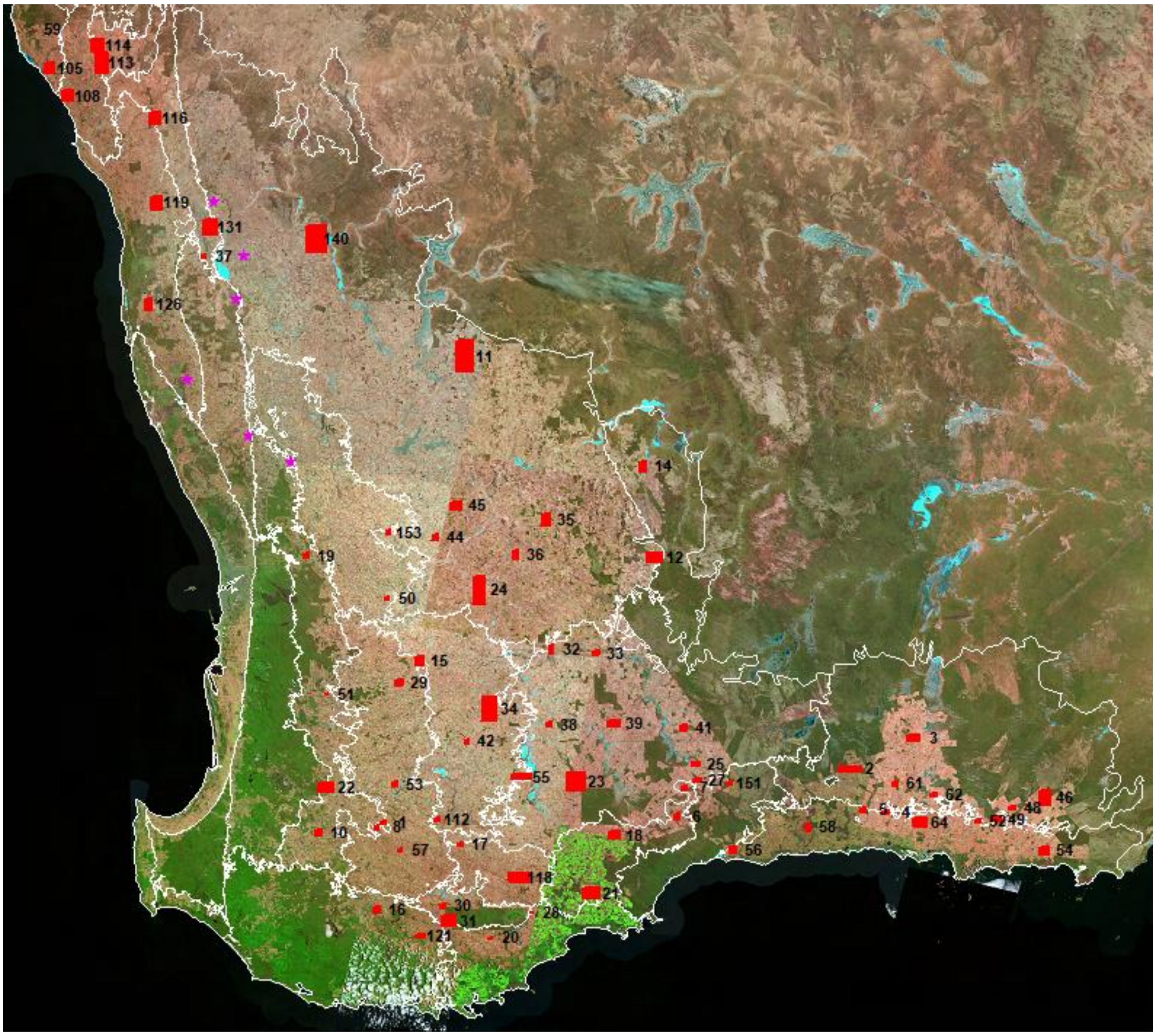


Figure 20. Location, extent and identification number for validation mapping locations.

The location and extent of expert mapping locations are identified by the red boxes and identification number (ID). The names of the locations are provided in the table below.

Table 22. Ground truth mapping location region index.

Study region identification and names					
Region			Region		
ID	Name	Area (ha)	ID	Name	Area (ha)
1	Kojonup Nth	526	**39**	Newdegate	4,772
2	Upper Lort River	7,139	**41**	Kathleen	2,423
3	Salmon Gums	4,249	**42**	Moulyinning	802

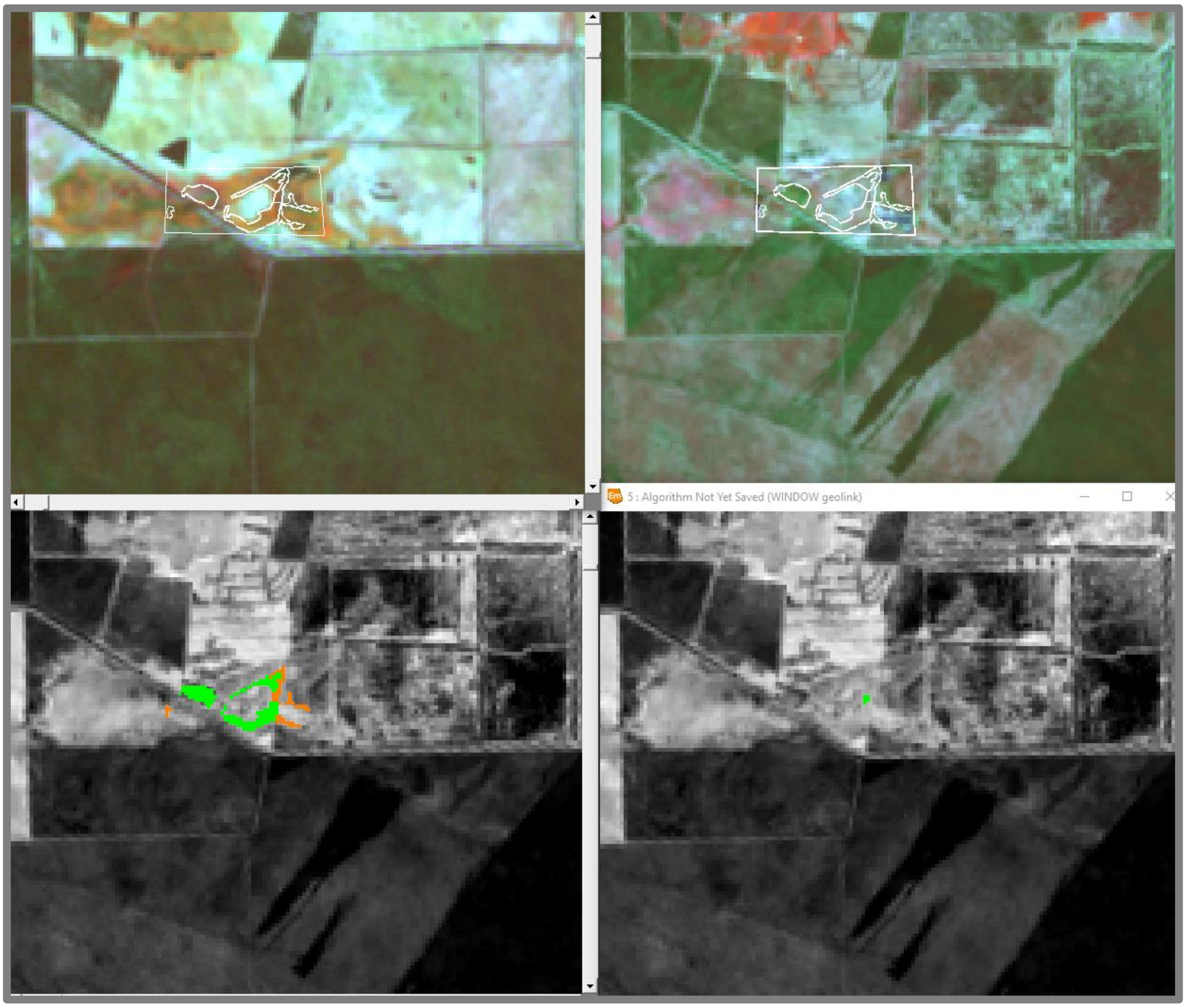
4	West Dalyup	1,448	**44**	Tammin	2,128
5	Lort River	1,025	**45**	Wallatin Creek	4,880
6	West River	1,177	**46**	Beaumont	9,885
7	Upper Phillips River	1,473	**48**	Mt Ney	882
8	Kojonup NW	759	**49**	Coolinup	1,803
10	Dinninup	2,044	**50**	Morbinning	713
11	Beacon	30,469	**51**	Dwarda	278
12	Skeleton Rocks	9,075	**52**	Backmans	801
14	Southern Cross	3,271	**53**	Queerfellows	1,163
15	Woodabulling	4,074	**54**	Condingup east	4,324
16	Frankland	1,602	**55**	Merilup	4,885
17	Broomhill	1,098	**56**	Hopetoun	2,675
18	Fitzgerald River	4,555	**57**	Byenup Hill	427
19	Yalanbie	1,585	**58**	Munglinup	2,145
20	Chillinup	297	**59**	Kulla Kulla Hill	63
21	Bremer River	11,316	**61**	Scaddan west	1,471
22	Bowelling	7,069	**62**	Scaddan east	1,203
23	Pingrup (Lake Bryde)	20,164	**64**	Dalyup West	6,709
24	Sth Yarding North	20,014	**105**	Harry Spring	5,252
25	Mt Madden	1,782	**108**	Woolawar Gully	7,055
27	Phillips River	1,584	**112**	Katanning	911
28	Mailalup	251	**113**	Hutt River	15,029
29	East Yornanning	2,392	**114**	Mongeragarry Spring	8,666
30	Cranbrook	1,770	**116**	Kockatea Gully	8,465
31	Kendenup	7,309	**118**	Borden	11,402
32	Karlgarin	1,565	**119**	Irwin River	8,248
33	East Hyden	1,608	**121**	Wamballup	1,765
34	Kulin	21,544	**126**	Bindoon Creek	4,671
35	Burracoppin	6,158	**131**	Geebulla Creek	11,321
36	East Belka	2,754	**140**	East Perenjori	29,863
37	Wilton Well	535	**151**	Mooyal Woodenup	933
38	Dingo Rocks	1,236	**153**	Cunderdin	1,093
Total sites = 70			**Total Area = 354023 ha**		

Common Picture Legend:

1990 (1987 to 1991) Landsat image, bands 3 (red), 5 (SWIR1) and 4 (NIR) in BGR. Study area and training polygons overlaid in white	2018 Landsat image, bands 3 (red), 5 (SWIR1) and 4 (NIR) in BGR, same enhancement as 1990. Study area and training polygons overlaid in white
Greyscale image background with training polygons coloured by type: Revegetated Salinity = Green Bare = Cyan (light blue) Severe Salinity = Red Moderate Salinity = Orange	Greyscale image background with salinity classification: Yellow = 2018 masked salinity Green = 1998 masked salinity that is not salinity in 2018.

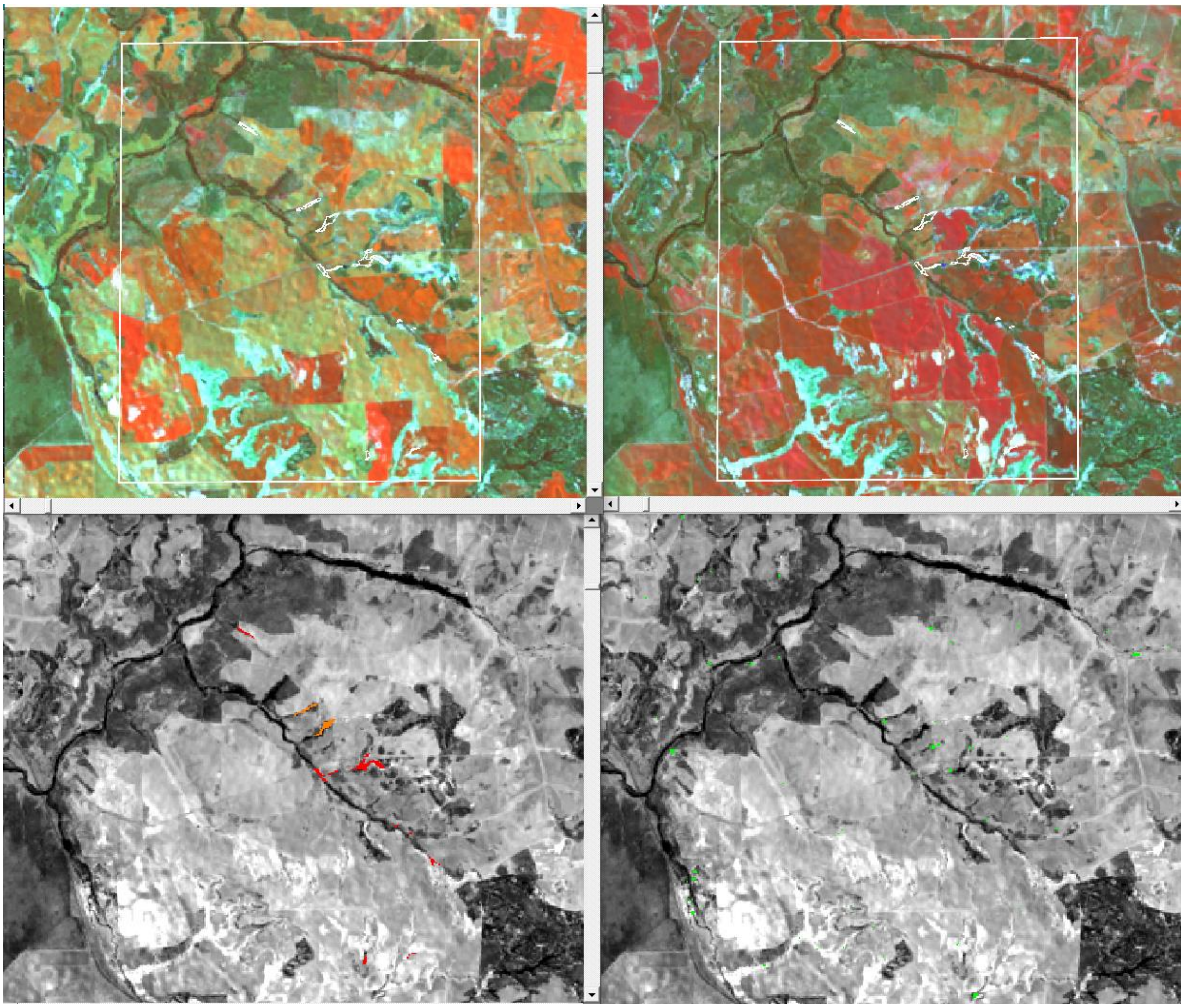
Note that all values in the tables presented here are in 25m-by-25m pixel counts, not hectares.

Kulla Kulla Hill



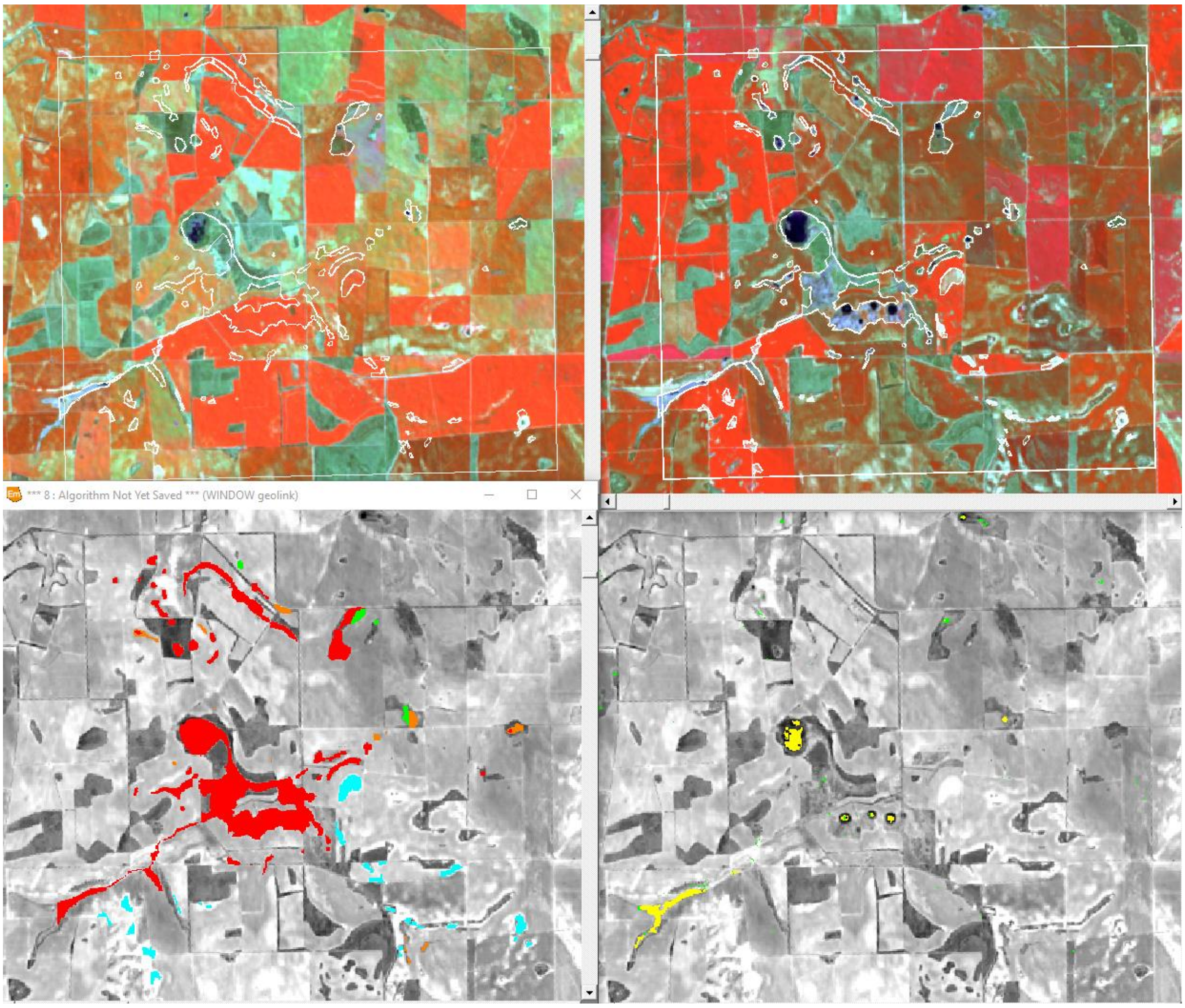
Kulla Kulla Hill					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	0	0	0	-
	RevSal	0	143	143	**100**
	SevSal	0	0	0	-
	Mod Sal	0	54	0	**100**
	Non-sal	0	796	796	**0.0**
	Total count	0	993	993	
	Commission Error %	**-**	**19.8**		**% Overall = 80.2**

Harry Spring:



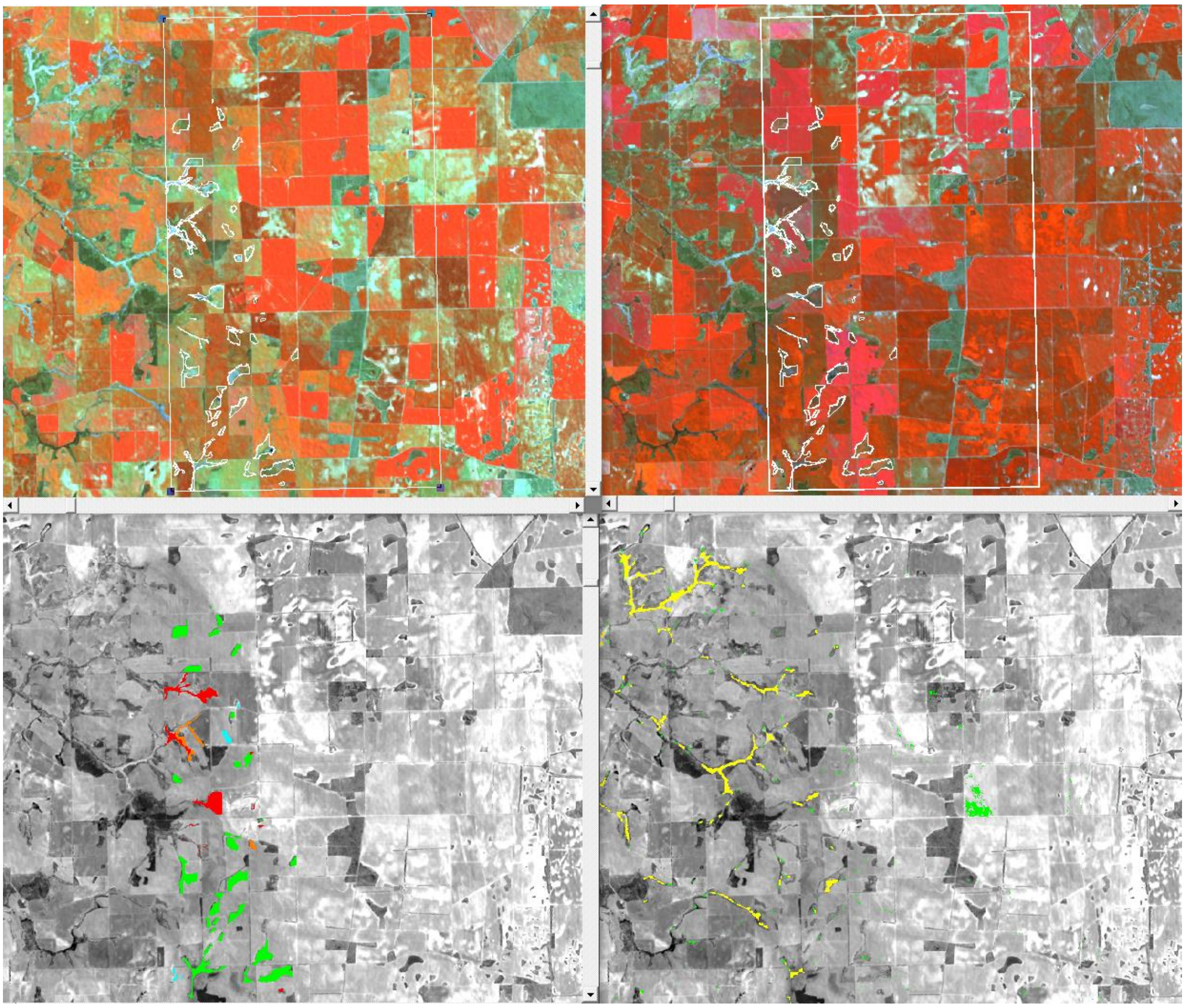
Harry Spring					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	0	0	0	-
	RevSal	0	0	**0**	-
	SevSal	0	177	177	**100**
	Mod Sal	0	79	79	**100**
	Non-sal	0	83785	83785	**0.0**
	Total count	0	84041	84041	
	Commission Error %	-	**0.3**		**% Overall = 99.7**

Mongeragarry Spring:



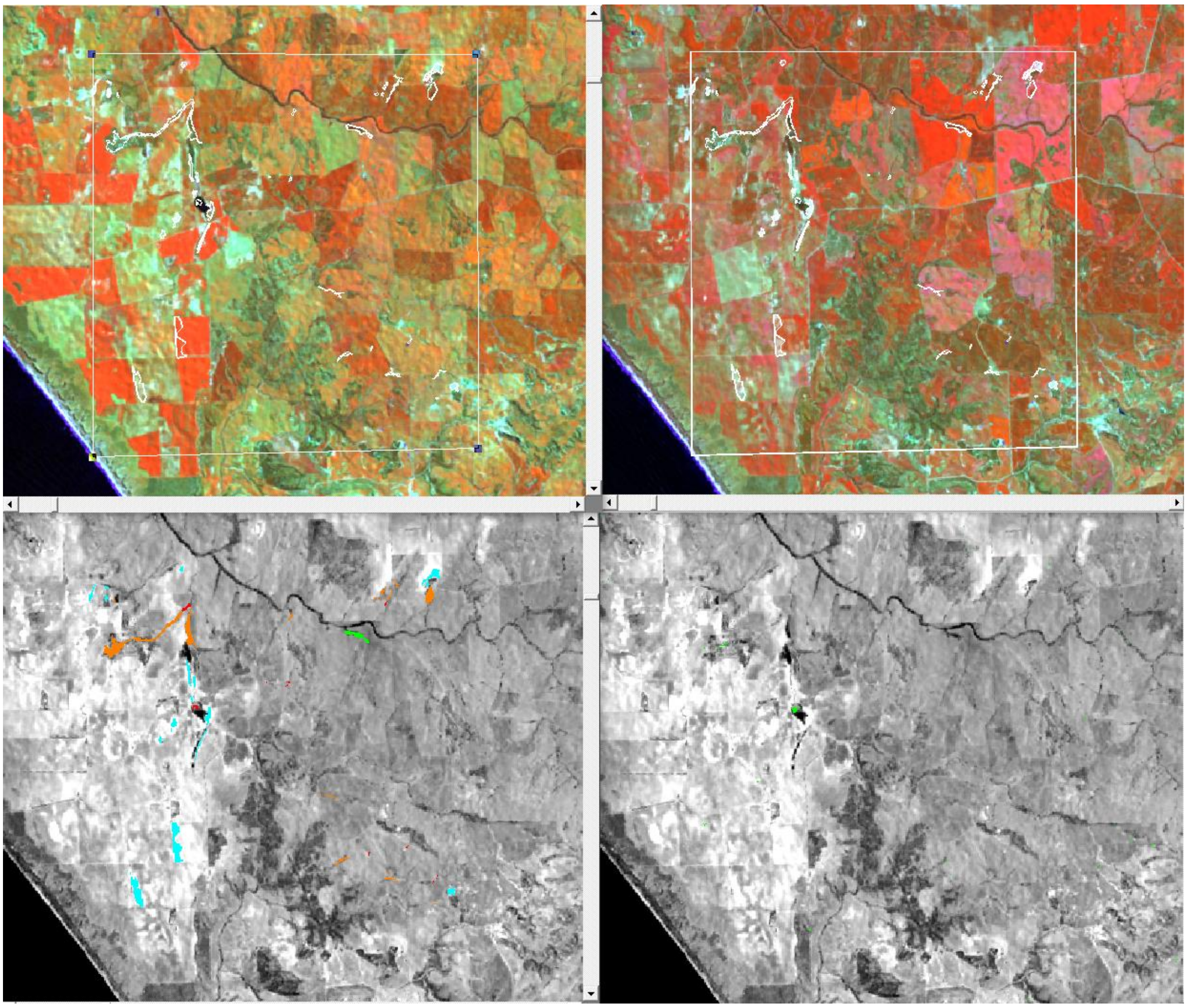
Mongeragarry Spring					
	Predicted Label				
		Salt	Not salt	Total count	**Omission Error %**
Ground Truth Label	Bare	0	1027	1027	**0.0**
	RevSal	15	169	184	**91.8**
	SevSal	416	6147	6563	**93.7**
	Mod Sal	0	372	372	**100**
	Non-sal	21	130483	130504	**0.0**
	Total count	452	138198	138650	
	Commission Error %	**4.6**	**4.8**		**% Overall = 95.2**

Hutt River:



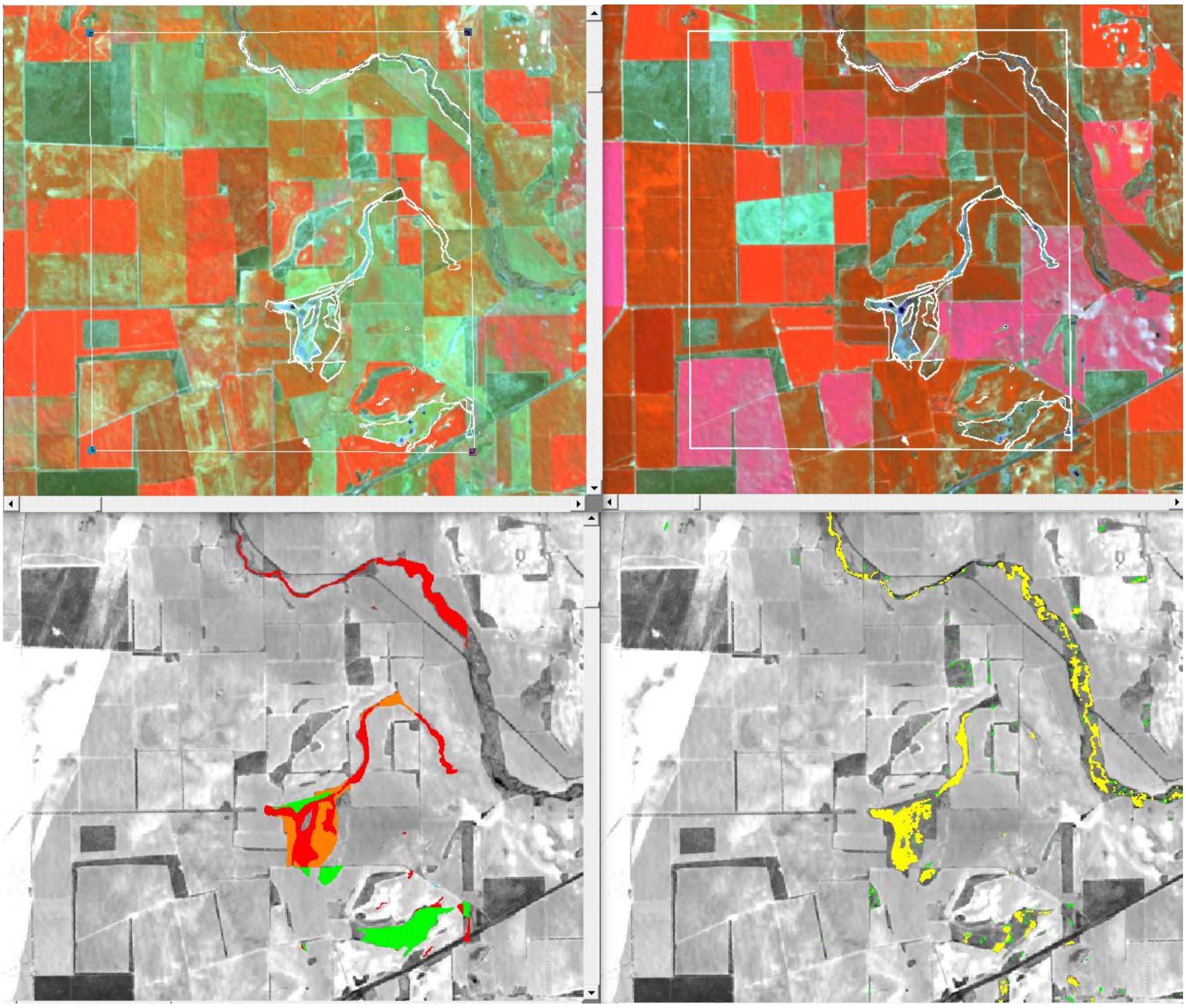
Hutt River					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	0	212	212	**0.0**
	RevSal	356	4166	4522	**92.1**
	SevSal	364	1203	1567	**76.8**
	Mod Sal	16	469	485	**96.7**
	Non-sal	58	233628	233686	**0.0**
	Total count	794	239678	240472	
	Commission Error %	**7.3**	**2.4**		**% Overall = 97.5**

Woolawar Gully:



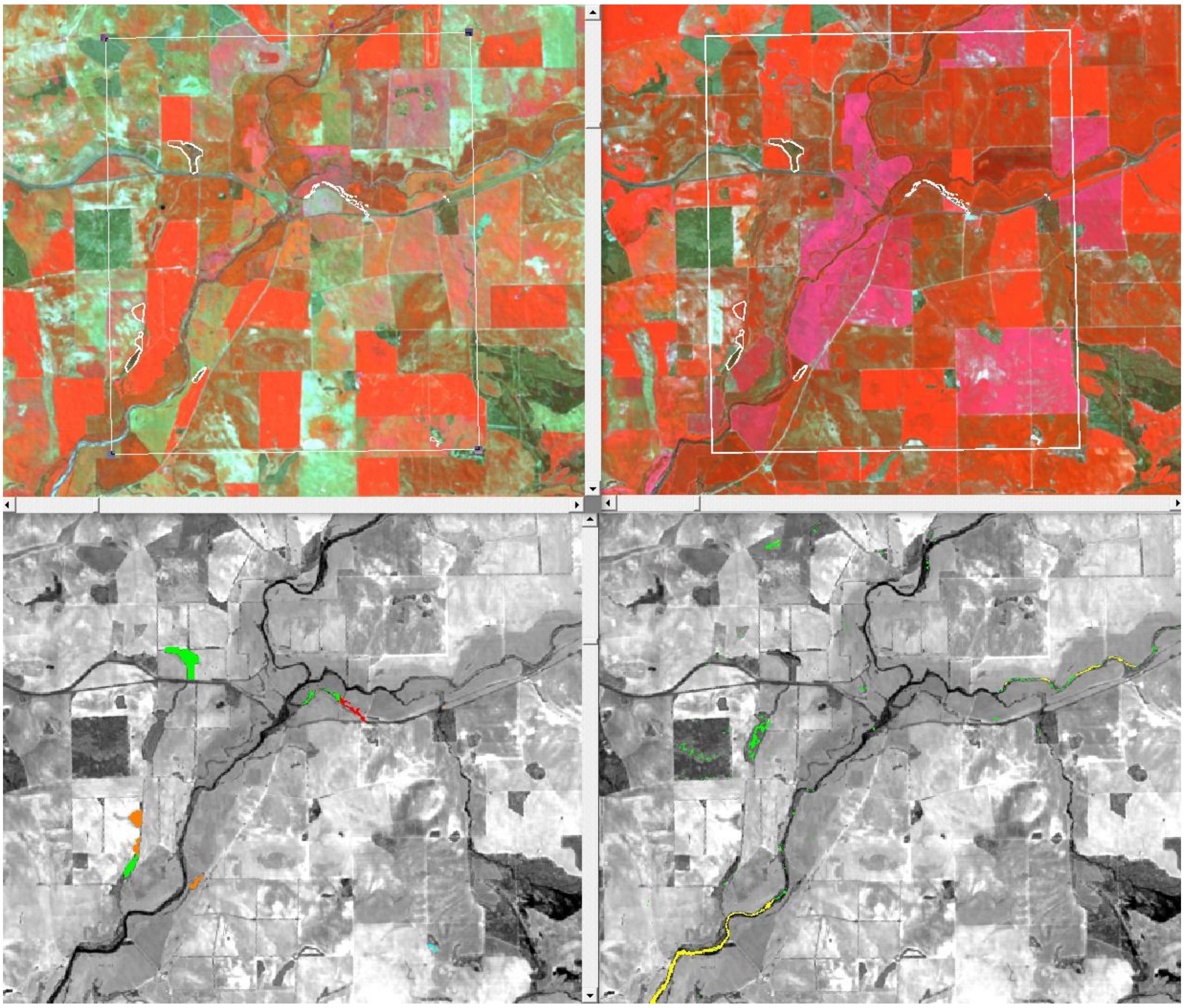
Woolawar Gully					
	Predicted Label				
		Salt	Not salt	Total count	**Omission Error %**
Ground Truth Label	Bare	0	637	637	**0.0**
	RevSal	0	70	70	**100**
	SevSal	0	58	58	**100**
	Mod Sal	0	556	556	**100**
	Non-sal	0	111541	111541	**0.0**
	Total count	0	112862	112862	
	Commission Error %	**-**	**0.6**		**% Overall = 99.4**

Kockatea Gully:



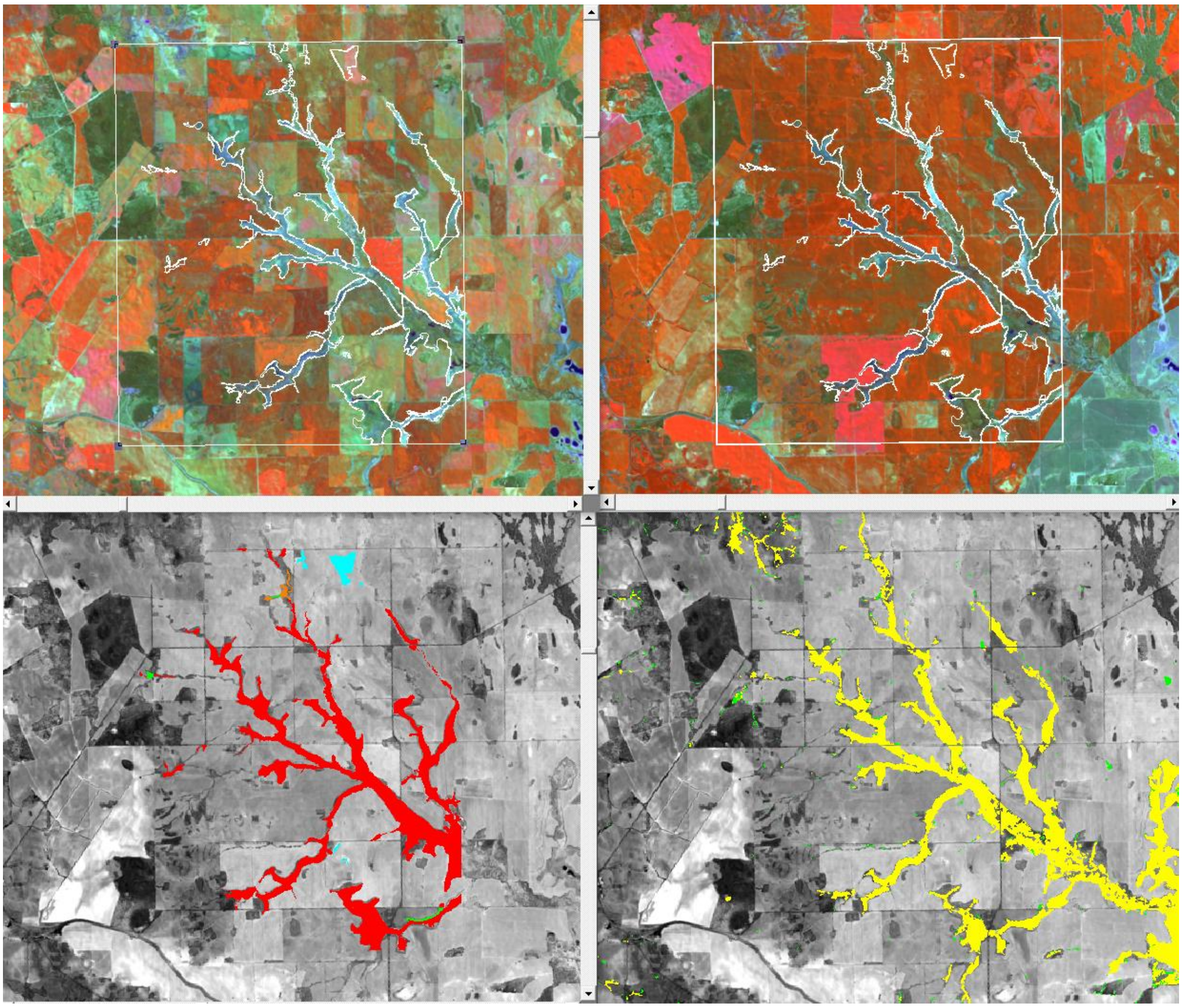
Kockatea Gully					
	Predicted Label				
		Salt	Not salt	Total count	**Omission Error %**
Ground Truth Label	Bare	0	6	6	**0.0**
	RevSal	398	1730	2128	**81.3**
	SevSal	2027	1942	3969	**48.9**
	Mod Sal	284	1387	1671	**83.0**
	Non-sal	231	127471	127702	**0.2**
	Total count	2940	132536	135476	
	Commission Error %	**7.9**	**3.8**		**% Overall = 96.1**

Irwin River:



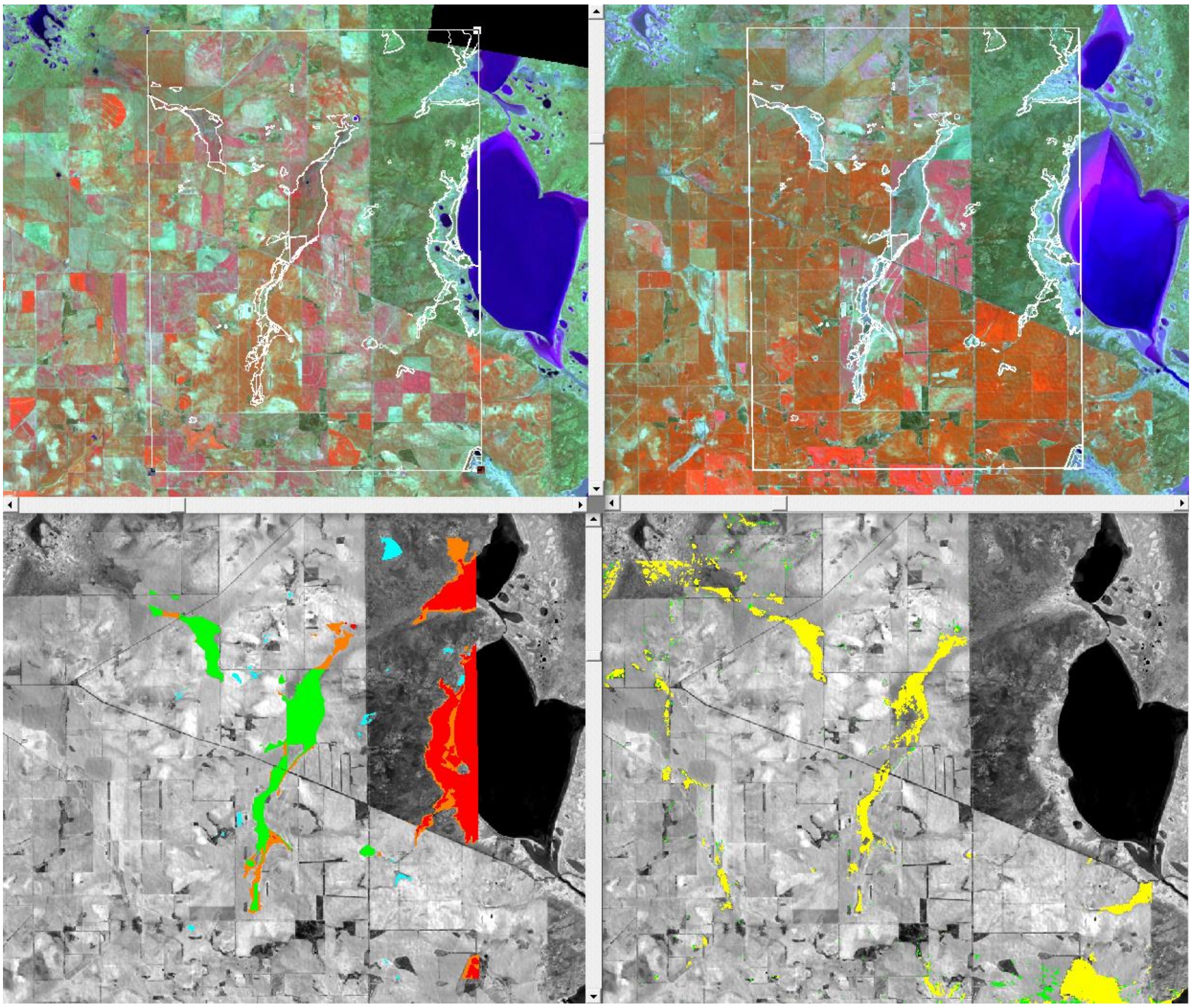
Irwin River					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	0	23	23	**0.0**
	RevSal	0	535	535	**100**
	SevSal	0	94	94	**100**
	Mod Sal	0	252	252	**100**
	Non-sal	192	130869	131061	**0.1**
	Total count	192	131773	131965	
	Commission Error %	**100**	**0.7**		**% Overall = 99.2**

Geebulla Creek:



Geebulla Creek					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	0	738	738	**0.0**
	RevSal	83	97	180	**53.9**
	SevSal	13892	3904	17796	**21.9**
	Mod Sal	85	88	173	**50.9**
	Non-sal	3698	158531	162229	**2.3**
	Total count	17758	163358	181116	
	Commission Error %	**20.8**	**2.5**		**% Overall = 95.7**

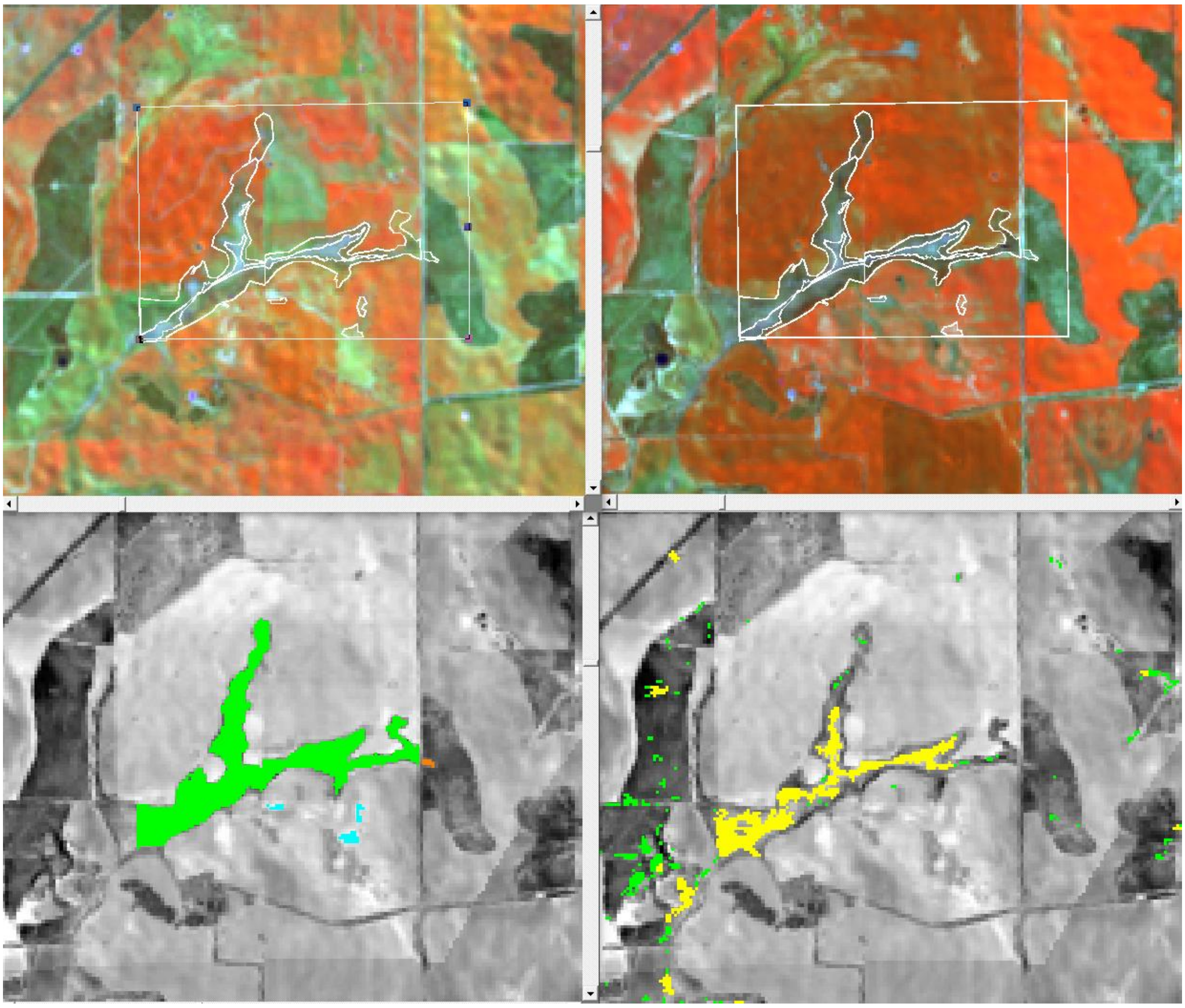
East Perenjori:



Note: Pixels outside the mapped area have been excluded from these summary statistics

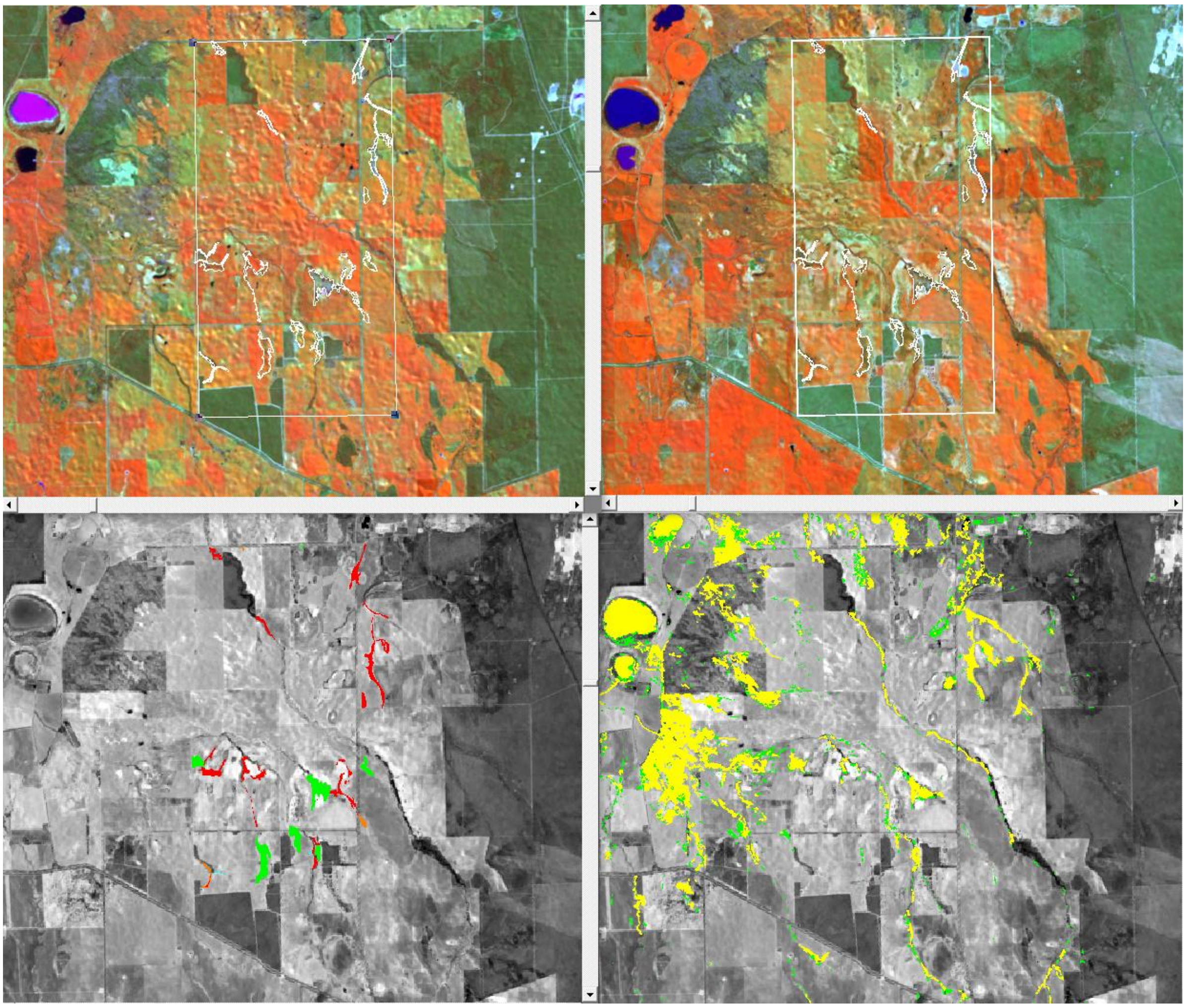
East Perenjori					
	Predicted Label				
		Salt	Not salt	Total count	**Omission Error %**
Ground Truth Label	Bare	4	1256	1260	**0.3**
	RevSal	10211	6102	16313	**37.4**
	SevSal	583	135	718	**18.8**
	Mod Sal	1828	3059	4887	**62.6**
	Non-sal	1301	348803	350104	**0.4**
	Total count	13927	359355	373282	
	Commission Error %	**9.4**	**2.6**		**% Overall = 97.2**

Wilton Well:



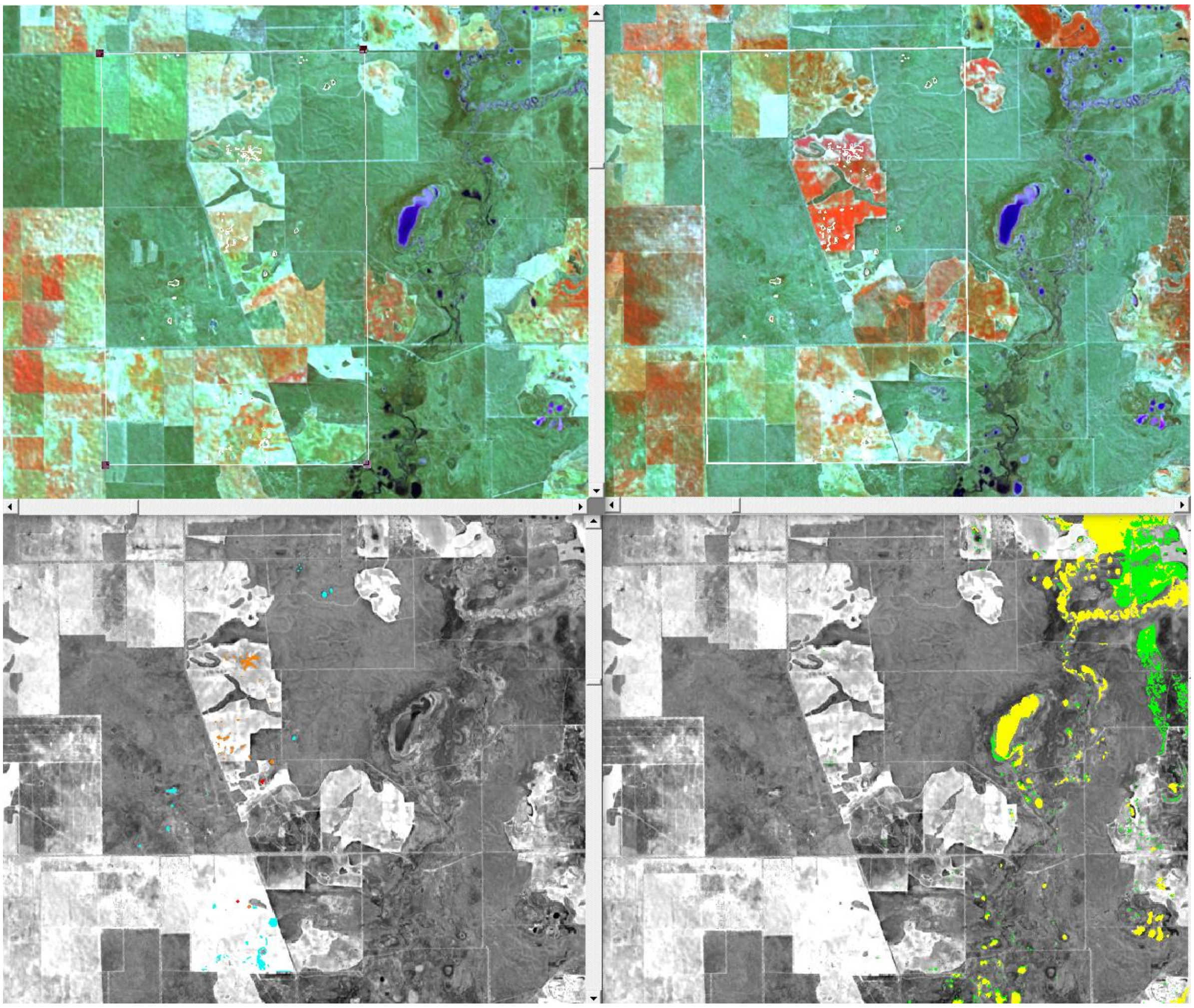
Wilton Well					
	Predicted Label				
		Salt	Not salt	Total count	**Omission Error %**
Ground Truth Label	Bare	0	39	39	**0.0**
	RevSal	414	841	1255	**66.9**
	SevSal	0	0	0	-
	Mod Sal	0	8	8	**100**
	Non-sal	4	7221	7225	**0.1**
	Total count	418	8109	8527	
	Commission Error %	**1.0**	**10.5**		**% Overall = 90.0**

Bindoon Creek:



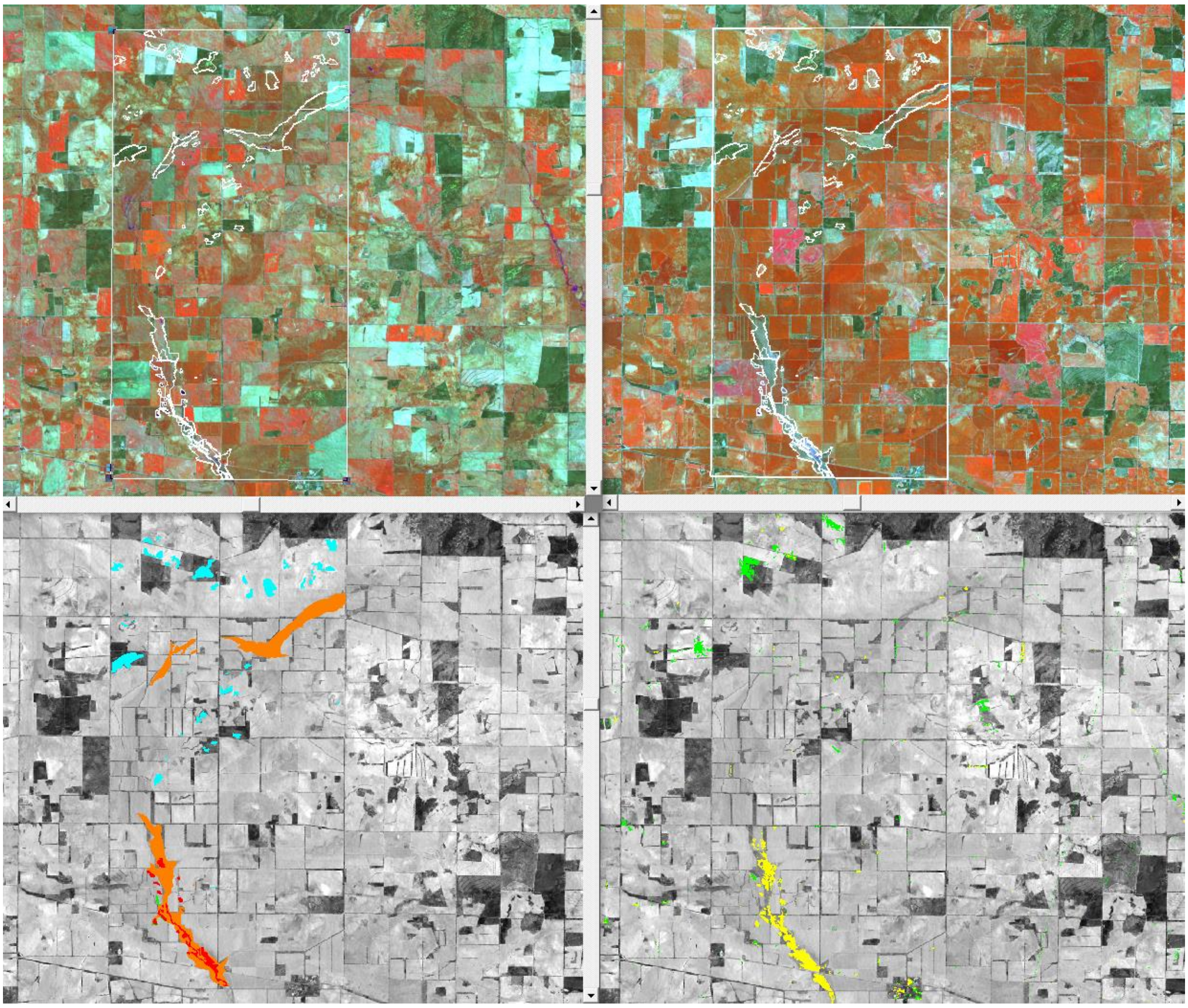
Bindoon Creek					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	0	18	18	**0.0**
	RevSal	438	712	1150	**61.9**
	SevSal	577	807	1384	**58.3**
	Mod Sal	0	117	117	**100**
	Non-sal	1941	70140	72081	**2.7**
	Total count	2956	71794	74750	
	Commission Error %	**65.7**	**2.3**		**% Overall = 95.2**

Capamaura Swamp:



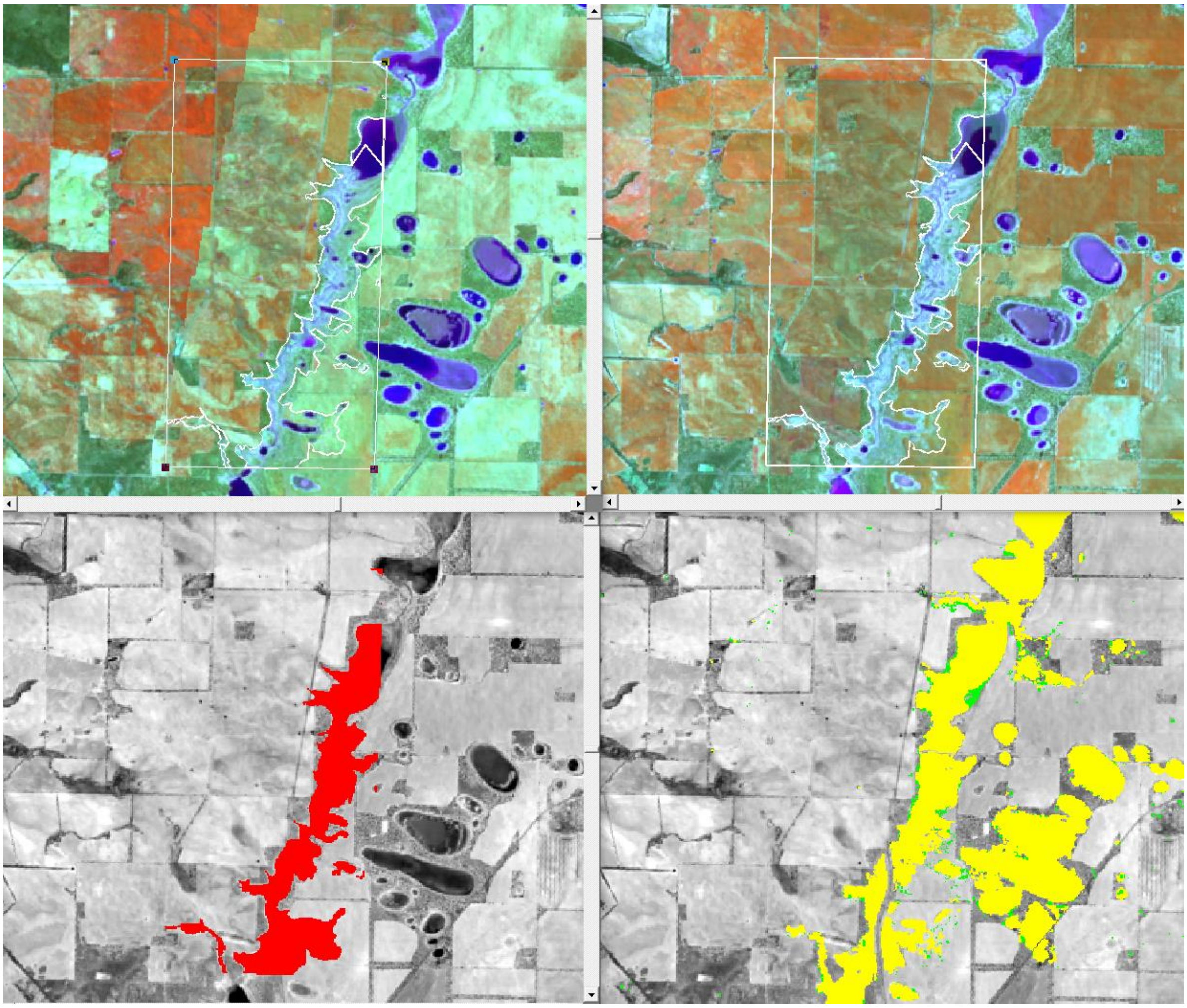
Capamaura Swamp					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	0	485	485	**0.0**
	RevSal	0	0	0	-
	SevSal	0	26	26	**100**
	Mod Sal	0	329	329	**100**
	Non-sal	2	138905	138907	**0.0**
	Total count	2	139745	139747	
	Commission Error %	**100**	**0.3**		**% Overall = 99.7**

Beacon:



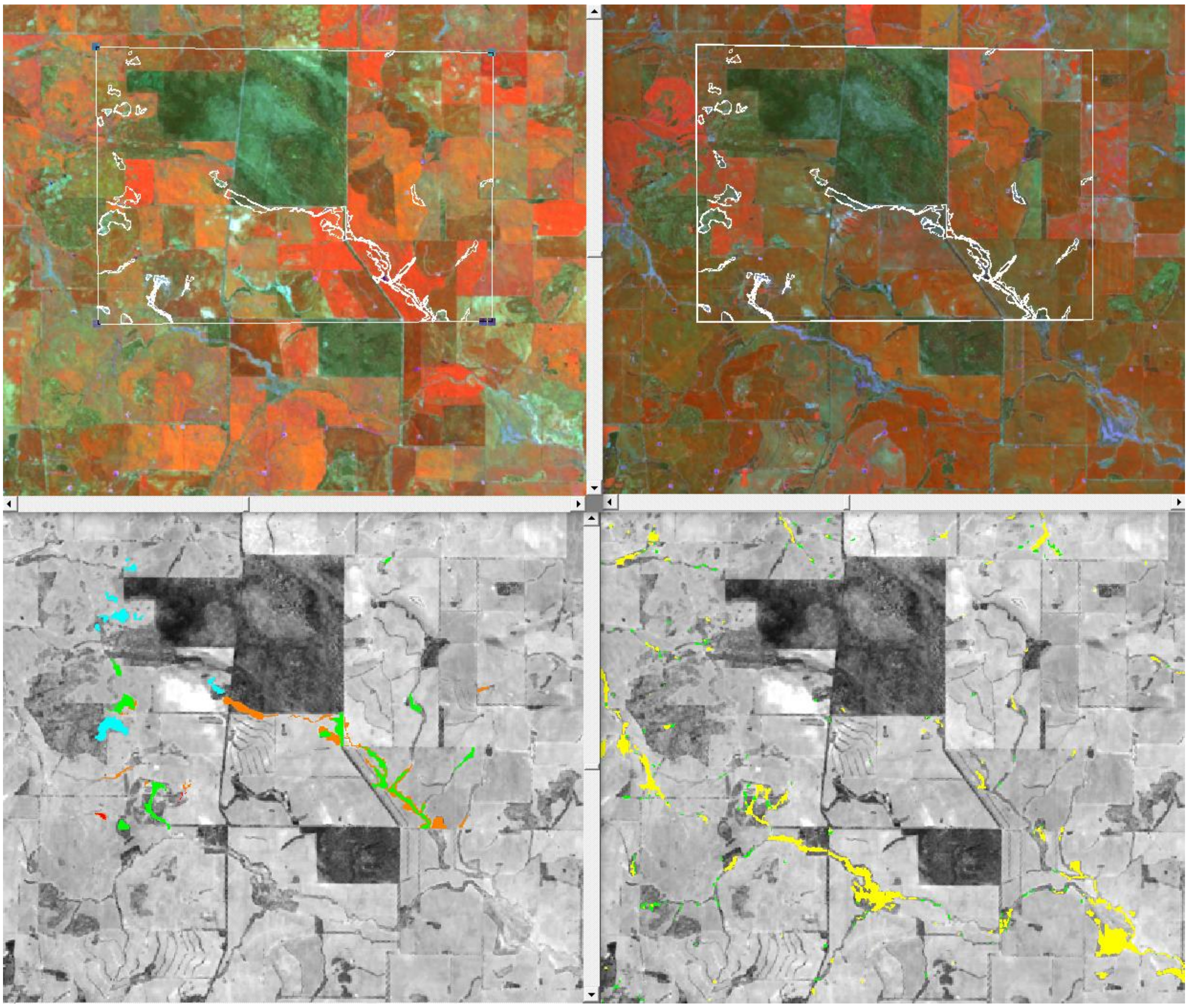
Beacon					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	5	7647	7652	**0.1**
	RevSal	25	117	142	**82.4**
	SevSal	2253	335	2588	**12.9**
	Mod Sal	3576	14704	18280	**80.4**
	Non-sal	777	458032	458809	**0.2**
	Total count	6636	480835	487471	
	Commission Error %	**11.8**	**3.2**		**% Overall = 96.7**

Southern Cross:



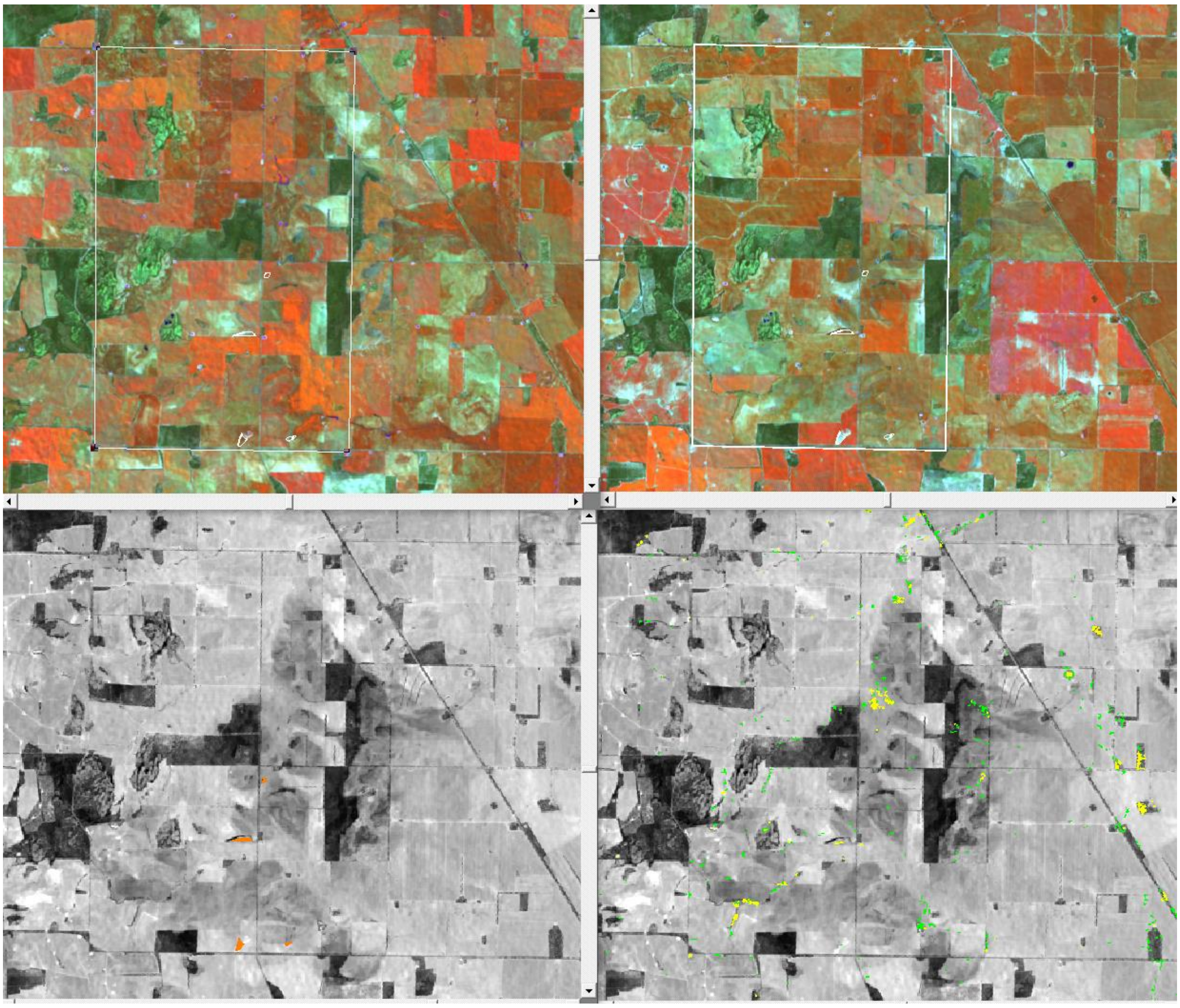
Southern Cross					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	0	0	0	-
	RevSal	0	0	0	-
	SevSal	7836	1716	9552	**18.0**
	Mod Sal	0	0	0	-
	Non-sal	1492	41279	42771	**3.5**
	Total count	9328	42995	52323	
	Commission Error %	**16.0**	**4.0**		**% Overall = 93.9**

Wallatin Creek:



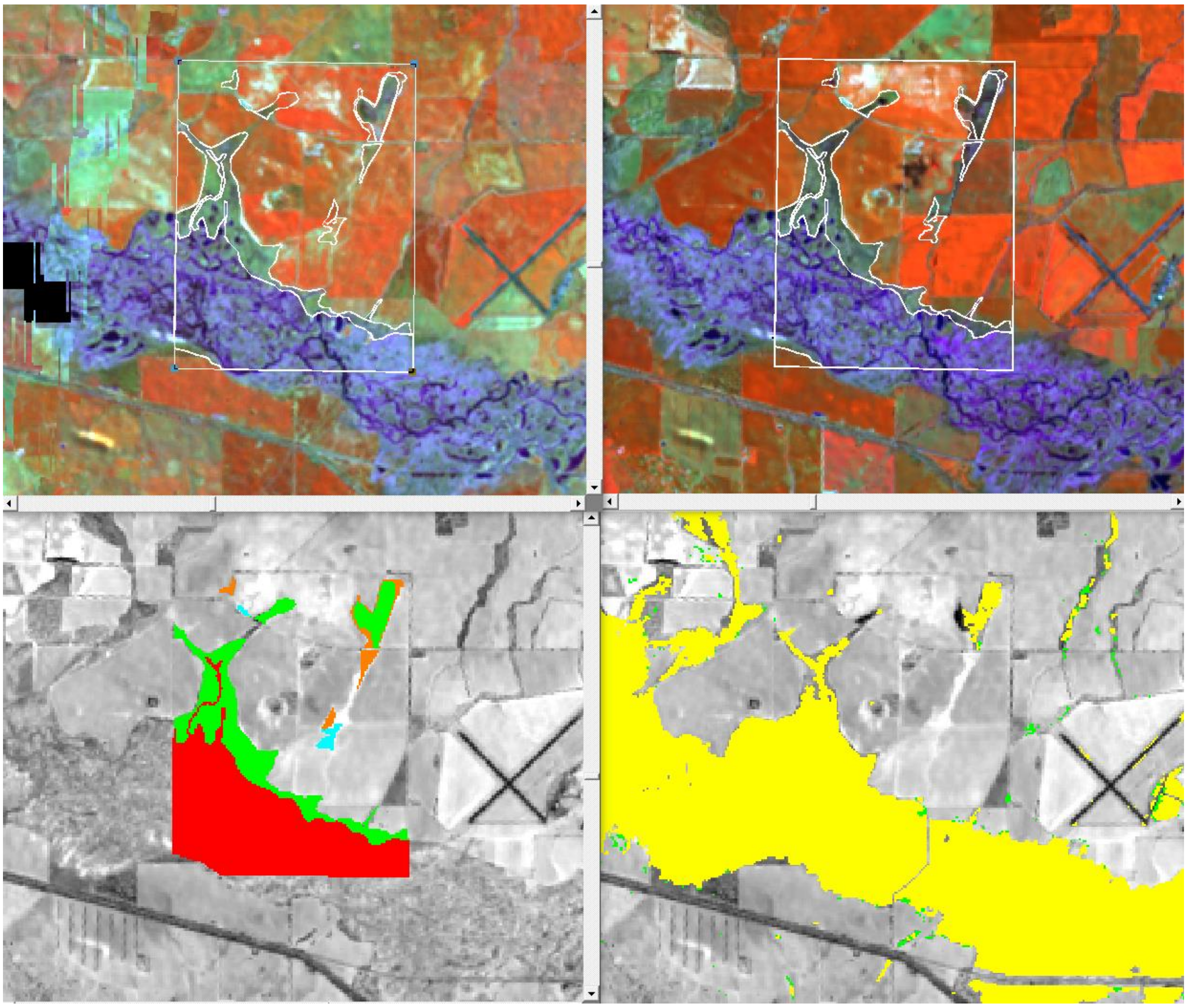
Wallatin Creek					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	10	60	60	**0.0**
	RevSal	231	913	1144	**79.8**
	SevSal	22	10	32	**21.9**
	39	39	962	1001	**96.1**
	Non-sal	141	75075	75216	**0.2**
	Total count	443	77568	78011	
	Commission Error %	**34.1**	**2.4**		**% Overall = 97.4**

Burracoppin:



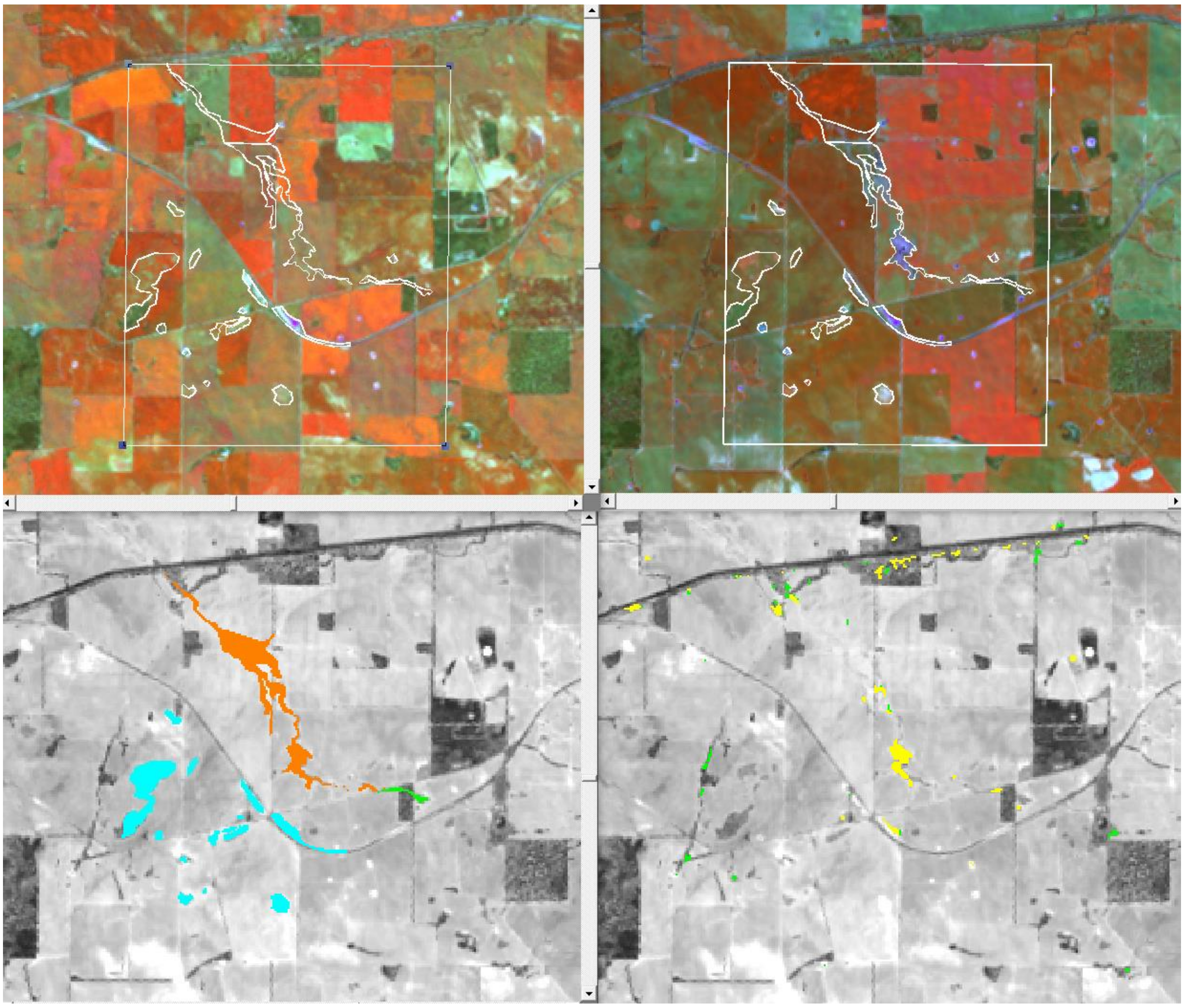
Burracoppin					
	Predicted Label				
		Salt	Not salt	Total count	**Omission Error %**
Ground Truth Label	Bare	0	0	0	-
	RevSal	0	0	0	-
	SevSal	0	0	0	-
	Mod Sal	12	150	162	**92.6**
	Non-sal	382	97977	98359	**0.4**
	Total count	394	98127	98521	
	Commission Error %	**97.0**	**0.2**		**% Overall = 99.5**

Cunderdin:



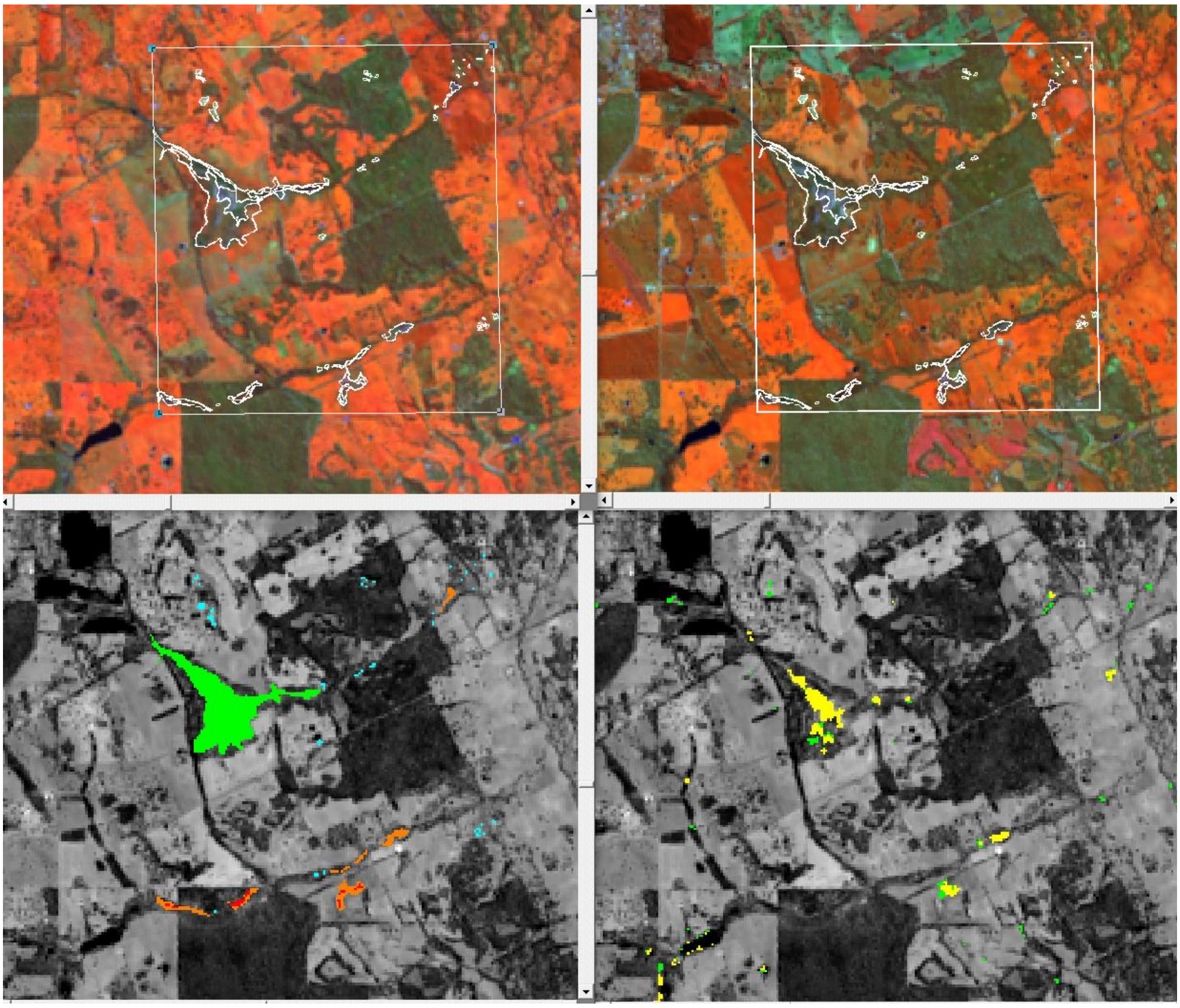
Cunderdin					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	0	91	91	**0.0**
	RevSal	1510	471	1981	**23.8**
	SevSal	4516	38	4554	**0.8**
	Mod Sal	31	218	249	**87.6**
	Non-sal	82	10556	10638	**0.8**
	Total count	6139	11374	17513	
	Commission Error %	**1.3**	**6.4**		**% Overall = 95.4**

Tammin:



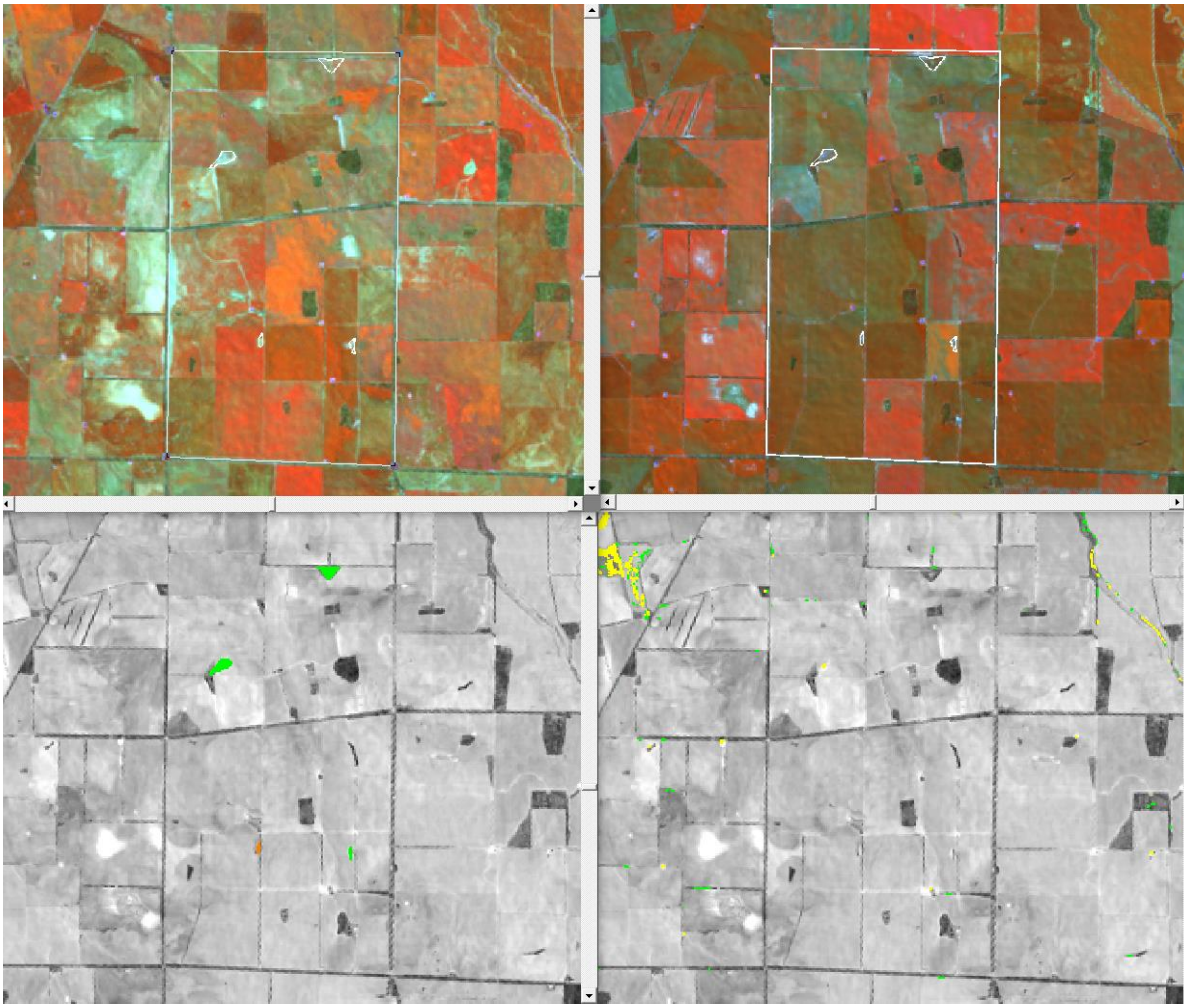
Tammin					
	Predicted Label				
		Salt	Not salt	Total count	**Omission Error %**
Ground Truth Label	Bare	22	927	949	**2.3**
	RevSal	9	38	47	**80.9**
	SevSal	0	0	0	-
	Mod Sal	168	764	932	**82.0**
	Non-sal	40	32025	32065	**0.1**
	Total count	239	33754	33993	
	Commission Error %	**25.9**	**2.4**		**% Overall = 97.5**

Yalanbie:



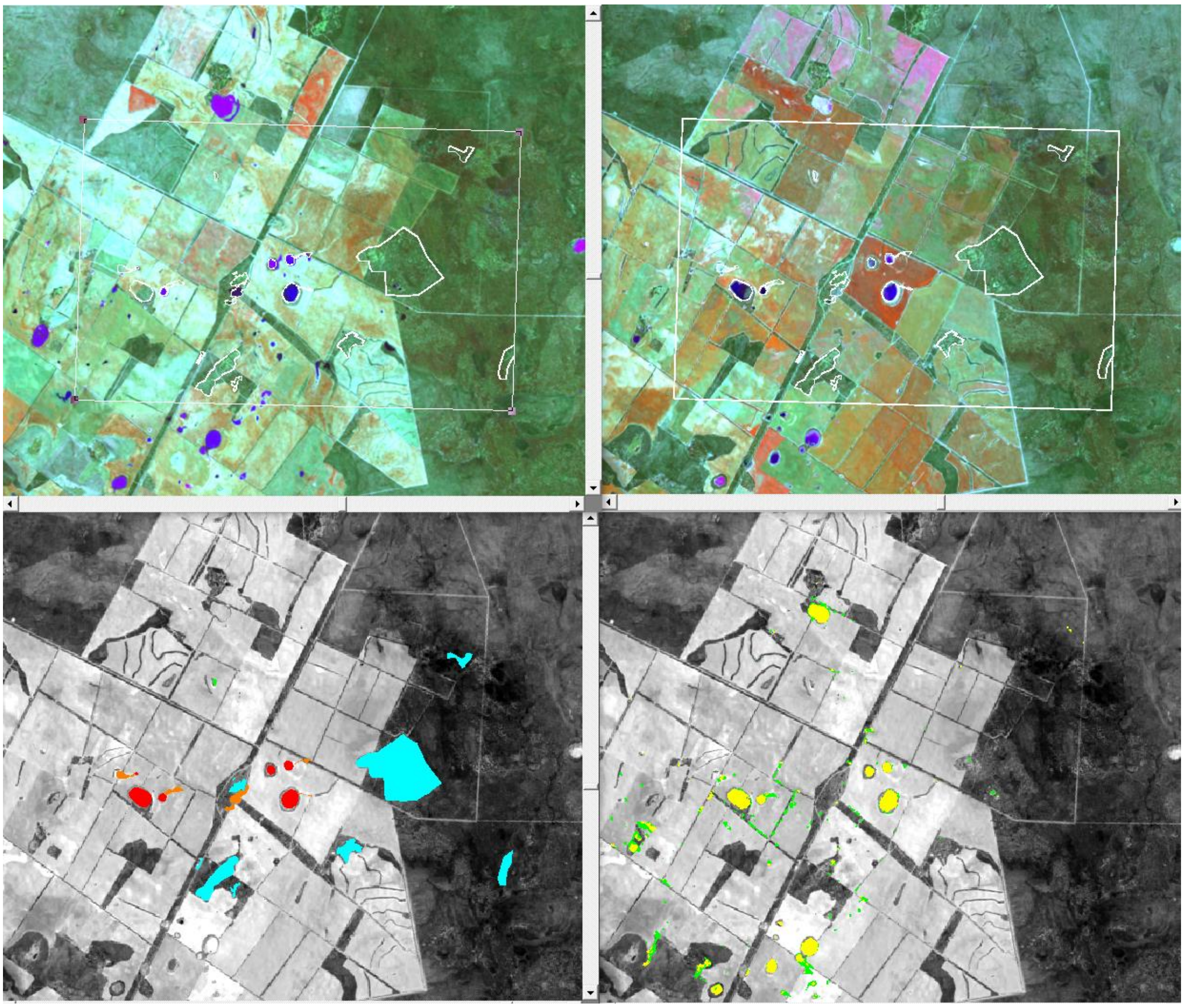
Yalanbie					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	0	81	81	**0.0**
	RevSal	217	661	878	**75.3**
	SevSal	3	34	37	**91.9**
	Mod Sal	51	156	207	**75.4**
	Non-sal	16	24150	24166	**0.1**
	Total count	287	25082	25369	
	Commission Error %	**5.6**	**3.4**		**% Overall = 96.6**

East Belka:



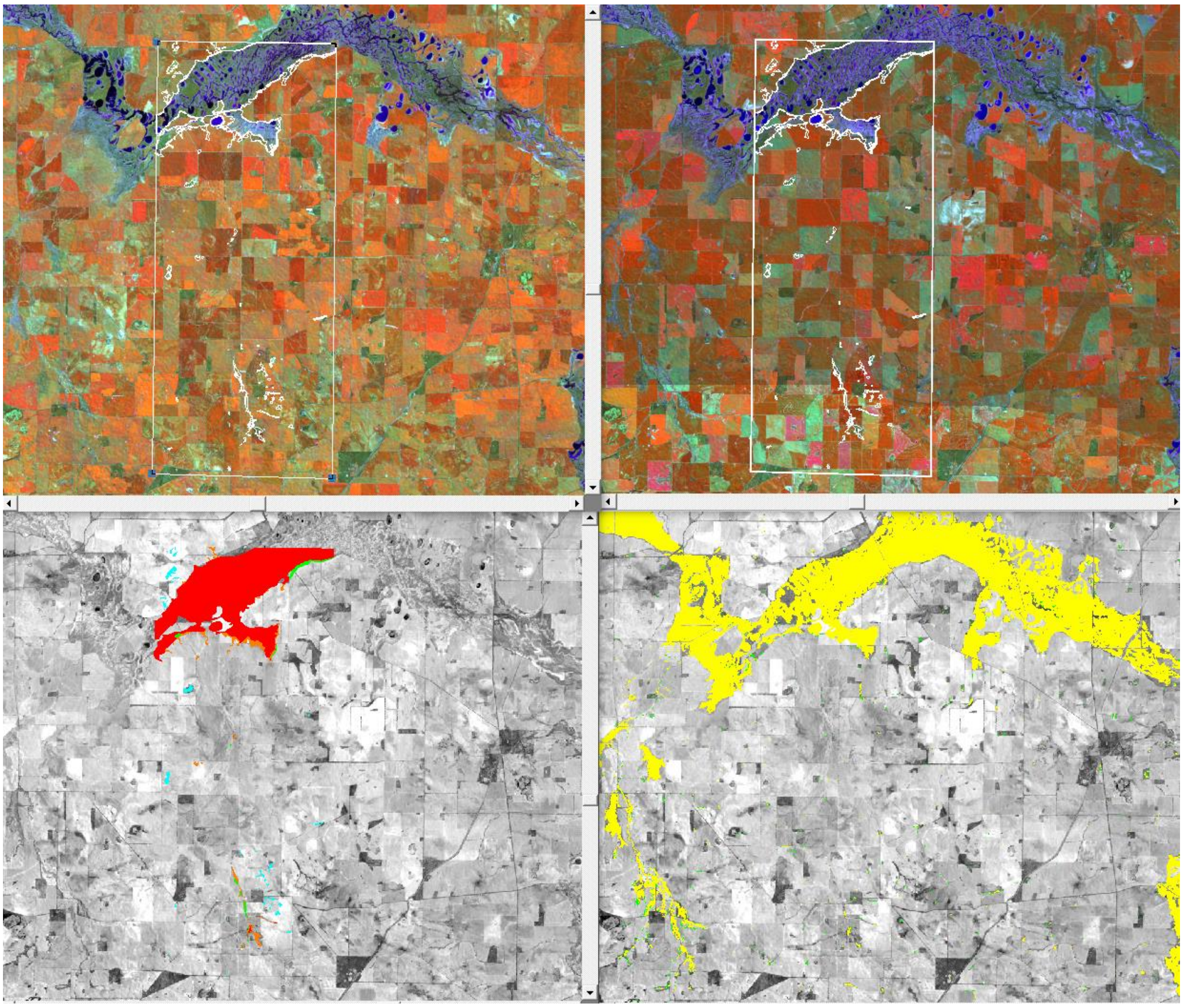
East Belka					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	0	0	0	-
	RevSal	8	193	201	**96.0**
	SevSal	0	0	0	-
	Mod Sal	0	22	22	**100**
	Non-sal	4	43850	43854	**0.0**
	Total count	12	44065	44077	
	Commission Error %	**33.3**	**0.5**		**% Overall = 99.5**

Skeleton Rocks:



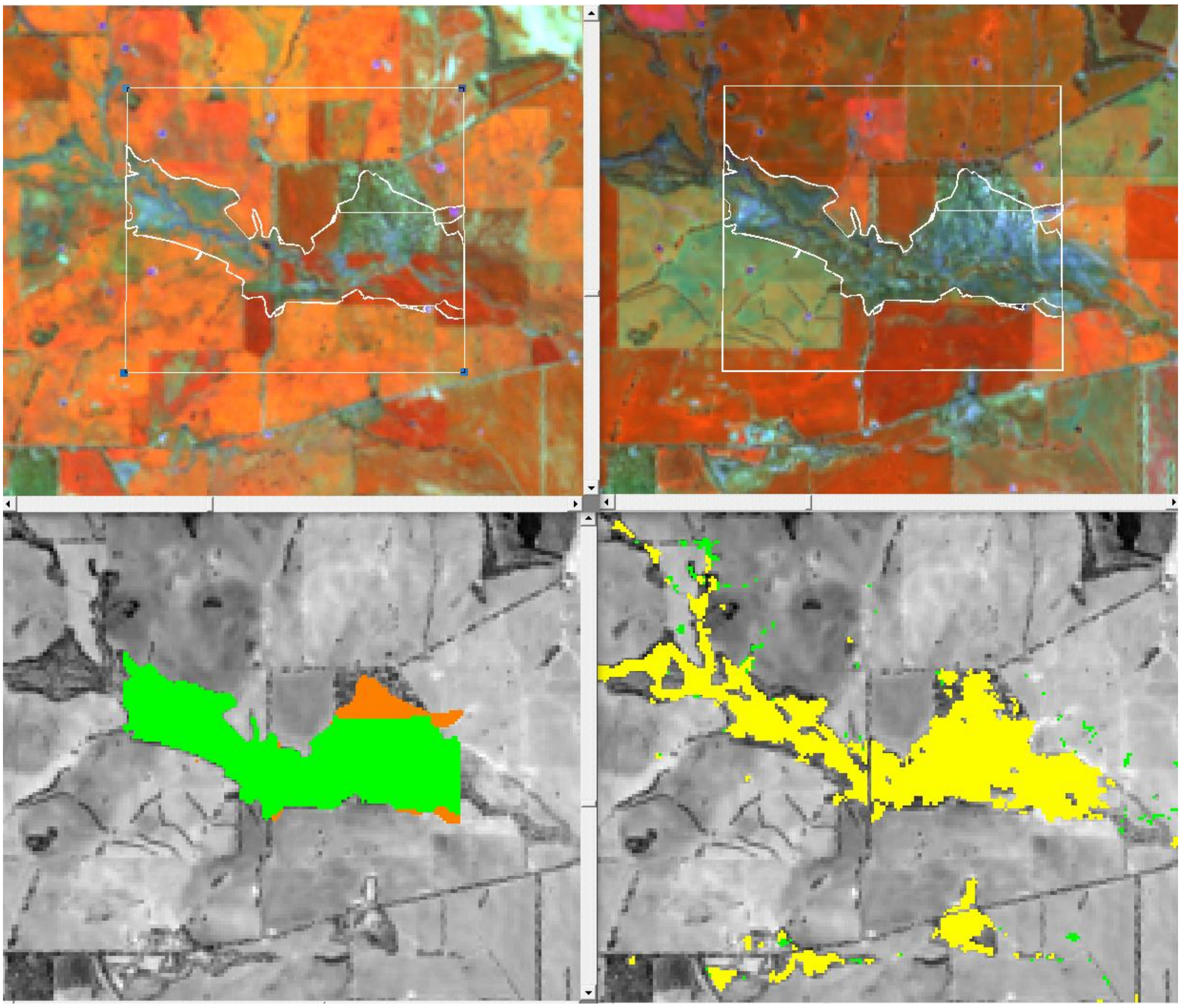
Skeleton Rocks					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	18	5318	5336	**0.3**
	RevSal	0	23	23	**100**
	SevSal	871	38	909	**4.2**
	Mod Sal	31	423	454	**93.2**
	Non-sal	217	117235	117452	**0.2**
	Total count	1137	123037	124174	
	Commission Error %	**20.7**	**0.4**		**% Overall = 99.6**

Sth Yarding North:



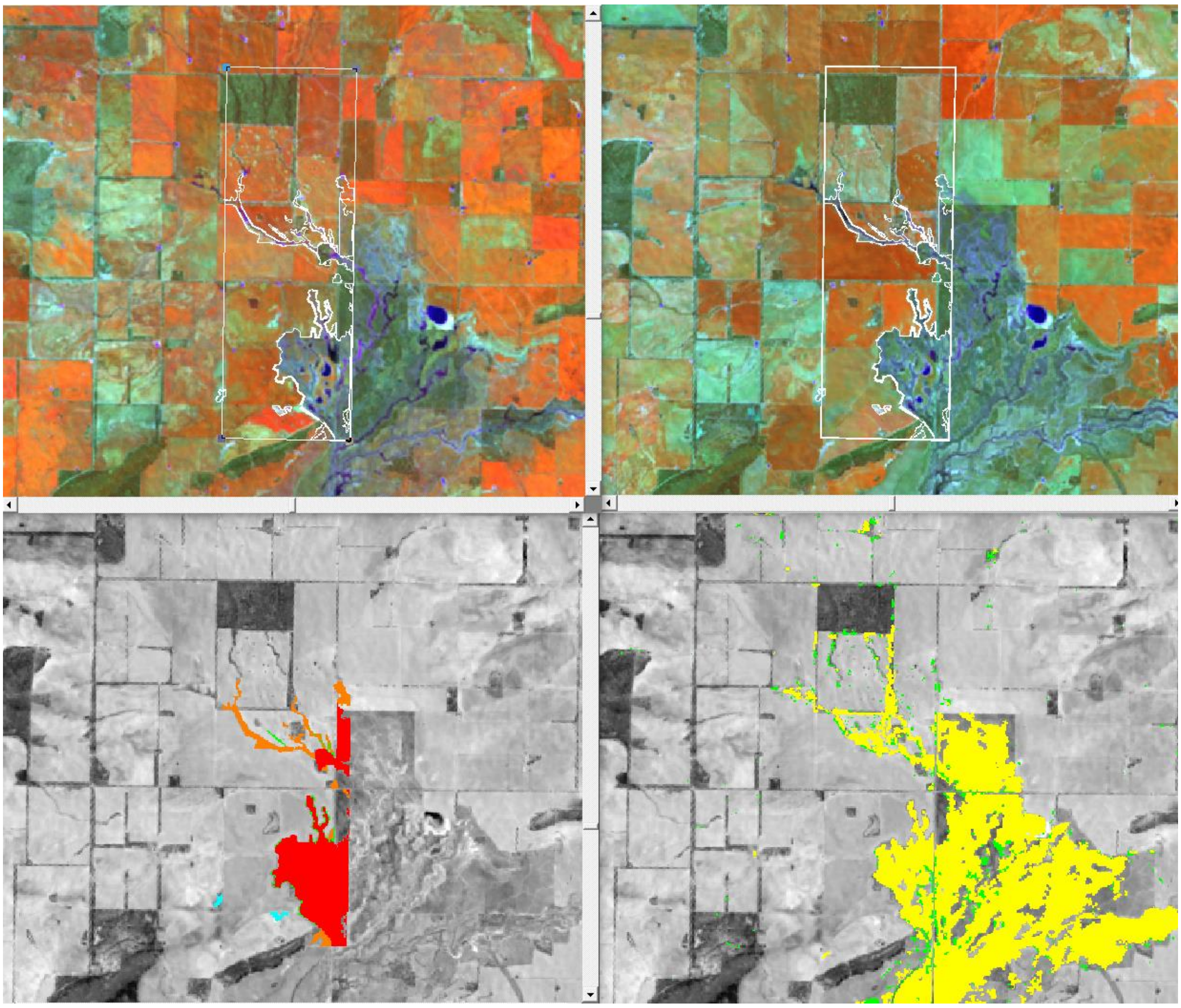
Sth Yarding North					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	17	1455	1472	**1.2**
	RevSal	70	815	885	**92.1**
	SevSal	28993	4412	33405	**13.2**
	Mod Sal	364	2133	2497	**85.4**
	Non-sal	530	281435	281965	**0.2**
	Total count	29974	290250	320224	
	Commission Error %	**1.8**	**2.5**		**% Overall = 97.5**

Morbinning:



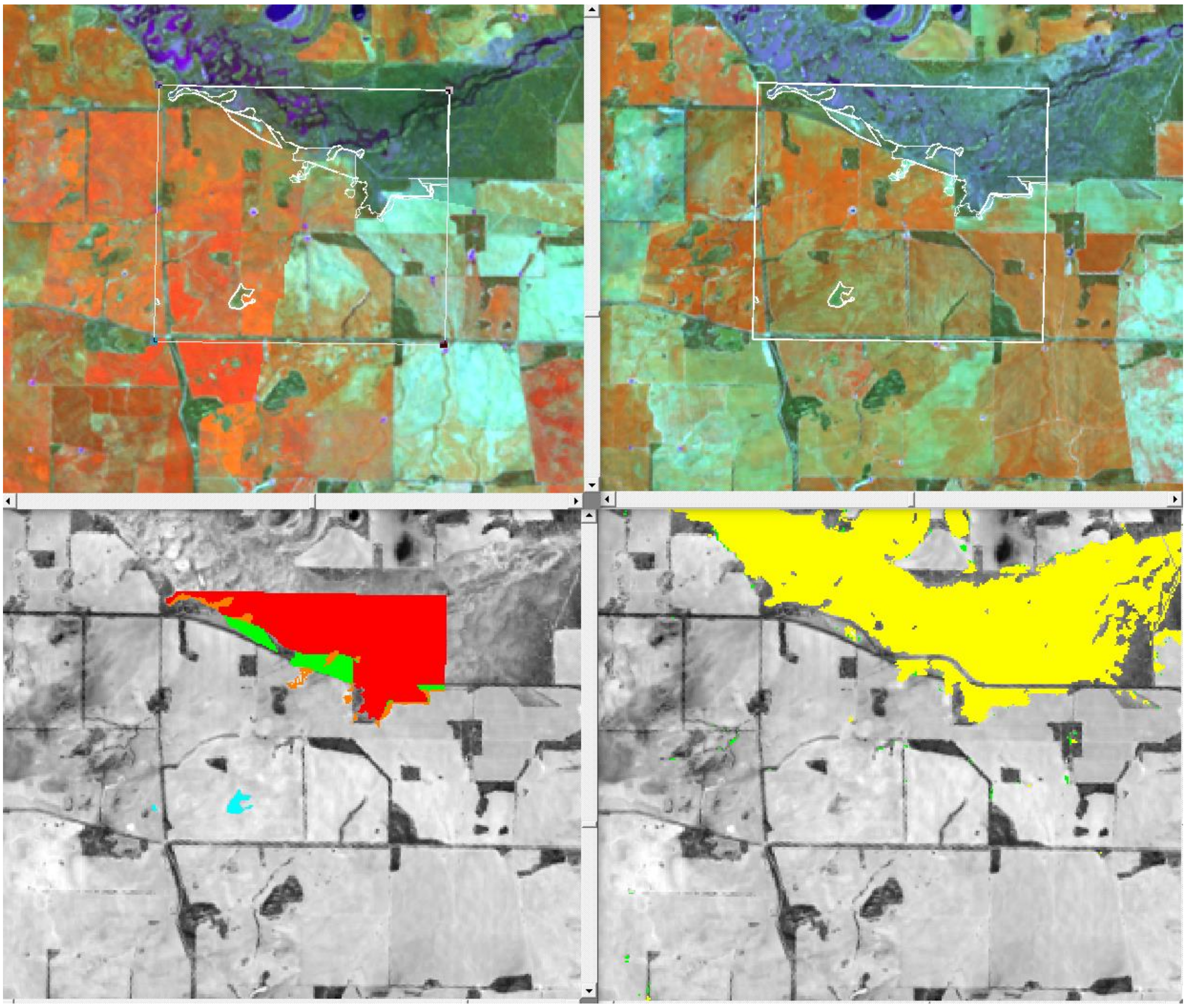
Morbinning					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	0	0	0	-
	RevSal	2270	686	2956	**23.2**
	SevSal	0	0	0	-
	Mod Sal	203	151	354	**42.7**
	Non-sal	114	7951	8065	**1.4**
	Total count	2587	8788	11375	
	Commission Error %	**4.4**	**9.5**		**% Overall = 91.6**

Karlgarin:



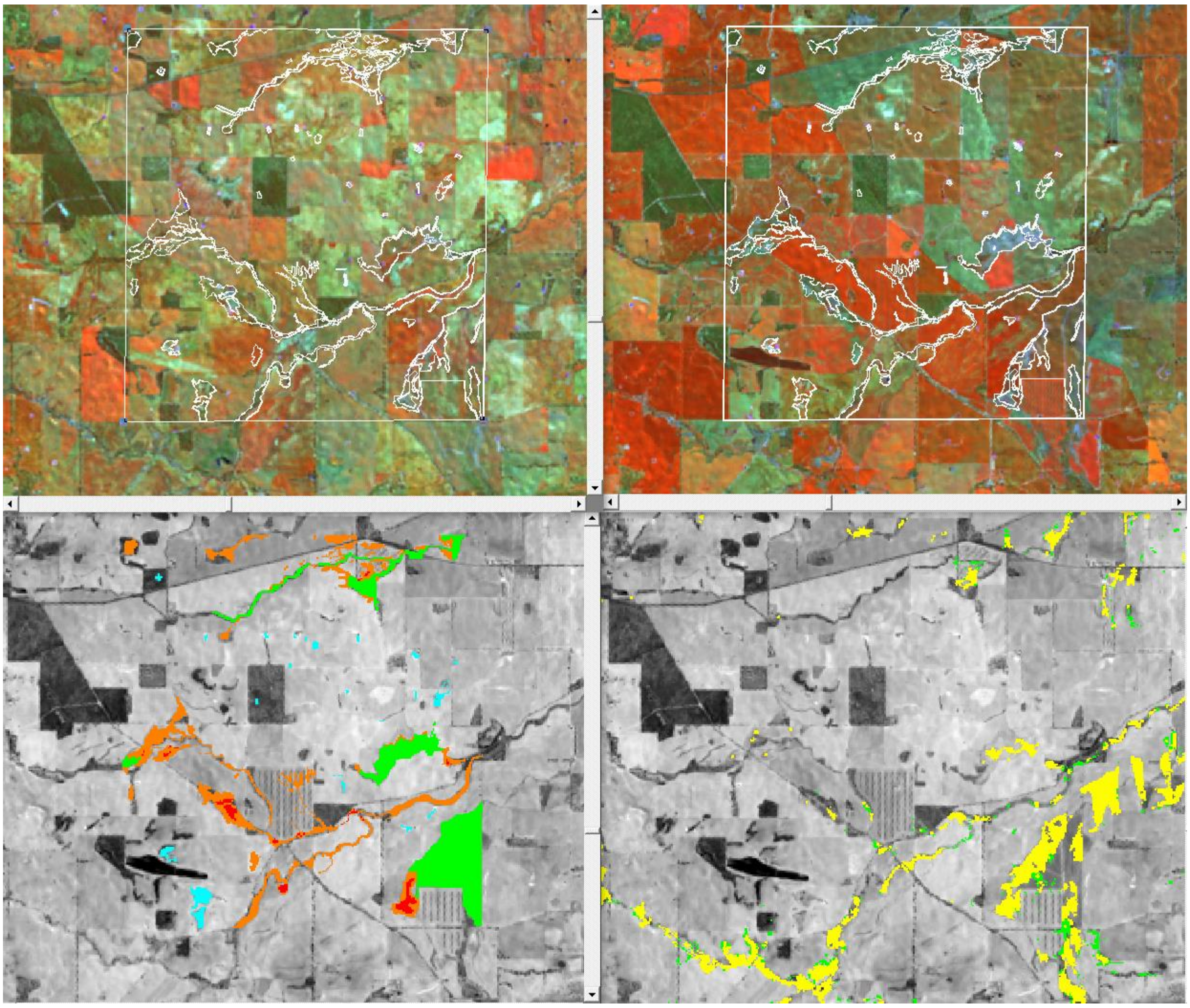
Karlgarin					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	0	58	58	**0.0**
	RevSal	77	71	148	**48.0**
	SevSal	2890	728	3618	**20.1**
	Mod Sal	375	457	832	**54.9**
	Non-sal	962	19428	20390	**4.7**
	Total count	4304	20742	25046	
	Commission Error %	**22.4**	**6.1**		**% Overall = 91.1**

East Hyden:



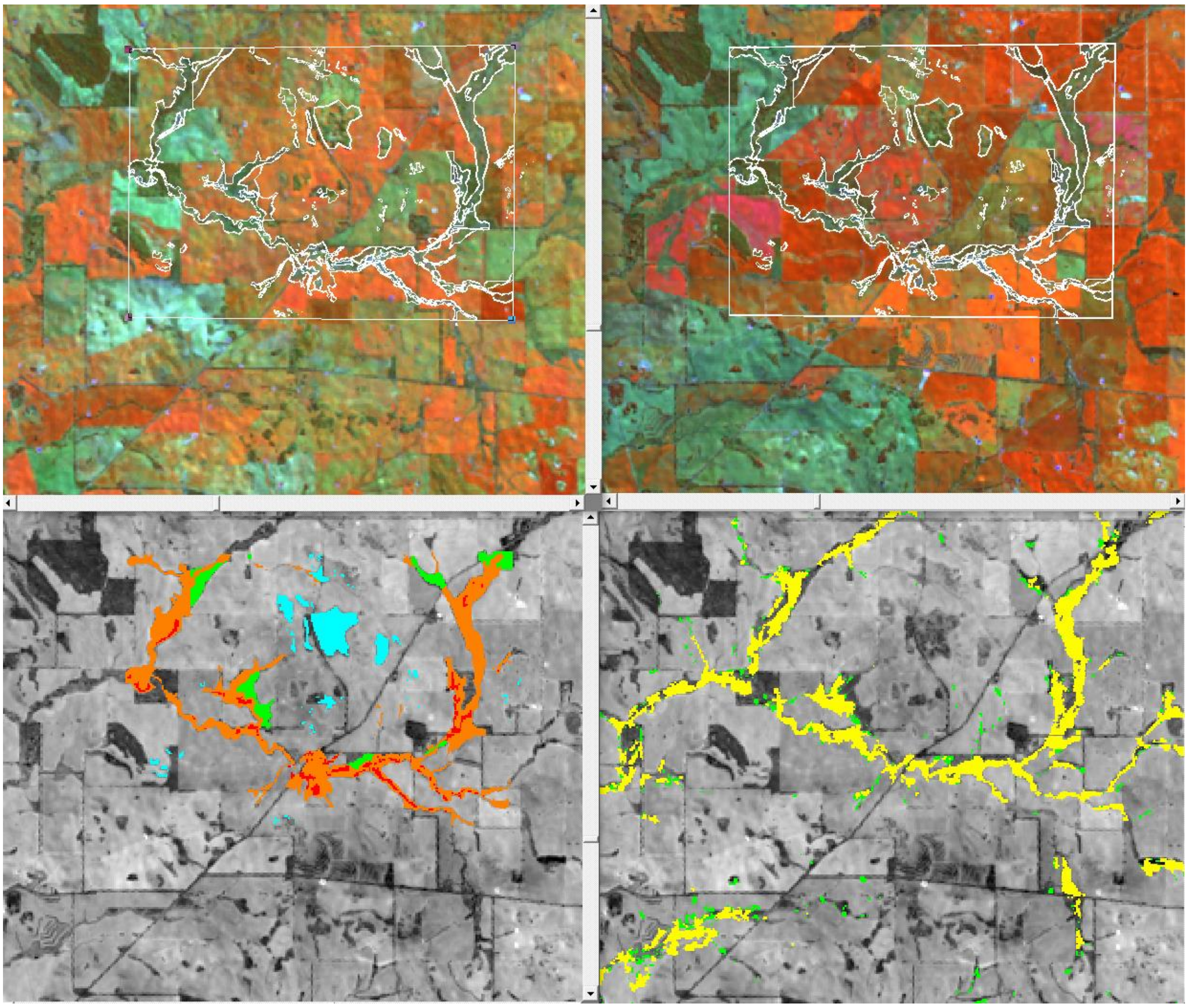
East Hyden					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	0	107	107	**0.0**
	RevSal	293	356	649	**54.9**
	SevSal	5251	350	5601	**6.2**
	Mod Sal	198	196	394	**49.7**
	Non-sal	76	18909	18985	**0.4**
	Total count	5818	19918	25736	
	Commission Error %	**1.3**	**4.5**		**% Overall = 96.2**

Woodabulling:



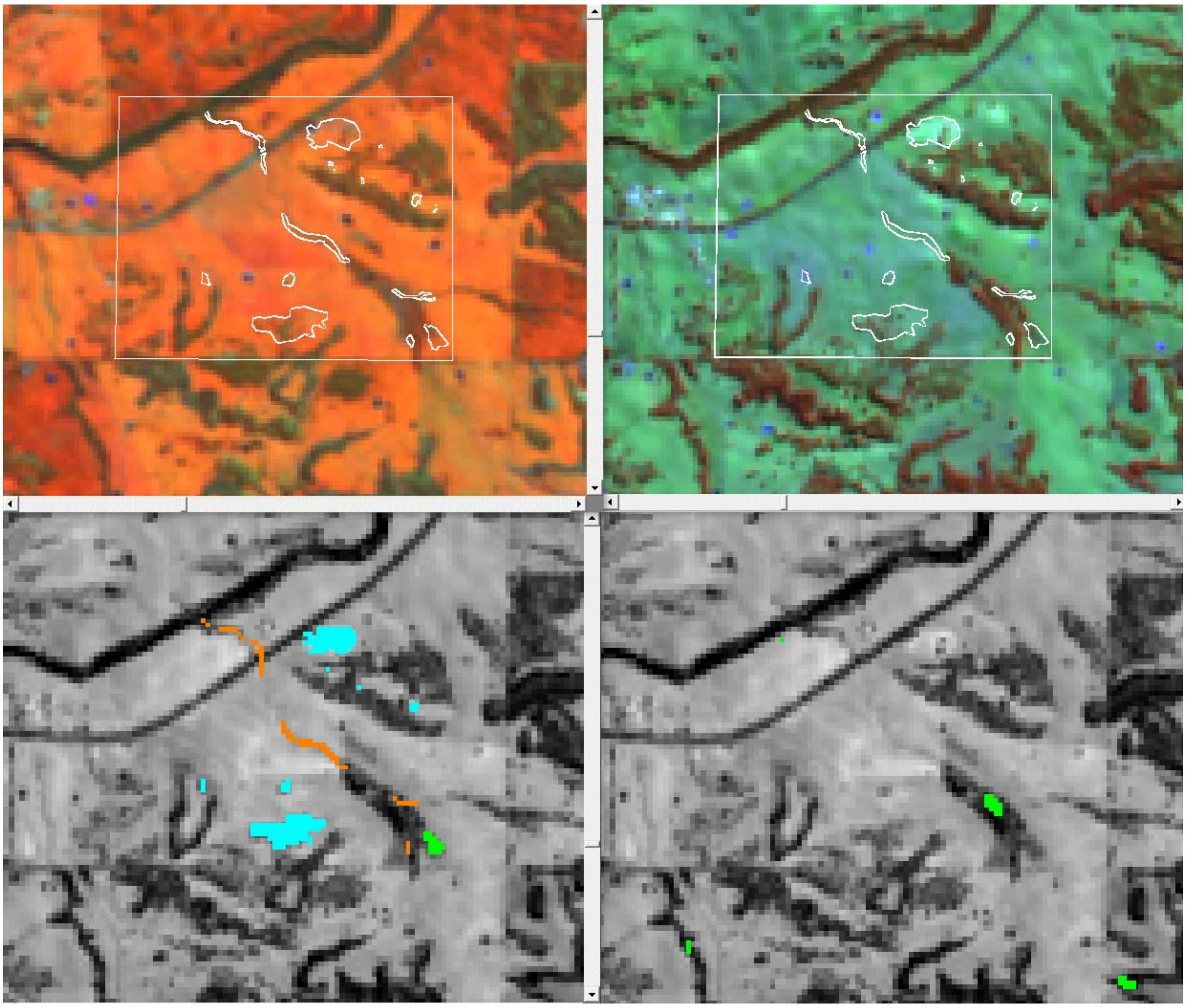
Woodabulling					
	Predicted Label				
		Salt	Not salt	Total count	**Omission Error %**
Ground Truth Label	Bare	0	462	462	**0.0**
	RevSal	1165	2394	3559	**67.3**
	SevSal	190	109	299	**36.5**
	Mod Sal	464	2974	3438	**86.5**
	Non-sal	327	57156	57483	**0.6**
	Total count	2146	63095	65241	
	Commission Error %	**15.2**	**8.7**		**% Overall = 91.1**

East Yornanning:



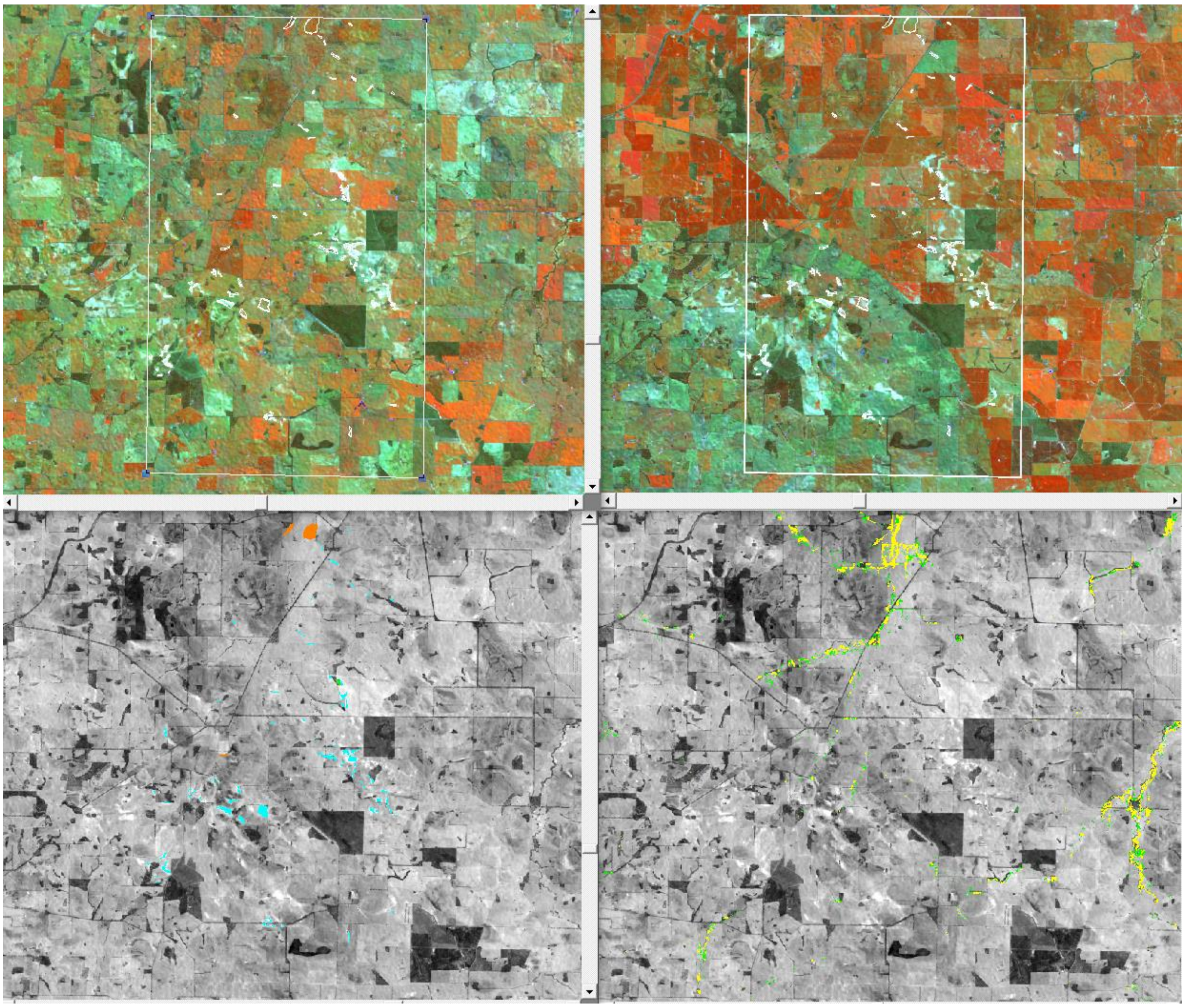
East Yornanning					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	0	1087	1087	**0.0**
	RevSal	188	544	732	**74.3**
	SevSal	414	88	502	**17.5**
	Mod Sal	2261	2079	4340	**47.9**
	Non-sal	862	30741	31603	**2.7**
	Total count	3725	34539	38264	
	Commission Error %	**23.1**	**7.8**		**% Overall = 90.7**

Dwarda:



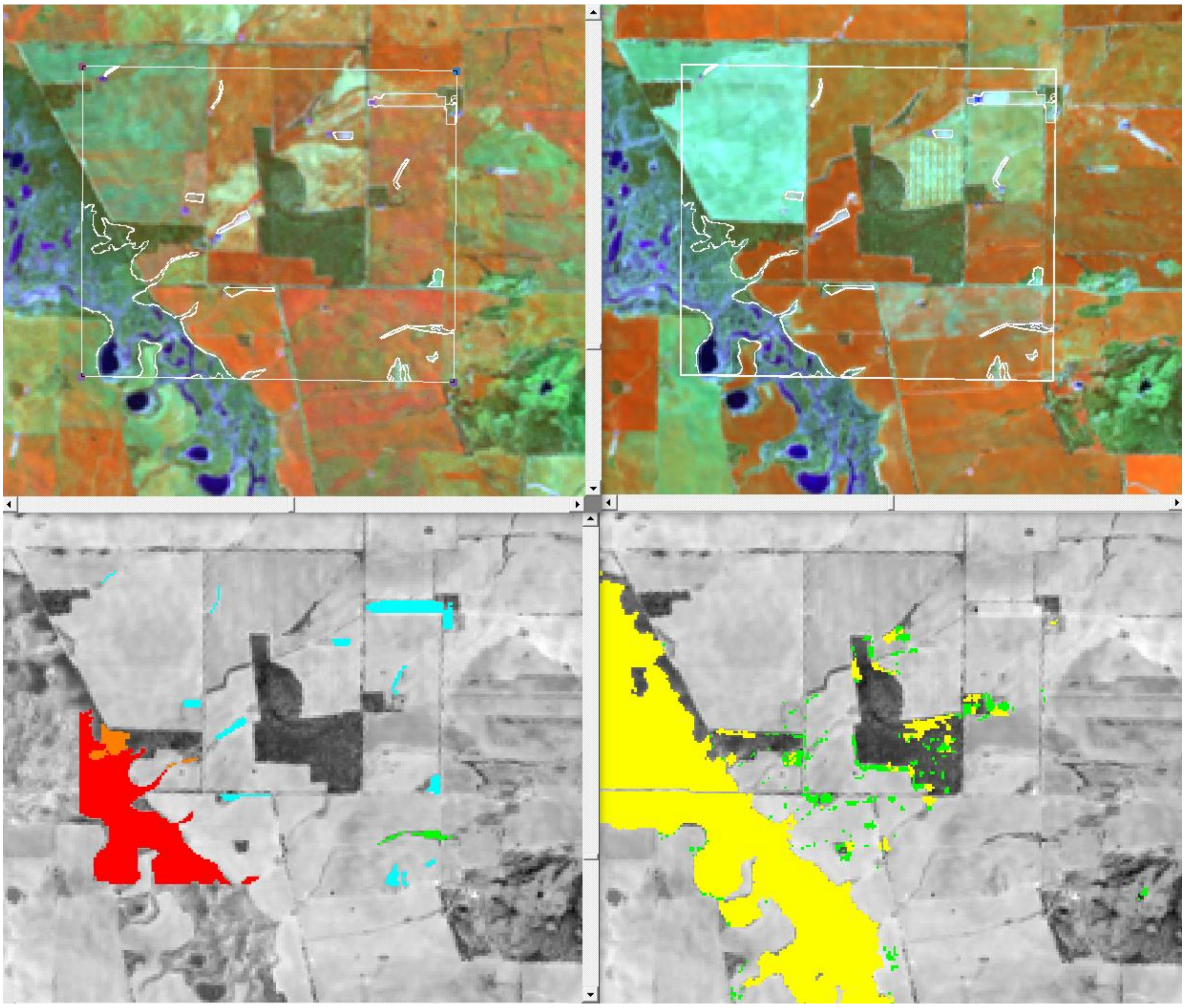
Dwarda					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	0	153	153	**0.0**
	RevSal	0	15	15	**100**
	SevSal	0	0	0	-
	Mod Sal	0	53	53	**100**
	Non-sal	0	4229	4229	**0.0**
	Total count	0	4450	4450	
	Commission Error %	**-**	**1.5**		**% Overall = 98.5**

Kulin:



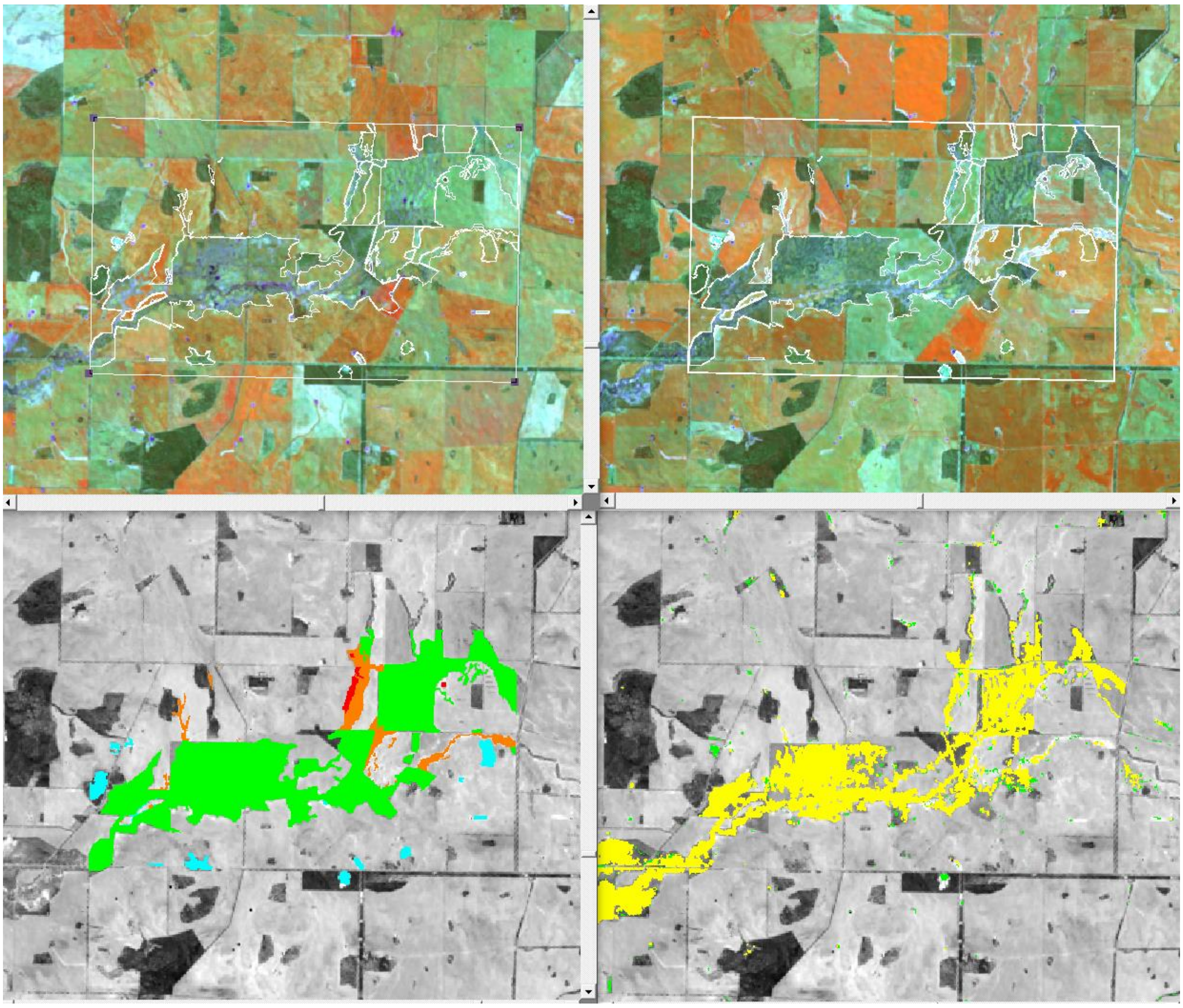
Kulin					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	1	2233	2234	**0.0**
	RevSal	0	39	39	**100**
	SevSal	0	0	0	-
	Mod Sal	54	595	649	**91.7**
	Non-sal	2834	338937	341771	**0.8**
	Total count	2889	341804	344693	
	Commission Error %	**98.1**	**0.2**		**% Overall = 99.0**

Dingo Rocks:



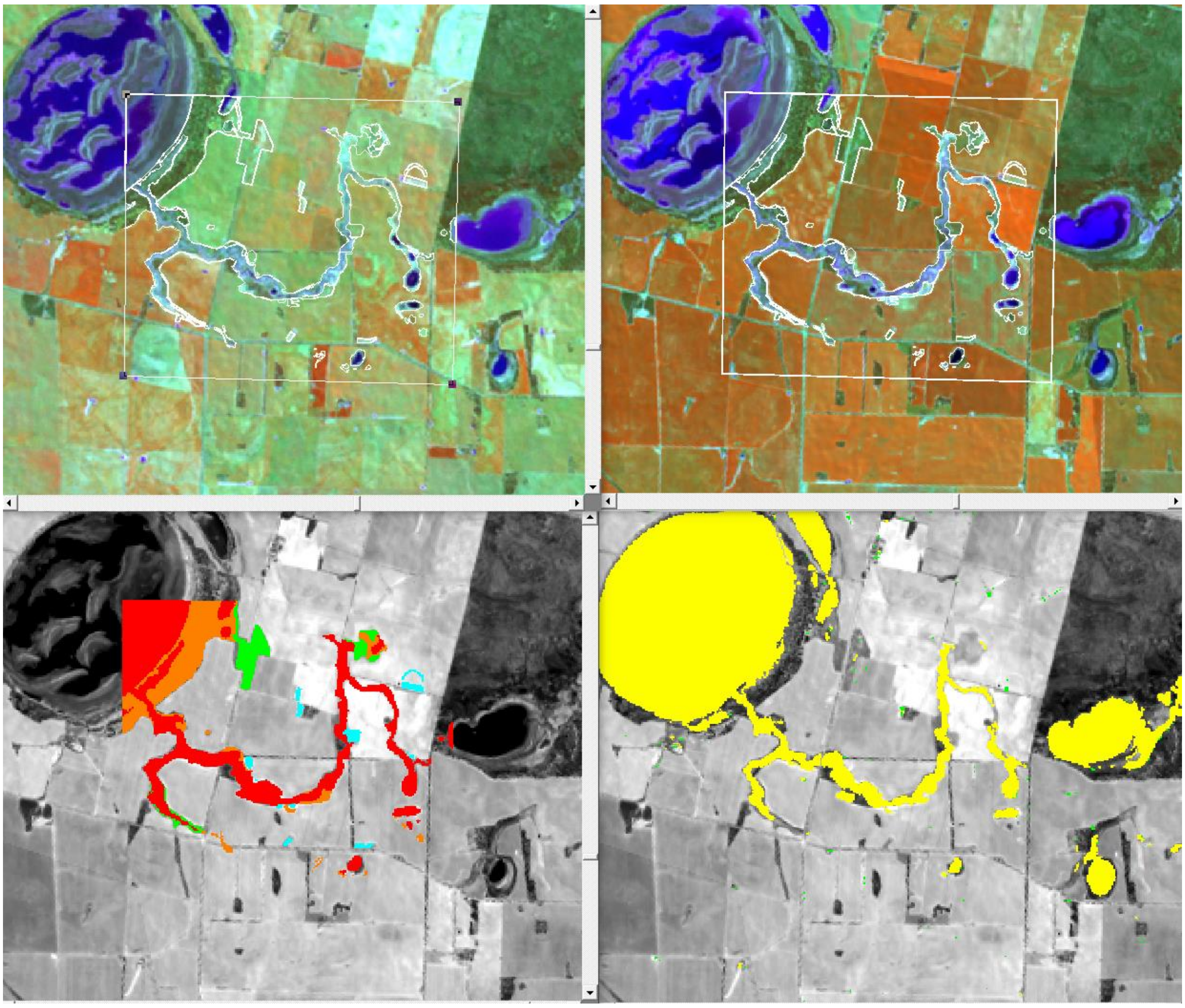
Dingo Rocks					
	Predicted Label				
		Salt	Not salt	Total count	**Omission Error %**
Ground Truth Label	Bare	1	407	408	**0.2**
	RevSal	0	44	44	**100**
	SevSal	1660	99	1759	**5.6**
	Mod Sal	42	86	128	**67.2**
	539	539	16872	17411	**3.1**
	Total count	2242	17508	19750	
	Commission Error %	**24.1**	**1.3**		**% Overall = 96.1**

Newdegate:



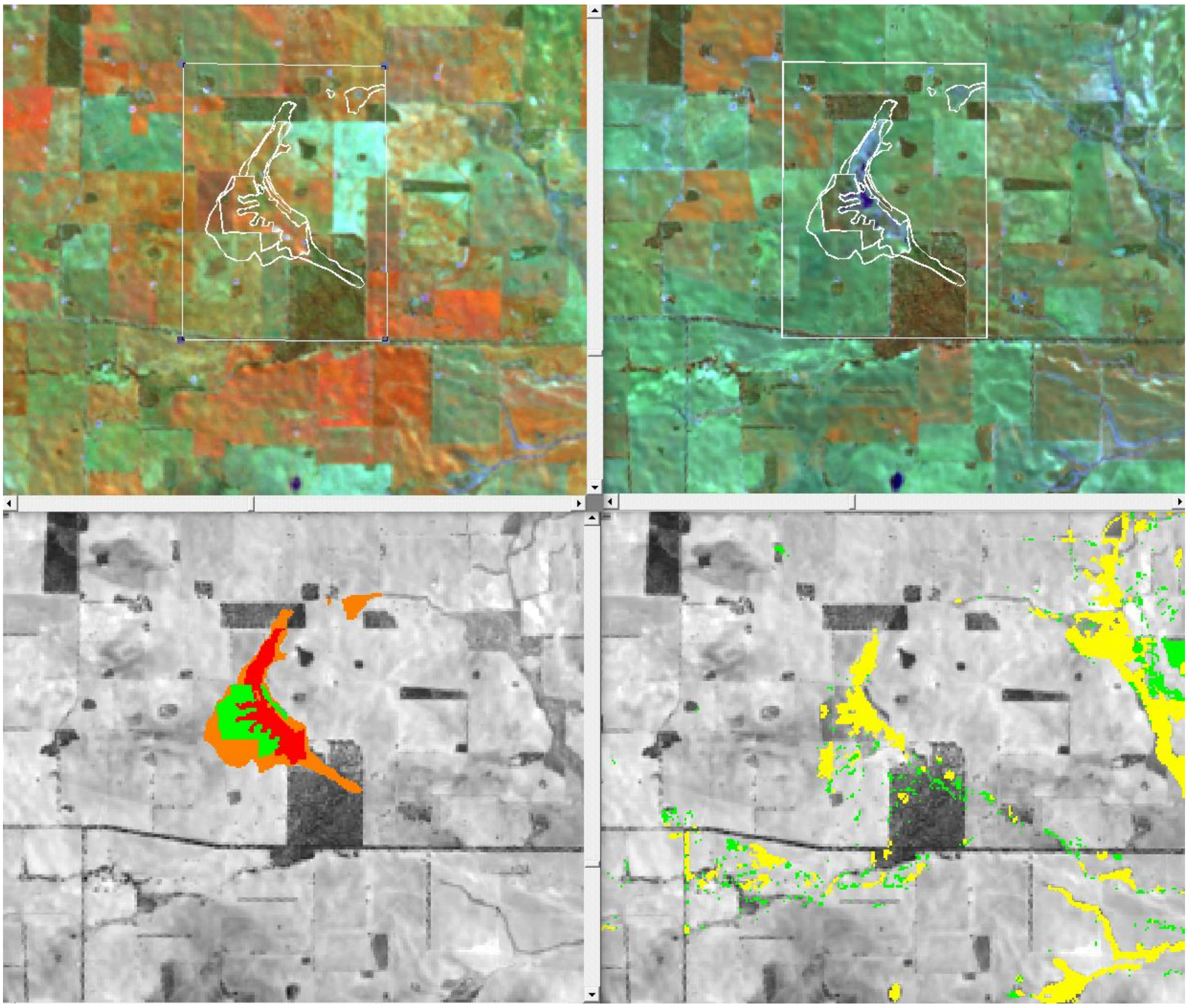
Newdegate					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	24	1068	1092	**2.2**
	RevSal	11134	5515	16649	**33.1**
	SevSal	133	71	204	**34.8**
	Mod Sal	757	1006	1763	**57.1**
	Non-sal	476	56154	56630	**0.8**
	Total count	12524	63814	76338	
	Commission Error %	**4.0**	**10.3**		**% Overall = 90.7**

Kathleen:



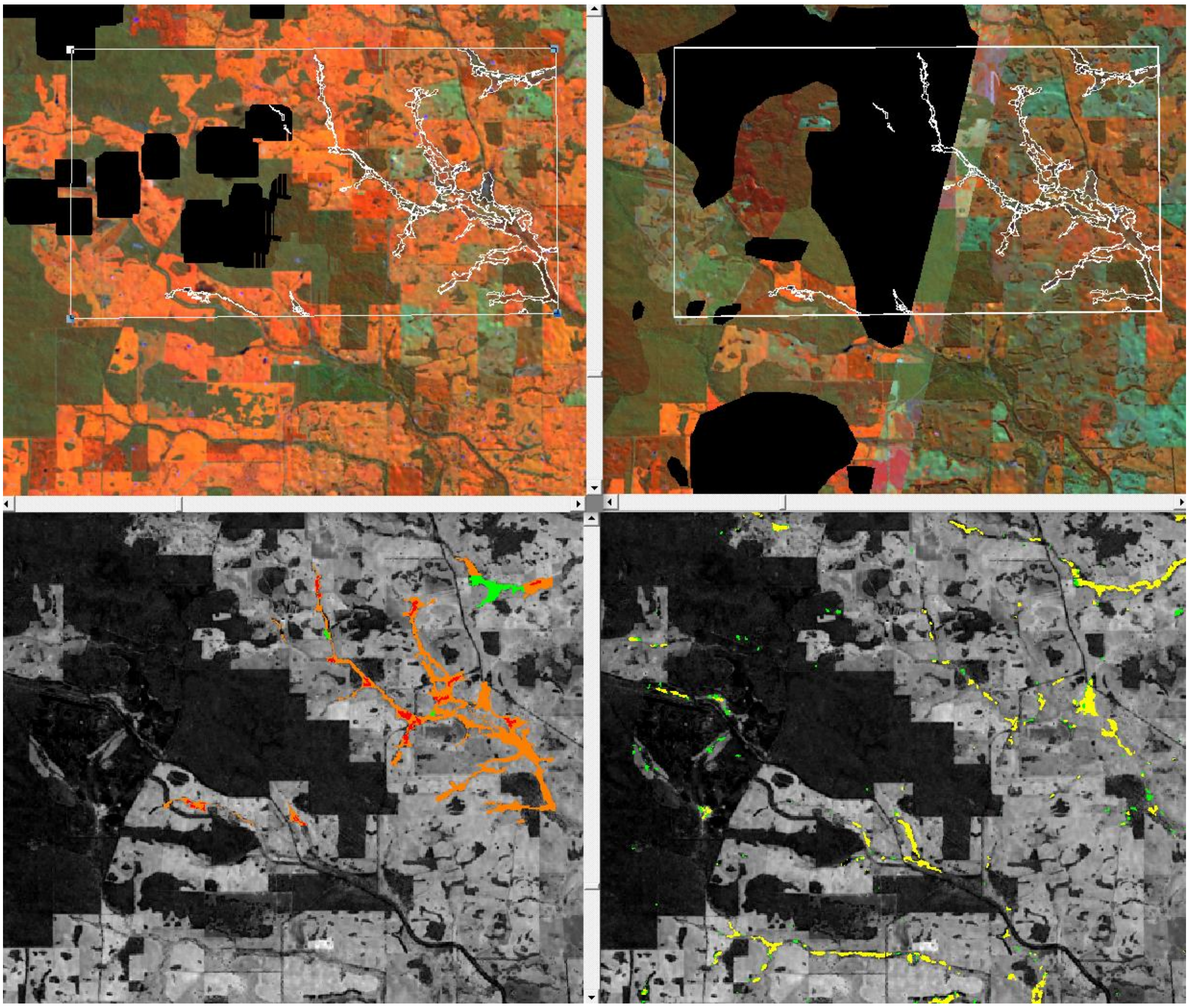
Kathleen					
	Predicted Label				
		Salt	Not salt	Total count	**Omission Error %**
Ground Truth Label	Bare	26	301	327	**8.0**
	RevSal	8	758	766	**99.0**
	SevSal	4563	789	5352	**14.7**
	Mod Sal	238	1860	2098	**88.7**
	Non-sal	159	30084	30243	**0.5**
	Total count	4994	33792	38786	
	Commission Error %	**3.7**	**10.1**		**% Overall = 90.7**

Moulyinning:



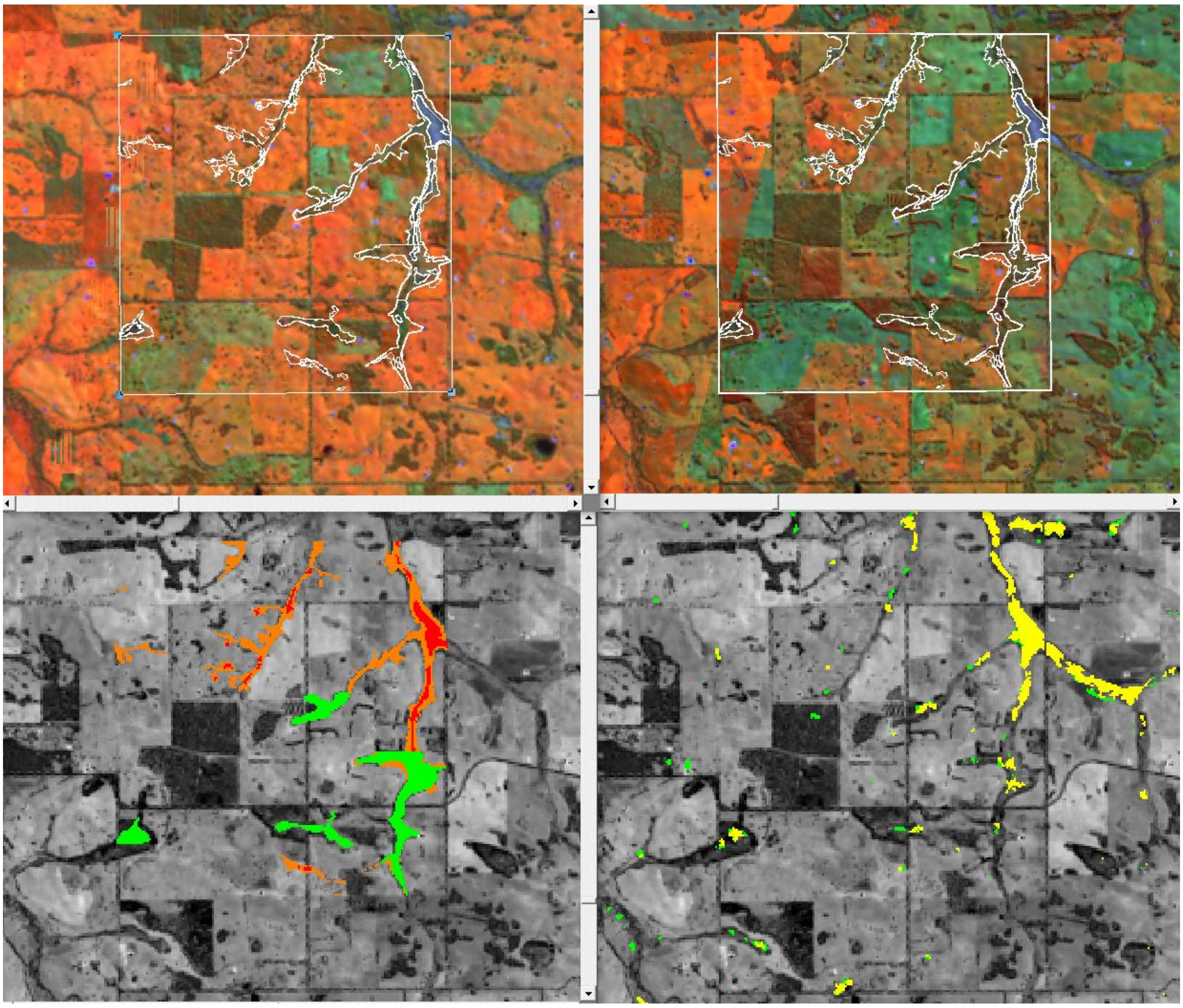
Moulyinning					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	0	0	0	-
	RevSal	88	411	499	**82.4**
	SevSal	431	193	624	**30.9**
	Mod Sal	105	882	987	**89.4**
	Non-sal	101	10697	10798	**0.9**
	Total count	725	12183	12908	
	Commission Error %	**13.9**	**12.2**		**% Overall = 87.7**

Bowelling:



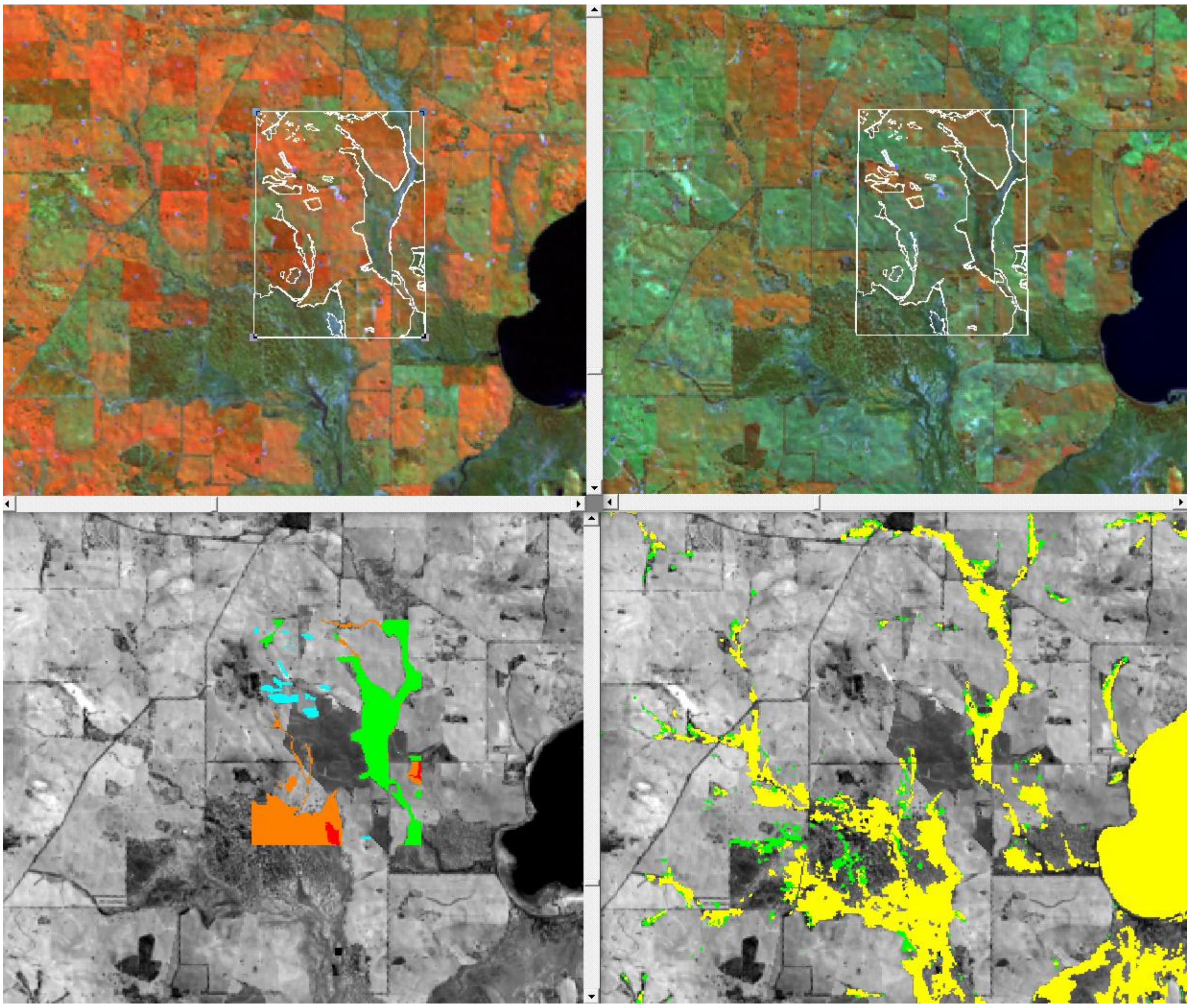
Bowelling					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	0	0	0	-
	RevSal	233	253	486	**52.1**
	SevSal	196	315	511	**61.6**
	Mod Sal	792	4204	4996	**84.1**
	Non-sal	298	106794	107092	**0.3**
	Total count	1519	111566	113085	
	Commission Error %	**19.6**	**4.3**		**% Overall = 95.5**

Dinninup:



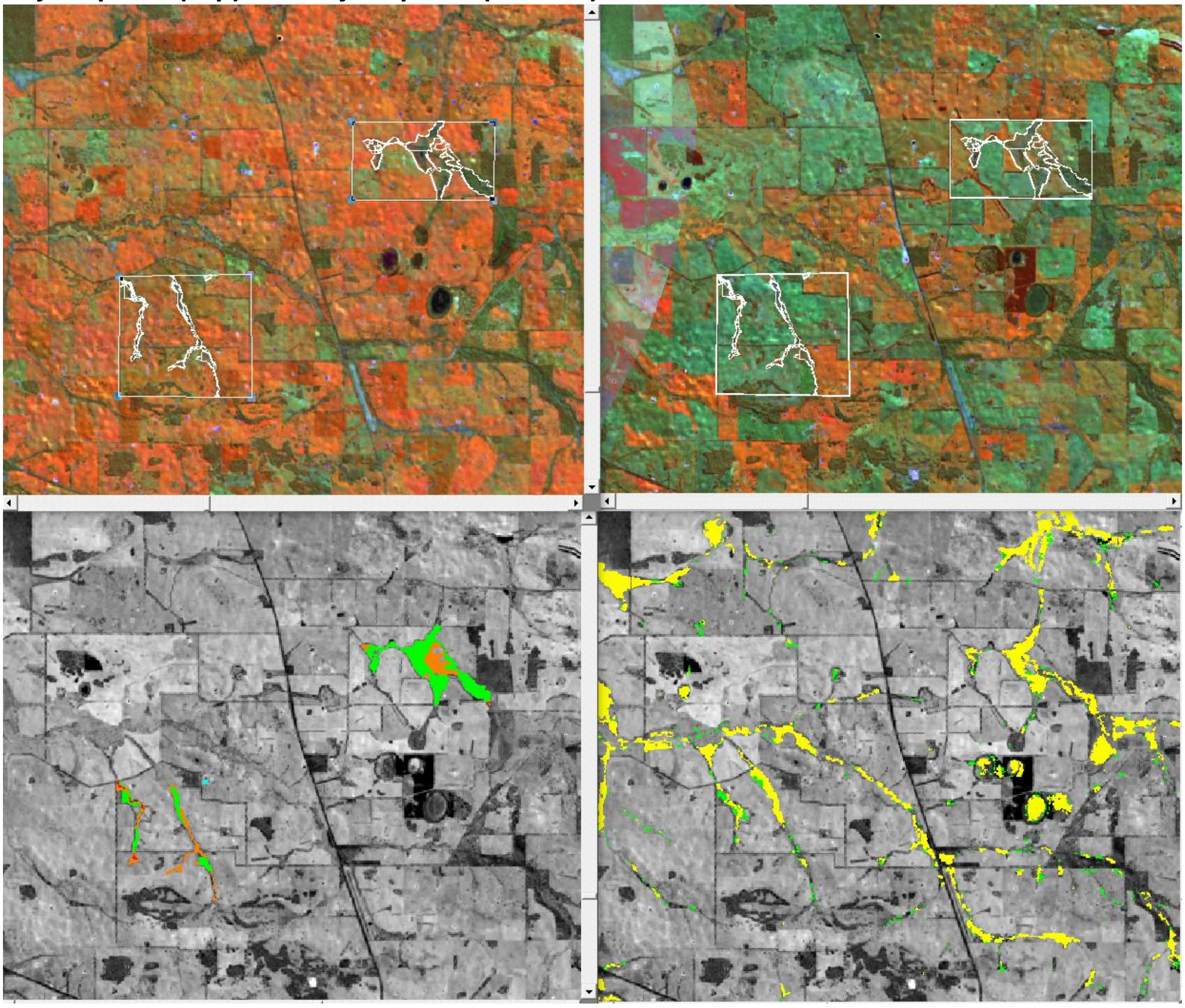
Dinninup					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	0	0	0	-
	RevSal	149	1082	1231	**87.9**
	SevSal	255	108	363	**29.8**
	Mod Sal	246	1319	1565	**84.3**
	Non-sal	84	29413	29497	**0.3**
	Total count	734	31922	32656	
	Commission Error %	**11.4**	**7.9**		**% Overall = 92.1**

Queerfellows – Chain Gulley:



Queerfellows – Chain Gulley					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	0	395	395	**0.0**
	RevSal	1227	1324	2551	**51.9**
	SevSal	101	35	136	**25.7**
	Mod Sal	988	1078	2066	**52.2**
	Non-sal	203	13179	13382	**1.5**
	Total count	2519	16011	18530	
	Commission Error %	**8.1**	**15.2**		**% Overall = 85.8**

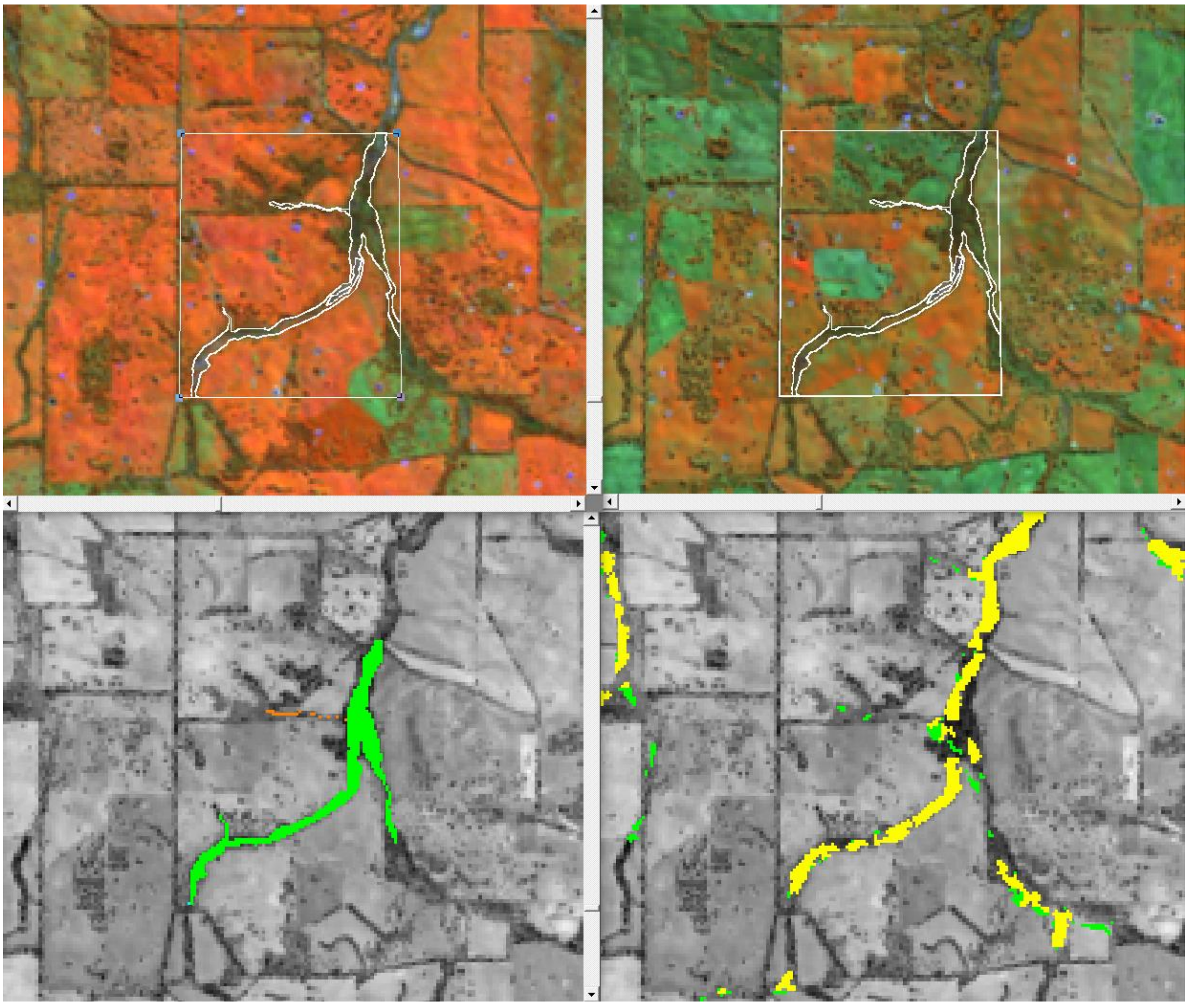
Kojonup Nth (top) and Kojonup NW (bottom):



Kojonup Nth					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	0	0	0	-
	RevSal	851	661	1512	**43.7**
	SevSal	1	2	3	**66.7**
	Mod Sal	108	294	402	**73.1**
	Non-sal	27	6445	6472	**0.4**
	Total count	987	7402	8389	
	Commission Error %	**2.7**	**12.9**		**% Overall = 88.3**
Kojonup NW					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	0	15	15	**0.0**
	RevSal	176	192	368	**52.2**
	SevSal	23	19	42	**45.2**
	Mod Sal	87	306	393	**77.9**

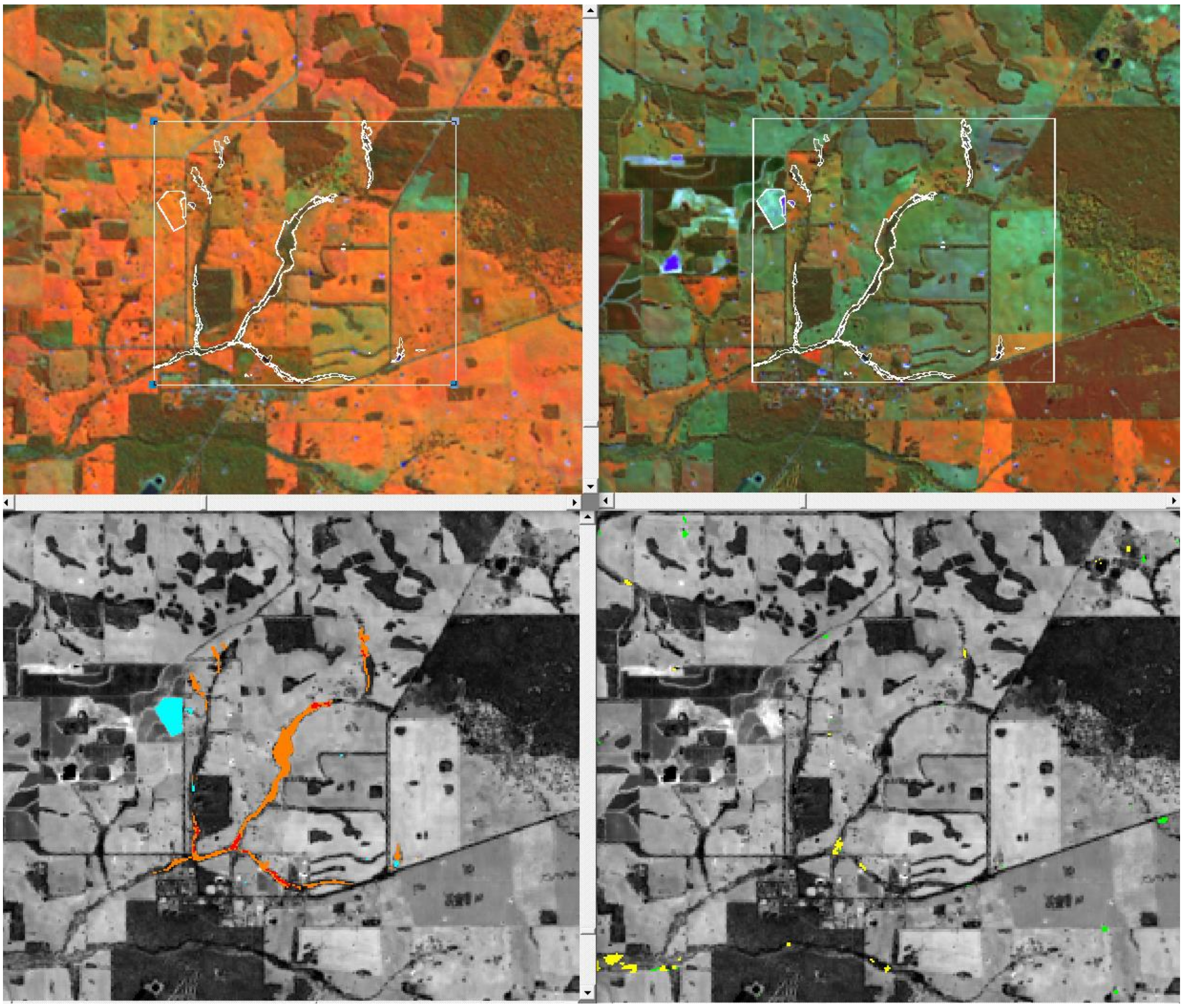
	Non-sal	107	11215	11322	**0.9**
	Total count	393	11747	12140	
	Commission Error %	**27.2**	**4.4**		**% Overall = 94.9**

Byenup Hill:



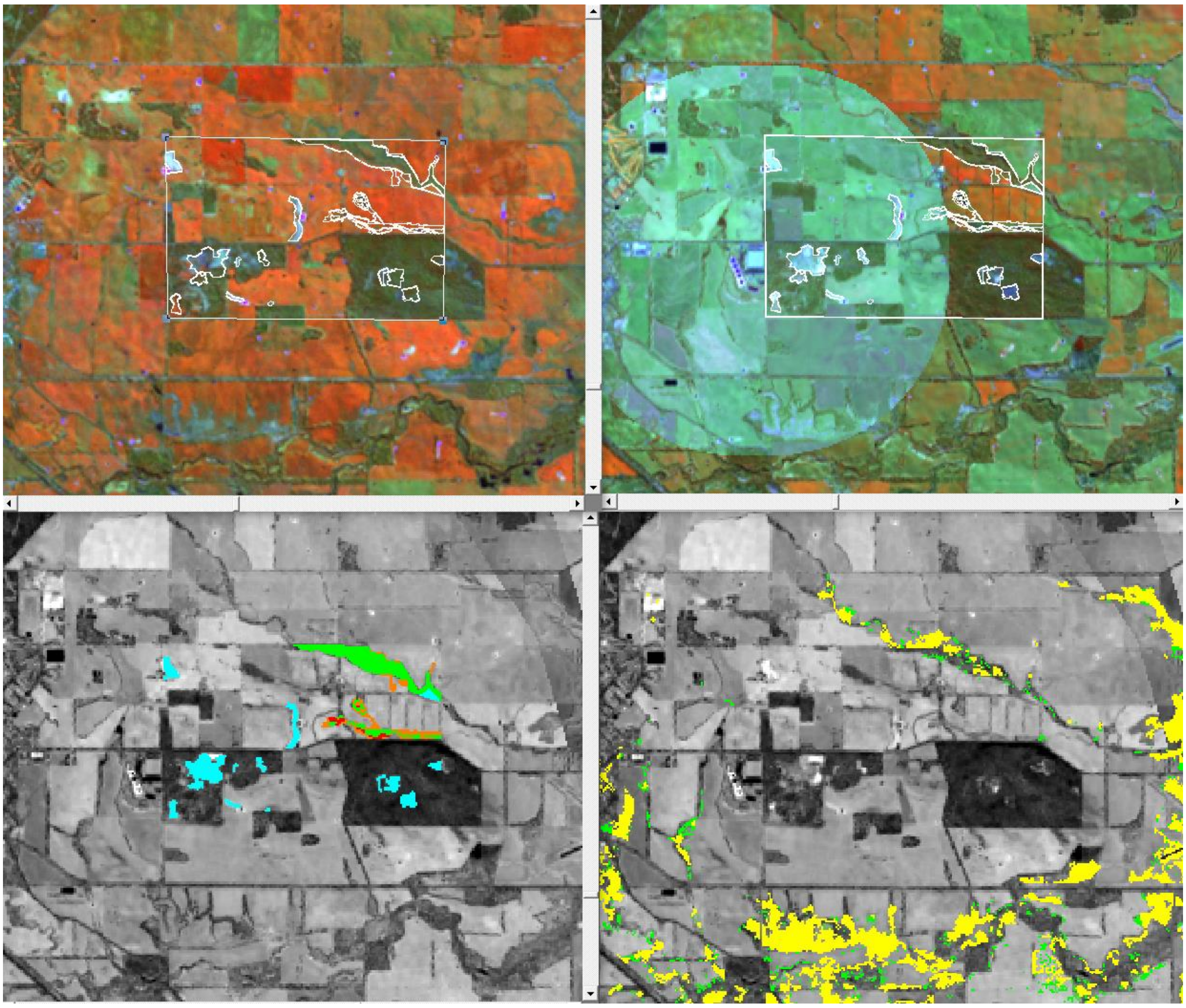
Byenup Hill					
	Predicted Label				
		Salt	Not salt	Total count	**Omission Error %**
Ground Truth Label	Bare	0	1	1	**0.0**
	RevSal	309	294	603	**48.8**
	SevSal	0	0	0	-
	Mod Sal	1	18	19	**94.7**
	Non-sal	127	6088	6215	**2.0**
	Total count	437	6401	6838	
	Commission Error %	**29.1**	**4.9**		**% Overall = 93.6**

Frankland:



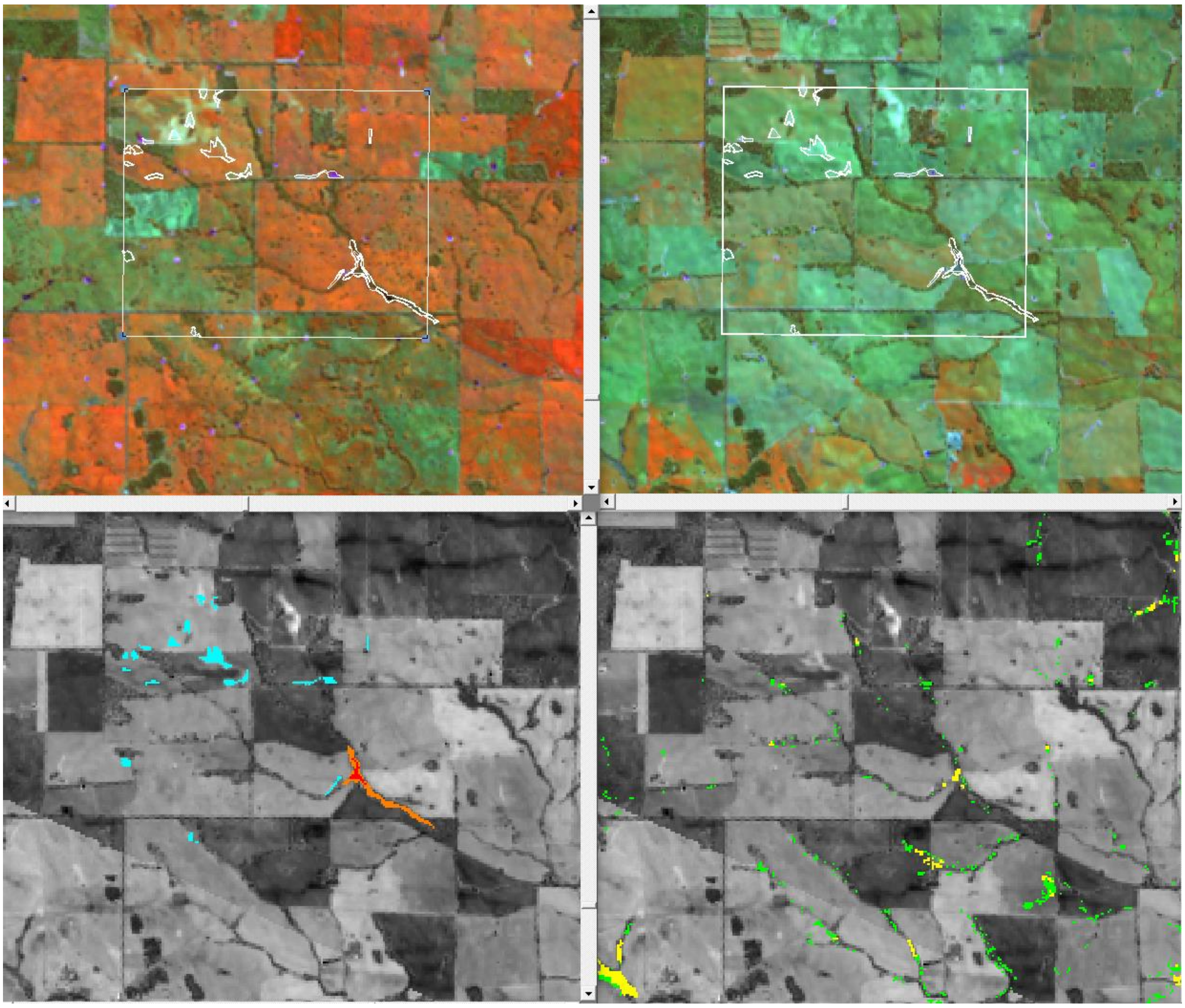
Frankland					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	1	279	280	**0.4**
	RevSal	0	0	0	-
	SevSal	15	73	88	**83.0**
	Mod Sal	16	790	806	**98.0**
	Non-sal	15	24290	24305	**0.1**
	Total count	47	25432	25479	
	Commission Error %	**34.0**	**3.4**		**% Overall = 96.6**

Katanning:



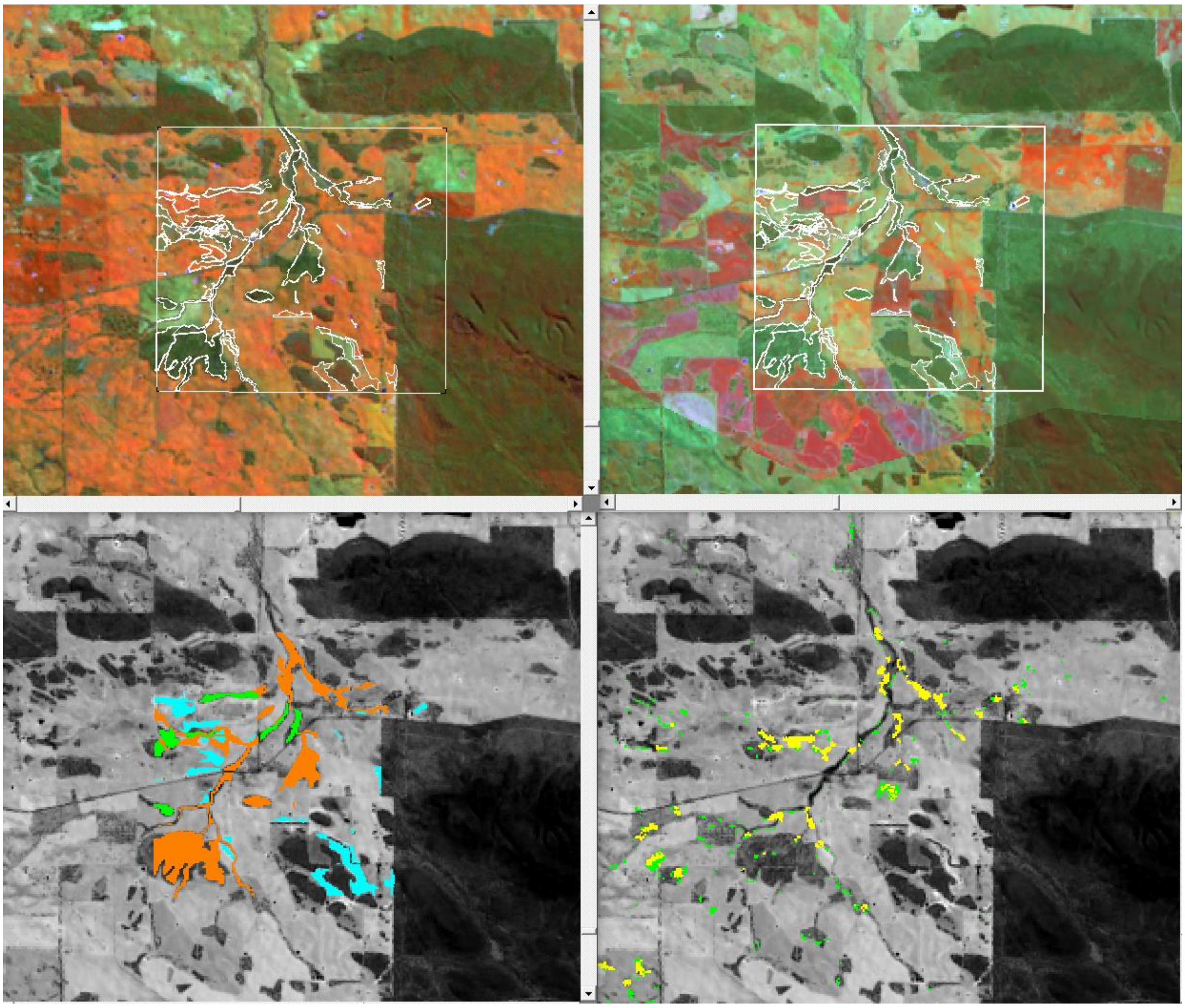
Katanning					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	0	682	682	**0.0**
	RevSal	97	566	663	**85.4**
	SevSal	0	48	48	**100**
	Mod Sal	1	251	252	**99.6**
	Non-sal	2	12945	12947	**0.0**
	Total count	100	14492	14592	
	Commission Error %	**2.0**	**6.0**		**% Overall = 94.1**

Broomhill:



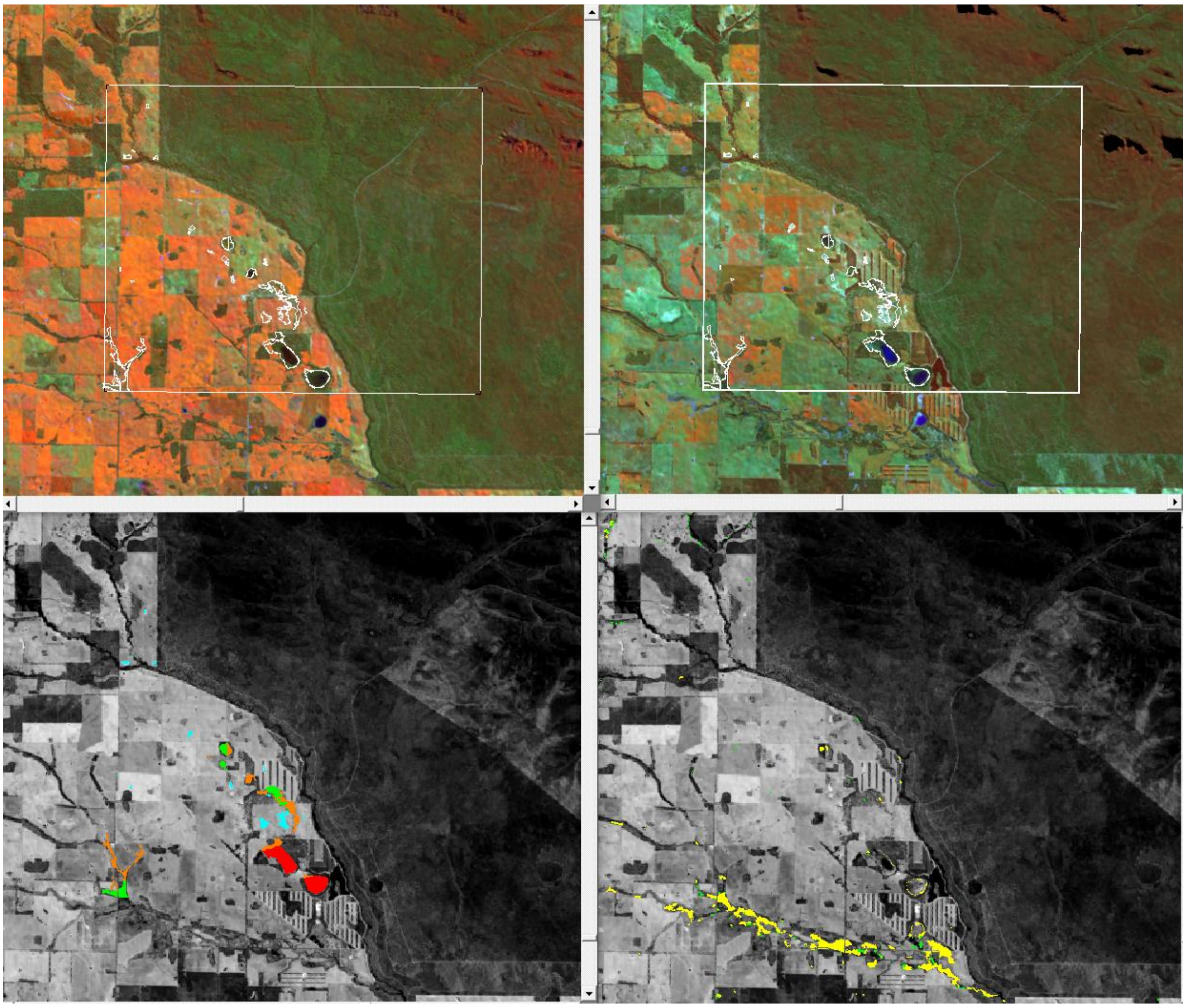
Broomhill					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	0	275	275	**0.0**
	RevSal	0	0	0	-
	SevSal	14	12	26	**46.2**
	Mod Sal	6	125	131	**95.4**
	Non-sal	13	17136	17149	**0.1**
	Total count	33	17548	17581	
	Commission Error %	**39.4**	**0.8**		**% Overall = 99.1**

Cranbrook:



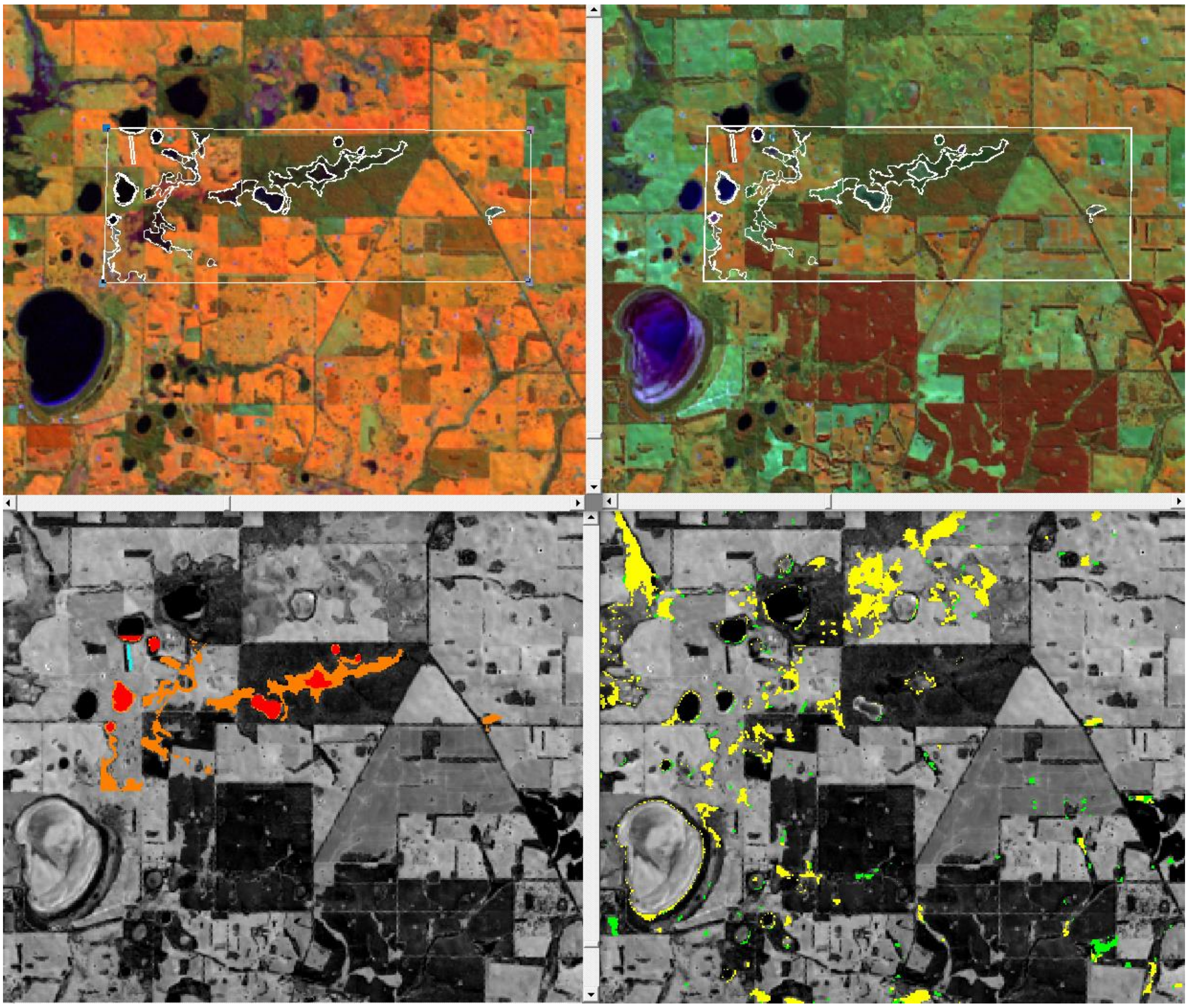
Cranbrook					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	5	1081	1086	**0.5**
	RevSal	87	354	441	**80.3**
	SevSal	0	0	0	-
	Mod Sal	310	2253	2563	**87.9**
	Non-sal	280	23958	24238	**1.2**
	Total count	682	27646	28328	
	Commission Error %	**41.8**	**9.4**		**% Overall = 89.8**

Kendenup:



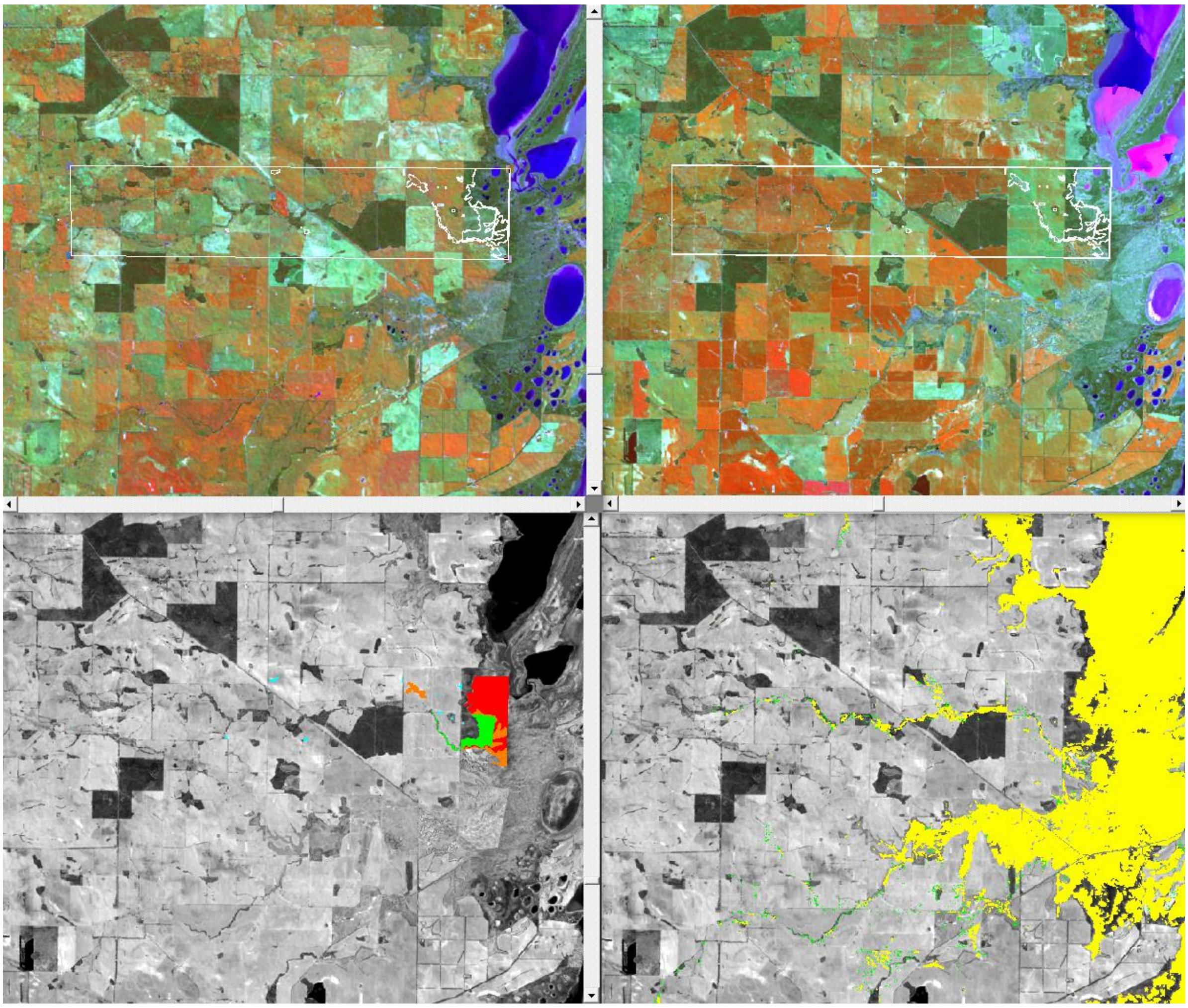
Kendenup					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	0	309	309	**0.0**
	RevSal	92	305	397	**76.8**
	SevSal	42	718	760	**94.5**
	Mod Sal	20	731	751	**97.3**
	Non-sal	30	114713	114743	**0.0**
	Total count	184	116776	116960	
	Commission Error %	**16.3**	**1.5**		**% Overall = 98.5**

Wamballup:



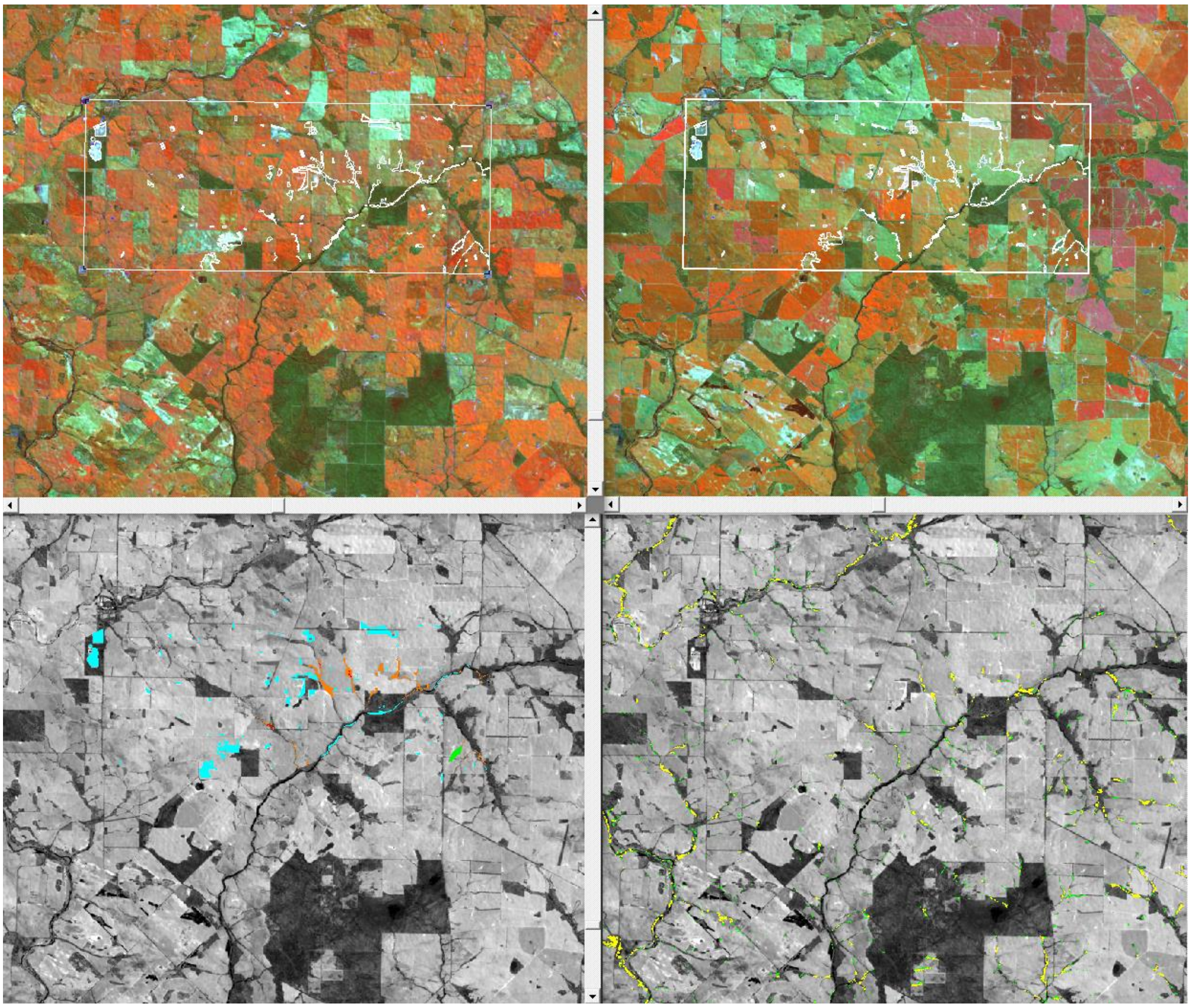
Wamballup					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	0	34	34	**0.0**
	RevSal	0	0	0	**-**
	SevSal	18	598	616	**97.1**
	Mod Sal	450	1653	2103	**78.6**
	Non-sal	229	25248	25477	**0.9**
	Total count	697	27533	28230	
	Commission Error %	**32.9**	**8.2**		**% Overall = 91.2**

Merilup:



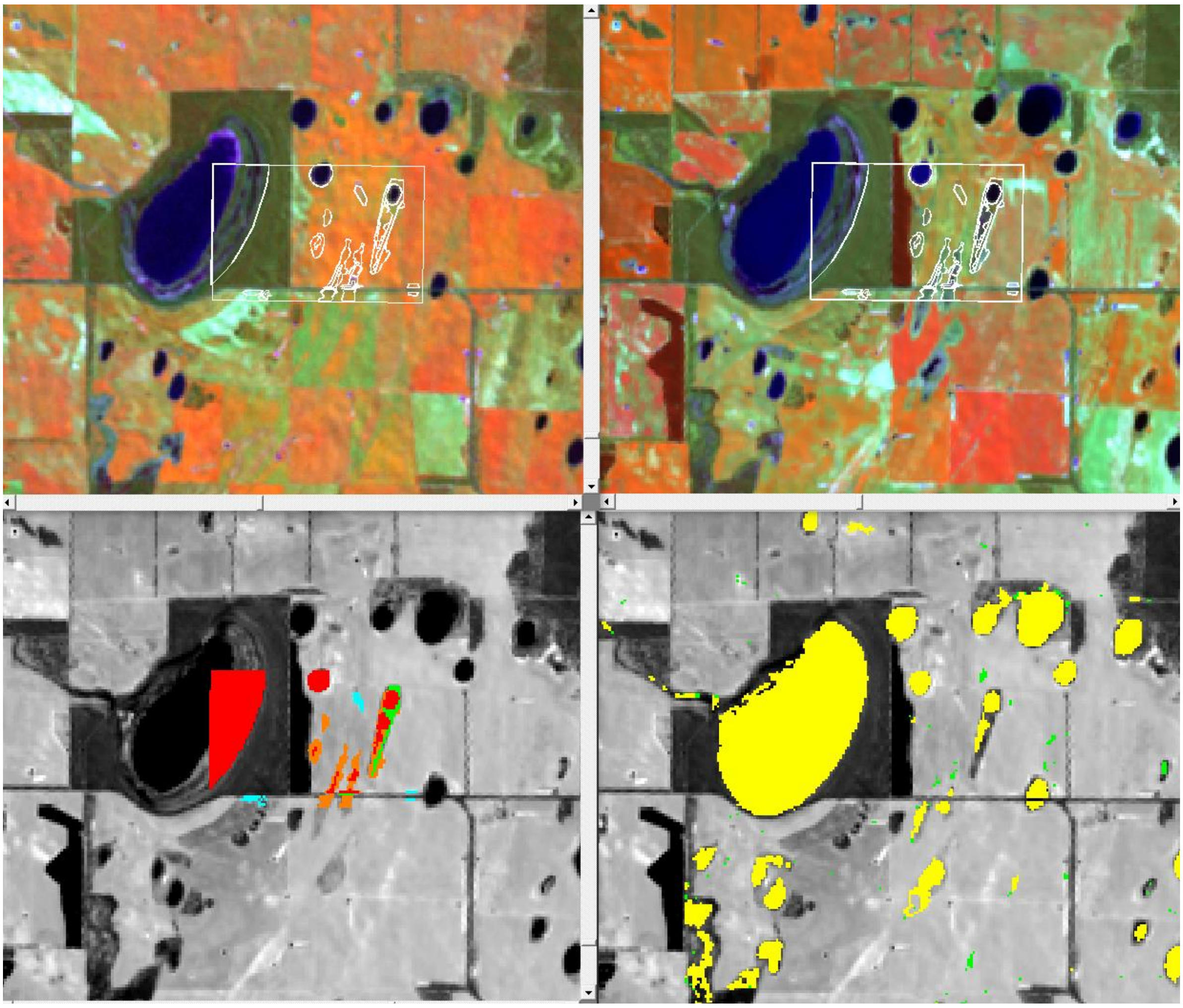
Merilup					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	4	180	184	**2.2**
	RevSal	751	650	1401	**46.4**
	SevSal	2835	707	3542	**20.0**
	Mod Sal	295	951	1246	**76.3**
	Non-sal	2473	69311	71784	**3.4**
	Total count	6358	71799	78157	
	Commission Error %	**39.0**	**3.2**		**% Overall = 93.9**

Borden:



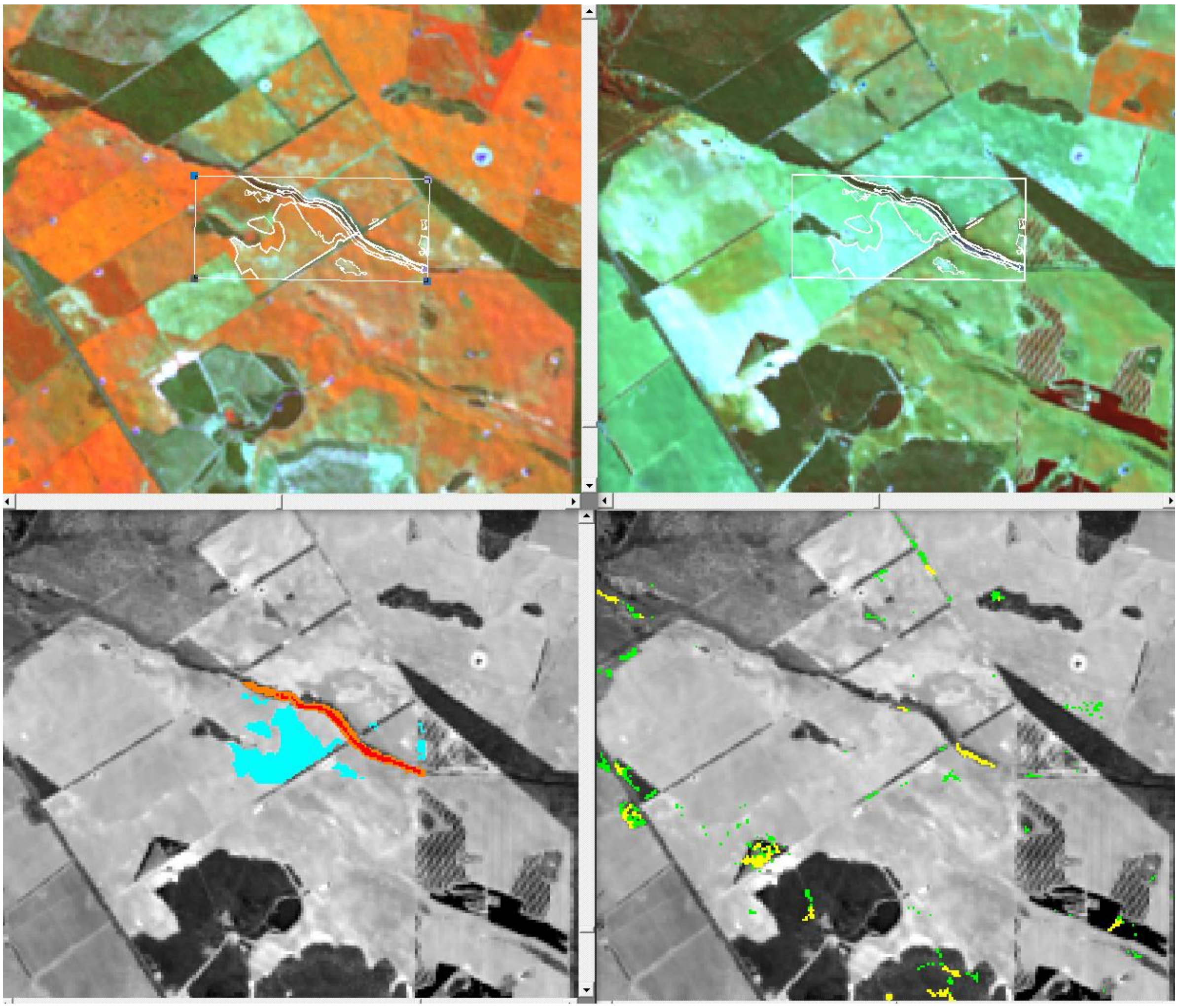
Borden					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	80	4239	4319	**1.9**
	RevSal	27	176	203	**86.7**
	SevSal	51	7	58	**12.1**
	Mod Sal	317	1029	1346	**76.4**
	Non-sal	397	176113	176510	**0.2**
	Total count	872	181564	182436	
	Commission Error %	**54.7**	**0.7**		**% Overall = 99.1**

Chillinup:



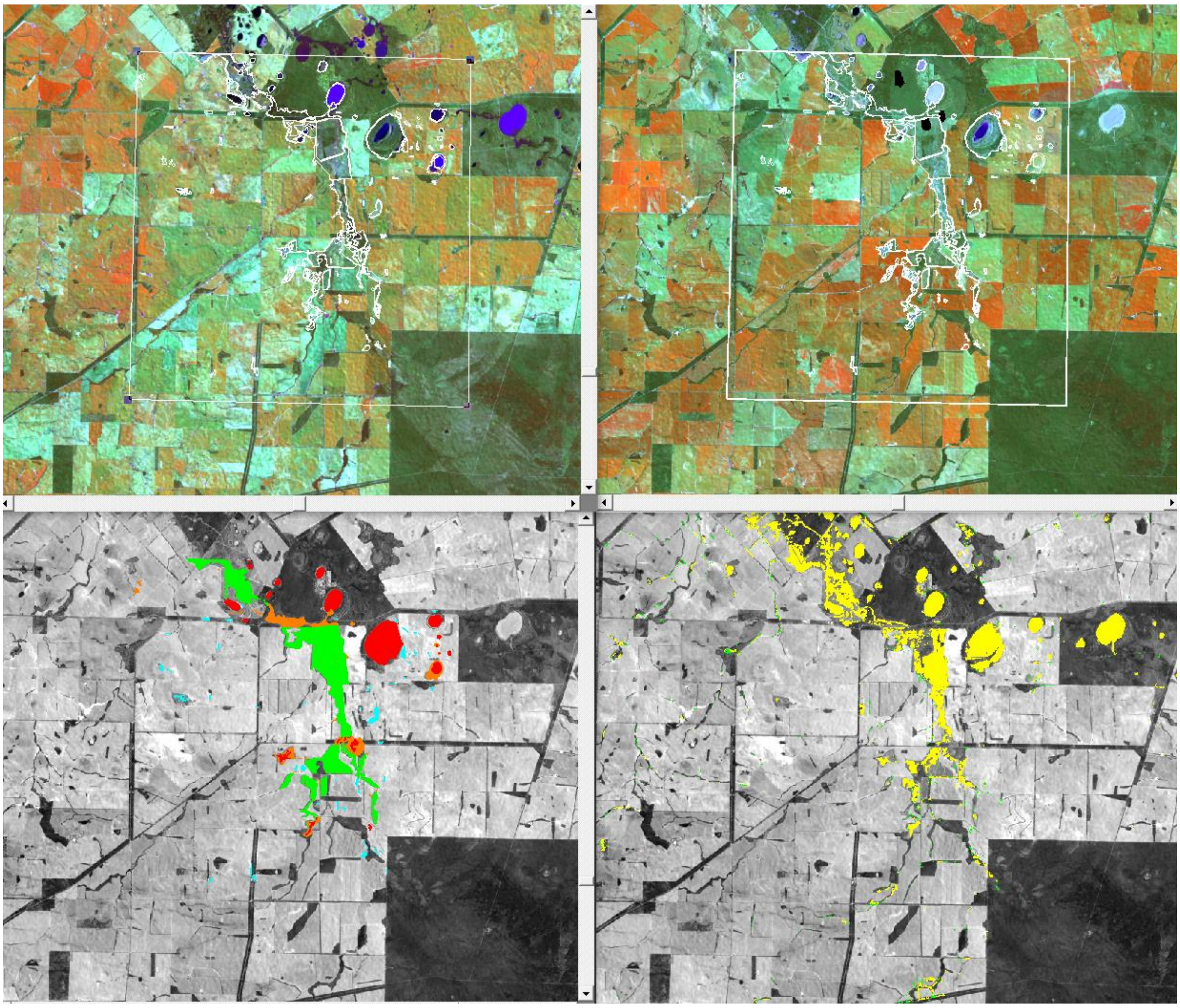
Chillinup					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	0	52	52	**0.0**
	RevSal	3	68	71	**95.8**
	SevSal	883	58	941	**6.2**
	Mod Sal	35	221	256	**86.3**
	Non-sal	41	3402	3443	**1.2**
	Total count	962	3801	4763	
	Commission Error %	**4.3**	**9.1**		**% Overall = 91.9**

Mailalup:



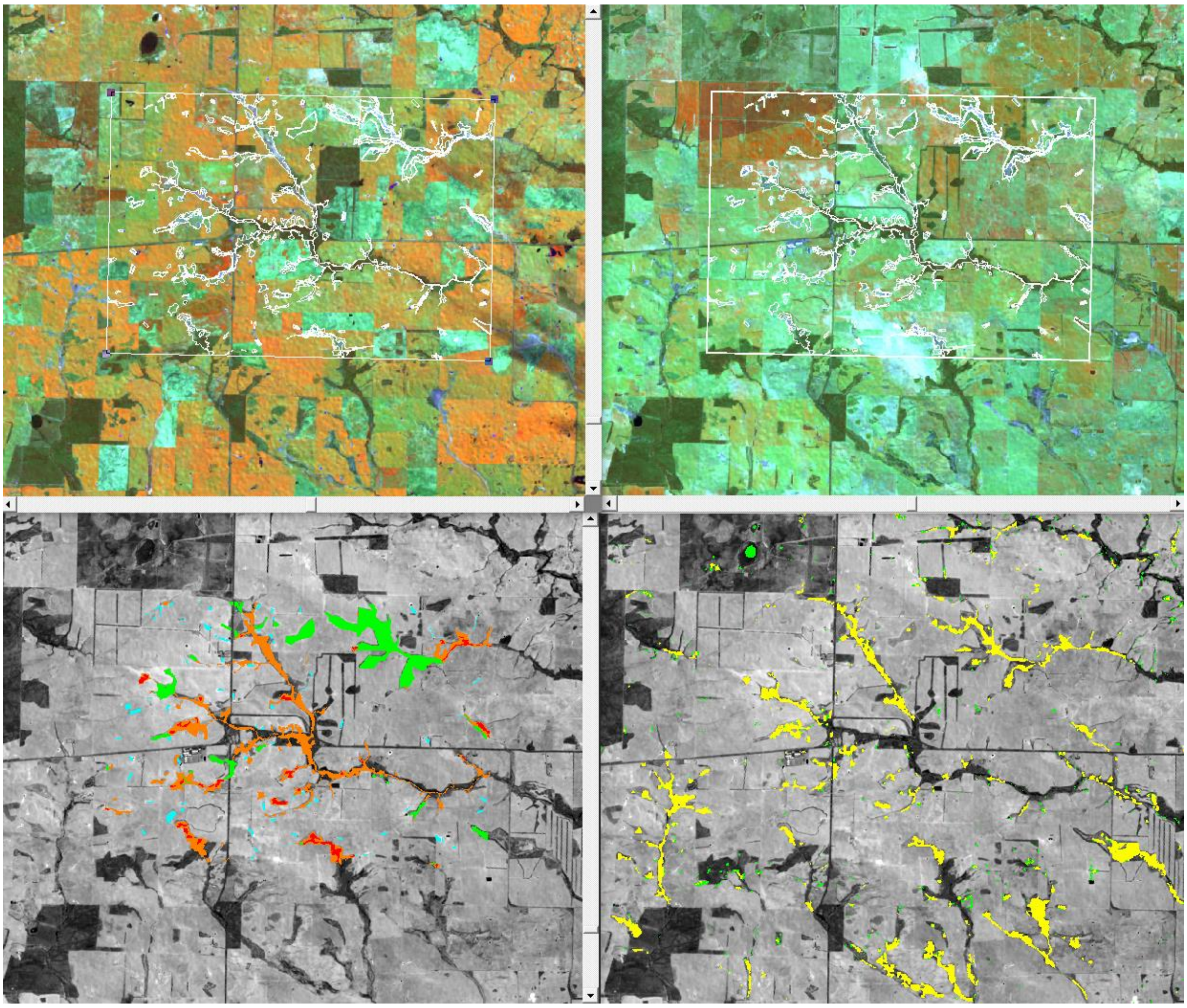
Mailalup					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	0	756	756	**0.0**
	RevSal	0	0	0	-
	SevSal	32	74	106	**69.8**
	Mod Sal	5	196	201	**97.5**
	Non-sal	0	2955	2955	**0.0**
	Total count	37	3981	4018	
	Commission Error %	**0.0**	**6.8**		**% Overall = 93.3**

Pingrup (Lake Bryde):



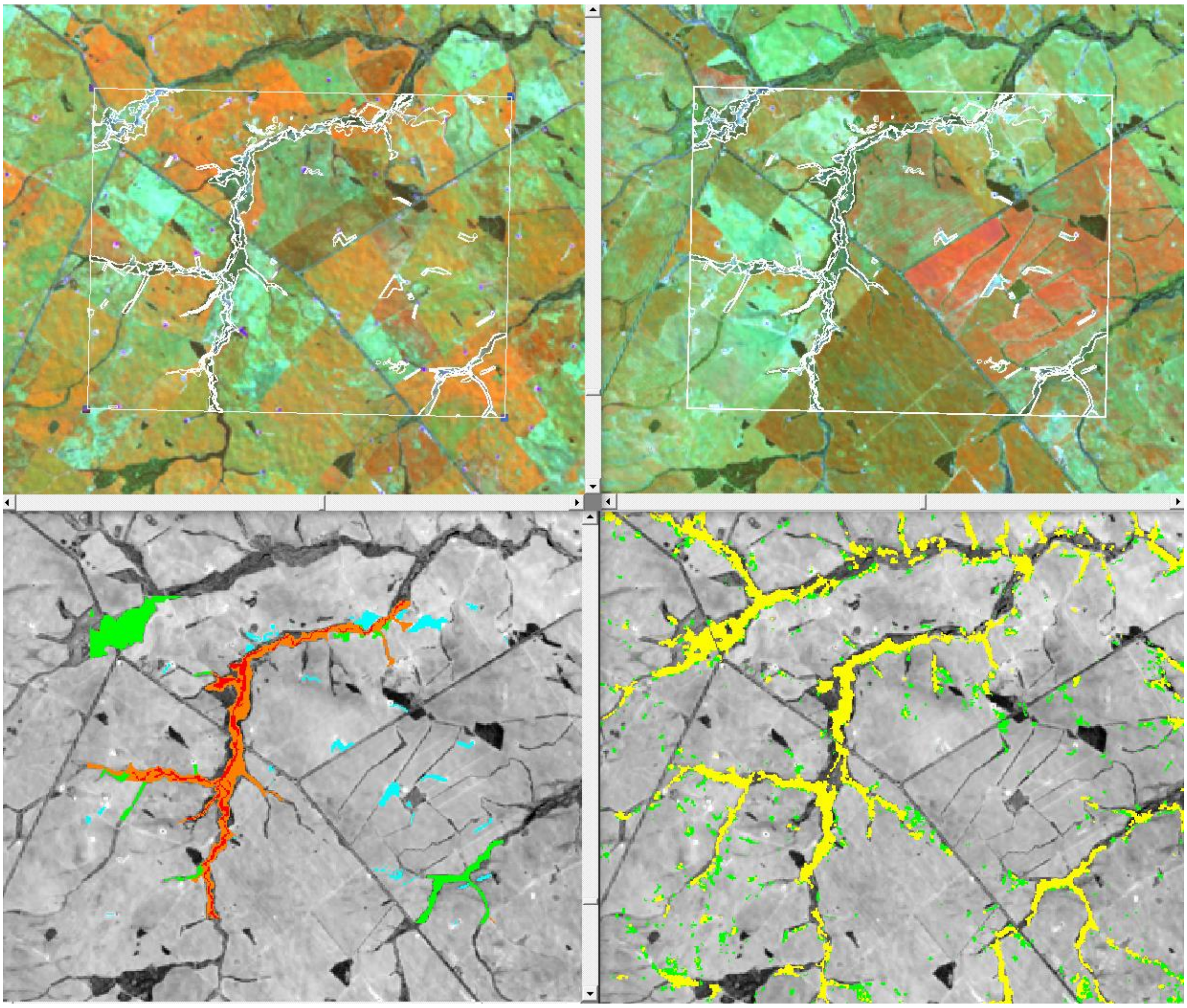
Pingrup (Lake Bryde)					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	98	1603	1701	**5.8**
	RevSal	8643	5930	14573	**40.7**
	SevSal	5168	1053	6221	**16.9**
	Mod Sal	828	2732	3560	**76.7**
	Non-sal	3076	293486	296562	**1.0**
	Total count	17813	304804	322617	
	Commission Error %	**17.8**	**3.2**		**% Overall = 96.0**

Bremer River:



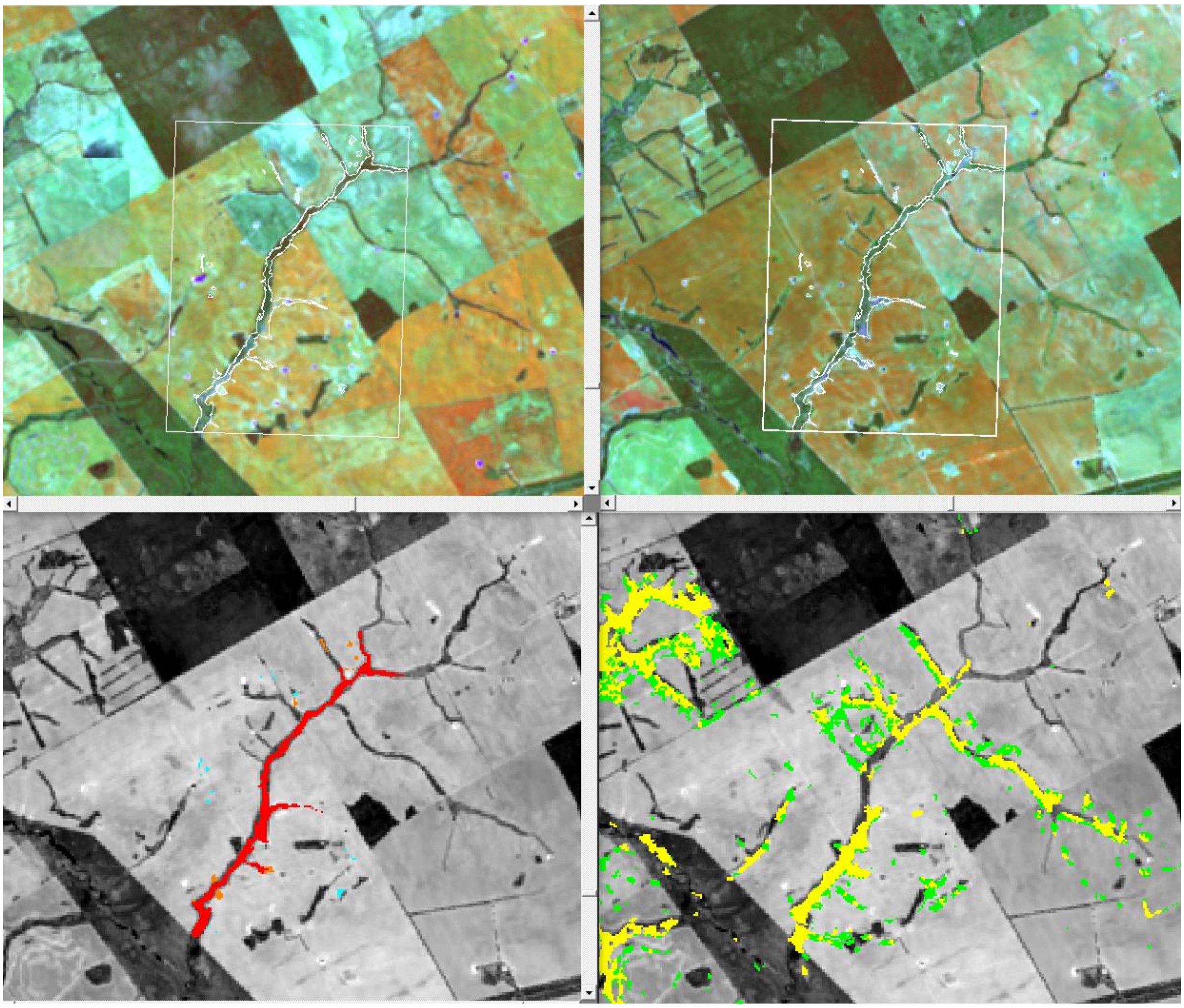
Bremer River					
	Predicted Label				
		Salt	Not salt	Total count	**Omission Error %**
Ground Truth Label	Bare	28	1590	1618	**1.7**
	RevSal	2353	3996	6349	**62.9**
	SevSal	1181	146	1327	**11.0**
	Mod Sal	3305	6066	9371	**64.7**
	Non-sal	743	161586	162329	**0.5**
	Total count	7610	173384	180994	
	Commission Error %	**10.1**	**5.9**		**% Overall = 93.9**

Fitzgerald River:



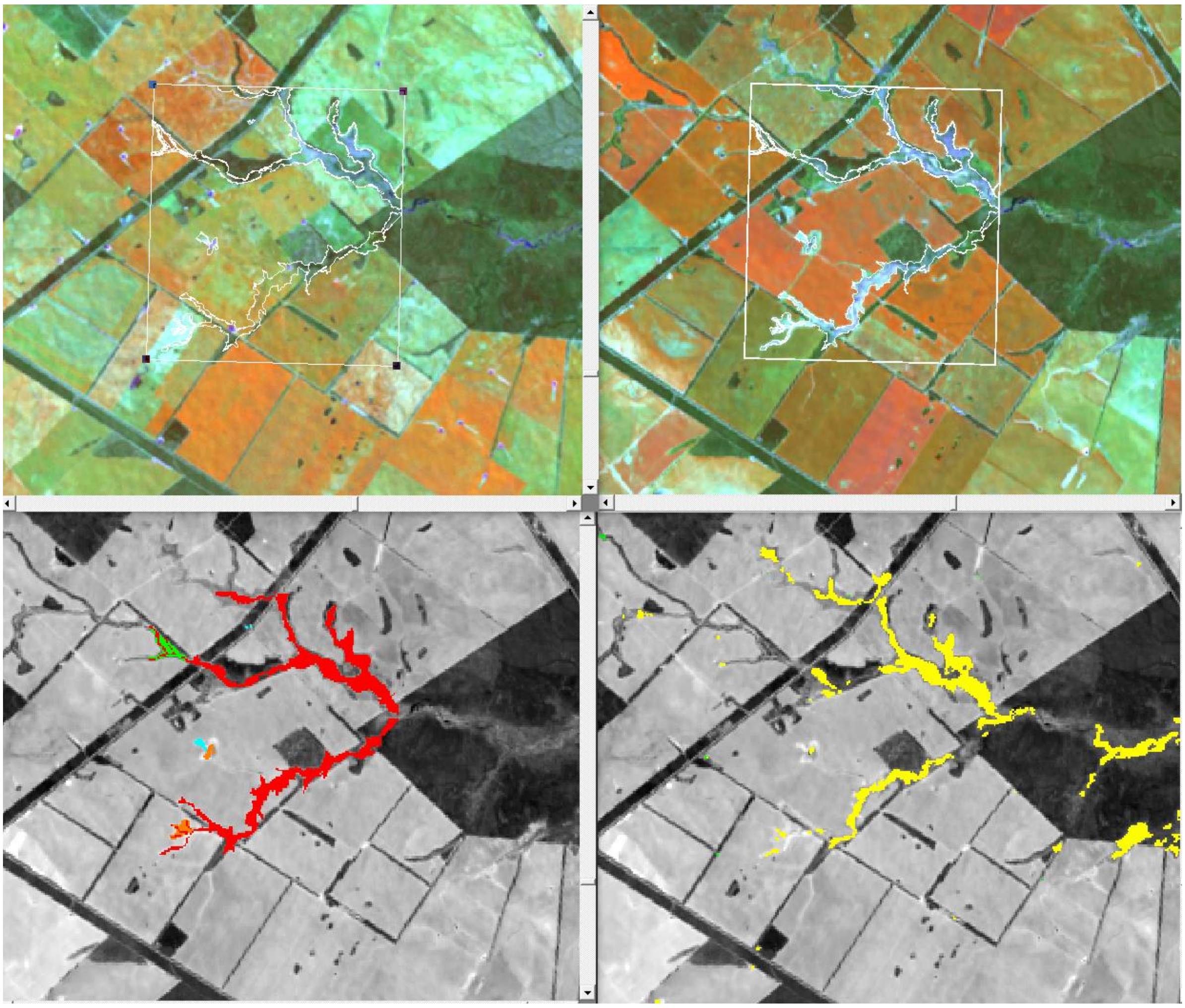
Fitzgerald River					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	30	986	1016	**3.0**
	RevSal	1417	610	2027	**30.1**
	SevSal	677	136	813	**16.7**
	Mod Sal	1513	1096	2609	**42.0**
	Non-sal	1862	64559	66421	**2.8**
	Total count	5499	67387	72886	
	Commission Error %	**34.4**	**2.7**		**% Overall = 94.9**

West River:



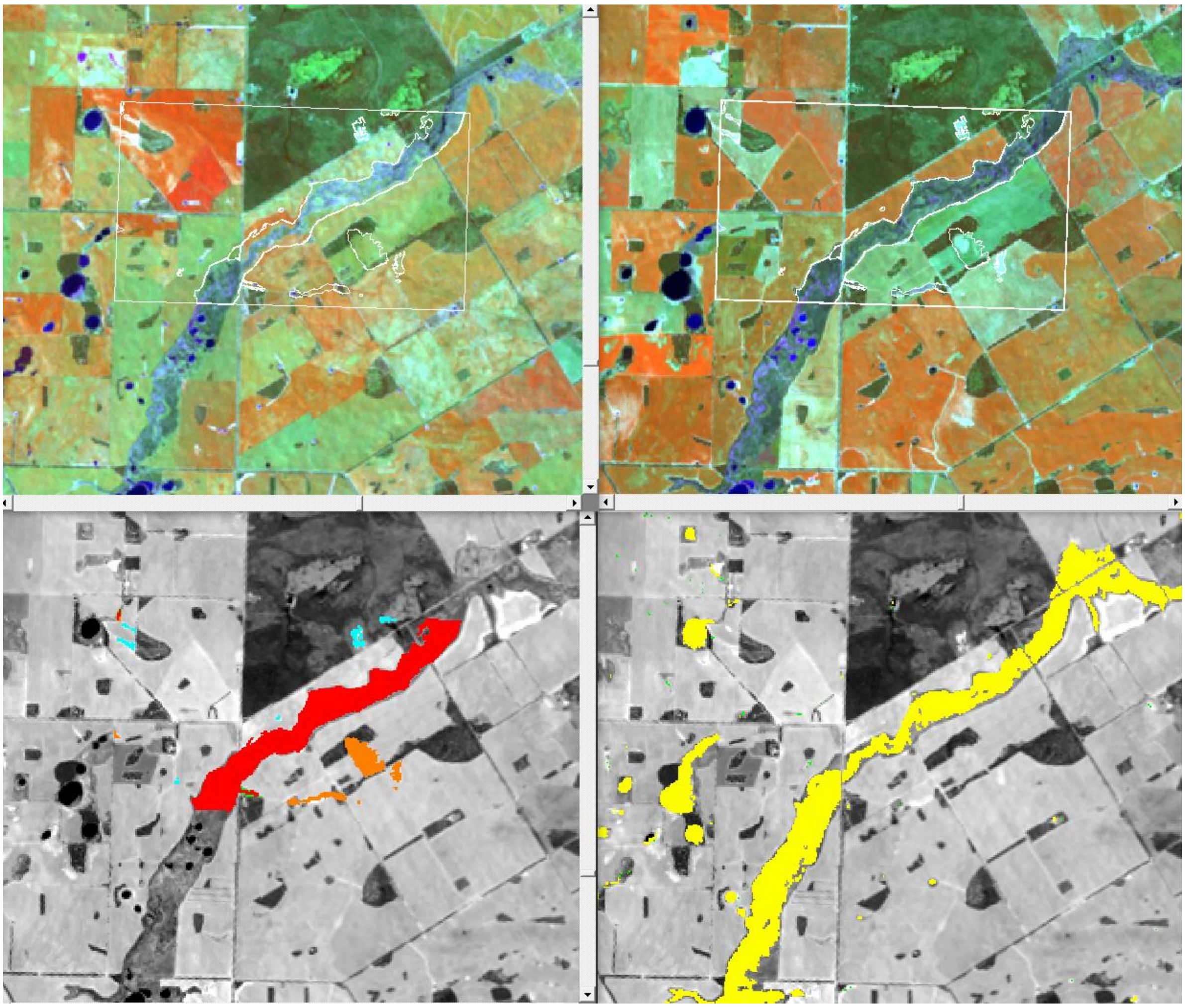
West River					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	7	32	39	**17.9**
	RevSal	0	0	0	-
	SevSal	382	373	755	**49.4**
	Mod Sal	26	45	71	**63.4**
	Non-sal	916	17048	17964	**5.1**
	Total count	1331	17498	18829	
	Commission Error %	**69.3**	**2.4**		**% Overall = 92.9**

Upper Phillips River:



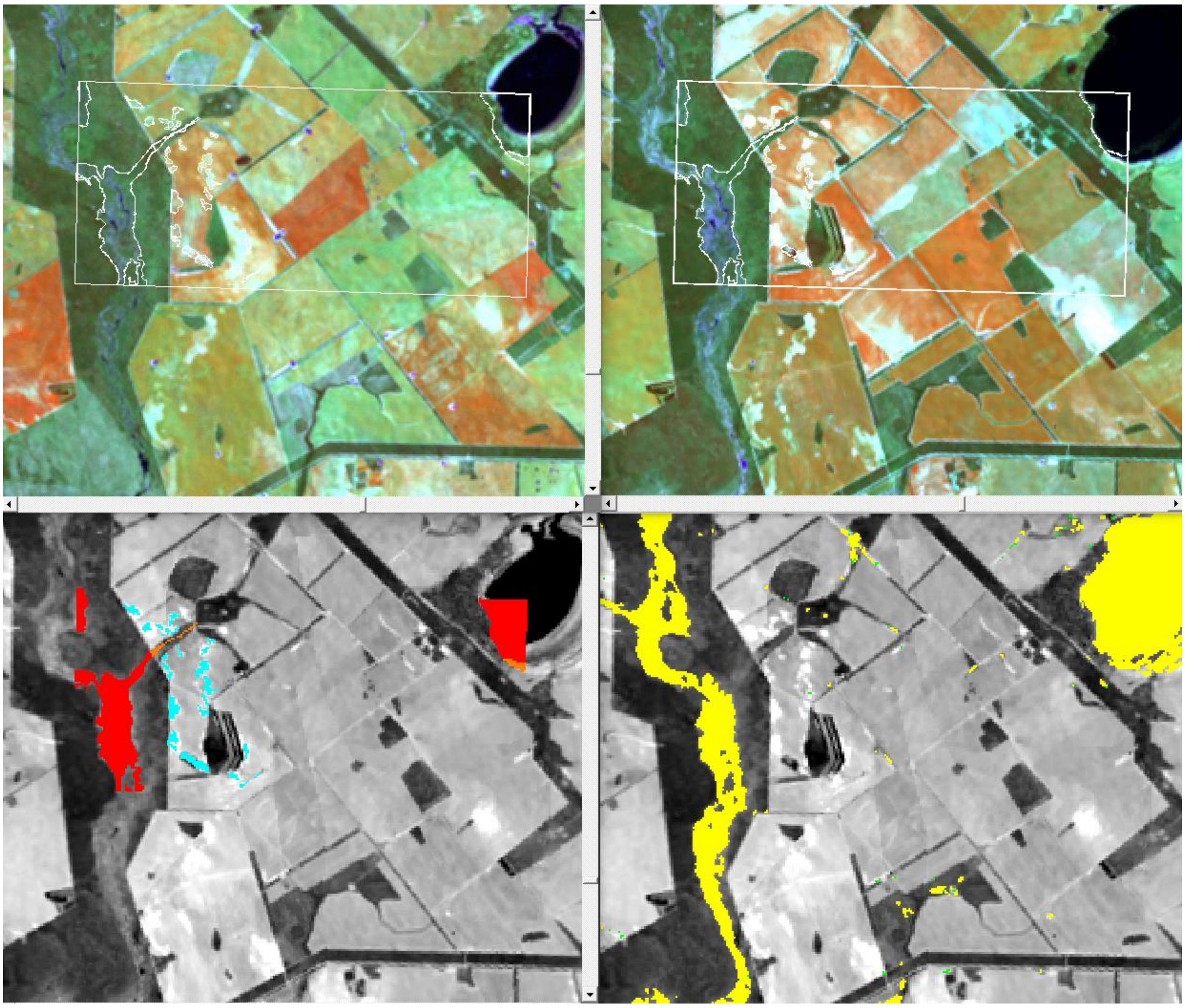
Upper Phillips River					
	Predicted Label				
		Salt	Not salt	Total count	**Omission Error %**
Ground Truth Label	Bare	0	30	30	**0.0**
	RevSal	0	97	97	**100**
	SevSal	1416	876	2292	**38.2**
	Mod Sal	18	73	91	**80.2**
	Non-sal	1229	20831	21060	**1.1**
	Total count	1663	21907	23570	
	Commission Error %	**13.8**	**4.8**		**% Overall = 94.6**

Mt Madden:



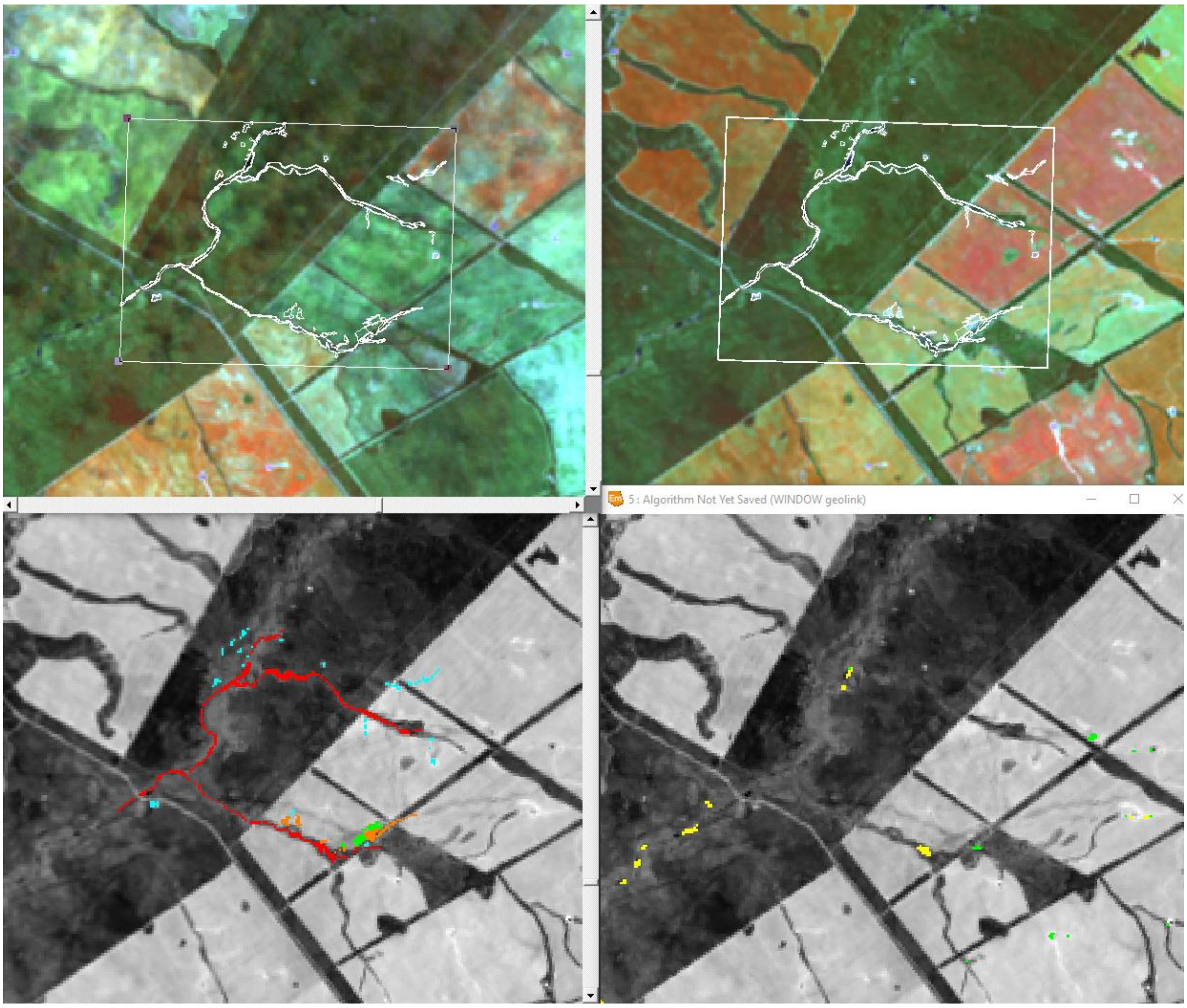
Mt Madden					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	0	175	175	**0.0**
	RevSal	0	17	17	**100**
	SevSal	2670	840	3510	**23.9**
	Mod Sal	4	573	577	**99.3**
	Non-sal	46	24195	24241	**0.2**
	Total count	2720	25800	28520	
	Commission Error %	**1.7**	**5.5**		**% Overall = 94.8**

Lake Chidnup:



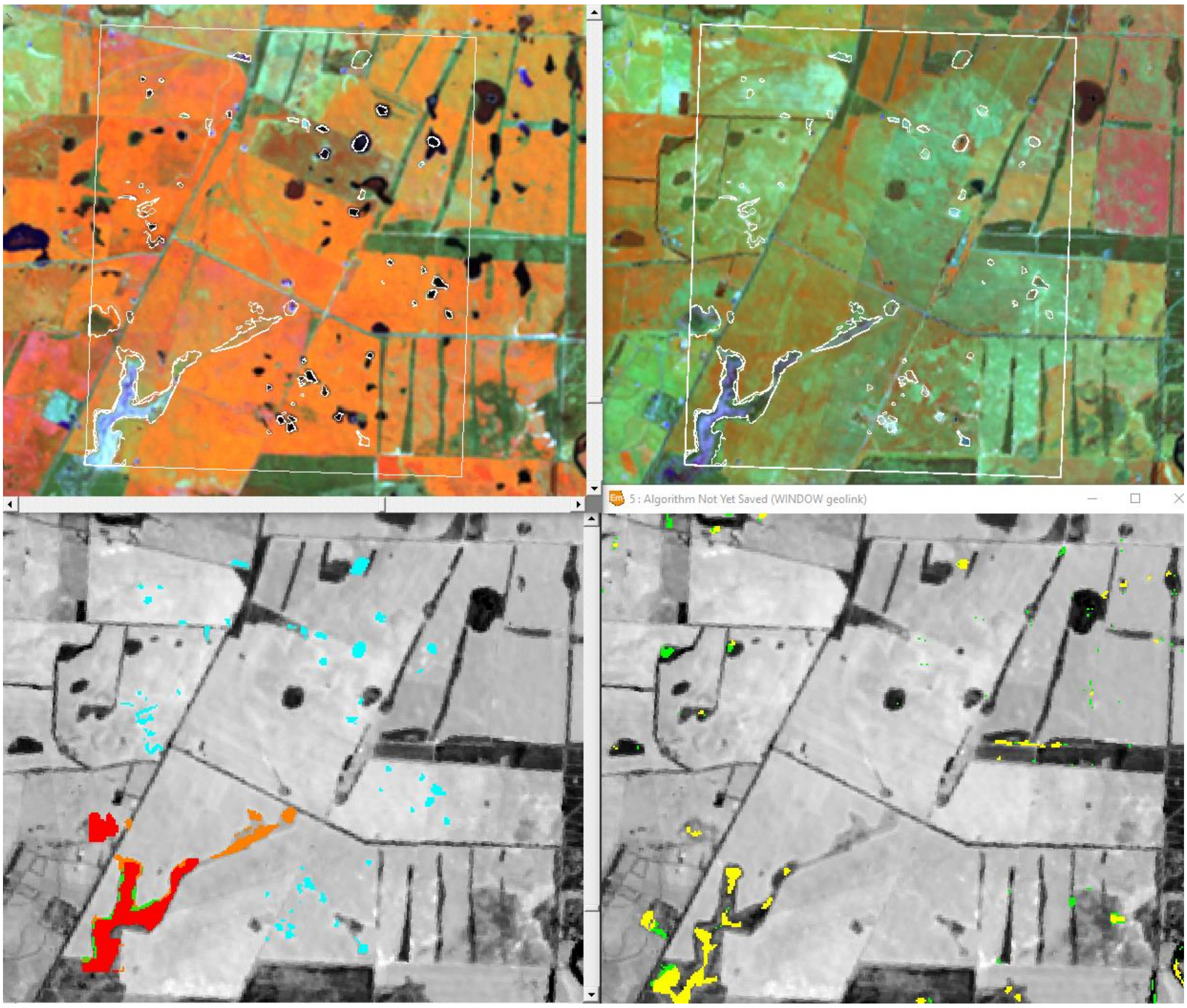
Lake Chidnup					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	0	396	396	**0.0**
	RevSal	0	0	0	
	SevSal	1546	253	1799	**14.1**
	Mod Sal	17	60	77	**77.9**
	Non-sal	178	22896	23074	**0.8**
	Total count	1741	23605	25346	
	Commission Error %	**10.2**	**1.3**		**% Overall = 98.1**

Mooyal Woodenup:



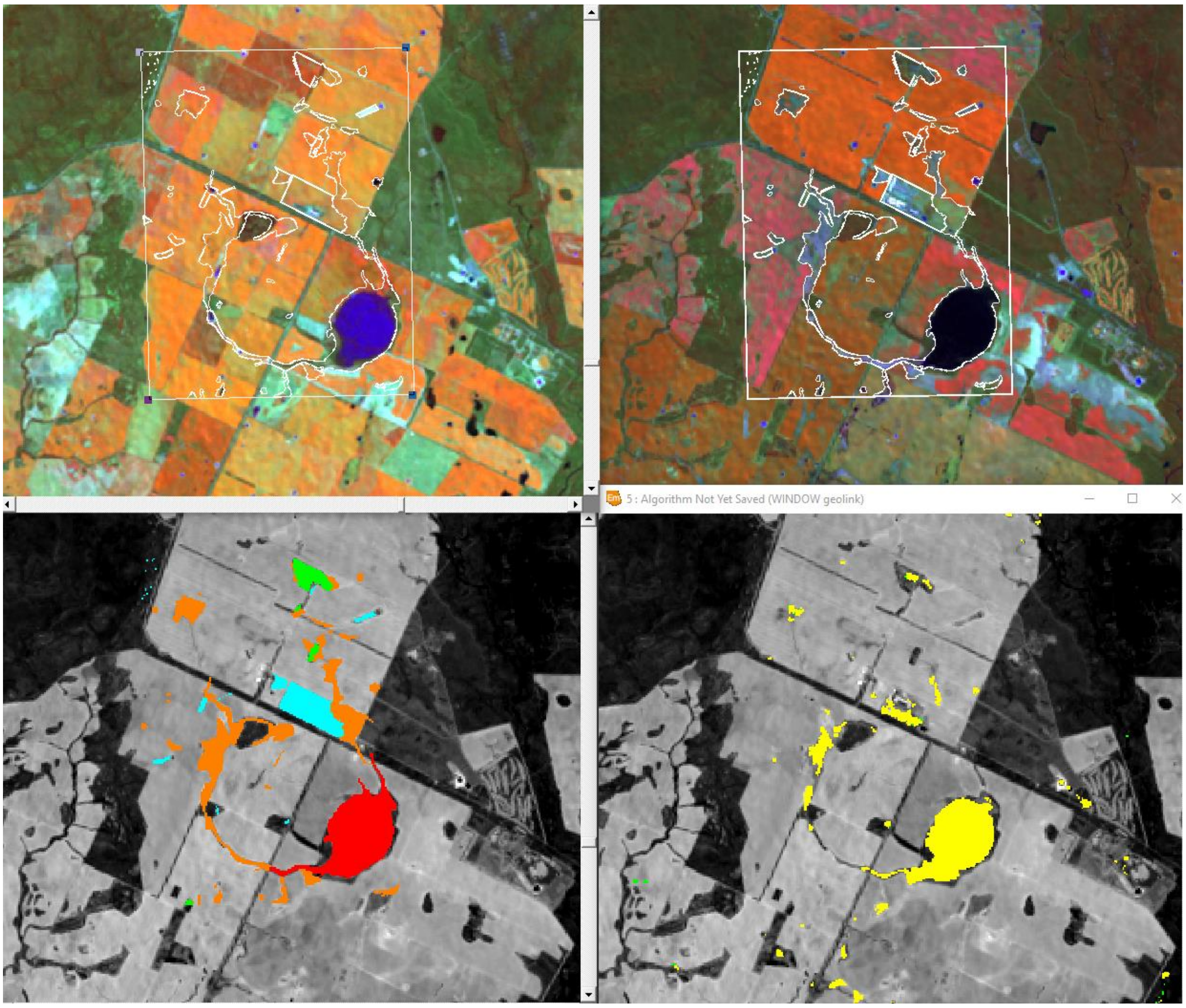
Mooyal Woodenup					
	Predicted Label				
		Salt	Not salt	Total count	**Omission Error %**
Ground Truth Label	Bare	0	85	85	**0.0**
	RevSal	0	38	38	**100**
	SevSal	23	328	351	**93.4**
	Mod Sal	0	71	71	**100**
	Non-sal	4	14376	14380	**0.0**
	Total count	27	14898	14925	
	Commission Error %	**14.8**	**2.9**		**% Overall = 97.0**

Hopetoun:



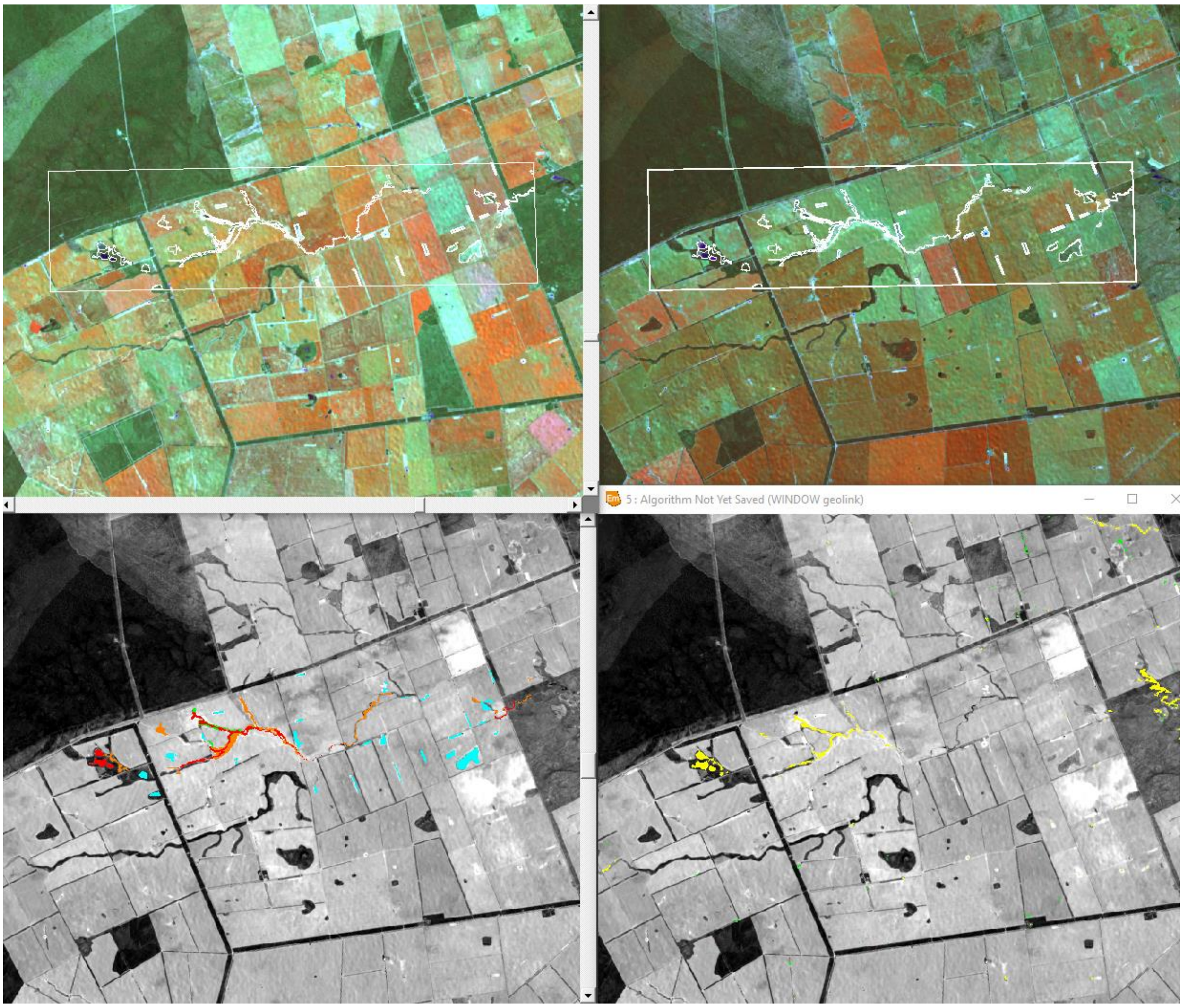
Hopetoun					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	24	591	615	**3.9**
	RevSal	1	85	86	**98.8**
	SevSal	221	791	1012	**78.2**
	Mod Sal	0	336	336	**100**
	Non-sal	66	40692	40758	**0.2**
	Total count	312	42495	42807	
	Commission Error %	**28.8**	**2.9**		**% Overall = 97.0**

Munglinup:



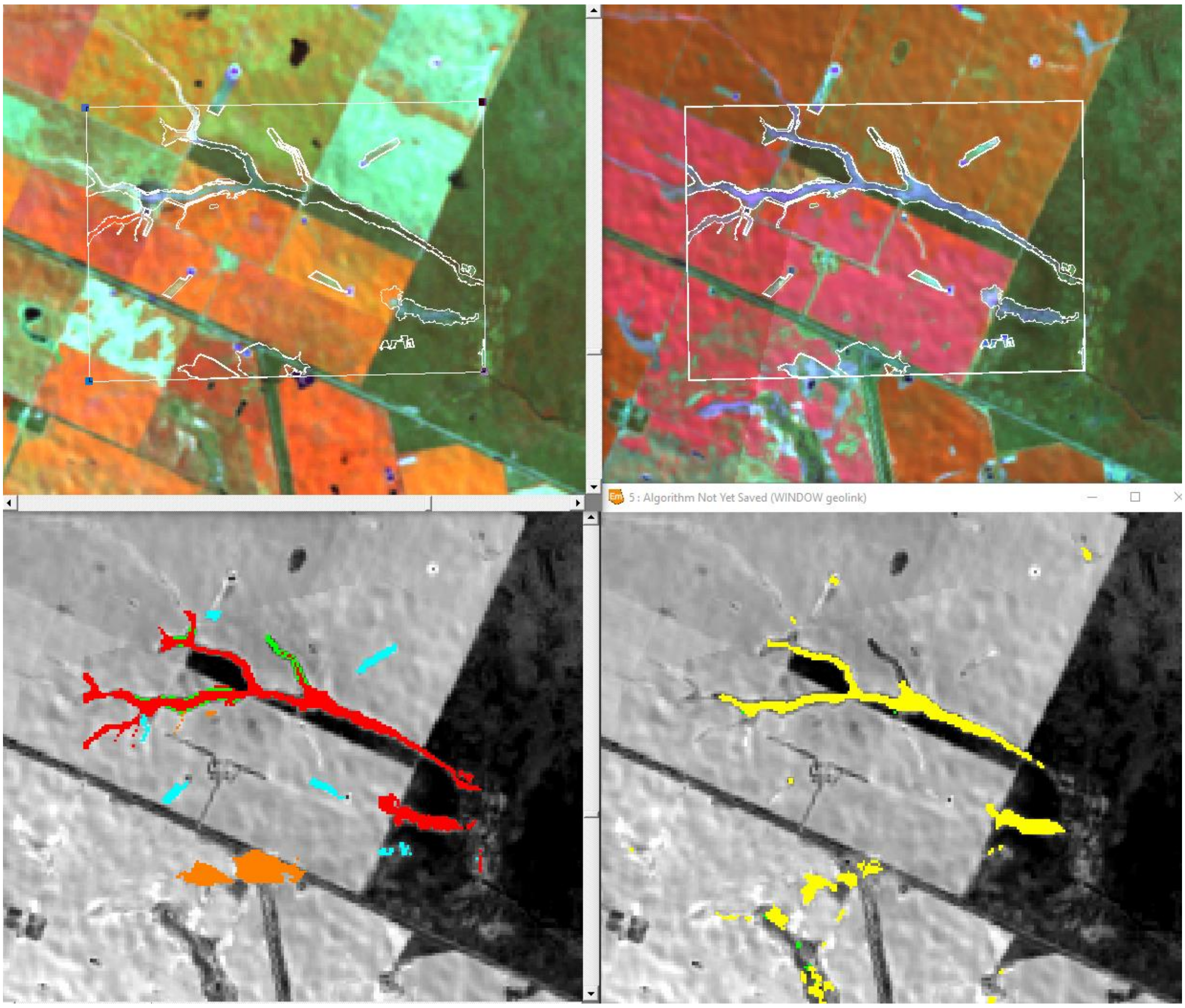
Munglinup					
	Predicted Label				
		Salt	Not salt	Total count	**Omission Error %**
Ground Truth Label	Bare	157	675	832	**18.9**
	RevSal	44	277	321	**86.3**
	SevSal	1606	244	1850	**13.2**
	Mod Sal	438	1879	2317	**81.1**
	Non-sal	106	28818	28924	**0.4**
	Total count	2351	31893	34244	
	Commission Error %	**11.2**	**7.5**		**% Overall = 92.2**

Upper Lort River:



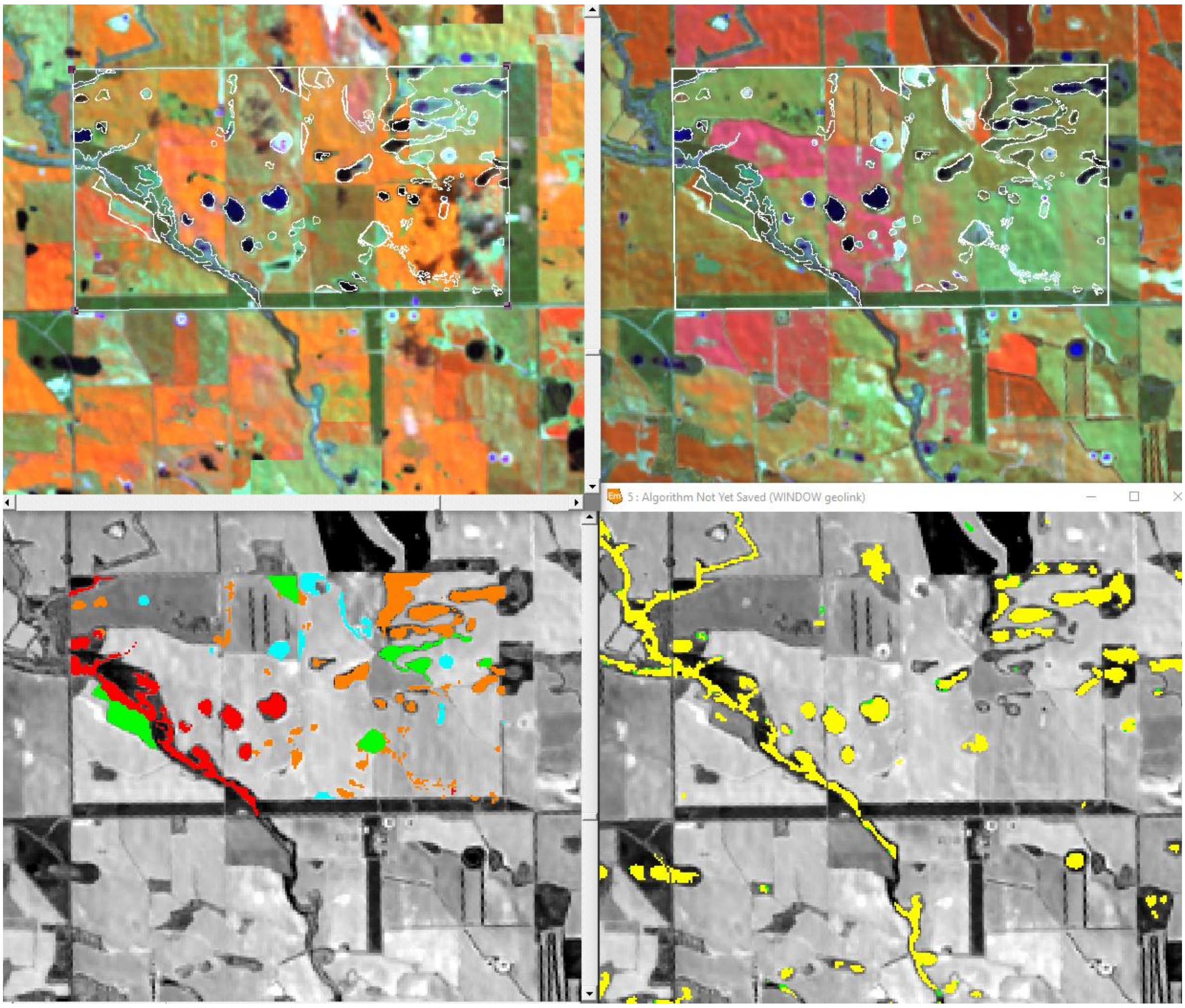
Upper Lort River					
	Predicted Label				
		Salt	Not salt	Total count	**Omission Error %**
Ground Truth Label	Bare	0	1784	1784	**0.0**
	RevSal	17	169	186	**90.9**
	SevSal	833	393	1226	**32.1**
	Mod Sal	206	1158	1364	**84.9**
	Non-sal	129	94078	94207	**0.1**
	Total count	1185	97582	98767	
	Commission Error %	**10.9**	**1.8**		**% Overall = 98.1**

Lort River:



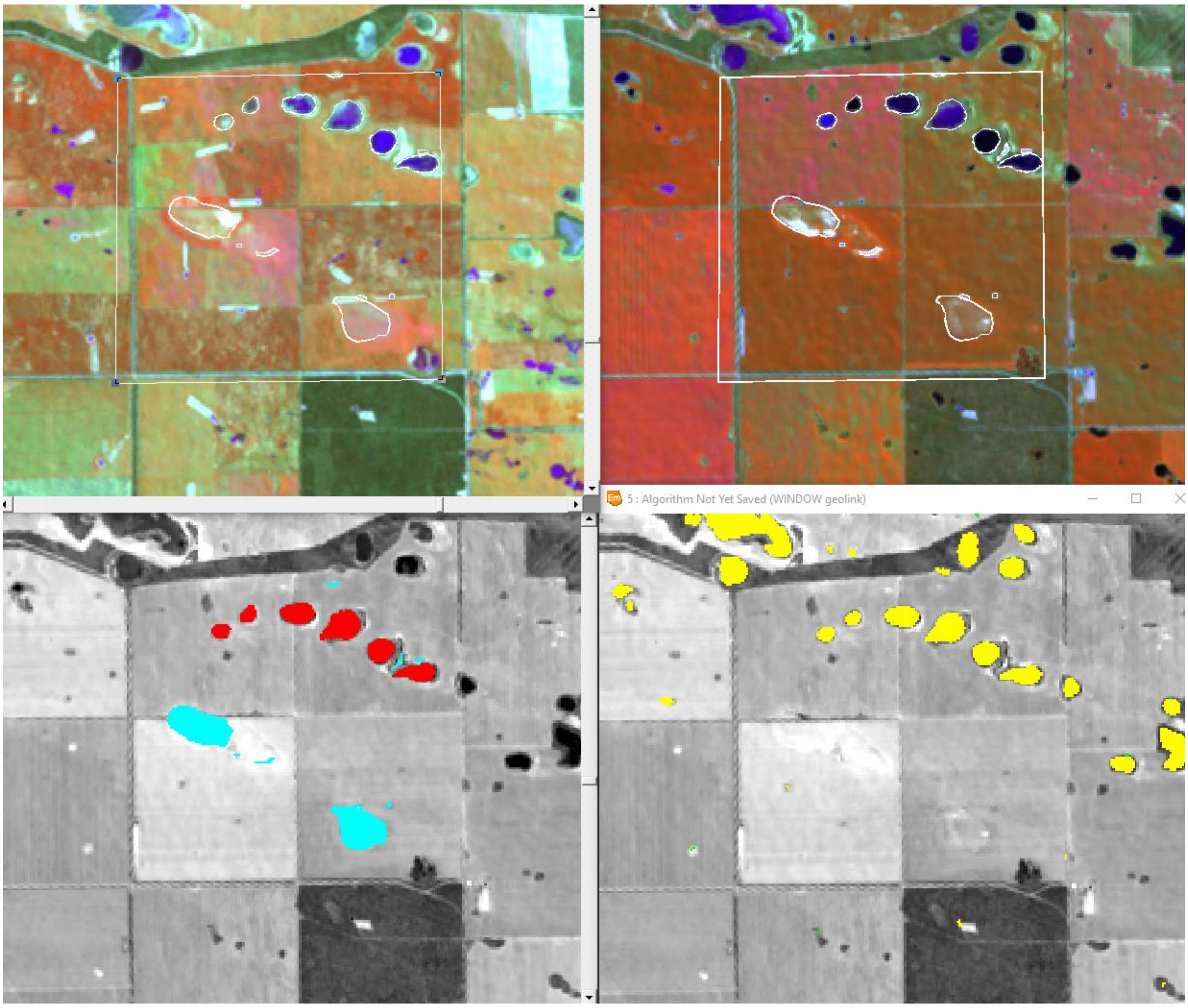
Lort River					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	2	189	191	**1.0**
	RevSal	2	104	106	**98.1**
	SevSal	681	391	1072	**36.5**
	Mod Sal	107	259	366	**70.8**
	Non-sal	83	14536	14619	**0.6**
	Total count	875	15479	16354	
	Commission Error %	**9.7**	**4.9**		**% Overall = 94.9**

West Dalyup:



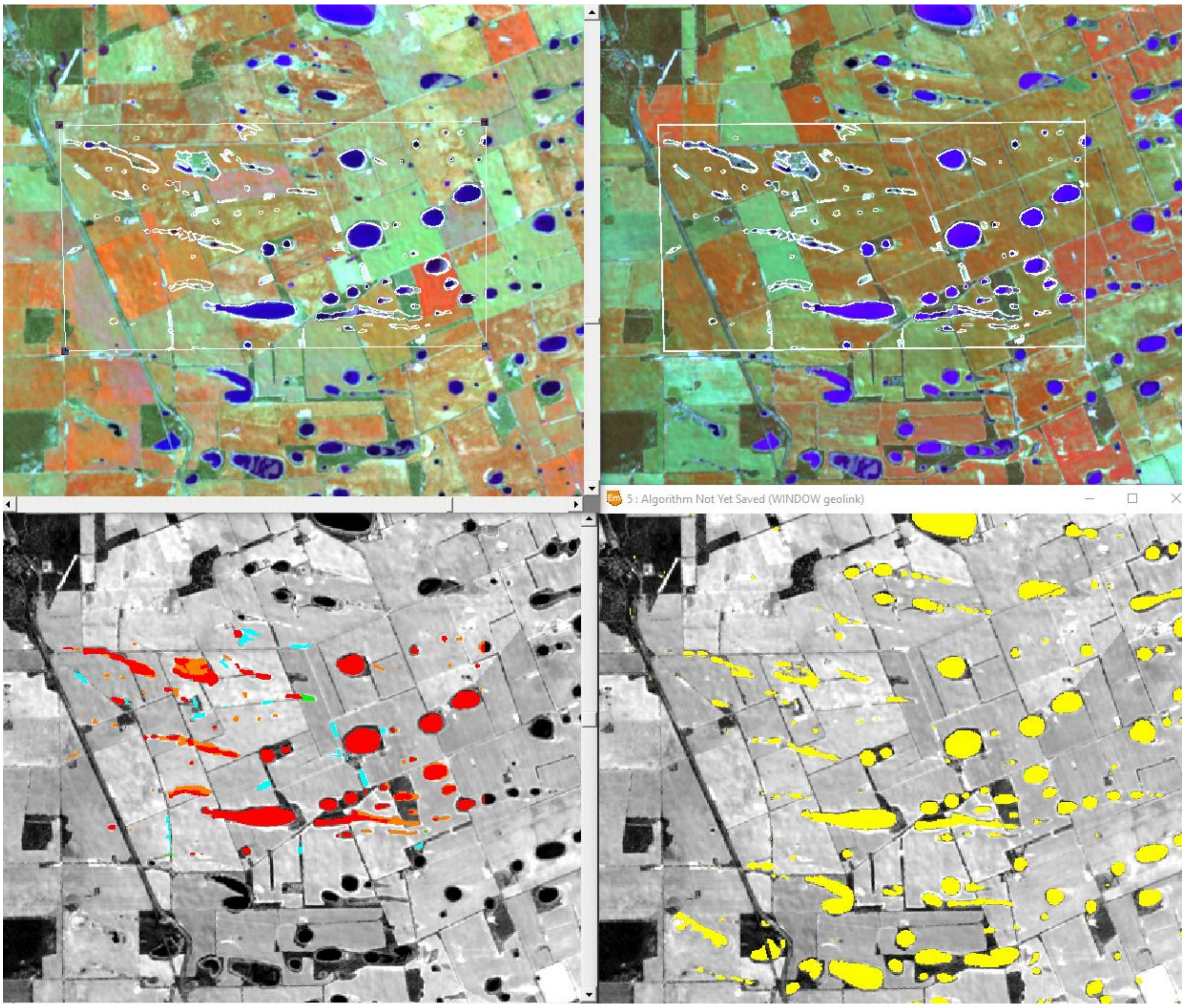
West Dalyup					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	0	354	354	**0.0**
	RevSal	80	620	700	**88.6**
	SevSal	795	170	965	**17.6**
	Mod Sal	503	864	1367	**63.2**
	Non-sal	175	19503	19678	**0.9**
	Total count	1553	21511	23064	
	Commission Error %	**11.3**	**7.7**		**% Overall = 92.1**

Scadden West:



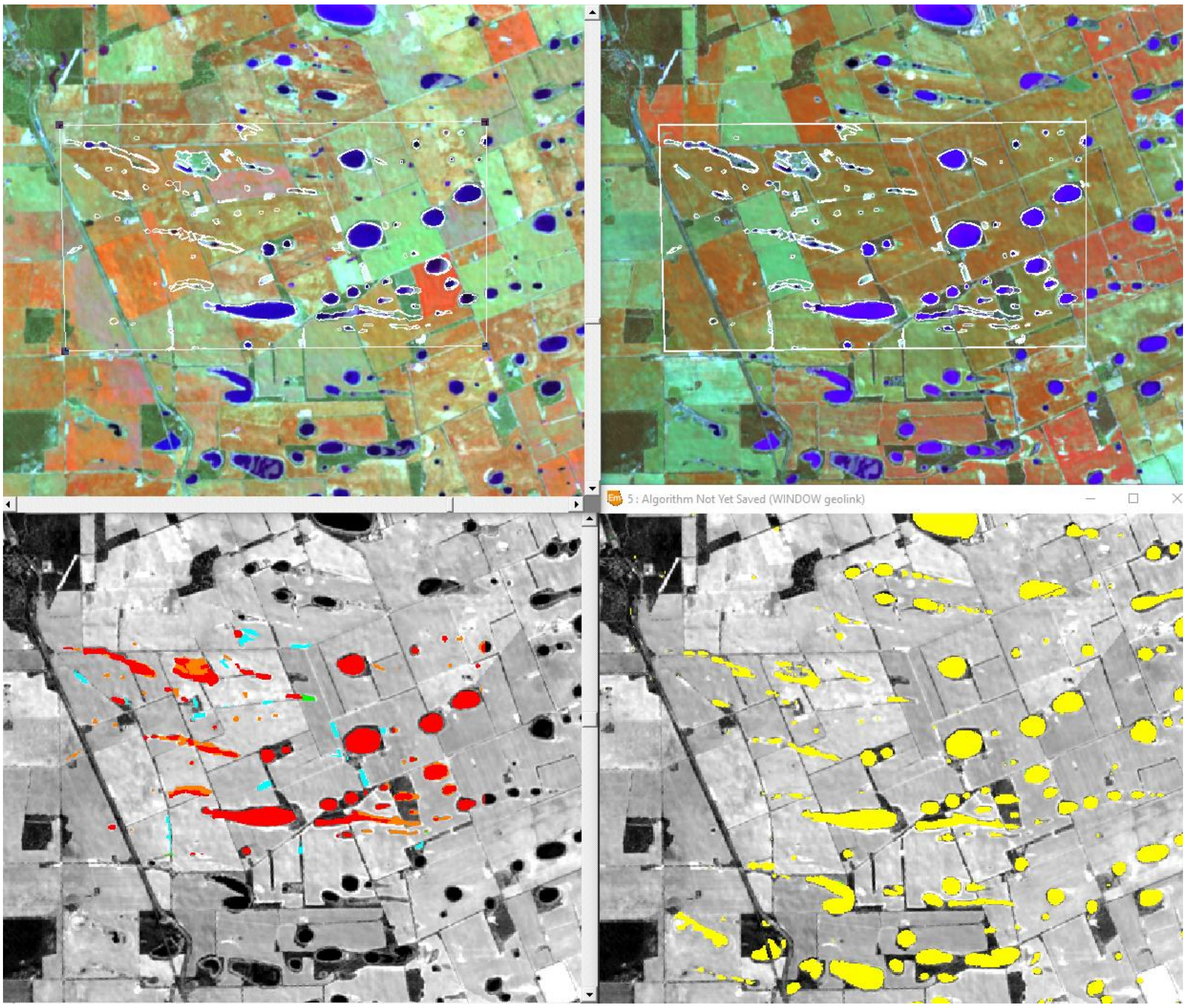
Scadden West					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	0	881	881	**0.0**
	RevSal	0	0	0	-
	SevSal	657	32	689	**4.6**
	Mod Sal	0	0	0	-
	Non-sal	23	21862	21885	**0.1**
	Total count	680	22775	23455	
	Commission Error %	**3.4**	**0.1**		**% Overall = 99.8**

Salmon Gums:



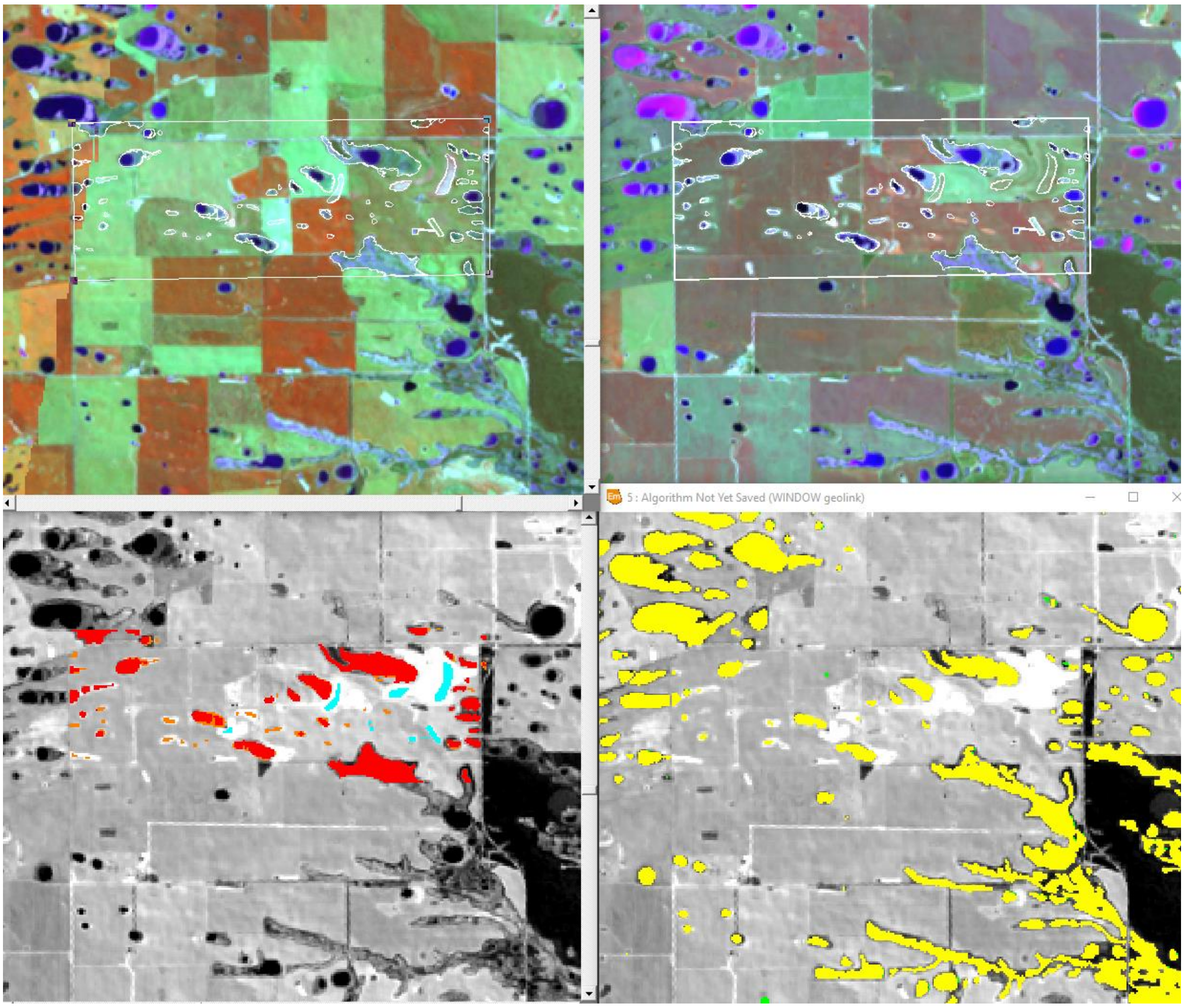
Salmon Gums					
	Predicted Label				
		Salt	Not salt	Total count	**Omission Error %**
Ground Truth Label	Bare	32	628	660	**4.8**
	RevSal	7	47	54	**87.0**
	SevSal	4566	339	4905	**6.9**
	Mod Sal	415	942	1357	**69.4**
	Non-sal	720	60067	60787	**1.2**
	Total count	5740	62023	67763	
	Commission Error %	**13.1**	**2.1**		**% Overall = 96.9**

Dalyup West:



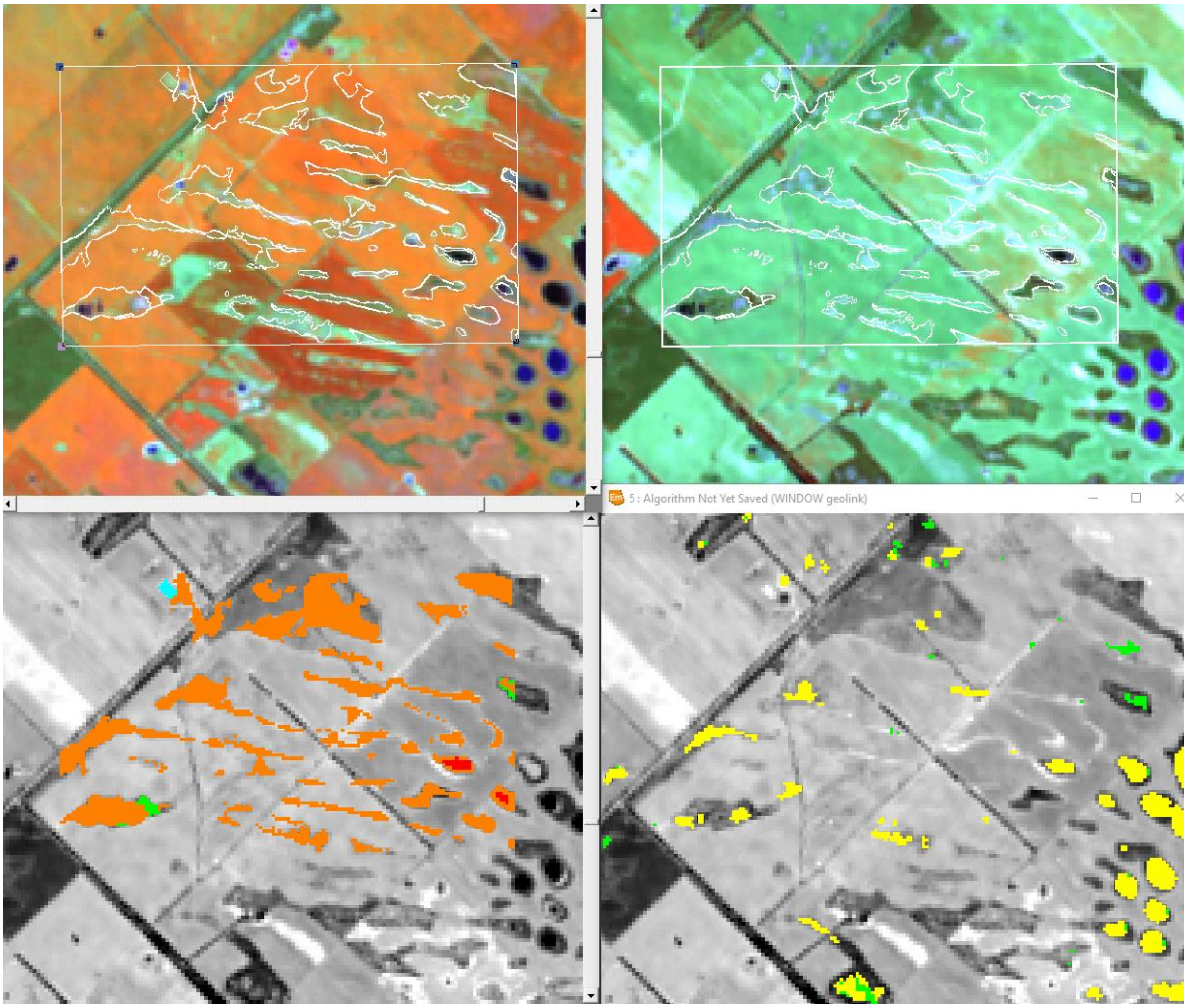
Dalyup West					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	27	416	443	**6.1**
	RevSal	35	2418	2453	**98.6**
	SevSal	4276	4686	8962	**52.3**
	Mod Sal	280	4660	4940	**94.3**
	Non-sal	180	89865	90045	**0.2**
	Total count	4798	102045	106843	
	Commission Error %	**4.3**	**11.5**		**% Overall = 88.8**

Scadden East:



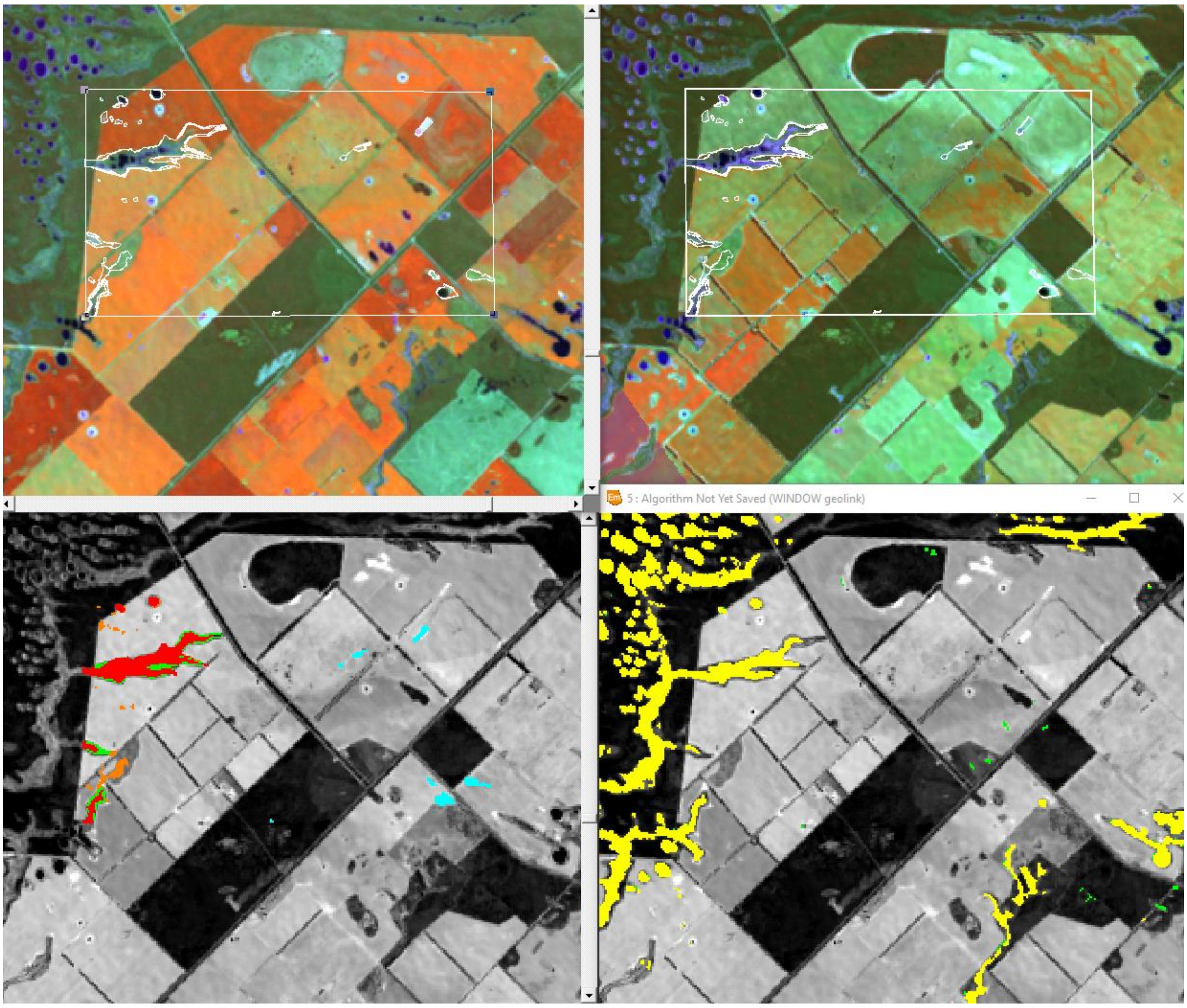
Scadden East					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	0	254	254	**0.0**
	RevSal	0	0	0	**-**
	SevSal	1688	304	1992	**15.3**
	Mod Sal	46	250	296	**84.5**
	Non-sal	35	16587	16622	**0.2**
	Total count	1769	17395	19164	
	Commission Error %	**2.0**	**3.2**		**% Overall = 96.9**

Backmans:



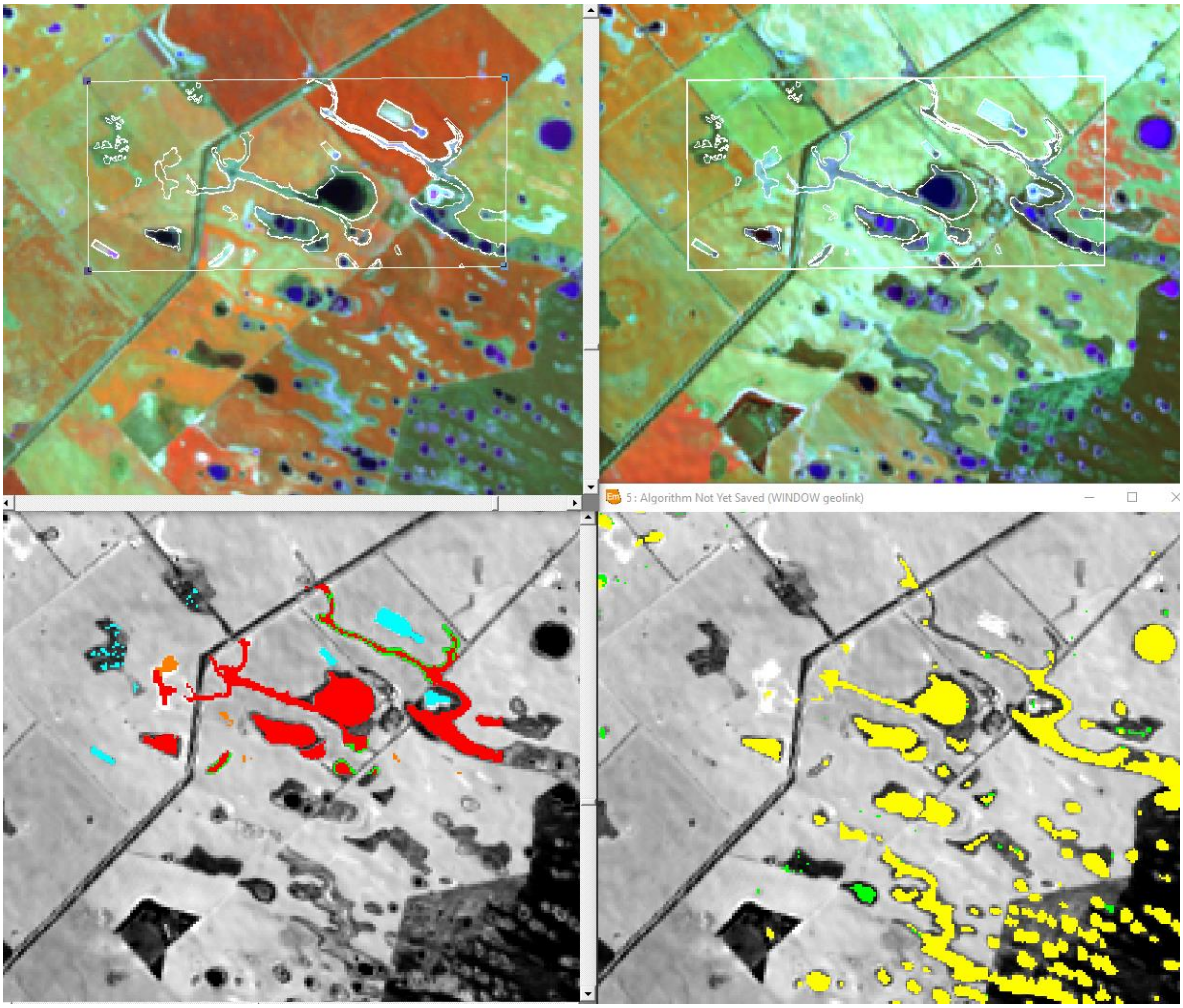
Backmans					
	Predicted Label				
		Salt	Not salt	Total count	**Omission Error %**
Ground Truth Label	Bare	0	20	20	**0.0**
	RevSal	0	35	35	**100**
	SevSal	34	0	34	**0.0**
	Mod Sal	237	1949	2186	**89.2**
	Non-sal	31	10440	10471	**0.3**
	Total count	302	12444	12746	
	Commission Error %	**10.3**	**15.9**		**% Overall = 84.2**

Coolinup:



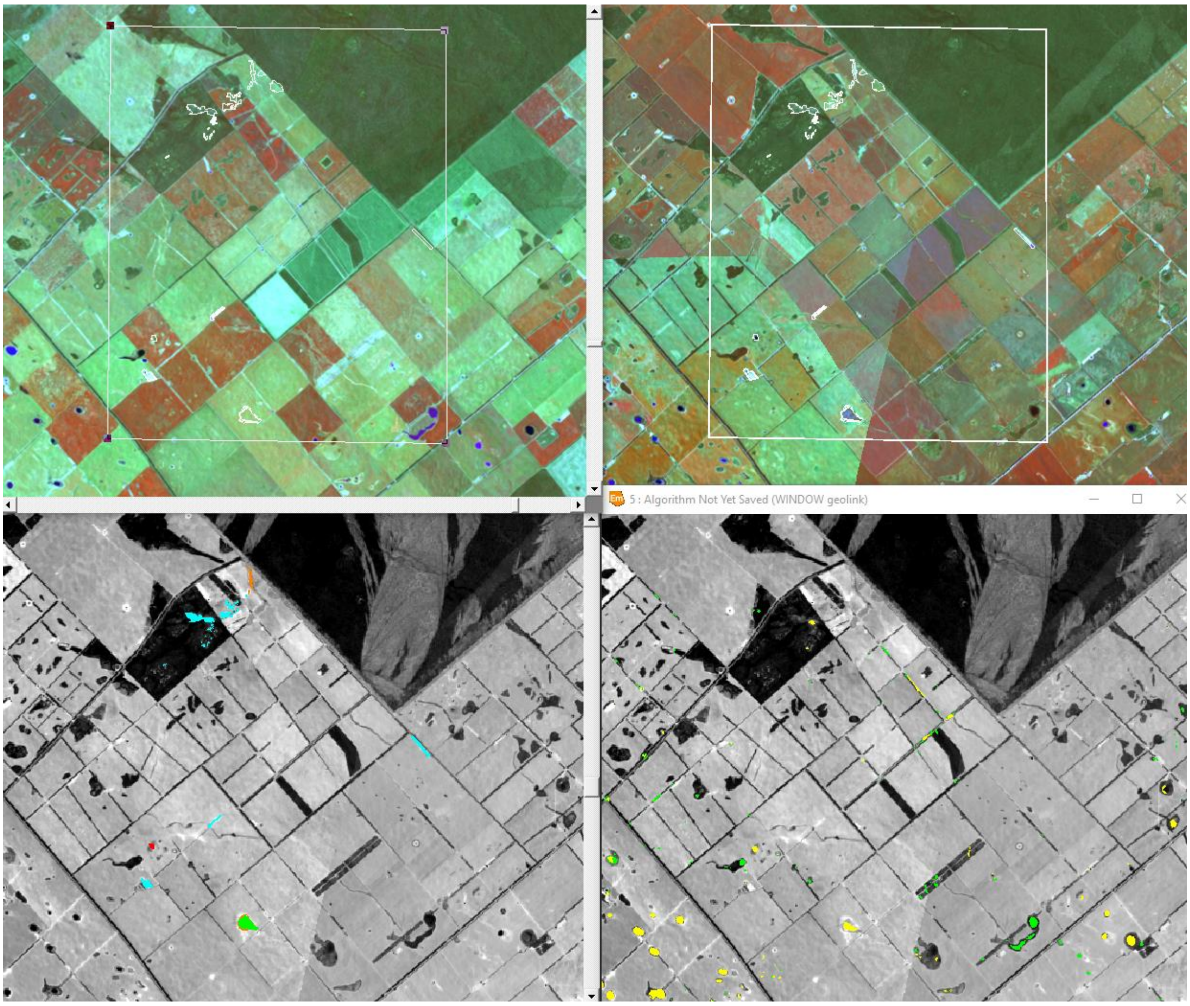
Coolinup					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	15	174	189	**7.9**
	RevSal	18	218	236	**92.4**
	SevSal	643	167	810	**20.6**
	Mod Sal	0	177	177	**100**
	Non-sal	3	27262	27265	**0.0**
	Total count	679	27998	28677	
	Commission Error %	**2.7**	**2.0**		**% Overall = 98.0**

Mt Ney:



Mt Ney					
	Predicted Label				
		Salt	Not salt	Total count	**Omission Error %**
Ground Truth Label	Bare	2	271	273	**0.7**
	RevSal	2	166	168	**98.8**
	SevSal	1209	507	1716	**29.5**
	Mod Sal	0	67	67	**100**
	Non-sal	44	11747	11791	**0.4**
	Total count	1257	12758	14015	
	Commission Error %	**3.7**	**5.8**		**% Overall = 94.4**

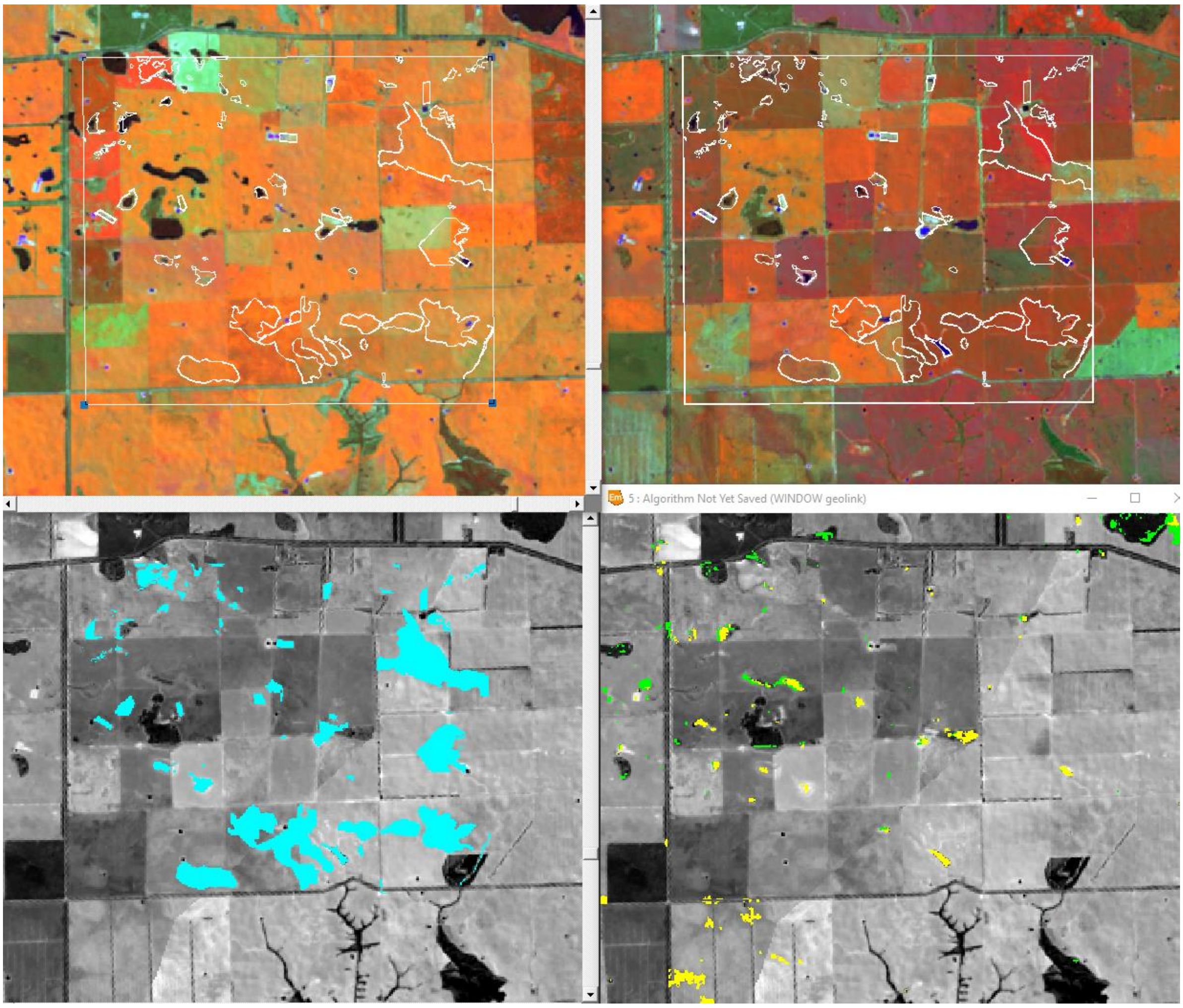
Beaumont:



Note: Pixels outside the mapped area have been excluded from these summary statistics

Beaumont					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	28	553	581	**4.8**
	RevSal	77	118	195	**60.5**
	SevSal	25	5	30	**16.7**
	Mod Sal	0	118	118	**100**
	Non-sal	126	129386	129512	**0.1**
	Total count	256	130180	130436	
	Commission Error %	**60.2**	**0.2**		**% Overall = 99.7**

Condingup east:



Condingup east					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total count	**Omission Error %**
	Bare	258	7446	7704	**3.3**
	RevSal	0	0	0	-
	SevSal	0	0	0	-
	Mod Sal	0	0	0	-
	Non-sal	334	60665	60999	**0.5**
	Total count	592	68111	68703	
	Commission Error %	**100**	**0.0**		**% Overall = 99.1**

Appendix C Amalgamated Hydro-zone mapping-based region statistics

C.1 Amalgamated Hydro-zone study region validation tables

Table 23. Mapping validation regions grouped according to amalgamated hydro-zone

Grouping of mapping validation regions by amalgamated Hydro-zone	
Amalgamated hydrozone ID	Mapped validation region ID
1	59,114,113,105,108,116,131,37
2	140,11,14,45,35,153,44,36,12,24
3	19,50,29,51,53,22,1,8,10,57
4	15,32,33,34,38,39,41,42,25,55,23,112
5	16,121,30,31,20,17,118,28,21,18,6,7
6	151,56,58,2,5,4,61,3,64,62,52,49,48,46,54
7	119,126

Table 24. *Land Monitor* region-based validation statistics.

This table provides the overall error rates for the mapped regions (*sa-data*) versus mapped labels (LM) for 2018. Numerical entries are pixel counts, all mapped regions pooled.

All Mapped-regions pooled, pixel counts					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total	Omission error %
	RevSalt	45,904	49,395	95,299	51.8
	ModSalt	22,678	75,087	97,765	76.8
	SevSalt	110,421	37,641	148,062	25.4
	Total GT Salt	**179,003**	**162,123**	**341,126**	**47.5**
	Bare	924	52,338	53,262	1.7
	Not-salt	31,751	5,025,502	5,057,253	0.6
	Total	211,678	5,239,963	5,451,641	

	Commission error %	15.4	3.1	Overall accuracy = 96.4 %

Table 25. Amalgamated Hydro-zone 1 region-based validation statistics.

This table provides the error rates for the mapped regions (*sa-data*) versus mapped labels (LM) for 2018. Numerical entries are pixel counts, mapped regions pooled.

Amalgamated Hydro-zone 1, Mapped-regions pooled, pixel counts					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total	Omission error %
	RevSalt	1,266	7,216	8,482	85.1
	ModSalt	385	3,313	3,698	89.6
	SevSalt	16,699	13,431	30,130	44.6
	Total GT Salt	**18,350**	**23,960**	**42,310**	**56.6**
	Bare	0	2,659	2,659	0.0
	Not-salt	4,012	852,660	856,672	0.5
	Total	22,362	879,279	901,641	
	Commission error %	17.9	2.7	Overall accuracy = 96.9%	

Table 26. Amalgamated Hydro-zone 2 region-based validation statistics.

This table provides the error rates for the mapped regions (*sa-data*) versus mapped labels (LM) for 2018. Numerical entries are pixel counts, mapped regions pooled.

Amalgamated Hydro-zone 2, Mapped-regions pooled, pixel counts					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total	Omission error %
	RevSalt	12,064	8,672	20,736	41.8
	ModSalt	6,049	22,435	28,484	78.9
	SevSalt	45,074	6,684	51,758	12.9
	Total GT Salt	**63,187**	**37,791**	**100,978**	**37.4**
	Bare	76	16,754	16,830	0.5
	Not-salt	4966	1,506,267	1,511,233	0.3
	Total	68,229	1,560,812	1,629,041	
	Commission error %	7.4	2.4	Overall accuracy = 97.4 %	

Table 27. Amalgamated Hydro-zone 3 region-based validation statistics.

This table provides the error rates for the mapped regions (*sa-data*) versus mapped labels (LM) for 2018. Numerical entries are pixel counts, mapped regions pooled.

Amalgamated Hydro-zone 3, Mapped-regions pooled, pixel counts					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total	Omission error %
	RevSalt	5,620	5,712	11,332	50.4
	ModSalt	4,737	9,658	14,395	67.1
	SevSalt	993	601	1,594	37.7
	Total GT Salt	**11,350**	**15,971**	**27,321**	**58.5**
	Bare	0	1,813	1,813	0.0
	Not-salt	1,838	240,205	242,043	0.7
	Total	13,188	257,989	271,177	
	Commission error %	13.9	6.2	Overall accuracy = 93.4 %	

Table 28. Amalgamated Hydro-zone 4 region-based validation statistics.

This table provides the error rates for the mapped regions (*sa-data*) versus mapped labels (LM) for 2018. Numerical entries are pixel counts, mapped regions pooled.

Amalgamated Hydro-zone 4, Mapped-regions pooled, pixel counts					
	Predicted Label				
Ground Truth Label		Salt	Not salt	Total	Omission error %
	RevSalt	22,256	16,751	39,007	42.9
	ModSalt	3,361	12,563	15924	78.9
	SevSalt	25,791	4,987	30,778	16.2
	Total GT Salt	**51,408**	**34,301**	**85,709**	**40.0**
	Bare	154	7,276	7,430	2.1
	Not-salt	11,071	948,174	959245	1.2
	Total	62,633	989,751	1,052,384	
	Commission error %	17.9	3.5	Overall accuracy = 95.7 %	

Table 29. Amalgamated Hydro-zone 5 region-based validation statistics.

This table provides the error rates for the mapped regions (*sa-data*) versus mapped labels (LM) for 2018. Numerical entries are pixel counts, mapped regions pooled.

Amalgamated Hydro-zone 5, Mapped-regions pooled, pixel counts					
	Predicted Label				
		Salt	Not salt	Total	Omission error %
	RevSalt	3,979	5,606	9,585	58.5

Ground Truth Label	ModSalt	6,021	14,278	20,299	70.3
	SevSalt	4,711	3,071	7,782	39.5
	Total GT Salt	**14,711**	**22,955**	**37,666**	**60.9**
	Bare	151	9,663	9,814	1.5
	Not-salt	5,755	651,839	657,594	0.9
	Total	20,617	684,457	705,074	
	Commission error %	28.6	3.4	Overall accuracy = 95.9 %	

Table 30. Amalgamated Hydro-zone 6 region-based validation statistics.

This table provides the error rates for the mapped regions (*sa-data*) versus mapped labels (LM) for 2018. Numerical entries are pixel counts, mapped regions pooled.

Amalgamated Hydro-zone 6, Mapped-regions pooled, pixel counts					
	Predicted Label				
		Salt	Not salt	Total	Omission error %
Ground Truth Label	RevSalt	281	4,191	4,472	93.7
	ModSalt	2,125	12,471	14,596	85.4
	SevSalt	16,576	7,966	24,542	32.5
	Total GT Salt	**18,982**	**24,628**	**43,610**	**56.5**
	Bare	543	14,132	14,675	3.7
	Not-salt	1,976	625,348	627,324	0.3
	Total	21,501	664,108	685,609	
	Commission error %	11.7	3.7	Overall accuracy = 96.0 %	

Table 31. Amalgamated Hydro-zone 7 region-based validation statistics.

This table provides the error rates for the mapped regions (*sa-data*) versus mapped labels (LM) for 2018. Numerical entries are pixel counts, mapped regions pooled.

Amalgamated Hydro-zone 7, Mapped-regions pooled, pixel counts					
	Predicted Label				
		Salt	Not salt	Total	Omission error %
Ground Truth Label	RevSalt	438	1,247	1,685	74.0
	ModSalt	0	369	369	100.0
	SevSalt	577	901	1,478	61.0
	Total GT Salt	**1,015**	**2,517**	**3,532**	**71.3**
	Bare	0	41	41	0.0

	Not-salt	2,133	201,009	203,142	1.1
	Total	3,148	203,567	206,715	
	Commission error %	67.8	1.2	Overall accuracy = 97.8 %	

Appendix D All Landsat image dates used

For the figures below, each colour represents a separate source image acquisition date.

Year 2019

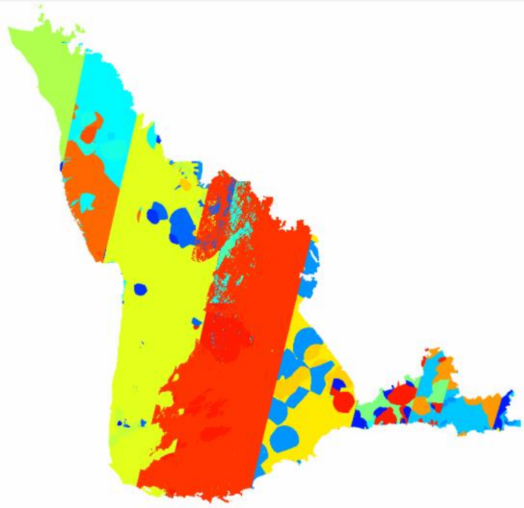


Figure D 1: Raster image date extent display for the 2019 Landsat image composite.

Month	Days
June	1,2,8,10,12,14,17,24,26,30
July	3,7,10,12,16,17,19,30
August	2,4,11,12,13,15,18,20,21,22,27,29,31
September	2,3,5,6,7,9,12,14,16,17,21,23,25,28,30
October	2,7,16,18,20,23

Number of Images: 52

Year 2018

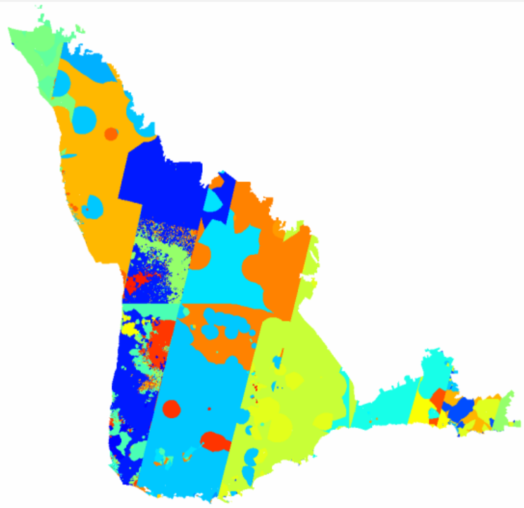


Figure D 2: Raster image date extent display for the 2018 Landsat image composite.

Month	Days
May	2,4,11,12,13,29
June	2,7,14,21,23,25,30
July	4,8,9,11,13,14,16,20,23,25,29
August	1,5,8,10,12,15,17,19,21,24,25,26,28
September	2,4,6,7,9,11,13,16,18,20,25
October	2,8,11,17,20,22,24,27,28,29
November	5,7,9,13,14,21,25,28,30

Number of Images: 67

Year 2017

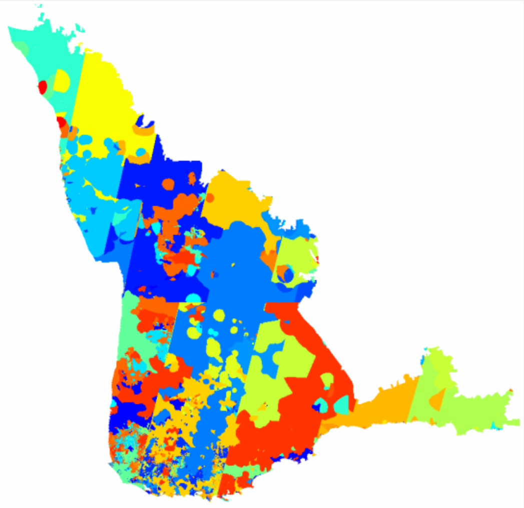


Figure D 3: Raster image date extent display for the 2017 Landsat image composite.

Month	Days
May	3,5,10,12,15,18,19,26,30
June	4,11,12,13,18,19,20,22,24,27,28,29
July	1,4,5,6,8,10,12,13,15,20,21,22,24, 26,27,29,31
August	5,6,7,8,11,13,14,16,18,21,23,25,28,30
September	1,3,6,8,10,13,14,15,16,17,19,23,24, 26,28,29,30
October	1,2,8,10,12,15,17,19,21,24,26,28,30, 31
November	1,2,4,9,10,11,16,18,20,25,27

Number of images: 93

Year 2016

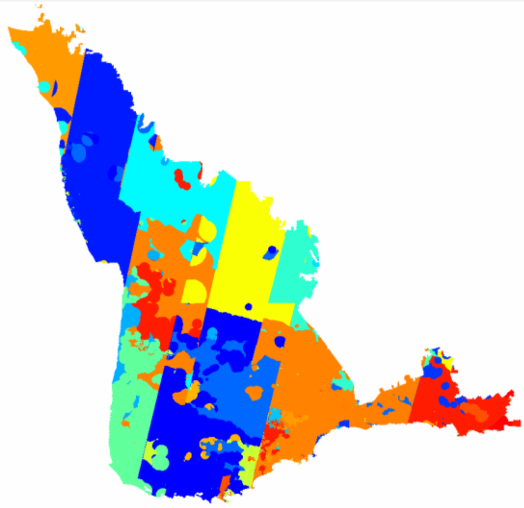


Figure D 4: Raster image date extent display for the 2016 Landsat image composite.

Month	Days
May	9,11,18,25
June	1,3,8,10,24,26,28
July	1,5,7,14,19,20,21,23,26,28,30
August	2,6,11,13,18,20,22,24,25,27,31
September	3,5,7,9,12,14,16,19,21,25,26,28,30
October	2,5,12,13,16,23,25,27,30
November	3,8,10,13,14,15,17,19,22,24,26,27,30

Number of images: 68

Year 2011

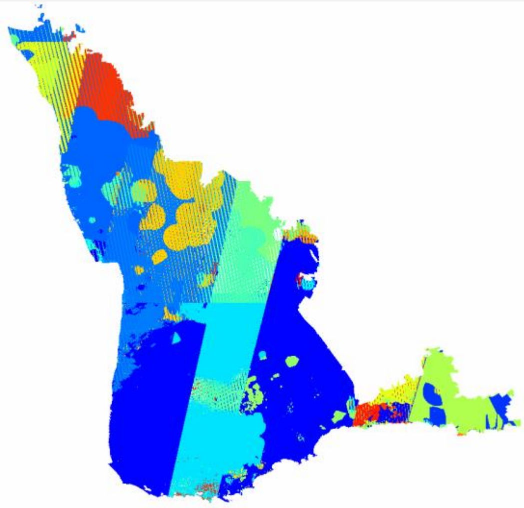


Figure D 5: Raster image date extent display for the 2011 Landsat image composite.

Month	Days
May	29
June	3,10,17,19,26,28,30
July	2,3,5,12,14,16,18,19,21,25,30
August	1,4,5,6,10,15,17,18,19,20,26,27, 29,30,31
September	1,2,3,4,5,6,7,9,11,14,16,17,18,20, 23,25,27
October	1,7,9,10,11,13,15,16,19,20,23
November	1,3,21

Number of images: 65

Year 2010

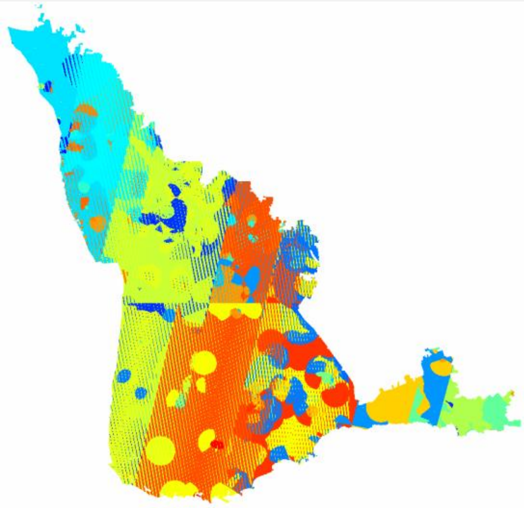


Figure D 6: Raster image date extent display for the 2010 Landsat image composite.

Month	Days
May	28,31
June	7,9,13,14,16,18,23,25,30
July	2,11,15,18,20,25,27,31
August	1,3,5,10,15,16,17,19,21,26,28,29,30
September	2,4,6,7,10,11,13,15,18,20,21,22, 23,25,27
October	4,6,7,8,9,13,14,15,16,18,19,22,23, 24,25,29,31
November	3,19,28

Number of images: 67

Year 2009

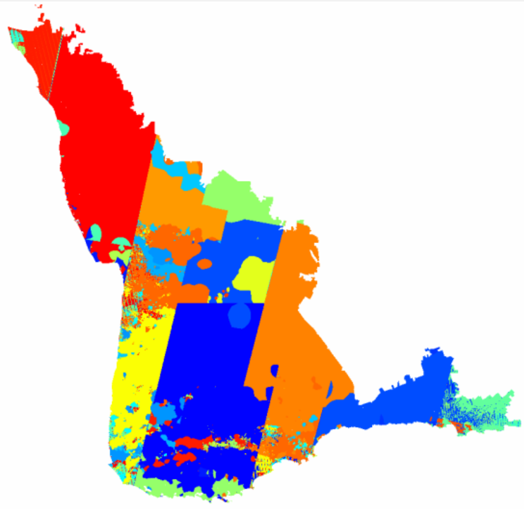


Figure D 7: Raster image date extent display for the 2009 Landsat image composite.

Month	**Days**
May	28,29,30
June	1,4,10,13,15,17,20,21,26,28,30
July	1,7,9,12,13,14,15,24,26,29,31
August	1,2,3,4,8,11,13,14,15,17,18,19,20, 24,26,28,29,30,31
September	2,4,5,9,11,14,16,18,25,27
October	1,2,3,4,10,11,13,15,17,18,19,20, 21,22,27
November	2,3,22

Number of images: 72

Appendix E Mapping extent additional information

The south-west agricultural zone extent was obtained from https://catalogue.data.wa.gov.au/dataset/south-west-agricultural-region-dpird-008. Inspection of the vector layer showed that it aligns quite well with the visible edge of paddocks in the Landsat data at the inland edge of the agricultural area but aligns very poorly with the coastline in the south and west. The hydrological zones vector aligns much better with the coastline, although still has areas of mismatch) and so was used to provide the mapping extent along the land/water boundary. Figure 24 shows a comparison of the two vector files near Cervantes.

The hydrological zones for Western Australia were accessed from https://catalogue.data.wa.gov.au/dataset/hydrological-zones-of-western-australia (DPIRD-069). The vector obtained was locally edited to include only those hydrological zones that overlap the south-west agricultural region. Within this region small polygons (less than approximately 50 hectares) were merged with the surrounding hydrological zone.

The Local Government Authority (Shire) boundaries were obtained from https://catalogue.data.wa.gov.au/dataset/local-government-authority-lga-boundaries. Again, the vector file was edited to include only those Shires that overlap the south-west agricultural region. This dataset was used primarily for providing area summaries of salinity extent.

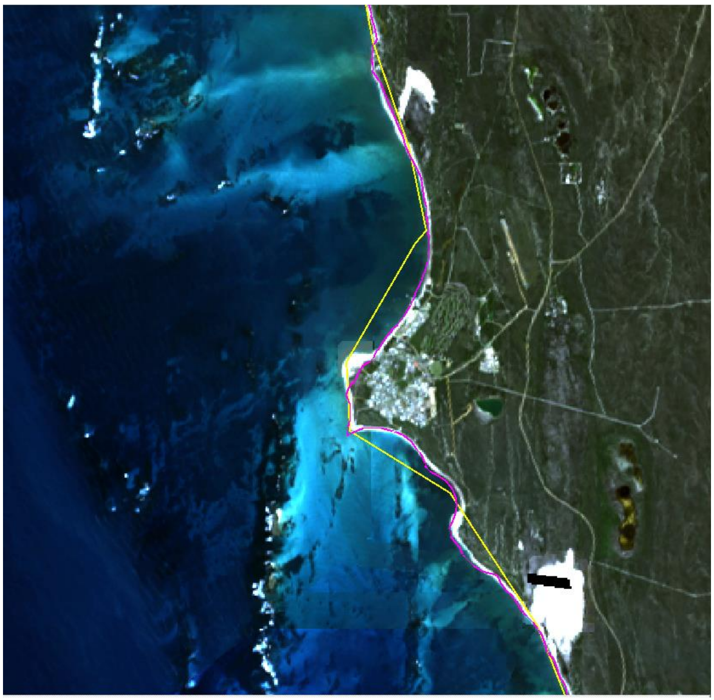


Figure 21. Mapping extent additional information.

The figure depicts the 2018 Landsat image (RGB) with the hydrological zones (pink) and south-west agricultural region extent (yellow) vectors overlaid

Appendix F Project output map-based files

GDA94/MGA50 includes the Ravensthorpe to Esperance region in extended zone 50 coordinates (light grey in table). The Ravensthorpe to Esperance region is also provided in its local GDA94/MGA51 coordinates (white in table)

Mask type	Source/note	Proj/zone	GSD (m)	Filename
Salinity Estimate Extent Mask (SEMZ50)	Defines New extent 0 = not processed 1 = processed	GDA94/ MGA50	25	lm50_salt_mapping_area_extents_original.tif lm50_salt_mapping_area_extents_recent.tif
Status indicator	Masking legend 0 = not masked 1 = masked by dams only 2 = buildings only 3 = roads only 4 = D + R 5 = B + R 6 = B + D 7 = all	GDA94/ MGA50	25	lm50_1990_saltclean_mask.tif lm50_1998_saltclean_mask.tif lm50_2009_saltclean_mask.tif lm50_2010_saltclean_mask.tif lm50_2011_saltclean_mask.tif lm50_2016_saltclean_mask.tif lm50_2017_saltclean_mask.tif lm50_2018_saltclean_mask.tif lm50_2019_saltclean_mask.tif
Salinity Estimate Extent Mask (SEMZ51)	Defines New extent	GDA94/ MGA51	25	lm51_salt_mapping_area_extents_original_mga51.tif lm51_salt_mapping_area_extents_recent_mga51.tif
Status indicator	Masking legend 0 = not masked 1 = masked by dams only 2 = buildings only 3 = roads only	GDA94/ MGA50		lm51_1990_saltclean_mask_mga51.tif lm51_1998_saltclean_mask_mga51.tif lm51_2009_saltclean_mask_mga51.tif lm51_2010_saltclean_mask_mga51.tif lm51_2011_saltclean_mask-mga51.tif lm51_2016_saltclean_mask_mga51.tif

	4 = D + R 5 = B + R 6 = B + D 7 = all			lm51_2017_saltclean_mask_mga51.tif lm51_2018_saltclean_mask_mga51.tif lm50_2019_saltclean_mask_mga51.tif
Water Masks				
1990s	LM1/reproj/extended 0 = not mapped 1 = not water 2 = water	GDA94/ MGA50	25	lm50_NBAR2_original_water_masked.tif
2009	New RF/ Landsat	GDA94/ MGA50	25	lm50_NBAR2_2009_water_masked.tif
2010	New RF/ Landsat	GDA94/ MGA50	25	lm50_NBAR2_2010_water_masked.tif
2011	New RF/ Landsat	GDA94/ MGA50	25	lm50_NBAR2_2011_water_masked.tif
2016	New RF/ Landsat	GDA94/ MGA50	25	lm50_NBAR2_2016_water_masked.tif
2017	New RF/ Landsat	GDA94/ MGA50	25	lm50_NBAR2_2017_water_masked.tif
2018	New RF/ Landsat	GDA94/ MGA50	25	lm50_NBAR2_2018_water_masked.tif
2019	New RF/ Landsat	GDA94/ MGA50	25	lm50_NBAR2_2019_water_masked.tif
1990s	LM1/reproj/extended	GDA94/ MGA51	25	lm51_NBAR2_original_water_masked_mga51.tif
2009	New RF/ Landsat	GDA94/ MGA51	25	lm51_NBAR2_2009_water_masked_mga51.tif
2010	New RF/ Landsat	GDA94/ MGA51	25	lm51_NBAR2_2010_water_masked_mga51.tif
2011	New RF/ Landsat	GDA94/ MGA51	25	lm51_NBAR2_2011_water_masked_mga51.tif
2016	New RF/ Landsat	GDA94/ MGA51	25	lm51_NBAR2_2016_water_masked_mga51.tif

2017	New RF/ Landsat	GDA94/ MGA51	25	lm51_NBAR2_2017_water_masked_mga51.tif
2018	New RF/ Landsat	GDA94/ MGA51	25	lm51_NBAR2_2018_water_masked_mga51.tif
2019	New RF/ Landsat	GDA94/ MGA51	25	lm51_NBAR2_2019_water_masked_mga51.tif
Digital Elevation Model				
mosaic	LG/Shuttle/smoothed	GDA94/ MGA50	10	lm50_smoothed_dem.tif
Flow path prediction/ depressions	DISPLAY version RGB	GDA94/ MGA50	10	lm50_flowpaths_display_masked.jp2
Salinity Mapping				
Year	**Source/note** **0 = not mapped** **1 = not salt** **2 - salt**	**Proj/zone**	**GSD (m)**	**Filename**
"Old_Salt" (~1990)	LM1/reproj/extended	GDA94/ MGA50	25	lm50_NBAR2_1990_salinity_masked.tif
"New_Salt" (~1998)	LM1/reproj/extended	GDA94/ MGA50	25	lm50_NBAR2_1998_salinity_masked.tif
2009	New time-series Landsat/newdem (water as salt)	GDA94/ MGA50	25	lm50_NBAR2_2009_salinity_masked.tif
2010	New time-series Landsat/newdem (water as salt)	GDA94/ MGA50	25	lm50_NBAR2_2010_salinity_masked.tif
2011	New time-series Landsat/newdem (water as salt)	GDA94/ MGA50	25	lm50_NBAR2_2011_salinity_masked.tif
2016	New time-series Landsat/newdem (water as salt)	GDA94/ MGA50	25	lm50_NBAR2_2016_salinity_masked.tif
2017	New time-series Landsat/newdem	GDA94/ MGA50	25	lm50_NBAR2_2017_salinity_masked.tif

	(water as salt)			
2018	New time-series Landsat/newdem (water as salt)	GDA94/ MGA50	25	lm50_NBAR2_2018_salinity_masked.tif
2019	New time-series Landsat/newdem (water as salt)	GDA94/ MGA50	25	lm50_NBAR2_2019_salinity_masked.tif
“Old_Salt” (~1990)	LM1/reproj/extended	GDA94/ MGA51	25	lm51_NBAR2_1990_salinity_masked_mga51.tif
“New_Salt” (~1998)	LM1/reproj/extended	GDA94/ MGA51	25	lm51_NBAR2_1998_salinity_masked_mga51.tif
2009	New time-series Landsat/newdem (water as salt)	GDA94/ MGA51	25	lm51_NBAR2_2009_salinity_masked_mga51.tif
2010	New time-series Landsat/newdem (water as salt)	GDA94/ MGA51	25	lm51_NBAR2_2010_salinity_masked_mga51.tif
2011	New time-series Landsat/newdem (water as salt)	GDA94/ MGA51	25	lm51_NBAR2_2011_salinity_masked_mga51.tif
2016	New time-series Landsat/newdem (water as salt)	GDA94/ MGA51	25	lm51_NBAR2_2016_salinity_masked_mga51.tif
2017	New time-series Landsat/newdem (water as salt)	GDA94/ MGA51	25	lm51_NBAR2_2017_salinity_masked_mga51.tif
2018	New time-series Landsat/newdem (water as salt)	GDA94/ MGA51	25	lm51_NBAR2_2018_salinity_masked_mga51.tif
2019	New time-series Landsat/newdem (water as salt)	GDA94/ MGA51	25	lm51_NBAR2_2019_salinity_masked_mga51.tif
Landsat Imagery				
~1989	Landsat spring	GDA94/MGA5	25	l5att_1987-

	mosaiced image	0		1991_NBAR2_lm50_spring_mga50.tif
~1994	Landsat spring mosaiced image	GDA94/MGA50	25	l5att_1994-1996_NBAR2_lm50_spring_mga50.tif
~1999	Landsat spring mosaiced image	GDA94/MGA50	25	l5att_1996-2000_NBAR2_lm50_spring_mga50.tif
2009	Cloud-masked Landsat spring composite image	GDA94/MGA50	25	l5att_2009_NBAR2_lm50_spring_mga50.tif
2010	Cloud-masked Landsat spring composite image	GDA94/MGA50	25	l7att_2010_NBAR2_lm50_spring_mga50.tif
2011	Cloud-masked Landsat spring composite image	GDA94/MGA50	25	l7att_2011_NBAR2_lm50_spring_mga50.tif
2016	Cloud-masked Landsat spring composite image	GDA94/MGA50	25	l8att_2016_NBAR2_lm50_spring_mga50.tif
2017	Cloud-masked Landsat spring composite image	GDA94/MGA50	25	l8att_2017_NBAR2_lm50_spring_mga50.tif
2018	Cloud-masked Landsat spring composite image	GDA94/MGA50	25	l8att_2018_NBAR2_lm50_spring_mga50.tif
2019	Cloud-masked Landsat spring composite image	GDA94/MGA50	25	l8att_2019_NBAR2_lm50_spring_mga50.tif
~1989	Date extent indicator image	GDA94/MGA50	25	l5att_1987-1991_NBAR2_lm50_spring_mga50_rde.tif
~1994	Date extent indicator image	GDA94/MGA50	25	l5att_1994-1996_NBAR2_lm50_spring_mga50_rde.tif
~1999	Date extent indicator image	GDA94/MGA50	25	l5att_1996-2000_NBAR2_lm50_spring_mga50_rde.tif
2009	Date extent indicator image	GDA94/MGA50	25	l5att_2009_NBAR2_lm50_spring_mga50_rde.tif
2010	Date extent indicator image	GDA94/MGA50	25	l7att_2010_NBAR2_lm50_spring_mga50_rde.tif
2011	Date extent indicator image	GDA94/MGA50	25	l7att_2011_NBAR2_lm50_spring_mga50_rde.tif
2016	Date extent indicator image	GDA94/MGA50	25	l8att_2016_NBAR2_lm50_spring_mga50_rde.tif

2017	Date extent indicator image	GDA94/MGA50	25	l8att_2017_NBAR2_lm50_spring_mga50_rde.tif
2018	Date extent indicator image	GDA94/MGA50	25	l8att_2018_NBAR2_lm50_spring_mga50_rde.tif
2019	Date extent indicator image	GDA94/MGA50	25	l8att_2019_NBAR2_lm50_spring_mga50_rde.tif
~1989	Landsat spring mosaiced image	GDA94/MGA51	25	l5att_1987-1990_NBAR2_lm51_spring_mga51.tif
~1994	Landsat spring mosaiced image	GDA94/MGA51	25	l5att_1994_NBAR2_lm51_spring_mga51.tif
~1999	Landsat spring mosaiced image	GDA94/MGA51	25	l5att_1997-2000_NBAR2_lm51_spring_mga51.tif
2009	Cloud-masked Landsat spring composite image	GDA94/MGA51	25	l5att_2009_NBAR2_si51_spring_mga51.tif
2010	Cloud-masked Landsat spring composite image	GDA94/MGA51	25	l7att_2010_NBAR2_si51_spring_mga51.tif
2011	Cloud-masked Landsat spring composite image	GDA94/MGA51	25	l7att_2011_NBAR2_si51_spring_mga51.tif
2016	Cloud-masked Landsat spring composite image	GDA94/MGA51	25	l8att_2016_NBAR2_si51_spring_mga51.tif
2017	Cloud-masked Landsat spring composite image	GDA94/MGA51	25	l8att_2017_NBAR2_si51_spring_mga51.tif
2018	Cloud-masked Landsat spring composite image	GDA94/MGA51	25	l8att_2018_NBAR2_si51_spring_mga51.tif
2019	Cloud-masked Landsat spring composite image	GDA94/MGA51	25	l8att_2019_NBAR2_si51_spring_mga51.tif
~1989	Date extent indicator image	GDA94/MGA51	25	l5att_1987-1990_NBAR2_lm51_spring_mga51_rde.tif
~1994	Date extent indicator image	GDA94/MGA51	25	l5att_1994_NBAR2_lm51_spring_mga51_rde.tif
~1999	Date extent indicator image	GDA94/MGA51	25	l5att_1997-2000_NBAR2_lm51_spring_mga51_rde.tif

2009	Date extent indicator image	GDA94/MGA51	25	l5att_2009_NBAR2_si51_spring_mga51_rde.tif
2010	Date extent indicator image	GDA94/MGA51	25	l7att_2010_NBAR2_si51_spring_mga51_rde.tif
2011	Date extent indicator image	GDA94/MGA51	25	l7att_2011_NBAR2_si51_spring_mga51_rde.tif
2016	Date extent indicator image	GDA94/MGA51	25	l8att_2016_NBAR2_si51_spring_mga51_rde.tif
2017	Date extent indicator image	GDA94/MGA51	25	l8att_2017_NBAR2_si51_spring_mga51_rde.tif
2018	Date extent indicator image	GDA94/MGA51	25	l8att_2018_NBAR2_si51_spring_mga51_rde.tif
2019	Date extent indicator image	GDA94/MGA51	25	l8att_2019_NBAR2_si51_spring_mga51_rde.tif

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