Wetland Spatial Analysis

South East Grampians Cluster

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Cover:

(Top left: Litoria raniformis, Top right: brolgas feeding across a modified wetland, bottom: wetland scene near the Grampians)

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EXECUTIVE SUMMARY

Over 2200 wetlands were investigated across the South East Grampians wetland cluster. This area has been identified as a priority wetland region within the Glenelg Hopkins catchment management area. It spans approximately 85km extending from the Serra Range of the Grampians in the west, the lower Hopkins River in the south and the goldfields in the east, with Lake Bolac as a central feature.

A spatial analysis of extent of cropping has revealed that at least 55% of wetlands in the area are cropped to some extent. Of these, 21% have been entirely cropped, 16% have been cropped at the edge and across areas of the bed and 18% have been cropped at the edge only. In terms of area, approximately 24,000 Ha (60 %) of the total wetland area has been cropped to some extent, with 3784 Ha or 10% being entirely cropped. Cropping is higher in temporary systems, particularly temporary freshwater marshes and meadows which are the most common wetland type and are most likely associated with the critically endangered Seasonally Herbaceous wetland community. The rate of increase of cropping between 2016 to present is lower than for the period from 2010 to 2016 but is still increasing.

Investigation of wetland connectivity, based on two focal species (brolga and growling grass frogs), has identified priority sites for further investigating potential to maintain or enhance available breeding habitat. Recommended actions are outlined for 27 individual wetlands for a combination of:

- preliminary assessments of existing site values,
- hydrological restoration feasibility, and
- surveys to better inform species distribution, particularly for *Litoria raniformis*.

These recommendations form a starting point for further exploration however, the acquisition of additional data, combined with cross-referencing with existing data, is an ongoing task and will likely lead to additional priority sites for investigation.

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1. INTRODUCTION

The Glenelg Hopkins Catchment Management Area contains some of the highest density clusters of wetlands found across the state of Victoria. Since European settlement, approximately half of the wetland extent across the region has been lost (Glenelg Hopkins CMA, 2013). Whilst drainage and unrestricted stock access has contributed significantly to this decline, and still does, a more recent proliferation of cropping has seen a new and rapid wave of localised decline.

A spatial assessment undertaken in 2016 found that shallow, temporary freshwater wetlands were at higher risk of cropping than other wetland types and that the rate of impact had increased from 5% in 2010 to 45% in 2016 (Casanova and Casanova, 2016). Whilst wetlands have demonstrated recovery potential following removal of threats associated with drainage and stock impact, repeated and widespread cropping is far more deleterious and has potential to permanently remove impacted sites from the landscape (Casanova and Casanova, 2016). Given these types of wetlands make up almost three quarters of the wetlands found across the region (Glenelg Hopkins CMA, 2013), efforts to understand drivers of loss and identify priority actions for management in the short-term are critical for maintaining catchment health. In addition, wetlands of this type often include features consistent with the definition of "Seasonal Herbaceous Wetlands" which are listed as Critically Endangered under the Environment Protection and Biodiversity Conservation Act (EPBC), 2009).

Surveys of landholders in western Victoria found that a majority judged cropping or drainage of wetlands as unacceptable although perception changed with more business-oriented farmers considering it acceptable (Mendham and Curtis, 2019). There does appear to be a consensus that wetlands are "unproductive", in terms of what can be grown, and therefore detract from the value and profitable acres of the farm. Given the high prices paid for land there is a perceived imperative on getting a return on investment and the small margins farmers are currently faced with, seems more pronounced than previous years or generations (Curtis and Meis Harris, 2020). Interconnected with this are specific sustainability requirements for the European biodiesel industry, which is a major purchaser of Australian canola. Compliance requires that canola has not been grown on land converted after 2008 from areas such as primary forest or wooded land, nature protected areas, highly biodiverse grasslands, wetlands, and peatland.

Increasingly, there is opportunity to communicate unrecognised "asset" values in order to shift historical perceptions of "loss" associated with on-farm wetlands. Hence a continued and focussed targeting of landholders with wetlands for their recognition and active management beyond that required by law, and facilitation of learning opportunities around wetlands is recommended (Mendham and Curtis, 2019).

By improving a contemporary understanding of the trajectory and magnitude of the threat of cropping, and identifying and communicating the long-term impacts this has on regional wetland services, ongoing management, protection and restoration can be geared to minimise these impacts. Central to addressing this problem, and directing limited resources accordingly, it is vital that priority areas be identified and the Our Catchments Our Community (OCOC) project focuses on one such priority area. This spatial analysis project offers a "next-step" approach by drilling down and identifying which sites within the area constitute site-specific priorities in terms of exposure to threat and value in maintaining landscape function. At a landscape scale, connectivity assessment (e.g. Morris 2012) presents as a useful tool for identifying wetlands and wetland clusters of local and regional value with respect to catchment health and function.

This project aims to provide a contemporary snapshot of the magnitude of threat to a priority wetland region, and provide a framework for identifying key sites or locations for management in the short term which will maintain or benefit and allow direction of management actions toward the most critical elements.

1.1. Project objectives

The objectives of the project are to, in the south east Grampians cluster:

- Repeat the initial Casanova and Casanova (2016) assessment of cropping in 453 wetlands with the most recent Google earth images;
- Expand this analysis to all wetlands in the cluster, (an additional 1750);
- Assess the landscape connectivity of wetlands in the cluster using dispersal parameters for iconic wetland dependent species;
- Identify wetlands important in the context of current connectivity and assist focusing search effort to targets for restoration actions which may improve connectivity.

2. STUDY AREA, WETLAND FEATURES AND LANDUSE

The South East Grampians cluster contains approximately 2250 wetlands and spans an area running approximately 85km diagonally from east to west (Figure 1). Casanova and Casanova (2016) provide the following description of the landscape of this area

> *defined by a change to sloping topography and exorheic drainage to the north and the occurrence of a "stony rise" landscape and exorheic drainage to the south. The west is bordered by the Serra Range (Grampians) and lower Hopkins River, and the east is bordered by the goldfields, with a change in topography and soil type at Mt Emu Creek.*

Older volcanics (4 to 6 Ma) associated with the Hamilton basalt lava flows lie across the northern half of the project area while mid-term (1 to 3 Ma) and newer (0.3 to 1 Ma) deposits associated with the 'Dunkeld' and 'Rouse' flows respectively, occur across the southern sections (Joyce, 1999).

Fifty-nine percent of the total number of wetlands (57% by area) are temporary or ephemeral in nature although a large proportion (37%) have not been classified (Table 1). Forty percent (906) are small (less than 5 Ha), with the larger systems primarily being permanent freshwater and saline lakes (Figure 2). The largest feature is Lake Bolac, which is in approximately 1,400 Ha. Temporary freshwater marshes and meadows constitute the most numerous wetland type and also cumulative wetland area. The nationally critically endangered Seasonal Herbaceous Wetland community is commonly associated with this type of wetland. Likelihood modelling (Papas et al. 2016) reveals that, of the 300 wetlands in this area with a greater than 50% likelihood of occurrence, 280 are classified as temporary freshwater marshes and meadows.

Table 1 Representation of wetland types across the project area (Bold indicates features most likely associated with being Seasonal Herbaceous Wetlands)

Wetland type	Area (Ha)	% Total Area	Number	% Total Number
Permanent freshwater lakes	1819	4.57	11	0.49
Permanent saline lakes	2234	5.61	32	1.42
Permanent saline marshes and meadows	69	0.17	2	0.09
Temporary freshwater lakes	1588	3.99	62	2.76
Temporary freshwater marshes and meadows	**17564**	**44.11**	**1212**	**53.94**
Temporary freshwater swamps	236	0.59	15	0.67
Temporary freshwater swamps/marshes/meadows	6	0.02	1	0.04
Temporary saline lakes	1613	4.05	72	3.20
Temporary saline marshes and meadows	1778	4.47	14	0.62
Temporary saline swamps/marshes/meadows	23	0.06	2	0.09
Unknown	12888	32.37	824	36.67
TOTAL	39818		2247	

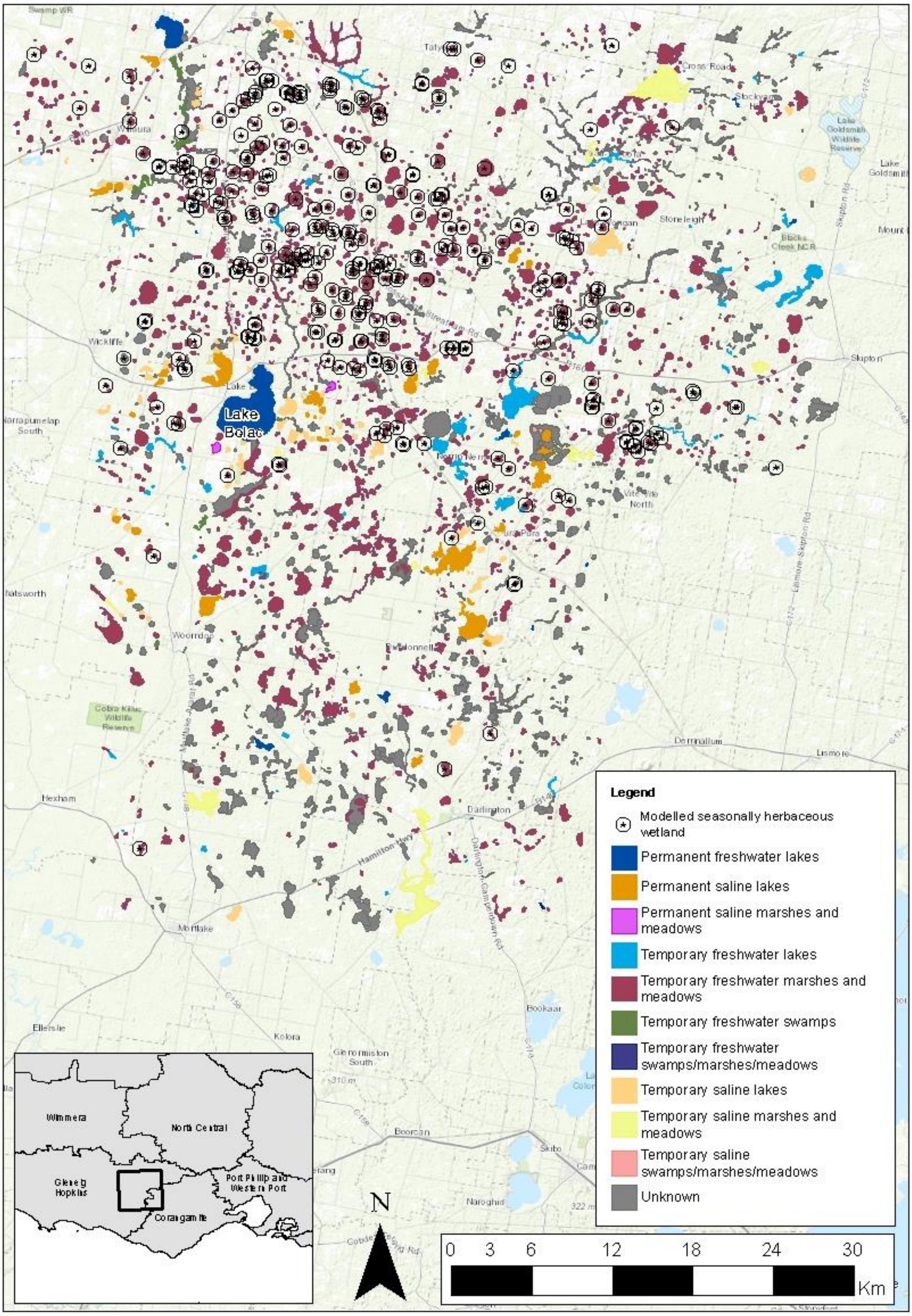


Figure 1 South East Grampians wetland cluster project area (defined by box) and wetland types, including wetlands with a likelihood of being seasonally herbaceous

Figure 2 Number of wetlands related to size class

Whilst it is difficult to quantify transitions from other landuses to cropping prior to 2010 (i.e. not distinguishable from other non-woody vegetation-production in Victorian Landuse Information System datasets) regional patterns available via a landuse history dataset (Sinclair et al. 2012) suggest cropping has been fairly widespread through the northern section of the project area since the early to mid 1900's, but has expanded through the southern sections since 2005/2006, and to the present day forms the predominant land use across the area (Figure 3).

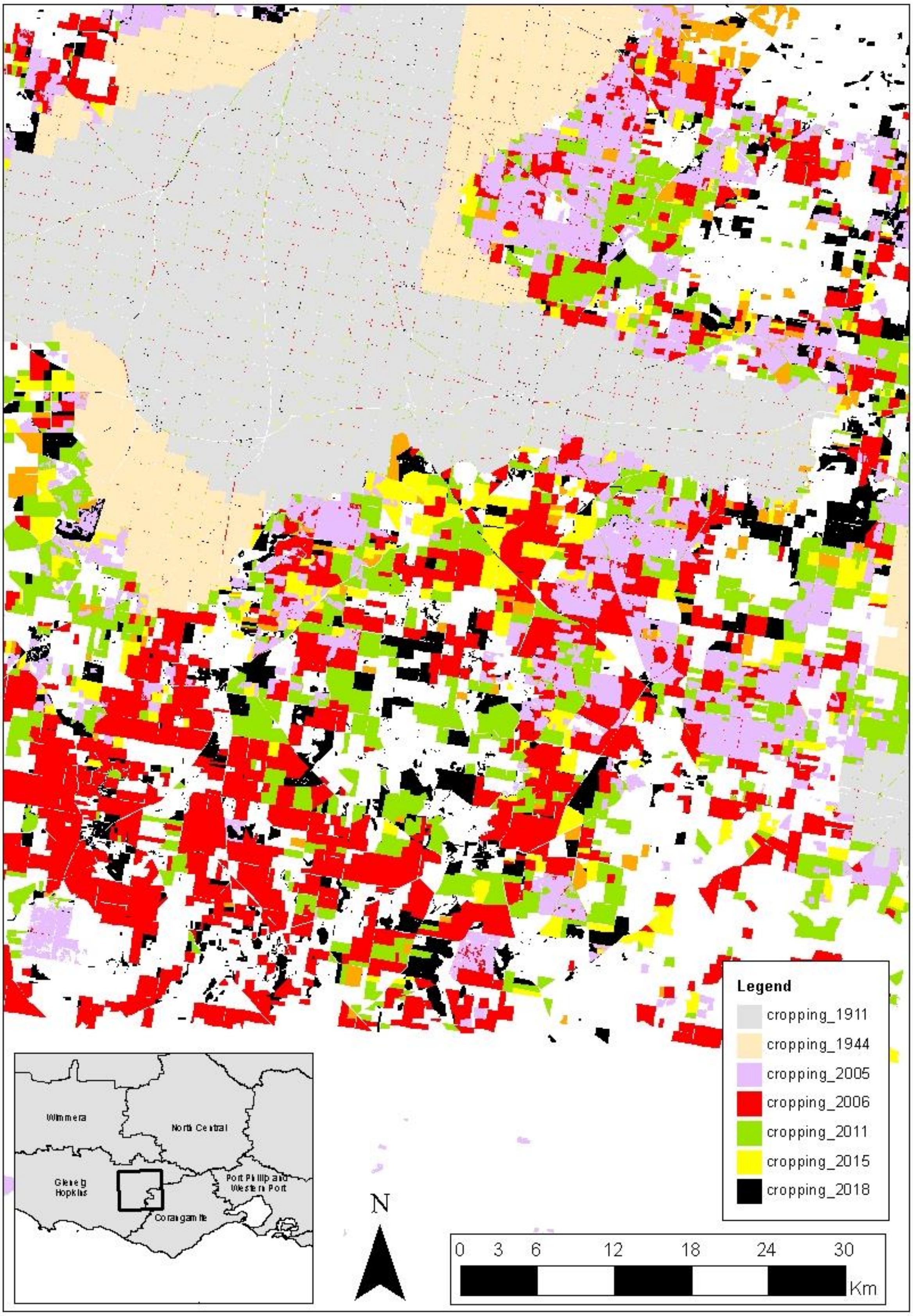


Figure 3 Comparison of extent of cropping across the project area showing additional areas where cropping has increased over time.(1911 to 2005 based on Sinclair et al. 2012, 2011-2017 based on Victorian Landuse Information System, 2018 based on Pelletier et al. 2019b)

3. APPROACH AND METHODOLOGY

3.1. GIS source data

This project draws on Vicmap base layers which are available at data.vic.gov.au (see Table 2). Features for investigation were selected from The Wetland_Current layer by Glenelg Hopkins CMA based on potential for exposure to cropping, and these formed the basis of cropping extent investigations. A subset of each layer was extracted for the area including and buffering the South East Grampians cluster by 5 km for connectivity analyses.

Table 2 Base GIS layers used for mapping and landscape analysis

Layer	Attributes used	Measure
Vicmap Hydro		Wet areas
Vicmap Property (Property_MP)		Property boundary
Vicmap Property (Parcel_MP)		Parcel boundary
Vicmap Transport (TR_Road)	CLASS Code	Major roads
	SAL_REGIME	Saline waterbodies and saline wet areas
Weltand_Current	WTRREG	Temporary and Permanent Water
	WETLAND_TY	Wetland type
Farm_Dam Boundaries		Permanent Water
Victorian Land Information System Landuse	LU-DESC	Type of landuse
Landuse-2018 (Pelletier et al. 2019)	Raster classes	Type of landuse

3.2. Determination of the extent of cropping in individual wetlands

A geospatial analysis to identify cropped wetlands and as-yet uncropped wetlands followed the method of Casanova and Casanova (2016). This used visual examination of available satellite imagery overlain by an existing wetland boundary shapefile. Dates of imagery varied across the study area (Figure 4) but provided an overall update to classifications provided by Casanova and Casanova (2016).

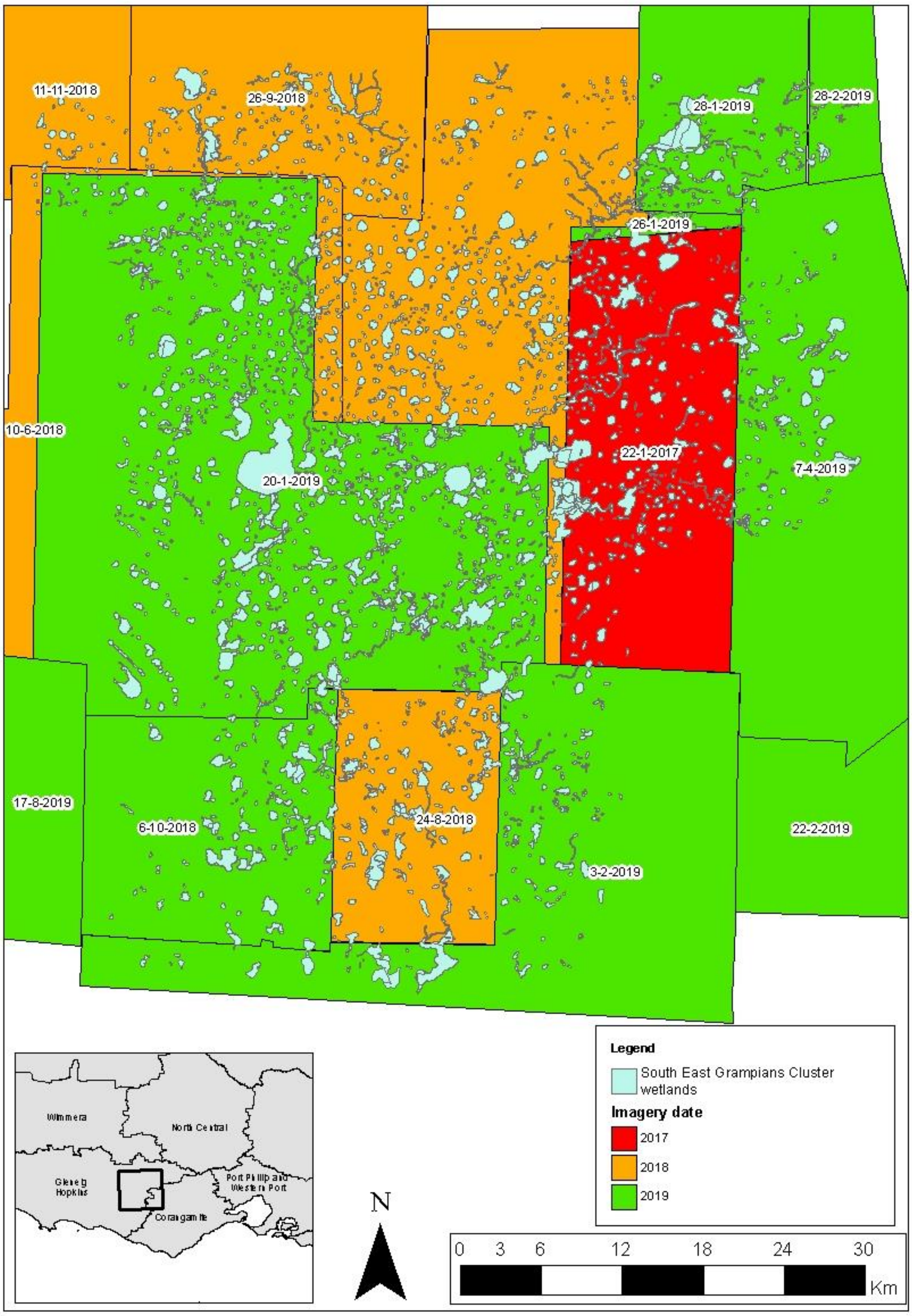


Figure 4 Dates of most recent aerial imagery available via Google Earth, across the project area

Cropping classifications were initially applied to 453 wetlands done in Casanova and Casanova (2016), followed by a further 1794 wetlands in the same cluster.

Efficiencies associated with the visual classification of the wetlands were achieved by using a bespoke dashboard that allowed rapid navigation to a wetland, where the dashboard presented the latest available google earth satellite imagery with the existing wetland polygon (Figure 5). The interface allowed efficient cycling through each wetland polygon to visually assess and assign a cropping class, identify any relevant surface features and digitise visibly cropped areas (Figure 6). The digitising interface included functionality to allow a “cropped” or “wetland” area to be drawn over the top of the existing polygon. This area was spatially clipped by the existing wetland polygon to avoid requiring the team to manual editing or movement of vertices on the existing polygon. This method had the following benefits:

- Eliminated delays associated with finding specific wetlands (e.g. compared to map navigation in a desktop GIS);
- Sped up tasks associated with polygon edits by defining clipped areas instead of manually reshaping polygons;
- Allowed multiple users to classify separate wetlands simultaneously;
- Simplified the process to finding “un-classified” wetlands (the “next” button selects the next wetland ID that hasn’t been classified);
- Improved data quality and reproducibility due to predefined classification option buttons;
- Streamlined the internal review process by automating the creation of “wetland reports” that presented every wetland alongside its classifications; and
- Maintained a complete audit trail for edits.

Following the review and classification of the first 453 wetlands, it was identified that some additional features of interest could be captured. The flexibility of the bespoke dashboard meant that adding these additional choices to the interface was straightforward. Overall, the dashboard tool allowed for an efficient and consistent method of capturing GIS information, tracking the associated works and editing polygon features.

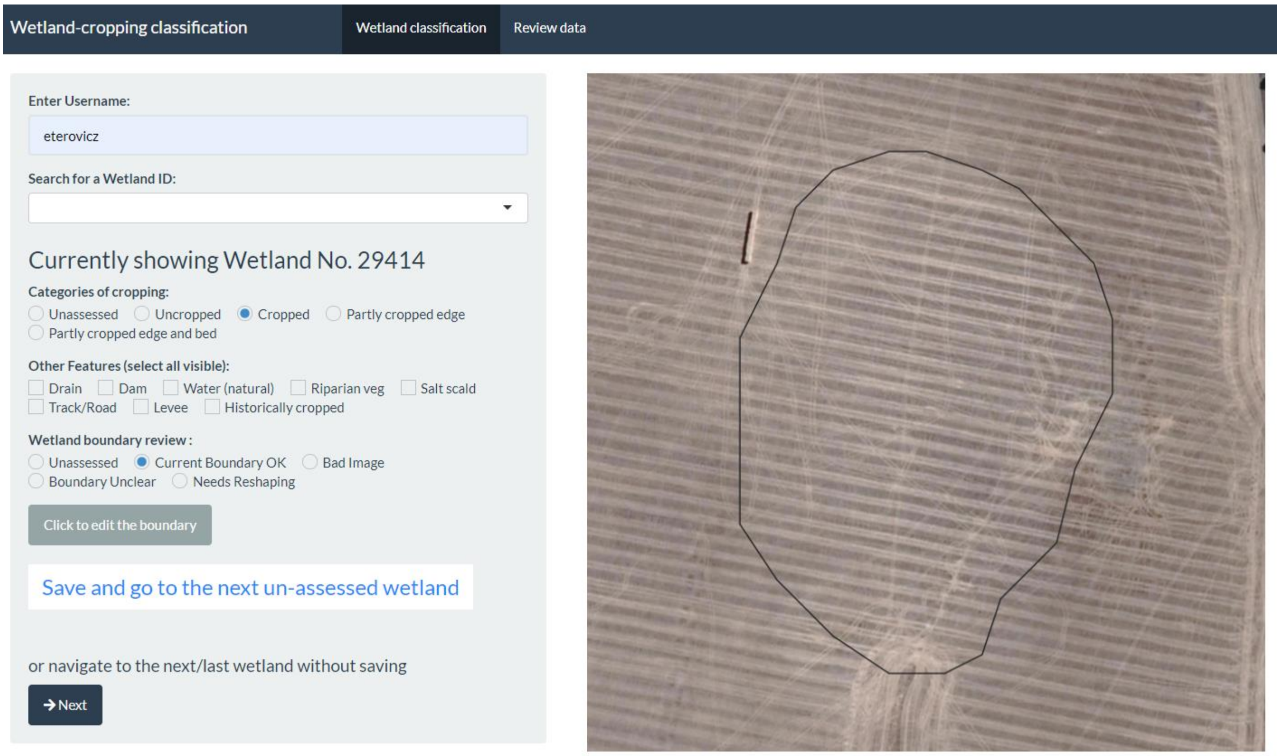


Figure 5 Screenshot of the wetland-cropping classification tool (cropped wetland example)

Figure 6 Screenshot of the digitising tool (blue polygon denotes the cropped area)

3.2.1 Determination of cropping in individual wetlands

Broadacre cropping in Google Earth images was distinguished by the presence of GPS-guided rows in aerial images. What was observed in any given image depended on the type of crop, the time of year and season. For instance, if the image was taken in a wet year, then the wetland would appear darker or be covered in water, despite it being cropped. Generally, grain crops appeared as white/silver while canola was yellow.

Casanova and Casanova (2016) describe a GIS approach to classifying wetlands as 'Uncropped', 'Cropped', 'Partly cropped edge' and 'Partly cropped edge and bed' using visual examination of the latest available satellite image overlain by an existing wetland boundary shapefile. Examples of these categories are presented in Figure 7 and described below.

Uncropped – No crop present and an absence of GPS-guided rows (Figure 3a). In this example, the wetland boundary is identified by a black polygon. There is a dam dug within the wetland with a connecting drain between the dam and adjacent cropped area.

Cropped – Visual indication of cropping over the entire wetland (Figure 7b). In this example, the cropped area is characterised by a darker colour as a result of varying soil conditions and waterlogging during crop growth

Partly cropped edge – Evidence of infringement of cropping into a wetland margin (Figure 7c)

Partly cropped edge and bed – Cropping evident through a section of the wetland (Figure 7d). In this example, the wetland has been bisected by a property boundary. Most of the wetland is characterised by cropped areas with the uppermost segment being uncropped.

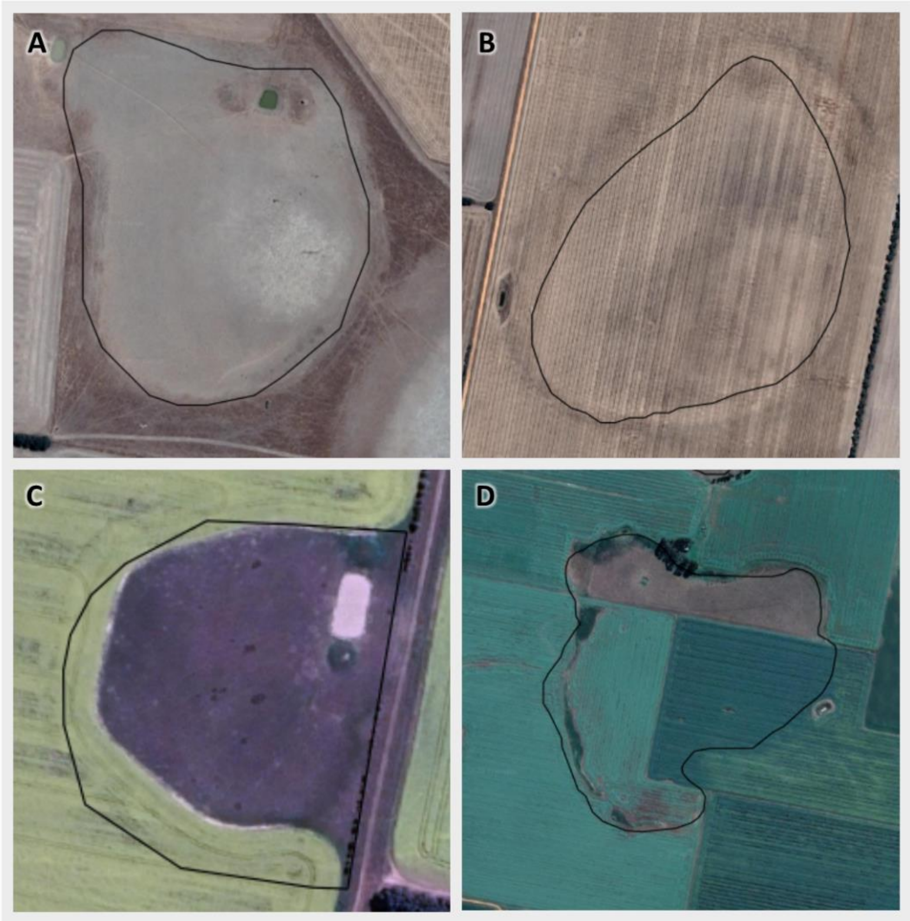


Figure 7 A) Uncropped wetland, (B) fully cropped wetland, (C) wetland cropped at the edge and (D) wetland cropped at the edge and across the bed (paddock boundary)

3.2.2 Classification methodology

The cropping classification methodology and workflow is summarised in Figure 8. The wetland-cropping classification process primarily comprised four steps:

Assigning a cropping category – Cropping classification utilised the Casanova and Casanova (2016) GIS approach to classifying wetlands. Occasionally, satellite image quality made it hard to discern between cropped and uncropped areas, particularly for larger wetlands with poorer spatial resolution. In these instances, large wetlands were analysed in QGIS (Version 3.12-Bucharest) with the zooming tool allowing for a more accurate examination.

Digitising cropped areas – Only cropped areas in wetlands classified as being 'partly cropped edge' or partly cropped edge and bed' were digitised. This was done to isolate wetland segments from cropped segments for connectivity analysis as well as provide an indication of total cropping area compared to the entire wetland.

Selecting visible features – Surface features capable of influencing wetland condition were also noted during cropping classification. This included dams, levees, drains, roads, riparian vegetation, open water bodies, salt scald and areas that looked to have been cropped in the past. Historically cropped areas were particularly noted given the long-term biological impacts associated with cropping and wetland recovery times. In some cases, Goggle satellite imagery made current cropping and historical cropping differentiation difficult, as with salt scald and surface water.

Wetland boundary review – The final stage of classification involved visual inspection of the wetland polygon boundaries. Wetlands with unclear boundaries due to certain landscape features and poor image quality were noted. Poorly drawn wetlands were also identified during the classification and noted as needing reshaping.

Overall, 2247 wetlands were classified according to varying degrees of cropping utilising the GIS approach as described by Casanova and Casanova (2016). Once finalised, all information captured in the dashboard was exported and consolidated with the existing wetland shapefiles. Summary statistics were also run based on the cropped area for each wetland. Newly created attributes from the wetland cropping classification include:

User – CDM Smith staff performing the classification

Date – date the classification was completed

Cropping category – as per the four categories highlighted in Figure 3

Options – wetland boundary review outputs

Others – all identified features within each wetland polygon

Areasrc – area (m^2) of the original wetland polygon

Area – area (m^2) of the clipped/reshaped polygon

Areatype – either “cropped area” or “wetland area” (partly cropped wetlands will have two polygons)

Areaprop – proportion of new polygon compared to the original wetland area

The resulting layer “CDMSmith_classification” is provided as an output for this project and forms the basis for additional connectivity modelling (Section 3.3).

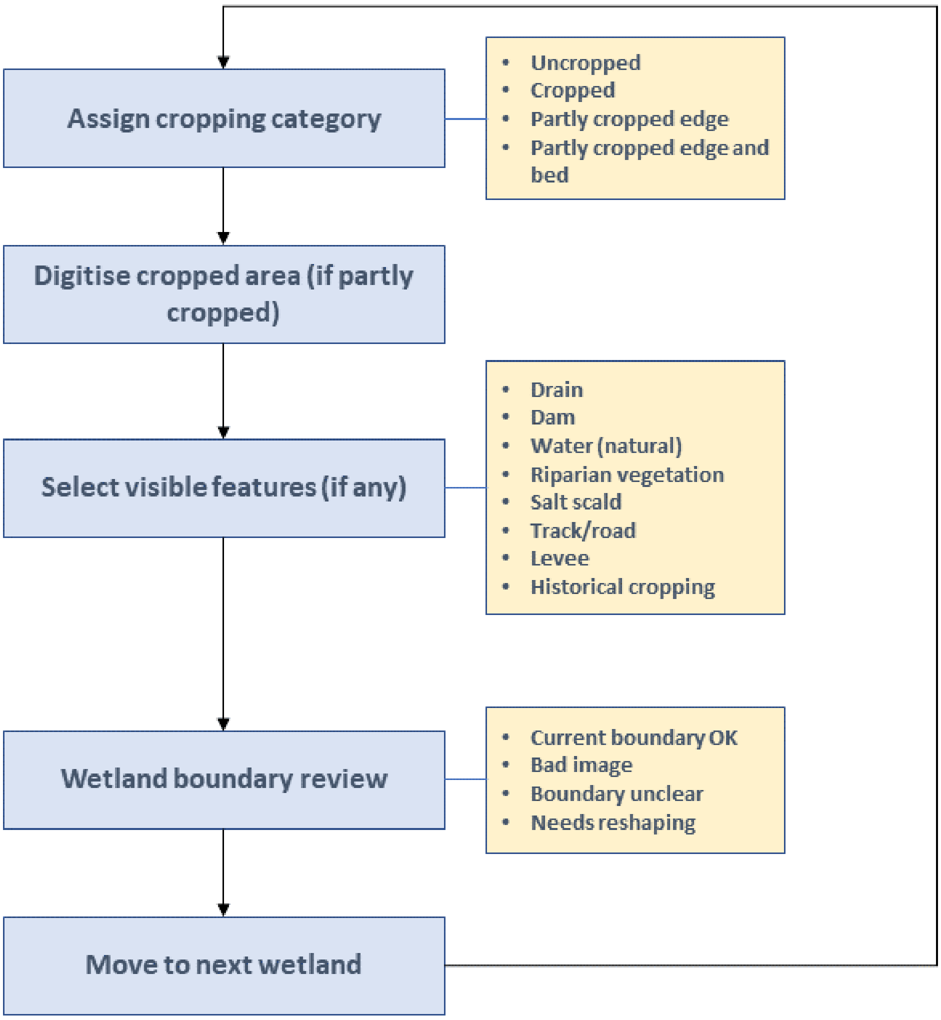


Figure 8 Wetland-cropping classification workflow

3.3. Connectivity

Wetland connectivity can be measured at different scales. Connectivity modelling often focusses on specific elements of flora and fauna, and thus entails both the distances different taxa can disperse and their capacity to disperse across different types of landscapes and barriers. Specific information relating to connectivity drivers in Victorian wetland flora and fauna are reviewed by Morris (2012).

Wetland connectivity models have been developed for Victorian wetlands by Morris et al. (2012) for waterbirds, amphibians and plants. This modelling is based on the assumption that every mapped wetland is functional and is of equal value as a stepping stone across the landscape. The layers which have been developed are not available in a format which allows updating based on new information (e.g. functional change to wetlands as a result of cropping). Hence a primary consideration for this project requires recalculation to reflect our updated assessment of wetland cropping and overall functionality.

In addition, the underlying assumptions about connectivity patterns for waterbirds as modelled by Morris et al. (2012) incorporate large dispersal distances which, across the range of this study area, can be considered largely homogenous. Hence the overall approach of defining both habitat and landscape permeability metrics remains relevant but the method and underlying GIS layers require further investigation and development in order to provide higher resolution across the study area. For the purposes of modelling connectivity across this study area, we have chosen to focus on two charismatic but threatened species (growling grass frogs – *Litoria raniformis* and brolga - *Grus rubicunda*) which typify wetland dependent species with quite specific breeding requirements but show variable adult dispersal capabilities. Furthermore, these species are well known and appreciated amongst local communities in terms of their declining status and as indicators of wetland loss through time. An overview of species biology and considerations for informing potential habitat and connectivity assessments from existing GIS information is provided below.

For the purposes of connectivity modelling across the project area, habitat areas were defined using the updated wetland classifications with respect to cropping. An additional area covering a buffer of 5km outside the study area was included from all datasets to account for edge. Visual inspection was applied for non-permanent and unknown non-permanent wetlands to categorise cropping and salinity (e.g. salt scalds) in the additional area.

3.3.1 Amphibian (*L. raniformis*) connectivity modelling

Growling grass frog habitat prediction has identified that a combination of wetland hydrology, complexity of aquatic and fringing vegetation and water temperature are important variables (Wassens 2010). They primarily need still or slow moving water with mats of floating and submerged plants. Favourable habitat features include abundant aquatic vegetation, rock piles around the margins and in the shallows, minimal tree canopy cover, moderate to low salinity, and water for at least six months of the year over the breeding season (DELWP, 2017). Recent observations have identified that adult frogs seek refuge in long pasture grass surrounding wetlands during their dryer phases (Greg Kerr pers. observation at Green Swamp, 2020), indicating that riparian vegetation may be an important consideration. Where several waterbodies occur in close proximity, metapopulation dynamics appear to be important (Heard et al. 2004). Localised extinction of the species within a geographic area is determined by a combination of inability to persist within or around a given wetland, pool or pond and also limitations on colonisation from other populations. Site persistence depends primarily on wetland size, permanence and cover of aquatic vegetation; extinction probability is lower in larger permanent wetlands with a high cover of aquatic vegetation, particularly submerged and floating species (Heard et al. 2010). The colonisation rate depends on the number, proximity and size of neighbouring populations, combined with barriers to dispersal (Heard et al. 2013), all of which dictate how frogs can move between sites as conditions change.

The adult phase of the species is relatively mobile, being able to move up to one kilometre in 24 hours. Breeding begins in August when calling males begin being able to attract females, although females usually don't begin to lay eggs until October or November. Eggs are laid in spring, so the frogs need water to last over the summer for their tadpoles to develop (DELWP, 2017). The age at first breeding is about 1 year and the generation length is estimated to be three to six years (Heard et al. 2012)

A key consideration in determining persistence of populations therefore relies on determining elements of permanent to semi-permanent freshwater, combined with aquatic vegetation, riparian ground-cover and pathways for connection between habitat elements (ephemeral freshwater wetlands associated with dams, riverine pools and deeper, vegetated drains).

Spatial investigations of connectivity were undertaken by defining habitat elements (as above) and landscape permeability between habitat elements. Habitat in this sense is defined as potential breeding sites where there is an interaction between the margin of permanent freshwater systems (natural and artificial) and nearby ephemeral wetlands.

3.3.1.1 Habitat and permeability layers

A *L. raniformis* habitat element layer was developed by creating and merging both the re-classified wetlands (uncropped Section 3.2) and a permanent freshwater margins layer. This layer was created using both the Permanent Freshwater categories in the Water regime field of the wetlands_current layer and the farm dams layer. Features were modified to extract a 25m perimeter, to better reflect zones of likely occupation for both adults and tadpoles, i.e. with a higher likelihood of being vegetated as opposed to open water. Saline areas were identified using the salinity regime field in the wetland layer, or where unknown, visually examined for evidence of salinity (e.g. salt scalds) and these areas were saved as a layer (saline_wetlands). Permanent freshwater margins intersecting saline wetlands, or within 0.5 km of saline wetlands were removed from the permanent freshwater margins layer. In summary, three additional layers were developed to represent hydrological features:

- Permanent, freshwater wetlands (from the Current_wetlands layer)
- The Farmdam layer (with those intersecting or within 500m of saline wetlands removed),
- Non-permanent, freshwater wetlands which were categorized as uncropped (Section 3.2.2).

Other wet areas were defined from the Vic Map Hydro layer with areas intersecting other layers above removed.

A landscape permeability layer was developed using a combination of estimates of likelihood of movement of adults across different landscapes and barriers. These features were underpinned by a landuse layer developed using the Landuse_2017 layer and manual correction to reflect more contemporary landuse (specifically increases in areas of cropping) as informed by the Monash Veg Map (Pelletier 2019a, Pelletier 2019b). An intersect analysis (ArcGIS) was undertaken for the landuse layer was intersected with the freshwater_wetlands, permanent_freshwater_margins, saline_wetlands and wet_area layers to provide a broken down version of the landuse layer which reflected relevant landscape units in addition to property and easement boundaries. Road easements were categorised in terms of the underlying road Class Code to identify major roads. Landuse types were updated where cropping was identified in previously classified grazing and/or wetland parcels. The permeability and resistance rankings for each landuse category are provided in Table 3 and an overview of landtypes across the study area is provided in Figure 9.

Table 3: Landuse and land feature permeability and resistance scores

Land type	Permeability score	Resistance Score
Dry crop	1	10
Wet crop	2	7
Dry pasture/grassland	2	7
Wet pasture/grassland	7	2
Habitat patch	10	1
Urban/industrial	1	10
Major Roads	1	10
Minor Roads	2	7
Saline Wetlands	1	10

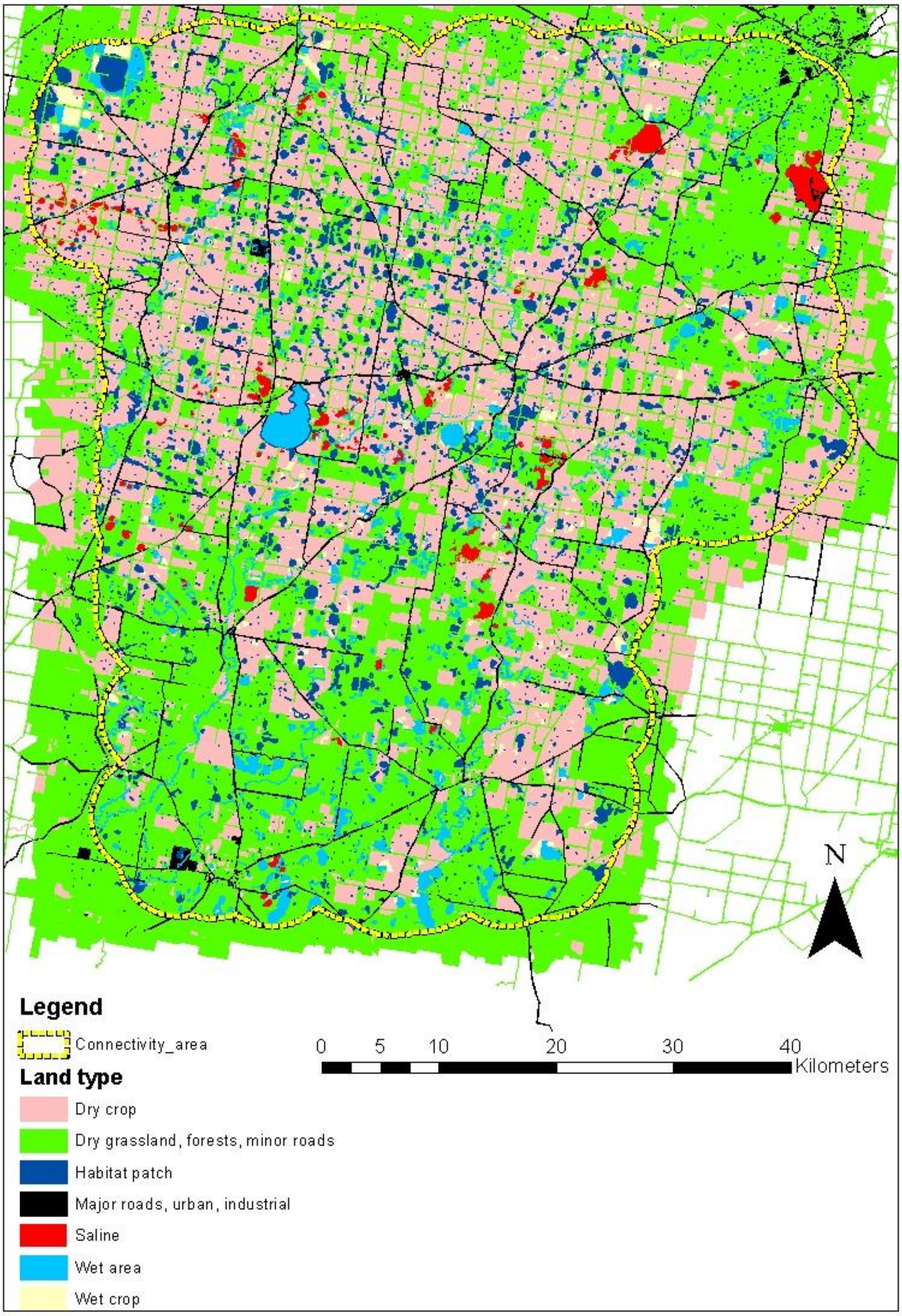


Figure 9: Land types inferred from landuse mapping and feature delineation across the project area and additional connectivity area (within yellow dashed line)

A permeability layer was developed by converting the landscape permeability vector layer to a raster with 25m grid cells. Focal statistics were used to generate mean pixel scores for a neighbourhood area of 3km around each 25m grid cell, creating a neighbourhood permeability layer.

A resistance layer was produced using the inverse score of the permeability scores (Table 3) to generate a 25m grid raster.

A cost distance layer was produced by undertaking a cost distance analysis using the ArcGIS toolbox function using the frog_breeding_habitat vector layer features as source data and the resistance layer as the input cost raster.

Both the resistance and cost distance raster layers were reclassified using geometric interval classification to produce scores from 1 to 100 (100 classes) (see ESRI Help, esri.com.au, for more information on this process). Resulting layers are provided in Figure 10 and Figure 11

The final connectivity layer was produced by merging the resistance and cost distance layers using the raster calculator function in ArcGIS, via the following formula to give a score out of 100.

$$Connectivity = Permeability - Cost$$

The result was a layer indicating areas where permeability was high and cost distance (likelihood of movement around breeding habitat) was low. Morris et al. (2012b) suggest that this combined approach is useful in demonstrating potential areas for habitat improvement outside of the presumed dispersal range of modelled habitat patches.

Individual wetland features were assigned a mean score for all connectivity cells underlying the polygon boundary to arrive at a final connectivity score for each wetland in the project area.

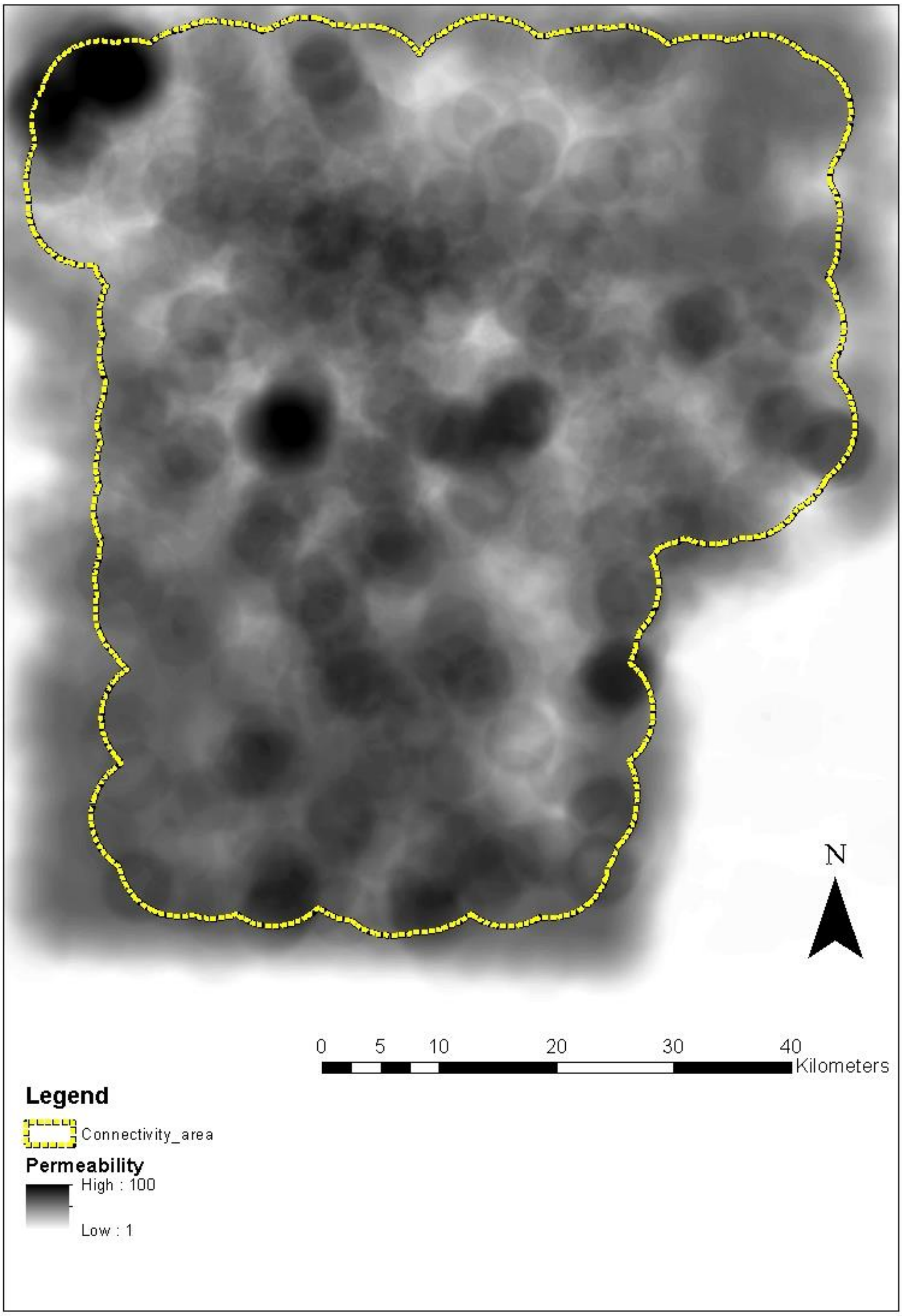


Figure 10 Permeability layer for modelled* L. raniformis *movement across the study area

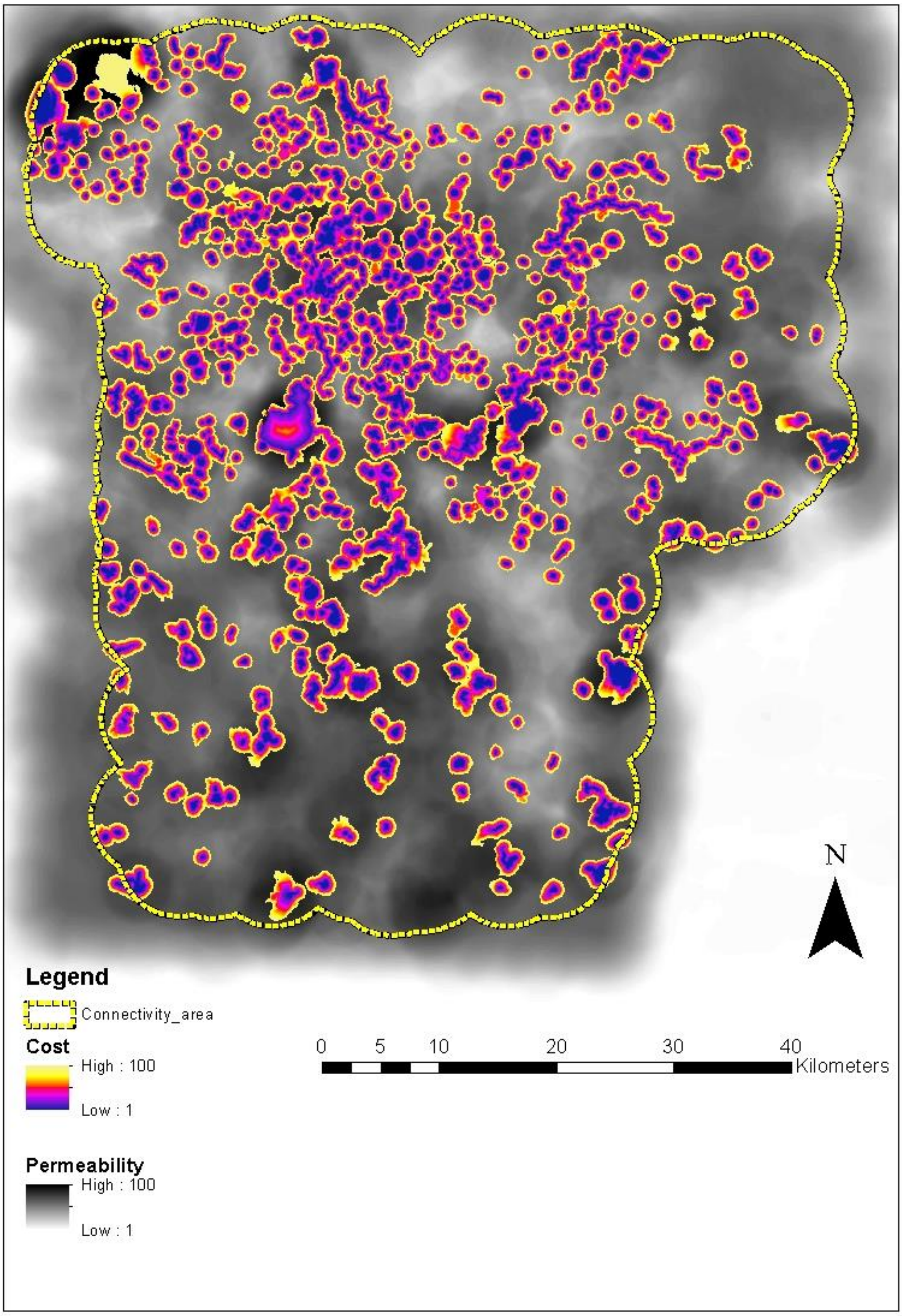


Figure 11 Cost distance layer for predicted **L. raniformis** ***movement across the project area***

3.3.2 Brolga connectivity modelling

Brolga habitat use varies with life history and follows an annual cycle. Adults generally move from non-breeding to breeding areas between May to June whereas juveniles may move over an extended time i.e. May to August (Veltheim, 2019). The pattern of movement also differs between areas. For example, Veltheim (2019) observed birds from east of the Hopkins River to undertake partial migration whereby some birds moved a relatively short distance (20km) between breeding and non-breeding areas and a majority stayed resident at non-breeding sites. In contrast, birds from Willaura and Penshurst largely relocate to different regions on a seasonal basis. This latter pattern appears to coincide with fluctuations in areas of habitat suitability i.e. birds concentrated during times of lower habitat availability (March to June and October to January). These patterns are also influenced by annual temperature and rainfall patterns.

While brolga nest and roost in wetlands (Marchant and Higgins, 1993) they forage across multiple habitats, primarily using freshwater wetlands and agricultural crops (Marchant and Higgins 1993, Pizzey 1994, King 2008).

Breeding brolgas prefer shallow, seasonally inundated freshwater marshes and meadows that are well vegetated, and herb dominated (Corrick 1982, White 1987, Marchant and Higgins 1993, Herring 2001, Myers 2001). Wetlands less than one hectare in size are generally considered unsuitable as nesting habitat for Brolga (White 1987, Meine and Archibald 1996). Current recommendations for protecting, creating and enhancing brolga breeding habitat focus on managing single wetlands (Arnol et al. 1984, Herring 2001, Du Guesclin 2003), whereas Veltheim’s (2019) results suggest that creating and restoring wetland complexes (clusters of wetlands) is more likely to improve breeding success. The risk of predation for chicks is typically elevated when they are walking between habitats, suggesting that wetlands should be as close to each other as possible. Hence, a mean distance (0.4 km per day) walked by brolga chicks (Veltheim et al. 2019) could be used as a guide when identifying suitable radii between wetlands within a cluster around breeding sites. The chicks fledge 90-100 days after hatching (White 1983, Marchant and Higgins 1993).Veltheim (2019) concluded that the presence of at least three wetlands within home ranges, and proximity of other wetlands to nest or roost sites may therefore be important for breeding success (wetlands within 400–900 m of each other, based on mean distances moved daily and between night roost wetlands. In addition to distance, fences pose a potential barrier to chick movement (e.g. Herring, 2005). This has recently been recognised and promoted among wetland restoration workers, specifically with respect to ringlock or mesh fences, which are more impenetrable to chicks passing from one area to another than standard wire fences.

Based on the above considerations, it has been determined that important influences in determining brolga breeding likelihood across the project area include:

- Areas of freshwater, temporary wetlands with intact or relatively intact vegetation communities (i.e. uncropped), and
- Lack of fences and between wetlands within approximately 0.5km to 1.0 km from wetland edges, specifically fences designed for sheep containment.

The key habitat element to assess is therefore the number and area of temporary freshwater wetlands which are not cropped and these have been filtered from the CDMSmith_classification layer using the Water_regime (removing permanent) and Salinity regime (Fresh) attributes, combined with selection of only those wetlands (or specific areas of partially cropped wetlands) which are categorised as “uncropped” in the current cropping determination analysis and not identified as being historically cropped.

3.3.2.1 Brolga permeability and cost-distance layers

Land units, as developed for the amphibian layers, were reclassified and scored according to the likelihood of chicks to move across terrain. This ranges from a high score of 10 at breeding habitat patches, through to 1 across urban, industrial and major road components of the landscape. A full breakdown of land categories and permeability and resistance scores is provided in Table 3.

Table 4 Land use categories and weightings for resistance and permeability with respect to chick movement

Land category	Resistance	Permeability
Conservation	2	7
Cropping	2	7
Deep water	7	2
Property boundaries (grazing)	5	5
Property boundaries (other)	2	7
Forestry	5	5
Grazing	2	7
Habitat patch	1	10
Lake margins	2	7
Major roads	10	1
Minor roads	7	2
Urban and Industrial	10	1

To determine an estimate of fencing in proximity to wetlands, the Vicmap Property layers have been chosen to indicate likelihood of fencing, combined with contemporary land categorisation as above. Property boundary intersecting grazing properties were weighted higher than for cropping areas, in an attempt to reflect both likelihood of fence maintenance and potential for use of less penetrable fences i.e. constructed and maintained to contain stock. Whilst roads also present a potential barrier, the property layer accounts for this in the form of road easements, although major roads were weighted higher to reflect additional restrictions associated with higher traffic use. Elements relating to adult dispersal are difficult to predict across the study area and rather than incorporate additional considerations relating to adult dispersal into a landscape modelling framework, potential constraints such as proximity to windfarms and powerlines, should form the basis of evaluating sites post identification through connectivity modelling as outlined below.

The overall land category feature layer was converted to a 25m grid raster where each grid value was assigned according to the underlying land category score.

Permeability layers were developed using two different neighbourhood areas (0.5 and 1km) and combining the layers.

A resistance layer was produced using the inverse score of the permeability scores (Table 3) to generate a 25m grid raster.

A cost distance layer was produced by undertaking a cost distance analysis using the uncropped, freshwater temporary features from the reclassified wetland later as source data and the resistance layer as the input cost raster. The maximum distance was set at 1km to reflect literature estimates of chick movement (see above).

Both the permeability (Figure 12) and cost distance (Figure 13) raster layers were reclassified using geometric interval classification to produce scores from 1 to 100 (100 classes).

The final connectivity layer was produced using the same methods outlined for *L. raniformis* (Section 3.3)

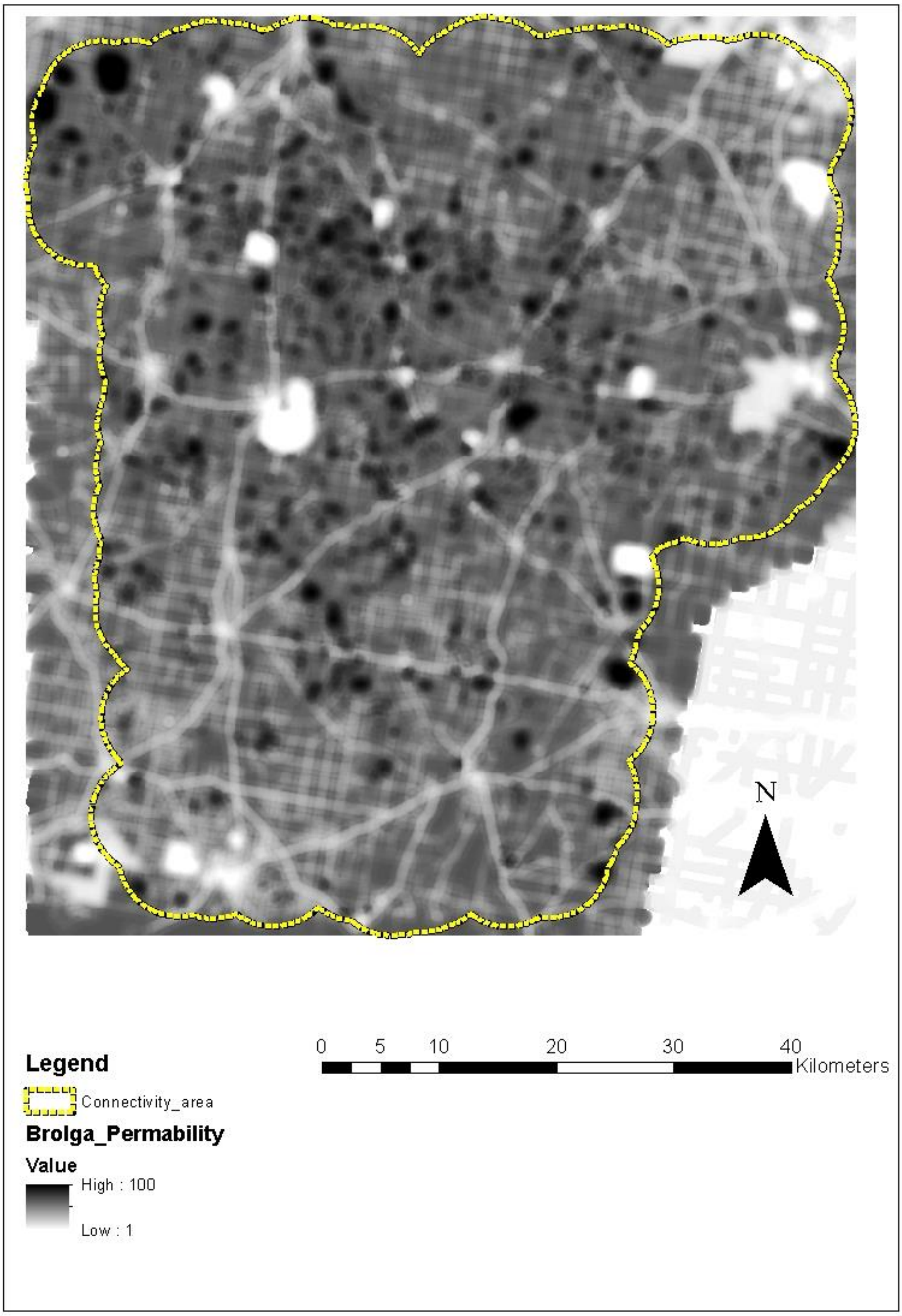


Figure 12 Permeability layer for modelled brolga chick movement across the study area

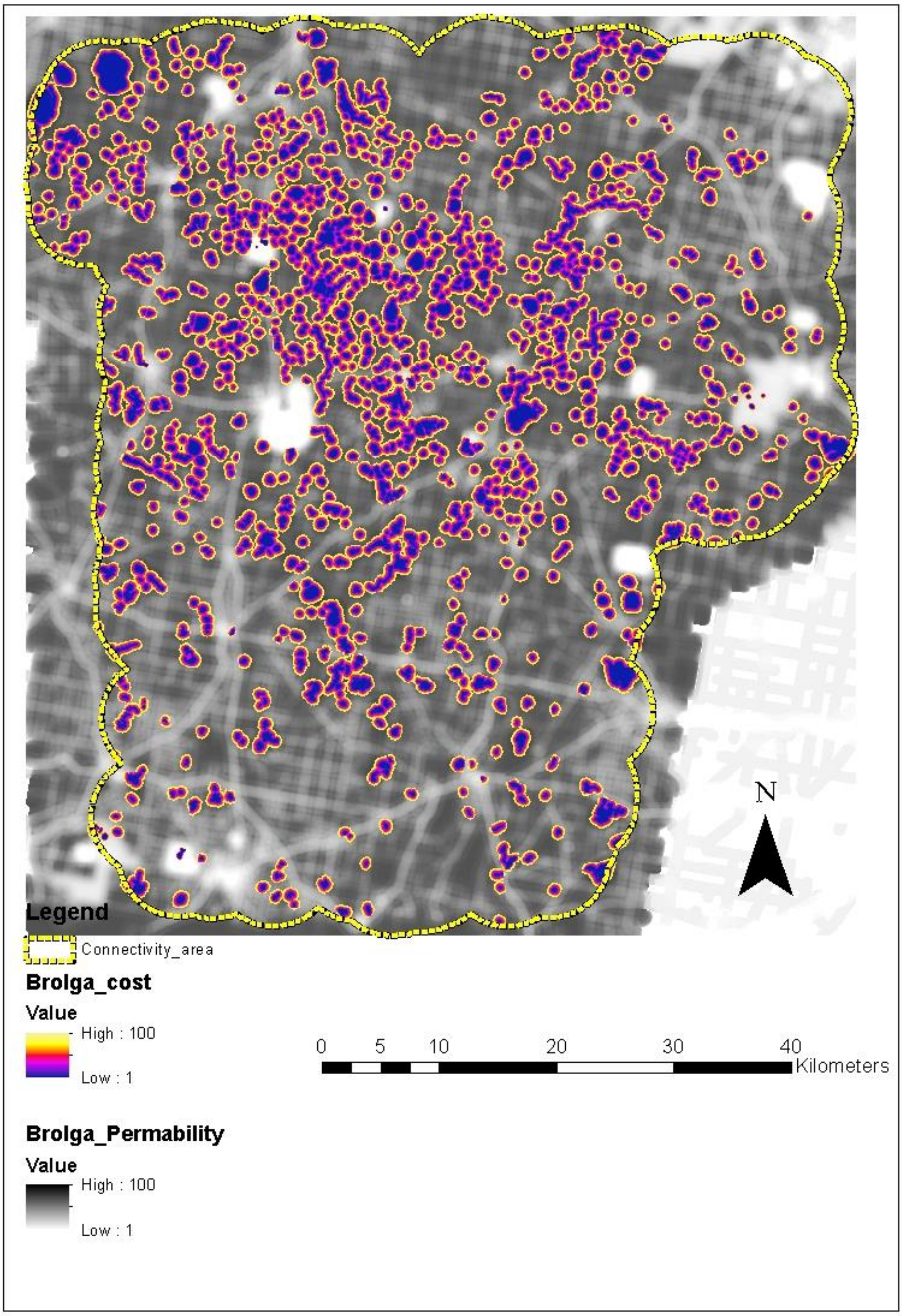


Figure 13 Cost distance layer for predicted brolga movement across the project area

4. RESULTS

4.1. Extent of cropping and change over time

For the 2247 wetlands investigated, 55% were cropped to some extent. Twenty-one percent have been entirely cropped, 16% have been cropped at the edge and across areas of the bed and 18% have been cropped at the edge. In terms of area, approximately 24,000 Ha (60 %) of the total wetland area has been cropped to some extent, with 3784 Ha or 10% being entirely cropped (Table 5).

Table 5: Incidence of cropping in assessed wetlands in number and area.

Land use within the wetland	Number of wetlands	Proportion (%)	Area of wetlands (Ha)	Proportion of area (%)
Uncropped	1019	45	15947.3	40
Partly cropped edge	414	18	8780.9	22
Partly cropped edge and bed	353	16	11214.3	28
Fully Cropped	461	21	3874.1	10
Total number of wetlands assessed	2247		39816.6	

Similar to Casanova and Casanova (2016), incidence of cropping was higher in rainwater filled wetlands i.e. those with a low or medium groundwater influence (Table 6). Equally, cropping is more likely for palustrine wetlands compared to lacustrine systems. For systems where groundwater influence or aquatic system status is unknown or uncategorised in the wetlands layer, cropped wetlands are more common than uncropped wetlands. This may reflect that characteristic features in wetlands which were cropped during the time of classification were not visually apparent.

Table 6: Incidence of cropping in assessed wetlands in relation to ground water influence and aquatic system as described in the wetlands layer attributes table. Data is given as number of wetlands and percent of wetlands in each category (within each column) to determine the proportion of wetlands in each category that were subject to cropping

Landuse within the wetland	Groundwater influence				Aquatic system		
	High	Moderate	Low	Unknown	Lacustrine	Palustrine	Unknown
Uncropped	180 (68%)	370 (37%)	80 (40%)	389 (49%)	131 (74%)	540 (40%)	348 (48%)
Partly cropped edge	46 (17%)	**184 (19%)**	**35 (17%)**	149 (19%)	28 (16%)	**239 (18%)**	147 (20%)
Partly cropped edge and bed	23 (9%)	**169 (17%)**	**22 (11%)**	139 (18%)	15 (8%)	**208 (16%)**	130 (18%)
Fully Cropped	15 (6%)	**268 (27%)**	**65 (32%)**	113 (14%)	4 (2%)	**354 (26%)**	103 (14%)
Total number of wetlands per category	264	991	202	790	178	1341	728

In terms of water regime, cropping was higher in temporary systems. This pattern holds for both freshwater and saline systems. In terms of wetland type (wetland typology, DELWP 2016), cropping of the entire wetland was highest in temporary freshwater marshes and meadows, which make up the most numerous wetland type across the study area (Table 7). These systems are less reliably inundated, less obvious to the average farmer and also less likely to yield failed crops given the lower frequency and duration of inundation. These systems are also affiliated with the critically endangered Seasonal Herbaceous Wetlands community and hence illustrate the overall level of threat this landuse transition has and currently does hold for future preservation.

Initial classification of Victorian wetlands was based on the Corrick wetland classification system (Corrick and Norman, 1976), prior to reclassification using the Australian National Aquatic Ecosystem in 2014 (DELWP, 2016). Hence, comparisons with historical investigations of extent of cropping rely on the Corrick classification (see Table 8). The relationship between Corrick type wetlands and cropping are:

- freshwater meadows are the most numerous and also most cropped features, with approximately one-third entirely cropped and two-thirds subject to some level of cropping (fully cropped, edge and bed, and edge),
- Shallow freshwater marshes, which make up the second most abundant type, show the second highest proportion of cropping, with approximately half cropped to some extent,
- Saline wetlands (semi-permanent and permanent saline) have the highest number of uncropped wetlands,
- Freshwater permanent wetlands have a slightly lower proportion entirely cropped than saline wetlands, but more numerous edge and partial bed cropping,
- Deep freshwater marshes have a lower incidences of entire, bed and edge cropping compared to shallow freshwater meadows and marshes but higher rates of cropping compared to both the permanent freshwater and saline systems, and
- Wetlands that have been uncategorised show incidences of cropping consistent with shallow freshwater systems.

It terms of historical comparisons across three time periods for wetlands in the project area, the rate of increase in cropping appears higher in the intervening period between 2010 (WETLAND_1994 layer) and 2016 Casanova and Casanova (2016) (14%), than for the period 2016 to current (this study) (3%) (Table 9). The rate of increase of cropping for sites that weren't assessed in 2010 (unassessed Table 9) shows a similar trend for the period 2016 to current (increase of 4%).

Table 7: Incidence of cropping in assessed wetlands in relation to water regime as described in the wetlands layer attributes table. Data is given as number of wetlands and percent of wetlands in each wetland typology (within each column) to determine the proportion of wetlands in each category that are subject to cropping.

Landuse within the wetland	Permanent freshwater lakes	Permanent saline lakes	Permanent saline marshes and meadows	Temporary freshwater lakes	Temporary freshwater marshes and meadows	Temporary freshwater swamps	Temporary freshwater swamps/ marshes/ meadows	Temporary saline lakes	Temporary saline marshes and meadows	Temporary saline swamps/marshes/meadows	Unknown
Uncropped	10 (91%)	27 (84%)	2 (100%)	34 (55%)	460 (38%)	13 (87%)	1 (100%)	60 (83%)	6 (43%)	2 (100%)	404 (49%)
Partly cropped edge	1 (9%)	5 (16%)	0	13 (21%)	**220 (18%)**	2 (13%)	0	8 (11%)	**3 (21%)**	0	**162 (20%)**
Partly cropped edge and bed	0	0	0	13 (21%)	**192 (16%)**	(%)	0	2 (3%)	**4 (29%)**	0	**142 (17%)**
Cropped	0	0	0	2 (3%)	**340 (28%)**	(%)	0	2 (3%)	**1 (7%)**	0	**116 (14%)**
Total number of wetlands per category	11	32	2	62	1212	15	1	72	14	2	824

Table 8: Incidence of cropping in assessed wetlands in relation to the Corrick wetland category as described in the wetlands layer attributes table. Data is given as number of wetlands and percent of wetlands in each category (within each column) to determine the proportion of wetlands in each category that are subject to cropping.

Landuse within the wetland	Freshwater meadows	Shallow freshwater marsh	Deep freshwater marsh	Permanent open freshwater	Semi-permanent saline wetlands	Permanent saline wetlands	Unclassified
Uncropped	369 (36%)	93 (49%)	23 (59%)	99 (70%)	80 (77%)	37 (82%)	318 (46%)
Partly cropped edge	**180 (18%)**	**43 (22%)**	7 (18%)	28 (19%)	15 (14%)	7 (16%)	**134 (19%)**
Partly cropped edge and bed	**163 (16%)**	**27 (14%)**	7 (18%)	15 (10%)	6 (6%)	1 (2%)	**134 (19%)**
Cropped	**313 (30%)**	**29 (15%)**	2 (5%)	2 (1%)	3 (3%)	0 (0%)	**112 (16%)**
Total number of wetlands per category	1025	192	39	144	104	45	698

Table 9: Comparison of cropping estimates for wetlands assessed by Casanova and Casanova (2016), over three time periods.

2010		**2106**			**2020**		
		Uncropped	Partly cropped edge and bed	Cropped	Uncropped	Partly cropped edge and bed	Cropped
Uncropped	157 (35%)	97 (21%)	51 (11%)	9 (2%)	83 (18%)	62 (14%)	12 (3%)
Unassessed	296 (65%)	154 (34%)	80 (18%)	62 (14%)	134 (30%)	87 (19%)	75 (16%)

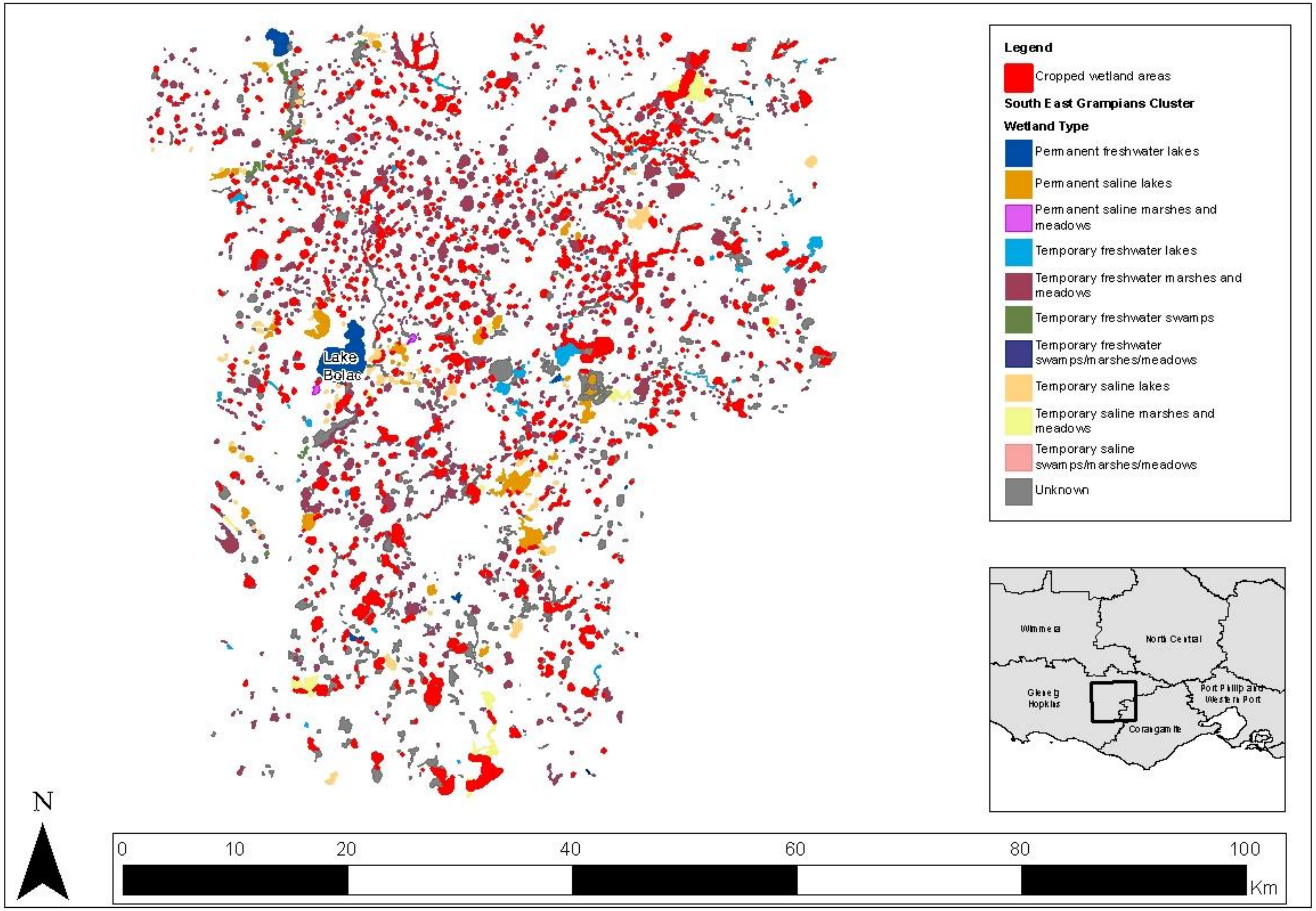


Figure 14 Overview of extent of cropped wetland areas compared to overall wetland coverage

4.2. Wetland connectivity

The following section provides an example of how the connectivity layers and wetland connectivity scores can be used to prioritise wetlands for NRM management. Whilst there are additional factors that are important in assessing site suitability (e.g. frequency, depth and duration of inundation, suitability of vegetation type and cover, salinity in permanent water bodies), these often rely on on-ground inspections and measurement i.e. a secondary phase of investigation. For each of the modelled components (e.g. amphibian and brolga), examples draw on a subset of ranked sites and illustrate how the GIS outputs can be used to zoom in on areas of the landscape and prioritise sites for further follow up or phase two investigation.

Overall connectivity scores for each of the wetlands investigated in this project have been broken down into size classes to reflect tentative priority categories. This class-based assignment is largely subjective and is based on breaking the data down into manageable units.

4.2.1 Amphibian connectivity

For further investigation, we have selected wetlands which score higher than 70 as being the top priority class, capturing 20 uncropped features from the initial wetland set selected for the study (Figure 15).

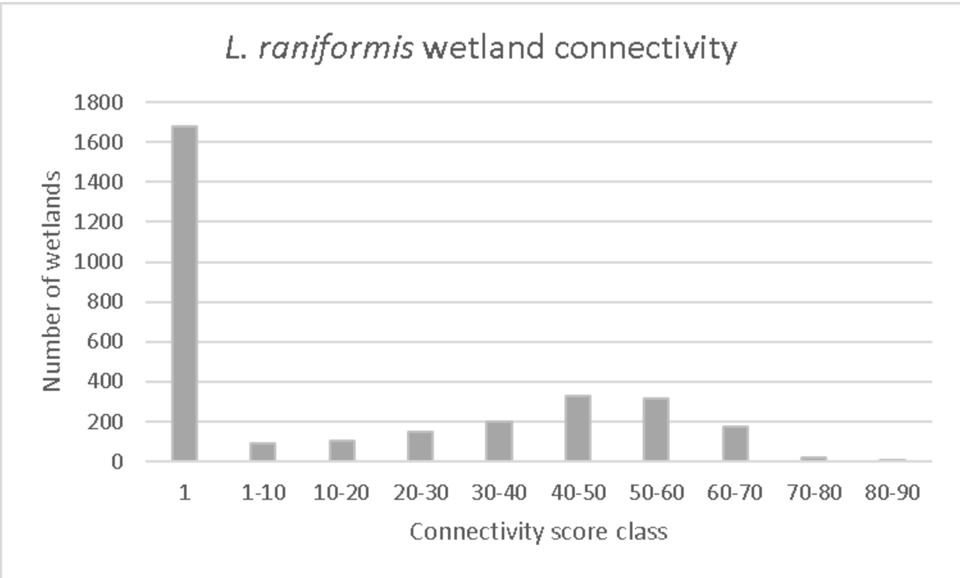


Figure 15 Frequency histogram showing number of wetlands for different connectivity score classes, based on* L. raniformis *connectivity modelling

The connectivity surface layer for modelled *L. raniformis* breeding sites and adjacent wetlands is provided in Figure 10 . Wetlands are colour coded to reflect representative size classes as above. These wetlands are annotated numerically and wider clusters incorporating multiple wetlands within this size class are annotated alphabetically and described in more detail below.

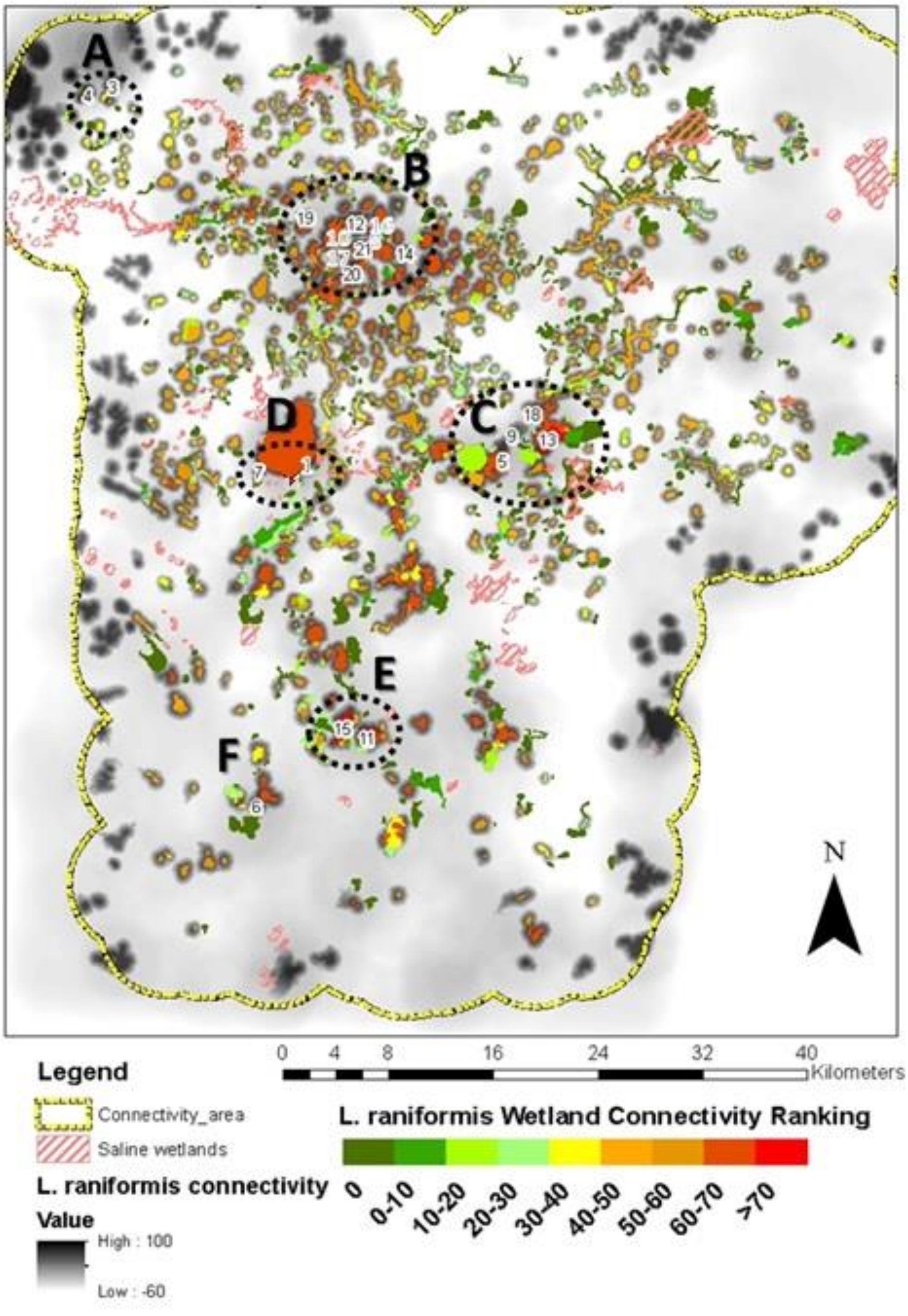
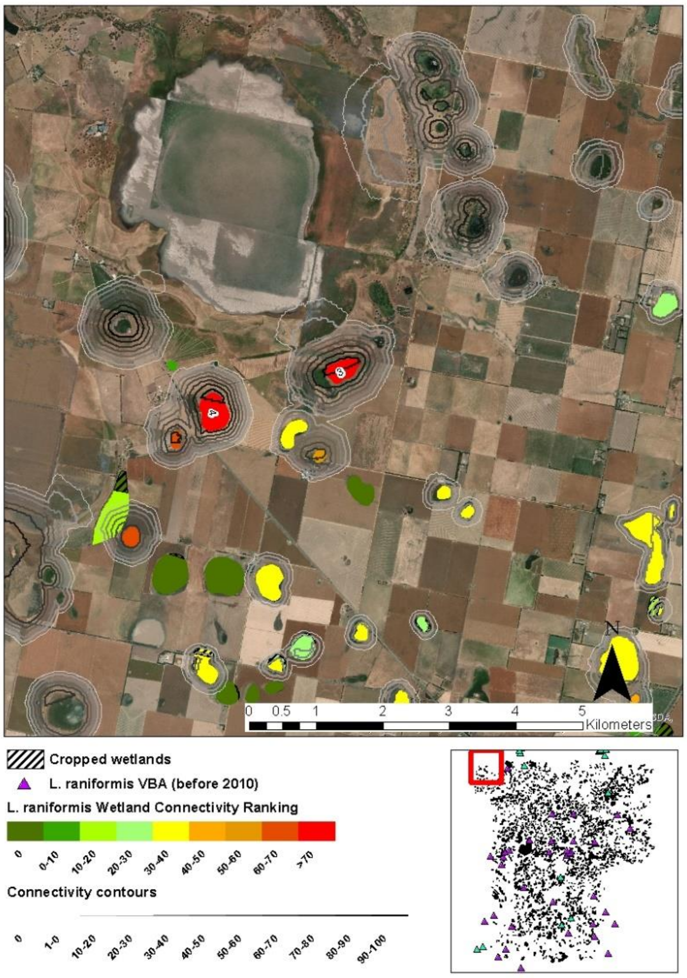


Figure 16 Connectivity surface for* L. raniformis *and overall ranking of wetlands in terms of connectivity, with top 20 sites and associated clusters indicated alphabetically.

Cluster A

Two high priority class wetlands occur to the northwest of the study area (Figure 17). These wetlands appear isolated from one another in terms of connectivity contours although share connectivity features with other, lower ranked wetlands. They both lie near Mount William Swamp, which was not included in the assessment as a habitat element but was incorporated into the connectivity modelling framework. Mount William Swamp is a priority wetland in the GHCMA area and is listed in the Directory of Important Wetlands of Australia. *Litoria raniformis* has not been recorded from this area. Water observations from space (WoFS) data suggests that wetland 4 is intermittently inundated in 20% of observations whereas wetland 3 rarely shows inundation signatures. This needs to be interpreted in context of small size of the wetlands and likely influence of vegetation on water signatures. Aerial imagery indicates vegetation zonation consistent with both sites being existing wetlands. Both wetlands appear to be influenced by drains. Recommendations for initial assessment are:

- Verify presence of *L. raniformis* in local area
- Investigate opportunities for hydrological restoration



Connectivity Rank	Wetland No.	Wetland Type	WoFS % observtions	Size (Ha)	Connectivity Score (Mean)
3	31824	Temporary freshwater marshes and meadows	<1	12.2	79.3
4	31815	Temporary freshwater marshes and meadows	20	18.8	76.89

Figure 17 **L. raniformis** ***connectivity rankings for wetlands associated with Cluster A and location of VBA records for the species (inset map - purple from 1982 to 2010, blue 2010 to present).***

Cluster B

Cluster B contains eight wetlands (Figure 18). Five of these (8,10,12,17 and 21) are contained within a connectivity contour envelope which contains 84 mapped wetlands. Details for each wetland are contained in Table 10. A majority exhibit infrequent inundation signatures (WoFS). Seven contain drains. The remaining site, wetland 29702, appears to be reliably inundated. It is bisected by a property boundary fence but is worth further investigation for existing site values and management actions consistent with protection. It is surrounded by cropping but does appear to have a buffered verge. The closest record for *L. raniformis* is approximately 5km to the south east, an observation from 1982 near Chinaman Swamp. Frog surveys undertaken by Wallace (2018) failed to detect the species.

Recommendations for this cluster are:

- Follow up surveys to verify presence of *L. raniformis*
- Investigate hydrological restoration feasibility at drained sites
- Investigate site values and ongoing asset protection at wetland 29702

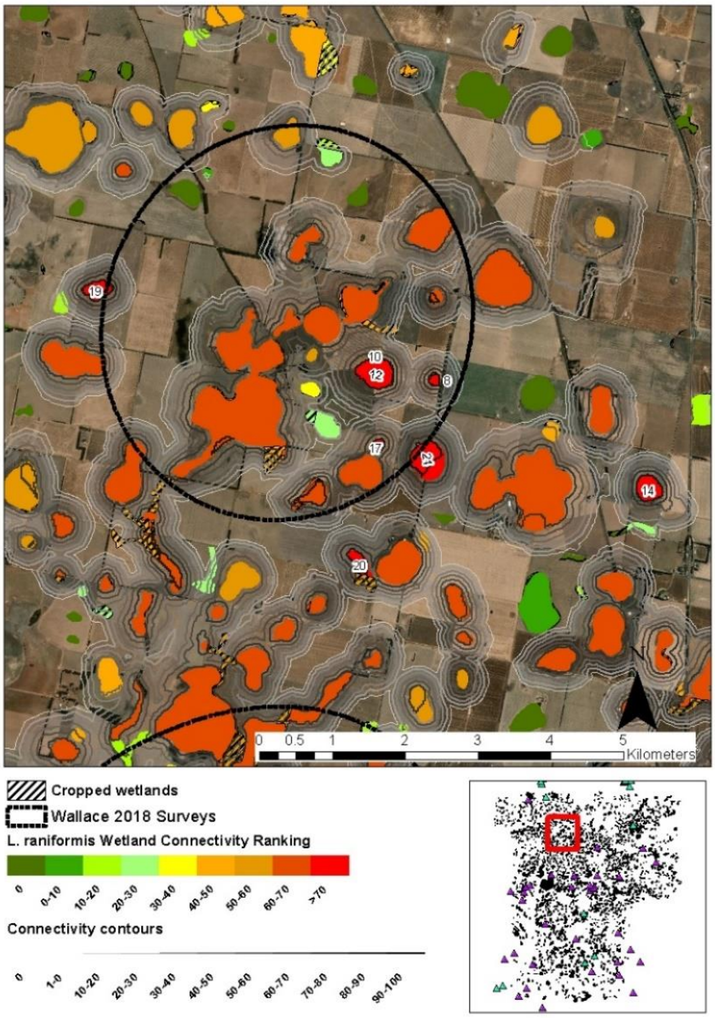


Figure 18* L. raniformis *connectivity rankings for wetlands associated with Cluster B and location of VBA records for the species (inset map - purple from 1982 to 2010, blue 2010 to present).

Table 10 Cluster B wetland details

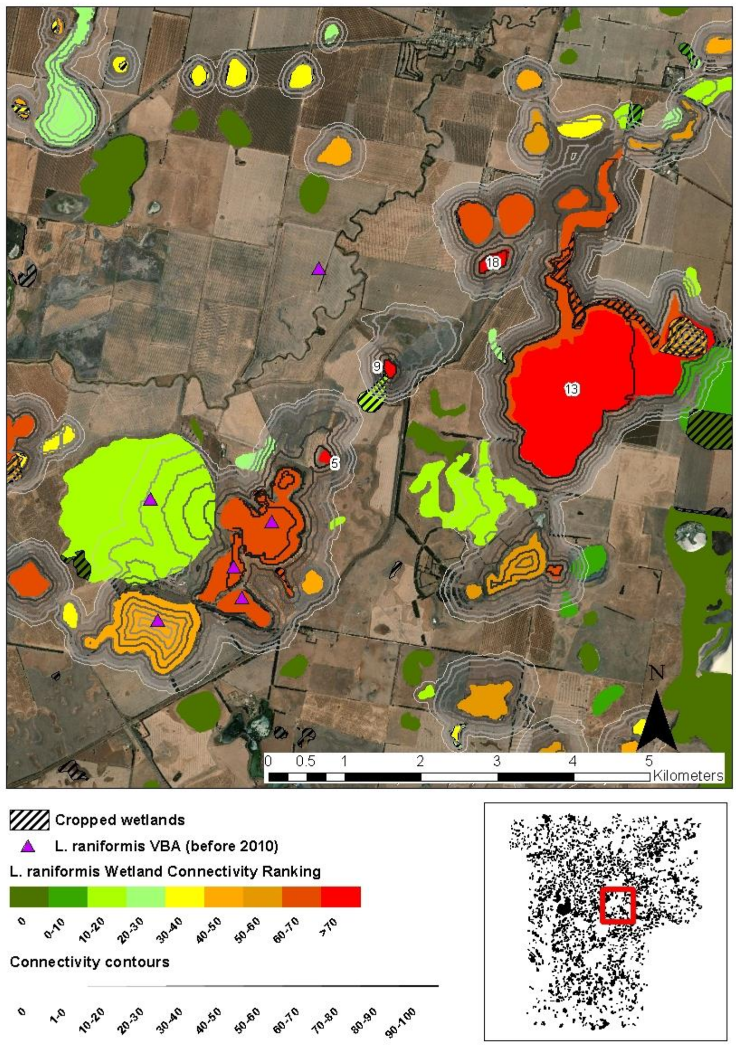
Connectivity Rank	Wetland No.	Wetland Type	WoFS % observations	Size (Ha)	Connectivity Score (Mean)	Drained
8	29707	Temporary freshwater marshes and meadows	5	1.7	71.8	Yes
10	29677	Temporary freshwater marshes and meadows	<1	16.1	71.6	Yes
12	29677	Temporary freshwater marshes and meadows	5	16.1	71.3	Yes
14	29814	Temporary freshwater marshes and meadows	5	9.9	70.8	Yes
17	29676	Temporary freshwater marshes and meadows	5	2.8	70.5	Yes
19	29533	Temporary freshwater marshes and meadows	20	8.3	70.5	Yes
20	29668	Temporary freshwater marshes and meadows	20	11.1	70.3	Yes
21	29702	Temporary freshwater marshes and meadows	50	18.3	70.1	No

Cluster C

Wetlands within this cluster are surrounded by historical records of *L. raniformis* (1982, 1992 and 1993) (Figure 19), notable at Nerrin Nerrin Swamp and Lake Jollicum. Lake Mclaren (Wetland 32761) is a notable priority feature within this cluster and given its private land status, inundation reliability and overall size, requires assessment and/or collation of current site values. Lake Nerrin Nerrin Swamp and Lake Jollicum, which aren't classed as priority features, still constitute a significant areas for future focus and it would be worth investigating the contemporary status of *L. raniformis* at these wetlands and the role wetland feature 32646 may play in the persistence of the species here. Of particular interest is the observation of several linear marks through Nerrin Nerrin Swamp, which indicate it may have been subject to historical or current pasture sewing, despite its status as a crown reserve.

Recommendations for this cluster are:

- Follow up surveys to verify presence of *L. raniformis*
- Investigate site values and ongoing asset protection at wetland 32761
- Investigate current landuse at Nerrin Nerrin Swamp



Connectivity Rank	Wetland No.	Wetland Type	WoFS % observations	Size (Ha)	Connectivity Score (Mean)
5	32646	Temporary freshwater lakes	20	1.6	72.9
9	32669	Temporary freshwater marshes and meadows	5	14	71.7
13	32761	Temporary freshwater lakes	50	293.9	70.9
18	32721	Temporary freshwater marshes and meadows	20	7.2	70.5

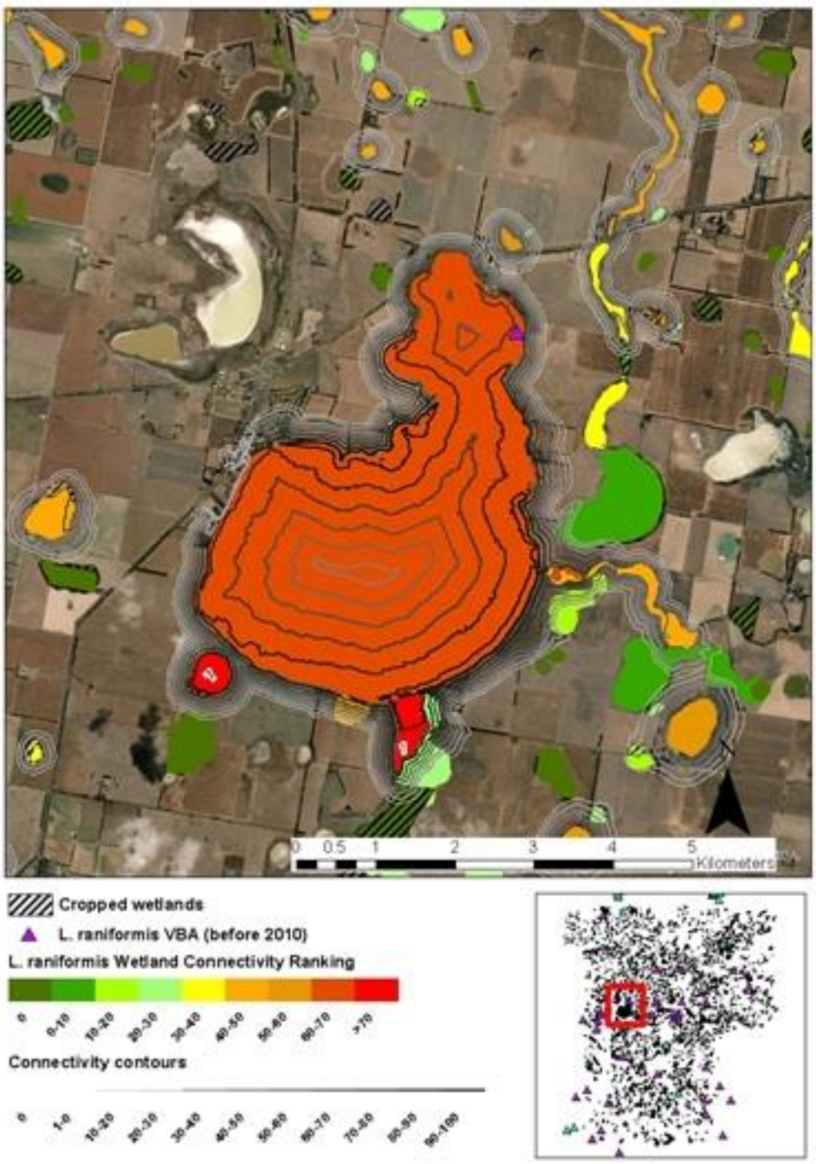
Figure 19 **L. raniformis** ***connectivity rankings for wetlands associated with Cluster C and location of VBA records for the species (inset map - purple from 1982 to 2010, blue 2010 to present).***

Cluster D

Cluster D wetlands are associated with Lake Bolac. The only record for *L. raniformis* is from 1982. Despite containing the highest-ranking site, the overall reliance on Lake Bolac as defining feature of the contour envelope suggests this cluster is probably of a lower priority than others investigated. Whilst wetland 29395 does exhibit characteristics of wetland values, its relative isolation suggests it is probably at the lower end of significance with regards to connectivity for *L. raniformis* across the study area. This interpretation highlights the necessity for undertaking a second phase investigation to provide contextual interpretation of connectivity rankings.

Recommendations for this cluster are:

- De-escalate priority



Connectivity Rank	Wetland No.	Wetland Type	WoFS % observations	Size (Ha)	Connectivity Score (Mean)
1	30204	Unknown	<1	23.9	79.6
7	29395	Temporary freshwater marshes and meadows	20	19.4	72.3

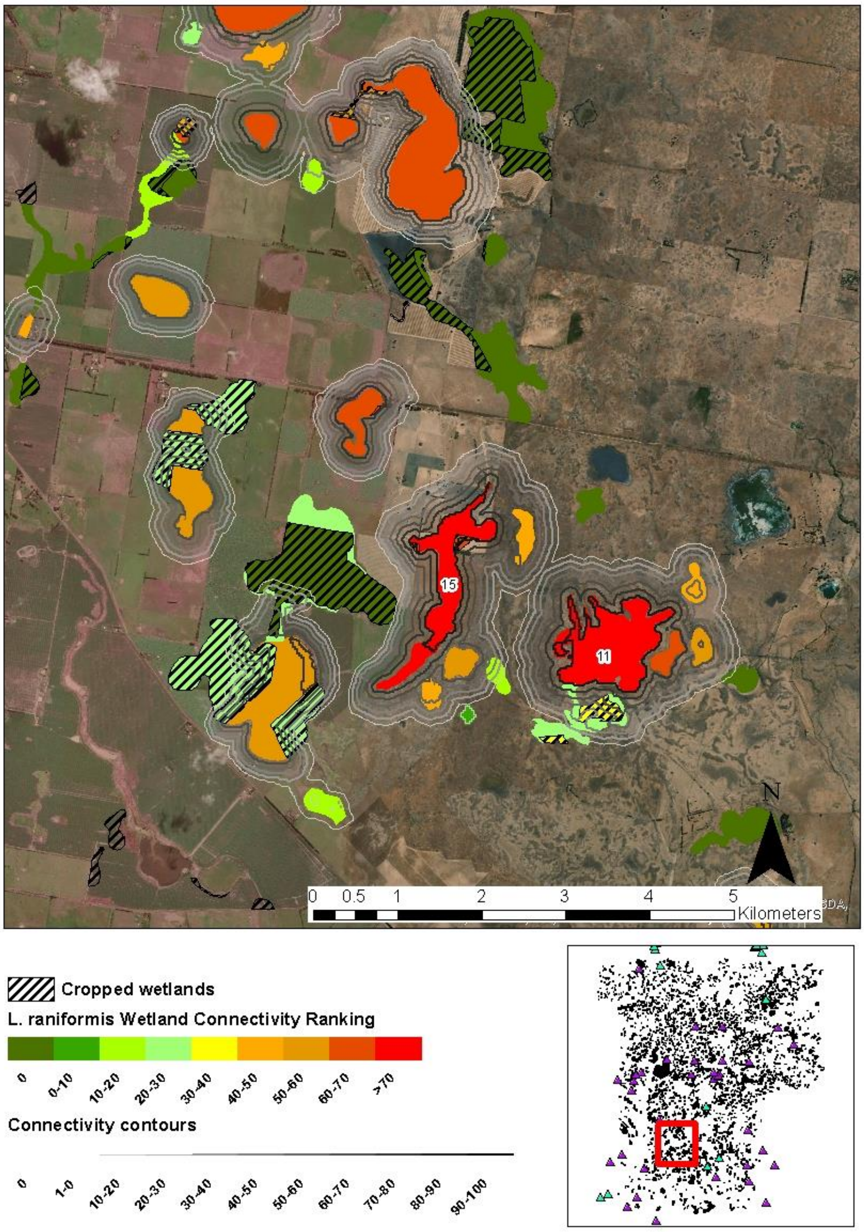
Figure 20 **L. raniformis** ***connectivity rankings for wetlands associated with Cluster D and location of VBA records for the species (inset map - purple from 1982 to 2010, blue 2010 to present).***

Cluster E

The closest *L. raniformis* record to this cluster is from 1992 at Dundonnel Swamp (4.5 km to the north east). Both of these wetlands are drained and according to WoFS inundate irregularly. Wetland 30241 appears highly modified however wetland 29718 does exhibit features consistent with maintenance of wetland values. Given the relatively small contour envelope, and lack of historical or contemporary records for *L. raniformis* in close proximity, the cluster can be considered lower priority. However, potential hydrological restoration capacity may be worthy of further exploration outside of *L. raniformis* connectivity.

Recommendations for this cluster are:

- Investigate hydrological restoration at site 30241



Connectivity Rank	Wetland No.	Wetland Type	WoFS % observations	Size (Ha)	Connectivity Score (Mean)	Drained
11	29718	Temporary freshwater marshes and meadows	<1	90.6	71.4	Yes
15	30241	Unknown	<1	64.3	70.8	Yes

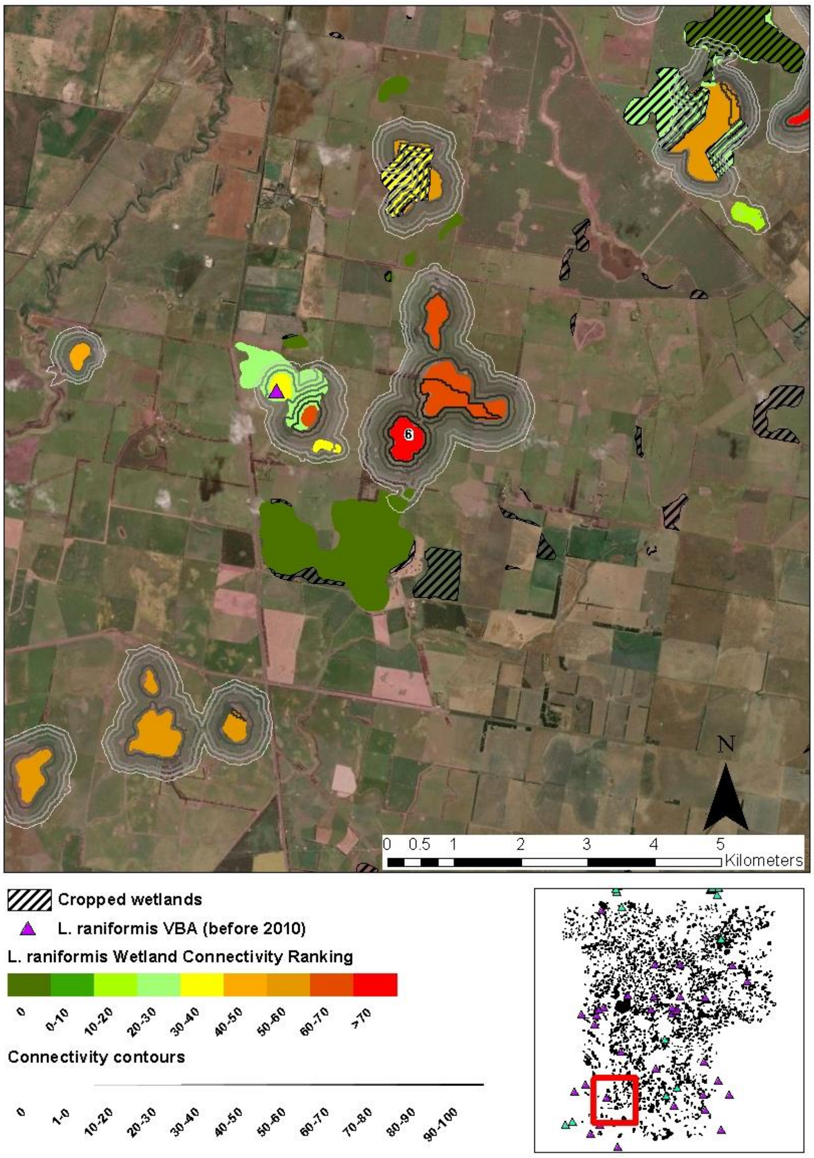
Figure 21 **L. raniformis** ***connectivity rankings for wetlands associated with Cluster E and location of VBA records for the species (inset map - purple from 1982 to 2010, blue 2010 to present).***

Cluster F

Whilst only containing a single higher-ranking wetland, this “cluster” does represent an area for further investigation given proximity of an incidental historical records from 1992. The priority feature itself appears irregularly inundated but is drained and may be compatible with hydrological restoration. Further investigations to determine presence of *L. raniformis* in nearby wetlands are warranted.

Recommendations for this cluster are:

- Follow up surveys to verify presence of *L. raniformis*
- Investigate hydrological restoration feasibility at drained sites



Connectivity Rank	Wetland No.	Wetland Type	WoFS % observations	Size (Ha)	Connectivity Score (Mean)	Drained
6	29389	Temporary freshwater marshes and meadows	<1	21.1	72.8	Yes

Figure 22* L. raniformis *connectivity rankings for wetlands associated with Cluster E and location of VBA records for the species (inset map - purple from 1982 to 2010, blue 2010 to present).

4.2.2 Brolga Connectivity

For further investigation, we have selected wetlands which score higher than 95 as being the top priority class, capturing 12 uncropped features from the initial wetland set selected for the study (Figure 23).

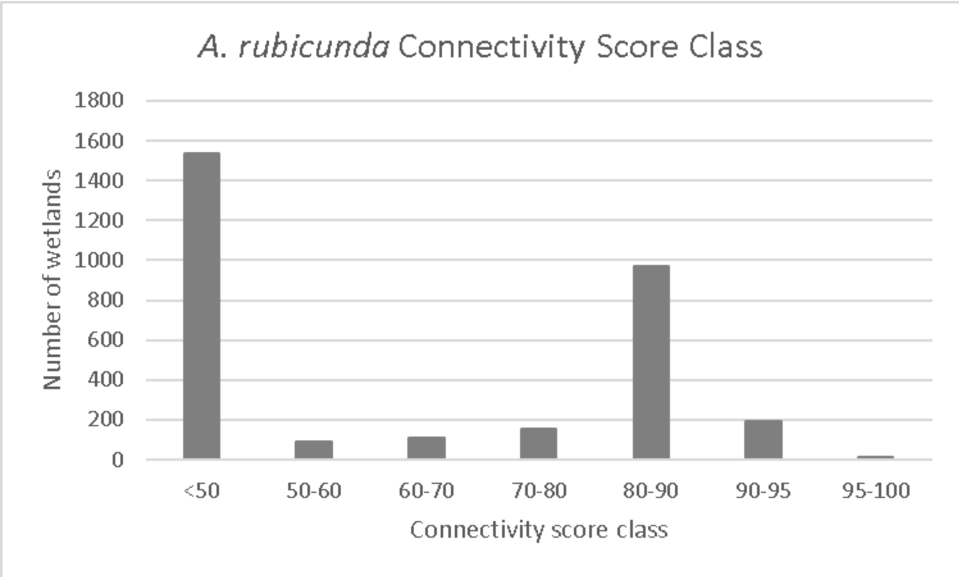


Figure 23 Frequency histogram showing number of wetlands for different connectivity score classes, based on* A. rubicunda *connectivity modelling

The connectivity surface layer for modelled *A. rubicunda* breeding sites and adjacent wetlands is provided in Figure 24. Wetlands are colour coded to reflect representative size classes. These wetlands are annotated numerically and wider clusters, incorporating multiple wetlands within this size class are annotated alphabetically and described in more detail below. Other high-ranking wetlands which are not in geographic proximity to other priority ranked sites are also discussed.

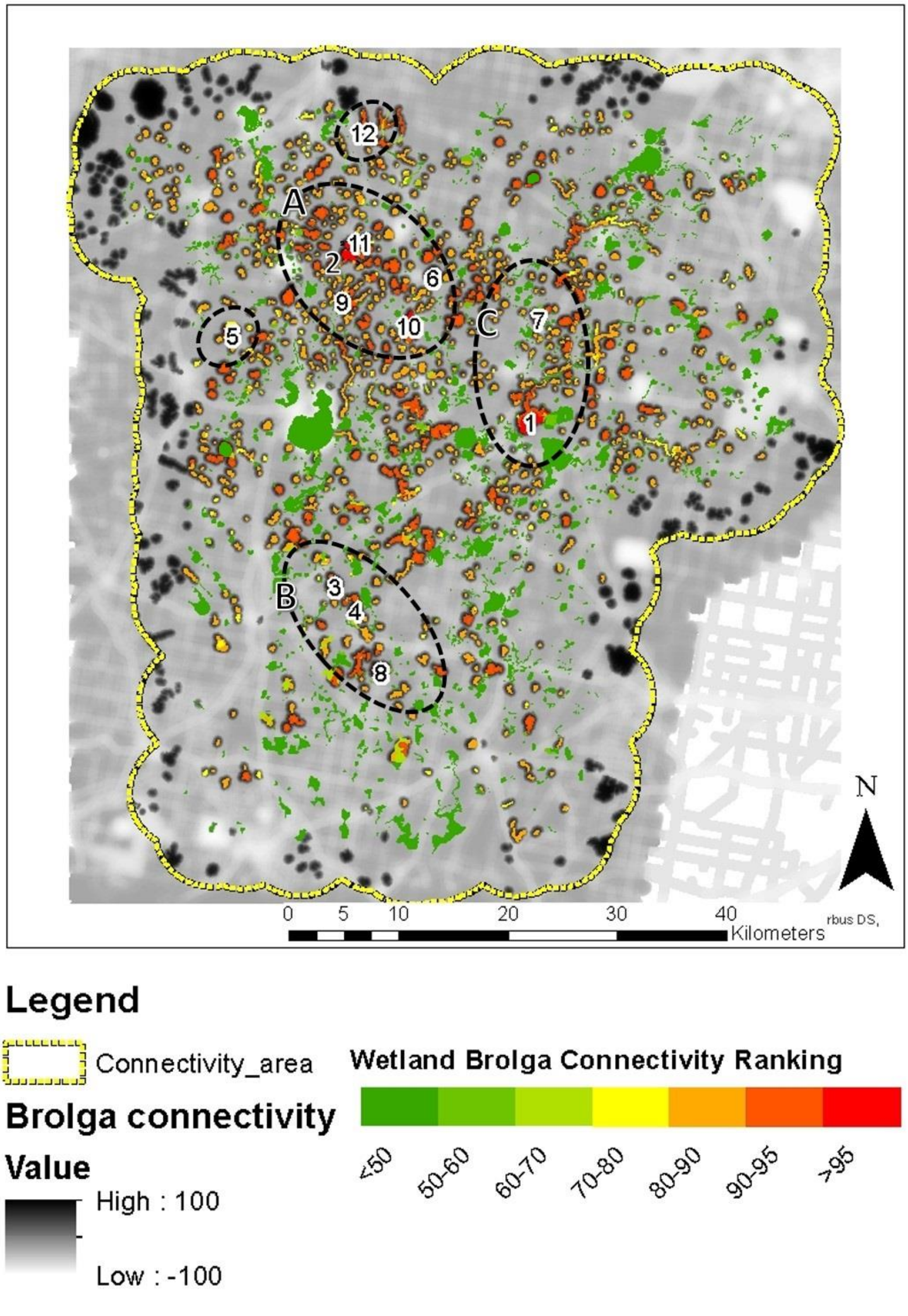


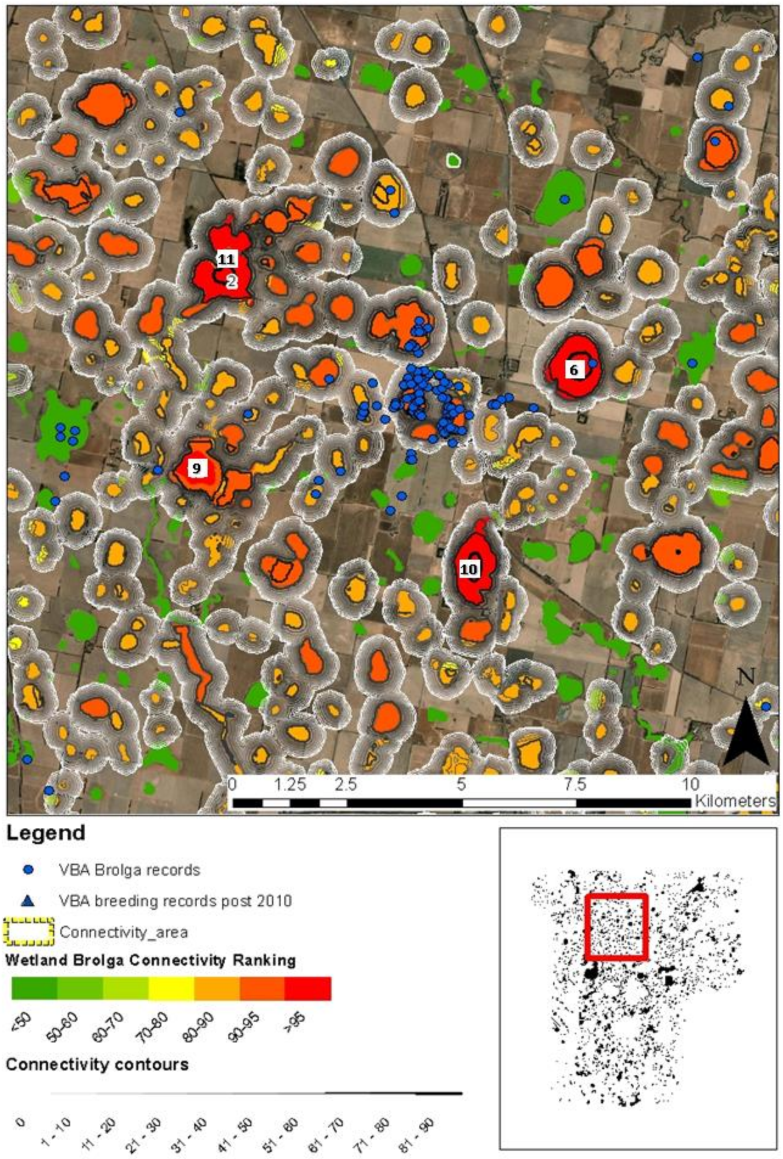
Figure 24 Connectivity surface for* A. rubicunda *and overall ranking of wetlands in terms of connectivity, with top 14 sites and notable clusters indicated alphabetically.

Cluster A

Wetlands within this cluster surround historical records of *A. rubicunda* (Figure 25). Wetlands 29606 and 29594 are mapped as separate feature but constitute a single hydrological unit. This unit, and two other priority wetlands are drained, and all warrant further investigation for hydrological restoration feasibility, particularly with regard to increasing depth and duration of inundation through late spring and early summer.

Recommendations for this cluster are:

- Investigate hydrological restoration feasibility at wetlands 29606/29594, 29887 and 29819
- Investigate site values and ongoing asset protection at wetland 29575



Connectivity Rank	Wetland No.	Wetland Type	WoFS % observations	Size (Ha)	Connectivity Score (Mean)	Drained
2	29606	Temporary freshwater marshes and meadows	20	29.5	96.5	Yes
6	29887	Temporary freshwater marshes and meadows	5	116.7	95.5	Yes
9	29575	Temporary freshwater marshes and meadows	5	47	95.1	No
10	29819	Temporary freshwater marshes and meadows	20	103.6	95.1	Yes
11	29594	Temporary freshwater marshes and meadows	<1	105.9	95.1	Yes

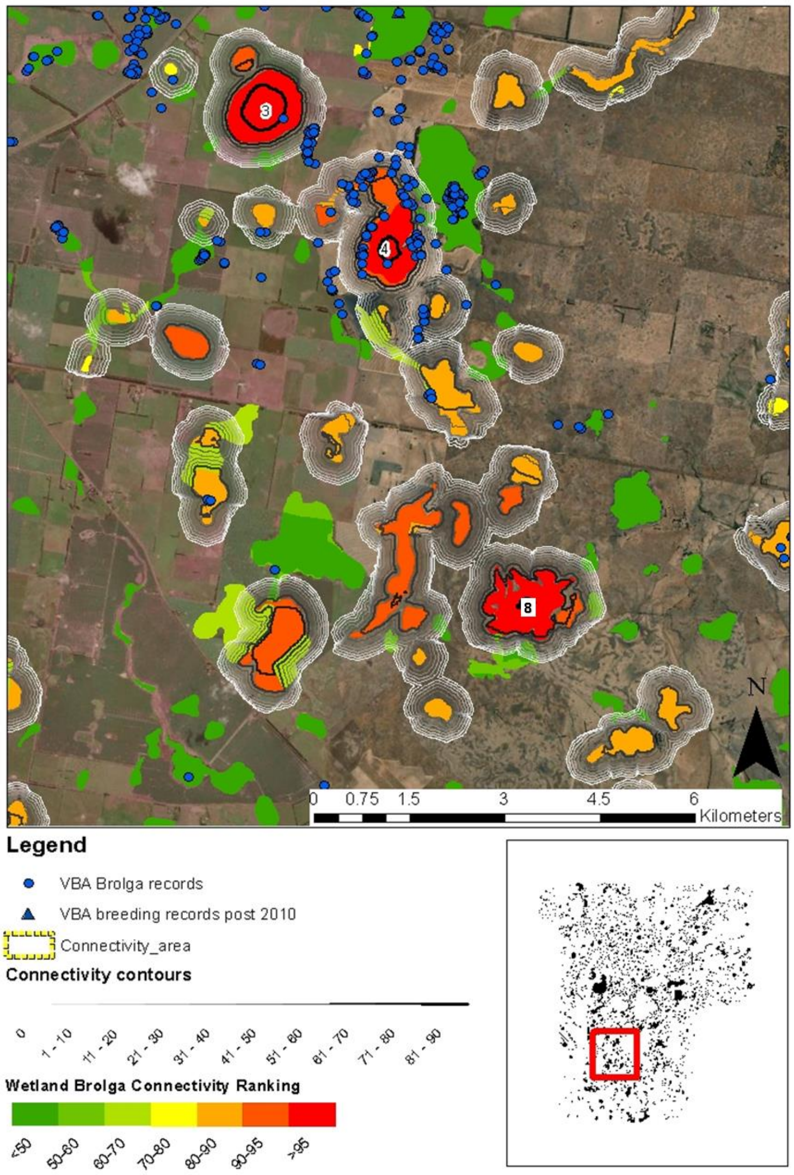
Figure 25* A. rubicunda *connectivity rankings for wetlands associated with Cluster A and location of VBA records for the species.

Cluster B.

Wetlands 29547 and 29614 have records from satellite tracking (Veltheim, 2019) which confirm brolga activity. Connectivity modelling indicates that wetlands 29614 and 29718 are part of potentially wider clusters brolga site management guidelines. Both wetlands 29547 and 29718 exhibit irregular inundation (WoFS) but, due to drainage, may be compatible with hydrological restoration.

Recommendations for this cluster are:

- Investigate hydrological restoration feasibility at wetlands 29547 and 29718
- Investigate site values and ongoing asset protection at wetland 29614



Connectivity Rank	Wetland No.	Wetland Type	WoFS % observations	Size (Ha)	Connectivity Score (Mean)	Drained
3	29547	Temporary freshwater marshes and meadows	<1	97.9	96.5	Yes
4	29614	Unknown	50	66	96.0	No
8	29718	Temporary freshwater marshes and meadows	<1	90.6	95.1	Yes

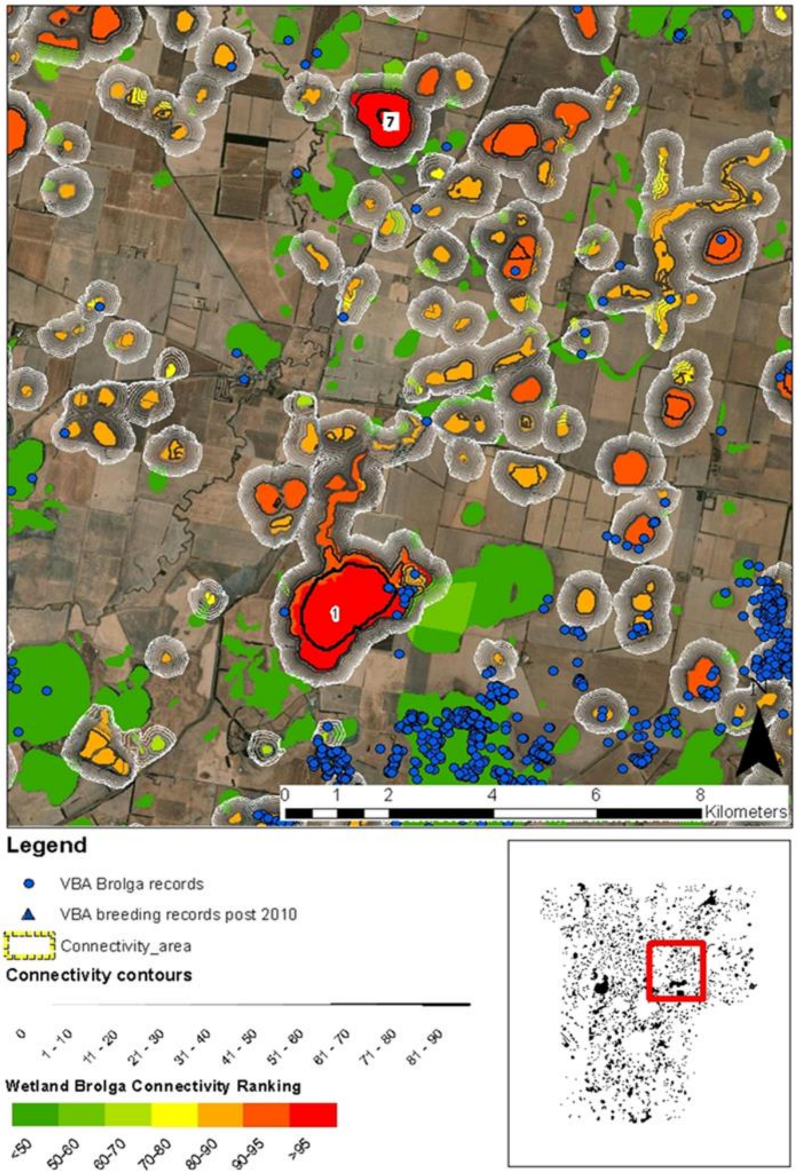
Figure 26 **A. rubicunda** ***connectivity rankings for wetlands associated with Cluster B and location of VBA records for the species.***

Cluster C

Wetland 32761 (Lake Mclaren), which is the highest-ranking site for brolga breeding, is reliably inundated and has had brolga recorded in its fringing area and on peripheral wetlands. Wetland 32791 does not have any brolga records but is drained and may benefit from hydrological restoration.

Recommendations for this cluster are:

- Investigate site values and ongoing asset protection at wetland 32761
- Investigate hydrological restoration feasibility at wetland 32788

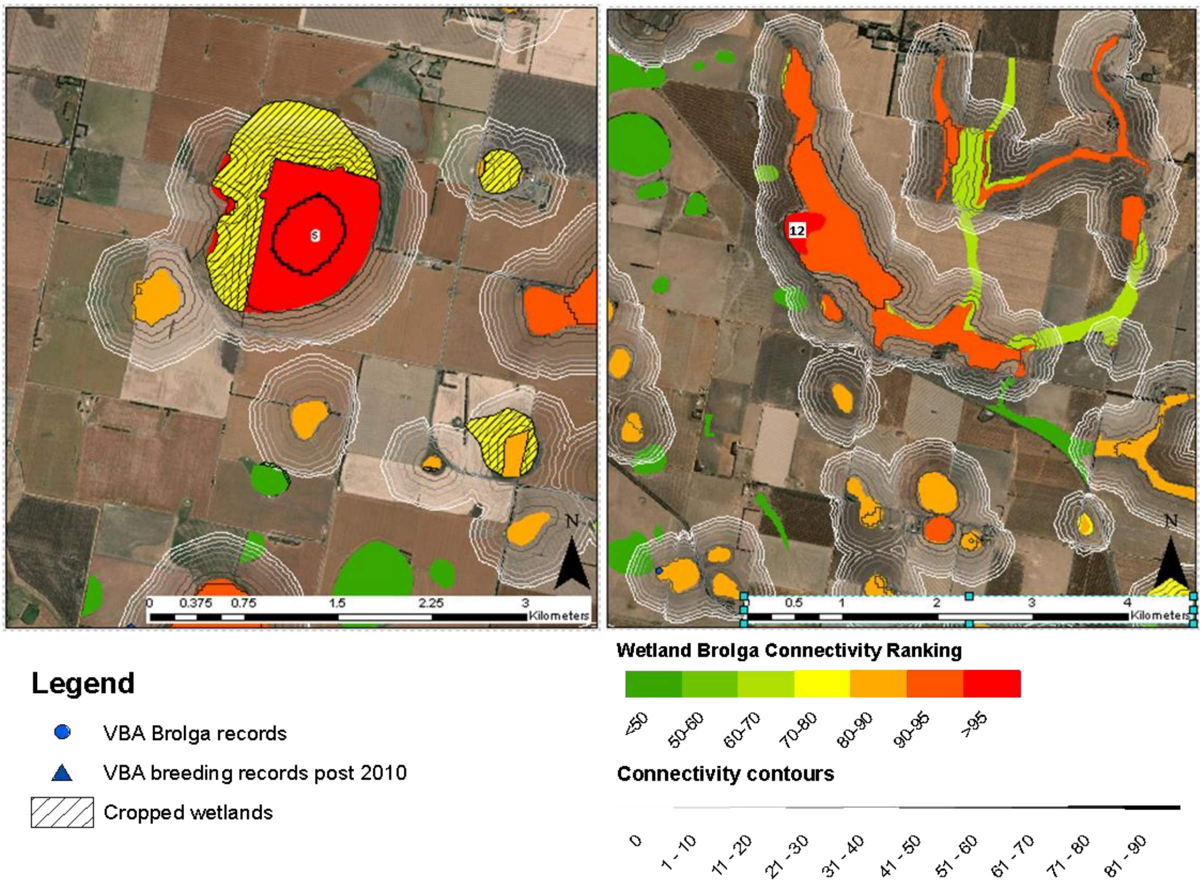


Connectivity Rank	Wetland No.	Wetland Type	WoFS % observations	Size (Ha)	Connectivity Score (Mean)	Drained
1	32761	Temporary freshwater lakes	50	293.9	97.3	No
7	32788	Temporary freshwater marshes and meadows	20	92.9	95.2	Yes

Figure 27* A. rubicunda *connectivity rankings for wetlands associated with Cluster C and location of VBA records for the species.

Additional sites

Both the additional high-ranking sites which are geographically isolated from other high rankings sites, are not associated with any brolga records. Wetland 23231 has been substantially modified by cropping across tis northern and western areas. It is also fairly isolated (i.e. doesn't appear well connected to other surrounding wetlands, despite its overall high average connectivity score. Wetland 31888 appears to be a sub-unit of a larger, linear shaped feature. It is recommended that follow up investigations at these sites are probably not warranted in lieu of focus on wetlands associated with clusters as outlined above.



Connectivity Rank	Wetland No.	Wetland Type	WoFS % observations	Size (Ha)	Connectivity Score (Mean)	Drained
5	29231	Temporary freshwater marshes and meadows	20	179.9	95.97023	No
12	31888	Temporary freshwater marshes and meadows	20	11.9	95.057	No

Figure 28* A. rubicunda *connectivity rankings for other high ranking wetlands and location of VBA records for the species.

5. SUMMARY AND RECOMMENDATIONS

Of 2247 wetlands investigated across the South East Grampians wetland cluster, 55% were cropped to some extent. Twenty-one percent have been entirely cropped, 16% have been cropped at the edge and across areas of the bed and 18% have been cropped at the edge. In terms of area, approximately 24,000 Ha (60 %) of the total wetland area has been cropped to some extent, with 3784 Ha or 10% being entirely cropped. Cropping was higher in temporary systems, particularly temporary freshwater marshes and meadows, which are the most common wetland type across and are most likely associated with the critically endangered Seasonal Herbaceous wetland community. The rate of increase of cropping between 2016 to present is lower than for the period from 2010 to 2016.

Investigation of wetland connectivity, based on two focal species (brolga and growling grass frogs), has identified potential priority sites for further investigating potential to maintain or enhance available breeding habitat. Recommended actions include preliminary assessments of existing site values and potential for ongoing management actions which promote protection. Hydrological restoration is also considered a potentially advantageous action where sites are drained, but where characteristics consistent with providing suitable breeding habitat are exhibited in modelling outputs. For *L. raniformis*, an overall low number of observations in biodiversity databases requires future surveys in order to provide a better indication of species presence.

A summary of wetlands ranking highest in connectivity metrics, combined with recommended actions, is provided in Table 11. These recommendations form a starting point for further exploration but should also be interpreted in the context of opportunity (willing landholders). The acquisition of additional data, combined with cross-referencing to existing data, is an ongoing task and will likely lead to additional priority sites for investigation as well as further informing whether sites identified in this study are either already being effectively managed or are not realistically conducive to management for conservation purposes. Additional modelling of connectivity for other species (including plants) is also likely to further inform broader patterns of connectivity and therefore enhance landscape connectivity between wetlands within this priority area.

Table 11 Priority ranked sites and actions

Focal species	Wetland			Priority actions		
		L raniformis rank	*A. rubicunda* rank	Protection	Restoration	Survey
Both	29718	11	8		x	x
	32761	13	1	x		x
L. raniformis	31284	3			x	x
	31815	4				x
	32646	5				x
	29389	6			x	x
	29707	8			x	x
	32669	9				x
	29677	*10			x	x
	29814	14			x	x
	30241	15			x	x
	29676	17			x	x
	32721	18				x
	29533	19			x	x
	29668	20			x	x
	29702	21		x		x
A. rubicunda	29606/29594		2,11		x	
	29547		3		x	
	29614		4	x		
	29887		6		x	
	32788		7		x	
	29575		9	x		
	29819		10		x	

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