

Current and Future Risks of Cropping Wetlands in Victoria

Technical Report



"THE TRACTORS came over the roads and into the fields, great crawlers moving like insects, having the incredible strength of insects.....straight down the country, across the country, through fences, through dooryards, in and out of gullies in straight lines.....They ignored hills and gulches, water courses, fences, houses..... The driver could not control it—straight across country it went, cutting through a dozen farms and straight back"

John Steinbeck, *The Grapes of Wrath*, 1939

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Cover Image: Photograph of a cropped wetland area near Lake Bolac (Fiery Creek Catchment) The open water area was cropped, the area with emergent vegetation was not. May 2011.

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Executive summary

Victoria has over 35,000 wetlands, of which approximately 25,000 are defined as “naturally occurring”. These wetlands provide a number of ecosystem services and values. Many of these values are reliant on maintenance of the condition of wetlands.

Wetlands in Victoria are managed in accordance with the Victorian Waterway Management Strategy (VWMS). The VWMS identifies cropping as a threatening process to wetlands in fragmented landscapes and specifies a number of actions to address the risks to wetlands from cropping. Consistent with achieving the vision and actions of the VWMS, this project provides a review of the knowledge related to wetland values and cropping in the Victorian landscape. The information contained in this report can be used to inform policy development, prioritise research and develop management guidance for natural resource managers and landholders.

This review obtained information in three ways:

- literature review of written resources in grey and refereed published literature, unpublished reports and websites
- consultation with wetland managers (including farmers) and wetland researchers; and
- geospatial analysis of wetland distribution and cropping.

This information was used in a vulnerability assessment framework to assess the vulnerability of wetlands to cropping in Victoria at two spatial scales: site scale (individual wetlands) and landscape scale (regions or clusters of wetlands).

Wetland vulnerability at the site scale

Cropping in Victoria is generally a dryland activity, with broadacre production of grains such as wheat and barley, covering over 3 million hectares. These crop species are intolerant of long-term waterlogging and high salinities. Therefore, wetlands that are most likely to be exposed to cropping are frequently dry, generally shallow, and fresh to brackish. In addition, cropping does not occur on very steep or heavily forested land, so wetlands at risk identified in this study usually occur on plains areas with endorheic (internal) drainage patterns.

The factors that influence the likelihood that a farmer can and will crop a wetland include:

- the physical attributes of the wetland, e.g. wetland size (smaller wetlands are more likely to be cropped than larger wetlands) and soil constraints (the presence of heavy clay reduces the likelihood of cropping)
- the likelihood of economic gain, i.e. the potential crop yield versus the potential return on expenditure
- the risk of crop failure, e.g. frost, droughts and waterlogging risks
- legal limitations such as protection of endangered or rare species, and government legislation; and
- the farmer’s attitude towards conservation.

The overall aim of cropping practices is to produce a plant monoculture that results in a high yield of seed or grain. Broadacre cropping entails soil preparation (chemical amelioration, cultivation), sowing seed, application of biocides and fertilisers, and harvest. Each of these activities has the potential to impact on the biota and processes of wetlands.

There are multiple ecological consequences from cropping of wetlands. Cropping in wetlands has been found to reduce the germination of plants from the seed bank, and reduce the diversity of plants that establish. Invertebrate diversity and abundance can be impacted by the physical changes associated with cropping, as well as changes in hydrology that occur when wetlands are modified to enhance their value as cropland. Chemical and physical disturbances associated with cropping wetlands can modify food availability and reduce the numbers of amphibians, reptiles and mammals that use dry wetlands as a

refuge. Cropped wetlands support fewer waterbirds that rely on a mosaic of wetlands for feeding and breeding.

The inherent resilience (or 'adaptive capacity') of temporary wetland plant and animal communities allows them to tolerate disturbance of different kinds. The seed bank, the high levels of biodiversity in the plant, plankton and invertebrate communities, as well as connectivity with other wetlands convey resilience and can ameliorate some potential impacts. Despite this, wetlands are highly vulnerable to cropping because a large number of their attributes (soil, seed bank, vegetation, invertebrates, vertebrates, water regime, water quality) and processes (germination, establishment, trophic interactions) are sensitive to the physical and chemical disturbances applied in cropping.

Therefore, although temporary wetlands are naturally resilient to disturbance, repeated and widespread cropping is likely to have a negative effect on their condition, and therefore the values and services they provide. Cropping has the capacity to remove shallow, temporary wetlands from the landscape altogether.

Wetland vulnerability at the landscape scale

At a landscape scale, wetlands are exposed to cropping in those agricultural areas of high wetland density where the topography, soil characters and rainfall are amenable to cropping. There is a low likelihood of cropping and impacts of cropping to wetlands on public land. The approximately 20,000 privately owned wetlands of natural origin are at the highest risk.

Geospatial analysis identified seven clusters of Victoria's wetlands that could be exposed to the impacts of cropping. The incidence of cropping in the southern Victorian landscape is limited by a combination of landform and alternate agricultural enterprises. Wetland clusters at Bessiebelle and near Mt Gambier in western Victoria are currently only lightly impacted by cropping, but are potentially vulnerable to cropping in the future (with higher temperatures and more evaporation due to climate change).

Two of the wetland clusters in western Victoria (South East Grampians and West Wimmera) are currently impacted by cropping and were examined in detail to determine the scale of that impact. The results of this analysis indicate that changes in cropping practices and machinery that have occurred in the past decade (e.g. rock removal, direct-drill sowing, landscape clearance, use of airseeders with 20 m widths, sprayers with 33 m span), have increased the amount of cropping in wetlands in these regions.

A comparison of data collected for this study and data collected in c. 2010 revealed that the incidence of cropping in wetlands is now much higher than was previously recorded, with nearly 45 % of wetlands sampled in the South East Grampians cluster of wetlands impacted by cropping to some degree, compared to an estimate of 2 % in 2010. In the South East Grampians cluster cropping occurs on freshwater, rain-filled wetlands on volcanic-derived soils. There do not appear to be any substantial physical restrictions to an increase in the incidence of cropping in South East Grampians wetlands in dry years. In contrast, the percentage of wetlands cropped in the West Wimmera has remained relatively stable since 2010, at approximately 20 %. The West Wimmera cluster of wetlands occurs on a mosaic of undulating farmland and forested land, where wetlands are formed from groundwater and rainfall. Wetland cropping in the West Wimmera occurs at the edges of saline and fresh permanent wetlands, as well as in temporary wetlands. Cropping in the West Wimmera region is restricted by soil type, and the presence of trees and shrubs.

In both the East Grampians and West Wimmera regions the likelihood that a wetland will be cropped is related to:

- surrounding land use - wetlands adjacent to crop land are highly likely to be cropped
- wetland size and depth - shallow wetlands up to approximately 8 ha are more vulnerable than are larger wetlands
- wetland water regime - permanent wetlands are less likely to be fully cropped than temporary ones
- water quality - saline wetlands are not much cropped, brackish and freshwater more so
- presence of trees and shrubs across the wetland - wetlands dominated by non-woody vegetation are more likely to be cropped than those dominated by woody vegetation; and

- the conservation ethic of the land manager.

Wetlands, like all ecosystems, have some degree of adaptive capacity or resilience that allows them to withstand disturbance. One of the mechanisms that provides adaptive capacity in temporary wetlands is the connectivity among individual wetlands in a wetland mosaic. Cropping can increase fragmentation of that mosaic by reducing wetland size, removing smaller wetlands, and increasing the distances and resistance to dispersal among wetlands, thereby reducing wetland resilience at a landscape scale.

The outcomes of this review were used to briefly explore management recommendations for natural resource managers. There are three management options in relation to cropping in wetlands: do nothing, conserve what remains, or conserve **and** try to restore wetlands that are already impacted. Given the value of temporary wetlands in the Victorian landscape and their capacity to support high biodiversity and cultural values it is recommended that management should seek to conserve and improve the condition of the remaining unimpacted wetlands, and restore wetlands that are currently impacted where they contribute to landscape connectivity.

Actions could include:

- developing guidelines for management of unimpacted wetlands in cropping landscapes
- establishing buffers between cropping activities and wetlands
- identifying and preserving connectivity among wetlands; and
- prioritising wetlands and wetland mosaics for restoration.

There are significant barriers to the implementation of management actions. These barriers include:

- the fact that most of the wetlands are privately owned
- their dispersed nature across the landscape
- the availability of funding
- the lack of knowledge among landowners; and
- the difficulties in implementation of effective communication with landowners.

It is recommended that management actions target the economic and social drivers that make cropping in wetlands profitable and acceptable to farmers. The rapid rate of change that has been detected makes it necessary to implement conservation measures as soon as possible, before the majority of wetlands are removed from the landscape altogether, and the species dependent on them become rarer, more threatened or extinct.

1. Introduction

1.1. Scope of this report

Agricultural cropping (cultivating the land to produce seed or grain plant products) is identified in the Victorian Waterway Management Strategy (VWMS: DEPI 2013a) as a threatening process to wetlands in fragmented landscapes in Victoria. Cropping has the potential to impact on the condition and values of wetlands in Victoria, including wetland biodiversity.

In line with the vision for Victoria's wetlands stated in the VWMS ("*Victoria's rivers, estuaries and wetlands are healthy and well-managed, supporting environmental, social, cultural and economic values that are able to be enjoyed by all communities*": DEPI 2013a), this report is focused on identifying the current and future risks of cropping to the values of naturally occurring wetlands in Victoria. The project has reviewed existing evidence to identify and assess the risks to wetlands from cropping. This technical report is intended as a resource to inform policy development, prioritise research and develop management guidance for natural resource managers and landholders.

The Victorian Waterway Management Strategy specifies three actions that support this investigation:

- Action 12.5 Prepare guidance for landholders on sustainable use of wetlands, including guidance on sustainable stock grazing in appropriate circumstances.
- Action 12.7 Investigate the extent and impact of different land use practices on high value wetlands.
- Action 12.14 Improve the framework for identifying high value wetlands and assessing risk.

This report addresses Action 12.5 in relation to the sustainable use of wetlands where cropping is a land use, and Action 12.7, the impact of cropping on high value wetlands. The mapping and spatial analysis has contributed to the identification of wetlands at risk from cropping (Action 12.14).

The objective of this report, in recognition of the VWMS vision and actions, is to review and summarise knowledge about wetlands and cropping in the Victorian landscape. We identify wetlands that are currently cropped, and how this impacts on their condition. The distribution of those wetlands, and their occurrence in the landscape is documented, along with the factors that have allowed or encouraged cropping to occur in them. Cropping practices that impact on wetlands at the site and landscape scale are described. The specific impacts of cropping on wetlands, on their condition and values, were determined with reference to the literature (published and unpublished) and expert opinion (where appropriate), along with the capacity of wetlands to recover from those impacts. Guidance is provided for natural resource managers and landholders, and key knowledge gaps about cropping in wetlands are outlined.

1.2. Victoria's wetlands

Wetlands are broadly defined under the International Convention on Wetlands (Ramsar Convention Secretariat 2004; known as the Ramsar Treaty, to which Australia is a signatory). This internationally accepted definition states that wetlands are:

"areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, salt, brackish or fresh, including areas of marine water, the depth of which at low tide does not exceed six metres".

Within the Victorian wetland classification framework, the definition is further constrained to be:

"Surface waters, whether natural, modified or artificial, subject to permanent, periodic or intermittent inundation, which hold static or very slow moving water and support biota adapted to inundation and the aquatic environment. This includes water bodies such as lakes, swamps, fens, marshes, peatlands, springs and supratidal and intertidal (but not subtidal) areas".

It is important to note that wetlands do not have to be wet all the time.

There are more than 35,000 wetlands categorised as 'naturally occurring' in Victoria, covering more than 1.8 million hectares. Of these, approximately two thirds are fully on private land (Figure 1).

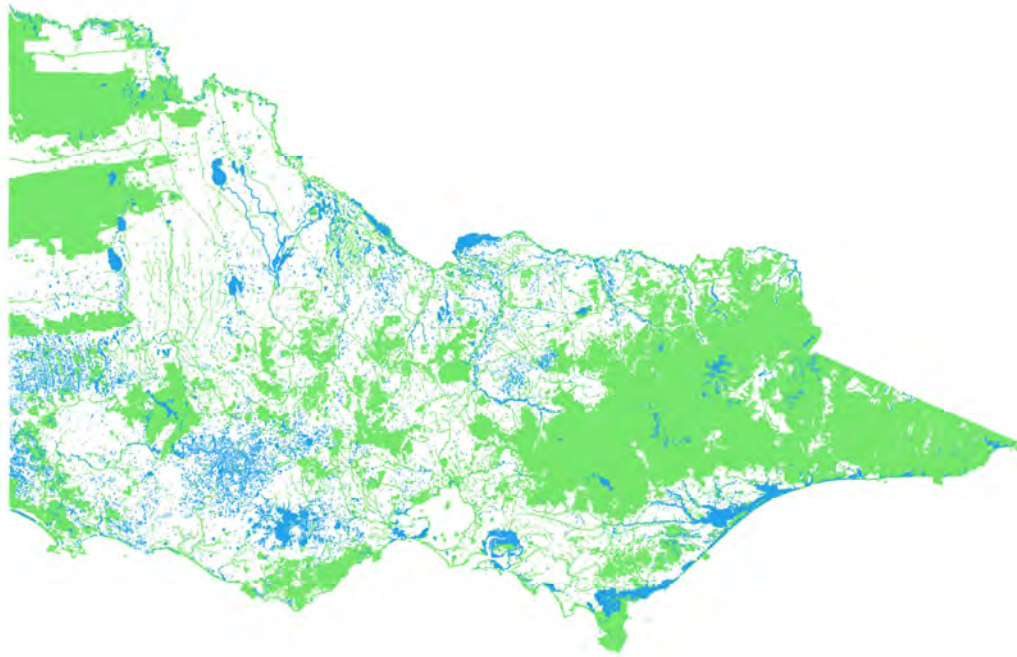


Figure 1. The distribution of naturally occurring wetlands in Victoria (DELWP 2016). Green indicates public land, white is privately owned land, blue is wetland area.

Natural wetlands in Victoria vary in relation to their water regime (the depth, duration, frequency and timing of inundation), their salinity and source of water (riparian: associated with rivers, palustrine: shallow vegetated wetlands or lacustrine: lakes; rain-fed or ground-water fed) (Table 1). Impacts on wetlands can occur at the site scale (e.g. contamination of a wetland with chemicals) or at the landscape scale (e.g. fragmentation of a wetland mosaic by degradation of some of the wetlands).

The wetlands of interest in this study are those that are at risk from broadacre cropping to produce grain (wheat, barley, oats) and seed (pulses, canola) (see Section 1.3). These are largely shallow, rain-filled wetlands, often formed by endorheic (internal) drainage, or in areas without clearly defined drainage lines (Table 1). These wetlands are usually vegetated and have a seasonal or episodic water regime. Such wetlands occur widely throughout the state of Victoria, but are most abundant in the centre and west of the state, particularly in the Glenelg-Hopkins, Corangamite, North Central, Goulburn-Broken and Wimmera NRM regions. They are variously called 'marshes', 'wet meadows', 'gilgais' and 'swamps' throughout Victoria.

The Victorian Wetland Classification (DELWP in prep.) classifies wetlands according to a number of variables (Table 1). Those that are most relevant to the assessment of cropping are:

- lacustrine or palustrine
- naturally occurring
- no vegetation, sedge/grass/forb, shrub or forest/woodland
- groundwater or rainfall water sources
- periodically inundated; and
- fresh to hyposaline.

Table 1: Victorian Wetland Classification (DELWP in prep).

Wetland system	Lacustrine (< 30 % cover of emergent vegetation)	Palustrine (> 30 % cover of emergent vegetation)	Marine (intertidal wetlands in embayments)	Estuarine (semi-enclosed tidal wetlands and supratidal wetlands)
Wetland habitat	Wetland origin: <ul style="list-style-type: none"> • Naturally occurring • Human-made <ul style="list-style-type: none"> ○ aquaculture pond ○ farm dam ○ salt works ○ water storage ○ excavation pond ○ sewage treatment pond ○ stormwater treatment pond 			
	Dominant vegetation: <ul style="list-style-type: none"> • Forest/woodland • Shrub • Sedge/grass/forb • Moss/heath • No emergent vegetation 		Dominant vegetation: <ul style="list-style-type: none"> • Mangrove • Coastal saltmarsh 	
	Water source: <ul style="list-style-type: none"> • Groundwater • River • Tidal • Artificial 			
	Water regime: <ul style="list-style-type: none"> • Permanent • Periodically inundated <ul style="list-style-type: none"> ○ seasonal ○ intermittent ○ episodic 		Water regime: <ul style="list-style-type: none"> • Supratidal • Intertidal 	
	Salinity regime: <ul style="list-style-type: none"> • Fresh (0 – 3,000 mg/L) • Hyposaline (3,000 - 10,000 mg/L) • Mesosaline (10,000 - 50,000 mg/L) • Hypersaline (50,000 - 350,000 mg/L) • Saline (3,000 - 350,000 mg/L) 			

In this study we exclude man-made wetlands (dams, tanks, sewerage-treatment works), coastal wetlands, irrigated cropping infrastructure (e.g. rice bays), as well as the extensive floodplain wetland areas associated with riparian zones in the Wimmera, Mallee, North Central and Gippsland regions of Victoria. These riparian wetlands are excluded because management of these areas is complicated by issues associated with river regulation (including their susceptibility to irrigated agriculture, the risk of flooding, the vulnerability of these wetland areas to river regulation and the importance of flow in maintaining wetland values). Wetlands that are never likely to be cropped (e.g. permanent deep wetlands, hyper-saline wetlands) are included in analyses where they occur in regions where there is a high density of these wetlands.

A large proportion of shallow wetlands are on private land (81 %, Papas and Moloney 2012), and disturbance from agricultural enterprises within their catchments and within the wetland itself is not

unusual. Condition assessments using the *Index of Wetland Condition* in 2009–10 revealed that cultivation was recorded for 20 to 21 % of wetlands on private land (Papas and Moloney 2012).

Wetlands provide a range of ecosystem services as well as being highly valuable to the community, and when wetland condition is impaired it can degrade the wetland's capacity to provide those values and services. There is some evidence that cropping can impact on wetland condition, but the degree to which it does, and the capacity of wetlands to recover from those impacts has not been well documented for Victorian wetlands.

Climate change is likely to impact both on wetlands (Nielsen and Brock 2007) and on the economics of agriculture in Victoria. Temporary wetlands are likely to be wet less frequently and for shorter durations in the future. Water regimes might change from seasonal to episodic. Cropping enterprises are likely to be more opportunistic, and be undertaken in higher rainfall zones in Victoria than has occurred in the past. However, the scope and extent of these changes, and the impact on wetlands is not well known.

Before the Millennium Drought (1998–2010) most undrained temporary wetlands in Victoria had been impacted by agricultural land use, but many retained a degree of resilience, biodiversity and connectivity. We can only guess at the values and services provided by wetlands before settlement by Europeans, but it is likely that they were high, from the population density of aboriginal people and their dependence on wetlands (e.g. Humphries 2007).

Despite that long history of agricultural exploitation and drainage, temporary wetlands in Victoria have been significant repositories of biodiversity in the Victorian landscape (Willis 1964). There were relatively few studies on temporary wetlands in Victoria undertaken before the Millennium Drought (Corrick and Norman 1980, Corrick 1981, Corrick 1982, Corrick 1992, Roshier et al. 2001, Butcher 2003, Robson and Clay 2005), but these studies indicate the general high biodiversity and functional values of temporary wetlands in the landscape. Even during the Millennium Drought, temporary wetlands retained high biodiversity values when they filled (Casanova 2012, Casanova and Powling 2014).

1.3. Cropping

Broadacre cropping is the agricultural practice of obtaining grain or seeds from annual plant species on a large scale. Crop plants are typically grasses or forbs bred specifically for their seed yield. In southern Australian dry-land cropping regions species cultivated include wheat (*Triticum aestivum*), barley (*Hordeum vulgare*), oats (*Avena sativa*), canola (*Brassica rapa*) and various leguminous plants (e.g. Faba beans *Vicia faba*).

Cropping is a widespread agricultural enterprise in regions where the topography is flat or undulating, the vegetation is naturally grassland or has been extensively cleared, and the soil is arable (not rocky). These conditions exist in the Goulburn-Broken, North Central, Wimmera, Mallee, Glenelg-Hopkins and Corangamite CMA regions, but cropping is not generally undertaken where there is dairying or horticulture, as these enterprises are more profitable than cropping (Appendix C). In parts of West and East Gippsland and North East Victoria the topography is rarely amenable to cropping. Although cropping as a land-use is mapped on the Victorian Land Use Information System 2014/2015 (LANDUSE_2014/) spatial layer, the information available lags current land use change (see Appendix E).

Cropping has been a long-term land use in the Victorian landscape. The key drivers of cropping in Victoria are suitable agronomic conditions for crop growth (topography, soil, moisture, temperature), the economic return, the availability of infrastructure and the skills and knowledge of the farming community. Although there has been a general increasing trend in land being cropped in Victoria over the last 150 years, there is evidence that the transition to cropping is growing at an increasing rate in the Victorian landscape (Appendix C). This is largely a consequence of the greater profitability of cropping compared to other enterprises over time, and the development of new chemicals, protocols and machinery. Changes in protocols and procedures in cropping enterprises are almost exclusively directed towards increasing productivity and profitability.

There has been a continual expansion of cropping into previously inaccessible terrain as a consequence of developments in mechanisation (Donald, 1982). Among the largest technological changes in agriculture

between 1975 and 2010 was the widespread adoption of use of an array of herbicides (Appendix B) and development of sophisticated sowing techniques (Kingwell, 2002). In 2016 the process of producing grain-crops for human consumption or biofuels is highly industrialised. It uses large machinery (tractors, combines, groupers, airseeders, headers, trucks) and is done over thousands of hectares of land (35 % of the agricultural land in Victoria (ABS 2016)), and results in millions of tonnes of yield (e.g. 2.3 million tonnes of wheat grown (ABARES 2015), 1.8 million tonnes of barley, 420,500 tonnes of canola (Australian Crop Forecasters 2015) in Victoria in 2015/16). It is not uncommon for a single farmer to sow 5000 ha in a season.

The overall aim of cropping practices is to produce a plant monoculture that results in a high yield of seed or grain. Common cropping practices are as follows:

- removal of rocks and standing vegetation (grasses, forbs, shrubs) allows the creation of a uniform seed bed
- land-forming activities such as drainage and raised-bed formation are designed to reduce waterlogging and improve soil aeration to enhance crop growth
- application of herbicide(s) before sowing to remove any perennial or annual competing plants
- the use of sowing machinery that is precisely engineered to ensure correct spacing and placement of the seed (depth, cover, row distance) and fertiliser to optimise crop growth
- addition of fertiliser to provide the correct ratio of nitrogen and phosphorus for maximum growth and yield of crop plants
- application of herbicide(s) after sowing (pre-emergent and post-emergent sprays) to remove the seedlings of germinating non-crop species that might compete with crop plants (these herbicides can have long residual effects)
- application of insecticides and malacocides to kill invertebrates (insects and molluscs) that might interfere with crop-growth
- application of fungicides to destroy pathogenic fungi on crops (rusts, smuts, blights and moulds)
- post-harvest activities such as burning and grazing are undertaken to reduce plant biomass in preparation for the next year's crop (Consultation, Appendix A); and
- plant-free fallowing (after harvest) to control of pathogens that cannot be controlled by chemicals.

The likelihood of obtaining successful crop growth in wetland soil is related to soil treatment (see *Ameliorants* in Section 3.4.3), the crop species/variety, and management responses to waterlogging. There is active research into the selection of crop varieties for waterlogging tolerance in the world (Verhoeven and Setter 2010) as well as in Victoria, with the objective of selecting characteristics that would enable crops to better withstand short term flooding (Verhoeven and Setter 2010). There is direct agronomic advice concerning application of urea to waterlogged crops (see *Fertilisers* in Section 3.4.3). These strategies enable farmers to respond to waterlogged wetland soils, and to overcome agronomic limitations to cropping in wetlands. Multi-peril crop insurance is now being offered to farmers in Australia. This includes cover for the risk of flooding and heavy rain, and there is a federal government program to promote its uptake¹. The ability to insure against crop loss in wetlands could increase the likelihood that farmers will crop wetlands (Cox and Rundquist 2013).

The ethos of cropping is to increase productivity (yield) at the expense of biodiversity. This occurs by increasing environmental homogeneity at the expense of environmental heterogeneity. Further to that, once cropping is started on an area of land it is likely to continue unless there are significant barriers, such as frequent flooding, catastrophic, uncontrollable weed, herbivore or pathogen infestations, or a major economic collapse in the market for grain or crop products.

¹ Multi-peril crop insurance <http://www.abc.net.au/news/2015-01-14/multi-peril-crop-insurance-payout/6015664>. Cover for the risk of flooding and heavy rain <http://www.mpciaustralia.com.au/ambassador-program/>. Federal government program (<http://www.agriculture.gov.au/ag-farm-food/drought/assistance/mfrp>)

Shallow, temporary, freshwater wetlands can, in most circumstances, be used as cropping land when they are dry and are likely to remain so for the duration of the cropping season (Consultation, Appendix A). The Millennium Drought stimulated a steady increase in cropping area in Victoria (van Dijk et al. 2013), including an increase of 6.7 % in area cropped in the south-west of Victoria over the decade to 2003 (WatLUC 2005). Some of that increase occurred in areas occupied by temporary wetlands (Casanova 2012).

The level of impact of cropping on wetland condition and values is likely to be affected by the attributes of the wetland (see Section 3.1), the nature of the cropping practices employed (see Section 3.2), as well as factors that guide the decision about whether or not to crop a wetland (see Section 3.2.2).

1.4. Vulnerability assessment framework

Schröter et al. (2004) developed a model for vulnerability assessment for the European human-environment system (Figure 2). This model was used to assess of the capacity of Australia’s industry and community to adapt to climate change (Allen Report 2005), and further by Hobday *et al.* (2006), to assess the impacts of climate change on Australian marine life. A similar model was used by the International Union for the Conservation of Nature (IUCN) to assess species responses to climate change (IUCN 2016): *“The greatest vulnerability to climate change occurs when species are exposed to large and/or rapid climate change driven alterations in their physical environment, are sensitive to those changes, and have low adaptive capacity”*. This model can be adapted to assess wetland vulnerability to cropping.

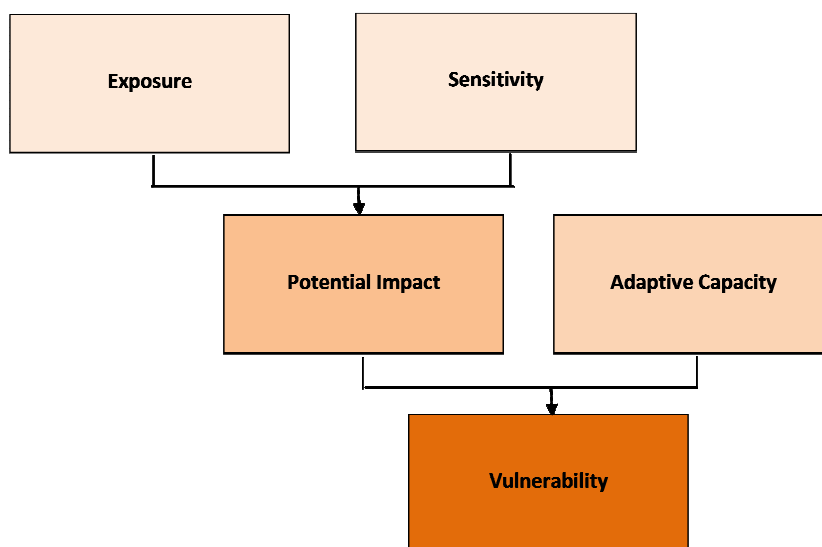


Figure 2. Model of vulnerability assessment (after Schröter et al. (2004)).

The model is a form of risk assessment with the following components:

Exposure is the likelihood of a wetland, type of wetland or region of wetlands to be subject to activities associated with cropping (e.g. direct cultivation, exposure to chemicals). This is largely based on its position in the landscape, combined with predicted trends in cropping practices and climate impacts.

Sensitivity is the degree to which exposure to cropping, or a specific component of cropping, elicits a response. It is equivalent to the “consequence” component of a traditional risk assessment. Wetland attributes (physical, chemical, biological) that can tolerate significant exposure without change, are assessed as having low sensitivity. Those attributes that undergo change in response to exposure are assessed as having high sensitivity.

Potential impact is the product of exposure and sensitivity.

Adaptive capacity is a term originally used to refer to human capacity to change their behaviour in relation to a stressor. In biological systems this is often defined as ‘resilience’, since the evolutionary process of adaptation is likely to take place over a longer time-frame than is available in relation to current changes in land use. Attributes that contribute to ‘adaptive capacity’ in wetlands include seed banks, connectivity, and

biodiversity. It should be recognised that although cropping consists of component impacts (i.e. soil amelioration, chemical application etc.) in current agricultural practice all components are regularly undertaken as ‘a package’ to ensure crop productivity. If, for example, there is a recommendation that herbicides should not be used in cropping in wetlands, it is unlikely to be taken up, since a lack of herbicide treatment virtually ensures failure of the crop.

Vulnerability (in this model) is a product of the potential impact of cropping and cropping related activities, mitigated by the adaptive capacity.

1.5. Cropping and wetlands

The purpose of this project was to assess the current and future risks to wetlands in Victoria from cropping, through an application of the vulnerability assessment framework. The outcomes of this assessment can be used to inform NRM managers in the development of tools to address wetland vulnerability to cropping.

The specific objectives were to:

- describe the attributes and values of wetlands both at the site and landscape scale
- describe the components of cropping systems and their potential impact on wetlands. These include the procedures undertaken (e.g. cultivation, herbicide application) as well as the social influences that motivate farmers to crop wetlands
- evaluate the sensitivity and adaptive capacity of wetlands in relation to cropping and assign vulnerability (high, medium or low)
- delineate the regions or areas where wetlands are at risk of cropping, and determine the landscape characteristics associated with high vulnerability; and
- provide guidelines on potential management responses for NRM managers.

1.5.1. The structure of this report

Section 2 outlines the methods used to review the literature and engage the input of the community in meeting the objectives. The methods used for determining the scale and locations of cropping in wetlands are also outlined (GIS and spatial analysis).

Section 3 provides an assessment of wetland types at risk of cropping, their condition and values at the site scale, outlining their attributes and processes, especially in relation to water regime. Exposure of wetlands to cropping is a function of the choices made by farmers/landowners, and the procedures used to establish, grow and harvest crops. The different components of cropping are assessed with reference to their impact on wetlands, as well as wetland sensitivity to those impacts. The overall vulnerability of individual wetland components to cropping is tabulated.

Section 4 provides an assessment of wetland vulnerability at the landscape scale. Landscape level consequences of cropping are described. The exposure of Victorian wetlands to cropping now, and in relation to climate change is outlined, and two case study clusters are examined in detail in relation to the current exposure to cropping. The landscape level patterns of cropping in wetlands are used to inform the assessment of the vulnerability of wetlands to cropping at the landscape scale, along with the landscape-level attributes of wetlands and their adaptive capacity. These are used to determine predictors of wetland vulnerability at the landscape scale.

Section 5 provides guidelines for natural resource managers.

Section 6 makes recommendations about future projects to fill knowledge gaps about wetland processes and the implementation of management tools.

2. Methods

2.1. Literature review

An extensive literature review was undertaken, accessing written resources in grey and refereed published literature and websites. The focus of the review was on:

- the direct and indirect impacts on wetland condition from cropping
- the impacts on wetland values and ecosystem services, for example, on carbon storage and sequestration
- the ecological pathways through which impacts on wetland condition and values are likely to be expressed
- the types of wetlands that are most vulnerable to cropping
- changes to individual wetland condition, ecosystem services and values from cropping
- the effects of cropping and predicted changes to cropping practices on wetland condition, ecosystem services and values at a landscape scale; and
- the capacity for wetland environmental condition and values to recover after cropping and the scale of the interventions required.

Search terms used included 'cropping'; 'agriculture'; 'condition'; 'soil disturbance'; 'utilisation' in conjunction with a variety of phrases describing different wetland types: 'wetland'; 'swamp'; 'lagoon'; 'playa' etc. as well as landscape variable e.g. 'landscape', 'connectivity', 'riparian'; 'low-land'; 'temporary'.

Search engines included Google, Google-Scholar, Research Gate, and library search engines in Wiley Online, Cambridge Journals, Elsevier, CSIRO Journals, JSTOR, BIOSIS databases, and the resources of the USGS National Wetland resource database. Published papers were downloaded and are available on request.

2.2. Expert consultation

Consultation was undertaken with wetland managers (including farmers) and wetland researchers throughout the focus areas of Victoria and in nearby states. Initial contact was made with CMAs, universities and research institutions. Face to face meetings and telephone meetings were undertaken throughout the project to ascertain information about the current extent, drivers and potential change in the practice of cropping in wetlands and wetland catchments (referred to in the text as 'Consultation, Appendix A'). Additionally, interviews were undertaken with individual land-managers to determine the techniques and inputs used in cropping programs. The results have been provided as an appendix summarising the communications. A list of the people contacted and interviewed along with their contact details is available on request.

As this study progressed it was found that there were sources of information about chemicals (data safety sheets; labels) that were highly informative about the functions, application and effects of chemicals on target and non-target organisms, so questions about these were not included in the consultation. The actual occurrence of cropping in the landscape can be easily determined from Google Earth and other spatial resources, and, as this constituted a more objective source of information than personal communications, the GIS information was used to determine the extent and distribution of cropping in the Victorian landscape.

2.3. Geospatial analysis

A computer-based geospatial investigation was undertaken to assist in the identification of cropped wetlands and as-yet uncropped wetlands that were at risk from cropping. The open source Geographical

Information System program QGIS (Version 2.14.1-Essen) was used for this task. The purpose was to address the following questions:

- the areas in Victoria where cropping occurs in wetlands
- the current overall incidence of cropping in wetlands
- how this differs from information available before this study
- the wetland types that are currently cropped
- the characteristics that help to explain the incidence of wetland cropping; and
- how that informs the risk of cropping in other wetlands.

The methods used to complete this analysis involved matching visual satellite imagery with other layers of spatially arranged data. Layers are readily available for location specific information, such as wetland size and extent, soil types, water courses and tree cover. Large amounts of data, covering an extended geographical area, can be manipulated in a short period of time. These non-satellite layers typically comprise polygons or lines, stored as vector data with attached tables of attribute data for individual locations. This enables the selection of subsets of data, whether based on geographical location, specific attributes within the vector layer, or on the attributes within another layer. An example of the latter would be the selection of privately managed wetlands that occur on a specific soil type in a given location. Selected data was exported for further investigation, in a spreadsheet, database or statistical program.

The tasks in this project were broken into discrete steps in order to gain an overview of the status of wetlands. The initial overview was followed by investigation, in more detail, of regions identified to have at-risk wetlands. Case studies were undertaken on two selected wetland clusters to quantify the impact of cropping on individual wetlands. This involved making observations of the incidence and types of cropping in randomly sampled wetlands within the clusters, and also the incidence of cropping in the surrounding district. These data were then assessed to characterise the wetland features that distinguish high risk wetlands, and to identify non-wetland characteristics that contribute to the risk that a wetland will be cropped.

2.3.1. GIS source data

A specific set of raster and vector GIS data was used in the geospatial analysis (Table 2).

Table 2. Shapefile layers accessed in land use evaluations for this report.

Title	File	Currency	Source
Bing Maps - road		2016	web
1 in 100 year flood extent	extent_100y_ari	12may2016	data.vic.gov.au
Google Maps - satellite		2016	web
Public Land Management	plm25	08sep2014	data.vic.gov.au
Tree density 1:25,000	tree_density_dense tree_density_medium tree_density_scattered	01oct2001	data.vic.gov.au
Victorian land Use Info System (VLUIS)	landuse_2014	31dec2015	data.vic.gov.au
Victorian primary production landscapes	ppl	01jul2010	data.vic.gov.au
Victorian Soil type mapping	soil_type	29feb2016	data.vic.gov.au
Victorian Wetland Environments and Extent	wetland_current	01jan2013	data.vic.gov.au
Watercourse Network	hy_watercourse	current	data.vic.gov.au

An acknowledgement of the satellite images used throughout this report is fully disclosed as follows: QGIS enables access to Google Maps, and the Google satellite layer was chosen as one option within this selection. Each image in that layer is from one or a number of satellite sources, depending on geographical location and the degree of magnification chosen. Where the copyright insignia is not clear on images displayed in this report, the following sources are acknowledged:

- **Google Maps / Google Earth** <https://developers.google.com/maps/>
- **TerraMetrics** <http://www.trueearth.com/>
- **Centre National d'Études Spatiales** <https://cnes.fr/fr>
- **Astrium** <http://csr.astrium.eads.net/#/hp>
- **Spot Imagery** <http://www.intelligence-airbusds.com/en/143-spot-satellite-imagery>
- **DigitalGlobe** <https://www.digitalglobe.com/>
- **Landsat** <http://landsat.usgs.gov/>

2.3.2. Overview of Victoria's wetlands

The wetland_current layer has been compiled over time from a number of sources and contains information about Victorian wetlands in its associated attributes table. The layer was interrogated against maps and ground-truthed against landmarks known to the authors to verify some of the data. No systematic errors were detected except where separate attributes of crop-levee-drain had matching values in some cases. Some attribute values have associated confidence levels to account for data quality.

It was decided that a precautionary principle should be used, and to not exclude wetlands from evaluation that, because of classification (e.g. permanent, artificial), might be thought to be of low risk from cropping. Available satellite images have sufficient resolution to discern differences in land forms and uses. Wetland features can be observed, especially when combined with the wetland_current polygon layer. The default polygon display was changed, so that only the wetland outline was shown, which enabled the details in the underlying satellite image to be observed.

2.3.3. Filtering of the wetland dataset

There are a total of 35,499 Victorian wetlands in the wetland_current layer. These were filtered to exclude those wetlands, on the basis of land-form or locality, to be at low risk from cropping. Categories excluded comprised:

- coastal and high country wetlands of the categories; 'coastal saltmarsh', 'estuary', 'high country peatlands' and 'intertidal flats'
- wetlands on public managed lands (using the plm25 layer); and
- highly modified wetlands such as sewage treatment ponds.

A total of 19,973 wetlands remained to be evaluated for cropping risk.

Wetland clusters in Victoria were identified with the use of a 'heat-map' algorithm within QGIS. This was done by converting wetlands to points and then creating a raster map layer that associates pixel colour intensity with proximity among wetlands. Areas of high wetland density then appear more brightly coloured. The choice of wetland clusters was further informed by examination of the natural and artificial drainage in the landscape, along with the development of artificial water bodies on farms (dams). Each cluster was examined for the type of wetlands and the incidence of cropping. Clusters that contained both a high incidence of cropping and a large number of wetlands were chosen for further exploration of the number and types of wetlands, the distribution and density of cropping as a land use, and the incidence of cropping within wetlands.

2.3.4. Determination of the extent of cropping in individual wetlands

The presence of broadacre grain cropping in Google Earth images could be discerned by the presence of GPS-guided 'cropping lines', traces on the ground indicating the passage of sowing or harvesting

equipment; 'sowing rows' and 'header rows'. The authors have a long personal experience with different types of cropping methods, and were also able to calibrate satellite images for different crops against paddocks of known cropping histories. Crops were able to be distinguished from hay-making activities by the pattern of rows. Hay-making typically follows the circumference of the paddock, whereas cropping is usually undertaken in long-linear tracks (see section 4.2). An exception is for canola that has been windrowed by a tractor, but in this case there is usually a different turning pattern at corners in comparison with hay making. Grazing was also able to be distinguished from cropping. Less distinct differences occurred in areas where forage crops are grown in dairying areas and the satellite images are from winter or spring. Grain cropping is most readily distinguished from images taken over summer.

Four categories of cropping in wetlands were distinguished using Google Earth images of wetlands (Figure 3):

- Uncropped – no grain/seed crop present and absence of evidence of GPS-guidance autosteer cultivation (Figure 3a). In this example the wetland perimeter is identified by a black polygon, there is a dam dug within the wetland, and signs of grazing (tracks leading to the dam). The surrounding area has been sown to crop or cut for hay sometime in the past.
- Cropped – with a strong visual indication of a grain crop over the whole wetland. Sometimes the crop has a darker colour near the centre of the wetland (Figure 3b) due to different soil conditions or waterlogging during crop growth. Large wetlands are sometimes sown separately to the surrounding paddock due to perimeter trees, or steep sides (Figure 3c).
- Partly cropped edge – evidence of encroachment of cropping into wetland margins (Figure 3d).
- Partly cropped edge and bed – cultivation or crop evident through a section of the wetland bed (Figure 3e, f) These two examples were placed in the same category, but are distinguished here because the first (Figure 3e) is where a wetland is bisected by a property boundary. One owner has cropped the wetland, the other has not. The second example (Figure 3f) is where a single landowner has made a decision to crop part-way across the wetland on the day the paddock was sown (i.e. on the basis of the nuisance cost of turning the tractor and soil conditions).

2.3.5. Assessment of wetland clusters

The heat-map depiction of wetlands showed that there were several important regions for investigation of cropping. Each wetland cluster was given a name. Two of the largest of these were investigated in more detail. For both of these, a rectangular grid of 42–50 cells was applied to the spatial layer of wetlands, based on the areal extent of the cluster. The size of grid cells varied between clusters (12 x 15 km, and 11 x 14 km), based on the density of wetlands occurring, so that an average of 45 wetlands was contained within each cell. A sample of seven to 10 cells was chosen (via random number generation) to obtain a total of approximately 450 (440 West Wimmera– 453 South East Grampians) wetlands per cluster. A central reference-point was marked in each cell to determine the distance to the nearest cropped land, to derive a measure of crop density across the cluster.

Privately owned wetlands within each cell were examined for evidence of cropping (in the categories Section 2.3.4 above). Three additional attribute columns were created for sampled wetlands: cropping category (absent, all cropped, edge, and edge and bed), cell number, and whether there was cropping adjacent to the wetland. Confidence in allocation of the categories was high in all cases.

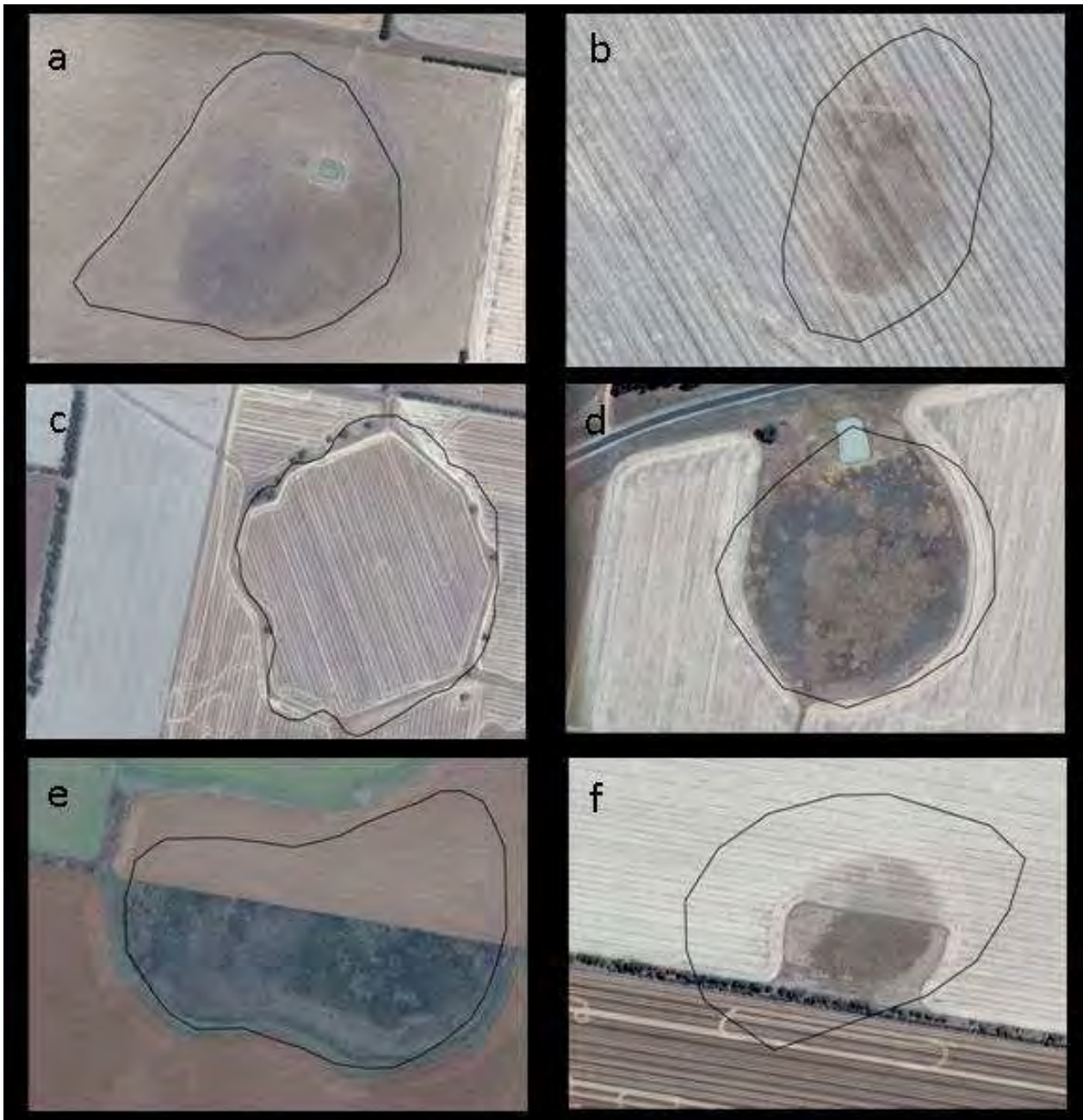


Figure 3. Wetlands in a Victorian cropping landscape; a) uncropped wetland, b) fully cropped wetland, c) fully cropped wetland (separate paddock surrounded by *Eucalyptus camaldulensis*), d) wetland cropped at the edge, e) wetland cropped at the edge and across the bed (paddock boundary), e) wetland cropped at the edge and across the bed (failure to turn).

2.3.6. Analysis of wetland clusters

The attributes for sampled wetlands from the two major clusters provided in the spatial wetlands layer, and the attributes determined by examination of aerial photography were entered into a Microsoft Access Database and interrogated to summarise wetland attributes associated with the incidence of cropping in and near wetlands. The statistical program Minitab (minitab.com) was used for descriptive statistics and for some data plotting. The chi-squared statistic was used to compare observations (observed and expected) to determine the probability of observations occurring by chance alone, or if they could be reliably allocated to a wetland attribute (e.g. whether the incidence of cropping was higher in freshwater wetlands than saline wetlands).

2.3.7. Determination of the southern limit of cropping

Climate change will result in increased evaporation rates across southern Victoria (leading to a higher likelihood of wetlands being dry), and a gradual decrease in rainfall across the Victorian landscape towards the south (CSIRO 2016b). Therefore, the southern limit of cropping was determined to assess the risk of cropping in wetlands outside the regions where cropping currently occurs.

The Victorian spatial layer was overlaid with a rectangular grid of cells (5 x 6 km) from Geelong to the South Australian border. Google Earth images of the landscape were examined to determine the presence of cropping. A central reference-point was marked in each cell to determine the distance from the centre of each cell to the nearest cropped land, to derive a measure of crop density across the landscape. This was recorded in a graduated colour scale, ranging from crop present at the centre of the cell (red), through to the nearest crop up to 8 km from the cell centre (blue). Only cells along the transition were marked. The confidence of the determination of cropping was recorded in an attribute table for each cell assessed (high or medium, low confidence was not used) to account for the potential confusion between forage cropping (a less intensive land use, and one that has occurred historically) and broadacre cropping. Each north-south series of cells was recorded sequentially until the southern limit of cropping was detected. No grain crops were detected south of the last blue cell in each line. This resulted in a ‘heat diagram’ showing the limits of cropping as a major land use.

2.4. High, Medium and Low: tabulation and colours

Where values of high, medium or low ‘strength of link’ are provided in tabular form (e.g. Table 6) these are based on an assessment of the number of studies that indicate a link exists (e.g. low = 0 – 2 studies indicate a link, medium = 3 -5 studies indicate a link, high = > 5 studies indicate a link) where there was no contrary information found.

A high, medium or low ‘vulnerability’ score is equal to the ‘potential impact’ where the adaptive capacity is not known or not relevant (e.g. Table 13). The value is based on the highest score in the other two categories on the rationale that high exposure or high sensitivity will result in high potential impact and vulnerability even if the other category score is low. When calculated from potential impact and adaptive capacity (e.g. Table 13) the vulnerability score is given as low or medium where adaptive capacity is high (i.e. the converse of the exposure and sensitivity) because adaptive capacity mitigates the potential impact. The colours assigned are yellow (for low), orange (for medium) and red (for high). Where the score cannot be easily evaluated the table cells are left uncoloured.

Table 3. Explanation of the scores for High, Medium and Low ‘vulnerability’ in this study in relation to ‘exposure’, ‘sensitivity’ and ‘adaptive capacity’.

Exposure	Sensitivity	Vulnerability
Low	Low	Low
Low	Medium	Medium
Low	High	High
Medium	Low	Medium
Medium	Medium	Medium
Medium	High	High
High	Low	High
High	Medium	High
High	High	High

Potential Impact	Adaptive Capacity	Vulnerability
Low	Low	Low
Low	Medium	Medium
Low	High	Low
Medium	Low	Medium
Medium	Medium	Medium
Medium	High	Low
High	Low	High

High	Medium	High
High	High	Medium

3. Wetland vulnerability at the site scale

For wetlands to be at risk from cropping they have to be dry at the time of sowing and the soil has to be amenable to cropping (not saline). Wetlands that dry frequently are generally shallow, and shallow fresh (to brackish) wetlands can be well-vegetated. Cropping does not occur on very steep or heavily forested land, so wetlands at risk usually occur on plains areas with endorheic (internal) drainage patterns (Table 4).

A definition of wetlands specifically at risk from cropping is based on their hydrology and water source: *“precipitation-filled, temporary water bodies that remain flooded for a sufficiently long period of time (usually during winter and spring) to allow the development of aquatic or semi-aquatic plant and animal communities. The waterlogged or pooled water stage is followed by extreme desiccating soil conditions, frequently of extended duration.”* (Keeley and Zedler 1998; Zacharias et al. 2007).

Such wetlands have been variously defined as freshwater swamps, gilgais (Wilson and Hendy 2011) and ponds (Willis 1964), wet meadows, shallow and deep freshwater marshes (Corrick and Norman 1980), and seasonal herbaceous wetlands (EPBC 2012). Under the Victorian wetland classification system, these would be defined as lacustrine or palustrine, naturally occurring, periodically inundated, fresh to hyposaline dominated by forest/woodland, shrub or sedge/grass/forb vegetation. These wetlands support a number of Ecological Vegetation Communities (EVCs) including Aquatic Grassy Wetland (EVC 306), Red Gum Swamp (EVC 292), Aquatic Sedgeland (EVC 308), Spike Sedge Wetland (EVC 819), Tall Marsh (EVC 821), Plains Grassy Wetland (EVC 125), Plains Sedgy Wetland (EVC 647), Plains Rushy Wetland (EVC 961), Sedge Wetland (EVC 136), Sedge-rich wetland (EVC 281), Claypan Ephemeral Wetland (EVC 284), Canegrass Wetland (EVC 291), Aquatic Herbland (EVC 653), Lignum Swamp (EVC 104), Submerged Aquatic Herbland (EVC 918), Dwarf Floating Aquatic Herbland (EVC 949), and complexes among these.

Table 4 Attributes of wetlands at risk of cropping in Victoria.

Characteristic	Justification
Shallow	In medium and low rainfall areas shallow wetlands become dry, and thus amenable to cropping
Freshwater or brackish	Highly saline soils are not amenable to crop growth, so only fresh or brackish wetlands can be used
Rain-filled	Wetlands fed by ground-water are less likely to be predictably dry
Endorheic, not part of a drainage line	These wetlands occur in flat (plain) landscapes, where cropping is a prevalent land use, not likely to be filled by river/stream flow

3.1. Attributes of wetlands at the site scale

Individual wetlands are recognised to have a number of important values in society, including environmental, cultural, social and economic values (DELWP in prep. 2014). In addition, wetlands provide a number of services to society, including flood mitigation (Zedler 2003), carbon sequestration (Fennessy and Craft 2011, Tangen et al. 2015), ground-water recharge and provision of biodiversity (Zedler 2003, Fennessy and Craft 2011). These values and services are supported by the environmental condition of the wetland and the water within it. The attributes of wetlands that impact on condition, values and provision of services are the quality and quantity of habitat provided, water quality and quantity, and patterns of water presence and abundance over time (the water regime). Those attributes of wetlands are affected by natural events, development activities, land use (such as cropping) and climate change, which in turn affect wetland condition. The focus of this report is about how land use, specifically cropping practices, affects the environmental condition of wetlands, and therefore provision of wetland values i.e. provision of habitat to

flora and fauna (including rare, vulnerable or threatened species), maintenance of biodiversity (Willis 1964, Casanova and Powling 2012), cultural values, such as the maintenance of significant cultural objects (e.g. birthing trees) and improvement of quality of life (e.g. aesthetic qualities such as the sound of frogs). Additionally, many species of birds that depend on wetlands are of agricultural (ibis) or recreational value (ducks) (EDO 2012).

3.1.1. Water regime

Temporary wetlands contribute to both aquatic and terrestrial condition and values, at different times. The major influence on components and processes in temporary wetlands is the variation in wetting and drying (Figure 4) i.e. the water regime: the depth, duration, frequency and timing of inundation. The water regime impacts on soil attributes, water quality, biodiversity, connectivity, nutrient cycling and habitat diversity. Water regime is itself a consequence of climate (rainfall, evaporation, temperature, seasonality), connectivity with groundwater and the topography or bathymetry of the wetland and its surrounding landscape.

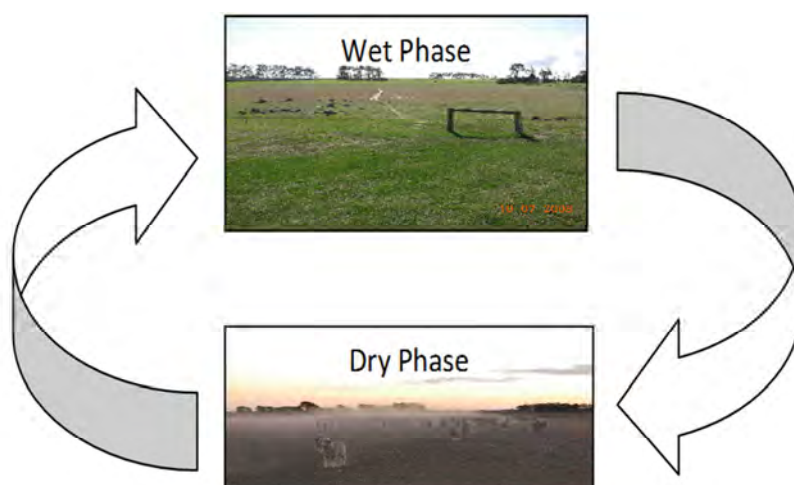


Figure 4. Cyclic changes in temporary or ephemeral wetlands. The example is a seasonal herbaceous wetland from the Glenelg Hopkins region, grazed by sheep in the dry phase. During the wet phase the depth is never more than 60 cm deep. Wet phases rarely last more than 8 months, dry phases can last from 6 months to 6 years (Casanova and Powling 2014). Fluctuations from wet to dry are characteristic of the ‘stable state’ of temporary wetlands.

Water regime provides the stimulus for aquatic vegetation, and the planktonic and epiphytic micro-fauna and flora to germinate or hatch from the seed bank (Figure 5). Each group of biotic trophic levels (plants, detritivores, herbivores, carnivores) provides resources to others. The diversity of the top level consumers (birds and reptiles) is dependent on the diversity of resources provided by the consumers of plants and microalgae. Microalgal diversity depends on water quality as well as habitat provision and amelioration of growing conditions by water plants. The diversity of invertebrates depends on the provision of a diversity of resources for habitat and consumption. The initiation of processes (such as germination, herbivory) is mediated by the water regime, and the diversity of the primary producers and invertebrates is conditional on integrity of the seed bank (for germination, hatching and establishment) (Butcher 2003, Casanova and Powling 2014). Migration of propagules (seeds, spores, eggs) from distant or nearby sources, can also contribute to vegetation and microbial establishment, but this is recognised as a secondary source of propagules. The seed bank provides a large degree of resilience to temporary wetlands (Wilson and Hendy 2011), but is a finite and somewhat fragile resource (Brock 2011).

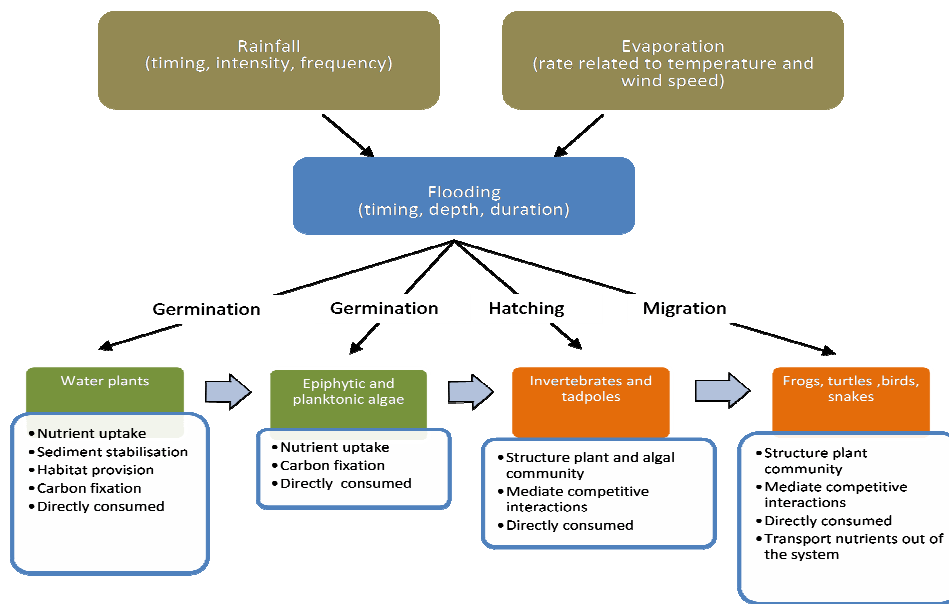


Figure 5. Elements of the food web and biotic processes that occur in temporary wetlands. Climatic variables influence water regime, which in turn influences biotic events, and the flow of energy and carbon (after Casanova and Powling 2012).

3.1.2. Diversity of biota

Individual wetlands are biodiversity ‘hot-spots’ in agricultural landscapes (Casanova and Powling 2014), often containing unique or restricted native species. Species of special significance that can occur in wetlands at risk from cropping include many plant species (Appendix E), at least one endemic undescribed desmid species (I.J. Powling pers. comm.), two species of charophyte that occur only in seasonal wetlands in Victoria (*Chara karolii* Casanova 2015, *Nitella* sp. aff. *cristata* Casanova and Karol in prep.) and state-listed invertebrate species (Butcher 2003, Robson and Clay 2005, EPBC 2012). Among vertebrate species associated with these wetlands are Fat-tailed Dunnarts (*Sminthopsis crassicaulis*), listed as near threatened on the DELWP advisory list (DSE 2005), Striped Legless Lizards (*Delma impar*, listed as threatened), frog species *Littoria raniformis* (nationally vulnerable Growling Grass Frog), *Pseudophryne semimarmorata* (state-listed Southern Toadlet) and *Uperoleia rugosa* (state-listed Rugose Toadlet) (SHW 2012). The nationally endangered Corangamite Water Skink (*Eulamprus tympanum marnieaeare*) and other state-listed reptiles (*Lissolepis coventryi*, *Pseudomoia rawlinsonii*) can also occur in association with temporary freshwater wetlands (EPBC 2012).

Temporary wetlands provide breeding habitat for threatened Brolga (*Grus rubicunda*), and feeding grounds for a large number of endangered, threatened, near threatened or vulnerable wading birds (e.g. Australasian Bittern, Royal Spoonbill, herons, egrets, Glossy Ibis) as well as migratory birds protected by international agreements (e.g. Latham’s Snipe, sandpipers) (Stevens 2006).

3.1.3. Cultural values

Individual wetlands provide a number of cultural values to the community. They represent historic landmarks recorded and named by explorers (e.g. Cockajemmy Lakes), they provide recreational and ambient quality-of-life values (e.g. catching yabbies, hearing frogs). Many wetlands hold significant value for Aboriginal groups. Cultural heritage values have been mapped for different regions of Victoria, and an example (BBCAG 2016) is of an area surrounding Lake Bolac that contains a large number of wetlands at risk of cropping (Figure 6).

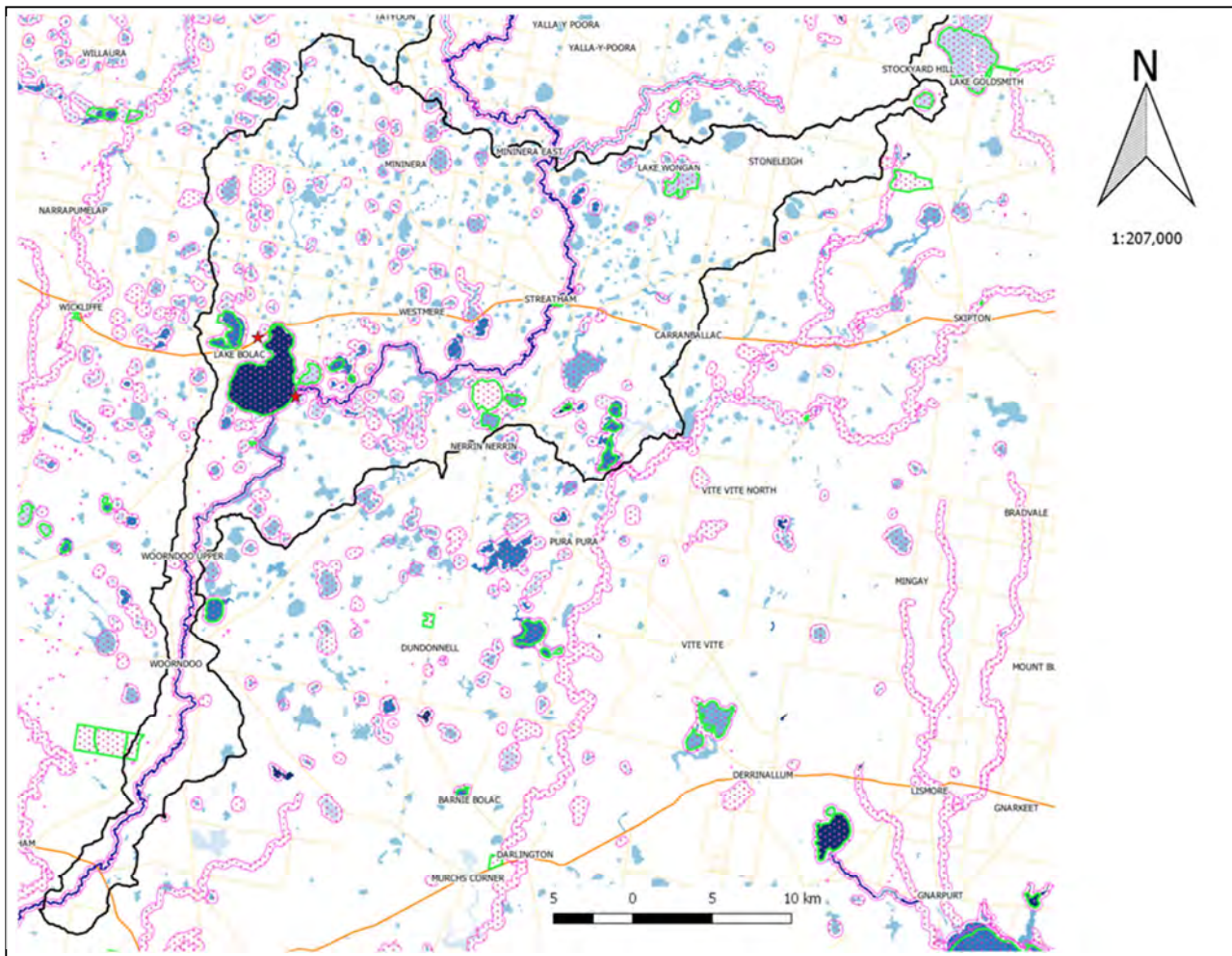


Figure 6. Map of cultural heritage sensitivity (pink), associated with wetlands (blue). These areas are either known to contain, or are likely to contain Aboriginal cultural heritage places and objects as defined in the *Aboriginal Heritage Regulations 2007*. High significance occurs mainly along waterways and around wetlands, as these are the areas where it is most likely to find evidence of aboriginal existence.

3.1.4. Wetland services

Temporary wetlands provide a number of services, although some of these (groundwater recharge, provision of habitat for agriculturally important fauna (e.g. dragonflies, frogs as consumers of pest insects; snakes as consumers of feral mice), carbon and nutrient cycling) have not been well quantified.

Wetlands, particularly peaty wetlands, have an important role in carbon storage and sequestration (Verhoeven and Setter 2010). Wetlands can acquire carbon by high rates of primary production by plant growth, deposition of plant material and a lack of degradation under anaerobic conditions (Verhoeven and Setter 2010, McLaughlin and Cohen 2013) or via burial by erosion and sedimentation (McCarty et al. 2009). However, while carbon sequestration is frequently mentioned as being a service provided by wetlands in good condition, it is difficult to find any targeted studies that show how much carbon is retained in typical wetland soils, how that is related to wetland condition or water regime, and how it might change with management. Undisturbed dryland soils are able to store more carbon than soils that are cropped or grazed (Foster et al. 2012, Tangen et al. 2015, Lal et al. 2011), and this is likely to be so in wetlands as well (Smith et al. 2011).

3.1.5. Wetland processes

The ecological processes that maintain the integrity and function of temporary wetlands in Victoria include germination of seeds and spores of plants, and hatching of eggs and resting cysts of micro-invertebrates and crustaceans from the seed bank, migration of animals and plant propagules from other wetlands, decomposition of plant and animal remains, as well as the interactions (competition, facilitation, symbiosis,

herbivory, carnivory) among different organisms within the wetland. The prime influence on the activity and character of these processes in temporary wetlands is the water regime. An additional influence is the abundance of resources other than water (light, nutrients). Management of the land around and within the wetland can also influence these processes.

3.2. Exposure of individual wetlands to cropping

Wetlands are exposed to cropping if they occur in suitable landscapes, and a farmer decides to crop them.

3.2.1. Land management decisions made by farmers

Where land is suitable for farming (i.e. land capability is not limiting), farmers actively intensify production to optimise profitability (Zhang et al. 2014). Although some of the increases in farm productivity that have been seen in the last two decades are due to increased scale and innovation, part of that increase is also due to a depletion of natural resources, or 'natural capital' (Mullen 2002). An example of this is when a cropping farmer increases economic productivity by removing impediments to the passage of machinery, such as wetlands, rocks, fences and trees.

Farming can be equated to a board game, or gambling, with winners and losers, where the rules are set by local and global economics (Makeham and Malcolm, 1981). An over-riding influence on Australian farmers is the relentless decline in their terms of trade, i.e. a decline in the ratio between income from production, and costs (Wright 2002). There has been a three-fold increase in agricultural productivity between 1953 and 1993, compared to a four-fold decrease in real prices received for agricultural produce over that period (Mullen, 2002). These challenges have produced a population of farm managers who trust their own instincts and who jump at opportunities (Wright, 2002). Examples of this are the speed with which grazing replaced cropping in western Victoria following the drop in grain prices in the early 1930s (Anon, 1936; Appendix C), and the speed with which cropping has replaced grazing in recent decades.

Making the decision to crop a wetland can be straightforward to a farmer. In the first instance she or he evaluates the possible benefits versus the likely costs, followed by an assessment of the potential physical and social constraints (Figure 7 and Figure 8). The value a farmer places on the natural environment and how it is managed can be different to the value placed on it by the rest of society. Unless there is a strong case to value a wetland in its own right, it can be devalued or ignored (Fellows and Buhl 1995), or thought of as being 'undeveloped'. This suite of attitudes, combined with technological advancements (such as GPS steering and zero tillage), as well as drier than average seasons, have combined to result in an increased incidence of cropping in wetlands, and a substantial risk from cropping to wetlands that remain unimpacted (Casanova 2012).

3.2.2. Factors that influence the decision to crop

The factors that influence the likelihood that a wetland can and will be cropped include physical attributes of the wetland and how easily constraints are overcome (Figure 7), the likelihood of economic gain, and social considerations such as the value given to a wetland by the farmer (Figure 8). A wetland is cropped only as the result of a conscious decision. Therefore, the factors that influence the decision-making process need to be taken into account.

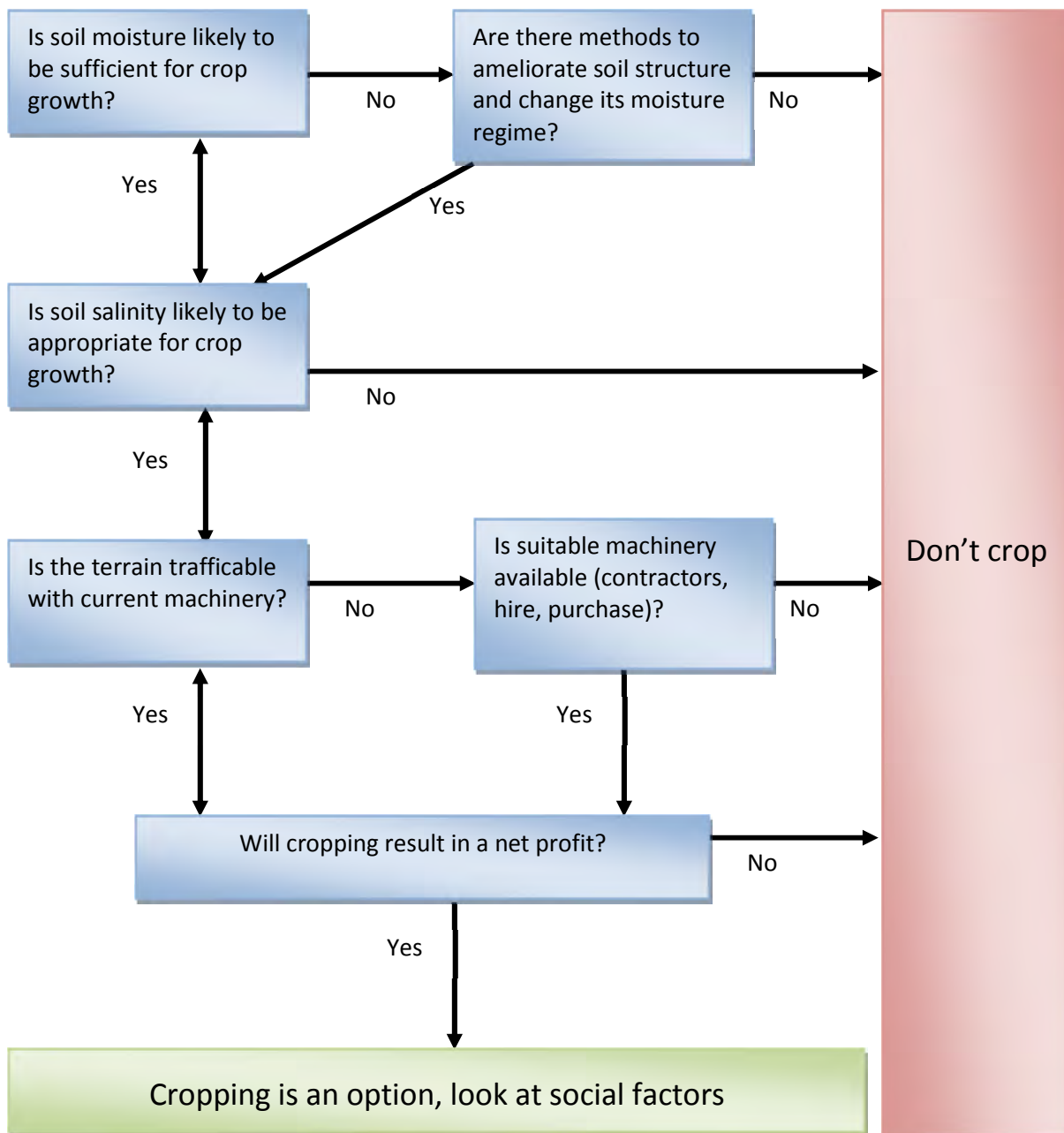


Figure 7. Physical and economic factors that influence a farmer’s decision to crop a wetland.

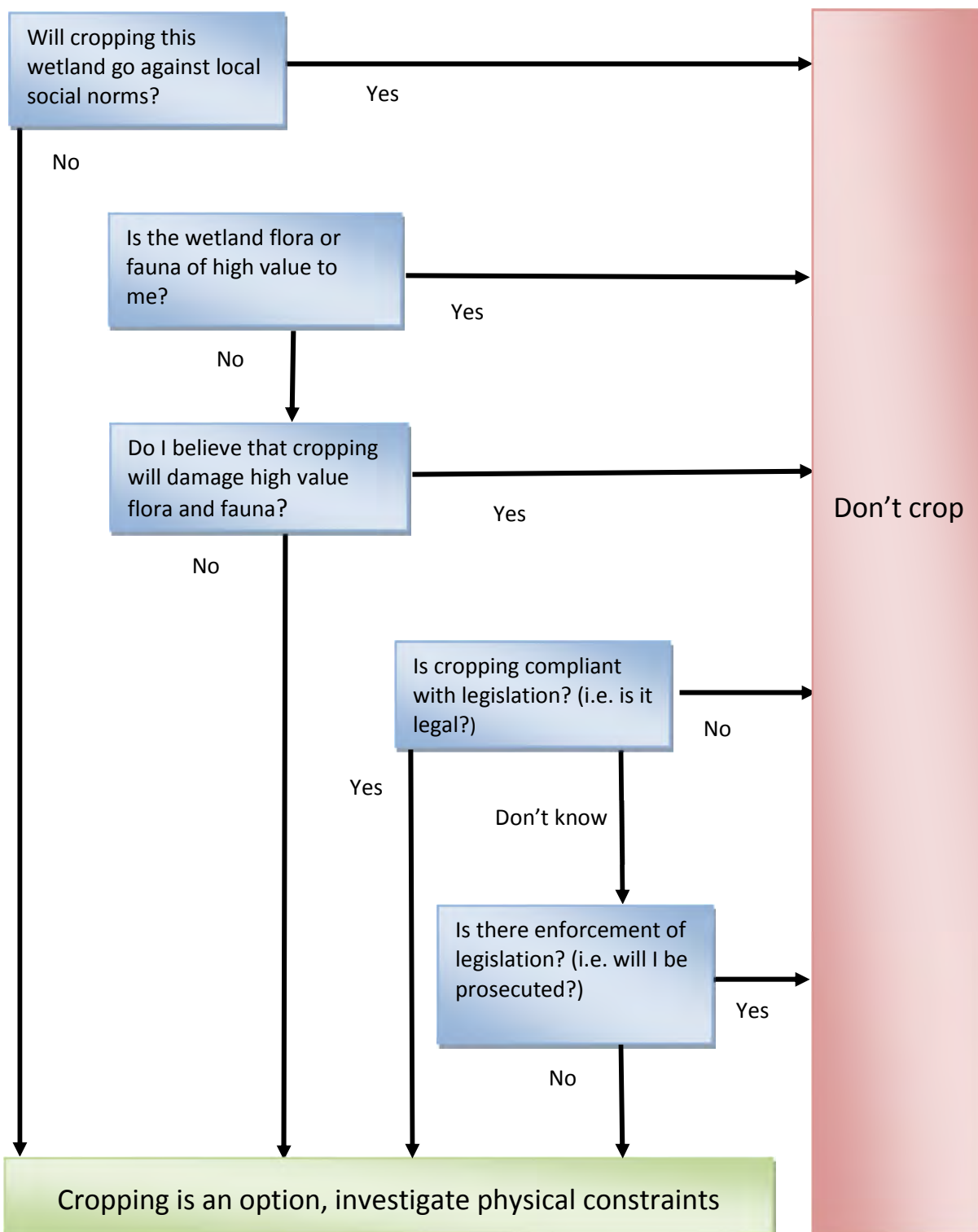


Figure 8 Social factors considered in the assessment of a wetland for cropping.

Factors that influence the decision to crop a wetland include:

Physical attributes of the wetland

In practice, many of the physical constraints to cropping a wetland can be overcome. Wetlands vary in size, shape and topographical attributes. In general wetlands that have a long hydroperiod (i.e. are relatively permanent) are unlikely to be seen as potential crop-land. They are often highly valued for other services they can provide. Wetlands that are episodic or temporary are exposed to cropping. The presence of standing vegetation in a wetland is not always considered a hindrance to cropping. Red gum trees can be

avoided (and/or removed) and large tussocks can be burnt. Other characters that are taken into account are:

- catchment size (which affects the likelihood of inundation of the wetland)
- edge profile – if there is a gradual gradient from dry land to wetland, a gradual change in soil characteristics, a gradual change in species composition, then it is possible for cropping to incrementally encroach into the wetland over successive years. Steep edges to a wetland decrease the likelihood of incremental or edge cropping
- soil salinity – hypersaline soils are hostile to crop production. Brackish wetlands can be cropped at the edges
- wetland size – a small wetland can result in a small economic loss if crop failure occurs, so small wetlands are more likely to be cropped than large ones (Van Meter and Basu 2015)
- the presence of drainage, which can lower the risk of waterlogging
- the presence of rocks; in the past, if rocks were present they needed to be avoided or removed. There is the development of machinery that can cope with the presence of rocks, and rock-crushing is sometimes undertaken; and
- soil constraints (e.g. heavy clay soils).

Economics

A farmer will assess the potential economic benefit of cropping a wetland. S/he will consider:

- the potential crop yield, and calculate the economic return on expenditure
- agricultural practices that might improve economic prospects e.g. raised beds; and
- the economic pressure to utilise all available land, especially following land purchase.

Risk of crop failure

In every year there is some risk of crop failure in dryland farming through drought, waterlogging or frost. Assessment of the risk of crop failure is slightly different in cropping wetlands as the farmer must consider:

- waterlogging risk (which can be assessed by examining Bureau of Meteorology climate trends and predictions)
- tolerance of crop cultivars under different soil constraints (Verhoeven and Setter 2010)
- frost risk (higher in low-lying areas such as wetlands) which can interfere with seed set. This can be managed by sowing date, using an unproductive crop for hay, or using a different crop cultivar
- drought risk. This could be a lower risk in wetlands than in drylands where wetland soil has been optimally ameliorated for cropping (in the absence of amelioration there can be poor yields in wetland soils as a consequence of drought); and
- the possibility of using a failed crop for hay.

Legal limitations

If a farmer is aware of legal limitations to cropping or removing native vegetation these could influence the likelihood of using a wetland for cropping. There are some marketing options that give farmers a benefit if they do not crop wetlands, such as grain market declarations (for selling canola to EU markets). If a farmer makes such a declaration (e.g. that cropping is undertaken without damaging native vegetation) they are obliged to adhere to that declaration. There can be protection covenants or lease conditions that prohibit cropping in wetlands. There are also the Victorian *Flora and Fauna Guarantee Act 1988* (FFG Act) and the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) that restrict actions that might damage native vegetation or communities. Legislation, however, has an initial time-limitation, so that if cropping occurred before the legislation was enacted, or is a long-term land use, the relevant Act does not apply. This can create an incentive to crop a wetland before restrictions are enforced. These types of unintended consequences are known as 'perverse incentives' because they can produce an opposite result to what was intended. This is not an uncommon outcome in liaison work for biological conservation projects (Bean et al. 2003), which suggests that farmer engagement should be well planned. Also, perceptions of legal limitations are influenced by whether the legislation is seen to be enforced. Although Seasonal Herbaceous Wetlands are listed as "critically endangered" under the EPBC Act in 2012, there has not been much visible enforcement of that legislation to date.

Farmer's attitude towards conservation

A farmer's willingness to crop a wetland will be influenced by their perception of conservation values (Dobbie and Green 2013). There is a need to recognise that temporary wetlands are, even when dry, still wetlands (Fellows and Buhl 1995). Government-funded projects that refer to 'soils in former swamps' (<http://www.evergraze.com.au/library-content/south-west-victoria-lower-soils/>) can influence or remove that awareness. Of greatest importance is whether there is willingness to trade biodiversity for economic gain ('aware but don't care'). These attitudes are highly individual, and a consequence of education, cultural norms and societal attitudes.

Farming cultural practices

Cultural practices are methods that have been developed over time by trial and error, some of which are widespread. If there is established agronomic advice about cropping in wetlands, previous experience with cropping wetlands, either personal or through observations of other farmers, suitable machinery available, (owned or contracted), and where there is no interest in animal husbandry, wetlands are at a high risk of being cropped (Consultation, Appendix A).

Direct drill cropping is the sowing of seed and fertiliser without prior cultivation. This method of crop establishment has become standardised in Victoria, with the proportion of crop area that is direct drill sown increasing from 15 % in 1995-96 to more than 70 % by 2011 (Barson 2013). This trend is also evident in the CMA regions where wetland clusters are at risk from cropping (Table 5) (Barson 2013). Direct drill cropping is dependent on the use of herbicides before and after sowing, and minimises the preparation time required for sowing crops. Its use increases the ease of cropping in wetlands.

The elimination of non-crop plants is one of the principles of crop production. Weed control strategies such as chemical fallowing between harvest and sowing the next season's crop are used to reduce in-crop competition (Agriculture Victoria 2012) and remove pathogens. *Rhizoctinia* is a serious fungal root disease of barley that uses a wide range of plants as hosts and cannot be controlled by crop rotation or cultivar selection (Agriculture Victoria 2013) so removal of plants between crops is recommended to farmers as a control tool. This leads to removal of wetland vegetation between crops as well as when crops are growing.

Crops are grown on raised beds in southern Victoria on "land prone to waterlogging" where there is sufficient slope to drain water away from the crop area (Wightman et al. 2016). This makes it possible to crop wetlands where drainage can be created. Raised beds are constructed by removal of all obstacles, cultivation to 20 cm depth, paddock levelling and application of lime and gypsum where necessary. The beds are then formed to a width of 1.7-2.0 m, separated by furrows 10-30 cm deep (Wightman et al. 2016).

Table 5. Trends in percentage of area direct drilled for three CMA regions (Barson 2013).

CMA region	2007-08	2009-10
Corangamite	60 %	85 %
Glenelg-Hopkins	70 %	84 %
Wimmera	60 %	70 %

Procedures for cropping a wetland for the first time

The most common practice for incorporating a wetland area into a cropping program is to treat the area as if it were already part of the crop area. The decision can be planned and intentional, or it can be a split-second decision, i.e. to drive straight through with the herbicide sprayer, then the airseeder, following the GPS, instead of turning the wheel.

If a dry autumn occurs several tasks can be undertaken in an opportunistic manner. In the summer/autumn prior to sowing the farmer can employ an excavator to remove rock, and prepare the soil by spreading gypsum or lime. During the autumn the farmer sows her/his dryland cropping area, and if, by early winter, there has not been inundation of the wetland, and the seasonal outlook is not wetter than average, the farmer can prepare to crop the wetland.

Given the right weather outlook the farmer might spray the wetland with glyphosate, which kills standing vegetation within about 2 weeks. The dead vegetation can be burnt to remove biomass, and sown to crop (with seed and fertiliser) the next day. Different pre- or post-emergent herbicides (i.e. used before or after

the crop species emerges from the ground) can be applied if there is a large germination event of native or exotic, non-crop species in the wetland. For the remainder of the growing season the cropped wetland is treated in the same way as the rest of the cropping area (e.g. sprayed with post-emergent herbicide, insecticide or fungicide, spread with malacocide (slug-killer) or additional fertiliser, depending on circumstances). Agronomic advice is readily available for decisions about crop variety, biocides or fertiliser application.

Once a crop is established in a wetland the crop-plants can cope with several days of waterlogging, especially in cold weather (although this varies between crop species, triticale (a hybrid of *Triticum*: wheat, and *Secale*: rye) is the most waterlogging tolerant, oats can also provide a relatively high yield in sub-optimal conditions). If waterlogging occurs additional fertiliser (nitrogen, usually in the form of urea) can be applied to overcome the removal of nitrogen from soil by anaerobic de-nitrifying bacteria. If waterlogging continues longer than several days, or areas of standing water develop, crop plants will die and decompose, resulting in a loss to the farmer.

Longer-term planned cropping of a wetland

If incorporation of a wetland area into a cropping program is part of a long-term strategy, during the year preceding the planned crop, the wetland will often be grazed by sheep (winter) in order to enter spring with short green herbage on the wetland. Sheep will be removed in August/September, and the wetland sprayed to kill the standing vegetation. Many farmers will establish a brassica-based herbage crop during spring (grazing rape or turnips), to be lightly grazed over summer and then heavily grazed (eaten-off) in early autumn. The intent is to inhibit wetland plants from contributing seed to the seed bank, and to have bare ground ready for establishing the broadacre crop in late April.

3.3. Wetland resilience

Temporary wetlands are largely regarded as resilient ecosystems because of their seed bank, and capacity to respond if you 'just add water' (Wilson and Hendy 2011). Similarly, the diversity of different organisms (plants, microbes, algae, zooplankton, invertebrates, frogs, birds, reptiles) convey a degree of 'biodiversity resilience' to wetlands, so that if one step in a food-chain, or one vital process is missing, the role can be taken by another species (Folke et al. 2004). Temporary wetland biodiversity is an attribute that can be measured on a local (within wetland) basis, or in relation to the landscape (Section 4.3).

3.3.1. Seed banks

The biodiversity of seasonal wetland systems in Australia is thought to be reliant on germination and hatching from the bank of drought and disturbance-resistant seeds, spores, eggs and resting bodies in the soil, otherwise known as the seed bank (Casanova and Brock 1990, Nielsen et al. 2009, Brock 2011). Responses to inundation can be rapid when water becomes available (within hours for phytoplankton and microinvertebrate emergence, days for seed and spore germination). It follows that the quality and persistence of the seed bank is a vital component of the wetland's capacity to respond to seasonal water availability. Victorian temporary wetland seed banks can be highly diverse and responsive (Casanova 2012), and the history of natural wetting and drying (and other forms of disturbance) in the landscape mean that seed banks have a high degree of dormancy and longevity (Brock 2011). If a wetland is not inundated in one year, the seeds and propagules in the seed bank will remain dormant. Seed banks are known to still respond after dry periods longer than 5 years in western Victorian wetlands (Casanova and Powling 2014).

3.3.2. Biodiversity resilience

During the wet phase, temporary wetlands can be recognised as 'islands of biodiversity' (Willis 1964, Butcher 2003, Hall et al. 2004, Casanova and Powling 2014), containing more plant, animal and plankton species than permanent wetlands in the same landscape (Casanova and Powling 2014), and more than in surrounding dry-land (Willis 1964). A single Victorian temporary wetland had c. 100 different phytoplankton taxa, most emerging from the seed bank within weeks of inundation (Casanova and Powling 2014). High diversity levels of invertebrates (15–45 taxa) were also recorded in a study on southern Victorian 'pasture' wetlands near Warrnambool (Robson and Clay 2005). These wetlands were recognised as valuable for conservation, containing unique macroinvertebrate communities, despite the presence of

exotic pasture grasses and grazing by domestic animals (Robson and Clay 2005). This is supported by overseas studies where up to 107 different taxa of invertebrates (between 23 and 36 taxa per wetland sampling) occur in temporary playa wetlands in southern USA, significantly more than occur in permanent wetlands in the same landscape (Hall et al. 2004).

These high biodiversity levels mean that if one species becomes extinct, there are others that can take over its function, e.g. if Australian Sweet-grass (*Glyceria australis*) does not germinate in one year because its habitat requirements are not met, other grasses e.g. Swamp Wallaby Grass (*Amphibromus fluitans*) or Blown Grass (*Lachnagrostis filiformis*) might germinate instead and supply carbon capture and habitat values to other inhabitants of the wetland. Temporary wetlands possess complicated food webs, allowing species replacement at all trophic levels.

3.3.3. Step changes, multiple stable states and hysteresis

Temporary wetland ecosystems can be thought of as persisting in a regime of cyclic disturbance; wetting and drying in relation to a relatively predictable water regime. This can be interpreted as a stable state (*sensu* Briske et al. 2003) that varies within a range of parameters (Colloff and Baldwin 2010), where cycling through wet and dry phases is part of the 'stable' condition to which they are adapted. In temporary wetlands vulnerable to cropping (Table 4) the wet phase lasts usually less than 6 months, the dry phase can last from 6 months to several years, or decades (Briggs and Jenkins 1997, Casanova and Powling 2014).

The natural condition and attributes of wetlands can be represented by a ball, within a 'cup' of environmental parameters, wetting and drying, physical, biological and climatic conditions to which it is adapted (cup-and-ball concept: Figure 9). In classical studies of shallow wetlands the process that causes transition from one state to another is usually the addition of nutrients (a change in trophic conditions imposed by human utilisation of the landscape or wetland itself). With reference to temporary wetlands and cropping, usual conditions are a fluctuating water regime and inherent biodiversity. Imposition of the disturbances provided by cropping (physical disturbance, chemicals, removal of vegetation: Section 3.5) could provide the degree of disturbance required for a 'step-change' or transition to a new state (Figure 9), from which it could be difficult to return (hysteresis).

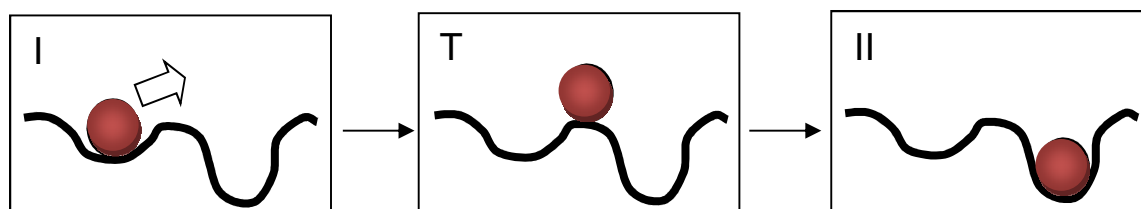


Figure 9. The cup and ball analogy (after Laycock 1991 in Briske 2003). According to state and transition models (I) the community (ball) moves within a range of fluctuating conditions (within the cup), but retains diversity and processes within that range in the absence of a transition. The transition (T) forces the community out of the range of conditions and responds to a new condition (II), from which it is difficult to return.

There is a large amount of evidence that shallow permanent wetlands can exist in different states, and transition between them (Scheffer et al. 1993, Jeppesen et al. 1997, Casanova et al. 1997) largely in relation to nutrient concentrations, turbidity, and abundance of phytoplankton or vegetation. Stable states and transitions in relation to salinity have also been reported (Sim et al. 2006). However, in a meta-analysis of reports concerning alternative stable states (Capon et al. 2015) shallow, vegetated permanent wetlands were the only ecosystems for which there was good evidence of this occurring. There is, however, evidence from the literature that temporary wetlands can be pushed, by cropping, into an alternative state from which it is difficult (or impossible) to return (Figure 10).

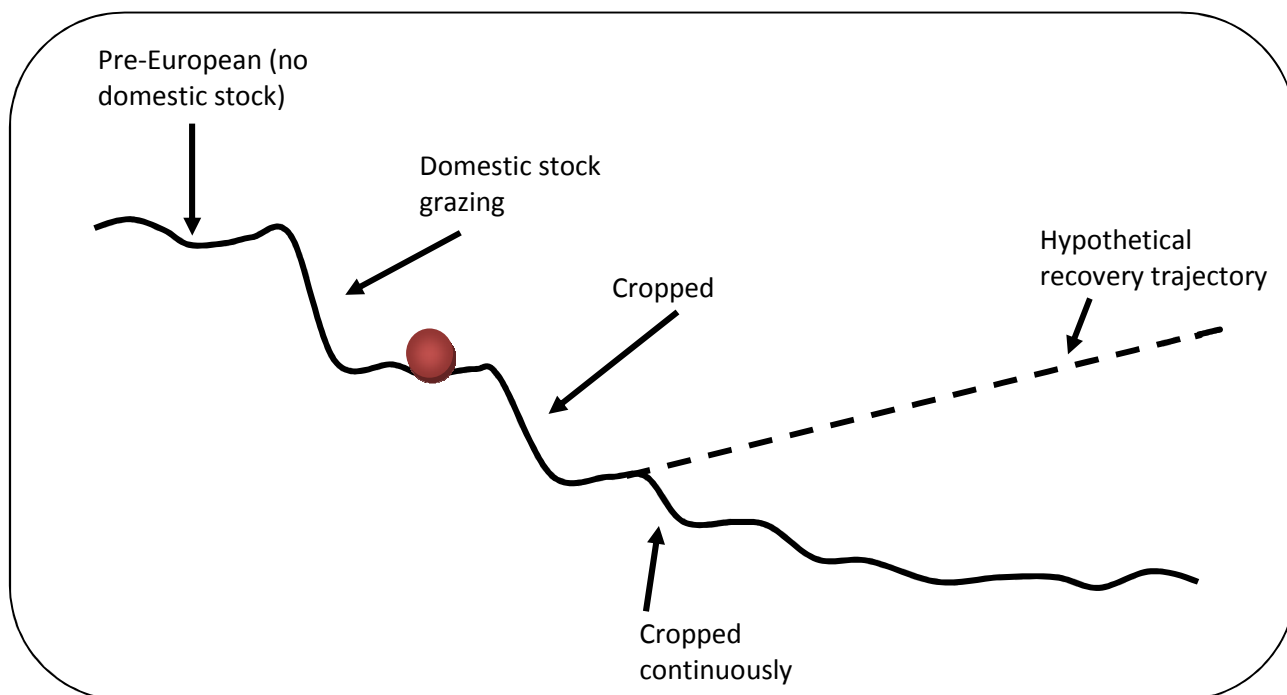


Figure 10. Hypothetical state and transition model for temporary wetlands in Victoria following the introduction of European agricultural practices, indicated by the position of the red ball. In pre-colonisation times wetlands were exposed to Aboriginal land management and native animal grazing. From c. 1840 domestic livestock were introduced, species vulnerable to grazing were largely removed and animal extinctions occurred (bandicoots, spotted quolls etc.). When wetlands are cropped for the first time this causes a transition to a changed level of diversity and functioning (Waters et al. 2012, Casanova 2012). If cropping is removed there could be gradual recovery to pre-cropping conditions. However, if cropping is continued the decline in condition and provision of services is likely to continue to a new stable state.

3.4. Potential impact of cropping practices on wetlands

Where cropping is not a widespread land use (parts of West and East Gippsland and North East Victoria) and there are few temporary wetlands, cropping is generally not undertaken in wetlands (Consultation, Appendix A). Where the climate is semi-arid, and cropping is a successful enterprise at least some of the time (e.g. Mallee, northern Wimmera CMA regions, south of the Murray basin), any wetlands that could be cropped or drained have been extensively cropped in the past (Consultation, Appendix A). Cropping is not seen as a viable land use in the wetlands that remain in those latter regions (generally more permanent, deeper, or irrigation storage wetlands). Land managers in those areas have stated that temporary wetlands have largely ‘disappeared’ (Consultation, Appendix A). Natural resource managers working in other regions in Victoria (Glenelg Hopkins, south-west Wimmera and Corangamite regions) have observed that cropping of wetlands has been occurring, and that it has increased during and since the Millennium Drought (1998–2009) (Consultation, Appendix A). There is also the observation that it is likely to increase further as the climate warms (Consultation, Appendix A). These observations are supported by spatial analysis of the incidence of cropping in Victorian wetlands (Section 4.1)

Although there are few Australian studies into the effects of cropping on wetlands (e.g. Briggs and Jenkins 1997, Wilson and Hendy 2011, Waters et al. 2012, Casanova 2012), there are numerous overseas examples where the effects of cropping have been assessed. Australian cropping systems are based on those that occur in the Northern Hemisphere, however, they lag the development of those in North America. It is in the USA and Canada where there is most concern about the impacts of cropping on wetlands (Cox and Rundquist 2013). There are a few studies from the Northern Hemisphere where cropping is thought to provide a beneficial disturbance, vital to the conservation of rare wetland species (Devictor et al. 2007, Pukacz et al. 2009), largely through soil disturbance providing stimulus to germination. However, in the majority of cases cropping is thought to be deleterious to wetlands. In Briggs and Jenkins’ (1997) study they

confined their discussion to ‘organic’ or ‘low-impact’ cropping of lake-beds in western NSW that did not involve artificial watering or removal of structural vegetation (e.g. *Lignum Duma florulenta*), and to which chemicals and nutrients were not usually added. This contrasts with the high-input methodology currently used in most cropping enterprises in Victoria (Section 4.1). Briggs and Jenkins (1997) did not suggest that cropping was good for wetlands, but argued that the economic benefits (particularly for local communities in western NSW) of opportunistic, ‘organic’ cropping compensated for the amount of harm that might be done. Despite the overall positive tone of the study by Briggs and Jenkins (1997), Briggs (1996) found that the abundance and diversity of small mammals and reptiles was lower on cropped lake beds than on uncropped lake beds, and that a lower diversity of invertebrates emerged from the seed bank where there was cropping (Briggs and Jenkins 197). Wilson and Hendy (2011) give a good review of the impacts of cropping on mammals, reptiles, amphibians, birds, plants and the seed bank, largely from overseas studies. In the study by Waters et al. (2012) in the Macquarie Marshes (NSW) it was found that cropping (even for short periods of time) reduced the capacity for native plant regeneration, even when compared to grazing as an agricultural land use. Casanova (2012) found that the plant diversity in wetlands, the density of plants emerging from the seed bank, and therefore the resilience and integrity of western Victorian wetlands was reduced by cropping. The results of these few Australian studies mirror the results in more comprehensive studies overseas (see Section 3.4.1 *et seq.*).

3.4.1. Overall impacts

Most scientific studies on the effects of cropping in wetlands do not separate the impacts of the individual components of cropping. In general, Australian studies show that the seed bank (plant seeds and spores, animal eggs and cysts) of cropped wetlands is less diverse and that fewer plants and animals emerge when they are reflooded. These effects have not been allocated to any particular component of cropping. In overseas studies, wetlands that are cropped support fewer bird species in lower abundance than uncropped wetlands (Kantrud and Stewart 1984, Naugle et al. 2000). Based on Australian and overseas studies we can expect cropped wetlands to have lower biodiversity and habitat values than uncropped wetlands in the same landscape (Table 6). It is possible to ‘unpack’ some of these effects (physical disturbance, chemicals and harvesting) based largely on overseas studies (section 3.4.2 *et seq.*).

Table 6. The overall potential impact of cropping on wetlands. Strength of link determination and colour codes are explained in Section 2.4.

Land use	Impact on wetland	Impact on processes	Consequence	Strength of link
Cropping	Conversion to crop-land	Reduction in diversity of plants and zooplankton from seed bank Removal of rhizomes Reduction in density of plants and zooplankton from seed bank More weeds	Lower habitat values, decreased diversity and numbers of plants, invertebrates and birds	High

3.4.2. Physical disturbance associated with cropping

Physical disturbances are those that change the bathymetry or morphometry of a wetland or modify the soil surface. This section excludes the digging of tanks or dams in the bed of the wetland (this is a common disturbance to wetlands, but not undertaken for cropping, and dams are more likely to be filled in when a wetland is converted to cropping) (Table 7).

Rock removal

Rock removal impacts directly on the provision of animal habitat and drought refuge. The consequences of rock removal activities vary in the degradation of animal habitat and refuge: rocks can be piled together on the wetland bed (least impact), removed from the wetland and placed in an adjacent pile (intermediate impact), or buried in a hole dug in the wetland bed (most impact).

Cultivation

The physical disturbance provided by cultivation within a wetland, is, on its own, not necessarily damaging to wetland ecosystems in the long-term. There is some anecdotal evidence that cultivating wetlands does no great harm, mostly in farmers' stories of cropping wetlands in the past (1950s and 60s: Consultation, Appendix A) and in the literature (Briggs and Jenkins 1997). Temporary wetlands and dry lake-beds in Victoria have been occasionally cultivated during dry years (Consultation, Appendix A), in a way similar to that reported by Briggs and Jenkins (1997), i.e. usually without removal of structural vegetation or addition of biocides, fertilisers or soil ameliorants (Anon. 1915). These efforts can be thought of as low-input, opportunistic cropping. Although Briggs and Jenkins (1997) provide guidelines to retain ecosystem integrity and responses (e.g. retention of a percentage of the area uncultivated; avoidance of areas thought of as biodiverse or vulnerable) their study was not designed to provide evidence to support implementation of those guidelines. The situations described by them, where wetlands appear to retain certain values after cropping, entailed cultivation, sowing and harvest alone, and were different from the intensive land-preparation that occurs routinely today (Section 4.1). Cultivation of wetland soils can reduce levels of organic carbon and total nitrogen in the soil (Briggs and Jenkins 1997, Kamiri et al. 2013). This is not always detectable when a wetland is cropped once only (Briggs and Jenkins 1997), however cropping over multiple years is likely to have a cumulative effect.

Some plant species require some form of disturbance or baring of the soil to expose their seed bank to light and stimulate germination (Casanova and Brock 1996, Devictor et al. 2007). Cultivated pothole wetlands in Germany and Poland are the only places the internationally threatened (IUCN Red List) charophyte *Chara baueri* is found in those regions (Pukacz et al. 2009). Menindee Nightshade (*Solanum karsense*), a listed threatened species (vulnerable) in NSW, grows abundantly on cropped lake beds (Briggs and Jenkins 1997). In a study of French wetlands Devictor et al. (2007) found that disturbance from cultivation had a positive effect on ephemeral wetland vegetation. However, the species that respond positively to cultivation are those that are adapted to take advantage of other 'gaps' in the wetland plant canopy (e.g. from draw-down or grazing), and rely on the integrity of the seed bank. It is not likely that they require cropping to persist in wetlands where there are other, more natural, disturbances.

Cultivation can impact on certain zooplankton and invertebrates emerging from the seed bank. Rotifer numbers (microscopic herbivores in the plankton) were lower on cropped lake bed soils than uncropped soils (Briggs and Jenkins 1997), but cladocerans, ostracods and copepods (crustaceans) did not appear to be impacted by cultivation, possibly due to the differences in their propagules (rotifer eggs are less robust than crustacean resting bodies (Hathaway et al. 1996)). This is in contrast with a study by Euliss et al. (1999) who found that the abundance of snails, cladocerans and ostracods emerging from cropland wetlands was lower than from grassland wetlands. The crushing effect of farm machinery can also have an effect on microcrustaceans since only small forces (< 1 newton) can crush microinvertebrate cysts, particularly when they are wet (Hathaway et al. 1996). These impacts could have effects further up the food chain (Briggs and Jenkins 1997). Briggs and Jenkins (1997) did not detect effects on waterbirds or fish, however detrimental effects of cropping in wetlands on birds have been recorded in North America's Prairie Pothole region (Kantrud and Stewart 1985, Naugle et al. 2000).

Permanent removal of perennial plants and soil cracks and crevices by cultivation is likely to remove habitat for birds that use the wetland when it is dry (Briggs and Jenkins 1997), and mammal (planigales and dunnarts) and reptile (lizard and snake) numbers can also be affected (Briggs 1996, Briggs and Jenkins 1997). Dunnarts and planigales have the capacity to build up numbers rapidly, are highly mobile (Friend et al. 1997, Dickman et al. 2001), and reinvade habitat once it becomes available (Briggs 1996, Briggs and Jenkins 1997), however, repeated cultivation, and post-harvest activities (fallowing, fire) are likely to have deleterious impacts on their populations (Briggs 1996). In overseas studies, maintenance of non-cultivated patches in rice-cropping landscapes is recommended for conservation of the Indian Sarus Crane (*Grus antigone*), because of its nest-site selection (Borad et al. 2001), since cultivation has the potential to remove or kill perennial rhizomatous (e.g. *Eleocharis* spp) or tuberous (e.g. *Potamogeton* spp) plant species that provide nesting material in wetlands. Removal of perennial species is not always completely effective in the first year of cropping (personal observation), but repeated physical disturbance usually obliterates perennial vegetation after a few years.

In some cases increased runoff from surrounding cultivated ground can result in higher water-levels within wetlands and increased diversity of invertebrates (Hall et al. 2004). In other cases, runoff that mobilises the soil can result in higher sediment loads, buried propagules, shallower wetlands and reduced diversity (Euliss and Mushet 1999, Beas et al. 2013). The runoff and sediment loads can impact on the expression of the water regime (shallower wetlands, shorter flooding periods, or conversely, longer durations and a more permanent water regime). While the wetland still exists, cropping can facilitate the invasion of weed species (Whalley et al. 2011) and feral animals (mice), which can change the conditions for plant growth and animal survival in a non-restorable way (Whalley et al. 2011). Kantrud and Newton (1996) found lower plant species richness in Prairie Pothole wetlands where cropping was the dominant adjacent land cover. However, Galatowitsch et al. (2000) did not find such an association.

Table 7. Impact of components of physical disturbance (e.g. cultivation) on wetland condition and values. (See Section 2.4 for an explanation of the colour coding).

Component (physical disturbance)	Impact on wetland	Impact on processes	Consequence	Strength of link
Rock removal	Decreased heterogeneity	Reduction in refuges and habitat	Fewer vertebrate fauna	High
Tillage/cultivation	Removal of cracks, disruption of soil structure, exposure of seeds to light	Reduction in refuges and habitat	Fewer vertebrate fauna	High
		Increased germination of some species, decreased germination of other species	Altered flora (fewer plants, less diverse)	High
Ripping	Increased permeability of clay base	Reduced water holding capacity	Altered water regime (drier)	Medium
Raised bed construction	Increased drainage	Reduced inundation, reduction in refuges and habitat	Altered water regime (drier)	High
	Deep burial of seed bank			

Ripping

Ripping (i.e. deep cultivation) has been known to mechanically damage underlying clay layers and prevent the retention of water in temporary wetlands (Baskin 1995). However, this disturbance can be mitigated by the capacity of wetland soils to ‘self-mulch’, and where the clay layer is deeper than the machinery can reach (therefore this has been listed as ‘medium’ in Table 7).

Raised bed construction

Construction of raised beds (which alter the topography, placing some parts of a wetland at a higher elevation, and facilitating drainage off the bed of the wetland into lower, tank or dam areas) can alter the composition and diversity of the vegetation that establishes by changing the water regime (Brock and Casanova 1997), although with raised bed cropping there is usually also the application of herbicides that can prevent native wetland plants from establishing at all.



Figure 11 The third year of cropping of a wetland in the South East Grampians region of Victoria in 2010. Rocks were removed from the bed of the wetland in 2007, the soil was sprayed, cultivated and sown to a cereal crop when dry in 2008 and 2009. The wetland was inundated in summer 2010-11, and some wetland vegetation established (*Eleocharis acuta*), however its diversity and density was much lower than the uncropped portion on the other side of the fence (Casanova 2012). When this was cropped again in 2015-16 no wetland plants were present.

3.4.3. Impact of chemicals

Ameliorants

Addition of soil ameliorants (gypsum and lime) is intended to reduce the soil constraints on crop growth by controlling dispersion in clays, reducing the risk of waterlogging to plants, and reducing the development of typical, cracking clay structure in soils. Unlike wetland plants, dryland crops depend on their roots having access to both moisture and air within the soil.

An unmodified wetland soil profile often has a thin, friable, surface-layer of high organic matter content, below which the soil has a uniform massive structure, with large peds that have high strength when dry. The typically high cation content of these soils, coupled with wet-dry cycles over geological time scales causes expansion when wet followed by cracking (Figure 12), with surface soil dropping into the cracks when dry. This promotes the formation of a uniform, self-mulching soil profile. The high strength of the soil hinders the growth of roots. They tend to remain shallow and to follow cracks between peds, which results in crop plants being vulnerable to moisture stress as the soil dries.

Figure 12. Deep cracks in unameliorated wetland soil.



Most of the cropped soils in the Wimmera region have been treated with Gypsum (CaSO_4) (Draper et al. 2004), which allows greater infiltration of water into the soil, and reduces runoff. Gypsum promotes the creation of small stable soil aggregates and the displacement of sodium ions. There are two benefits of these structural changes to the crop plants. Firstly, the soil density is lowered, which reduces the

penetration resistance to the roots. Secondly, the infiltration rate of moisture into the soil will be greater, so that if an intensive rainfall event occurs when the soil is at a lower moisture content than waterlogging, there is a low likelihood of short-term waterlogging, as the water can move quickly down the soil profile. Application of gypsum to crop soils has resulted in less frequent flooding of low-lying areas in the Wimmera (i.e. areas that are likely to have been wetlands in the past) (Draper et al. 2004).

Soil ameliorants have the potential to affect the ecological values of wetlands, by removing habitat and refuges (cracks and crevices in the soil). The effect of a changed pH (from addition of lime) on wetland vegetation and invertebrate establishment is not documented in Australia, but has been found to reduce the cover of wetland mosses, grasses, *Carex* sp., *Drosera* sp. and *Hypericum* sp. in North American wetlands (Mackun et al. 1994). A similar effect is likely in Australian wetlands, but although a reduction of diversity with changed pH has been observed (M.A. Brock pers. comm.) there are few published studies on this. In the USA lime is not generally recommended for wetlands because of potential deleterious effects on plant and animal life (<https://pubs.ext.vt.edu/420/420-254/420-254.html>).

Fertiliser

Application of fertilisers is part of normal cropping procedures to ensure adequate plant nutrition during crop growth (Figure 13). The fertilisers usually applied are MAP, DAP (mono- and di-ammonium phosphate) and urea. If a wetland is cropped as a spontaneous decision (see Section 3.2.1) it is likely that fertilisers will be applied at the same rates as for the adjacent dry land. If there are plans to crop a wetland it is possible that the wetland soil will be analysed to determine optimal fertiliser application rates. Wetland soils typically release large amounts of nutrients upon inundation (Venterink et al. 2002), and during dry-down (McComb and Qiu 1998), and can have naturally high nutrient concentrations while dry. Despite that, temporary wetlands with a responsive seed bank of wetland plants rarely exhibit signs of eutrophication under natural inundation events (Casanova 2015). However, when fertilisers are added it is likely that this provides sufficient nutrient ratios for microbial metabolism of organic carbon to carbon-dioxide, reducing the carbon storage potential of wetland soils.

Farmers often apply nitrogen as urea after waterlogging in crop paddocks to reduce damage to the crop. Under anaerobic conditions (i.e. waterlogging) soil bacteria that use nitrate, rather than oxygen, as the electron acceptor increase in abundance, causing a net decrease in plant-available nitrogen. Addition of urea replaces soil nitrogen needed by crop plants for optimal growth.

Addition of fertilisers to wetlands provides the potential impact of excessive nutrient loading (i.e. eutrophication). This has been well-studied for shallow, permanent freshwater lakes in the Northern Hemisphere, along with management and recovery from the undesirable effects (e.g. Scheffer et al. 1993). Eutrophication alters the productivity, structure and function of food webs, and results in shifts in vegetation patterns and nutrient cycling (Sánchez-Carillo et al. 2011). This is usually apparent from an increase in algal abundance (often cyanobacteria), depletion of oxygen in the water and soil, and changed nutrient ratios enabling carbon release through anaerobic methanogenesis. The extent to which eutrophication occurs in temporary wetlands in cropping landscapes has not been documented in Australia, although it is a relatively common occurrence in farm dams (Casanova et al. 1997). Well-vegetated wetlands with intermittent drought can be resilient to nutrient additions (Lucassen et al. 2005), but eutrophication from agricultural activities has been identified as a threatening process in Europe (Serrano et al. 2006, Zacharias and Zamparas 2010, Angler et al. 2008) and the USA (Kneitel and Lessin 2010).

Biocides

A large variety of biocides are used in modern cropping practices (herbicides, insecticides, fungicides, malacocides: Appendix B). The application of these is intended to reduce non-crop plant competition and prevent fungal and herbivore degradation of the crop plants. For most of the chemicals there are limitations and warnings about their use on or near wetlands. However, when a wetland is being prepared for cropping it is (almost invariably) dry, and potentially not recognised as a wetland (see section 3.2.2). Fertiliser and pesticide contamination are well-known problems for off-site impacts on waterways (Kingwell, 2002).

The potential deleterious effects of chemicals on wetland biota are outlined in detail in the labels and advice supplied by chemical companies (Table 8, Appendix B). For these reasons there are restrictions to

their use. There are records of pesticide contamination of permanent and temporary wetlands in Europe and North America from surrounding land use (Everts 1997, Donald et al. 1999, Lahr et al. 2000, Elliot et al. 2001, Zacharias and Zamparas 2010), so it can be expected to occur in similar situations in Australian cropping systems (EPBC 2012).

Table 8. Categories of commonly used herbicides for crop production in Victoria. Effects on aquatic organisms are examples of the terms included in the registered product labels from some typically used herbicides.

Herbicide category	Withholding time (from grazing)	Warnings and effects on aquatic organisms
Knock-down	nil	“Do not contaminate wetlands or waterways”
Pre-emergent	7 days	“Highly toxic” or “Very toxic”
Post-emergent	11–15 weeks	“Avoid” or “Do not contaminate wetlands or waterways”

Particular chemicals

Herbicides (knock-down, pre- and post-emergence) are designed to kill plants. If they are sprayed onto wetlands, or spray drifts into wetlands, they are likely to kill wetland plants. A large number of herbicides are recommended for use in cropping, but the most common chemical for large-scale removal of vegetation is glyphosate (Roundup™). Many herbicides have residual effects (Appendix B), but glyphosate breaks down rapidly when exposed to clays and soil colloids. Some herbicides are purported to have deleterious effects on animals. Field experiments do not always show that glyphosate itself is directly toxic to animals (amphibian larvae) at typical application concentrations (Edge et al. 2011), but laboratory studies demonstrate toxic effects of some formulations (Edginton et al. 2004, Relyea and Jones 2009), probably due to additives and surfactants present in glyphosate preparations (although these are usually unable to be ascertained because they are commercial-in-confidence) (Edge et al. 2011).

Tri Allate and 2,4-D are biocides with residual activity, that are used in Australian cropping systems (Appendix B), and these have been found to be present in Canadian wetlands in agricultural land after very little precipitation and runoff (Donald et al. 1999). If biocides are applied to wetlands when they are dry or wet, they are likely to result in death of both target and non-target organisms. Application of biocides, particularly knock-down herbicides, is a regular occurrence prior to cropping in dry wetlands in western Victoria (see Communication, Appendix A). This can have flow-on effects in relation to the values and services provided by wetlands (Table 9). Post-emergent herbicides can have long-term residual effects. If a wetland is inundated after these are applied it is possible they can have deleterious effects across the whole wetland, even if only a portion is cropped.

Table 9. Impact of components of chemicals on wetland condition and values. (See Section 2.4 for an explanation of the colour coding).

Component (chemicals)	Impact on wetland	Impact on processes	Consequence	Strength of link
Soil ameliorants	Removal of cracks, disruption of soil structure	Reduction in refuges and habitat	Fewer vertebrate fauna	High
	Changed pH	Physiochemical soil and water	Altered flora (different species)	Medium
Fertiliser	Eutrophication	Physiochemical water	Altered flora (different species, weeds) Different invertebrates	High High
Biocides	Death of non-target species	Alteration of food webs	Less diverse and abundant flora	High
			Less diverse and abundant fauna	High

Crop growth, harvest and post-harvest activities

Harvesting crops in wetlands probably does not have a large potential impact on wetland condition and values, since it creates little further disturbance to the actual growing and maintenance of the crop. The application of pre-harvest herbicide on mature crops (as is done for legumes such as Faba beans) would be an additional effect, if soil conditions were suitable for the growth of legumes.

Post-harvest activities include following (Briggs and Jenkins 1997) and fire. Both of these are used to reduce standing biomass, and create a vegetation-free soil surface for sowing. Following is not a common procedure in Victorian wetland cropping, and is likely to have the same effects as the initial cultivation (see section 3.5.2). Vegetation-free following is a recommended activity for the control of some fungal pathogens. Fire is a natural part of the Victorian landscape, and wetlands (and wetland condition and values) have persisted with occasional fires since settlement (and before). Although wetland plant biomass is removed by fire, most perennial species have the capacity to regenerate (sprouting or shooting), and annual species that rely on the seed bank are also able to re-establish. Regular annual fire is likely to have a potential impact, but this might be outweighed by the effect of cropping anyway (Table 10).

Table 10. Impact of components of harvest activities on wetland condition and values. (See Section 2.4 for an explanation of the colour coding).

Component (harvest activity)	Impact on wetland	Impact on processes	Consequence	Strength of link
Pre-harvest herbicide	Death of non-target species	Alteration of food webs	Fewer plants species, lower density of plants	High
Harvest	Soil compaction	Reduction of soil spaces	Less germination	Low
Fire	Burning	Removal of above-ground plants and animals	Destruction of flora Fewer fauna	Low



Figure 13. Fertiliser application to crop land in the vicinity of wetlands in Saskatchewan, Canada. The vehicle is a fertiliser spreader with a 30 m ‘throw’, so avoiding wetlands and leaving a buffer can be difficult. Source: <https://www.youtube.com/watch?v=6j60slt2bx>

3.4.4. Causes and impact of differential cropping patterns

Three patterns of cropping in wetlands could be distinguished on the basis of Google Earth images (Figure 3), fully cropped, partially cropped at the edges and partially cropped at the edges and across the bed. These are likely to have different causes, and different potential impacts (Table 11).

Where wetlands have been detected as ‘fully cropped’ this is a consequence of a ‘spur-of-the-moment’ decision for shallow wetlands within the perimeter of the paddock, or planned land management. Either

way, it results in the removal of all standing vegetation, reduced seed bank integrity and potentially a change in food webs. There will also be the impact of complete wetland loss on the landscape scale (see Section 4).

Where wetlands were detected as having had the edges cropped this could be due to misalignment of the Google Earth image and the spatial layer describing wetlands. Confidence can be ascribed, depending on the extent of encroachment onto the wetland edge, and whether that edge is marked in some way by vegetation or topography (Table 11). Edges of wetlands are cropped where wetlands are saline or brackish, or shallow and rocks are present, or when they are deep and waterlogged soils prevent traffic. Where wetlands are deep there can be incremental encroachment inwards from the edge over a number of years. In each case removal of edge vegetation occurs, there is no buffer between the wetland and the impacts of cropping (spray drift, fertiliser) and there will be increased landscape resistance and fragmentation via a decrease in wetland size (see 4).

Where cropping in both the edge and bed occurs this can be the consequence of a wetland occurring across a boundary with different land tenure, exposed to different landowners or land use. In both cases the activity results in substantial removal of vegetation and impact on the seed bank. When chemicals are applied to part of the wetland bed there can be spray-drift when the wetland is dry, and if the wetland is inundated any application of herbicide and fertiliser can impact on the whole wetland.

If we exclude misinterpretations from misalignment of the wetland spatial layer, the only kind of wetland cropping with a lower potential impact than the others is where the edge alone is cropped. The impact of this will depend on how much of the edge is cropped, and the water level in relation to that when the wetland is inundated. There the impact of partially cropping both edge and bed will be similar.

Table 11. Causes and consequences of differential cropping practices in wetlands.

Cropping pattern	Confidence in image	Wetland type/impediment	Wetland locality	Consequence	Confidence in consequence
Fully cropped	High	Shallow, no rocks, sedge, grass, herb vegetation	middle of paddock	Removal of all vegetation, reduction in seed bank integrity, chemical inputs, change in food web, increased fragmentation (see Section 4.4.1)	High
	High	Deep, red gum perimeter	separate paddock		High
Partially cropped, edges	Medium (dependent on extent), could be misalignment of image and spatial layer	Shallow, rocks present		Removal of edge vegetation, increased landscape resistance (see Section 4.4.3)	High
	High	Deep, soil waterlogging impediment to cropping			High
Partially cropped, edges and bed	High	Different landowner	Across land tenure	Substantial removal of vegetation, reduction in seed bank integrity, chemical inputs, change in food web, increased landscape resistance (see Section 4.4.3)	High
	High	Soil waterlogging impediment to cropping	Within a paddock		High

3.5. Wetland sensitivity to cropping

Individual wetland attributes and processes can be variably sensitive to the different potential impacts of cropping (Table 12).

3.5.1. Wetland attributes

Physical form

The physical form of a wetland can be permanently altered by adjacent cropping, rock removal or raised bed forming. Sedimentation can cause wetlands to be more shallow and raised bed formation alters both soil characteristics and drainage. Hydrology can be impacted by sedimentation (altering the depth and duration of inundation) and raised bed formation. Rock removal might have less impact because rocks generally only cover a portion of the wetland bed.

Wetland soils

Wetland soils are impacted by sedimentation and compaction, but are often self-mulching, so there is some natural restoration of the soil porosity over time. However, application of gypsum and lime along with cultivation and raised bed formation can have more severe impacts.

Physiochemical characteristics and water quality

The quality and physiochemical characteristics of water are most impacted by fertiliser application because this can cause eutrophication while water is present. However, temporary wetlands dry out, and they are characterised by rapid nutrient release and uptake naturally. Wetlands might be resilient to the addition of fertilisers. Chemicals (ameliorants, fertilisers, biocides) added to the soil or water can be dissolved in the water with consequent biological impacts.

Hydrology

Raised bed formation and deep ripping can alter the capacity of a wetland to retain water for any length of time. Cultivation of surrounding land can increase sedimentation (making a wetland shallower), but can also result in increased run-off, both of which alter the natural water regime.

Soil biota

Soil biota in wetlands is not well known or studied, but based on the responses of dryland soil biota fertilisers and fungicides are likely to have severe impacts, cultivation can result in nitrogen and carbon release from the soil, and the disturbance of raised bed formation can alter soil microbe communities.

Seed banks

The seed bank and extant vegetation are impacted by the variety of herbicides applied in cropping practice, and for the dryland components of the vegetation that survive herbicides, the growing crop provides competition for light and resources.

Extant vegetation

Extant vegetation is removed by cultivation and raised bed formation. Herbicides are designed to kill plants and are generally effective on native plants. The residual effects of herbicide can continue to inhibit plant establishment for different periods of time after application.

Invertebrates

Invertebrates are likely to be impacted by raised bed formation (removing their propagules from exposure to inundation) and insecticides. Other biocides might also have an effect, as does the physical impact of cultivation for some sensitive groups.

Birds, amphibians and other vertebrates

Amphibians appear to be sensitive to a variety of impacts, particularly chemical application and removal of shelter. Birds could be affected by chemicals that pass up the food chain, and by the reduction in food resources from application of biocides. Nesting birds and sheltering birds can also be impacted by harvesting, however birds are mobile over the landscape, and they can choose which wetland they visit. Other vertebrates will be impacted by reduction in available habitat for feeding and nesting, and potentially by chemical impacts on their food.

Wetland component /process	Other vertebrate animals	Birds	Amphibians	Invertebrates	Extant vegetation	Seed bank	Soil biota	Hydrology	Physio-chemical and water quality	Wetland soils	Physical form
Adjacent cropping						sedimentation		sedimentation		sedimentation	
Rock removal	refuge removal		refuge removal								
Raised bed forming	refuge removal		refuge removal					drainage patterns		soil structure	
Gypsum addition			?				changed ecology			structure chemistry	
Knockdown herbicides		food chain ?	absorption	?							
Cultivation and ripping	direct, indirect		direct, indirect			Soil mixing	N release			soil structure	
Fertiliser application			?	?							
Soil fungicide	food chain ?		?	?							
Post-emergent herbicides	food chain ?	food chain ?	absorption	?		?					
Malacocide	food chain	food	food chain ?	?			?				
Crop competition						seed bank depletion					
Pre-emergent herbicides	food chain ?	food chain ?							if residual		
Foliar fungicides	food chain ?	food chain ?	absorption?	?			?		?		
Insecticide application	food chain	food chain	absorption	toxicity			if infiltration				
Harvesting		nests								compaction	

Table 12. Assessment of sensitivity levels for Victorian temporary wetlands. Question marks indicate possible effects for which there is no data. (See Section 2.4 for an explanation of the colour coding).

3.6. Adaptive capacity at the site scale

The inherent adaptive capacity of temporary wetland plant and animal communities allows them to tolerate disturbance of different kinds. The seed bank, the high levels of biodiversity in the plant, plankton and invertebrate communities, as well as connectivity with other wetlands convey resilience and can ameliorate some potential impacts.

Soil disturbance from cultivation is similar (but more wide-spread) to the disturbance created by digging animals (nowadays rabbits, but in the past swamp-rats and bandicoots), and this favours the germination of plant species that require exposure to light for germination (e.g. some charophytes; de Winton et al. 2004). Removal of the standing vegetation through fire or hay making (which can be an intermittent, opportunistic activity in Victorian wetlands) is known to change plant community structure, but is not necessarily a deleterious event. Removal of the standing vegetation via chemical application is likely to be deleterious to plant communities, and could reduce animal habitat, while its effect on the seed bank is unknown. Although the most frequently used chemical (glyphosate) denatures rapidly in contact with soil or soil colloids (Appendix B), many other chemicals have residual activity.

Harvesting is unlikely to introduce new disturbances, except in relation to sheltering animals and nesting dry-land birds such as quail. Nest and young can be disturbed by harvesting machinery, but there is usually the dense shelter of stubble to retreat to, and quail might even be facilitated by cropping via the introduction of grain crop as food.

Changed soil properties, removal of shelter on the wetland bed when it is dry, application of fertilisers, herbicides, insecticides, fungicides and other biocides are likely to be deleterious when applied during any part of the hydrological cycle in wetlands. If there is sufficient connectivity at the landscape scale, local plant or animal population declines or extinctions need not be permanent. There is, however, the likelihood that cropping induces a radical change in the character of a wetland especially where there is raised bed development, and total removal of the extant vegetation (Consultation, Appendix A; Figure 10). The recovery potential of wetlands after cropping is not well known, but in general, wetlands that have been actively 'restored' in overseas studies recover to only c. 75 % of their original functioning and diversity (Roberts et al. in prep., Zedler 2003).

3.7. Vulnerability at the site scale

Wetlands are highly vulnerable to cropping because a large number of their attributes (soil, seed bank, vegetation, invertebrates, vertebrates, water regime, water quality) and processes (germination, establishment, trophic interactions) are sensitive to the physical and chemical disturbances applied in cropping (Table 13). The resilience of individual wetlands to natural disturbance is high, because of their seed banks and biodiversity. However, the studies that have been undertaken on Australian temporary wetlands, wetlands in the Prairie Pothole region of North America, and Mediterranean temporary ponds of southern Europe, North Africa and California show that the additive and repeated disturbances created by cropping can degrade wetland condition and values, and even remove individual wetlands from the landscape. Temporary wetlands are most at risk, and the most temporary ones of these (seasonal herbaceous wetlands, shallow freshwater marshes, grassy wetlands) are currently disappearing from the western Victorian landscape (Consultation, Appendix A).

Table 13. Vulnerability assessment for individual wetlands (questions marks indicate possible but unknown vulnerability). (See Section 2.4 for an explanation of the colour coding).

Cropping component	Attribute affected	Sensitivity	Likely impact	Adaptive capacity	Vulnerability	Confidence
Physical disturbance	Soil	High	altered water regime, fewer biota	Low	High	High
	Seed bank	Low		High	low	High
	Vegetation	High		Medium	High	High
	Invertebrates	Medium		Medium	Medium	Low
	Water regime	High		Low	High	High
	Mammals	High		Medium	High	Medium
	Reptiles	High		Medium	High	Medium
	Amphibians	High		Medium	High	Medium
Chemicals	Seed bank	High	fewer biota	Low	High	High
	Vegetation	High		Low	High	
	Invertebrates	High		Low	High	
	Amphibians	High		Low	High	
Harvest activity	Soil	Low	compaction, mortality	Medium	Low	Medium
	Birds and mammals	Med		High	Low	Medium
Overall	Seed bank	High	altered biota, altered processes	Medium	High	High
	Vegetation	High		Low	High	High
	Food web	?		?	?	?

4. Wetland vulnerability at the landscape scale

Wetlands do not exist in complete isolation. They are connected to the dryland by proximity, and they can have hydrological, aerial and biological connections with other wetlands. Wetlands come and go in geological time and for temporary wetlands, the water comes and goes seasonally, or at other temporal scales. Therefore, the loss of a single wetland in a well-connected landscape is usually of minimal significance to the retention of wetland values and services.

The current vulnerability of wetlands as landscape features depends on the spatial scale of the disturbance, the potential impact of that disturbance, the sensitivity of wetlands and the adaptive capacity (or inherent resilience) of the mosaic of wetlands in relation to that disturbance. It is important to understand why cropping occurs where it does, and what influences its spatial distribution, in order to understand the future vulnerability of wetlands to cropping at the landscape scale.

4.1. Exposure of wetlands to cropping

Wetlands are exposed to cropping as a land use choice by farmers, especially in those agricultural areas of high wetland density where the topography, soil characters and rainfall are amenable to cropping. The layer of wetland distribution for the state of Victoria (Figure 1, p. 2) was filtered as a first step to identify wetlands at risk of cropping.

4.1.1. Areas of high wetland density

Victoria's wetlands occur in higher densities in particular regions in the landscape (Figure 14). These are displayed as 'hotspots', where the intensity of colour is related to the number and proximity of wetlands in an area. This figure includes 19,973 privately owned wetlands of natural or unknown origin. It excludes those wetlands that are of low risk from cropping such as wetlands on public managed land, coastal and high country peatlands. Seven 'hot-spot' clusters of high wetland density were investigated to establish their wetland cropping status (Table 14). Minor clusters are discussed first, and then major clusters are evaluated in further detail.

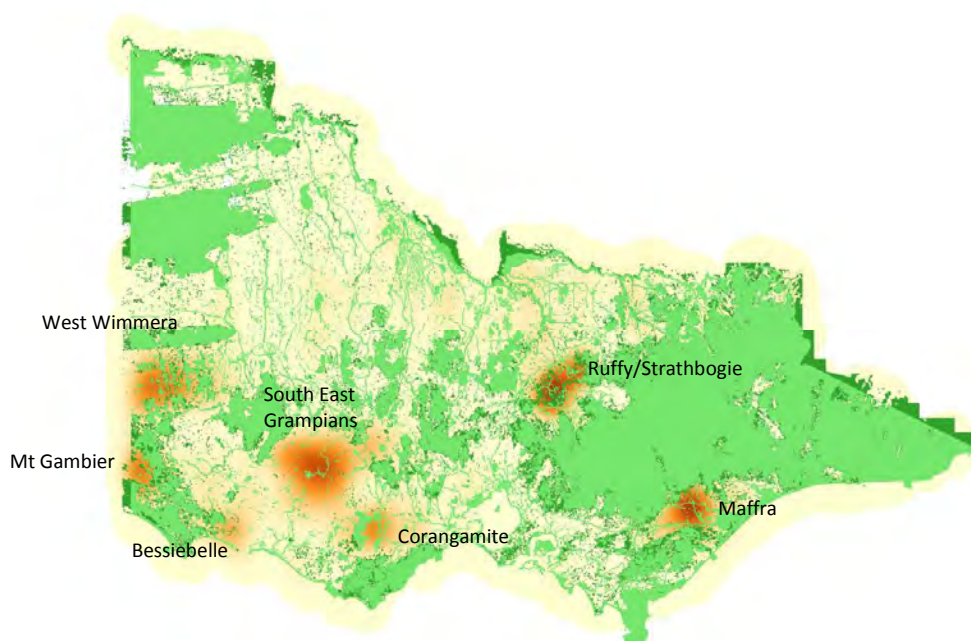


Figure 14. Areas of high density of privately owned wetlands, where colour intensity represents numbers of wetlands per unit area. Coastal, high country peatlands and publicly managed wetlands are excluded. Public managed land is shown (light green) as are those areas of high tree density on private

Table 14. Summary of attributes of Victoria's wetland clusters. Details here are for wetlands on both public and private land. Boundaries are not exact, and so values are approximates only. (See Section 2.4 for an explanation of the colour coding).

Cluster	Land area (km ²)	Number of wetlands	Wetland density (/km ²)	Total wetland area (ha)	Current incidence of cropping in wetlands
Corangamite	1200	640	0.53	34400	High (> 20 %)
South East Grampians	5800	2700	0.47	41500	High (> 20 %)
Mt Gambier	2500	1000	0.40	11800	None detected
Maffra	1200	2300	0.52	3300	None detected
Bessiebelle	1800	490	0.27	3344	None detected
Ruffy/Strathbogie	2100	1580	0.75	1560	Low (< 5 %)
West Wimmera	8200	2400	0.29	37800	Medium (5–20 %)

Maffra cluster

The Maffra cluster is one of four locations identified in the density mapping that have wetlands that are either outside the scope of the project or which are currently at low risk from grain cropping. The Maffra cluster (Figure 15) in West Gippsland consists largely of riparian billabong wetlands, which are often associated with trees in drainage lines or palaeochannels. Cultivation for pasture and hay production is evident in this area, with low impact on wetlands except on river flats. Aird Morass (wetland 92452) is one of these. It is a large palustrine fresh water wetland that is currently under cultivation, as are several in the Sale area. No broadacre cropping was observed.

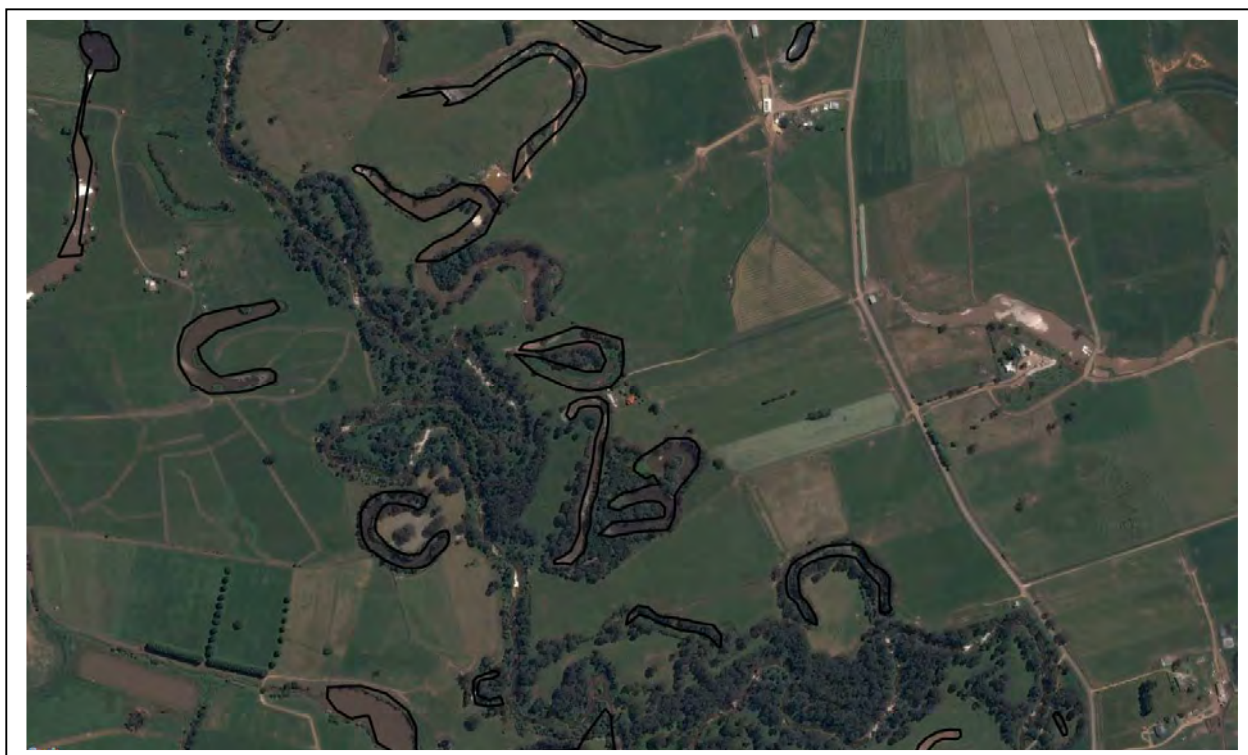


Figure 15. Maffra riparian wetlands

Ruffy/Strathbogie Cluster

Another wetland cluster that is at low risk from cropping is East of the Hume Freeway at Ruffy near Avenel. This area is on the lower slopes of the Great Dividing Range, and many of the wetlands are on riparian drainage lines (Figure 16). Some cropping is evident near drainage lines, but has not been identified as extending into the wetlands.



Figure 16. Ruffy/Strathbogie cluster. Wetlands are mostly riparian or associated with drainage lines.

The remaining wetland clusters are in western Victoria.

Bessiebelle Cluster

The wetlands in the Bessiebelle cluster are currently associated with plantation forestry and grazing agriculture (Figure 17). This area has an annual rainfall of approximately 700 mm, and is in a region of high cultural heritage values (web-ref 2, 2016). It contains a smaller number of wetlands than other clusters and the degree of future risk from cropping depends on the location-specific presence or absence of rocky barriers, and future rainfall and evaporation patterns. The Tower Hill area to the east of Bessiebelle was one of the first wheat-growing regions in Victoria, and given current cropping techniques, this area of rich soils could become attractive for crop production in the future.



Figure 17. Bessiebelle cluster wetlands (highlighted in blue to improve visibility as the major surrounding land use is grazing or forestry).

Mt Gambier Cluster

The Mt Gambier cluster lies east of the South Australian border, extending to the north of Strathdownie (Figure 18). Land uses encompass a complex mixture of forestry, public land, grazing and centre-pivot ground-water irrigation (most likely for lucerne). Some of the wetlands in this group are covered by plantation forests. No broadacre cropping is evident, but the risk to wetlands from cropping should be considered in light of higher anticipated evaporation rates with climate warming in the future.



Figure 18. Example of wetlands in the Mt Gambier cluster, showing wetlands on grazing land, circular centre pivot irrigation and pine forests (dark green).

Corangamite Cluster

The Corangamite wetland cluster lies at the interface between cropping at its northern end near Cressy, and dairying at the southern extent near Colac (Figure 19). Cropping extends to the south east towards Winchelsea, which during the 1990's was one of the points of origin for the raised-bed techniques for cropping in wet soils. Towards the west, there is a continuation of cropping across the predominantly basalt plains, which join the South East Grampians cluster of wetlands. The results of the evaluation of cropping in the South East Grampians wetlands cluster are also relevant to the Corangamite cluster.

The southern limits to cropping occur near the Corangamite cluster. This limit extends across western Victoria and tapers out near Branxholme. The boundary between cropping and no-cropping is determined largely by topography (the Otway Ranges; the Stony Rises), more profitable agricultural enterprises (dairying), and forestry. Winter waterlogging was a problem before the development of raised bed cropping, but has now been overcome as a soil constraint. This implies that climate change *per se* (higher temperatures and more evaporation leading to drier wetlands) might not influence the southward migration of cropping enterprises in this region as much as change in the profitability of dairying and forestry. It also explains the intensification of effort in the regions where cropping already occurs.



Figure 19. Grain crops and wetlands in the Corangamite cluster.

4.1.2. Case study: South East Grampians

The South East Grampians cluster contains the most temporary wetlands of any of the clusters identified for Victoria (Table 14). There are approximately 2700 wetlands in the cluster, the edges of which are defined by a change to sloping topography and exorheic drainage to the north and the occurrence of the 'stony rises' and exorheic drainage to the south (Figure 20). The west is bordered by the Grampians (Serra Range) and lower Hopkins River, and the east is bordered by the goldfields, with a change in topography and soil type at Mt Emu Creek. The east-west width of the cluster is approximately 85 km.

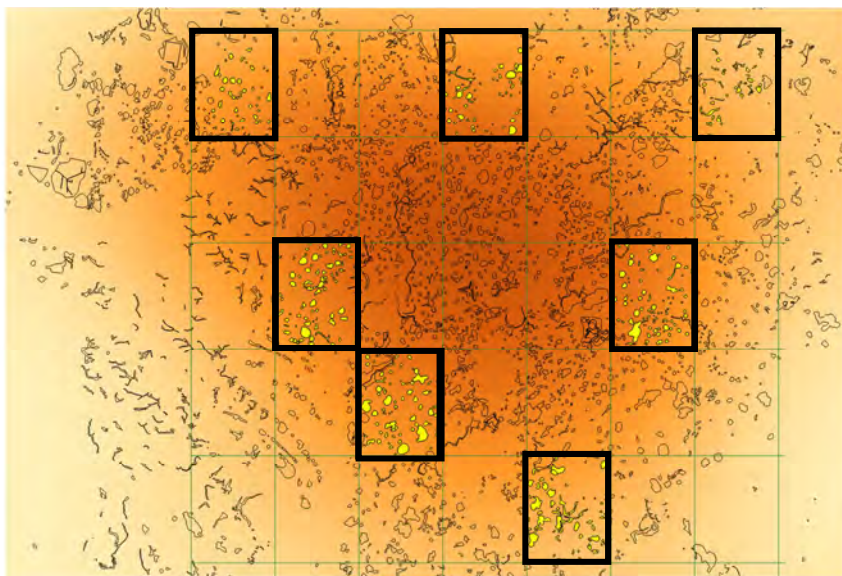


Figure 20. East Grampians wetland cluster from the heat-map indicating density of wetlands. Darker colour indicates higher density. The map is overlaid with a grid. Randomly selected cells (in black) were used to identify incidence of cropping (wetlands on private land in yellow).

The most dense section of the South East Grampians wetlands cluster map was overlaid with a grid of 42 cells, each 11 x 14 km in area. For the whole grid the distance from the centre point to the nearest crop was determined (Figure 21). The cell centroid points were located within a crop for 40 % of cells, and were within 300 m of the nearest crop for another 19 % of cells. The maximum distance to the nearest crop was greater than 3 km for only two cells. Cropping is a dominant land use in the South East Grampians wetland cluster (Figure 21).

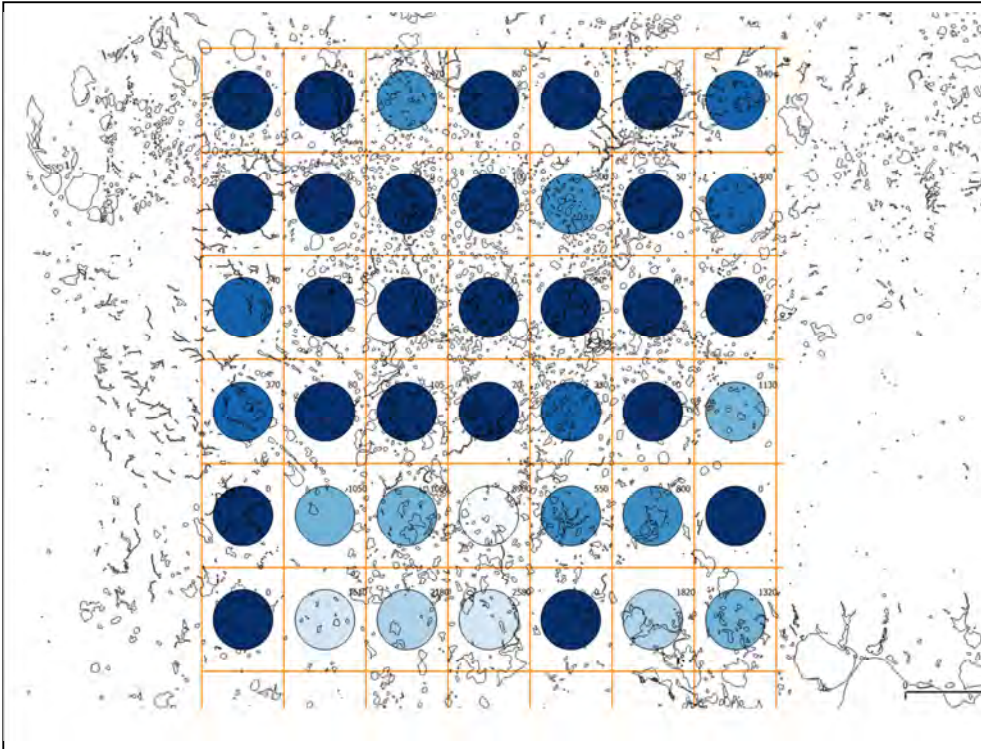


Figure 21. Occurrence of cropping as a landuse in each cell of the South East Grampians cluster. Darkest colour indicates a shorter distance from the centre of the cell to a crop (0 km, i.e. the central point was in a cropped paddock), lighter colours indicate a greater distance (up to 8 km).

A sample of seven cells was randomly selected to determine the incidence and types of cropping occurring within privately owned wetlands, and proximity of cropland to wetlands. Almost half (45 %) of the wetlands assessed showed evidence of cropping (Table 15).

There is a positive relationship between the density of cropping and the density of wetlands in the South East Grampians cluster (Figure 21). The coloured circles indicate the distance from the centre of the cell to the nearest crop (metres). Where a high proportion of the land area is devoted to crop production the central point of a cell is likely to be close to the nearest crop. Crop density decreases toward the bottom of the grid, which approaches the southern boundary of cropping in the South East Grampians cluster, near Mortlake. The left and right boundaries are marked by the Hopkins River and Mt Emu Creek respectively, which represents a change from endorheic to exorheic drainage in the landscape. Soil type does not provide predictive value for wetland distribution in the South East Grampians cluster because of the relative uniformity of soil type in that region. Topography is a good predictor of both cropping and wetland occurrence (i.e. the incidence of cropping is lower in the south of the South East Grampians cluster because the basaltic stony rises impose physical constraints, and there are fewer wetlands to the north because there is more slope).

Table 15. Incidence of cropping in wetlands in contained in the evaluated cells the South East Grampians cluster.

Land use within the wetland	Number of wetlands	Proportion (%)	
Not cropped	251	55	
Cropped at the edges (part)	66	14	
Cropped at the edges and on the bed (part)	65	15	45 % of all wetlands had some cropping
Completely cropped	71	16	
Total number of wetlands	453	100	

assessed

When the attributes of individual wetlands were examined in relation to the occurrence of cropping in the South East Grampians cluster it was found that rainfed wetlands are at greater risk of cropping than those influenced by groundwater (Table 16). Wetlands with a low (60 %) or medium (56 %) groundwater influence were much more likely to be either fully or partially cropped than were wetlands with a high groundwater influence (19 %).

When the wetlands were assessed in relation to the aquatic system (lacustrine, palustrine or unknown) it was found that 53 % of palustrine wetlands were fully or partially cropped, compared to 24 % of lacustrine wetlands that were partially cropped. This supports the observation that shallow, temporary wetlands are at a higher risk of cropping than other wetlands.

Table 16. 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. Results of particular interest are bolded.

Land use within the wetland	Ground water influence				Aquatic system		
	High	Medium	Low (i.e. rain-fed)	Unknown	Lacustrine	Palustrine	Unknown
Not cropped	33 (83 %)	32 (44 %)	90 (47 %)	96 (6 %)	26 (76 %)	214 (46 %)	101 (66 %)
Cropped at the edges (part)	1 (3 %)	13 (18 %)	31 (16 %)	20 (13 %)	4 (12 %)	44 (16 %)	17 (11 %)
Cropped at the edges and on the bed (part)	5 (13 %)	12 (17 %)	26 (21 %)	23 (15 %)	4 (12 %)	38 (14 %)	24 (16 %)
Completely cropped	1 (3 %)	15 (21 %)	45 (23 %)	10 (7 %)	0	61 (23 %)	10 (7 %)
Total number of wetlands per category	40	72	192	149	34	267	152

Where wetlands could be classified in relation to salinity and water regime (284 wetlands) only temporary systems were cropped (the edges of 45 % of temporary freshwater lakes and the edges of 18 % of temporary saline lakes, the edges of 31 % of temporary freshwater marshes and meadows and the entirety of 23 % of temporary freshwater marshes and meadows) (Table 17).

Classification of wetlands in relation to salinity alone revealed that where salinity was determined (329 wetlands) 51 % of freshwater wetlands (30 % partially cropped, 21 % completely cropped) and 12 % of the edges of saline wetlands were cropped. When wetlands were classified in relation to the vegetation that was present (296 wetlands), 45 % of all wetlands in all cropping categories had emergent vegetation consisting of sedges, grasses and forbs. Of these 26 % were partly cropped and 19 % were completely cropped.

Classification on the basis of Corrick's categories provided some guidance in relation to the incidence of cropping in different categories of wetlands (Table 18). Out of 324 wetlands that could be allocated to categories, cropping occurred in 59 % of freshwater meadows, 39 % of shallow freshwater marshes, 27 % of permanent open freshwater, and the edges of 17 % of deep freshwater marshes, 25 % of semi-permanent saline, and 7 % of permanent saline wetlands. This supports the observation that shallow, vegetated wetlands are at greatest risk of cropping. The subset of wetlands that are in the 'unknown' category (for each of the attributes) is a large proportion of all wetlands in this cluster. Clarification of the status of these wetlands would enhance this analysis. For some categories this can be determined via desk-top investigation i.e. the presence of stock dams dug within a wetland indicate that the soil and water are not

saline, or were not saline when the dam was dug. Those that have not been cropped should be prioritised for investigation over those that have.

Table 17. 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 category (within each column) to determine the proportion of wetlands in each category that were subject to cropping. Results of particular interest are **bolded.**

Land use within the wetland	Permanent freshwater lakes	Permanent saline lakes	Temporary freshwater lakes	Temporary freshwater marshes and meadows	Temporary saline lakes	Unknown
Not cropped	2 (100 %)	4 (100 %)	6 (55 %)	113 (45 %)	14 (82 %)	112 (66 %)
Cropped at the edges (part)	0	0	4 (36 %)	43 (17 %)	0	18 (11 %)
Cropped at the edges and on the bed (part)	0	0	1 (9 %)	36 (14 %)	3 (18 %)	26 (15 %)
Completely cropped	0	0	0	58 (23 %)	0	13 (8 %)
Total number of wetlands in each category	2	4	11	250	17	169

Table 18. 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 were subject to cropping. Results of particular interest are **bolded.**

Land use within the wetland	Freshwater meadow	Shallow freshwater marsh	Deep freshwater marsh	Permanent open freshwater	Semi-permanent saline	Permanent saline	Unclassified
Not cropped	85 (41 %)	28 (61 %)	10 (83 %)	24 (73 %)	9 (75 %)	14 (93 %)	81 (63 %)
Cropped at the edges (part)	34 (17 %)	8 (17 %)	2 (17 %)	3 (9 %)	0	0	18 (14 %)
Cropped at the edges and on the bed (part)	31 (15 %)	5 (11 %)	0	5 (15 %)	3 (25 %)	1 (7 %)	21 (16 %)
Completely cropped	56 (27 %)	5 (11 %)	0	1 (3 %)	0	0	9 (7 %)
Total number of wetlands per category	206	46	12	33	12	15	129

4.1.3. Changes since February 2010 in South East Grampians cluster

Of the 453 wetlands in the evaluated cells in the South East Grampians cluster, 157 had been evaluated for the presence or absence of cropping by aerial survey in February 2010. In 51 wetlands where cropping was recorded as 'absent' in 2010 it was present on the bed or at the edge in 2016. Another nine wetlands that were not cropped in 2010 were fully cropped in 2016. This represents an increase of 40 % of the wetlands assessed 'going under the plough' in 6 years. The actual time period is likely to be shorter, because of the date of Google Earth images (between 2014 and 2016), and some caution should be used in the interpretation of 'part-cropping' because the categories have not been standardised among the scorers.

4.1.4. Case study: West Wimmera

The West Wimmera cluster contains the second highest density of temporary wetlands of the clusters identified for Victoria (Figure 22). There are c. 2400 wetlands in the cluster. The cluster is bounded by the Little Desert National Park to the north, the South Australian border to the west, the Grampians National Park to the east and the Dundas Tablelands to the south (Figure 22).

These wetlands and publicly managed land can be seen to exhibit north-south patterning, which is related to differences in soil types from relic shorelines (Figure 23). The relationship between wetlands and soil type is important, as it is a determinant of suitability for different agricultural enterprises, and soil type is also related to wetland salinity (CSIRO 2016a).

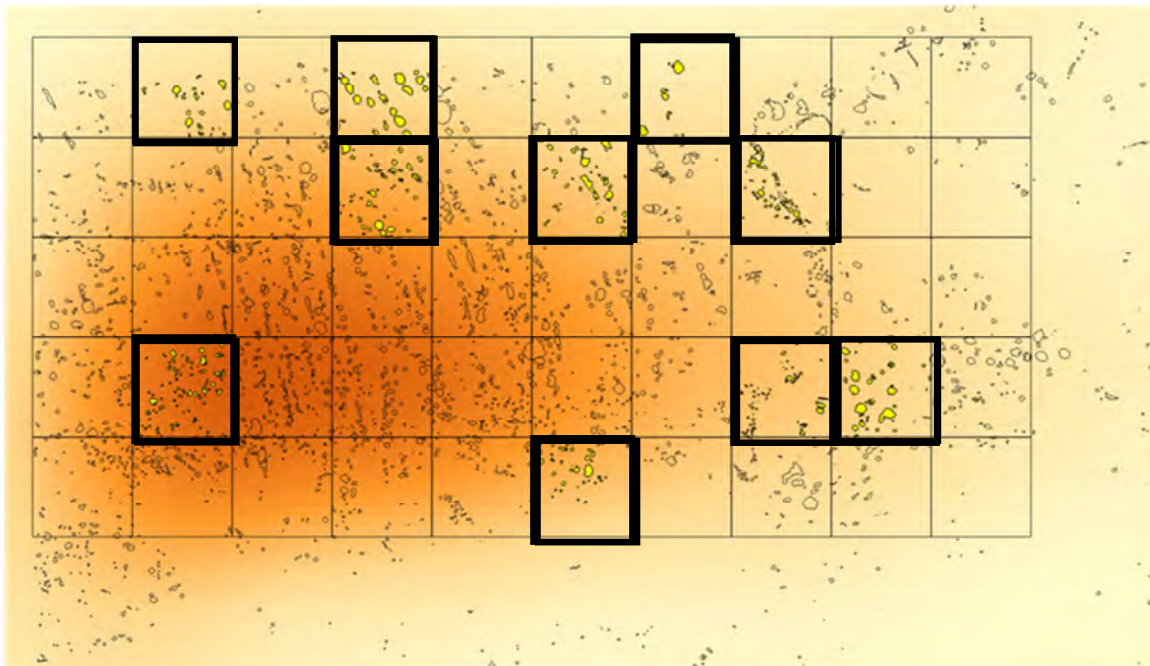


Figure 22. West Wimmera wetland cluster from the heat-map indicating density of wetlands. Darker colour indicates higher density. The map is overlaid with a grid. Randomly selected cells (in black) were used to identify incidence of cropping (wetlands on private land in yellow).

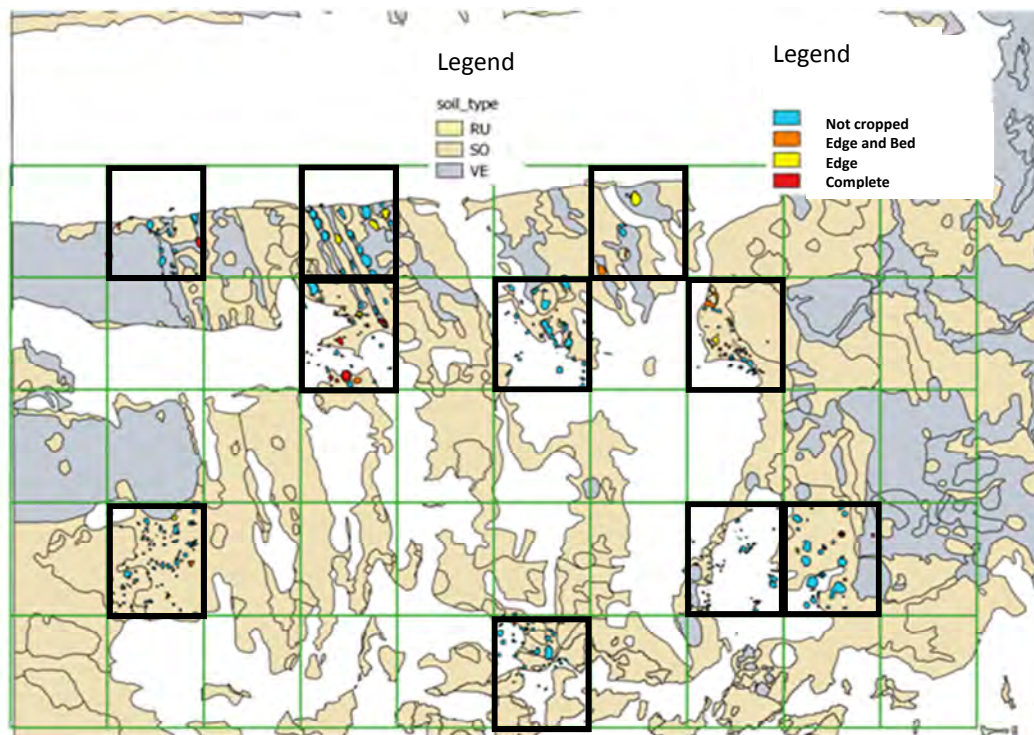


Figure 23. West Wimmera wetlands with the sample cells outlined, and the wetland cropping characteristics coded. Soil types are RU: rudosol soils (mostly sandy), SO: solodic soils, VE: vertisol soils. Different soils have different susceptibility (arability) to cultivation.

The map of West Wimmera wetlands was overlaid with a grid of cells 12 x 15 km in area. A sample of 10 cells was randomly selected to determine the incidence and types of cropping occurring, and proximity of crop land to wetlands. For the whole grid the distance from the centre of each cell to the nearest crop was determined.

Overall, cropping is less prevalent in the West Wimmera cluster than in the South East Grampians cluster (Figure 24). Within the West Wimmera it is related mainly to soil type (Figure 23) rather than north-south variation in rainfall. Cropping occurs preferentially on heavier vertisol and sodosol soils. Where the cell centroids were located on sandy rudosol soils, the distance to the nearest crop was generally greater, and it was more likely that the nearest crop was located on a different soil type. A sample of 10 cells was randomly selected to determine the incidence and types of cropping occurring in 440 wetlands. In the West Wimmera 19 % of the wetlands assessed showed evidence of cropping (Table 19).

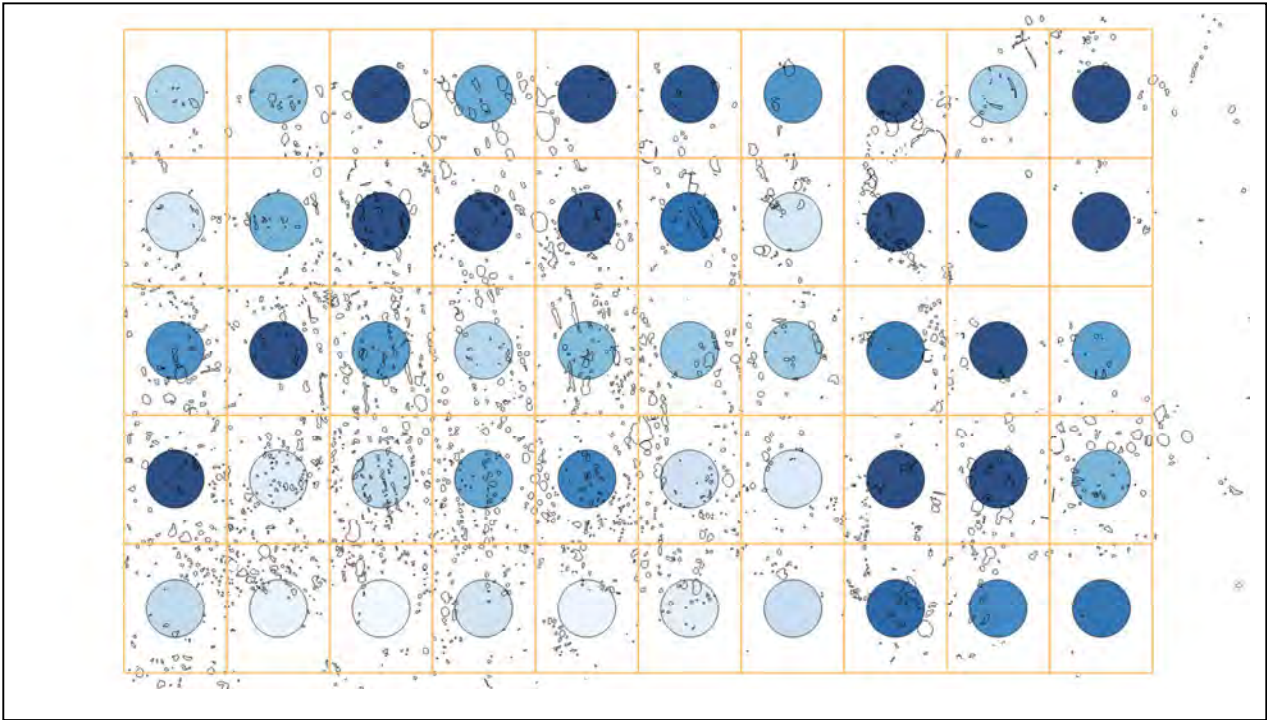


Figure 24. Occurrence of cropping as a land use in each cell of the West Wimmera cluster. Darkest colour indicates a shorter distance from the centre of the cell to a crop (0 km, i.e. the central point was in a cropped paddock), lighter colours indicate a greater distance (up to 7.5 km).

Table 19. Incidence of cropping in assessed wetlands in the West Wimmera cluster.

Land use within the wetland	Number of wetlands	Proportion (%)	
Not cropped	356	81	
Cropped at the edges (part)	19	4	
Cropped at the edges and on the bed (part)	32	7	19 % of all wetlands had some cropping
Completely cropped	33	8	
Total number of wetlands assessed	440	100	

When the attributes of individual wetlands were examined in relation to the occurrence of cropping in the West Wimmera cluster, it was found that the majority of wetlands had either low or very high ground water influence. Of the 'low influence of ground water' category 33 % had evidence of cropping, and of the 'high influence of ground water' category 29 % had evidence of cropping (Table 20).

Table 20. 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. Results of particular interest are **bolded.**

Land use within the wetland	Ground water influence				
	Very high	High	Medium	Low (i.e. rain-fed)	Unknown
Not cropped	95 (77 %)	26 (70 %)	24 (83 %)	163 (83 %)	48 (94 %)
Cropped at the edges (part)	2 (2 %)	3 (8 %)	1 (3 %)	13 (7 %)	0
Cropped at the edges and on the bed (part)	16 (13 %)	2 (5 %)	5 (16 %)	8 (4 %)	1 (2 %)
Completely cropped	11 (9 %)	6 (16 %)	2 (6 %)	12 (6 %)	2 (4 %)
Total number of wetlands per category	124	37	32	196	51

Where wetlands could be classified in relation to salinity and water regime (188 wetlands), the only group that showed any consistent evidence of cropping were temporary systems, including temporary saline lakes (Table 21).

Table 21. 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 category (within each column) to determine the proportion of wetlands in each category that were subject to cropping. Results of particular interest are **bolded.**

Land use within the wetland	Temporary freshwater		Temporary freshwater		Temporary saline		Unknown
	freshwater lakes	marshes and meadows	freshwater swamps	swamps/ marshes/ meadows	marshes/ meadows/ swamps	saline lakes	
Not cropped	9 (100 %)	20 (77 %)	98 (90 %)	1 (100 %)	23 (23 %)	4 (80 %)	198 (79 %)
Cropped at the edges (part)		3 (12 %)	1 (1 %)	0	2 (6 %)	0	13 (5 %)
Cropped at the edges and on the bed (part)		2 (8 %)	7 (6 %)	0	5 (14 %)	1 (20 %)	17 (7 %)
Completely cropped		1 (3 %)	3 (3 %)	0	5 (14 %)	0	24 (10 %)
Total number of wetlands per category	9	26	109	1	35	5	252

Classification of wetlands in relation to salinity alone revealed that where salinity was determined (436 wetlands) 18 % of freshwater wetlands (11 % partially cropped, 7 % completely cropped) and 27 % of the saline wetlands (18 % partially cropped, 9 % completely) were cropped.

When wetlands were classified in relation to the vegetation that was present (189 wetlands, 45 % of all wetlands in all cropping categories) 26 % had no emergent vegetation and 23 % had vegetation consisting of sedges, grasses and forbs. Of these 35 % were partly cropped and 14 % were completely cropped. Significantly, two categories of vegetation exist in the West Wimmera that were not recorded in the South East Grampians cluster: forest or woodland (11 % had evidence of cropping) and shrubland (none of which were cropped).

Classification on the basis of Corrick’s categories provided some guidance in relation to the incidence of cropping in wetlands (Table 22). Out of 436 wetlands that could be allocated to categories cropping occurred in 23 % of freshwater meadows, 14 % of shallow freshwater marshes, 26 % of semi-permanent saline, one permanent open freshwater, and the edges of one deep freshwater marsh, and in one permanent saline wetland. This supports the observation that shallow, vegetated wetlands are at high risk of cropping, but in the West Wimmera, saline, and permanent wetlands are also cropped.

Table 22. 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 were subject to cropping. Results of particular interest are bolded.

Land use within the wetland	Freshwater meadow	Shallow freshwater marsh	Deep freshwater marsh	Permanent open freshwater	Semi-permanent saline	Permanent saline	Unclassified
Not cropped	150 (77 %)	118 (86 %)	21 (95 %)	12 (92 %)	48 (74 %)	4 (100 %)	3 (75 %)
Cropped at the edges (part)	10 (5 %)	5 (4 %)	1 (5 %)	0	3 (5 %)	0	0
Cropped at the edges and on the bed (part)	14 (7 %)	9 (7 %)	0	1 (8 %)	8 (12 %)	0	0
Completely cropped	20 (10 %)	6 (4 %)	0	0	6 (9 %)	0	1 (25 %)
Total number of wetlands per category	194	138	22	13	65	4	4

4.2. Drivers of cropping in the landscape

The occurrence of cropping in the landscape depends on three factors:

- a suitable landscape (Section 3)
- farmer willingness (Section 3.2); and
- the technological capacity to crop, or enablement.

Innovations in crop machinery and techniques, enable production systems to be implemented that reduce cost. Crop production techniques and issues, and agronomic advice are publicised to farmers around Australia through effective communication strategies. This has produced a uniformity of best-practice agricultural activities. In the absence of effective social constraints, cropping will be taken up in all suitable parts of the landscape to maximise the return on capital investment and to gain the best economic return.

Innovation in techniques for cropping

Most broadacre crops are now precision-sown using zero tillage methods (Figure 25). This is also referred to as 'direct-drill' and incorporates the sowing of seed and fertiliser without prior cultivation. The objective is to provide an ideal environment for seedling establishment at the least cost per hectare. A slot is cut into undisturbed ground, seed and fertiliser are placed at the desired depth and then covered by fine tilth soil, all in one pass. This method of crop establishment has become standardised in Victoria, with the proportion of crop area sown using direct-drill increasing from 15 % in 1995-6 to more than 70 % by 2010-11 (Barson 2013). This trend is also evident in the three CMA regions where wetland clusters are at risk from cropping.

Wide airseeders commonly have independent hydraulic pressure and depth control for each individual sowing tyne, so that the sowing depth remains constant, even when there are variations in the soil surface, contour or soil strength. The lack of soil disturbance between the sowing rows promotes good soil structure, and means that the tractor and sowing rig can operate on wetter ground than was previously possible. Under these conditions tractors don't accumulate mud on their tyres (Figure 25) even when soil is quite damp. If the ground is ploughed prior to sowing, tracks from where the tractor presses down into the ground become visible in the sown areas (this is not occurring in Figure 25). Cropping in wetland areas (with these zero tillage methods) now presents far fewer technical problems than in the past.

Crop is grown on raised beds in southern Victoria on "land prone to waterlogging" where there is sufficient slope to drain water away from the crop area (Wightman et al. 2016). This means that exorheic, rather than endorheic wetlands are more likely to be used for raised bed cropping. Raised beds are constructed by a series of procedures, which include:

- the removal of all obstacles
- cultivation to 20 cm depth
- paddock levelling, and
- application of lime and gypsum if necessary.

The beds are then formed to a width of 1.7 – 2 m, separated by furrows 10 -30 cm deep (Wightman et al. 2016).



Figure 25. Zero tillage, direct-drill sowing into uncultivated pasture. Air-seeder points can penetrate the soil, place the seed and cover adjacent surface with soil. The pasture is likely to have been sprayed prior to sowing with a 'knock-down' herbicide to prevent pasture competition with the growing crop. Source: <https://www.youtube.com/watch?v=YHqheE3NfMM>.

Nuisance costs

Farming and cropping are economic activities, and all aspects of them are allocated a time or dollar value. Activities that increase the amount of time, or the dollar cost of completing a task are called 'nuisance costs', and these include the need to steer around obstacles (e.g. plantations, wetlands), the creation of unsowable areas or unproductive areas within paddocks (e.g. corner triangles, compacted areas) and time spent using machinery when it is not actively sowing crop (Danielson and Leitch 1986, Cortus et al. 2011)

We like long straight rows

Changes in the morphometry and technology of cultivation have had an impact on the retention of environmental heterogeneity within cropped areas. Paddocks cropped in Victoria during the 1900s were traditionally sown around and around, following the perimeter of the paddock, completing the sowing in ever decreasing circles. Sowing around obstacles presented few problems, as there was no real loss of time if rows did not remain parallel to each other. The effects of crooked lines generally diminished as the area left to be sown decreased.

In contrast, GPS steering control and larger machinery have led farmers to change the pattern of sowing. Wide airseeders work best when they run in straight lines. Turning is done with the sowing tynes lifted out of the ground, and this takes time, so efficiency is greatest when paddocks are in the shape of long rectangles. Farmers aim to maximise the number of minutes that the sowing rig is actually in the ground for every hour that the machinery is being used, because of the operating expense, and because of the small timing window for optimal crop establishment. Arranging a farm into large long paddocks reduces the amount of time that an airseeder spends turning during sowing, and it is less complicated to move from one field to the next (Figure 26). Having large, long paddocks also avoids soil compaction near gateways, and enables trucks supplying seed and fertiliser to remain near perimeter gateways without having to be shifted.



Figure 26. Drone footage of a sowing rig in the West Wimmera. Crop is being direct-drilled into the stubble of a previous year's crop. There is little heterogeneity and few obstacles in the paddock.
Source: <https://www.youtube.com/watch?v=6j60slt2bxs>.

The physical dimensions of most farm property survey titles are typically in the shape of parallel sided rectangles or squares. This is an ideal arrangement for GPS autosteer sowing. As a consequence, many farms in Victoria that formerly ran sheep in combination with cropping have now been modified to have a higher proportion of cropped area with few internal fences (Figure 27). It is common to find that where there were whole farms of many fields, plantations and fences ten years ago, there are now single

paddocks. GPS autosteering has introduced another efficiency to the final stage of sowing an area. The last pass that completes the sowing of a paddock will be exactly parallel to the starting edge along the whole length of the paddock, to a precision of several centimetres, even if the airseeder is over 20 m wide and the distance is over a number of kilometres. This avoids the need to finish sowing a long narrow triangle shape with multiple turns at the end of the paddock. This is both an economic concern and a matter of satisfaction or pride to farmers. The pattern of long parallel lines that is characteristic of zero tillage cropping can be seen in aerial photographs, even after the vegetation of the crop has decomposed or has been burnt.

Pure geometric shapes in a heterogeneous landscape

The perception and attitudes of people towards their surrounding environments is influenced by cultural values (Yu-Fi Yuan, 1974). For farmers, the concept of their farm is informed in part from their surroundings, and also from the explicit and implicit cultural world views of society. One of the principles inherited by western civilisation from ancient Greece is that geometric shapes such circles, squares and parallel lines represent a form of perfection (Farrington 1936). In this light, the biological value of small wetlands of irregular shapes and positions in a farm can be seen as being in competition with the desire to maintain an ideal sowing pattern. Zero tillage, GPS autosteering, drier than average seasons and attitudes towards wetlands combine to result in a capacity and desire to crop wetlands. As a consequence there are examples of individual farms (Figure 27) where owners have removed all internal fences and sown crop in a continuous pass, regardless of previous land use, topography, or soil and moisture variation.



Figure 27. Aerial view (Google Earth) of broadacre cropping in western Victoria, with an overlay of wetland area estimated from pre-European settlement mapping. Variations in greenness indicate wetter areas and differing soil fertility, the shadows of past paddocks. The parallel sowing rows throughout the area outlined in red show that the whole of this area is now covered by a single crop, with the exception of the central white line (public road), the homestead and a few areas of trees.

Incorporating a wetland into cropping areas

Incorporating an area that has not been cropped before into a cropping program can be undertaken using existing farm machinery and methods, except for areas occupied by rocks (throughout the area known as the 'Stony Rises', and on the Victorian Volcanic Plains this is often on the eastern margin of wetland areas). Specialist machinery (excavator, grader, rock-picker or crusher) is needed for rock removal. When existing machinery only is used no additional capital costs are incurred when incorporating wetland areas into the cropping program. Under those circumstances the cost of bringing new land into crop consists largely of the cost of seed, fertiliser, chemicals and gypsum and the operating costs of machinery.

When cropping land surrounds a wetland area, the infiltration of rainfall into the soil is increased compared to pasture, and run-off into the wetland area can be significantly reduced (Elliot et al. 2001). The reduction

in run-off leads to a reduced chance of waterlogging and inundation in the wetland. A lack of waterlogging and inundation makes it both easier and more economical for farmers to undertake cropping in wetland areas. Wetland areas surrounded by cropping land are less likely to be grazed by domestic stock during the crop-growing season, due to difficulties in fencing such areas. They are also more likely to be subject to the same land management (fire, post-harvest grazing) after the crop is harvested.

A shallower, drier wetland, surrounded by cropped dryland, is more vulnerable to cropping across the bed, as a consequence of surrounding land use. There are numerous examples of creeping cultivation, whereby the farmer encroaches onto the wetland bed further and further through a sequence of dry years, until the entire wetland is cultivated and incorporated into the cropping system. In some places cropping has caused degradation of temporary wetlands (sedimentation, change in topography, reduction of inflow) to the point where they have 'disappeared' from the landscape (Gallego-Fernández et al. 1999, Zacharias and Zamparas 2010).

4.3. Wetland attributes at the landscape scale

In the vicinity of Lake Bolac local wisdom states that 'there's a swamp every square mile' (Consultation, Appendix A). In fact, the density of wetlands in the Lake Bolac landscape is approximately 1 per 2 km². Wetland abundance at the landscape-level can contribute to the resilience of a system through the cumulative biodiversity of individual wetlands and the connectivity among them. If an element (plant or animal species) is lost from an individual wetland, it can be replaced via dispersal from other wetlands (Hazell 2003, McIntyre et al. 2014), given sufficient connectivity and lack of landscape resistance (Morris 2012). Biodiversity is an attribute of wetlands at a number of spatial scales (Figure 28), and biodiversity conservation needs to focus on preservation of multiscale ecological patterns and processes in natural systems, that support wetland condition and values. In the model provided (Figure 28) regional-scale species are represented by migratory waders and eels (that range across millions of hectares for breeding and feeding), at the coarse scale are Victorian bird species like Brolga. Intermediate scale species are those plant, invertebrate and animal species that have effective dispersal mechanisms, and are common to temporary wetlands throughout a consistent climatic zone. Local-scale species include some frogs, invertebrates, plants and algae (see section 3.1.2).

At the landscape (coarse) scale, groups of wetlands provide a higher density of resources for birds that use the whole landscape (e.g. Brolga, *Grus rubicunda*). For large cranes in the USA (Whooping Cranes, *Grus americana*) food resources obtained during the growth season (summer in Northern Hemisphere) are significant for survival during the non-growth season (winter in Northern Hemisphere) (Chavez-Ramirez 1996). Studies on Whooping Cranes indicate their breeding territory needs to range from 100–200 ha per pair in prime salt-marsh habitat (Stehn and Prieto 2010). If Brolgas were to require a similar area of wetland habitat, they would need 10–20 wetlands with an average area of 10 ha each to support one breeding pair in winter. Brolga can be considered 'the canary in the mine' with reference to wetland health in Victoria on a coarse-landscape scale, as they require large areas of productive temporary wetlands for feeding. Brolgas in western Victoria numbered in the thousands at the time of European settlement (Trust For Nature 2014), but the population has declined in recent decades (SWIFT 2016).

Frogs are a good example of intermediate-scale species. Although some species of frogs are widespread though out Victorian wetlands (Eastern Common Froglet, *Crinia signifera*), there are examples of frogs with more restricted (large-patch) distributions (e.g. Desert Trilling Frog, *Neobatrachus centralis* in the Wimmera, Lesueur's Frog, *Littoria lesueuri* in Gippsland).

Plant species can be examples of local-scale species (e.g. orchids), and at least two species of charophytes are restricted to temporary wetlands in western Victoria (Section 3.1.2).

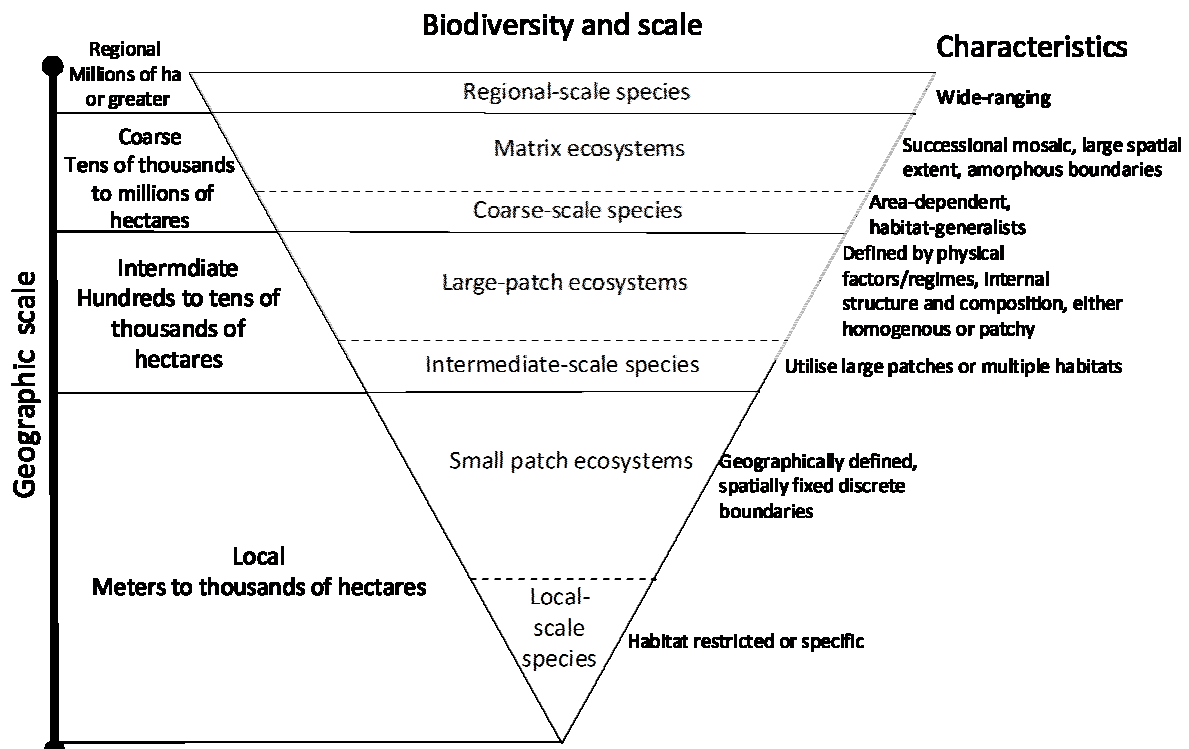


Figure 28. Biodiversity at various spatial scales. Levels of biological organisation include ecosystems and species. Ecosystems and species are defined at four geographic scales, including local, intermediate, coarse and regional. The general range in hectares is indicated (left of pyramid), as are the common characteristics of ecosystems and species at each of the spatial scales (right of pyramid). (After Poiani et al. 2000).

4.4. Sensitivity of wetlands to cropping at the landscape scale

Wetland mosaics are sensitive to cropping at the landscape scale: they are at risk of fragmentation in various ways, and intervening land use can affect the capacity of organisms to migrate across it (landscape resistance). This can affect the dynamics of populations of individuals that interact at a landscape scale (Table 24).

4.4.1. Fragmentation

Wetland connectivity is impacted at the landscape scale when individual wetlands are cropped. The geospatial analysis (Section 4.1) indicated that there are a range of wetland sizes and distributions within regions, and that cropping of wetlands can be complete, partial, around the edges, or partial including the bed (Figure 3, p. 12). The patterns of cropping in wetlands have the potential to impact on the kind of connectivity that remains among the fragments (Thompson and Ronce 2010), in relation to the isolation of individual fragments, the size of fragments and the number of fragments (Figure 29).

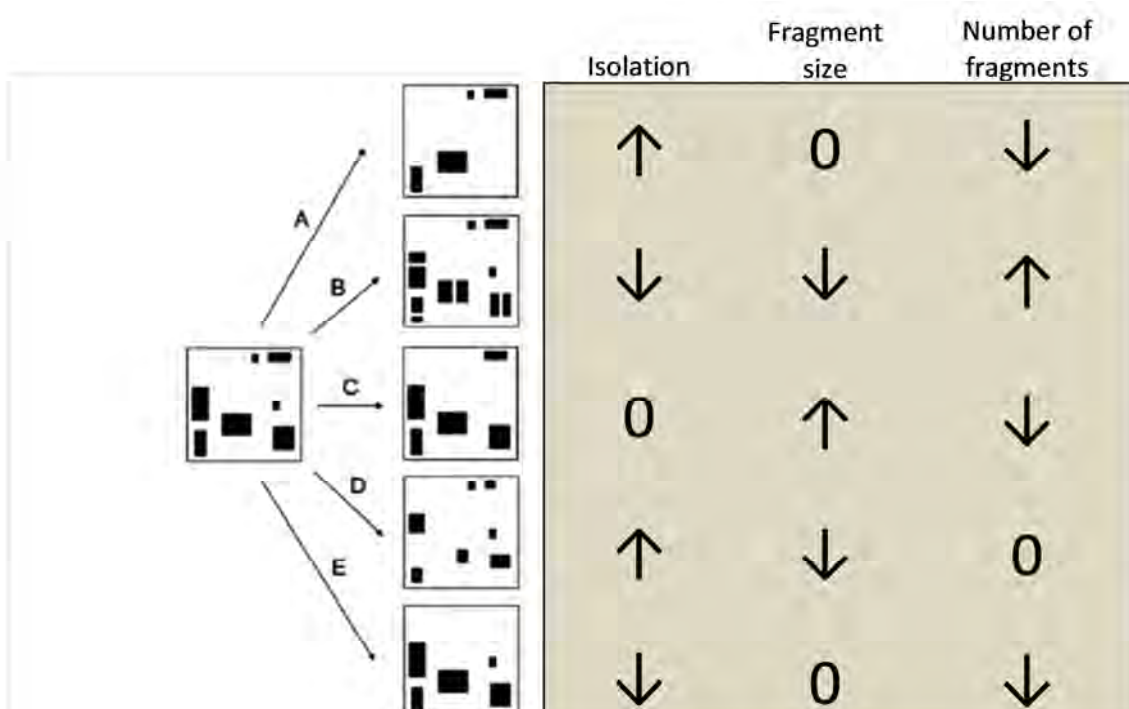


Figure 29. Connectivity impacts in terms of isolation, fragment size and number of fragments that result from five different types of habitat fragmentation (Thompson and Ronce 2010).

Landscape connectivity can be degraded or interrupted by cropping (Van Meter and Basu 2105). When the characteristics of fragmentation are considered, there are five ways that a wetland mosaic can be fragmented: complete removal of some wetlands resulting in fewer fragments and more isolation (A); cutting large fragments in half, resulting in decreased isolation, smaller fragment size and increased number of fragments (B); removal of just the smaller wetlands, resulting in an increase in average fragment size and decrease in number of fragments (C); all wetlands eroded from the edges, resulting in greater isolation and smaller fragment size (D); and removal of wetland patches, resulting in decreased isolation and fewer fragments (E). The spatial evaluation of wetlands shows that fragmentation types A, C, D and E occur with cropping. Types A and E represent the cropping of entire wetlands in different parts of the cluster, with different impacts on the isolation of wetlands. Type C is the preferential cropping of small wetlands, as commonly occurs where a wetland is in the middle of an otherwise uniform paddock. Type D relates to partially cropped wetlands that still remain, but become smaller, and the ratio of edge to bed increases. Type B fragmentation also exists in cropped wetland landscapes, however, it is usually where roads have been built through wetlands, rather than a consequence of cropping.

The distance between individual habitat fragments, as well as their number and size, will have implications for the genetic diversity of gene pools, the reproduction and dispersal success of the populations of individual wetland species that contribute to a functional wetland ecosystem. There is an opportunity for natural resource managers to take account of fragmentation patterning in order to identify individual wetlands and wetland groups that are of critical conservation value (Table 23).

Fragment size

There are size thresholds for habitat provision for different organisms. In a study of a fragmented wetland landscape, Drinnan (2005) found that remnant area was the best predictor of species richness for all taxa examined. Further analysis revealed remnant size thresholds of 4 ha for bird and frog species, and 2 ha for plant and fungal species richness. The limitations of habitat size could be overcome by connectivity, as the presence of corridors has been demonstrated to produce a positive result for birds, frogs and plants (Forman 1995).

Number of fragments

Number of remaining fragments can impact on metapopulation dynamics for intermediate and local-scale species that do not disperse well. Fewer fragments can be more isolated from each other and this can impact on genetic diversity.

4.4.2. Connectivity and isolation

The degree to which wetlands are connected to each other and other natural areas will influence their functioning, values and services. For waterbird dispersal and utilisation, wetlands can be tens, hundreds or even thousands of kilometres apart and still be connected. Many waterbirds use individual wetlands for breeding, but utilise wetland mosaics as feeding grounds (e.g. Brolga). It is not uncommon for waterbirds to migrate across large areas to take advantage of newly inundated temporary wetlands (e.g. Chestnut Teal (*Anas castanea*), Pacific Black Duck (*Anas superciliosa*), Black Swans (*Cygnus atratus*), White-necked Herons (*Egretta novaehollandiae*)) (Porter et al. 2006). As well, many waterbirds breed in temporary wetlands when they contain water, then migrate to more permanent wetlands when temporary ones dry out (Black et al. 2010). Migratory waterbirds regularly migrate from the Northern Hemisphere to take advantage of the seasonal abundance in resources provided by temporary wetlands in Victoria (e.g. Latham's Snipe, *Gallinago hardwickii*) (Black et al. 2010).

Amphibians require more proximity (a more connected landscape either via hydrological connections or corridors for migration) than waterbirds, and they can be classified into relatively restricted species (that can travel c. 0.5 km) or more vagile species (up to 3 km) (Morris 2012). Invertebrates can be classified into resident (i.e. without obvious dispersal adaptations, e.g. worms, snails) and transient (i.e. those that can fly between wetlands, e.g. dragonflies, beetles) (Hall et al. 2004). In common with waterbirds and frogs, transient species require a connected mosaic of wetlands to persist in the environment. Resident species richness is more likely to be affected by landscape attributes (e.g. surrounding land use) than transient species richness, presumably because transient species can choose which wetland they live in (Hall et al. 2004), and resident species are selected by their habitat characteristics (i.e. they persist or they die) (Euliss et al. 1999).

Wetland fragmentation theory is supported by several studies in relation to landscape connectivity (Hall et al. 2004, Weinstein et al. 2005, Alsfeld et al. 2009, Weinstein et al. 2014). The amount of surrounding wetlands area and proximity to the nearest wetland often increases wetland bird richness, and landscape features that increase habitat connectivity and provide movement corridors positively affect bird and vegetative community diversity.

In the USA and Canada rain-fed wetlands in plains areas are often referred to as 'Small Isolated Wetlands', and there is a body of research that has examined their value, and the degree to which they are actually isolated (O'Connell et al. 2013a, McLaughlin and Cohen 2013, Johnston 2013). They are very important for waterbirds, particularly those that migrate across the North American landscape. That importance is underpinned by wetland biodiversity and productivity (see Figure 5, p 22). Organisms that rely on particular vectors (e.g. water plants that rely on waterbirds for propagule dispersal) will become disconnected if the vector is absent or rare in the landscape (see Morris 2012 for a thorough review of wetland connectivity and its importance).

Cropping reduces connectivity by removing corridors between adjacent wetlands, by changing the topography and vegetation of the land between wetlands and by removing wetlands (or their capacity to provide habitat or shelter, to be stepping stones, between other wetlands) altogether (Figure 30, Table 24).



Figure 30. Cropping in a wetland-rich landscape in Saskatchewan, Canada. The tractor is being driven from left to right, it is pulling an airseeder and spray unit, the area between wetlands is modified to make those wetlands 'less connected'. Source: <https://www.youtube.com/watch?v=6j60slt2bx>

4.4.3. Landscape resistance

Resistance refers to the degree to which a surrounding landscape is permeable to movement. Cropping in the area surrounding a wetland has been shown to impact the diversity of 'resident' invertebrates in temporary wetlands (Hall et al. 2004). There are also the potential effects of spray drift, fertiliser throw (Figure 13), biological isolation from other wetlands, removal of stock-grazing and increased potential annual burning (see section 4.5.2). These can increase landscape resistance (Table 24).

Different organisms experience different degrees of resistance through the same landscape. Removal of corridors of native vegetation can cause landscapes to become resistant to movement of amphibians and reptiles (Morris 2012). A change in the macro- or microtopography, or a decrease in the density and proximity of wetlands in a wetland mosaic can make the landscape more resistant to dispersal of invertebrates. Cropping in the surrounding landscape alters the topography, and the abundance of shelter for animals (eels, frogs, invertebrates) moving between wetlands. This makes them more vulnerable to predation from birds and feral animals. Some observations suggest for small non-aerial vertebrates and invertebrates, the depth of a furrow can produce a trackway (to nowhere) that they cannot or do not exit (Consultation, Appendix A). A different kind of resistance exists where birds require a number of wetlands for sustenance. If the distance between wetlands is too large it is possible that the energy needed to travel to particular wetlands is more than could be obtained on arrival.

4.4.4. Metapopulations

Amphibian metapopulation dynamics (i.e. the movement and relationships among the complex of individual populations within a landscape) are impacted by the connectivity among habitat and refugia wetlands, and also their capacity to migrate (Heard et al. 2015), and this impacts directly on their probability of extinction. If frogs are able to shelter in cracks and vegetation during dry periods, they readily occupy rewetted habitat, however, their genetic diversity and population dynamics depend on movement among nearby wetlands (Heard et al. 2015). Frog migration is a common event among Victorian temporary wetlands. Adult frogs leave their shelter and move across the landscape, and are visible in the headlights of cars as the frogs cross roads. Studies in the USA have found that there can be high mortality of juvenile amphibians during migration (Rothermel 2004), depending on the permeability of the landscape, and the distances between suitable habitat (Table 23).

Table 23. Effects of fragmentation-inducing practices of cropping on the characteristics and causes of impacts on wetland processes. (See Section 2.4 for an explanation of the colour coding).

Component	Impact on wetland	Impact on processes	Consequence	Strength of link
Cropping surrounding land	Sedimentation	Reduced germination	Fewer plants in wetland	High
	Crop plants and tilled soil	Decreased depth, increase in landscape resistance	Increased metapopulation isolation	High
Cropping the edges of a wetland	Chemical inputs, seed bank disruption, removal of shelter, removal of buffer	Death of non-target species. Reduced germination, hatching, reduced edge habitat, reduced wetland size	Reduced species richness, simplification of food webs	High
				High
Cropping the bed of a wetland	Chemical inputs, seed bank disruption, removal of shelter	Death of non-target species. Reduced germination, hatching, reduced edge habitat Alteration of food webs	Reduced species richness, simplification of food webs Increased isolation of populations, increased fragmentation, reduced connectivity	High
Cropping every year	Reduction in diversity of flora and fauna (resistant species survive)	Alteration of food webs	“Disappearance” of wetland as a functioning ecosystem	High

4.5. Wetland adaptive capacity at the landscape scale

There is little capacity for a landscape wetland mosaic to ‘adapt’ to changing land use. Temporary wetlands exist in the landscape in geological time (although the water comes and goes on a shorter time scale). Formation of new wetlands could (in theory) replace existing wetlands if they were removed. However, there is little evidence that created wetlands actually replace all of natural wetland condition or values (Zedler 2003). Wetlands could be restored where they have been impacted, by restoration of the water regime and cessation of cropping. This is a new area for conservation of wetlands, and there needs to be on-going research and monitoring to determine its success.

4.5.1. Capacity to recover

The capacity for a wetland to recover from a disturbance depends on its resilience, and whether the attributes and mechanisms for recovery (biodiversity, connectivity) remain in place (Casanova 2015). Considerations include whether the physical and chemical characteristics of the wetland remain unchanged (water regime, salinity, topography), whether the seed bank remains intact, and whether there are biological constraints (e.g. grazing, weed competition) that will prevent the natural regeneration processes from occurring (Roberts et al. in prep.). Temporary wetlands can be highly resilient and it is possible that a cessation in cropping will allow the wetland to ‘self-restore’ (i.e. develop a diverse plant and animal community through natural processes and time), especially if there are filling events. Where wetland hydrology has been changed through drainage, drains can be blocked to restore the hydrology. If seed banks have been depleted by cropping, given sufficient connectivity (Morris 2012) (waterbird visitation, hydrological connectivity, aerial connectivity with adjacent intact wetlands) wetland vegetation and processes can probably recover. It would be possible to replant or reintroduce elements of the biodiversity if these were to become locally extinct. However, changes in salinity, widespread extinction of structural species, and invasion by exotic species to the exclusion of native species, present greater problems.

Table 24. Assessment of sensitivity of Victorian temporary wetland attributes to cropping at the landscape scale. (See Section 2.4 for an explanation of the colour coding).

Wetland landscape attribute	Adjacent cropping	Raised bed formation	Cropping the edge	Cropping the bed	Repeated annual cropping
Fragment size		High	High	High	High
Number of fragments				High	High
Connectivity	High	High	Medium		
Resistance	Medium	High	Medium		
Metapopulation dynamics	Medium	High	Medium	High	High

Where wetlands were cropped in dry years during the 1950s, 60s and 70s it is likely that at least some of the vegetation and values have recovered (see Appendix A), to the extent that we can measure them. However there has been no long-term quantitative assessment of recovery following such disturbance. The study by Briggs and Jenkins (1997) found that there were alterations to the invertebrate community in cropped and uncropped lake bed seed banks, and they suggested that leaving areas uncropped would assist in ensuring recovery during wet phases. However, the areas and quantities they suggested were not scientifically determined, rather an ‘educated guess’. This is an area for further research.

The only two studies examining the effect of cropping on the resilience (via seed bank responses) and plant germination response of wetlands following cropping in Australia (Waters et al. 2012, Casanova 2012) showed that cropping does impact on the diversity of the seed bank and density of plants that established. The conclusion of those studies was that wetlands retain some functions and values after cropping ceased, if the seed bank remained intact and connectivity was retained, but that cropping for only short periods of time impacted on the biodiversity and responses of wetland seed banks. One of the sites used in Casanova’s (2012) study has had its hydrology restored (Scale Swamp near Peshurst), and some native flora has re-established (personal observation). Monitoring of this site should continue, as it is likely to provide valuable information on the recovery trajectory of sites disturbed by cropping.

In a meta-analysis of published studies where wetlands were allowed or managed to recover from human impacts, it was found that on average, wetland functioning remained between 23 to 26 % lower after restoration compared to unimpacted wetlands (Moreno-Mateos et al. 2012). Where cropping has been the main impact there is little mention of recovery or restoration success (Galatowitsch and van der Valk 1996, Cox and Rundquist 2013, Eliot et al. 2001, Wight and Wimberley 2012, Zartman et al. 2010, Gallego-Fernández et al. 1999, Zacharias and Zamparas 2010). Rather, there is a realisation that cropping results in wetland loss, particularly for shallow, seasonal wetlands. Additionally, in an index to assess wetland quality

in North Dakota, cropping is given as an example of a land use that causes a wetland to be in 'poor condition' (i.e. highly disturbed with low functioning) (Hargiss 2009).

In the majority of cases where wetlands are being cropped in Victoria the regional hydrology is changing in relation to climate change. Since diverse and valuable wetlands can exist in a variety of different climates, it is possible that resilient temporary wetland ecosystems will be able to adapt to changing climatic conditions. This is especially so for wetlands that are adapted to fluctuating water regimes. Where wetland seed banks remain intact and diverse, connectivity (with other wetlands and the terrestrial environment) is retained at a high level, and biodiversity values are high, it is possible that wetland organisms will be able to adapt to a changing climate. However, we know that seed banks are less diverse and responsive after cropping, and consequently that cropping wetlands impacts on their capacity to provide landscape-level linkages. If an agronomist were asked to suggest the best way to permanently incorporate a wetland into a cropping program they would suggest that continuation of cropping is likely to remove all competing (native wetland) vegetation, and provide a good area to crop in the long term, in the absence of inundation. We can say with some confidence that the more you crop a wetland, the less likely it is to recover, or at best, the longer it will take to recover.

It is possible that some wetlands will be able to 'self-restore' following cessation of cropping, but the only conclusion that is possible at the moment is that we do not have enough information either from Australia or from overseas studies to be able to determine the probability of recovery, or even to what extent they can recover. Given the large number of wetlands that are currently cropped in the Victorian landscape, if we want to maintain their values and services, there is a real need to investigate the recovery potential of cropped wetlands, and how best to restore them.

4.6. Predictors of wetland vulnerability at the landscape scale

Wetland vulnerability to cropping can be assessed in relation to surrounding land use and soil type, attributes of the wetland, and the attitude and motivation of the land manager.

Relationship between cropping in wetlands and wetland size

The relationship between the incidence of cropping and wetland size was determined for the group of 453 sample wetlands in the South East Grampians cluster (Figure 31). This indicated that small wetlands were more likely to be cropped than those with a large surface area.

The data is displayed as a cumulative probability plot to highlight the differences in the incidence of cropping (uncropped versus full or part cropped) for wetlands in each size range. The most abundant wetland size range for each land use group is indicated by the steepest section of the curves. Wetland size has been shown as a log value to accommodate a small number of very large wetlands in the sample group.

Wetlands less than 5 ha ($10^{0.7}$) in area are more vulnerable to cropping than are larger wetlands. This is indicated by the divergence between the two curves for wetlands greater than 5 ha. Those wetlands with a

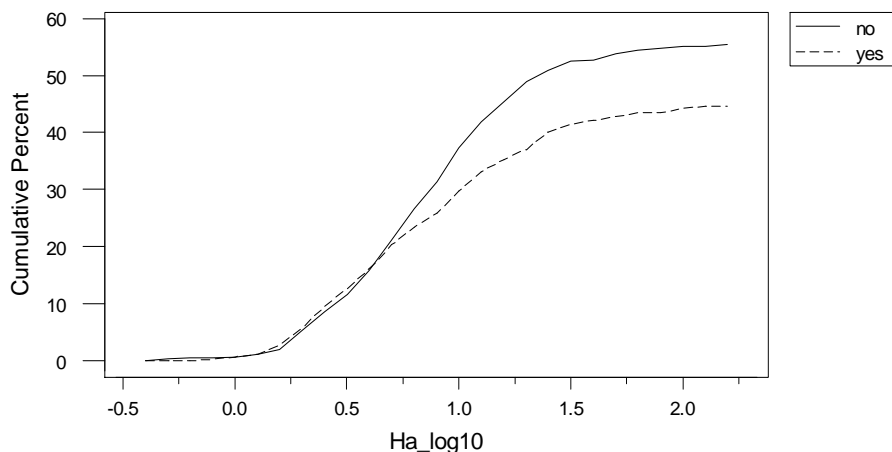


Figure 31. Cumulative probability curve for wetlands in the South East Grampians cluster, showing the effect of wetland size on cropping incidence. 'no' indicates not cropped, 'yes' indicates cropping occurs (fully cropped, cropped at the edge and/or cropped at the edge and on the bed).

surface area of less than 5 ha have an equal likelihood of being cropped or uncropped. These smaller sized wetlands account for 40 % (i.e. 20 % cropped + 20 % uncropped) of the sample group.

The two curves diverge from each other with increasing wetland size over the range from 5 to 30 ha. ($10^{0.7}$ to $10^{1.5}$). There is a trend towards decreased cropping with increasing size for wetlands within this size range. Wetlands in the 5 to 30 ha size range account for 50 % of the number of wetlands in the sample group. The maximum values for each curve shows that overall 55 % of the sampled wetlands were uncropped and that 45 % were either partly or fully cropped. All wetlands in this sample were less than 316 ha in area ($10^{2.5}$) and only a small proportion of all wetlands were greater than 30 ha ($10^{1.5}$) in size.

When the cropped wetlands in the group of 453 evaluated wetlands were considered separately in the three component cropping categories (fully cropped, edge, and edge and bed), it revealed that wetlands of 3–25 ha ($10^{0.6}$ – $10^{1.4}$) are more likely to be fully cropped than partly cropped (Figure 32). In this sample, wetlands larger than 25 ha are more likely to be partly cropped than fully cropped. Overall, the cropping category of ‘edge and bed’ is less common than is ‘full’ or ‘edge only’ cropping. However, the curve for ‘edge and bed’ continues to increase at wetland sizes greater than 25 ha, indicating that this type of cropping occurs across all but the smallest wetlands. Larger wetlands are more likely to occur across land title and paddock boundaries than smaller wetlands, and this ‘edge and bed’ cropping activity on larger

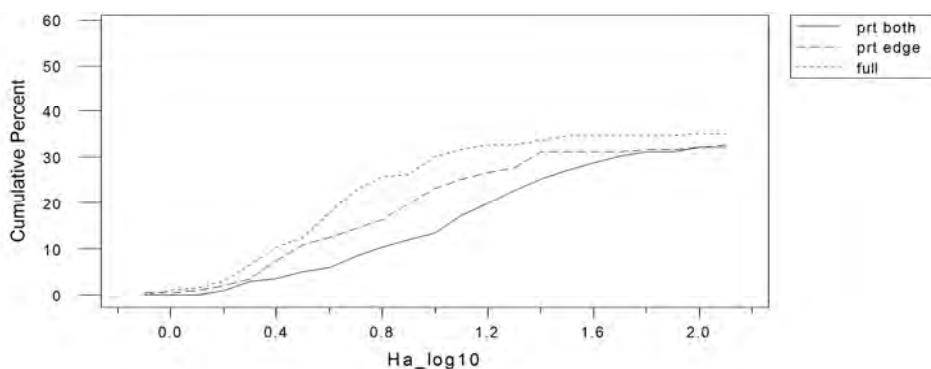


Figure 32. Cumulative probability curve for wetlands in the South East Grampians cluster: ‘prt both’ indicates cropped at the edge and on the bed, ‘prt edge’ indicates cropping occurs at the edge, ‘full’ indicates wetlands that are fully cropped.

wetlands is likely to be a reflection of contrasting land management decisions for adjacent paddocks.

Relationship between cropping in wetlands and cropping in adjoining land

Wetlands are unlikely to be cropped unless there is an adjacent crop. The sample of 453 wetlands in the South East Grampians cluster showed that only 2 % of wetlands with no adjacent crop were assessed as being cropped, versus the presence of cropping on 57 % of wetlands with adjacent crop (Table 25).

Table 25. Wetland cropping status in relation to the presence and absence of cropping in an adjacent area. Wetland cropping occurs more frequently where there is adjacent cropping.

Wetland cropping category	Adjacent dryland crop	
	absent	present
No cropping	102	149
Partly cropped (edge)	1	65
Partly cropped (edge and bed)	0	65
Fully cropped	1	70

This data can inform the degree of risk of cropping faced by wetlands that are not currently cropped. For example, the 149 wetlands that are not currently cropped (Table 25), but which have cropping adjacent to

them, face a higher future risk of being cropped than do the 102 wetlands without adjacent crop. Further, an evaluation of those 149 wetlands shows that almost half of them (49 %) fall into the ‘temporary fresh’ wetland type, and that 41 % of the remaining wetlands have not yet been classified (‘unknown’: Table 26). The subgroup that is exposed to the highest potential impact includes 37 of these wetlands (freshwater or unknown) that are less than 5 ha in area.

Table 26. Segregation of the 149 uncropped wetlands with adjacent cropping from the SE Grampians cluster sample (from Table 25). The potential cropping risk of these wetlands can be informed by their size classes and hydrological characteristics.

Wetland size	Temporary freshwater marshes and meadows	Unknown	Other
< 5 ha	16	21	5
5 – 10 ha	21	19	4
10 – 20 ha	19	11	4
> 20 ha	12	10	7

Within the South East Grampians cluster, small, fresh, temporary, uncropped wetlands with crop nearby are at the highest risk from cropping. Identifying wetlands of high conservation significance in the South East Grampians cluster will require:

- documenting which ones have already been cropped
- determining the saline/freshwater and permanent/temporary status of the approximately 950 “unknown” wetlands on private property; and
- identifying which of the small uncropped freshwater temporary wetlands have crop near them (representing the highest risk).

4.7. Climate change and wetland water regime

The frequency of wetland filling and inundation in isolated temporary wetlands in Victoria is dependent on annual rainfall patterns (Casanova and Powling 2014). This is important for the processes and functioning of wetland ecosystems. Water regime (seasonality, depth, frequency and duration of drying) is also a major determinant of the degree of risk that wetlands face from cropping. Therefore, future changes in the local climate will have a large impact on both the biology and the risk faced by these wetlands.

Climate change is predicted to have a deleterious effect on wetland water regime and salinity in southern Australia (Nielsen and Brock 2009). Permanent and seasonal rainfed wetland types are included in the most vulnerable category for the south west and north west of Victoria (DEPI 2013b). The consequences, even without additional impacts from landuse change (WatLUC 2002) are expected to be a loss of some temporary wetland types (ephemeral wetlands), shifting species distributions and species extinctions, and increased salinisation (Nielsen and Brock 2009). There is strong evidence that there has been a decline in the precipitation/evaporation ratio in southern Victoria since the mid 1800s, which has led to a long term decline in the water level in Maar lakes (Jones et al. 2001). Human activity was not responsible for this early decline (Jones et al. 2001).

The time scale over which emerging trends are likely to dominate seasonal variability needs to be considered. Climate model predictions for western Victoria show that the influence of variation in seasonal rainfall patterns is likely to outweigh a declining trend in average winter and spring rainfall until after 2030 (CSIRO 2016b). Evaporation rates also affect soil moisture regimes. From now until 2030 there is also projected to be an increase in temperature of between 0.4 and 1.1 °C for western and north western Victoria.

The impact of likely climate change on cropping has also been evaluated for Victoria (DEPI 2013b). The Great Dividing Range can be seen as a dividing line for likely effects, where Wimmera-Mallee grain yields are expected to decrease by an average of 10-20 % by 2050. Conversely, yields for south west Victoria are

projected to increase by 10-20 % and to hold until 2070 (DEPI 2013b). There is a high confidence of a decrease in the incidence of frosts, which currently is a risk to crops in wetlands, as cold air pools in lower positions in the landscape. There is also the possibility that there could be a sudden decrease in rainfall, as this has happened in the past (DEPI 2013b). The impact of climate change on crop yields will influence the degree of agricultural intensification at a regional scale. It can be expected that the current centres of crop production will shift, in the future, to those areas that emerge as having more reliable crop yields. This directly relates to an increased degree of risk that cropping poses to wetlands where there is a geographical overlap between cropping and wetlands.

4.7.1. Current limit of cropping

Cropping currently occurs widely throughout western Victoria. It does not appear to be limited towards the north of the state, but is limited to the south by landscape attributes and alternate, more profitable enterprises. There was a rapid change in the southern extent of cropping in the early 2000s in recent dry years, and through the innovation of raised bed cropping which reduced waterlogging as a soil constraint (especially towards Winchelsea).

The southern limit to cropping currently occurs across Western Victoria from north of the Otways near Moriac, north of Lake Colac near the Corangamite wetland cluster, to the southern edge of the South East Grampians wetland cluster near Mortlake (Figure 33). Further westwards, the incidence of cropping then decreases as a proportion of land use with isolated fields only detected towards Branxholme. Where grazing is the alternative enterprise in the south, cropping is typically observed to peter out over a scale of 10 km unless there were impediments such as stony rises. A more abrupt line is seen where cropping gives way to intensive dairying.

Economic returns from alternative enterprises are likely to account for part of the current southern limit to cropping. Climate change *per se* (higher temperatures and more evaporation leading to drier wetlands) might not influence the southward migration of cropping enterprises in this region as much as change in the profitability of dairying and forestry. Cropping could become a viable land use in the Bessiebelle and Mt Gambier regions of high wetland density if it can provide a better return on capital than current alternatives. At present the greatest intensification of cropping is occurring within existing cropping areas. This places wetland areas that are not currently cropped at risk of cropping in those regions.

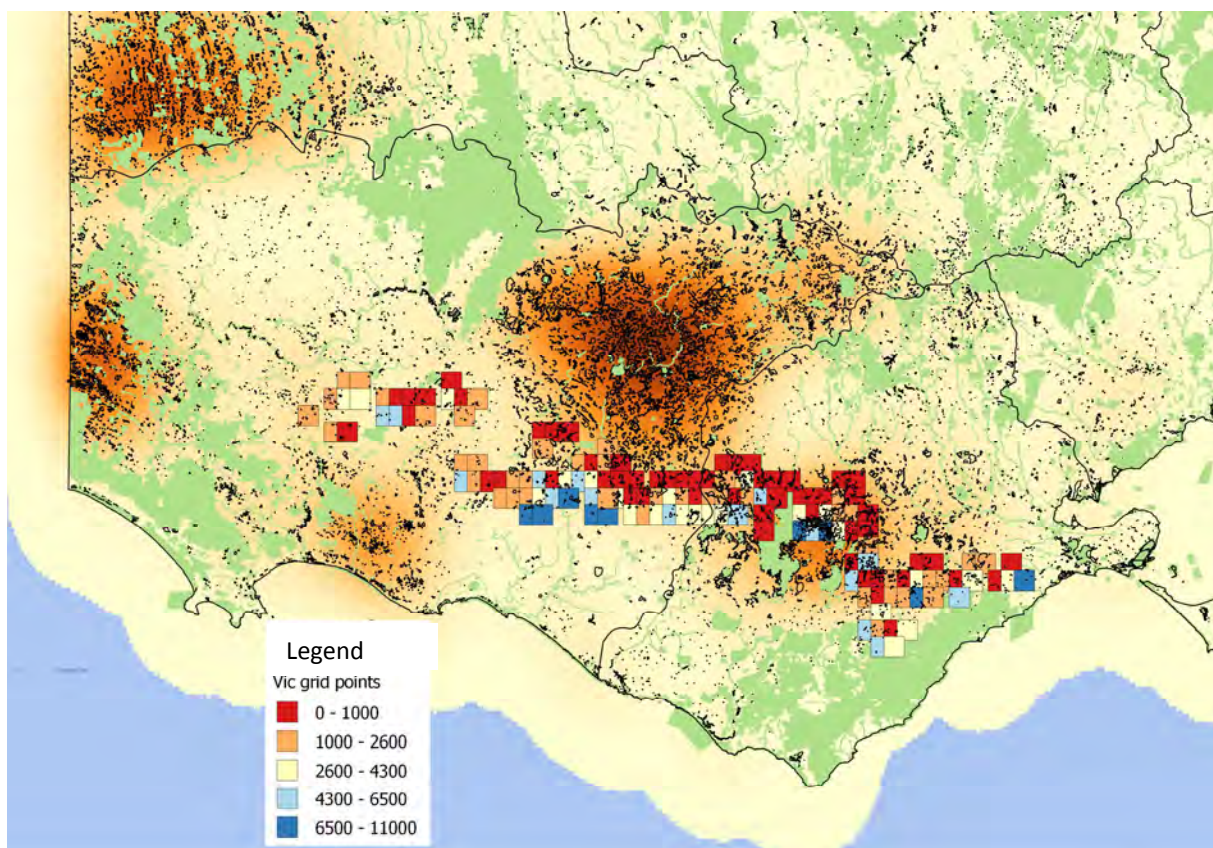


Figure 33. Map of the southern limit to cropping in western Victoria imposed on the 'heat-map' of wetland density. The colour of each square indicates the distance (in metres) from the centre of the square to the nearest crop. Incidence of cropping declines markedly to the west.

5. Guidelines for natural resource managers

Temporary wetlands at risk of cropping are ‘rainforests in miniature’ in relation to their diversity of components and processes. Although the wetlands currently being impacted have a degree of resilience to disturbance, repeated cropping is likely to reduce condition and values, so that the wetlands affected will provide economic values at the expense of their ecological, social and cultural values.

The recent increase in the rate of conversion of wetlands to cropping land is a more immediate risk to wetlands than is climate change, although the latter is likely to impact on their attributes and processes in the long run.

5.1. Management options

There are three approaches for Victorian natural resource management (NRM) agencies to achieve “*wetlands that are healthy and well-managed, supporting environmental, social, cultural and economic values*” in relation to the impacts of cropping in temporary wetlands.

The first would be to do nothing. There is a high likelihood that some wetlands would be retained in the landscape through the actions of Landcare groups and concerned individuals, but the overall landscape mosaic would be fragmented, and hence its capacity to support landscape level attributes and processes (e.g. Brolga populations, migratory birds) would be reduced. Endemic, rare and endangered species (e.g. Appendix D) would become rarer and more endangered, and extinction is highly likely. Temporary wetlands would become ‘low-lying areas’ that flood in very wet years, imposing economic loss on farmers. Their biodiversity and processes would be negatively affected by cropping.

A second approach is to enforce current regulations and implement incentives to conserve what remains. Because the potential impacts on these wetlands are incremental and persistent, conservation efforts in the face of these would have to be observant, pervasive and persistent. Retaining wetlands as natural providers of ecosystem services is a far cheaper and more effective option than trying to provide such services through man-made infrastructure (EDO 2012), or restoring wetlands to landscapes where they have been lost (Pfeifer-Meister et al. 2012, Peh et al. 2014).

A third approach would be to seek to restore wetlands, and the wetland mosaics that have already been impacted. Even where wetlands are dense in the landscape, they occupy a small proportion of available land. Integration of conservation and farming is possible, and should be promoted.

The current NRM framework of program delivery through CMAs and Landcare could (continue to) be an effective one for improving wetland conservation and managing risk. Strategic conservation and restoration using an adaptive management approach (*sensu* Zedler 2003), targeting groups of wetlands in crop production areas, could help to retain their values.

5.2. Management objectives

With reference to individual wetland sites there are two potential objectives: management of unimpacted sites (conservation of the current condition and values) and management of impacted sites (development of restoration strategies). Management of individual wetland sites must engage the landowner, through provision of reward or compensation, and through disincentives for destruction (‘carrot and stick’).

5.2.1. Constraints

Management should also aspire to restore the landscape mosaic of wetlands to retain landscape level processes and values. However, there are constraints on implementation of these aspirational objectives.

Land ownership

The overwhelming majority of these systems are on private land, and although protected in legislation (e.g. clearing of native vegetation, EPBC Act), are often subject to the management of a community that aims to maximise economic returns, at the potential expense of wetland condition and values.

Distribution

An additional challenge is the dispersed nature of temporary wetlands. They occur sporadically across specific landscapes, and are under the management of many individual landowners. Many are 'out-of-sight' and their change in condition can be hard to detect.

Funding availability

Implementation of a reward or stewardship program would only be successful on a large scale if compensation matched the potential return obtained from cropping. Currently economic gross margins for cropping in wetlands range from \$400-\$1400 per ha per year. Analysis of the magnitude of acceptable payment for wetland conservation, and how that is affected by landowner attitudes, planning and perception of wetland values is required (e.g. Yu and Belcher 2011).

Knowledge and communication

A more direct link between wetland condition and values, and farmer profitability and quality of life (the benefits of having a wetland on their farm) would make conservation more highly valued by farmers. An understanding of wetland food webs (e.g. do they just become home for mosquitos when they are cropped?) would assist with delivery of a conservation message.

The current mechanisms for delivery of information used by NRM professionals are not always effective with farmers. The timing, venues and method of delivery need to focus on when and where farmers obtain information.

5.2.2. Guidelines

The current guidelines for wetland conservation in an agricultural landscape are likely to be adequate for wetlands that have not been impacted by cropping (e.g. Wetland Tender guidelines, Wetland Grazing Guidelines: DELWP 2015). Privately owned temporary wetlands have existed in the presence of grazing and weeds for around 150 years and many still retain significant condition and values. More conservative grazing management and active weed control will enhance their provision of values into the future. Specifically:

- recognise wetlands when they are dry, and minimise agricultural impacts during that hydrological phase
- provide a buffer between crops and wetlands. This is likely to reduce the potential impact of cropping activities (i.e. sedimentation, biocide contamination)
- identify and preserve the linkages and pathways among wetlands. This is likely to assist in retaining their connectivity
- fencing is unlikely to be needed if the surrounding land use is cropping, but appropriate fencing could assist with implementation of grazing as a weed and biomass control strategy
- wetlands that are currently impacted by cropping should be assessed and prioritised in relation to the degree to which they are likely to recover and the amount of intervention that might be required. Results of a trial currently underway at Scale Swamp (Glenelg Nature Trust and Dunkeld Pastoral Co.) will be useful in informing the potential for recovery
- restoration of disrupted hydrology should be undertaken where possible. Climate change impacts (largely warming with concurrent increase in evaporation) are likely to have less impact than future variability in rainfall (to 2030)
- sites should be assessed in relation to the capacity of the seed bank to provide all the required elements for recovery; and
- active transplantation of seed banks, planting of structural vegetation and removal of weeds might be needed for restoration.

The most efficient management will be to prevent remaining wetland areas from being cropped.

5.3. Management actions

The analysis of land management decisions made by farmers (Section 3.2.1) reveals that the choice to crop wetlands is based on both economic and social drivers, and these drivers could be targeted to reduce the risk of cropping in wetlands.

5.3.1. Targeting economic drivers

Given that the main driver of cropping in wetlands is economic, providing a commensurate economic gain for **not** cropping in wetlands is likely to assist in their protection.

One of the important economic drivers is the real probability of crop failure if a wet year occurs. A newly emerging strategy to reduce the economic impact of crop failure is 'multi-peril crop insurance'. If farmers insure crops against loss due to waterlogging this reduces the likelihood of economic loss from cropping in wetlands. Multi-peril crop insurance is seen as having a major negative impact on wetland conservation in the USA (Cox and Rundquist 2013). If possible, legislation should be enacted to prevent insurance against waterlogging when crops are sown in wetlands.

5.3.2. Targeting social drivers

A comparison of the public profiles of Edenhope (in the vicinity of West Wimmera wetlands: <http://www.westwimmera.vic.gov.au/Discover/Edenhope>) and Lake Bolac (in the vicinity of South East Grampians wetlands: <http://www.travelvictoria.com.au/lakebolac/>) reveals that the Edenhope community embraces the presence of wetlands in their landscape, and Lake Bolac community ignores them (with the exception of the Beyond Bolac Catchment Action Group, which is a Landcare group).

Social drivers that could be used to reduce cropping in wetlands are:

- Education (What is a wetland? Why are they important?) aimed at increasing the intellectual 'ownership' of wetland values among farmers, and creating a social norm for conserving wetlands. As farming becomes increasingly outsourced many cropping farmers engage contractors to spray, cultivate and sow their cropping land. Contractors might not be well-informed about the existence or value of wetlands in the landscape, or the potential legal implications of disturbing listed wetlands. This group of people could be targeted for education, as they are the ones behind the steering wheel, following the GPS. In an ideal world a more informed group of contractors could be encouraged to avoid cropping wetland areas.
- Targeted engagement of landowners to develop positive conservation outcomes (e.g. Kalcic et al. 2015). Venues for engagement are CFA meetings and agricultural extension field days and activities that farmers choose to attend for other reasons (e.g. sport). There have been attempts to get farmers to attend specific wetland field days, but these are rarely successful at drawing crowds of 'non-believers'. Farmers attend events that are likely to enhance their economic outcomes. As well, farmers will come in large numbers to meetings when they feel their freedoms, or economic viability are at stake. With the current consolidation of farm ownership, there are fewer farmers that need to be engaged. There are areas of Victoria where significant numbers of wetlands are in the ownership of a few individuals. Engaging with those individuals could be a good strategy for both implementation and communication about the value of wetlands.
- Many wetlands that are currently and likely to be cropped conform to the definition of 'Seasonal Herbaceous Wetlands of the Lowland Plains', which was listed as a critically endangered wetland community (EPBC Act 1999) in 2012. Although the legislation provides for punitive measures against landowners that do not seek a referral before damaging or removing resources from a listed community, there has been no obvious prosecution of landowners in relation to these wetlands to date. Implementation of the punitive measures with good publicity could be used to inform the community about the wetland values and the consequences of cropping them.

5.3.3. Time frames

These strategies have varying time frames. Enforcement of restrictions under the FFG Act and EPBC Act could be initiated immediately given sufficient resources. Again, given sufficient resources, targeted

education programs could be implemented. There are tender programs and stewardship programs that have already been implemented, although broadacre farmers rarely participate in them. If such programs provided attractive, commensurate remuneration they could be more successful in conserving wetlands. Changing social norms and perceptions is a long-term project. However, the current rate of wetland cropping lends a degree of immediacy to implementation of education and engagement programs.

5.4. Prioritisation in the landscape

There are a number of important considerations for prioritising wetlands for conservation and / or restoration in the landscape. Wetlands considered a high priority include:

- Those areas of high temporary wetland density, in cropping landscapes (West Wimmera, South East Grampians and Corangamite regions). Noting that the Mt Gambier and Bessiebelle clusters would be at risk in a warmer climate and should also be considered a priority.
- Within clusters, wetland mosaics with clear connectivity and low levels of impact. Provision of maps of wetland connectivity would enhance NRM managers capacity to prioritise wetlands of high conservation value.
- Within mosaics, wetlands that provide connectivity among areas of high conservation value or unimpacted wetlands.
- In a social context, individual landowners with large numbers of wetlands, who are also community leaders, could be targeted for implementation of stewardship programs.

6. Conclusions and recommendations

This report shows that wetlands at risk of cropping have significant values and provide important services to the people of Victoria. Despite the fact that the wetlands are not permanently wet features of the landscape, when conditions allow, they can undergo a boom in productivity and biodiversity that supports landscape-level biodiversity values.

Temporary wetlands in the agricultural landscape have not been highly valued in the past. Despite that perception temporary wetlands were often not highly modified (except for grazing), due to the economic risk of crop loss and technical impediments. During the recent long-term droughts, temporary wetlands have filled less frequently and are currently perceived as potential cropland by farmers. Technical impediments are being reduced all the time via research into biocides and innovations in cropping machinery. Cropping has increased in Victoria over the past two decades, and is likely to occupy more 'marginal' lands (including wetlands) if it remains an economically viable land use.

Farmers choose to crop wetlands for economic and personal reasons, and there are few social or financial impediments to cropping wetlands. Cropping poses a significant risk to wetland condition and values. It has been shown to reduce seed bank diversity and density of seedlings, it can alter invertebrate communities and remove vertebrate refuges and it reduces environmental heterogeneity in landscapes.

Wetlands suitable for cropping in the Mallee, north Wimmera and North Central regions have already been largely altered or removed by cropping (Consultation, Appendix A), so workers in those regions did not generally perceive cropping as a risk. The current increase in cropping in the west Wimmera and Glenelg-Hopkins regions puts the abundant wetlands there at immediate and future risk. This will be exacerbated by the predicted change to a warmer climate.

6.1. Future projects to improve knowledge

This literature review has revealed many knowledge gaps. Further research is needed into the immediate and longer-term consequences of cropping on the resilience and functioning of temporary wetlands. Immediate research needs include:

- determination of the overall consequences and recovery trajectory for Victorian wetlands subject to cropping
- determination of whether there is a radical change when wetlands are cropped for the first time
- determination of how long the effects of cropping last. Does frequency of filling change the consequences or recovery trajectory?
- investigation into the impact of cropping on the overall metabolism of wetlands i.e. does an essentially autotrophic system (dominated by primary producers) become heterotrophic (dominated by detritivores and consumers)? Does this have flow-on effects in the food chain?
- although wetlands are thought to retain carbon at higher levels than dryland soil this needs to be quantified for temporary wetlands at risk of cropping. If wetlands prove to be a good carbon sink this could engage other (carbon-farming) programs for wetland conservation. More research is needed to quantify the value of wetlands at risk of cropping for carbon sequestration, and how that might be affected by cropping, water regime and other management activities
- develop guidelines for retaining connectivity and functioning in a wetland mosaic at appropriate landscape scales The guidelines should consider whether a high density of wetlands in some regions means some wetlands can be 'sacrificed' and while retaining landscape-level connectivity; and
- Investigations of tillage and weed management protocols to identify best practices for wetlands.



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Appendix A: Consultation

Summary

Aims

The aim of consultation was to answer the following questions:

- How widespread is the current and potential impact of cropping on wetlands?
- What is the perception of the extent and consequences?
- What impacts occur during cropping?
- What are the future risks in relation to predictions of land use and climate change?

We also aimed to

- Identify future vulnerable wetlands/areas, and
- Identify potential case-studies that would illustrate the main issues.

Methods

Respondents were identified via an extensive network of farmers, environmentalists, managers and conservationists, as well as through contact with CMAs, Landcare and farmer organizations. The list is comprehensive, but not exhaustive, there is always someone else to talk to. Thirty-seven people were interviewed for this study. The respondents were engaged in conversation face-to-face, or by telephone or email. Conversations were structured around the following questions

1. What is your perception about the current incidence of cropping in swamps?
2. Have you seen a change in the incidence of cropping in swamps? Is it increasing or decreasing?
3. What do you think the consequences of cropping in swamps might be? Why does it matter?

Usually conversations were wide-ranging, and more information was obtained than was asked for.

The recipient's region or area of knowledge was also identified, and their contact details obtained for follow-up consultation and communication in the future (i.e. dissemination of the results of the study).

Most interviewees expressed a desire to be informed about the outcome of the study.

Results

The majority of interviewees were familiar with the Glenelg-Hopkins, Wimmera, North Central and Corangamite regions (Table A1). There was less representation from other regions in Victoria. The majority of interviewees said that cropping was occurring in wetlands, and that it was increasing. There were no reports of increased cropping in wetlands in Gippsland, Port Phillip and Westernport or the North East regions. Interviewees from outside Victoria were mostly wetland scientists with knowledge of wetland processes and functioning. Not all interviewees answered all the questions directly, and some interviewees were familiar with more than one area of Victoria (so are counted in multiple rows).

Table A1. Region of recipient and incidence of cropping. 'Region' refers to the region discussed by the interviewee, rather than their physical location.

Region	Number of recipients	Wetland cropping absent	Wetland cropping present	Wetland cropping increasing	Wetland cropping decreasing
Corangamite	5		4	5	
East Gippsland	1	1			
Glenelg Hopkins	11	1 (off basalt), 1 (hills)	7	6	2 (urban interviewees)
Goulburn-Broken	3		2	1	
Mallee	2	1		1	
North Central	5		4	3	
North East	1	1	1 (near Rutherglen)		
Port Phillip & Westernport	1	1			
West Gippsland	1	1			
Wimmera	3	2	2	3	
Outside Victoria	4	1	2	2	1
Total	37	10	22	21	3

What is the incidence of cropping in wetlands?

Cropping was identified as a common land use in Corangamite, Glenelg-Hopkins, Goulburn-Broken, Mallee, North Central CMA regions. This is supported by each of the CMA's Regional Catchment Strategy documents. The recipients gave a general estimate of the incidence of cropping in wetlands in their local areas (Table A2). This indicates that cropping in wetlands is perceived as most prevalent in the Glenelg-Hopkins region, with occurrences in all other regions known to the recipients, except the Mallee (in that case the assessment was that wetlands were saline and not suitable for cropping).

Table A2. Perceived incidence of cropping in wetlands by region.

CMA region	Cropping not happening	Cropping is happening	Cropping is widespread
Corangamite		2	
Glenelg-Hopkins		3	6
Goulburn-Broken		1	1
Mallee	1		2
Wimmera		2	
Interstate			

Is there a change in cropping in wetlands?

The recipients were asked to assess whether there was more or less cropping in wetlands now in their region. Cropping in wetlands was perceived to be increasing in all the regions where it was occurring (Table A3). Where cropping in wetlands was thought of as slowing or low it was due to the perception that all the suitable wetlands had been cropped (Corangamite, Murraylands in South Australia). It was notable that in

the Glenelg-Hopkins region farmers assessed the incidence was not only ‘lots and lots of wetlands cropped’, but also that it was increasing due to land-ownership change and economic imperatives.

Table A3. Perceived incidence of the change in cropping in wetlands by region.

CMA region	Increasing	Stable	Slowing/low
Corangamite	2		1
Glenelg-Hopkins	6	1	1
Goulburn-Broken	1	1	
Wimmera	1		1
Interstate	1		1

What are the consequences of cropping?

In some cases the recipients were informed and informative about the potential consequences of cropping in wetlands.

Table A4. Perceptions of the consequences of cropping in wetlands.

CMA region	Depends how it is done	Habitat/biodiversity loss
Corangamite		2
Glenelg-Hopkins		6
Goulburn-Broken		1
Wimmera	1	
Interstate		1

Negative consequences of cropping

Issues that were identified were:

- Overall loss of wetland habitat in the landscape
- A loss of soil structure with cultivation (particularly with addition of gypsum)
- A loss of biodiversity with chemical application
- Loss of disturbance-intolerant species, and fertiliser-intolerant species
- A potential ‘step-change’ from functioning wetland, to a reduction in function after the first cultivation
- Negative impact on the seed bank
- Removal of vertebrate refuges (cracks in soil)
- Fewer local and migratory wetland birds
- Introduction of weed/undesirable species
- Reduction in landscape-level connectivity
- Change in trophic web/loss of trophic levels, simplification of system
- Potential loss of aquifer recharge
- “Hardening” of edges between land uses
- Loss of ecosystem services during the dry phase (e.g. animal habitat/terrestrial food web)
- Loss of carbon storage

Positive impacts of cropping

In some cases interviewees identified positive consequences of cropping (usually to the farmer)

- Farmers might have more money (from cropping) for environmental land management
- Reduction in liver-fluke
- Less soil compaction from livestock in the landscape
- Less grazing on swamps that aren't cropped
- Increased justification for investment in restoration
- Fewer problems with *Lachnagrostis filiformis* (Blown Grass)
- Increased average property value
- More flexibility with agricultural enterprises

Awareness of wetland land use

The reliability of perceptions of the recipients varied depending on their exposure to the rural environment and their income-source (i.e. either farmer, or a salaried employee of an organisation). Salaried employees were generally less likely to be familiar with the issues, usually due to geographic remoteness.

Table A5. Awareness of land use and issues in relation to income source.

Regional familiarity	Farmer	Salary
High	10	12
Medium	3	2
Low		9

Drivers of cropping

Recipients sometimes gave an assessment of why cropping might take place in wetlands:

- A spontaneous decision (spur-of-the-moment)
- An economic decision (need for profit/viability/debt payment)
- Change in landownership, with new owners unable to identify wetlands when dry
- Unquantified/poorly justified reasons not to crop
- Run of dry seasons
- Large cropping machinery can cope with wet soils
- Peer encouragement and competition, provision of advice on how to deal with waterlogged soils
- Development of raised beds
- Improved 'crop hygiene' (removal of untidy edges or harbours for pests)
- Disconnect between the farmer and the biology of the land (alienation)

Potential solutions

Recipients sometimes spoke about potential solutions to the problem of cropping in wetlands:

- Long-term funding from CMAs to protect wetlands
- Council rate rebates for wetland areas
- Incentive programs

Discussion

The aim of the consultation was to assist in determination of how widespread is the current and potential impact of cropping on wetlands, the perception of the extent and consequences, the impacts that occur during cropping, the future risks in relation to predictions of land use and climate change, and to identify future vulnerable wetlands/areas, and identify potential case-studies that would illustrate the main issues.

The information obtained has informed the initial mapping exercise, and has allowed a more focused assessment of regional incidence of cropping in wetlands. A lot of the information that was obtained from recipients was also obtained from personal experience, observations, use of GIS and reference to the scientific literature in this report. The additional value of consultation was assistance in determination of some of the drivers of cropping in wetlands, and some of the potential impacts (e.g. a step-change in wetland condition).

The information gathered in this consultation was used throughout the report.

Appendix B: Chemicals

A number of chemical pesticides are used in modern crop agriculture (Table B1). These are regularly recommended to farmers by agricultural advisors and suppliers. Temporary wetlands are not usually wet when being cropped so farmers might not identify hazards associated with application to wetlands and waterways as being relevant at the time of land-preparation or during crop-growth. Some of these chemicals are highlighted in the table and referred to in more detail in the following text.

Chemical registration for agriculture follows a tightly prescribed procedure in Australia. Each agricultural biocide has two information documents that are freely available to assist with their appropriate use. One is the product label, which define the conditions for use, including which crop can be sprayed, which weeds, appropriate weather conditions, application methods, and safety details. The other document is the material safety data sheet (MSDS), which includes a section on ecological considerations. Product approval requires that health and environmental impacts have been measured. Results from these tests are generally not publicly available.

The large number of herbicides that are registered for use are grouped according to their biochemical mode of action. These can range from general cell growth disruptors to inhibitors of highly specific enzymes used in amino acid synthesis. The letters A to M used to designate these herbicide groups (Chambers and Dean 2004). Agricultural herbicides are often described according to the stage of the crop cycle in which they are used.

- **Knock-down herbicides** allow all standing vegetation to be killed, but do not remain active in the soil for long periods (sometimes they denature in a matter of minutes).
- **Pre-emergent residual herbicides** allow non-crop plants to be killed by disrupting plant establishment, and remain active in the soil for weeks or months.
- **Post-emergent selective herbicides** target biochemical pathways in particular classes of plants (e.g. dicots vs monocots, specific species), and can have residual effects (days or weeks).

Seed treatments are applied as a coating on the grain before sowing.

Prosulfocarb + Metolachlor (herbicide groups J + K)

This chemical was introduced to Australia in about 2007 (See page 28 of 13926-prs-prosulfocarb.pdf for aquatic toxicity testing results: Aus. Pest & Vet. Chem. Dec 2007).

Contamination of a shallow (15 cm deep), static waterbody with direct overspray at the maximum application rate of 2000 g prosulfocarb/ha is calculated to give a notional concentration in the water of 1.3 mg ac/L. Based on the relevant ecotoxicity endpoints, acute risks from a direct overspray to sensitive aquatic species tested were unacceptable.

With a 10 % spray drift, the acute risk of prosulfocarb to daphnia, diatoms and duckweed can be mitigated, but it is unacceptable for daphnia from chronic exposure, and for acute toxicity to alga. A further refinement of risk to alga and daphnia from spray drift of prosulfocarb and its sulphoxide metabolite is possible from use of the more realistic Ganzelmeier spray drift values from ground application. This shows that a buffer distance is considered unnecessary based on the likely extent of spray drift for both acute and chronic exposures.

Because prosulfocarb is expected to show low to medium mobility in the environment, there is a potential for prosulfocarbs to enter aquatic habitats in water as a result of their presence in the runoff from treated land. A simple model of such runoff indicates unacceptable risk to alga and daphnia for acute and chronic exposure, respectively. Mitigation of this risk, based on a more realistic runoff scenario and one cycle of adsorption of prosulfocarb to the soil, shows that aquatic risk from runoff from the proposed use patterns is expected to be acceptable. Risk to groundwater is not anticipated from the proposed use patterns.

Pyroxasulfone (herbicide group K)

This chemical was introduced to Australia about 2011.

Very toxic to aquatic life. DO NOT contaminate wetlands or watercourses with this product or its used containers.

Atrazine (herbicide group C)

Atrazine is a pre-emergent herbicide that is commonly used in broadacre crops such as canola and lupins in Victoria. It is used to control both monocot and dicot weeds. A review was held in 2008 to reconsider its approval for use in Australia, especially in terms of potential adverse health and environmental impacts (APVMA 2008). The final review report and regulatory decision included the following text that is relevant to vulnerable wetlands:

Extract page xiv of volume 1.

“ At this stage the APVMA cannot conclude that the use of atrazine on TT canola, when applied post-emergence to raised beds, would not be likely to have an unintended harmful effect on the environment. However, evidence to date on this issue is very limited. Therefore the APVMA has determined that affected registrants will be provided with an opportunity to demonstrate that this potential problem is either non-existent or can be mitigated with enforceable amended label instructions. It is anticipated that it will require a further two cropping seasons for additional data to be generated and 12 months after that for the results to be evaluated and a regulatory position adopted.”

Extract page 7 of volume 1

“ Use of atrazine on Triazine Tolerant (TT) canola

As a result of feedback and further information provided in response to publication of the 2004 report, the DEWHA (Department of Environment, Water, Heritage and the Arts) has changed the proposed risk assessment finding in relation to the use of atrazine on raised beds, particularly in relation to TT canola. The issue of waterway contamination as a result of treatment of drainage lines was discussed in the 2004 report, where it was reported that: the pattern of atrazine contamination in Australian surface waters indicates that safety margins continue to be narrow in some areas [of] annual cropping. The key factor that determines the likelihood of aquatic contamination appears to be the vulnerability of the soil to surface runoff...A major risk factor in...annual cropping areas appears to be the treatment of ephemeral drainage lines. Ephemeral drainage lines should not be treated with atrazine, particularly if runoff events are likely to follow (pg 69). The use of atrazine on TT canola grown on raised beds was specifically highlighted, when it was reported that: there are potential future environmental concerns associated with use of atrazine on TT canola, particularly associated with raised bed cropping practices. Raised bed cropping is often employed in areas where soil tends to become waterlogged, thereby killing crops...Use on TT canola has substantially increased the amount of atrazine used in Australia, particularly in very wet areas. Because the primary problem with atrazine is its potential to run off and contaminate waterways, there are implications for greater ecosystem load of atrazine in these wet regions. “

Table B1. Examples of some of the chemicals commonly used in Broadacre cropping in Victoria.

Common name	Active ingredient	Chemical group	Part description of <i>PROTECTION OF WILDLIFE, FISH, CRUSTACEANS AND ENVIRONMENT</i> notice on product label
Knockdown herbicides			
Glyphosate CT	Glyphosate	M	DO NOT contaminate dams, rivers or streams with the product or used container. DO NOT apply to weeds growing in or over water. DO NOT spray across open bodies of water.
Sprayseed	paraquat and diquat	L	DO NOT contaminate streams, rivers or waterways with the chemical or used containers
Striker	Oxyfluorfen	G	This product is highly toxic to wildlife and fish. DO NOT contaminate lakes, ponds, streams, rivers or waterways
Surpass	2,4-D	I	DO NOT contaminate streams, rivers or waterways with the chemical or used container.
Pre-emergent residual herbicides			
Atradex WG	Atrazine	C	DO NOT contaminate streams, rivers or waterways with the chemical or used containers. This product is very highly toxic to algae and aquatic macrophytes. DO NOT apply this product within 60 m of natural or impounded lakes or dams. DO NOT use in channels or drains. DO NOT apply under meteorological conditions or from spraying equipment which could be expected to cause drift of this product or spray mix into adjacent areas, particularly wetlands, waterbodies or watercourses.
Avadex	Tri-Allate	J	Dangerous to fish. DO NOT contaminate dams, rivers or streams with Avadex® Xtra or used containers.
Boxer Gold	Prosulfocarb S-Metaclor	J, K	HIGHLY TOXIC TO AQUATIC ORGANISMS. DO NOT contaminate streams, rivers or waterways with the chemical or used containers. DO NOT apply under meteorological conditions or from spraying equipment which could be expected to cause spray to drift onto adjacent areas, particularly wetlands, waterbodies or watercourses.
Diuron 900DF	Diuron	C	DO NOT contaminate streams, rivers or waterways with the chemical or used container.
Rustler	Propyzamide	D	DO NOT contaminate streams, rivers or waterways with the chemical or used containers.
Sakura	Pyroxasulfone	K	Very toxic to aquatic life. DO NOT contaminate wetlands or watercourses with this product or used containers.
Simazine 900DF	Simazine	C	DO NOT contaminate dams, rivers or streams with herbicide or used containers.
TriflurX	Trifluralin	D	DO NOT contaminate streams, rivers or waterways with the chemical or used containers.
Post-emergent selective herbicides			
Eclipse	Metosulam	B	Avoid
Grasidim	Clethodim	A	DO NOT contaminate streams, rivers or waterways
Lonestar	Triasulfuron	B	Avoid
Lontrel	Clopyralid	I	Low toxicity
LVE Agritone	MCPA ester	I	Avoid
Tigrex	MCPA, Diflufenican	F, I	Avoid
Verdict	Haloxyfop	A	Avoid

Common name	Active ingredient	Chemical group	Part description of <i>PROTECTION OF WILDLIFE, FISH, CRUSTACEANS AND ENVIRONMENT</i> notice on product label
Insecticide			
Cosmos (seed treatment)	Fipronil	2B	DO NOT contaminate streams, rivers or waterways with the chemical or used containers. Toxic to galliform birds and related species. Highly toxic to fish and very highly toxic to aquatic invertebrates.
Ken-tac	Alph-cypermethrin	3A	Dangerous to fish and invertebrates
Fungicides			
Imapct	Flutriafol	C	DO NOT contaminate streams, rivers or waterways
Soprano	Epoxiconazole	3	Highly toxic to aquatic organisms. DO NOT apply SOPRANO aerially to waterbodies, watercourses or wetlands. DO NOT contaminate streams, rivers or waterways
Seed treatment (insecticide+fungicide)			
Baytan	Triadimenol, Triflumuron	3, 15A	Harmful to fish and aquatic arthropods. Do NOT contaminate dams, rivers, ponds, waterways or drains
Hombre Ultra	Imidacloprid, Tebuconazole	4A, 3	Do NOT contaminate ponds, waterways and drains with this product
Raxil Pro	Prothioconazole, Tebuconazole	3	Toxic to aquatic life. Do NOT contaminate streams, rivers or waterways
Malacocide (slug bait)			
Metarex	Metaldehyde		DO NOT contaminate streams, rivers or waterways with the chemical or used containers.

Appendix C. Historical increase in cropping

Cropping in wetlands has increased world-wide (Cox and Rundquist 2013), largely as a consequence of a widening gap between market returns for crops compared to grazing animals. Conversion of land to cropping has been occurring at a rate of 1–5.4 % annually in some states of the USA (Wright and Wimbley 2012), including conversion of wetland areas at a rate of 0.28–0.36 % annually (Johnston 2013). Although the rate seems low, cumulatively it represents a significant change to the use of wetland areas (Davidson 2014). World-wide more than 50 % of the area of digressional and other wetlands have been lost, mostly through conversion to agricultural use (Verhoeven and Setter 2010, Davidson 2014). The historical land use changes seen world-wide have been mirrored in Victoria, for similar reasons. Agriculture in Australia has developed from rapid expansion into easily occupied areas, followed, especially after the Second World War, onto more difficult soils through the development of new technologies (Donald, 1982).

Although Cattle are also raised in Victoria, and have, at times, been used for grazing (eating-down) the coarse vegetation that can grow in wetlands (Dow 1903), they have not been dealt with in detail in this review. Cropping and sheep have generally been seen as alternate enterprises in similar landscape and climate zones, and the land use in regions with wetlands at risk of cropping has alternated between these two main enterprises.

The rise and fall of sheep production:

Understanding the drivers of cropping and its alternative enterprises can inform the assessment of risk to wetlands, and identify long-term trends in land use.

The number of sheep in Victoria has followed a sequence of distinct phases since the 1880s (ABS 2016). In the first phase (until the end of the second world war) there was a general increase in the number of sheep per hectare. In the next phase numbers increased rapidly until the early 1970s, and this phase was driven by high wool prices, the increased use of superphosphate (which released the production potential of subterranean clover), plus the use of effective animal health products such as drenches for worm control. In the third phase (during the 1970s) there was a rapid decline in sheep numbers because of a decline in profitability due to the removal of subsidies on superphosphate (Figure C1). Other costs also rose steadily, and at the same time, the UK's entry into the European Union resulted in a drop in demand for wool exports (ABS 2016).

The most recent large rise in sheep numbers occurred during the 1980s, culminating in the collapse of the Wool Reserve Price Scheme. Since then wool prices have shown smaller fluctuations than in the past, while costs have gradually increased. Many farmers have adapted to declining wool profitability by switching to meat-sheep production. Despite this, the number of sheep in Victoria has halved over the period from the early 1990s to 2015, with no indication of a change in the trend (ABS 2016).

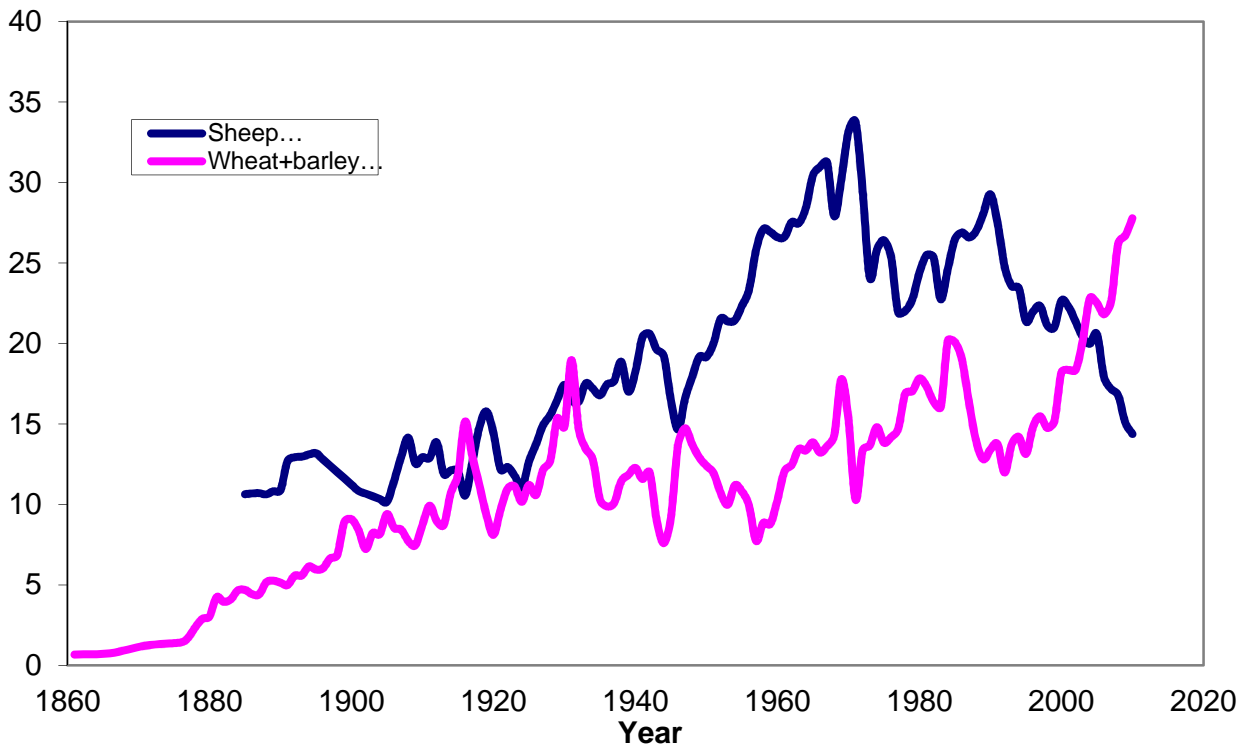


Figure C1. The number of sheep (millions) and the area of crop (wheat plus barley) ($\times 10^6$ ha) sown in Victoria over time (ABS 2016).

The rise and rise of crop production:

Ever since pastoral holdings in Victoria were opened up to closer settlement in the early 1890s the area sown to cereals in Victoria increased steadily (Figure C2), influenced by the expansion of the rail system. As an example of the speed of land use change in western Victoria, hundreds of farmers moved south from the Mallee and Wimmera to commence cropping on 250,000 acres south of Ararat over a five year period between 1902 and 1907 (Anon. 1937). This resulted in an expansion of small farms throughout the western district of Victoria. Farmers used trial and error to find the limits of areas suitable for growing crops, and undertook trials to crop on wetlands (Anon. 1915). During this period many wetlands that could be drained, were drained.

Soon after the 1900s crop yields declined due to exhaustion of the original soil fertility, especially depletion of phosphorus and nitrogen (Donald, 1982) and the amount of cropping did not increase substantially. By the 1930s subterranean clover had been introduced to Victoria, and a farming system had developed based on a rotation of cropping with a pasture (clover-rich) phase. This maintained animal grazing in the enterprise mix.

From the 1930s until the early 1990s the area cropped has tended to oscillate over a timescale of one to two decades (ABS 2016). Sheep numbers can decrease rapidly (Figure C1), but increase occurs more gradually, as a consequence of the biology of animal husbandry. In contrast, the area cropped can be increased rapidly when favourable prices and seasonal conditions occur, because only small amounts of seed are required for expansion.

From the early 1990s until the present day, continuous cropping of the same paddocks has become feasible in Victoria, allowing farmers to remove grazing from their system altogether. This is done by rotating the types of crop grown from year to year: cereals (wheat, barley and oats) are alternated with a 'break crop' such as canola or a legume. This system is dependent on the use of herbicides and fungicides for weed and disease control, on using specific fertilisers to overcome nutrient deficiencies, and on accessing appropriate agronomic advice. The widespread availability of nitrogenous fertilisers such as urea and mono- and di-ammonium phosphate (MAP, DAP) have eliminated the need for a clover based pasture phase to replenish soil nitrogen reserves.

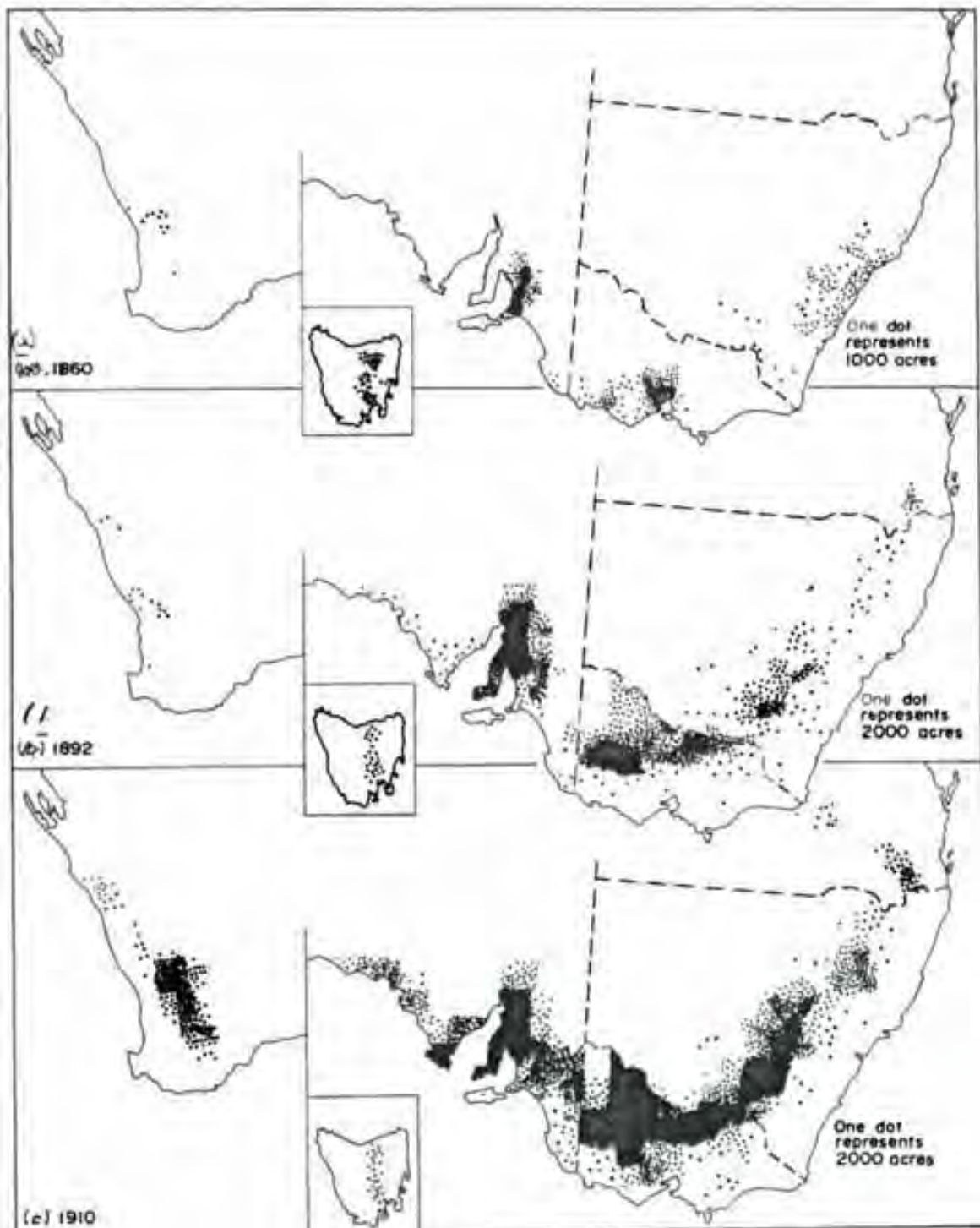


Figure C2. Development of wheat growing in Australia 1860-1910. Illustration from Grigg (1974).

The trend of increased cropping in recent decades has occurred in the Wimmera, and the Glenelg-Hopkins and Corangamite regions (Southern Victoria: Figure C3). Between 1994 and 2007 the area cropped for grain in the Wimmera increased by 72 %, while there was a 300 % increase in southern Victoria from a lower base. In 2007 the proportion of farmland devoted to grain production in these regions was 11.4 % and 3.5 % respectively (ABS 2016). The area cropped in southern Victoria has continued to increase over the last decade. As an example, the area sown to wheat for the Central Highlands plus Barwon ABS statistical divisions from 2005-06 to 2014-15 increased from 75,000 ha to 112,000 ha (T. Hayes, pers. comm.). An indication of the grain production capacity, and its recent increase in western Victoria, is given by the storage capacity of the recently constructed major grain receival sites within 40 km of Lake Bolac (Table C1). In addition to these storages, an increasing proportion of farm production is delivered directly to end users.

Although the amount of cropping undertaken by farmers is largely determined by world economics and climate, it appears that it will increase in Victoria until all the suitable land is taken up, or another enterprise becomes more profitable.

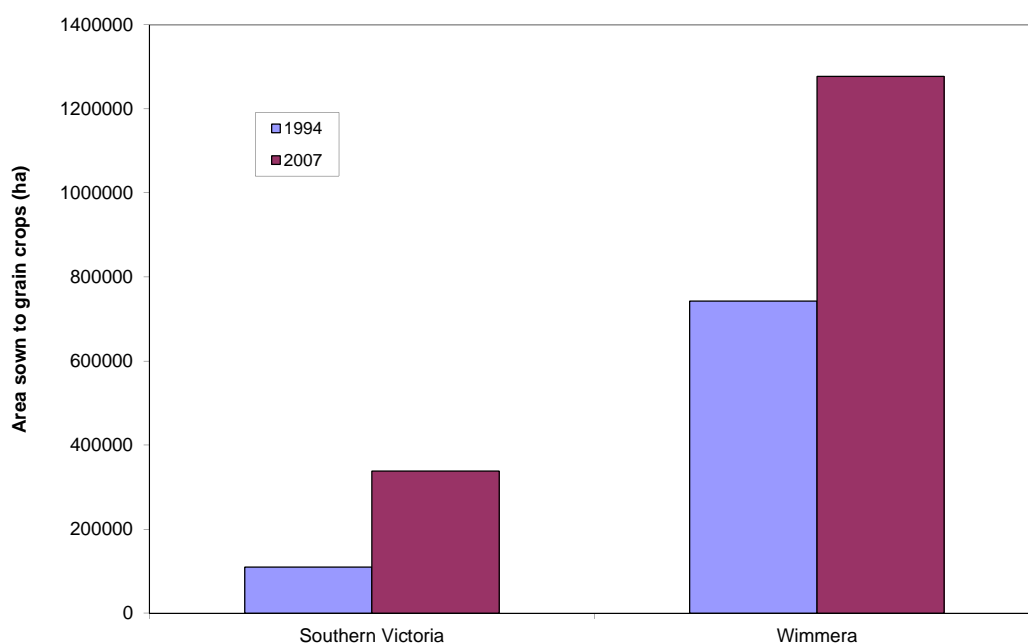


Figure C3. Area (ha) sown to grain crops in two regions of Victoria for 1993-94 and 2006-07. (ABS Agricultural commodities, small area data 2016). Southern Victoria includes the Barwon, Western and Central Highlands ABS statistical divisions.

Table C1. Storage capacity at grain receival sites surrounding Lake Bolac in western Victoria.

Site (creation date)	Storage capacity ('000 tonnes)
Willaura (1878)	75
Westmere (1913)	55
Lakaput (2000)	180
Lake Bolac (2001)	50

Current and future trends

Cropping is still increasing, 2016 has seen further conversion of grazing land to crop land through the South East Grampians cluster, and into the Corangamite CMA region. There are limits to its southward expansion that are not determined by rainfall and subsequent waterlogging, but by soil type, arability and topography. Because of this, expansion of cropping is likely to take place within each region (intensification), including expansion onto soils that were not cropped in the past (wetlands, stony rises), and incorporating efficiencies that entail removal of obstacles (rocks, trees, fences).

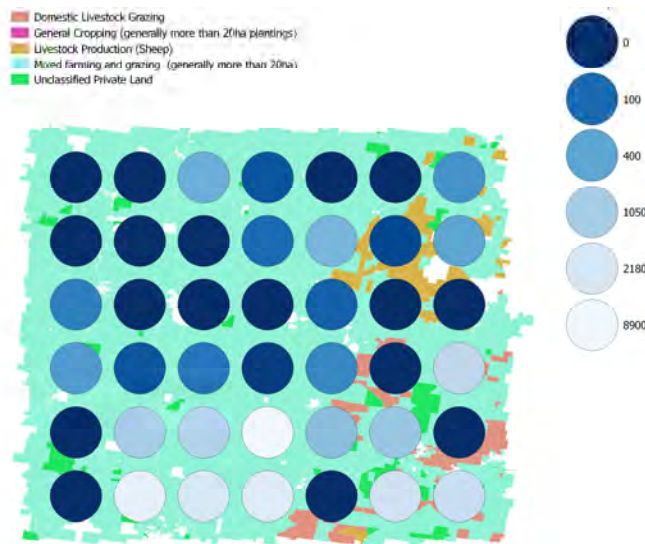
Appendix D. Listed plant species associated with wetlands at risk from cropping in Victoria.

Table D1. Vascular plant species listed under the EPBC Act, or the FFG Act, or DELWP list (rare, vulnerable, endangered or critically endangered). These species occur in shallow freshwater wetlands vulnerable to cropping.

Scientific name	Common name	Scientific name	Common name
<i>Amphibromus pithogastrus</i>	Plump Swamp Wallaby Grass	<i>Lachnagrostis punicea</i>	Purple Blown-Grass
<i>Amphibromus sinuatus</i>	Wavy Swamp Wallaby Grass	<i>Lemna trisulca</i>	Ivy Duckweed
<i>Austrodanthonia aff. caespitose</i>	Porphry Wallaby Grass	<i>Marsilea mutica</i>	Nardoo
<i>Carex bichnoviana</i>	Tufted Curly Sedge	<i>Microseris</i> spp.	Yam Daisies
<i>Carex gunniana</i>	Swamp Sedge	<i>Myriophyllum porcatum</i>	Ridged Water Milfoil
<i>Carex inversa</i>	Knob Sedge	<i>Myriophyllum striatum</i>	Striped Water Milfoil
<i>Carex tasmanica</i>	Curly Sedge	<i>Prasophyllum</i> spp.	Leek Orchids
<i>Craspedia</i> sp. 2	Derinnallum Billy-Buttons	<i>Ranunculus amplus</i>	Lacy River Buttercup
<i>Cyperus cocinnus</i>	Trim Flat-Sedge	<i>Ranunculus diminutus</i>	Brackish Plains Buttercup
<i>Cyperus flaccidus</i>	Lax Flat Sedge	<i>Schoenus carsei</i>	Wiry Bog-Sedge
<i>Cyperus lhotskyanus</i>	Lhotsky's Sedge	<i>Schoenus nanus</i>	Tiny Bog-Sedge
<i>Cyperus rigidellus</i>	Curly Flat Sedge	<i>Schoenus racemosus</i>	Tufted Bog-Sedge
<i>Cyperus subulatus</i>	Pointed Flat Sedge	<i>Schoenus sculptus</i>	Gimlet Bog-Rush
<i>Diurus</i> spp.	Donkey Orchids	<i>Schoenus turbinatus</i>	Top Bog-Sedge
<i>Eragrostis australasica</i>	Cane Grass	<i>Senecio psilocarpus</i>	Swamp Fireweed
<i>Eriocaulon australasicum</i>	Southern Pipewort	<i>Swainsona</i> spp.	Swainson Peas
<i>Hypoxis</i> spp.	Golden Stars	<i>Teucrium</i> spp.	Germanders
<i>Isoetes</i> spp.	Quillworts	<i>Thelymitra</i> spp.	Sun Orchids
<i>Isolepis congrua</i>	Slender Club-Sedge	<i>Triglochin alcockiae</i>	Southern Water Ribbons
<i>Isolepis wakefieldiana</i>	Tufted Club-Sedge	<i>Triglochin striata</i>	Streaked Arrow-Grass
<i>Isotoma tridens</i>	Hypsela	<i>Utricularia</i> spp.	Bladderworts; Fairy's Aprons
<i>Juncus psammophilus</i>	Sand Rush	<i>Utricularia uniflora</i>	Single Bladderwort
<i>Juncus revolutus</i>	Creeping Rush	<i>Utricularia violacea</i>	Violet Bladderwort
<i>Lachnagrostis adamsonii</i>	Adamsons Blown Grass		

Appendix E. Changes in land use

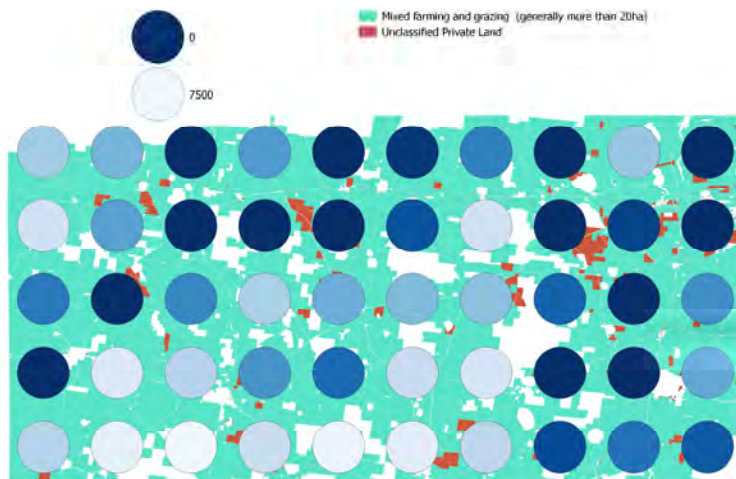
The Victorian Land Use Information System 2014/2015 (LANDUSE_2014/) spatial layer is used by policy makers and NRM managers to characterise the land use activities in particular areas. The information contained in this layer has lagged behind current land use in areas of the highest wetland density.



South East Grampians wetlands cluster

Most agricultural land in the South East Grampians cluster is classed as mixed farming and grazing (Figure E1). Smaller areas are classed as being used for livestock grazing and production. No land in this area is currently classed as general cropping, despite it being common to find large farms that have had few if any livestock for more than a decade.

Figure E1. Map based on VLUI agricultural land use categories for the South East Grampians wetlands cluster. The underlying map indicates that the major land use recorded is mixed farming. This map is superimposed with actual grain crop proximity (m) from the cell centroid, giving an estimate of the intensity of cropping in the landscape.



West Wimmera wetlands cluster

The West Wimmera region has a lower cropping intensity and a mixture of public and grazing agricultural land (Figure E2) in comparison to the South East Grampians cluster region. Most agricultural land is classed in the VLUI layer as mixed farming and grazing.

Figure E2. Map based on VLUI agricultural land use categories for West Wimmera wetlands cluster. The underlying map indicates that the major land use recorded is mixed farming. This map is superimposed with actual grain crop proximity (m) from the cell centroid, giving an estimate of the intensity of cropping in the landscape.

