Understanding the relationship between livestock grazing and wetland condition

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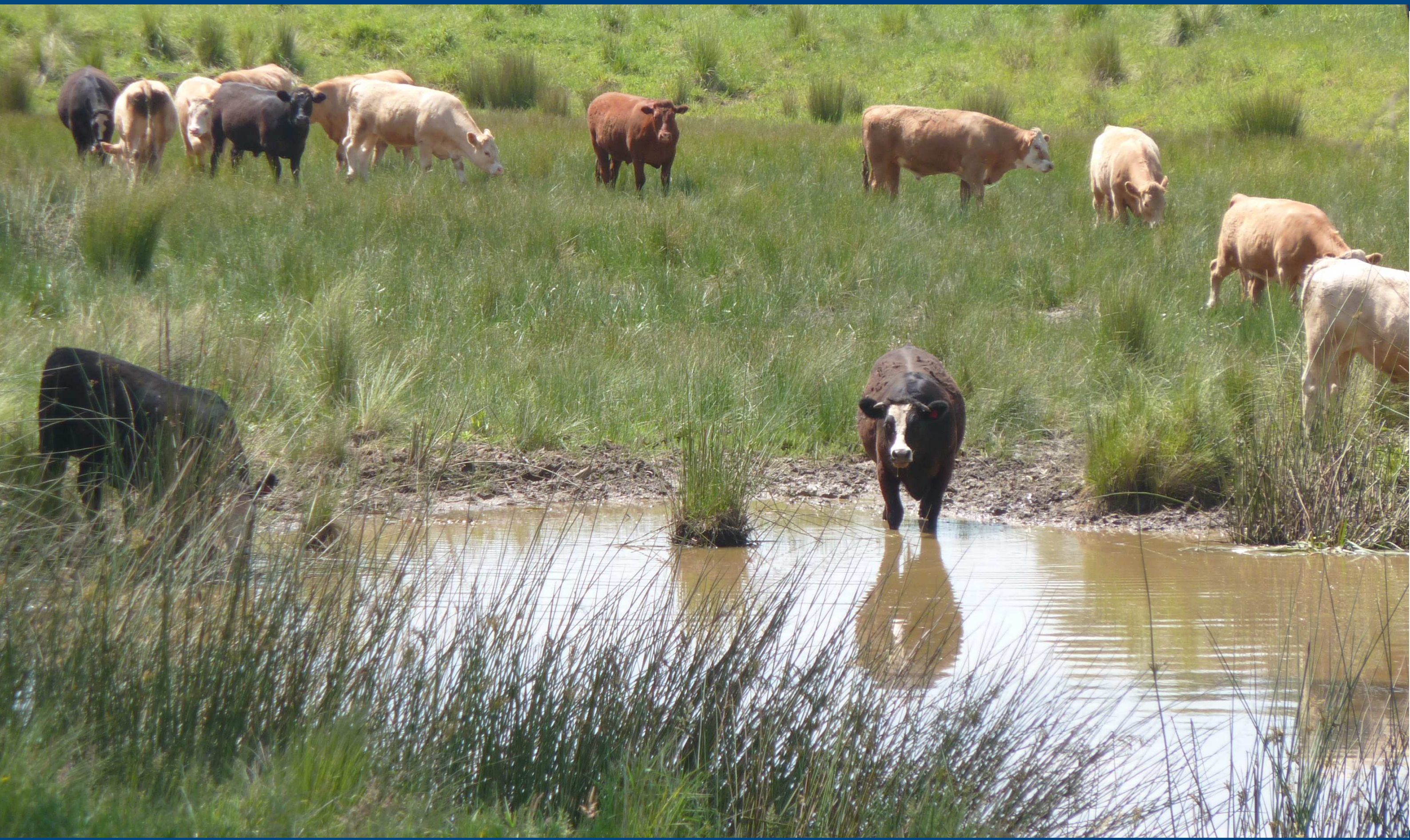

Arthur Rylah Institute for environmental research

Department of Environment and Primary Industries

State Government Victoria

Understanding the relationship between grazing and wetland condition

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Front cover photo: Cattle grazing in a wetland (Kay Morris).

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Summary

The sustainable use of wetlands for grazing is an important consideration in improving the management of wetlands on private land. Current understanding of the relationships among grazing, wetland condition and management outcomes in Victoria are represented in various models and documents that support the management of wetlands in Victoria. These models have been developed principally from expert opinion and there is a need to underpin and refine them with evidence drawn from the scientific literature and government reports. There is also a need to document the range of management activities that could be applied to mitigate grazing impacts and assess their efficacy. This understanding is needed to ensure grazing management approaches implemented to improve and/or protect wetland condition and values are appropriate and effective.

The aims of this report were to: (1) describe responses of wetland condition attributes to livestock grazing, (2) identify wetland attributes that exhibit variable responses to grazing and identify causes for this variability, (3) identify management practices used to reduce the negative impacts of grazing and report any evidence of their efficacy and (4) provide recommendations for further research to reduce uncertainties in predicting the effects of grazing management on wetland condition. It is expected that this knowledge would be used to refine existing models that represent the relationship between grazing management and wetland condition.

Wetland responses to grazing: The effects of grazing on wetland condition occur through four processes (1) treading in the wetland, (2) transport of plant seeds into the wetland, (3) deposition of urine and faeces in the wetland and (4) herbivory. These, in turn, change ecological attributes that underpin wetland condition and can lead to changes in water quality, water regime, soil properties, physical form, invasive flora and vegetation health, structure and composition. These changes are usually detrimental but under certain conditions grazing can be beneficial to some wetland attributes if carefully managed.

Response modifiers: Responses of wetland attributes to grazing are highly variable. Understanding factors that contribute to this variability is needed to select grazing regimes that are appropriate and effective for different types of wetlands and for particular locations. The most variable response to grazing is observed in the vegetation, which shows both positive and negative responses. For all other wetland attributes, the magnitude of change in response to grazing is variable, but responses are negative, with occasional exception.

Factors that contribute to this variability include: (1) current and/or historical grazing regimes (timing, duration, intensity, type of grazer, total grazing pressure), (2) the individual characteristics of the wetland (condition, size, volume, soil type, water regime, productivity, frequency of disturbance, plant assemblage, presence of invasive flora) and (3) landscape context (surrounding land use, geographical setting, regional species pool, connectivity).

Management practices: In some wetland systems, the careful management of grazing can prevent or reduce adverse impact, and in some cases controlled grazing may exert a positive effect on some aspects of wetland condition. In other systems even low levels of grazing will degrade wetland condition necessitating the complete exclusion of livestock to prevent adverse impacts.

Grazing management strategies manipulate the type and or the number of grazing animals, the timing or duration of grazing, and/or the areas that livestock access. In most cases ecological responses to grazing management are anecdotal and the relative merits of various practices remain uncertain. The exceptions are the complete exclusion of livestock and reductions in grazing intensity which have been subject to more rigorous experimental treatment. Faced with this uncertainty, a rigorous monitoring and reporting framework is needed to help safe

guard against ineffective or adverse management outcomes and to build the knowledge base that will improve confidence in management decisions.

Recommendations: In the short-term our current understanding of grazing in wetlands should be used to: (1) refine existing conceptual models that represent cause and effect relationships and assumptions between grazing regimes and management outcomes, (2) develop best practice guidelines to inform grazing management while research programs are undertaken to address key knowledge gaps.

Best practice guidelines should endeavour to: (1) provide a framework for assessing the sensitivity of wetlands to grazing, (2) guide the selection of appropriate grazing regimes for individual wetlands, (3) ensure grazing decisions are evaluated though an adaptive management framework.

To further our understanding of the outcomes of grazing management four research approaches are suggested:

1. Develop a grazing sensitivity database for native and invasive wetland flora.
2. Assess current wetland condition datasets (e.g. wetland tender programs) to determine if they capture sufficient information to test how various grazing practices influence wetland condition.
3. Establish targeted monitoring in strategically selected wetlands to address key knowledge gaps including:
   - How effective are various grazing management practices in maintaining wetland condition?
   - How do response modifiers influence the ecological outcomes of grazing management?
   - Does the application of grazing to manage weeds, wildfires or habitat structure have the same ecological outcomes as alternative approaches (e.g. fire, slashing, herbicide application)?
4. Undertake research to better understand current grazing practices in wetlands, perception of landowners of the risks and benefits of different management practices and barriers to change.

1 Background and objectives

The sustainable use of wetlands for grazing is an important consideration in improving the management of wetlands on private land. Responses of wetland systems to grazing can be highly variable with both positive and negative responses being reported for some wetland attributes. Understanding factors that contribute to this variability is needed to select grazing regimes that are appropriate and effective for a particular site and/or a particular wetland type and lead to desired outcomes. The impacts of grazing on wetland condition is currently captured in three DEPI documents that support the management of wetlands in Victoria and are outlined below.

1. The Victorian Index of Wetland Condition (IWC; DSE 2005) is the principal method for assessing the condition of wetlands in Victoria. The IWC recognises the impact that grazing has on wetland condition by linking livestock grazing to nutrient enrichment and pugging which result in lower condition scores.

2. Wetland conceptual models (Morris and Papas 2012) representing relationships between threats and management interventions. In these models managing livestock is recognised as a management intervention to reduce the threat of degraded wetland vegetation, invasive flora, degraded water quality (nutrients) and soil disturbance.

3. DEPI output data standard (DEPI 2013) provides program logic (conceptual models) to support the planning of environmental works programs. Program logic articulate cause and effect relationships and underlying assumptions between management goals (outcomes and resource condition change) and management interventions (outputs). Identifying appropriate management goals for site improvement through planned works requires that the condition of the site and the threats present be assessed. From an understanding of the relationships between threats and condition, management outcomes can be identified and appropriate interventions (outputs) selected using program logic (DEPI 2013).

   Program logic for grazing management is represented in DEPI's standard outputs (DEPI 2013, Figure 1). In this model grazing regime is a management output that may include: (1) livestock exclusion, (2) ongoing and uncontrolled access of livestock or (3) controlled livestock access, where the timing, density and duration of livestock access in an area is managed. The selected grazing regime determines the level of species control (i.e. livestock control) which determines the level of improvement in soil stability and vegetation structure and diversity (i.e. expected outcomes). The relationships between grazing regime and outcomes shown in Figure 1 are also represented in 1 and 2 above, however, program logic also identifies indirect outcomes of livestock control such as an increase in habitat availability and amenity.

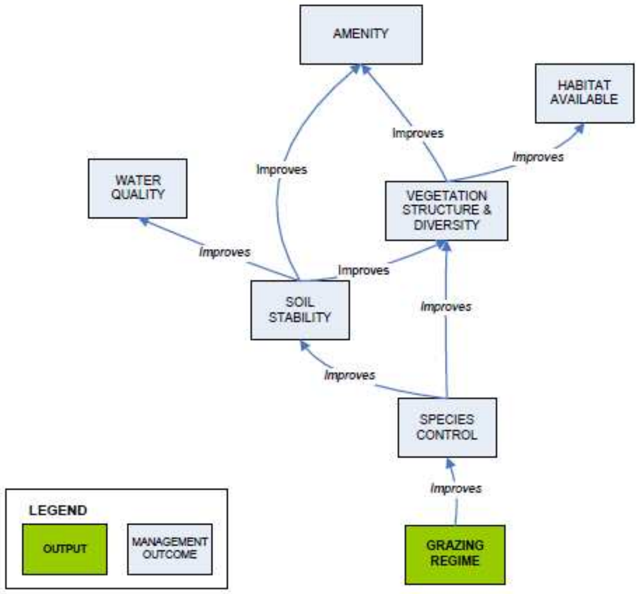

Figure 1. Program logic representing the relationship between grazing regime and management outcomes as presented in DEPI's standard outputs (DEPI 2013)

It is expected that over time program logic will be refined to better represent the complexity and level of confidence in these relationships. Knowledge to refine models will be generated through an examination of the literature and from monitoring and research data.

Relationships among grazing, wetland condition and management outcomes in DEPI's suit of conceptual models have been informed principally by expert opinion and scientific evidence supporting these relationships have not been explicitly represented in models. Moreover, management activities to mitigate the impact of grazing have not been identified and evaluated.

This report draws from the scientific literature and government reports to:

1. Describe responses of wetland condition attributes to livestock grazing.
2. Identify condition attributes that exhibit inconsistent responses to grazing and assess the likely causes for this variability.
3. Identify management practices used to reduce the negative impacts of grazing and report any evidence of their efficacy.
4. Provide recommendations for further work to reduce uncertainties in predicting the effect of different grazing regimes on wetland condition.

It is expected that this process will provide the body of evidence needed to refine existing models.

2 Methods

2.1. Relationships between grazing and wetland condition

To assess the effect of grazing on wetland condition we examined how grazing alters various attributes that underpin wetland condition. Wetland condition attributes were informed by the Victorian Index of Wetland Condition (IWC) (DSE 2005) and included:

- water properties
- soils
- hydrology
- wetland plants (ecological component of the IWC sub-index biota)
- invasive flora (used as a measure for wetland plants in the IWC).

The potential impacts and benefits of grazing on these selected wetland condition attributes were assessed from the scientific literature and government reports. In some cases responses of other ecosystems (e.g. grasslands, riparian systems) to grazing have been reported where information for wetlands was lacking, and where they provided insight into possible responses of wetlands to grazing.

As a number of wetland attributes show inconsistent responses to grazing the potential causes of this variability have been identified and are referred to as response modifiers. In some cases response modifiers are described in the literature, but in others the causes for variability are not reported and are inferred from an understanding of ecosystem processes.

The influence of grazing on each wetland condition attribute is summarised using the format shown below:

- *Responses*: describes reported responses of wetland attributes to grazing- these may be positive, negative or neutral.
- *Causes*: describes the mechanism(s) by which grazing modifies the state of each attribute.
- *Response modifiers:* where a wetland component demonstrates a variable response to grazing, the potential causes for this variability are described.

The ecological responses of wetlands to grazing are also represented as simple box and arrow models, these are causal chains that indicate how grazing alters the state of wetland attributes and influences condition. In these models each box represents an ecological attribute and arrows show how the impacts of grazing on one attribute leads to changes in other attributes. Wetland attributes are coloured to represent wetland condition attributes identified in the IWC.

3. Results

3.1. Relationships between grazing and wetland condition

The effects of livestock grazing in wetlands occur through four processes:

- Treading in the wetland.
- Transport of plant seeds into the wetland.
- Deposition of urine and faeces in the wetland.
- Herbivory.

These in turn alter attributes that underpin wetland condition including: water quality, water regime, soils, physical form, invasive flora and vegetation health and structure and composition. The ecological outcome of grazing in wetlands is often negative, but in some cases responses may be neutral or even positive. The potential impacts and benefits of grazing on wetlands are described below and summarised in Table 1 and Figures 1 & 2

3.1.1. Grazing impacts

3.1.1.1. Treading in the wetland, wetland buffer and wetland catchment

Livestock treading in the wetland physically damages plants, causes soil disturbance, increases turbidity, compacts the soil, and creates bare ground. These changes can alter water clarity, microclimate, the infiltration of water and air into the soil, soil strength and carbon stores. This adversely affects plant growth, results in compositional changes in vegetation, and can affect soil organisms and nutrient processing. Reduced vegetation cover, soil disturbance and compaction in the wetland buffer or in the wetland catchment can also reduce water quality as they increase surface runoff and erosion, reduce sediment trapping and increase the delivery of soil particles, nutrients, salts, and/or pollutants to the wetland.

Trampling of vegetation: Trampling of vegetation damages and/or kills plants. This reduces plant biomass and leaf litter and leads to the creation of bare ground. These changes, in turn, impact on wetland condition. Bare ground in the wetland buffer and/or catchment increases soil erosion and accelerates water runoff which increases the amount of soil particles, nutrients or other pollutants entering the water column. Reductions in plant biomass, leaf litter and increasing bare ground may provide opportunities for both native and invasive species to establish. Where grazing has reduced vegetation cover and leaf litter the microclimate can be altered; generally temperature and light are increased and can stimulate germination (van der Valk 1986) and contribute to compositional changes in vegetation. Reductions in leaf litter or vegetation cover represent reductions in surface and soil carbon stores which in turn influence soil organisms and nutrient processing with subsequent impacts on plant growth.

Soil compaction and pugging: Livestock treading in the wetland compacts the soil, reducing the size and number of air spaces in the soil (Crush and Thom 2011). These changes are usually measured as an increase in soil bulk density (grams of soil per unit volume) or a decrease in soil porosity. Saturated or near saturated soils have low mechanical strength and are vulnerable to physical damage and pugging (Eyles 1977a, 1977b, Prosser 1996, Evans 1998, Askey-Doran and Pettit. 1999). Pugging depth increases with repeated treading in wet soils (Greenwood and McKenzie 2001). Pugging can dislodge plants and damage and/or disrupt soil seed and egg banks.

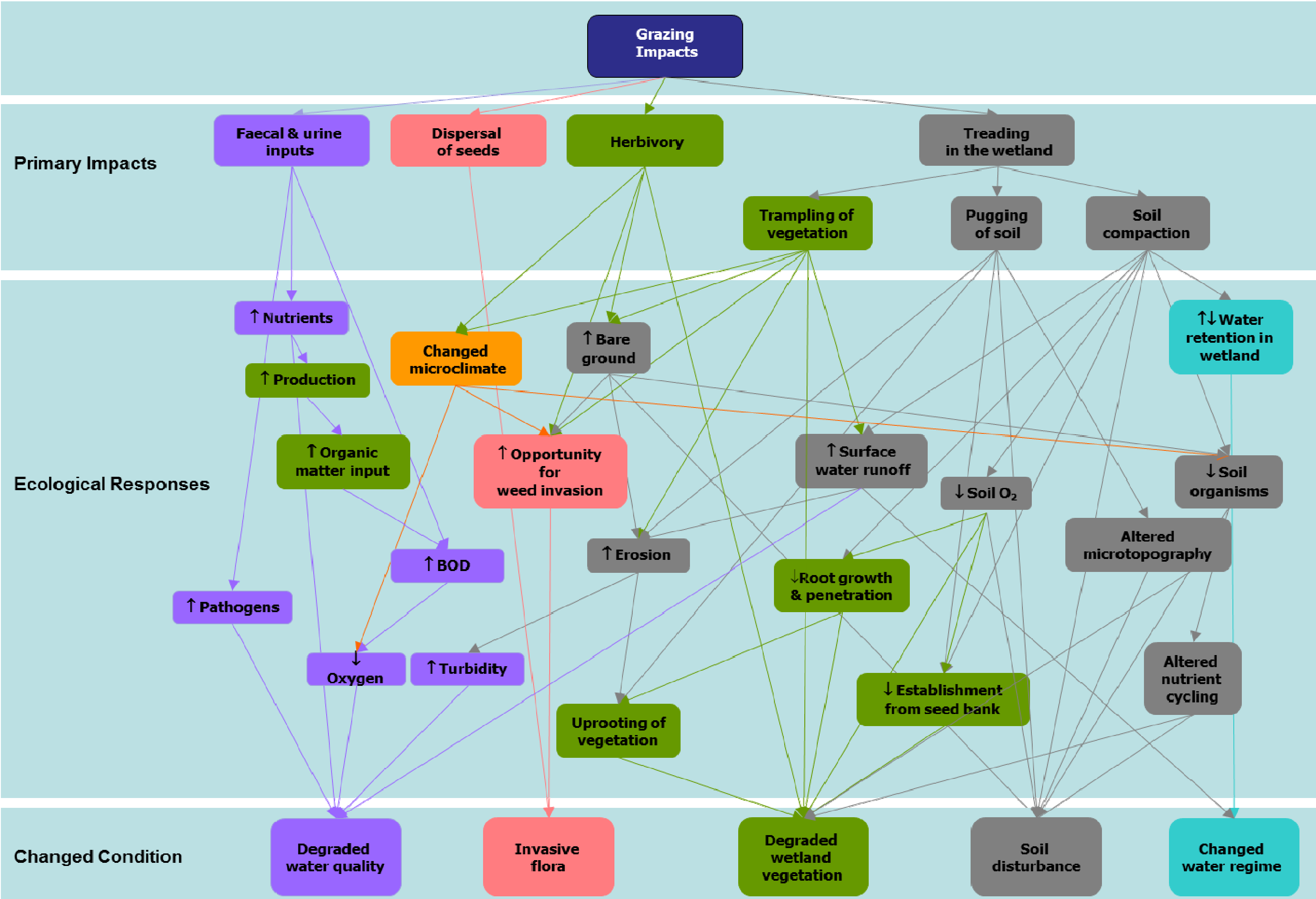

Figure 2. Primary impacts and ecological responses to livestock grazing in wetlands and their relationships to wetland condition attributes. Colours indicate variables associated with different wetland attributes: purple, water properties; pink, invasive flora; green, vegetation; grey, soil properties, blue, water regime; orange, microclimate. All attributes, excluding microclimate are used in the IWC. BOD, biological oxygen demand.

Table 1. The influence of livestock grazing on wetland attributes, underlying mechanisms and response modifiers. Wetland attributes captured in IWC assessments are indicated by an asterisk.

Wetland attributes	Responses to grazing	Mechanism	Response modifiers
*Water quality: Nutrients	*Negative* (*nutrients increase)* • Nutrient budgets performed for grazing systems in south-west WA found they produced surplus nutrients: mean 8 kg P Ha^{-1} and 76 kg N Ha^{-1}, respectively. Dairy systems produced average surpluses of 18 kg P Ha^{-1} and 128 kg N Ha^{-1} (Ovens et al. 2008) • Grazing exclusion in riparian zone reduced nutrient levels in an intermittent stream by 24% (Sunohara et al. 2012) • Grazing exclusion along riparian zones decreased loads of TN by 21-52%. (Miller et al. 2010) • The flux of TN in water collected from the outlet of a pastoral wetland in New Zealand was nine times higher during periods of livestock grazing (McKergow et al. 2012). *Neutral (no change in nutrients)* • Where nutrient enrichment has occurred from other sources such as fertiliser application, the contribution of grazing to the nutrient load may be relatively small and difficult to detect (Tanner & Terry 1991; Steinman et al. 2003) *Positive* (*nutrients decreased*) • Removal of livestock from grasslands increased nitrate in leachate entering springs as harvesting of plant biomass declined and leaf litter increased and reduced plant production (Jackson et al. 2006).	• Direct deposition of urine and faeces into water body • Faecal runoff from surrounding grazed catchment • Disturbance of vegetation and soil crusts increase soil erosion and reduce sediment trapping. This increases the sediment load carried in runoff. Nutrients bound to sediments contribute to increased nutrient loads.	• Strongly influenced by historic fertiliser use De Steven & Lowrance (2011) • Supplementary feeding of livestock • Nutrient uptake by plants • Soil nutrient storage capacity • Rates of nitrification-denitrification • Water volume • Hydraulic residence influences the rate nutrients are flushed out of system) • Soil aeration which influences the binding of P to soil and rates of nitrification-denitrification
*Water quality: Salinity	*Increased*: • Salinity increased 2.7 times in grazed sites cf. ungrazed sites in a lowland Flooding Pampa grassland (Chaneton & Lavado 1996). • Salinity decreased within 5 years following grazing exclusion in saline marshes (France) (Amiaud et al. 1998).	• Reduced vegetation cover increases soil temperature and in turn evaporation. When water evaporates salts are deposited at the soil surface (Lavado & Taboada 1987, Srivastava & Jefferies 1996) • Soil compaction reduces water infiltration and prevents the leaching of salt from the soil (Amiaud et al. 1998)	• Presence of a shallow saline groundwater table. • Ratio of precipitation: evaporation • Wetland water regime: frequency and duration of flooding, flushing • Soil type

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Table 1. Continued

Wetland attributes	Responses to grazing	Mechanism	Response modifiers
Water quality: Turbidity	*Increased*: • Livestock increased the turbidity of runoff reaching stream by 60% compared with runoff from areas where livestock were excluded. • High intensity grazing by cattle and sheep (3.2 DSE/ha/annum) increased turbidity in floodplain wetlands (Jansen & Healey 2003).	• Indirect: livestock reduces vegetation biomass, creates bare ground and disturbs soil crusts. This increases erosion by rain and wind and reduces sediment trapping by vegetation. This increases the amount of sediments carried in runoff to the wetland. • Direct: livestock treading in the water body disturbs soils, dislodges and damages plants and increases the level of suspended soil particles in the water column	• Slope • Vegetation cover • Rainfall events
Water quality: Pathogens	*Increased*: • Grazing increased faecal coliform (bacteria) counts in runoff from grazed pastures by 5-10 times cf. with fenced pastures (Doran & Linn 1979) • Cattle grazing increased faecal streptococci and faecal coliform counts of stream water. Elevated levels persisted for 9 days following removal of cattle (Kauffman and Krueger 1984) • Livestock exclusion decreased the level of faecal coliform and faecal enterococci contamination of adjacent stream by 66% and 57% respectively (Line 2003). • Grazing exclusion from riparian zones decreased total coliform and enterococcus counts by 23% (Sunohara et al. 2012) *Decrease*: • Grazing decreased faecal streptococci in runoff compared with fenced zones, reflecting an increased contribution of faecal inputs from wildlife (Doran & Linn 1979;Doran et al 1981) • Grazing exclusion from riparian zones increased Cryptosporidium and Giardia (protozoans that cause gastrointestinal illness) (Sunohara et al. 2012)	• See mechanisms for increased nutrients	• Use of wetland by other native and invasive fauna that also shed pathogens.

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Table 1. Continued

Wetland attributes	Responses to grazing	Mechanism	Response modifiers
Water quality: Dissolved oxygen	*Negative* • Decreased levels of dissolved oxygen are reported as a possible outcome of grazing but no direct evidence (Belsky et al. 1999)	• Oxygen levels in the water column can become depleted by high biological oxygen demand and/or high water temperature which reduces the amount of dissolved oxygen held in the water column. Grazing can increase biological oxygen demand through: (i) excretions from livestock, (ii) trampling vegetation which increases the amount of dead organic matter in the water, (iii) increasing algal biomass or plant biomass which lead to increased organic matter inputs (Belsky et al. 1999). Livestock increase water temperatures by trampling and consuming vegetation which shade the water.	• Productivity • Detrital inputs • Water column temperature
*Physical form	*Negative* Reduction in peatland size via increased drainage *Uncertain* Altered microtopography via pugging, erosion	• Peatland vegetation plays an important role in retaining water. Where livestock have reduced vegetation cover water retention decreases and this will contract the area of wetland inundation reducing the size of the wetland. • Topographical variation creates mosaics of water regimes that may allow species to co-exist (Raulings et al. 2010). An elevation difference as small as 10 cm favours some species and eliminates others (Bledsoe & Shear 2000). Although pugging by livestock creates topographic heterogeneity which may favour co-existence of species with different water regimes, repeated treading will prevent plant establishment.	• Vegetation type • Wetland type (e.g. peatlands) • Soil type

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Table 1. Continued

Wetland attributes	Responses to grazing	Mechanism	Response modifiers
*Water regime	*Increased duration* Grazing increased inundation by 50-80% compared with ungrazed spring wetlands (California USA) (Marty 2005). *Accelerated rate of filling* Increased runoff frequently reported and is likely to accelerate rates of wetland filling. *Decreased water holding capacity in peatlands*	• Increased duration of inundation attributed to either: (i) decline in cover and height of vegetation which reduced evapotranspiration or (ii) an increase in water holding capacity due to soil compaction • Reduced infiltration of water into soil due to compaction and loss of vegetation may accelerate the rate of wetland filling • In peatlands grazing reduces vegetation cover and leads to the channelling of water flow through the bog and a reduction in its water holding capacity (McDougall and Walsh 2007).	• Soil type • Wetland type • Vegetation type • Slope
Soil: *Pugging & compaction	*Increased* • Grazing increased soil compaction by ~ 13% cf. ungrazed ephemeral wetlands (US) (Marty 2005) • Increased soil bulk density by 16% in dry floodplain meadows (infrequent inundation) and by 32% in wet floodplain meadows (frequent inundation) (US) (Kauffman et al. 2004) • Exclusion of livestock from previously grazed riparian zones (Canada) reduced soil bulk density by 6-8% after 4-6 years) Miller et al. 2010) Note that the impact of livestock on soil occurs largely with the initial treading - grazing intensity influences more the spatial extent of impact than the magnitude of impact. Reducing grazing intensity slows the rate of degradation but in the long term will produce the same state as higher intensity grazing (Greenwood et al. 1997)	• Soil compaction occurs as livestock treading on the soil reduces the size and number of air spaces in the soil (Crush and Thom 2011). • Saturated or near saturated soils have low mechanical strength and animal hooves remould the soil surface leaving a depression or pug in the soil.	• Soil wetness: wet soils more susceptible than dry • Soil type: susceptibility increases with higher clay content and decreases with high organic content. • Physical processes reduce compaction o wetting & drying cycles o freezing & thawing o root growth o activity of soil organism

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Table 1. Continued

Wetland attributes	Responses to grazing	Mechanism	Response modifiers
Soil: Infiltration	*Decreased*: • ↓13 times in floodplain meadows (US) (Kauffman et al. 2004) • ↓ 25% in moderately grazed pastures and 50% under heavy grazing cf. ungrazed pastures (Gifford and Hawkins 1978)	• Soil compaction reduces micro and macro pores in the soil that facilitate the entry of water into and through the soil.	
Soil: Nutrients	*Negative (Increased nutrients):* • ↑Total N by 20% compared with grazing excluded sites in lowland Flooding Pampa grassland (Chaneton & Lavado 1996). • Heavy grazing increased soil N (2-3 times), P (2.5 times) (woodland, Australia, Yates et al 2000) • Heavy grazing by sheep increased TN by 11.4% and TP by 7.6% on the Mongolian steppe (Li et al. 2008) *Neutral:* • No effect of grazing exclusion on extractable P (Chaneton & Lavado 1996). • Light and moderate grazing by sheep on the Mongolian steppe did not alter soil N or P (Li et al. 2008). • No effect of grazing exclusion on fluxes of soluble reactive phosphorus from soils after 4 years (Tweel and Bohlen 2008)	• As for water quality: Nutrients	• Type of grazing animal • Grazing intensity (see Degraded water quality: nutrients)
Soil: Runoff & erosion	• Greater soil loss in moderate to heavily grazed plots (0.22 t/ha) cf. lightly grazed plots (0.05 t/ha) (Edwards 1987) • Fencing a stream to exclude cattle reduced sediment loss by 40%. (Owens et al. 1983) • Increased runoff and soil loss when ground cover < 70-75% (Lang & McCaffrey 1984, Costin 1980) • Runoff shown to increase linearly with increasing grazing intensity (Rauzi & Hanson 1966). Runoff from a heavily grazed watershed increased runoff by 9 x compared with lightly grazed watershed, and by 1.4 x compared with moderately grazed watershed.	• Herbivory and trampling of vegetation by livestock reduces leaf litter and vegetation cover which dampen the erosive forces of rain and wind • Treading in the wetland disturbs soil crusts increasing soil erosion • Soil compaction reduces the penetration of water into the soil increasing surface runoff.	• Vegetation cover • Slope
Soil disturbance: Bare ground	*Negative* • Bare ground strongly correlated with grazing intensity • Grazing exclusion in riparian zones (Canada) reduced bare ground by 72-93% and increased vegetation cover by 13-21% over 4-6 years) (Miller et al. 2010).	• Herbivory, trampling of vegetation, soil compaction and pugging reduces vegetation cover and increases bare ground.	• Interaction between water regime & type of aquatic plants present (e.g. in episodic wetlands aquatic plants that are dormant during drying may not be affected by grazing.

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Table 1. Continued

Wetland attributes	Responses to grazing	Mechanism	Response modifiers
Soil: Carbon storage	• Heavy grazing decreases litter cover and soil C (20%) cf. rarely/ungrazed sites (woodlands, Australia, Yates et al. 2000) • Grazing exclusion in riparian zones (Canada) increased standing litter by 38-742% cf. grazed zones (Miller et al. 2010) • Grazing has caused widespread peat loss in the Victorian alps (Grover 2006)	• Grazing reduces plant cover and biomass reducing carbon stores and the potential for carbon capture and subsequent storage as leaf litter and organic matter in the soil. • Grazing in alpine wetlands reduced water retention favouring aerobic decomposition and peat loss.	
*Presence of invasive flora	*Negative (increased weed cover)*: • Wetlands (Canada): probability of weed occurrence increased with increasing grazing intensity. Number of weed species increased at moderate grazing intensity and declined at high grazing intensity (Jones et al. 2011). • Woodlands (Australia): cover of exotic annuals increased with heavy grazing (Yates et al. 2000). • Flooding Pampa rangelands (Argentina): exotic annuals and forbs replaced perennial grasses (Facelli 1988). *Positive (decreased weed cover)* • Wetlands (California): cover of exotic annual grasses significantly increased by 60 - 88% in ungrazed sites or dry season grazed sites cf. continuously grazed sites. (Marty 2005). *Neutral (no change)* • Previously grazed riparian zones (Canada): No reduction in the cover or density of noxious weeds six years after livestock exclusion (Miller et al. 2010). • Previously grazed and degraded river red-gum forest (Barmah-Milliewa, NSW, Australia): No reduction in the prevalence of exotic plants 12 years after livestock exclusion (Lunt et al 2007a).	• Grazing can create gaps in wetland vegetation and create habitat niches that favour the establishment or expansion of invasive species in the wetland. • Grazing animals can transport invasive species into the wetland when seeds are carried on their fur or are ingested and deposited in their faeces.	• Evolutionary history of herbivory • Productivity • Palatability of weeds • Sensitivity of weed • Presence of weeds within wetland • Prevalence of weeds in regional species pool • Size of wetland: small wetlands are more influenced by surrounding landscape and are at higher risk of weed invasion from surrounding landscape • Grazing regime • Interaction between wetland water regime and sensitivity of weeds to inundation.

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Table 1. Continued

Wetland attributes	Responses to grazing	Mechanism	Response modifiers
*Vegetation: types of vegetation	*Types of vegetation that decrease*: • Forbs: Jones et al. (2011) (Canadian wetlands) • Tall grasses: Jones et al. 2011 (Canadian wetlands) • Perennials (McIntyre et al. 1995, Prober & Thiele 1995, Lunt et al. 2007b). Perennial species decrease 35% of the time across ecosystems (Diáze et al. 2007) • Amphibious responders (Berney 2010, Holmes et al. 2009) (Australian wetlands) • Species with short-lived seed banks • Perennial herbs and shrubs (Yates et al. 2000, Australian woodlands) • Fencing to exclude livestock restored structural vegetation layers in riparian zones after 6 years (Miller et al. 2010) *Types of vegetation that increase*: • Annuals (35% of the time) (Diáze et al. 2007). Exotic annuals increased (permanent and temporary wetlands Canada, Jones et al. 2011, McIntyre et al 1995, Prober & Thiele 1995, Lunt et al. 2007b) • Prostrate species favoured over erect species (Diáze et al. 2007, Berney 2010) • Stoloniferous and rosette architecture favoured over tussocks (Diáze et al. 2007) • Ruderal-competitive species (e.g. *Glyceria maxima*, *Ranunculus sceleratus* and *Lemna minor* increase in UK (Ausden 2005). • Species with long lived seed banks (Hald & Vinther 2000) • Short canopy height (Diáze et al. 2007)		

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Table 1. Continued

Wetland attributes	Responses to grazing	Mechanism	Response modifiers
Vegetation: Diversity	*Positive (increased diversity)* • Ephemeral wetlands (California): ungrazed sites had 25% less species cf. grazed sites (Marty 2005). • Tall-herb fen (UK): grazing increased diversity (Ausden 2005) • Grassland (Finland): removal of livestock reduced the number of rare plant species by 45% after 20-40 years (Luoto et al. 2003) • Wet grassland communities (France): Grazing increased species richness and shannon diversity (a measure of relative species abundance) (Marion et al. 2010). (Note that in some studies reported increases in diversity may result from increases in numbers of invasive species) *Negative (reduced diversity)* • Alpine rangelands (Northwest Yunnan): Grazing reduced species cover and diversity (Haynes et al. 2013) • Prairie wetlands (USA): Species diversity negatively correlated with the presence of cattle (Hornung & Rice 2003) • Swamp (Denmark): grazing reduced species richness (Anderson & Calov 1996)	• In productive wetlands, where the dominant plants are both palatable and within reach of livestock, grazing can maintain plant species diversity by preventing the competitive exclusion of species (Lunt et al. 2007b). • Where the regional species pool/wetland seed bank contains grazing insensitive weeds species, increases in diversity due to the control of competitive species may be due predominantly to increases in the number of weed species.	• Productivity • Evolutionary history of grazing • Regional species pool • Seed bank
Vegetation: Height /Biomass/Cover	*Decrease* • Reduced height and biomass in UK fens (Ausden 2005) • Grazing decreased below ground biomass by 50% in dry riparian meadows and 62% in wet riparian meadows (Kauffman et al 2004)	• Herbivory and trampling reduce plant biomass and the height of species or life stages with a canopy within reach of grazing animals. • Soil compaction can reduce water and air movement into the soil and increase soil strength which limit root growth. • Below ground biomass can decline as grazing plant shoots can shift carbon reserves from below ground structures to above ground tissues.	
Soil seed bank	• Increases disparity between extant vegetation and species in soil seed bank (Berney 2010). • Possible decline in abundance and diversity of seed bank in the long term (Berney 2010) • Sheep grazing depleted the number (↓ 85%) and diversity (↓56%) of seeds emerging from soil seed bank in an ephemeral wetland, Wentworth, NSW (Nicol et al. 2007)	• Grazing eliminates some species in the wetland which may persist as dormant seeds leading to disparity in species represented in extant vegetation and seed bank • Seed banks are depleted when conditions favour germination of grazing sensitive species which are subsequently eliminated before seed set.	

Pugging also increases fine scale topographical heterogeneity. This potentially provides a range of fine scale water regimes that may permit co-existence of species with different water regime requirements (Raulings et al. 2010) but recurrent trampling is likely to prevent plant establishment.

Increased soil bulk density adversely affects soils by decreasing the infiltration of air and water into and through the soil and increasing soil strength (Crush and Thom 2011). Water infiltration is impeded in compacted soils causing increased runoff. Where soil compaction is widespread in a catchment, flashy flows can be produced that can cause erosion within the wetland and accelerate the rate of filling. Soil compaction within the wetland reduces water infiltration though the soil profile increasing water retention within the wetland and may prolong the period in inundation (Marty 2005). Reduced infiltration of oxygen into the soil due to compaction can limit root penetration in some species and adversely affect some soil organisms (Whalley et al. 1995).

Soil strength refers to the amount of force required to deform (break or slip) soils. There is an upper and lower threshold of soil strength that is optimal for plants. Soils with low soil strength are too unstable for plants to form a secure anchor, and when soil strength is high root penetration is restricted (Masle and Passioura 1987, Crush and Thom 2011) and seed germination inhibited (Bacon et al 1994, Robertson 1997). Restricted root penetration in the soil due to increased soil strength or reduced soil oxygen causes plants to be more shallowly rooted and therefore more vulnerable to uprooting during grazing. Plants that are shallowly rooted will also have more limited access to water and nutrients, reducing growth and tolerance to drying (Crush and Thom 2011).

Response modifiers

Livestock consistently exert negative effects on soil structure, however a number of variables have been identified that can modify the magnitude and persistence of soil compaction and are described below.

Soil moisture: Compaction increases with soil moisture and is greatest when the top soil layer is at field capacity or wetter (Greenwood and McKenzie 2001).

Clay content: Susceptibility of soils to compaction increases with increasing clay content (Greenwood and McKenzie 2001). Clays are characterised by fine soil particles and this make them more compactable.

Organic content: Organic matter helps soils resist compaction for several reasons: (1) a surface layer of woody material can provide a protective mat, (2) living roots, and to a lesser extent dead roots provide a filamentous network within the soil, (3) organic matter in the soil increases resistance to deformation and/or increases the ability of the soil to rebound, (4) organic matter creates large voids which improve water and air infiltration, (5) organic residues are less dense (0.3-0.6 g. cm^3) than soil particles (1.4-1.6 g/cm^3), and (6) organic residues, fungal hyphae and exudates from roots, help bind soil particle together increasing resistance to deformation (Hoorman 2011, Greenwood and McKenzie 2001, Soane 1990).

Physical processes: The persistence of soil compaction is influenced by a range of natural processes that help to restore soil structure including:

- wetting and drying cycles
- freezing and thawing cycles
- the presence of roots
- soil fauna (and microbes).

Wetting and drying (particularly in soils with high clay content) as well as freezing and thawing cause soils to expand and shrink promoting the formation of air spaces and reducing compaction (Greenwood and McKenzie 2001). Similarly, root growth and soil organisms such as earth worms create pores in the soil that help reduce compaction (Whalley et al 1995).

Type of grazing animal: The depth of soil that becomes compacted with grazing increases as both the contact pressure and the width of the applied stress increase. Cattle have both a greater mass and hoof area (range 314-364 cm^2) than sheep (range 63-84 cm^2) and cause greater compaction. A comparison of pressures exerted on soils by grazing animals is shown in Table 2.

Duration of grazing: Most of the compaction to the soil occurs with the initial treading, and recovery from compaction is slow. Over time as the area that livestock have walked over expands so does the spatial extent of soil compaction.

Table 2. Loading pressures exerted on soil for different types of grazing animals. Adapted from Greenwood and McKenzie (2001)

Grazing animal	Range of pressures (kPa)
Sheep	48-83
Cattle	98-169
Humans	41-108
Horse	54-94
Kangaroos	42-92

Use of the wetland by livestock: Livestock do not utilise all areas of the wetland evenly and compaction will be greatest in areas that are more frequently utilised such as gateways, watering points and cattle camping areas (Greenwood & McKenzie 2001).

3.1.1.2. Deposition of urine and faeces in the wetland

It has been shown that cattle are more likely to defecate in wetlands than in surrounding paddocks (Collins et al 2007). The deposition of urine and faeces by livestock has the potential to degrade water quality in the wetland by introducing nutrients and pathogens, and by increasing the risk that the water column will become depleted in oxygen (Table 1, Figure 2).

Nutrients

Grazing animals assimilate only a small portion of the nutrients they consume and as a result substantial amounts of N, P and K are excreted in faeces and urine (Kirkham 2006). It is estimated that 80-90% of N and 50-75% of P consumed by cattle is excreted (Brundage 2010).

In closed systems, where livestock only feed within the wetland the total nutrient load is not increased but the form of nutrients is changed - nutrients held in plant tissues are consumed and then returned in faeces and urine and are more available to plant growth (Steinman et al. 2003; Scrimgeour and Kendall 2002). A portion of the nitrogen excreted by livestock vaporises and is lost from the system as ammonia gas (NH_3). It has been estimated that 22% of the N excreted by cattle is volatised as ammonia (Laubach et al. 2013).

In open systems, where livestock either feed outside the wetland and return to the wetland, or are provided grain or mineral supplement sourced outside the wetland, livestock excrement can increase the total nutrient load to the wetland. An analysis of grazing systems of south-west Western Australia found that they produced a surplus of N and P, with a mean surplus of 8 kg P Ha^{-1} and 76 kg N Ha^{-1}; dairy systems produced considerably greater surpluses with means of 18 kg P Ha^{-1} and 128 kg N Ha^{-1} (Ovens et al. 2008).

In wetlands, nutrients contained in faeces and urine may enter the water column directly when livestock have access to the water, or indirectly when they are leached by rainfall or irrigation water from excretions deposited on land. Nutrients reaching the water body increase the risk of algal blooms and the subsequent loss of submerged plants, while increased soil nutrients can favour competitive species (including exotic invasive species) which may reduce species diversity.

Grazing may indirectly alter the availability of nutrients by shifting species composition (Semmartin et al. 2004). Plants species differ in the concentration of nutrient stored in their tissues, rates of decomposition and their capacity to aerate the rhizosphere, all of which influence nutrient cycling (Tweel and Bohlen 2008). Changes in the composition of plant species as a result of grazing therefore have the potential to alter the availability of nutrients. Grazing has been found to lower rates of soil nitrogen mineralisation by promoting less palatable species which decompose more slowly (Pastor et al. 1993; Ritchie et al.1998) but this is not always the case. For example, grazing by reindeer favoured species with faster decomposition rates (Olofsson and Oksanen 2002). Current evidence indicates that the outcome of grazing on nutrient cycling is variable and influenced by grazing preferences and site-specific variables (e.g. climatic conditions) (Semmartin et al. 2004).

Response modifiers

Changes in water column nutrient levels in responses to livestock are highly variable, with positive, neutral and negative responses being reported (Table 1). This variability may result from differences in current and historic grazing practice including the duration, intensity and type of grazer and feeding practices. In addition to these variables, the extent that nutrient levels change in response to grazing will also be modified by the ability of wetlands to buffer nutrients introduced by livestock, as outlined below.

Other nutrient sources: Nutrient inputs from other sources, such as the application of fertilisers or nutrient-rich effluent increases the total nutrient input to the wetland and reduces the capacity of wetlands to buffer nutrient input from livestock. Where fertiliser has been applied in the past this may exert a long lasting impact on water column nutrients that overrides the influence of livestock on nutrients concentrations (De Steven and Lowrance 2011). The failure of some studies to report a positive effect on nutrient levels after livestock exclusion has been attributed to the overriding influence of high nutrient levels from other sources.

Water regime: Wetland water regime can modify the impact of nutrient inputs from livestock. The volume of water held in the wetland will determine the extent to which nutrients that enter the water body are diluted. Similarly, changes in water volume during drawdown events will determine to what extent nutrient already present becomes concentrated. The frequency of flushing events determine to what extent nutrients are removed from the system.

Plant growth and luxury uptake: The capacity of plants to take up nutrients through growth and/or accumulate nutrients in their tissues beyond their requirements (luxury uptake) can influence the system's capacity to buffer nutrient additions arising from grazing.

*Nitrification-denitrificatio*n: The nitrification-denitrification process is an important consideration in the nitrogen balance of wetlands as it results in the removal of nitrogen from the wetland as nitrogen gas (N_2). Denitrification removed 30-40% of N (fertiliser and liquid cattle caste) applied to a rice paddy (Zhou et al. 2009) and 28% of N introduced by grazing animals in a wet pasture (Fraser et al. 1994).

A range of factors regulate the activity of micro-organisms responsible for nitrification and denitrification in wetlands including temperature, pH, carbon and the presence of aerobic and anaerobic zones required for nitrification and denitrification, respectively. Treading by cattle has also been shown to increase rates of denitrification by compacting the soil and favouring anaerobic conditions needed for denitrification. It is unlikely that elevated rates of denitrification produced by cattle trampling would be sustained as the process will become limited by the availability of NO_3 produced by aerobic bacteria. Plants capable of convective gas flow (e.g. *Phragmites* spp, *Typha* spp., also see Brix et al. 1992) can increase aeration around their roots and produce aerobic and anaerobic zones in the soil that enhance rates of nitrification denitrification.

P adsorption: The capacity of sediments to adsorb P is influenced by soil type and sediment aeration. P is adsorbed by soils (i.e. adheres to soils particles and unavailable for uptake by plants) when it reacts with iron, aluminium, calcium and other ions in the presence of oxygen, and is released under anaerobic conditions. Wetland soils that are anaerobic or have a low concentration of these elements have limited capacity to buffer P additions from livestock. Temporal changes in sediment aeration will alter the levels of P adsorbed by the soil and produce fluctuations in water column concentrations.

Pathogens

Livestock faeces contain a range of pathogens including bacteria, protozoans and viruses that can cause disease in both livestock and humans. Studies examining the influence of livestock on the presence of pathogens in surface water have found that livestock increase levels of faecal coliform and streptococci bacteria –bacteria used as indicators of the presence of pathogens in surface water (Johnson et al. 1978 in Kauffman and Krueger 1984).

The pathogens most likely to be found in surface water that pose a risk to human health include various strains of the bacteria *Escherichia coli*, *Campylobacter* spp. *Cryptosporidium parvum* and *Giardia duodenalis* (the latter two are protozoans) (Billington et al. 2011). An assessment of public health issues associated with stock accessing waterways upstream of drinking water off –takes in Victoria found *Cryptosporidium parvum, Salmonella* spp., *Campylobacter* spp. and *Escherichia coli* to be the most important hazards to public health.

Response modifiers

Studies examining the level of protozoan pathogens present at grazed sites found that the influence of livestock was variable.

Habitat use by other fauna: In some cases livestock exclusion increased the use of the habitat by wildlife which also shed these pathogens in their faeces resulting in high levels of contamination (Doran & Linn 1979; Doran et al 1981).

Type and age of livestock. The prevalence of pathogens shed by livestock varies with livestock type, age and feeding system (i.e. feed lot or pasture). For example, the concentration of *Cryptospordium* spp. is higher in the manure of calves than it is in the manure of lambs. Concentrations of *Cryptospordium* spp. decrease greatly with age in both cows and sheep and restricting access of juvenile livestock is considered an important management intervention to reduce the risk of pathogens in waterways (see Billington et al. 2011. for a detailed account).

Site features: the extent to which pathogens contained in livestock manure are transported into waterways will be modified by rainfall events, the slope of the land, vegetation cover and the width of the riparian zone from which livestock are excluded from the waterway (Billington et al. 2011)

Depleted oxygen levels in the water column

Livestock excretions can deplete water column oxygen concentrations by increasing biological oxygen demand either directly when faeces are deposited in the water, or indirectly when they increase the availability of nutrients and stimulate primary productivity. Increased primary production can lead to increased detrital inputs into the water column and increases biological oxygen demand. If nutrients enter the water column they can trigger algal blooms, and increase biological oxygen demand when the bloom collapses. Where oxygen demands exceed supply, oxygen becomes depleted.

Response modifiers

The risk of oxygen depletion increases as water temperatures rises, as at higher water temperatures the concentration of oxygen that the water column can hold is depressed. Grazing can also increase water column temperatures by reducing the cover of vegetation that shades the water column (Belsky et al 1999).

3.1.1.3 Herbivory

Susceptibility to herbivory is influenced by two factors; (1) the preference of the grazing animal for particular species over other species and (2) the sensitivity of the species to grazing. Herbivory, along with trampling, causes reduced plant cover, biomass, height, diversity and abundance, as well as the loss of particular lifeforms with accompanied changes in canopy structure. Responses of vegetation to grazing are highly variable and the most commonly observed are detailed in Table 1.

Response modifiers

A review of 35 studies examining the responses of Australian rangeland flora to grazing found responses to be highly variable - 41.5% of the 324 species monitored in more than one trial responded inconsistently to grazing (Vesk and Westoby 2001). The more often the response of a species to grazing was recorded, the greater the variability observed. The authors concluded that context is important in predicting responses of flora to grazing. Some of the contextual variables that are likely to influence vegetation response to grazing are outlined below.

Evolutionary history of grazing pressure: In plant communities that have evolved with heavy grazing by large herbivores, grazers do not strongly prefer one plant species over another and grazing pressure is more evenly distributed among species. Under these conditions it is less likely that a particular species will be eliminated by grazing and for diversity to decline. In these systems, grazing helps to maintain diversity and grazing removal leads to a reduction in plant diversity. In Australia, where the flora has not evolved in the presence of heavy grazing by large ungulate (hoofed) herbivores the introduction of livestock has produced catastrophic impacts on soils, plant and faunal communities and landscape processes (Lunt et al. 2007b). Although Australian ecosystem have evolved with grazing pressure from native animals such as kangaroos they remain sensitive to very high levels of grazing pressure (Lunt et al 2007b). Australian wetlands are frequently subject to grazing by avian species, but these have a lesser impact on vegetation and soils than do heavy livestock such as cattle (Reeves and Champion 2004). As much of our understanding of grazing comes from regions with an evolutionary history of grazing it is unclear to what extent the patterns observed in these systems applies in Australia.

Historical exposure to grazing: In sites that have been grazed in the past, sensitive plants are likely to have been eliminated leaving only grazing tolerant species. Introducing grazing at these sites would be expected to have a lesser impact on vegetation than at rarely grazed/ ungrazed sites where grazing sensitive species are likely to have been retained (Lunt et al 2007b).

Total grazing pressure: Grazing pressure exerted by domestic stock can be exacerbated by grazing by wild exotic and native herbivorous mammals including feral goats, kangaroos, donkeys, rabbits, horses, pigs and camels (Fisher et al. 2004). Where there is significant grazing by wild herbivores the level of livestock grazing that can be sustained will be greatly reduced. An understanding of total grazing pressure, along with the productivity of the land is needed to determine livestock grazing densities that are sustainable (Fisher et al. 2004).

Disturbance, productivity and regional species pool: Intermediate levels of disturbance such as grazing have been shown to increase diversity (Grime 1973). However, the influence of disturbance on diversity is modified by both the productivity of the site and the regional species pool (Grime 1973, Frank 2005, Jones et al 2011).

It has been well established that interactions between productivity and grazing influence plant diversity and community assemblages (Olff and Ritchie 1998; Proulx and Mazunder 1998, Bakker et al. 2006). In productive systems, where resources for plant growth are not limiting, competitive species with fast growth rates can gain dominance, excluding other species and reducing diversity (Grime 1973). In these systems disturbance such as grazing can create gaps in vegetation that increase the availability of light, space and nutrients and provide opportunities for other species to establish and increase diversity. Where livestock preferentially graze dominant species, competitive interactions are weakened and diversity is favoured. Grazing in productive systems also prevents an accumulation of leaf litter which suppresses germination and early establishment (van der Valk 1986, Carson and Peterson 1990). The positive influence of livestock on diversity in productive systems may only apply if the competitive dominant species are palatable and within reach.

The relationship between diversity and disturbance in productive systems is also influenced by the number of species that are capable of living in the community- the regional species pool. Where the regional species pool is large and propagules (seeds and/or vegetative fragments) reach the wetland, it is more likely that a species will arrive that can exploit new niches created by disturbances such as grazing than when the species pool is small (Jones et al. 2011). In semi-permanent and permanent wetlands in Canada, with similar levels of productivity, intermediate levels of grazing increased diversity in the semi-permanent wetland which had a higher regional species pool than it did in the permanent wetland, which had a lower regional species pool (Jones et al. 2011).

Although disturbances such as grazing can prevent the competitive exclusion of species in productive systems and favour more diverse communities, in unproductive systems disturbances can cause diversity to decline (Proulx and Mazunder 1998). In low productivity systems growth is restricted by resource availability and recovery from grazing or other forms of disturbance is slow. In these systems grazing brings no benefit but increases the risk of local extinction and with it reductions in diversity (Proulx and Mazunder 1998).

A global review by Proulx and Mazunder (1998), encompassing a broad range of ecosystem types including lakes, streams, grasslands, marine and forest systems, concluded that grazing increases diversity in nutrient rich sites but decreases it in nutrient poor sites. Species richness was found to increase under high grazing pressure in 60% of the nutrient rich sites. In contrast, species richness declined in 100% of the nutrient poor sites. A similar response has been reported in response to soil moisture availability (Fujita et al. 2009), with diversity increasing in response to grazing in wet low lying zones and decreasing in dry upland zones of a Mongolian pasture.

These studies support the hypothesis that the effect of grazing on plant diversity is modified by productivity. These studies have been performed predominantly in regions with an evolutionary history of grazing by large herbivores. However, several Australian studies indicate that interactions between productivity and grazing may be similar to those reported elsewhere. Vesk and Westoby (2001) found that species number was more likely to decrease in response to grazing in areas of lower rainfall than in areas of higher rainfall. Grazing studies conducted in various vegetation communities within the Gwydir wetland (NSW) found that grazing increased diversity in the productive Marsh Club Rush (*Bolboschoenus fluviatilis*) community but decreased it in the low productivity Warrego Summer Grass (*Paspalidium jubiflorum*) community (Berney 2010).

Alpine and subalpine wetlands are low productivity habitats as conditions are only suitable for plant growth for a short period and soils are acidic and low in nutrients. These systems are considered very sensitive to disturbance including grazing and trampling (Williams and Costin 1994). *Sphagnum* is often a key component of the plant community and forms a layer that is inherently soft and usually saturated, as is the underlying peat and is very susceptible to trampling from livestock (White 2009). The hard hooves of livestock compacts and damages the *Sphagnum* and underlying peat and creates channels which increase drainage leading to reduced water retention (Trimble and Mendel 1995, White 2009). This initiates drying of the peatland and further loss of *Sphagnum* and other vegetation. The combination of drying and loss of overlying vegetation exposes the peat layers to oxygen and accelerates decomposition. This further reduces the systems water retention properties and increases the risk of wildfire (Tallis 1983) and wetland loss (van Breemen 1995).

Type of grazing animal: Grazing animals differ in the type and amount of vegetation they consume, the areas they access within the wetland and the way they graze. Consequently the type of grazer will strongly influence vegetation responses.

A comparison of grazing pressures exerted by different types of livestock is given in Table 3 & 4. Grazing pressure represents the dry mass of vegetation consumed per animal per day. Dry sheep equivalent (DSE) is used to express grazing pressure for a range of animals of different body sizes in equivalent terms to sheep (Fisher et al. 2004). DSE is the standardised body weight equivalent of a single sheep (*Ovus* spp.). Grazing pressure varies with the type of grazing animal and is higher in cattle than goats and kangaroos (Table 4). Grazing pressure varies with sex and life stage (Table 4).

Table 3. Comparison of grazing habits for some livestock (Burritt and Forst 2006, Lu 1988)

Grazing features	Comparison among grazers
Grazing pressure	1 cow = 8 sheep=11 goats= 12 kangaroos= 133 rabbits
Selective grazing	goats> sheep > cattle
Enter inundated areas	cattle≥ goats>sheep
Dietary preferences	cattle: grasses sheep: forbs goats: versatile feeder; woody plants & grasses; tolerant of plant chemical defences
Graze close to the ground	Sheep = goat> cattle
Containment	cattle are easier to muster and require lower fencing standards for containment than sheep or goats

Table 4. Dry sheep equivalents (DSE) for different types of stock under Australian conditions (Jansen and Roberston 2001, modified from Denney et al. 1990). Dry sheep equivalents (DSE) is the standardised body weight equivalent of a single sheep (*Ovus* spp.), based here on a 45 kg animal.

Type of animal	Sex/Life stage	Dry Sheep Equivalents (DSE)
Sheep	Rams	2
	Wethers	1
	Ewes	1.5
	Weaner lambs	1.5
Cattle	Bulls	14
	Steers	9
	Cows	8
	Cows and calves	15
	Weaner calves	6
Goats		0.73
Kangaroos		0.67

Selective grazers exert greater pressure on their preferred species causing some species to be eliminated. In general, small herbivores are more selective than large herbivores (DEEDI

2011). Large grazers, such as cattle are unable to graze selectively due to the size and shape of their mouth; they consume large amounts of fibrous herbaceous plants, particularly grasses. Sheep can graze more selectively than cattle, preferring forbs but consuming succulent grasses when available. Sheep generally avoid wet marshy areas and are less adapted to grazing tall dense vegetation than cattle (Burritt and Frost 2006). Goats are more selective in their diet than cattle or sheep and unlike sheep will graze in wet areas. They can remove leaves from woody species and are more tolerant of plant chemical defences than cattle or sheep (Burritt and Frost 2006).

Differences in grazing pressure, diet and behaviour of different types of livestock can be exploited to control specific weed infestations (see section 3.2.1. for examples). However, studies that compare the effects of different types of grazing animals on native vegetation communities are generally lacking. A review on the effects of grazing on Australian rangeland flora found that vegetation change was weakly correlated with the type of grazing animal (Vesk and Westoby 2001).

Duration of grazing: Vegetation may show good initial recovery from grazing due to carbohydrate reserves stored in underground tissues and seed banks. However, continued grazing will tend to deplete these reserves over time. Resilience will vary with the initial condition of vegetation, the abundance and longevity of seed stores and the level of grazing pressure applied. Grazing of native grasses in the understory of a Eucalypt woodland in northern Queensland was resilient to high grazing pressure (representing consumption of 75% of plant biomass) in the first year but recovery from grazing declined thereafter (Ash et al 2002).

Type of vegetation: The susceptibility of plants to grazing will vary depending on their palatability, whether they are within reach of grazers, their regeneration requirements, life history strategy and susceptibility to trampling and soil compaction. Examples of the varied response of plant communities to grazing are discussed below.

In subalpine grasslands grazing creates bare ground which enables shrub seedlings to establish and reduces the survival of the dominant grass Soft Snow-grass (*Poa hiemata*). Shrubs that are unpalatable and capable of regenerating from buds persist under grazing and may encroach upon grassland species. In contrast, shrubs that are palatable and can only regenerate from seed are suppressed by grazing (Williams and Ashton 1987).

Graziers in the Macquarie Marshes report that grazing increases the diversity of understory species in communities dominated by tall productive herbaceous species including Common Reed (*Phragmites australis*) and Cumbung (*Typha* sp.) (Holmes et al. 2009). Similarly in the Gwydir Wetlands (floodplain wetlands of the northern Murray-Darling Basin) grazing also increased diversity in Marsh Club Rush (*B. fluviatilis)* communities, a tall, productive and palatable species (Berney 2010, Holmes et al. 2009). In contrast, grazing reduced diversity of the low productive Warrego summer grass (*P. jubiflorum*) community. Grazing in both *B. fluviatilis* and *P. jubiflorum* communities within the Gwydir Wetlands favoured species with a prostrate and/or ruderal growth form. In plant communities already dominated by prostrate species, grazing is likely to maintain their dominance- Water couch (*Paspalum distichum*) is a short native, highly palatable perennial grass which maintained dominance when grazed.

In frequently inundated areas plant communities are dominated by amphibious responder species. Cattle frequently utilise these areas to access water, exposing plants to high levels of trampling. Amphibious responders are particularly vulnerable to trampling because they have minimal structural tissue, relying on the water column for support. Grazing in inundated zones was found to reduce the cover of amphibious responder species compared with ungrazed sites (Holmes et al. 2009: Wilson et al. 2008, 2009).

Weeds: Many studies show an increase in either the number or cover of weed species in response to grazing, including alpine systems (Walsh et al. 1984, Victoria; Gillieson 2004, Australia), riparian systems (Jansen and Robertson 2001, Murray-Darling Basin, Australia), flood-prone grasslands (Chaneton et al. 2002, South America) and wetlands (Jones et al. 2011, Canada; Silvers 1993, Australia).

Compositional change in wetland plant communities in response to grazing will be strongly influenced by the regional species pool that can respond to gap creation and changes in resource availability produced by grazing. Where invasive species comprise the regional species pool livestock grazing can result in the establishment of new incursions of invasive flora or increase the cover of those already present (Oesterheld and Sala 1990). In the Barmah Forest, proximity to farmlands which provide a source of weeds was considered an important factor contributing to weed invasion along with flooding and grazing (Silvers 1993). There is also growing recognition that livestock movements contribute to the dispersal of invasive flora (Hogan and Phillips 2011, see section 3.1.1.4).

Water regime: Water regime influences plant responses to grazing in three ways: (1) influencing areas accessible to grazers, (2) changing the prevalence of plant species preferred by grazers and (3) increasing susceptibility of plants to submergence (Voslamber and Vulink 2010, Marty 2005, Berney 2010, Middelton 1990). When water levels are low grazing animals have greater access to vegetation and palatable plants may be grazed throughout the growing season. Under low water levels grazing by cattle and horses reduced the cover of Common Reed in the Netherlands and altered the types of waterbirds that visited the site. Higher cover of Common Reed was preferred by breeding grebes and marshland passerines, while < 10% cover of Common Reed increased visitation by Eurasian spoonbill, smew, herons, ducks, waders and rails (Vulink et al. 2010).

In contrast, periods of high water levels restrict grazing to shallow areas and enables plants in deeper zones to recover and regenerate. Permanent freshwater wetlands may however experience high grazing pressure in the wetland buffer and in the shallow wetland margins when they provide a source of drinking water or cool conditions in hot weather

Compositional changes of vegetation in responses to changed water regimes can cause grazing pressure to shift to different species (Berney 2010). In the Gwydir wetland, NSW, livestock grazed low-growing species along the edge of Marsh Club Rush stands in preference to Marsh Club Rush, but in drier years grazing pressure on Marsh Club Rush increased as the unpalatable Lippia (*Phyla canescens*) invaded (Berney 2010). In a Mongolian pasture differences in productivity associated with soil moisture produced different responses to grazing. In wet low lying zones grazing increased species diversity but in dry upland zones it decreasing it (Fujita et al 2009).

Grazing combined with submergence reduces growth and survival of emergent plants more that either factor alone. A number of studies that have simulated grazing by clipping plants have shown that submergence exacerbates the effects of grazing on plant growth and causes mortality in some emergent species (Middleton 1990, Blanch and Brock 1994, Oesterheld and McNaughton 1991).

3.1.1.4 Transport of plant seeds in faeces and fur

There is growing national and international concern about the significance of livestock movements in the dispersal of invasive flora (Hogan and Phillips 2011). Seeds are readily dispersed by livestock through: (i) attachment to coats, (ii) consumption and excretion in faeces and (iii) vehicles used to transport livestock when they become contaminated with faeces and dirt (Hogan and Philips 2011). A study examining the role of cattle dung in dispersing seeds in Flooding Pampa grasslands of Argentina found that ~33% of species in the grassland germinated from cattle faeces and concluded that the dispersal of seeds of invasive species in cattle faeces contributed to weed invasion in this ecosystem (Vignolio and Fernández 2010).

Response modifiers

The effectiveness of livestock in dispersing plant seeds depends on both the traits of the seed and the type of grazing animal.

Plant traits: Seed traits that favour dispersal by livestock include the presence of barbs or mucilage that enhances the attachment of seed to the animals coat and the tolerance of seeds to passage through the gut. Plants that produce abundant seeds increase the likelihood of dispersal.

Type of animal: Although gut passage decreases germination, cattle faeces create gaps in vegetation and provide a moist, nutrient rich environment that can facilitate early establishment (Vignolio and Fernández 2010, Gardener 1993, Hogan and Phillips 2011). It has been estimated that at stocking rates of 4 cattle ha^{-1} dung pats will cover ~12% of the pasture each year, creating gaps in which seeds subsequently germinate. Small faecal pellets produced by sheep do not create environmental conditions conducive to seed germination and establishment.

3.1.2 Benefits of grazing

The complete exclusion of livestock is recommended in sites that are intact, uninvaded and unproductive, or contain vulnerable vegetation communities or rare or threatened species (Lunt et al 2007b). Grazing should also be prohibited when it is likely to alter landscape processes (e.g. water drainage in alpine areas) or result in weed invasions. Despite these recommendations there are certain conditions in which grazing can be beneficial if carefully managed. Grazing may be considered beneficial if it delivers social, economic or ecological benefits. Social benefits may result when grazing creates areas of open water that favour waterfowl species for hunting or facilitates boat access. Economic benefits may result when livestock production is profitable. Grazing can also deliver ecological benefit under certain circumstances. In this report we examine only the potential ecological benefits of grazing (Figure 3).

Possible favourable outcomes of grazing in natural ecosystem in Australia have been outlined by Lunt et al (2007b) and are described below.

- Control the biomass, or prevent the establishment or encroachment of potentially dominant grazing sensitive plants (native or exotic).
- Promote seed germination and plant establishment by reducing the leaf litter layer.
- Provide disturbance niches required by rare or significant plant species.
- Maintain habitat structure for particular faunal species.
- Enhance the diversity of species and vegetation structure across the landscape

Grazing may be used to control the biomass of competitive undesirable species (invasive or native) or to prevent their establishment or expansion (Lunt et al. 2007b). Grazing is used in European and US wetlands to control competitive species (van Deursen and Drost 1990; Vulink et al. 2000) and to manage particular weeds. Cattle have been used to control several alien aquatic species including willows, Reed Sweet Grass (*Glyceria maxima*) and Reed Canary Grass (*Phalaris arundinacea*) (Reeves and Champion 2004)). Goats have been used to control invasive woody plants in wetland meadows (Reshetiloff 2009) and invasions of Common Reed in the US (Brundage 2010). Controlling competitive undesirable plants groups can help maintain or restore species diversity (Brundage 2010) and habitat structure preferred by certain faunal groups such as waterbirds (Vulink et al. 2000). In some cases habitat niches generated by grazing can allow rare or significant species to establish, although examples for wetlands are lacking.

Reduced litter, bare ground and canopy gaps created by livestock grazing can be beneficial when it increases the germination and establishment of desirable plant species and enhances diversity. In landscapes where vegetation communities are homogenous, particularly in ungrazed landscapes, grazing can create patches of vegetation with different structure favouring different faunal groups and enhancing biodiversity at a landscape scale (Lunt et al. 2007b).

As grazing can reduce the accumulation of dead biomass in productive systems grazing has also been proposed as a means of reducing the risk of wildfires. In California, targeted grazing with sheep and goats is increasingly applied to reduce fire fuel loads and create firebreaks at interfaces between urban areas and bushland (Launchbaugh and Walker 2006).

It is likely that the appropriateness of grazing to reduce the risk or intensity of wildfires will differ among wetland types. In alpine and subalpine wetlands grazing is likely to increase, rather than decrease, the risk of wildfires. This occurs as livestock damage the hydrological structure of peatlands by creating channels and causing water to drain from the wetland (see section 3.1.1.3). High moisture content is an important factor in reducing the risk and impact of fire in these systems (Tallis 1983).

For other wetland types in Australia there is currently insufficient research to assess if grazing is an effective strategy to manage the risk of wildfires. The effectiveness of livestock grazing in reducing fuel loads relies on livestock selecting plants that produce a fuel hazard (DNRE 1996). Even where it can be demonstrated that grazing reduces the risk of wildfires, the level of grazing required to achieve this is likely to increase erosion, nutrient enrichment and result in the loss of flora and fauna. These impacts are likely to outweigh any fuel reduction benefits. In these cases the use of grazing to manage the risk of wildfires is inappropriate (DNRE 1996).

The potential benefits of grazing outlined here will only be realised if the target species are accessible to grazers and preferred over non-target species, when gaps created by grazers are not colonised by invasive or undesirable grazing tolerant species, and when the impacts on non-target species are minimal and closely monitored. Even when some benefit may be derived from grazing, other impacts such as soil compaction and degraded water quality will occur and need to be weighed up against the likely benefits.

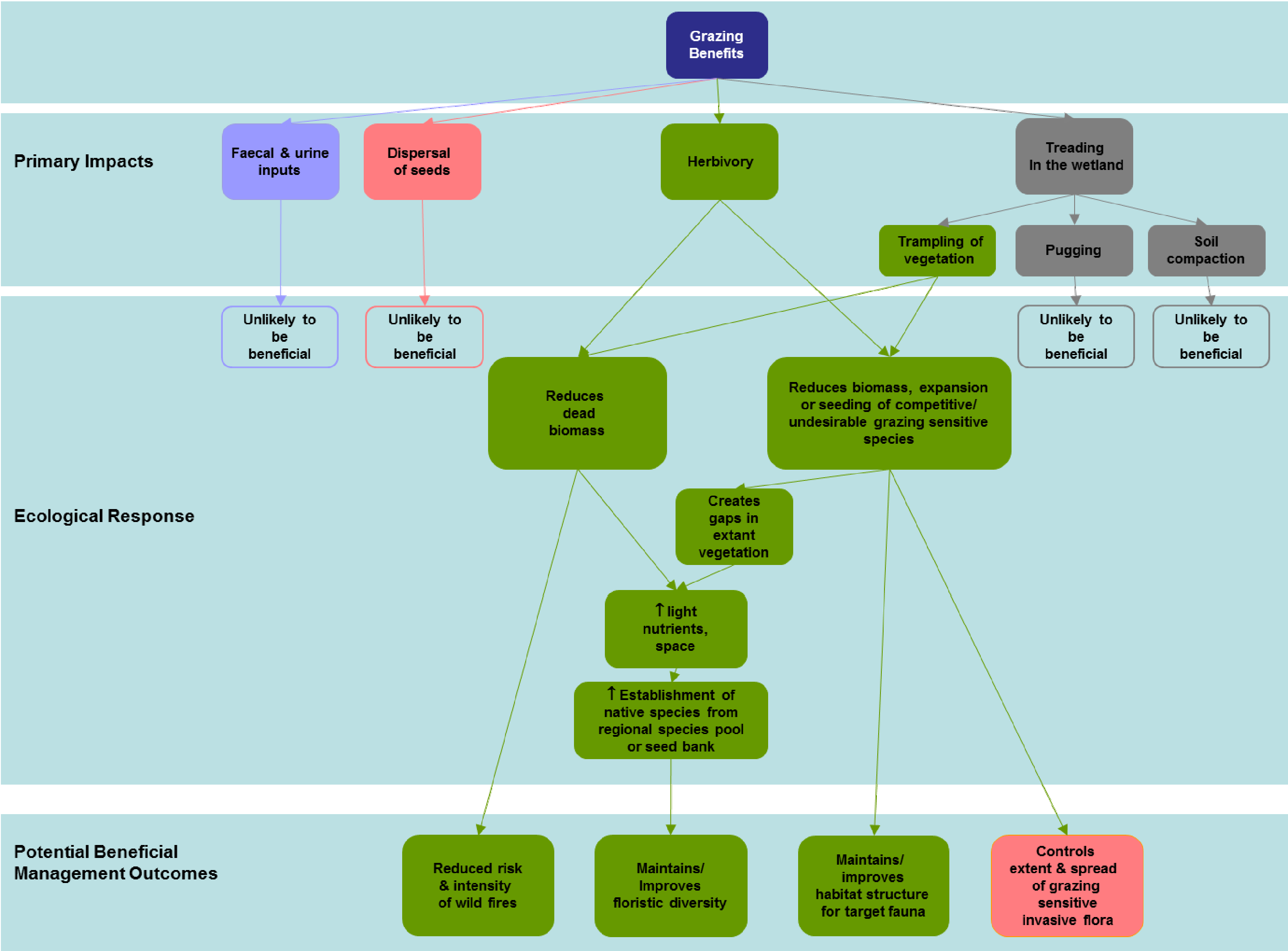

Figure 3. Primary impacts and ecological responses of wetlands to livestock grazing and their potential beneficial management outcomes. Colours represent variables associated with different wetland condition attributes: green, vegetation; pink, invasive flora; grey, soil properties; purple, water quality

Alternative management strategies such as the targeted use of herbicides, mowing, harvesting and fire may achieve the same vegetation management goals as grazing (Reeves and Champion 2004). The ecological, economic or social implications of each control strategy should be evaluated in deciding on an appropriate control strategy. Grazing may be economically more viable when large infestations require control and/or where access is difficult (Launchbaugh and Walker 2006). In the US targeted grazing by sheep and goats has proven to be a cheaper and more effective strategy than herbicide treatment or mechanical removal in controlling expansive infestations of several invasive species including: Leafy Spurge (*Euphorbia esula*), Kudzu (*Pueraria montana* var. *lobata*), Spotted Knapweed (*Centaurea maculosa*). In Montana and North Dakota sheep and goats are used to control Leafy Spurge costing 60c per acre – compared to $35 per acre for aerial herbicide spraying (Launchbaugh and Walker 2006). A US study examining the efficacy of goats in controlling invasion of Common Reed concluded that grazing by goats reduced Common Reed biomass and increased species diversity without any apparent detrimental effects (Brundage 2010).

3.2. Grazing management practices

In some wetland systems, the careful management of grazing can prevent or reduce adverse impacts on wetland condition, and in some cases controlled grazing may exert a positive effect on some aspects of wetland condition. In other systems even low levels of grazing will degrade wetland condition necessitating the complete exclusion of livestock.

Grazing is often managed to achieve one or more of the following objectives:

- Provide food and water for livestock with minimal impact on the ecological attributes of the wetland.
- Modify or maintain habitat structure for particular fauna (e.g. waterbirds).
- Control competitive species to improve biodiversity values.
- Control invasive flora.
- Reduce the risk of wildfire.
- Manage vegetation to support the social values of the wetlands (e.g. controlling vegetation to favour game birds and boating access).

The variety of grazing management strategies that may be applied are describe in Table 5 along with their potential benefits and risks. The selection of particular strategies should be based on the management objectives, the plant communities that are present, the current condition of the wetland, and the influence of response modifiers as described in Table 6 (e.g. productivity, risk of weed invasion or spread, nutrient buffering capacity).

Grazing management strategies manipulate the type and or the number of grazing animals, the timing or duration of grazing, and/or the areas that livestock access. In most cases ecological responses to grazing management are anecdotal and the relative merits of various practices remain uncertain. The exceptions are the complete exclusion of livestock and reductions in grazing intensity which have been subject to more rigorous experimental treatment to elucidate the impacts of grazing and are reported in Section 3.1.1 and Table 1.

Experimental studies of these management practices demonstrate that ecological responses to grazing management are highly variable and that context is important in predicting grazing responses. Further research is still needed to verify the influence of response modifiers before greater confidence in grazing management practices can be achieved.

Table 5. A description of grazing practices along with potential benefits and risks to wetland condition. (DSE, dry sheep equivalents)

Management Practice	Description	Potential Benefits	Potential Risks
Continuous/ Set stocking	Continuous grazing is the traditional grazing practice in Australian wetlands (Casanova 2007). Under continuous grazing, livestock graze the site all year with no significant regular spell periods.	In some cases low stocking rates may help to: • control palatable invasive species • manage habitat structure if dominant vegetation is palatable. However, these benefits are more likely to be achieved through controlled grazing regimes.	• Grazing pressure can vary spatially and temporally resulting in some areas being overgrazed even at acceptable stocking rates. • Under low stocking densities stock can selectively graze, resulting in the decline of palatable species. • When the availability of forage is low, set stocking practices can lead to overgrazing and compound impacts on vegetation (Hunt 2001 in Fisher 2004). The availability of forage may decline in wetlands when they dry or experience other disturbances such as fire, saline intrusion, or grazing by wild animals (native and/or exotic). • Even low stocking rates may impact on water properties, soils and vegetation.
Complete exclusion	Fencing to permanently exclude livestock (DSE 2012).	• Eliminates further impacts associated with grazing. • Most applicable to sites that are: (i) intact, (ii) unproductive, (iii) uninvaded; (iv) have grazing sensitive significant/rare/threatened flora; (v) where grazing will impact on landscape scale ecological process (e.g. drainage in alpine peatlands).	• Complete exclusion may not be beneficial when there is a high risk that palatable competitive species (exotic or native) are present or likely to establish and become dominant and exclude less competitive species. • Other threatening processes such as altered water regime or salinity may prevent revegetation success following livestock exclusion. • Loss of structural diversity at the landscape scale, where there are expansive areas of homogenous vegetation, particularly in ungrazed landscapes (Lunt et al 2007b).

(continued next page)

Table 5. Continued

Management Practice	Description	Potential Benefits	Potential Risks
Exclusion and revegetation	Complete exclusion and revegetation (DSE 2012).	• Used to re-establish native vegetation (particularly trees and shrubs) when it is unlikely to recover naturally once grazing has been excluded.	• Other threatening processes such as altered water regime or salinity prevent revegetation success. • Increase in the number and cover of invasive plants requiring control measures.
Partial exclusion	Exclude some parts of the landscape from grazing to maintain native species (Fisher et al. 2004).	• Protects native flora and helps to maintain native plant propagule sources. • May provide a refuge for native fauna • May maintain landscape connectivity for some species.	• Increase in the number and cover of invasive plants or feral animal within exclusion areas that require control (Fisher et al. 2004). • Other threatening processes such as altered water regime or salinity prevent species persistence despite livestock exclusion. • Protected vegetation may still be adversely affected through the impact of grazing on water properties and adjacent soils.
Manage stocking rate	The stocking rate is the number of livestock per unit area of land. The number of livestock that a pasture can support is determined by the amount and quality of forage available which varies with flooding regime, season, grazing history and local climatic conditions. Conservative stocking rates should be applied to accommodate temporal and spatial variation in pasture availability and should be based on the most sensitive parts of the system (Holmes et al. 2009). Varying stocking rates based on the availability of forage helps prevent overgrazing and ensures high livestock production (see set utilisation).	• Stocking rates of 0.3-1 head of cattle /ha have been recommended to protect wetland values whilst providing some level of disturbance needed to maintain species diversity in productive systems (Wilson et al. 2008). • Varying stocking rates to match forage availability prevents overgrazing vegetation.	• The higher the stock rate the greater the impact on wetland attributes. • Stocking rates of 7.4 -12.1 DSE/ha in the Gwydir wetlands are not considered viable in the long term (Holmes et al 2009).

(continued next page)

Table 5. Continued

Management Practice	Description	Potential Benefits	Potential Risks
Set utilisation	Pasture utilisation is the percent of forage growth in a year that is consumed by livestock (Ash et al. 2002). For example, 50% pasture utilisation is where half of the total dry biomass produced for the year is consumed by livestock. Stock numbers are determined from models that predict the forage available at the end of the growing season and the requirements of stock. Recommended utilisation rates are between 10%-30%.	• Continuous stocking at 25% utilisation or early wet season spelling followed by 50% utilisation maintains land in good condition (Ash et al. 2002). • Overall the condition of degraded sites improved, but the response across the site was patchy (Ash et al. 2002).	• Overgrazing from incorrect predictions of pasture production. • Recovery of vegetation to a particular utilisation rate will vary with climatic conditions (e.g. drought) soil condition and fertility. • Response lags: resilience of productive, palatable, native perennial grasses to high utilisation rates declined after a couple of years. (Ash et al. 2002).
Manage total grazing pressure	When determining stocking rates the grazing pressure exerted by all grazers in the system should be considered. This includes livestock and both native and feral animals.	• Allows livestock grazing rates to be adjusted to take into account the grazing pressure exerted by grazing animals other than livestock.	• Difficult to assess total grazing pressure. Underestimates will lead to overgrazing.
Targeted, controlled or strategic grazing	Where grazing regimes are modified based on local conditions (e.g. ground cover, regeneration, inundation phase, water quality) and are designed to achieve a vegetation management outcome (e.g. eliminate weeds, permit native plant regeneration, maintain habitat structure for waterbirds) (Launchbaugh & Walker 2006). May utilise a variety of grazing management approaches to achieve a specific management outcome (e.g. pulse grazing to sustain native pasture, crash grazing to reduce exotic annual grass seed fall and seasonal tracking to reduce grazing pressure on forbs and perennial natives.	• Travelling stock reserves (TSR) are remnants of native vegetation in NSW that were originally reserved in the 1800s for use by travelling stockmen to move livestock between pastures and to market. Strategic grazing is used to improve the conservation value of TSR (Davidson et al. 2005). (see benefits of practices below).	• Requires a high level of skill and monitoring. Incorrect decisions or inadequate monitoring may lead to unintended impacts.

(continued next page)

Table 5. Continued

Management Practice	Description	Potential Benefits	Potential Risks
Seasonal tracking	Livestock are restricted, reduced or exclude from pastures in accordance with seasonal conditions, forage availability and growth period of natives. *Key periods to avoid grazing*: o soils are saturated o native plants are establishing o replanting has occurred o native species are releasing seed o events that trigger germination of native species (e.g. heavy rain, fire, floods) o during very dry periods when plant growth is reduced. *Permit grazing* o when weed abundance is high and prior to seed set of exotics.	• Prevents overgrazing vegetation when growth is restricted by unfavourable conditions (e.g. drought). • Allows for regeneration of natives. • Reduces the severity of pugging and soil compaction. • Can be used to control invasive flora. • Seasonal tracking is used in the management of the Travelling Stock Reserves (NSW). Grazing during the early growth of annual plants (late winter early spring) is thought to favour native forbs and perennial grasses that have a summer growth phase (Davidson et al. 2005). Crash grazing is also used to eliminate weeds and every 4 to 5 years to prevent species gaining dominance and excluding other species in fertile floodplains (Davidson et al. 2005). An analysis of the conservation values of TSR has shown that spring grazing intensity is negatively correlated with conservation values (Spooner and Morris. 20012). This confirms the value of seasonal tracking and suggests that grazing to control exotics plants should occur as early as possible (i.e. late winter, early spring) to prevent impacts on establishment of natives).	• Requires a high level of skill. Incorrect decisions will result in unintended impacts (Fisher 2004).

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Table 5. Continued

Management Practice	Description	Potential Benefits	Potential Risks
Rotational grazing and spelling	Usually involves multiple paddock systems to allow spells from grazing. In rotational grazing, a paddock(s) is grazed until a desired residual dry matter level is reached while other paddocks are ungrazed to allow maximum growth and reproduction.	• Thought to reduce grazing pressure on natives and allow them to complete their life cycles. • Rotational grazing combined with re-seeding has been successful in re-establishing some native wetland species (Jackson 1999). • A comparison of continuous and rotational grazing practices in Flooding Pampa, Argentina, found rotational grazing increased leaf litter accumulation reducing the percentage of bare ground and promoted species with high forage value. Species diversity did not change with grazing approach. (Jacobo et al. 2006).	• No evidence that it is ecologically or economically effective (Fischer 2004). • A number of studies show either no benefit or negative effects on vegetation (see references in Jacobo et al. 2006).
Crash grazing	High stocking density for short duration.	• Can be used to reduce seed fall of invasive flora or to open gaps in dense stands of dominant vegetation. • Used by travelling stock reserve managers to control weeds.	• High number of livestock may produce highly compacted soils and a large pulse of nutrient from excrement. • Import and or export of invasive plant seeds if livestock are not purged.
Pulse grazing	Stock are grazed on a range of small paddocks and moved frequently to new paddocks allowing significant regular spell periods.	• Prevents selective grazing, resulting in more even grazing pressure. Spell periods allow recovery of all species.	• Doesn't eliminate other impacts of grazing. • Uncertain if all species recover.
Manage type of grazing animal	Grazing pressures and grazing habits differ among types of grazing animals and life stages and can be exploited to reduce grazing impacts and shift grazing pressure off certain species or areas.	Can be used to: • Shift grazing pressure off particular natives. • Selectively graze particular weeds. • Reduce grazing on wet areas. • Reduce compaction. • Reduce damage to woody vegetation. • Reduce risk of erosion.	• Requires a high level of skill. Incorrect decisions will result in unintended impacts.
Eliminate supplementary feeds	Food is sourced only within the system, creating a closed grazing system where there is no net gain in nutrients.	• Reduces nutrient loads to the system. • Improve water quality.	• Only reduces the impact of grazing on nutrients.

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Table 5. Continued

Management Practice	Description	Potential Benefits	Potential Risks
Managing livestock access within the wetland: (Fisher et al. 2004, Staton 2006)	*Watering points* Create watering points >200 m from unfenced wetland/stream or 100 m from fenced wetland /stream and away from shade clumps (Biograze 2000, Peck 2006). A distance of 3 km is recommended between water points (Staton & O'Sullivan 2006). Avoid placing watering points in areas of slope/channels where excrement will be carried to wetland. Avoid placing in vulnerable areas. If unable to locate water points away from wetland ensure watering points have: o gentle slope (max 1:6) o firm ground or stabilise with gravel o no shelter to discourage stock remaining in the area. o consider fencing to limit access to other areas Use portable watering systems or a large number of permanent troughs that are switched on and off to reduce damage to land around water points by spreading impact over a larger area.	• Reduces direct faecal contamination of water body. • Reduces trampling of vegetation, pugging and soil compaction from frequent treading in wet areas.	• May be insufficient to maintain wetland condition.
	Cattle camps o Establish shady/treed areas on flat ground > 100 m from wetland for cattle to loaf. o If food and mineral supplements are provided place them away from wetland	• Reduces faecal runoff into water body. • Reduces trampling of vegetation, pugging and soil compaction near water body.	
	Stock crossing o Locate stock crossing away from the wetland or stabilise access point with gravel and fence to limit access	• Reduces trampling of vegetation, pugging and soil compaction created by repeated use of an area.	
	Create pastures Water upland areas to create pasture away from wetland. Improve pastures away from wetland by planting palatable species	• Shifts grazing pressure from wetland vegetation to upland pasture.	
Prevent dispersal of invasive flora by livestock (DSE 2012)	*Purging stock* o Prior to letting stock into wetland from a weed infested area allow a period of 1-7 days for ingested seeds to be excreted. Time frame varies with type of livestock and invasive species. o If possible exclude sheep until after shearing o Purge stock after grazing weedy areas within wetland.(DSE 2012) o If livestock are transported between sites ensure good vehicle hygiene to prevent dispersal of weed seeds in soil and faeces carried in vehicle.	• Prevents or reduces weeds entering the wetland.	• Complete elimination of weeds may be difficult to achieve. • Other impacts of grazing are not addressed.

4. Managing grazing despite uncertainty

The growing body of knowledge describing the ecological responses to grazing in wetlands has identified key pathways though which grazing alters wetland condition. In most instances grazing degrades the condition of wetlands and threatens wetland values. The key threats caused by grazing include degraded water quality, soil disturbance, invasive flora, degraded vegetation condition and altered water regime. Of these threats, changes to the water regime are the most poorly documented.

Developing models that quantify the relationships between grazing management practices and changes in wetland attributes is a key priority as it guides the levels of investment needed to achieve management objectives. Although there is a strong evidence base that demonstrates the adverse impact of grazing on many ecological attributes of wetlands, the magnitude of change is highly variable, even when grazing is completely eliminated. Responses to other grazing regimes such as pulse grazing or rotational grazing (Table 5) are even less certain.

The variation exhibited in ecological responses of wetlands to grazing, particularly vegetation communities, limits confidence in management activities and hampers the development of sound management guidelines for grazing in wetlands- a conclusion reached by several grazing studies (Holmes et al. 2009, Reeves and Champion 2004 and reference within). The development of best management practices for grazing in the Gwydir and Macquarie wetland, NSW, concluded that large differences among wetlands in their wetting regime, soils, plant communities and climate make it difficult to apply knowledge of grazing in other areas to a particular system with any level of confidence (Holmes et al. 2009). Similarly, a review of grazing in New Zealand wetlands concluded that grazing decisions need to be based on the conservation objectives of individual sites as responses to grazing were too variable (Reeves and Champion 2004).

This review has identified a large range of response modifiers - variables that modify the impact of grazing on wetland components. Response modifiers can be broadly grouped as those associated with the grazing regime, the individual characteristics of the wetland and its landscape context (Table 6). Although many of these factors are known to influence ecological function and can therefore be expected to influence wetland responses to grazing, there are few studies that specifically demonstrate their influence on wetland responses to grazing. Without a clearer understanding of how these variables influence grazing responses, guidelines based on current knowledge must be developed with caution and adaptive management frameworks should be put in place to safeguard systems from adverse outcomes. To reduce uncertainty in management activities research programs should be undertaken to further our understanding of the role grazing plays in wetlands.

Table 6. List of response modifiers- variables that can alter responses to grazing in wetlands.

Type	Variables
Grazing regime	o timing o intensity o duration o type of grazer o total grazing pressure (grazing by feral and native animal) o historical grazing practices o evolutionary history of grazing
Wetland attributes	o initial condition of the wetland o wetland size o water volume o soil type o vegetation assemblage o water regime o presence of invasive flora/or risk of invasive flora establishing o primary productivity o frequency of disturbance
Landscape context	o surrounding land use o geographical setting (climate, altitude, slope), o regional species pool o connectivity

4.1. Next steps

The variability that characterises wetland responses to grazing presents a challenge to effective, evidence based management. While steps need to be taken to reduce this uncertainty managers are required to make decisions based on existing knowledge. A proposed structure for advancing the management of grazing using our existing knowledge base and for improving our understanding of grazing are described below and summarised in Figure 4.

4.1.1. Using our current knowledge to better inform grazing decisions:

Our current understanding of grazing should be used to (1) refine program logic and (2) develop best practice guidelines for managing grazing in wetlands.

These guidelines should have the following objectives:

- Provide a framework for assessing the sensitivity of wetlands to grazing.
- Guide the selection of appropriate grazing regimes for individual wetlands.
- Embed grazing decisions within an adaptive management framework.

Assessing the sensitivity of wetland systems to grazing

The sensitivity of wetlands to grazing should be assessed using both landscape scale and site based assessments. Landscape scale assessments should evaluate the significance of a particular wetland in the landscape as well as how landscape context may influence its sensitivity to grazing.

Landscape significance should consider the following:

- Rarity of wetland type in the landscape.
- Contributions to habitat complexity at a landscape scale.
- Disruption of landscape services such a drainage functions.
- Role in maintaining connectivity pathways and as a drought refuge.

Landscape contexts that may influence response to grazing include:

- surrounding land use

- geographical setting (climate, altitude, slope),
- regional species pool
- connectivity.

Our current understanding of the variables that influence grazing responses should be used to evaluate the sensitivity of particular wetlands to grazing pressure and inform grazing decisions.

Site-based risk assessments should consider:

- The sensitivity of native and invasive flora to grazing.
- Wetland type (ecological vegetation communities present, salinity, water regime).
- Wetland condition (e.g. changed water regime, vegetation condition, weed cover, salinity).
- Wetland size.
- Grazing regimes.
- The productivity of the site.
- Disturbance regimes.
- The regional species pool.
- The presence of invasive flora in the wetland and the risk of invasive flora establishing.

Sensitivity of vegetation: Grazing management decisions need to ensure the persistence of rare and threatened species and species that are most sensitive to grazing. This requires knowledge of the sensitivity of wetland species to grazing, particularly for rare and threatened species. There is currently no inventory of the sensitivity of wetland plants in Victoria to grazing and assessments rely on NRM and landowner knowledge.

Developing an inventory of grazing sensitivity will assist NRM and landowners to better predict the outcomes of grazing. Where field based information on grazing sensitivity is not known it may be possible to infer sensitivity from plant traits. Species sensitive to grazing are likely to have some of the following features: palatable, minimal structural tissue which makes them sensitive to trampling, adult foliage within the reach of grazers, lack basal meristems, do not reproduce readily from vegetative fragments, specific germination requirements, grow slowly, short lived seed banks, reach sexual maturity slowly and/or produce few seeds. Species that have sensitive juvenile stages may fail to reach maturity preventing regeneration and eventually causing their local extinction.

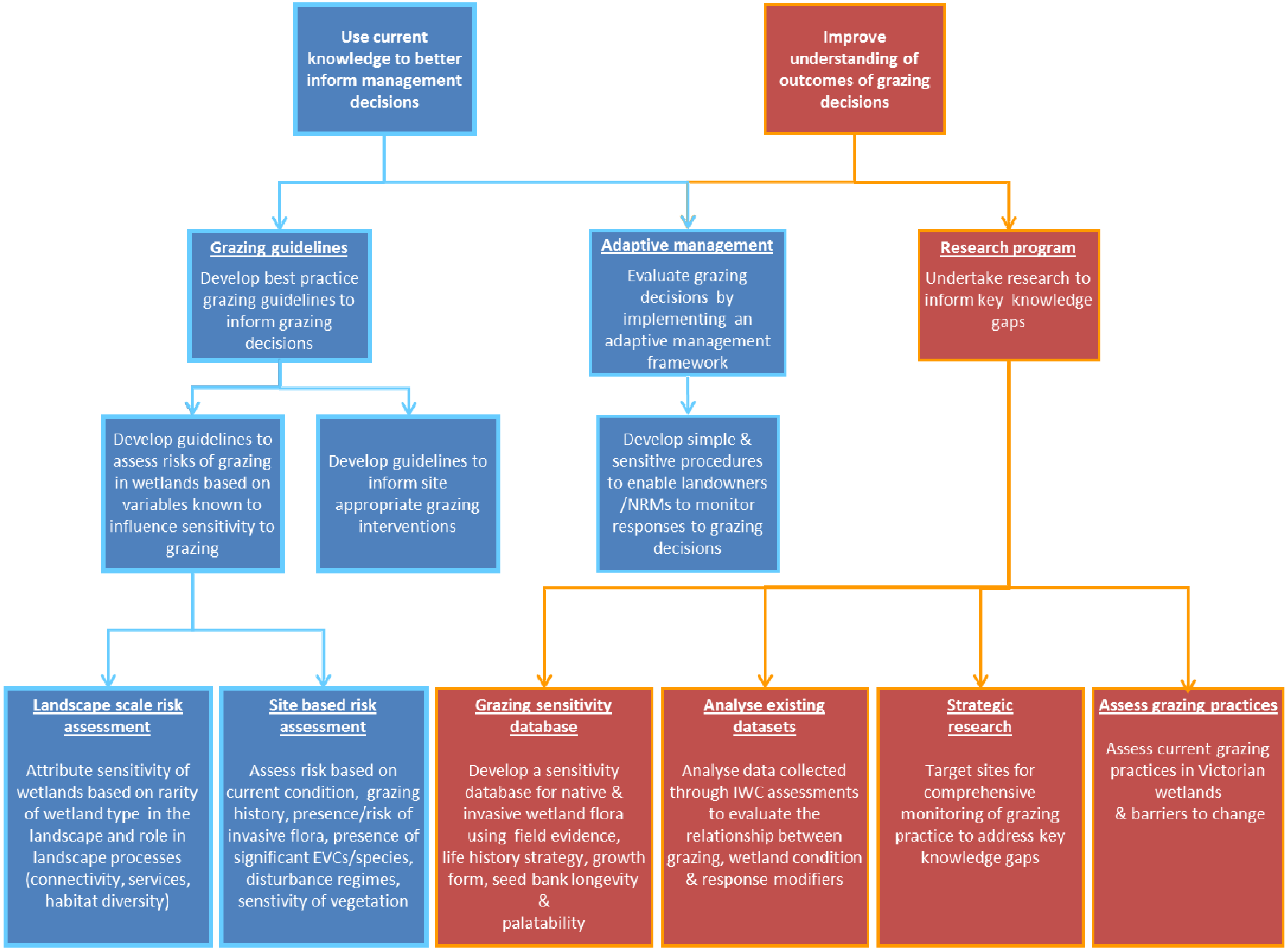

Figure 4. Framework for advancing the management of grazing in wetlands. Blue coloured boxes indicate approaches using current knowledge and red boxes indicated approaches than aim to extend current understanding.

Wetland type: A range of wetland attributes are used to classify wetlands including, but not limited to, landscape context, water regime, salinity, ecological vegetation communities and soil type. There exists some understanding of how these individual attributes influence grazing sensitivity but little is known about how these attributes collectively interact to determine the sensitivity of wetland types, with the exception alpine and subalpine wetlands which are recognised as being highly sensitive to grazing.

Wetland condition: The Index of Wetland Condition (IWC) assessments provide some information about the threats produced by grazing including soil pugging, nutrient enrichment and the condition of vegetation. The IWC also collects data on variables that can assist in assessing the sensitivity of the wetland to grazing including EVCs, weed cover, presences of high threat weeds, salinity and water regime. It is recommended that an index of grazing sensitivity incorporates data collected through IWC assessments as well as additional data to inform grazing sensitivity as detailed below.

Wetland size: The perimeter to area ratio is greater for small wetlands than large wetlands and this means that they are relatively more susceptible to external pressures than large wetlands. In regions where invasive flora is prevalent, small wetlands will be more vulnerable to weed invasion than large wetlands and are therefore more sensitive to weed invasion due to the presence of grazing livestock.

Grazing regimes: The current condition of the wetland, particularly the presence of grazing sensitive species, along with knowledge of the historical and current grazing regimes and grazing pressure from feral and native grazers, can help to inform the resilience of the system to grazing. This knowledge is needed to inform sustainable grazing regimes.

Productivity of the site: It has been demonstrated that grazing can improve the biodiversity of wetlands that are productive, but can reduce biodiversity in low production systems. Although most studies have been conducted in countries with an evolutionary history of grazing it seems likely that this response also applies to countries such as Australia where there has not been an evolutionary history of heavy grazing by large ungulate herbivores (Lunt et al 2007b).

Environmental conditions that constrain primary production such as water availability, temperature, light, nutrients and salinity can be used as latent variables in assessing primary productivity of wetland sites. It is recommended that a process to evaluate wetland productivity be explored which can be used to identify wetlands more vulnerable to grazing. Evaluating temporal changes in productivity in response to changes in resource availability (e.g. rainfall) and/or landuse practices would also prove useful in tracking changes in grazing sensitivity and determining appropriate stocking rates.

Natural levels of disturbance: Disturbances such as fire, grazing by native animals, drought, floods, storms or human activities can eliminate species and provide opportunities new species to establish or may allow inferior competitors to persist. In general, moderate levels of disturbance promote diversity in productive systems while in unproductive systems even low levels of disturbance may reduce diversity. In productive wetlands where natural levels of disturbance are diminished, grazing may help to reinstate the natural disturbance regime. In contrast, if systems already experience high levels of disturbance, grazing may reduce diversity. Evaluating levels of other disturbance in the system such as the frequency of flooding or drought may help evaluate the likely influence of grazing in the system.

Regional species pool: There is some evidence that where the regional indigenous species pool is large, gap creation produced by livestock may provide opportunities for new species to colonise the site and increase diversity. In contrast, where the species pool is small grazing is unlikely to enhance native floristic diversity, and where exotic species comprise a large portion of the regional species pool disturbances like grazing may lead to the establishment of invasive flora.

Invasive flora: Livestock create gaps in vegetation and create habitat niches that can favour the spread of invasive species already present in the wetland or the establishment of new invasive species. The IWC collects information on the prevalence of high threat weeds within the wetland. Evaluating the likelihood that invasive species will be introduced and establish in a wetland in response to grazing pressure should consider: (i) the composition and invasive capacity of the regional species pool, (ii) the likelihood of invasive flora being transported into the wetland via natural dispersal pathways (wind, water, waterbirds) or via livestock and (iii) the likelihood that conditions within the wetland are suitable for establishment. This information coupled with an understanding of the grazing sensitivity of these species can inform likely responses of invasive species to grazing pressure.

Adaptive management to build confidence in management practices:

Much of our understanding of grazing impacts is based on studies that have either completely excluded livestock or reduced stocking rates in previously grazed systems. Although this provides a basis for assigning confidence to these management practices, evidence of the benefits/risks of other management practices are lacking, with anecdotal reports comprising much of the evidence base.

There is a pressing need to develop a more rigorous monitoring and reporting framework around conservation investments related to grazing management. An adaptive management framework, informed by regular monitoring of key attributes is needed to help safe guard against ineffective or adverse management outcomes. This approach will also help to build the knowledge base that will improve confidence in management decisions.

An adaptive management framework should ensure baseline data on historic, current and planned grazing management practices, key ecological indicators and response modifiers are captured. Key ecological indicators of wetland responses to grazing pressure need to be sensitive but simple and inexpensive to measure. This approach will ensure sufficient monitoring can be supported to improve our understanding and better support decision making.

Quantitative estimates of change in the cover of vegetation and litter, occurrence of invasive flora, structural changes in vegetation and evidence of altered processes could arguably capture key responses to grazing. These parameters are sensitive to seasonal variation and would need to be measured at peak plant biomass (i.e. early summer). Although vegetation measures integrate many of the impacts of grazing the failure to also capture threatening processes produced by grazing (i.e. soil compaction, nutrient enrichment) may limit our understanding of why systems respond differently to grazing. To address this, a targeted research program is needed that specifically address key knowledge gaps.

4.1.2. Research to improve understanding of the outcomes of grazing decisions

To further our understanding of grazing impacts on wetlands and the effectiveness of grazing management practices it is recommended that a research program be developed. Four research approaches are recommended and are detailed below.

The first approach is to build a grazing sensitivity database for both native and invasive aquatic flora. The database would be informed by observed sensitivities of species to grazing. Where this data is lacking sensitivity could be inferred based on plant traits that are considered characteristic of sensitive species.

The second approach is to gather and evaluate existing data sets on wetland condition, grazing history, wetland types and landscape setting to assess if there are sufficient data to test the influence of these variables on wetland condition attributes. Data on wetland condition has been collected in two state wide assessments as well as through market-based instrument Wetland Tender programs. In total there have been approximately 1200 IWC assessments across the state. This dataset should be analysed to test for relationships between grazing, vegetation condition and response modifiers. The findings will identify if greater confidence can be assigned to grazing practices/impacts or the influence of response modifiers and where research should be focused to improve confidence.

The third approach is to conduct comprehensive monitoring in strategically selected wetlands to address key knowledge gaps. The broad areas requiring further research are:

- How effective are various grazing management practices in maintaining wetland condition?
- How do response modifiers influence the ecological outcomes of grazing management?
- Does the application of grazing to manage weeds, wildfires or habitat structure have the same ecological outcomes as alternative approaches (e.g. fire, slashing, herbicide application)?

The fourth approach is to undertake research to better understand current grazing practices in wetlands, perception of landowners of the risks and benefits of different management practices and barriers to change.

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