From Wasteland to Natural Treasure: Towards an Ecosystem Services Framework for South East Australia's Upland Peatlands

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Candidate's Declaration

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university. To the best of the author's knowledge, it contains no material previously published or written by another person, except where due reference is made in the text.

Anne Murray 23/10/2019

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Notes

1. Peatlands have been described using many terms. The term upland peatland is used in this thesis to refer to peatlands in montane, subalpine and alpine areas in South East Australia. Chapter 2 presents a discussion of peatland terminology and classification.
2. The subtle beauty of peatlands has inspired many poets. Excerpts of peatland poems are scattered throughout the thesis to enrich the accompanying content.

Abstract

This project explores the question: *how can understanding of the characteristics and services delivered by South East Australian upland peatlands be improved to enhance their management?* South East Australian upland peatlands are a rare type of freshwater wetland. They provide many important ecosystem services, including surface water supply and sediment filtration. The majority of South East Australian upland peatlands are found in national parks, but they are still being degraded. The current management of upland peatlands is inadequate because there is a lack of understanding of their characteristics and values. This deficiency arises from ambiguous peatland terminology and classification, as well as a lack of integrated information. Further, the ecosystem services provided by upland peatlands have not been systematically identified. In order to address these limitations, the current study considers three research sub-questions:

1. Can upland peatlands in South East Australia be understood as a distinct system for management purposes?
2. What ecosystem services are provided by upland peatlands in South East Australia?
3. What indicators can be used to assess the ecosystem services provided by upland peatlands in South East Australia?

The first sub-question was investigated by comparing the characteristics of upland peatlands across the Australian Alps, New England Tablelands, South Eastern Highlands and Sydney Basin bioregions. The analysis shows that they share most characteristics, and can be understood as a distinct, although spatially disjunct, system for management purposes.

The second research sub-question was explored using the "Common International Classification of Ecosystem Services" framework. The review demonstrates that upland peatlands provide many provisioning, regulating and cultural services, with regulating services being particularly important. Cultural services are rarely considered in peatland research literature, and deserve greater attention.

The final research sub-question was addressed by identifying potential indicators for each ecosystem service, and evaluating these against key criteria, including data availability. Potential indicators exist for every ecosystem service, but this potential is limited by a lack of available data. The study identifies directions for future monitoring and research.

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List of Acronyms and Abbreviations

ACT – Australian Capital Territory

ANAE – Australian National Aquatic Ecosystem Framework

AUA – Australian Alps

BC – NSW *Biodiversity Conservation Act 2016*

CICES – Common International Classification of Ecosystem Services

EPBC – Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*

ES – Ecosystem services

FFG – Victorian *Flora and Fauna Guarantee Act 1988*

FPOM – Fine particulate organic matter

KNP – Kosciuszko National Park

IBRA – Interim Biogeographic Regionalisation for Australia

IUCN – International Union for Conservation of Nature

LOI – Loss on ignition

MA – Millennium Ecosystem Assessment

MCAS-S – Multi Criteria Analysis Shell for Spatial Decision Support

NC – ACT *Nature Conservation Act 2014*

NCF – Northern Corroboree frog (*Pseudophryne pengilleyi*)

NET – New England Tablelands

NP – National Park

NR – Nature Reserve

NSW – New South Wales

SEEA – United Nations System of Environmental and Economic Accounting

SEH – South Eastern Highlands

SYB – Sydney Basin

TEEB – The Economics of Ecosystems and Biodiversity

THPSS – Temperate Highland Peat Swamps on Sandstone

UN – United Nations

VIC – Victoria

Chapter 1: Introduction

South East Australia is home to a special type of wetland: an upland peatland. Peatlands have been described by the International Union for Conservation of Nature (IUCN) as "amongst the most valuable ecosystems on earth" (IUCN, 2017, p. 1). They perform many environmental services including water supply and filtration, habitat provision and carbon sequestration. Upland peatlands are vulnerable because they are fragile (Hope, 2003; Belmer *et al.*, 2018) and rare (Pemberton, 2005; Hunter and Bell, 2007). They face several threats, including climate change, feral animals, grazing, urban expansion, and mining (Pemberton, 2005; Hope *et al.*, 2012; Fryirs *et al.*, 2019). Despite recognition of their importance, management research on upland peatlands is limited, and there is no overarching framework for their management.

Peatlands are one of the world's most common types of wetland (Charman, 2002). They are characterised by the presence of layers of accumulated organic matter, known as peat. Waterlogging hinders the breakdown of organic matter, enabling the layers to form. Peatlands have unique vegetation that has adapted to waterlogged, acidic and anoxic conditions (Gore, 1983; Charman, 2002).

When the first rains have percolated
through sand and stone,
sponge and bone, and the frogs

have hatched from their tombs of mud
and are singing in the sedge grass;
we turn to look east where the bleached
limbs of melaleucas make ghosts of time

Figure 1: Excerpt from the poem "The Swamp" by Nandi Chinna (2019)

Australian conditions are not suited to peat development (Keith *et al.*, 2014) and so peatlands are relatively uncommon (Whinam and Hope, 2005). Australian peatlands are found in isolated pockets, scattered across several locations, including deserts, floodplains and estuaries (Pemberton, 2005). This thesis examines upland peatlands, which are found in montane, sub-alpine and alpine areas in mainland SE Australia and Tasmania (Whinam and Hope, 2005). The scope of the study is restricted to mainland Australia because Tasmanian peatlands have different characteristics to those of the mainland (Whinam and Hope, 2005). The hanging swamps that occur in the Sydney Basin bioregion are also excluded for this reason (Fryirs *et al.*, 2019).

Many of SE Australia's upland peatlands have been degraded or lost. Pickering *et al.* (2004) estimate that only half of the pre-European extent of peatlands in the Australian

Alps remain, and that just a third of this is fully functional. This loss has resulted from threats such as bushfires, infrastructure development, the creation of dams for hydroelectricity, as well as feral animals and cattle grazing (Hope, 2003; Tolsma and Sutter, 2018). Upland peatlands in other areas of SE Australia have been damaged by activities including longwall mining, peat extraction, urbanisation, and drainage for agricultural purposes (State of New South Wales and Office of Environment and Heritage, 1998; Whinam *et al.*, 2003; NSW Threatened Species Scientific Committee, 2005a; Hunter and Bell, 2009).

Upland peatlands have been listed in state and federal environmental conservation legislation (NSW Threatened Species Scientific Committee, 2005b; Department of the Environment, Water, Heritage and the Arts, 2008; Fryirs *et al.*, 2014a), and included in national parks and conservation reserves (Hope *et al.*, 2012; Fryirs *et al.*, 2019). However, these peatlands are being damaged, and still face many threats, including climate change and altered water regimes. It is clear that further action needs to be taken to protect SE Australia's upland peatlands.

Upland peatlands continue to be degraded because we do not fully understand their value (Turner *et al.*, 2000; Hope *et al.*, 2012). There are many reasons for our failure to appreciate them, and these are discussed in detail in Chapter 2. Peatlands have been classified in a myriad of ways (Charman, 2002), limiting our ability to understand their function (Mactaggart *et al.*, 2008) and to uphold laws relating to conservation legislation (Murphy and Noon, 1991). Peatland research and the resulting literature is usually specific to particular characteristics and/or areas, and there has been little integration of this research, hampering its potential to inform conservation policy (Slocombe, 1993; Liu *et al.*, 2008). Finally, the services provided by upland peatlands in SE Australia have not been systematically identified. The central research question being explored in this thesis follows from these concerns: *how can understanding of the characteristics and services delivered by South East Australian upland peatlands be improved to enhance their management?*

There has been little work identifying whether upland peatlands in SE Australia could be considered a distinct system for policy and management purposes. This is a significant question, because if it can be established that upland peatlands in SE Australia share key qualities, then there is potential for a shared management framework. Drawing boundaries around ecosystems heightens understanding of their characteristics and values, and helps to ensure that management and data collection strategies are appropriate (Soranno *et al.*, 2010; Aquatic Ecosystems Task Group, 2012). Thus, an important question to be addressed is: *can upland peatlands in South East Australia be understood as a distinct system for management purposes?* This forms the first sub-question for this project, and is addressed in Chapter 3.

Ecosystem services analysis comprehensively identifies how ecosystem processes and functions contribute to human wellbeing (Alcamo *et al.*, 2005b). Identifying the ecosystem services provided by upland peatlands could improve recognition of their value, leading to better informed management and thus achievement of social goals (Pittock *et al.*, 2012). The limited nature of ecosystem service research on SE Australian upland peatlands gives rise to the second research sub-question for this study: w*hat ecosystem services are provided by upland peatlands in SE Australia?* This question is explored in Chapter 4.

A rigorous ecosystem service assessment is founded on indicators that reliably track the services delivered by upland peatlands (Crossman *et al.*, 2013). Indicators should provide information about four parts of the ecosystem service process: the capacity of peatlands to provide the services, the pressures that affect their capacity, as well as the demand for, and supply of, the services (Villamagna *et al.*, 2013). Existing research has established capacity and pressure indicators (Wild and Magierowski, 2015) but potential demand and supply indicators have yet to be developed for SE Australian upland peatlands. Thus, the third and final research sub-question is: *what indicators can be used to assess the ecosystem services provided by upland peatlands in SE Australia?* This question is discussed in Chapter 5.

In their report "Peat-forming bogs and fens of the Snowy Mountains of NSW", Hope *et al.* (2012, p. 46) conclude that the perception of peatlands as:

> "'wasteland' should be replaced by a new appreciation of the fascinating processes, environmental services and aesthetic highlights of these natural treasures".

Their words capture the essence of this project and have been honoured in its title.

Chapter 2: Literature review – South East Australia's upland peatlands

While there is a wealth of valuable research on upland peatlands in SE Australia, much of it deals with specific areas and characteristics. This review brings the literature together for the first time, and highlights the need for an integrated approach to peatland management. The chapter begins with an overview of the definitions and location of upland peatlands (Section 2.1). It discusses the services they provide (Section 2.2), and the threats they face (Section 2.3). The chapter concludes with a review of the barriers to the successful management of upland peatlands (Section 2.4).

2.1 Upland peatland definitions and location

Upland peatlands are a type of freshwater wetland. There are various definitions for peatlands, but Australian literature often uses the definition proposed by Whinam and Hope (2005): "terrestrial sediments more than 30cm thick, with more than 20% organic matter by dry weight" (p. 3). The classification of peatlands is varied, but most classification systems initially divide peatlands into fens and bogs (Gore, 1983). In general, bogs receive most of their water from precipitation, and so have very poor nutrient levels. Fens receive their water from a mix of sources, and so are more nutrient rich (Charman, 2002). Hope *et al.* (2012) state that bogs have complex vegetation with very little free water, whereas fens have simpler vegetation, with some open water. The term "mire" is used to describe peatlands that are actively accumulating peat. This thesis considers all upland peatlands in SE Australia, regardless of whether they are currently accumulating peat. This is because some SE Australian peatlands accumulate peat irregularly (Fryirs *et al.*, 2014a), but nevertheless provide important ecosystem services.

In mainland Australia, upland peatlands are found on humid parts of the Great Dividing Range (Whinam and Hope, 2005; Keith *et al.*, 2014) (see Figure 2). They occur in several bioregions, including the Australian Alps, South Eastern Highlands, Sydney Basin and New England Tablelands. In the Sydney Basin they are often termed "upland swamps" (see, for example, Cowley *et al.*, 2019).

Figure 2: Mainland Australian upland peatlands occur within the green area (Whinam and Hope, 2005)

2.2 Overview of the services provided by South East Australian upland peatlands

SE Australian upland peatlands provide many important hydrological services. They reduce water discolouration, filter sediment, and sequester toxic metals, releasing higher quality water downstream (Martin-Ortega *et al.*, 2014). This reduces filtration costs for drinking water (Martin-Ortega *et al.*, 2014), improves river health, and aids the production of hydroelectricity (Worboys and Good, 2011).

Peatlands also help regulate the water flow regime and local water table (Lawrence *et al.*, 2009). Ingram (1978) provides a basic model of peatland hydrology. The model shows peatlands as comprising a top layer, termed "acrotelm", and bottom layer, termed "catotelm". The acrotelm has high hydraulic conductivity, and so has variable water content. The catotelm has very low hydraulic conductivity, and consequently stays almost permanently saturated. The model has been shown to be overly simple (Fryirs *et al.*, 2014b), but is nevertheless useful for understanding the basic principles (Grover and Baldock, 2013).

Upland peatlands have been described as "sponges", with the acrotelm trapping water and releasing it over long periods, providing base flow to catchments during dry spells (Wahren *et al.*, 1994). However, this representation of their hydrological function may not always be applicable. In a study of peatlands in the Victorian high country, Western *et al.* (2009) found that peatlands were not a major source of base flow, instead providing a conduit for flows. Fryirs *et al.* (2014b) conclude that saturation levels in peatlands determine the extent to which they are able to store rainfall. If the peatland is highly saturated before rainfall, it transmits the rain as overland flow instead of storing it.

Degradation of peatlands causes harmful hydrological effects. Channelised and eroded peatlands release sediment into streams, reducing reservoir storage capacity and harming freshwater biodiversity. Channelisation also causes a flashier flow regime (Cowley *et al.*, 2018b).

The bent grass is burned to gold,
Pale gold upon the plains and hills,
But here in this hollow marsh a green
Oasis breathes of damp, and spills
A cool dream upon the air

Figure 3: Excerpt from the poem "Swamp-Water" by Nancy Cato (1957)

Australian peatlands provide crucial habitat for local fauna populations. Most of the water in a peatland is retained as pore water in the catotelm, ensuring it remains permanently saturated. Each cubic metre of saturated peat can store between 100 and 300 litres of water (Good *et al.*, 2010). Upland peatlands are "moist oases" within dryer landscapes, and "may prevent population extinctions across drought cycles" (Hope *et al.*, 2012, p. 50). Alpine *Sphagnum* bogs in the Australian Alps and South Eastern Highlands bioregions provide habitat for the critically endangered Northern (*Pseudophryne pengilleyi*) and Southern (*Pseudophryne corroboree*) Corroboree frogs (Threatened Species Scientific Committee, 2009; State of New South Wales and Office of Environment and Heritage, 2019s; State of New South Wales and Office of Environment and Heritage, 2019w). They also support many other species, such as the spiny freshwater crayfish (*Euastacus australasiensis*) and broad-toothed rat (*Mastacomys fuscus*) (Wild *et al.*, 2010b). Peatlands in the New England bioregion are habitat for the giant dragonfly (*Petalura gigantea),* sphagnum frog (*Philoria sphagnicolus*) and Latham's snipe (*Gallinago hardwickii*) (Gosling and Cobcroft, 2010).

Peatlands contain significant floristic biodiversity. Species composition changes according to the availability of water, soil nutrients, and elevation (Hope *et al.*, 2009; Hose *et al.*, 2014). In general, bog vegetation is characterised by sclerophyllous shrubs, while fens lack shrubs and contain sedges. Species richness varies across site and region. Keith and Myerscough (1993) found that upland swamps on the Woronora Plateau in the Sydney Basin bioregion contained up to 70 vascular plant species within a sampling area of 15m^2. A study of the vegetation of an upland swamp on the Budderoo Plateau recorded 50 different species from 24 families (Hose *et al.*, 2014). There are around 180 species across all peatlands in the ACT region (Hope *et al.*, 2009). Many species in peatlands are isolated and endemic (Commonwealth of Australia, 2009; Belmer *et al.*, 2018). For example, peatlands in the New England Tablelands contain the New England Gentian (*Gentiana wissmannii*) (Gosling and Cobcroft, 2010).

Peatlands are carbon sinks, storing more carbon per unit area than any other type of ecosystem (Pemberton, 2005; Keith *et al.*, 2014). Globally, they store more carbon than all other terrestrial vegetation types combined (IUCN, 2017). The level of carbon sequestration is dependent on the rate of organic matter accumulation and rate of peat decay (Belyea and Malmer, 2004). Draining, erosion and channelisation cause peatlands to transform from sinks to sources of carbon and toxic metals (Charman, 2002; Martin-Ortega *et al.*, 2014; Cowley *et al.*, 2018a).

Peatlands serve as records of long-term environmental history. Peat layers preserve the remains of the plants and animals that were present during the formation period. Carbon dating of the layers reveals how the environment changed over time, providing useful information for environmental management and research (Hope *et al.*, 2009).

2.3 Threats to upland peatlands

Peatlands face many threats, including climate change, mining, feral species, urban expansion and infrastructure development. The Australian climate is already marginal for peat formation, and climate change will mean there are even fewer suitable areas (Hope *et al.*, 2009; Fryirs *et al.*, 2014a; Keith *et al.*, 2014). Peat accumulation requires specific climatic conditions: high rainfall and humidity, as well as low evaporation (Pemberton, 2005). These conditions enable plant production to exceed decomposition (Baird and Benson, 2018). Higher temperatures accelerate decomposition, preventing peat formation. Climate change is also increasing the rate of surface drying, and reducing the amount of rain peatlands receive (Keith *et al.*, 2014).

Climate change will also increase the exposure of peatlands to other threats, including storms and fires (Worboys and Good, 2011). Fires have caused major peatland loss in the past two decades in the Australian Alps and South Eastern Highlands (McDougall, 2007; Wild *et al.*, 2010b; Hope *et al.*, 2012). Storms cause vegetation loss and can heighten channelisation (Worboys and Good, 2011). Higher temperatures increase peatland susceptibility to weed invasion (Gosling and Cobcroft, 2010).

Keith *et al.* (2014) found that climate change will decrease the area and suitability of environments for upland swamps in the Sydney Basin bioregion by at least 30%, and potentially up to 87%, by 2080. The direct impact of climate change is likely to be even greater in the New England Tablelands bioregion, where peatlands are at the edge of their distributional limits (Hunter and Bell, 2013). Hunter and Bell (2013) conclude that the vegetation of New England Tablelands peatlands is more influenced by climatic factors, such as temperature and rainfall, than landform and spatial factors.

Longwall mining can have severe negative impacts on upland peatlands. It causes erosion (Tomkins and Humphreys, 2006), and increases stormwater concentration and channelisation (Commonwealth of Australia, 2014b). Mining subsidence fractures the peatland bedrock, causing them to dry out (Krogh, 2007), which in turn makes them more vulnerable to fire and storms (Krogh, 2007). Longwall mining has been noted as a key threatening process to Temperate Highland Peat Swamps on Sandstone, a type of upland peatland in the Sydney Basin (NSW Threatened Species Scientific Committee, 2005a).

Figure 4: A drying upland swamp, located near a longwall mine (Hannam, 2019) (Photo: Nick Moir)

Feral animals are causing extensive degradation to SE Australian upland peatlands. Feral horses are particularly damaging in the Australian Alps, where they graze on palatable species including *Carex gaudichaudiana* and *Sphagnum* moss, trampling the peatland soil and vegetation. This causes channelisation and exposure of the peat surface, both of which alter the water chemistry and sediment level, and lead to a more rapid flow regime (Robertson *et al.*, 2019). Channelisation and exposure of the peat surface significantly heighten the susceptibility of the peatland to fire. Peat fires can eradicate all surface plants and cause erosion (Hope, 2003). The combination of climate change and feral animal activity is thus particularly threatening. Feral horses are less widespread in other bioregions, but these regions face threats from feral pigs, deer and cattle (Keith, 2004; Hunter, 2013; Brown *et al.*, 2016). These animals cause similar types of damage to feral horses (Keith, 2004). Cattle grazing is still permitted in areas of Victorian state forest, threatening their remaining peatlands (McDougall, 2007; Tolsma and Sutter, 2018). The majority of fens in the New England Tablelands occur on freehold land or travelling stock reserves, and these areas are particularly affected by cattle grazing (Hunter and Bell, 2009).

Similar consequences arise from urban expansion. Peatlands in urban catchments have less plant and invertebrate diversity (Belmer *et al.*, 2018). This is partly because the increase in impervious surface area leads to more sediment flow, which introduces nutrients and weed propagules into peatlands (Hensen and Mahony, 2010). Urbanisation reduces groundwater flows (Pittock *et al.*, 2015), on which fens depend. It also intensifies runoff volume, causing gullying and channelling (Cowley *et al.*, 2018b).

Infrastructure development can harm and even eliminate peatlands. Peatland loss has occurred as a result of dam creation for hydroelectricity (McDougall and Walsh, 2007). Ski infrastructure in Kosciuszko National Park (KNP) and in the Victorian high country has also caused degradation (McDougall and Walsh, 2007; Hope *et al.*, 2012). A large fen in KNP was covered by the main carpark at the Perisher ski resort (Hope *et al.*, 2012). Many fens in the New England region contain farm dams (Hunter, 2013), and drains (Hunter and Bell, 2009).

2.4 Management of upland peatlands – the need for an integrated framework

Despite the importance and vulnerability of SE Australia's upland peatlands, they continue to be degraded. There are several factors limiting their successful management. First, the values and services of upland peatlands are not well-known, and have not been systematically outlined. Second, there is no one commonly agreed classification system for upland peatlands. Third, existing literature focuses on specific areas and/or specific biophysical variables. Management literature is also specific, focusing on either practical actions or on particular threats. Finally, upland peatlands lack an overarching management framework or set of common management principles.

All are appropriate – bog, and marsh, and fen,
Are only poor to undiscerning men;
Here may the nice and curious eye explore
How Nature's hand adorns the rushy moor

Figure 5: Excerpt from the poem "The Lover's Journey", by George Crabbe (1812, p. 26)

Peatland degradation has been exacerbated by a lack of knowledge and appreciation of their value. Hope *et al.* (2009) remark that there is a perception of peatlands as "wasteland" (p. 46). Turner *et al.* (2000) argue that wetland regulation has been insufficient partly because politicians and the public do not adequately understand the role and function of wetlands. Peat mining was permitted in Wingecarribee Swamp until 1998, when as a result of mining, 70% of the swamp collapsed (Whinam and Hope, 2005). Sainty (1999) contends the swamp's decline was underpinned by an undervaluing of the swamp's ecological role. Similarly, Baird and Benson (2018) argue that the long-term conservation of peatlands in the Cudgegong River catchment relies on improved recognition of their value.

Without an appreciation of the values and services provided by upland peatlands, their management and protection will remain insufficient. Principle 10 of the NSW Wetlands Policy states that, where possible, wetland destruction should be avoided, but if it is in the "public interest" that damage or destruction to a wetland occurs, the damage should be offset (Department of Environment, Climate Change and Water, 2010). In this case, the offset must provide "equivalent values, functions and services" (p. 26). Similarly, the Victorian Waterway Health Program assesses the links between wetland values and threats to prioritise management interventions (Morris and Papas, 2012). The values, functions and services of SE Australian upland peatlands have not been systematically identified, limiting the application of these strategies. A recent example is the extension of a longwall mining licence in the Sydney catchment. The mining company has acknowledged the potential impacts of its activities on upland swamps. In the submitted environmental impact statement, the company has proposed to offset any decreased sediment filtration resulting from damage to upland swamps, by maintaining unsealed roads and implementing fire management (Drewitt-Smith and Huntsdale, 2019). However, this offset addresses only one of the services that upland swamps provide in the catchment.

Well-defined ecosystem classifications enhance our understanding of the ecosystem characteristics (Rowe, 1996), while confusing terminology restricts our understanding, and limits knowledge transfer (Mactaggart *et al.*, 2008). Charman (2002) argues that "classification of peatlands is probably one of the most fraught and misunderstood systems of all". Problems include a multiplicity of category types, overly narrow definitions and confusing terminology.

Upland peatlands have been categorised using many different biophysical variables, including vegetation, geomorphology, and water source. As a result, they have been given many different names. Keith (2004), for example, divides NSW and ACT peatlands into three vegetation classes, while Victoria's "Ecological Vegetation Classes" classify wetland vegetation into 143 types (Department of Sustainability and Environment, 2012). Lawrence *et al.* (2009) categorise Victorian high-country peatlands into four geomorphological types. Conservation legislation relies on another form of classification: categorisation according to ecological community. Ecological communities are groups of flora and fauna that naturally occur and interact in a unique habitat (Keith, 2009). Table 1 displays the upland peatland ecological communities which are listed as threatened under federal and state conservation legislation. The table shows the variation in names for upland peatlands.

Ecological community listing is an important part of conservation action, as it guides how governments and community groups respond (Keith, 2009). However, narrow classification means that some peatlands do not appear on any conservation listings (Mactaggart *et al.*, 2008). For example, WetlandCare Australia's "Save our Swamps" program targeted the Temperate Highland Peat Swamps on Sandstone (THPSS) ecological community (Hensen and Mahony, 2010). Peatlands in the Cudgegong River catchment were overlooked, as they are not explicitly identified in the THPSS listing, despite having very similar ecological characteristics (Baird and Benson, 2018).

Table 1: Threatened peatland ecological communities in SE Australia listed under conservation legislation

Act	**Ecological Community**
Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*	Temperate Highland Peat Swamps on Sandstone
	Coastal Upland Swamps in the Sydney Basin
	Alpine Sphagnum Bogs and Associated Fens
NSW *Biodiversity Conservation Act 2016*	Newnes Plateau Shrub Swamps in the Sydney Basin Bioregion
	Coastal Upland Swamps in the Sydney Basin Bioregion
	Blue Mountains Swamps in the Sydney Basin Bioregion
	Montane Peatlands and Swamps of the New England Tableland, NSW North Coast, Sydney Basin, South East Corner, South Eastern Highlands and Australian Alps
	Carex Sedgeland of the New England Tableland, Nandewar, Brigalow Belt South and NSW North Coast Bioregions
VIC *Flora and Fauna Guarantee Act 1988*	Alpine Bog Community
	Fen (Bog pool) Community
ACT *Nature Conservation Act 2014*	High Country Bogs and Associated Fens

Unclear terminology reduces the effectiveness of conservation legislation, and can result in disputes (Murphy and Noon, 1991). For example, in an application to change its colliery discharge practices, Centennial Coal stated that Long Swamp, near Lithgow NSW, is a "*Typha orientalis* Wetland". The Lithgow Environment Group responded that Long Swamp is a THPSS (Centennial Coal Company Limited, 2018). The distinction is an important one, as different laws apply to listed ecological communities (Keith, 2009).

There is little research that combines individual peatland studies to provide integrated information across regions. Most peatland studies canvass a particular geographic area, and/or focus on certain characteristics, such as vegetation, geomorphology and hydrology. Similarly, management research has focused on specific and practical conservation actions, such as the use of shade cloth for UV radiation protection (Good *et al.*, 2010) or channel blocking (Whinam and Hope, 2005). Other literature is threat-specific, such as Krogh's (2007) analysis of the management of longwall mining impacts in the Sydney Basin, and Robertson et al.'s (2019) assessment of feral horse impacts in the Australian Alps.

Organisation and integration of scientific knowledge is necessary for it to be useable in decision-making processes (Slocombe, 1993; Liu *et al.*, 2008). The implementation of the ecosystem approach, the central strategy of the Convention on Biological Diversity (to which Australia is a signatory), also requires integration of different forms of information (Secretariat of the Convention on Biological Diversity, 2004). There is thus a need for research that builds on and integrates existing knowledge in order to better determine and communicate the functions of upland peatlands in SE Australia. However, integrating information about upland peatlands across regions is only meaningful if the peatlands share key characteristics.

Establishing and drawing boundaries around ecosystems is an important part of management (Grumbine, 1994; Ruhl *et al.*, 2013). It means that ecosystems can be consistently named, an essential part of communicating their value (Mactaggart *et al.*, 2008). It also ensures that common management and data collection principles can be created (Aquatic Ecosystems Task Group, 2012). The Interim Australian National Aquatic Ecosystem (ANAE) Classification Framework (Aquatic Ecosystems Task Group, 2012) has observed that: "sorting aquatic ecosystems into appropriate groups, according to their characteristics and/or ecological functioning is a primary step in managing those systems" (p. 2). In other contexts where widely distributed but similar ecosystems occur, it is common to develop consistent management approaches. For example, the Federal Government has established a set of principles for integrated management of coastal zones (Clark and Johnston, 2016), an approach often mirrored at state level (State of New South Wales and Office of Environment and Heritage, 2018e).

Soranno *et al.* (2010) agree that resource constraints mean that it is impossible to properly manage ecosystems site-by-site. However, they point out that adopting a "one-size fits all" approach to ecosystem management also results in degradation. Instead, management classes should be created so that within one class sites will respond similarly to one set of management principles. To date, there has not been an examination of whether upland peatlands across bioregions share common characteristics. If it can be established that upland peatlands in SE Australia share key qualities, then there is potential for a shared management framework across sites, a question to which we now turn.

Figure 6: Mura Swamp, a peatland in Namadgi National Park, ACT (Photo: Anne Murray)

Chapter 3: Assessment of whether South East Australian upland peatlands are a distinct system for management

This chapter addresses the first research sub-question: *can upland peatlands in South Eastern Australia be understood as a distinct system for management?* The chapter begins with an outline of the methods used to answer this question (Section 3.1). Section 3.2 describes the four bioregions included in the study. Section 3.3 compares the characteristics of upland peatlands in each bioregion, and Section 3.4 summarises the findings.

3.1 Method

Two frameworks, the Millennium Ecosystem Assessment (MA) and the Interim Australian National Aquatic Ecosystem (ANAE) Classification Framework, were used to assess whether SE Australian upland peatlands are a sufficiently distinct system to warrant the generation of common data and management principles. Variables from these frameworks were combined to create a set of characteristics on which to base the analysis.

The MA was the first global study of human impact on the world's ecosystems (Carpenter *et al.*, 2009). The MA framework is widely used in ecosystem services literature (Fisher *et al.*, 2009). The ANAE is the Australian Government framework for aquatic ecosystem classification. It was chosen for the current study as it is specific to Australian aquatic ecosystems, and integrates several state-based classification frameworks (Aquatic Ecosystems Task Group, 2012).

Chapter two of the MA framework provides guidance on how to classify an ecosystem (Alcamo *et al.*, 2005b). The MA states that regionally distributed ecosystems can be assessed using a series of "basic structural units" (Alcamo *et al.*, 2005b, p. 51). These units include both biophysical and social variables, such as "climatic conditions" and "dominant use by humans" (Alcamo *et al.*, 2005b, p. 53) (see Table 2). The MA framework provides a pragmatic way of setting ecosystem boundaries so that they are suitable for policy purposes and also adhere to scientific principles (Ruhl *et al.*, 2013).

Table 2: Millennium Ecosystem Assessment structural units (Alcamo *et al.*, 2005b)

Geophysical conditions
Climatic conditions
Species composition
Surface cover – water (for aquatic ecosystems)
Resource management systems and institutions
Dominant use by humans

The MA framework is most often used to distinguish between two bordering ecosystems. For example, Saastamoinen *et al.* (2013) use the MA framework to draw boundaries between peatland and forest ecosystems in Finland. Maynard *et al.* (2010) group South East Queensland ecosystems that occur in the same region in "ecosystem reporting categories". The current study adopts a novel approach. To date, there are there have been very few studies that use the framework to determine if regionally distributed ecosystems, such as upland peatlands, are similar to each other.

The ANAE is the second module of the Australian Government "Aquatic Ecosystems Toolkit". Unlike the MA, the variables in the ANAE are purely biophysical. It has three levels, each concerned with different attributes. Levels 1 and 2 contain broad regional (e.g. surface water drainage divisions) and landform variables (e.g. climate, topography). Level 3 is finer-grained, dividing aquatic ecosystems into ten classes: marine, estuarine, lacustrine, palustrine, riverine, floodplain, fractured aquifers, porous sedimentary rock aquifers, unconsolidated aquifers, and caves/karsts.

The framework describes the types of variables, such as substrate, vegetation and water source, that should be used to identify each ecosystem. Upland peatlands are palustrine ecosystems (Aquatic Ecosystems Task Group, 2012) and so the variables in the Level 3 palustrine class were chosen to compare peatlands from each bioregion. These variables are shown in Table 3.

Table 3: Australian National Aquatic Ecosystem Classification Framework - Level 3 variables for palustrine ecosystems (Aquatic Ecosystems Task Group, 2012)

ANAE variable	**Metrics**
Landform	High energy: upland, sloping Low energy: upland plateau, lowland
Soil/substrate	Soil: porous or non-porous Substrate: clay, sedimentary, unconsolidated or volcanic
Vegetation/ Fringing vegetation	Forested, shrub, sedge/grass/forb, none
Water source	Surface water and/or groundwater, localised rainfall
Water type	Salinity: fresh, brackish or saline
Water regime	Commonly wet, periodic inundation or waterlogged

The specific biophysical variables used in this study, and their relationship to the MA and ANAE frameworks, are shown in Table 4. They comprise the most common variables used in research literature to describe SE Australian upland peatlands. The two major frameworks include similar biophysical variables for ecosystem classification. For example, “geophysical conditions” in the MA is comparable to “landform” in the ANAE. The biophysical variables from both frameworks are highly applicable to upland peatlands, and can be applied mostly unaltered.

The main difference between the ANAE and the MA is the presence of social variables in the MA. The present study included social variables, because as the MA (2005b) points out, “humans are an integral part of ecosystems” (p. 49). Kohlhagen *et al.* (2013) argue further that because of social and political influence in environmental management, management approaches should take into account social values. The MA’s “dominant use by humans” variable was modified for the current study to become “land use pressures” and “other pressures” (see Table 4). This change reflects that most upland peatlands in SE Australia are not directly “used” as such by humans, but are nevertheless subject to significant pressures. Grizzetti *et al.* (2016) argue that it is necessary to consider the relationship between such pressures and ecosystem function for management. *Sphagnum* moss harvesting used to occur from wild sources (Whinam *et al.*, 2003), but is now illegal (Department of Primary Industries, Parks, Water and Environment, 2018). Instead, upland peatlands in SE Australia are generally impacted by human activity in the wider catchment (Pemberton, 2005). For example, peatlands in the Sydney Basin Bioregion are being degraded by changes in water flow caused by the placement of groundwater bores (Fryirs *et al.*, 2016).

Table 4: Mapping from ANAE and MA variables to the variables used in this study to determine if SE Australian upland peatlands are a sufficiently distinct system to warrant a common management approach (Alcamo *et al.*, 2005b; Aquatic Ecosystems Task Group, 2012)

ANAE variable	**MA variable**	**Variable used in this study**
Landform	Geophysical conditions	Altitude
		Hydrogeomorphology
Soil/substrate	-	Soil
		Substrate
-	Climatic conditions	Rainfall
		Temperature
Water source	-	Water source
Water regime	Surface cover - water	Surface cover – water
Water type	-	Water type
Vegetation/fringing vegetation	Species composition	Vegetation
-	Resource management systems and institutions	Land tenure
		Conservation status
	Dominant use by humans	Land use related pressures
		Other pressures

3.1.1 Scale of assessment

The first research sub-question for this study is whether SE Australian upland peatlands share key qualities, such that they can be considered sufficiently distinct for common data collection and management principles. In order to answer this question, peatlands were grouped together according to their Interim Biogeographic Regionalisation for Australia (IBRA) bioregions (Thackway and Cresswell, 1997). This grouping was undertaken for two reasons.

At a broad level, IBRA bioregions represent ecologically distinct areas. They are groups of "ecosystem types amalgamated on the basis of similarities in geology, geomorphology, soils, vegetation, and climate" (Thackway and Cresswell, 1997, p. 242). Upland peatlands within a bioregion will share a similar climate, soil, geology and so on. The variables used to determine an IBRA bioregion (geology, geomorphology etc.) are very similar to those being used in the current study from the ANAE and MA frameworks. This means it can be assumed that the peatlands within a bioregion are similar enough to be considered together. If there are key differences between upland peatlands in SE Australia, it could also be expected that the differences would be evident between bioregions, since each bioregion has distinct ecological features.

The bioregional scale was also chosen because it allows literature operating at different scales to be compared and synthesised. Most research analysing the characteristics of SE Australian upland peatlands focus on a particular geographic area that is within a single bioregion (see, for example, Grover, 2006; Hunter and Bell, 2009; Fryirs *et al.*, 2014b). Broader studies that classify vegetation often report the bioregions within which each vegetation community occurs (see, for example, McDougall and Walsh, 2007; Armstrong *et al.*, 2013). Conservation listings also use the bioregions to describe the location of ecological communities (see, for example, Commonwealth of Australia, 2009; State of New South Wales and Office of Environment and Heritage, 2017g)

3.2 Bioregions

This study examines upland peatlands in four IBRA bioregions (Thackway and Cresswell, 1997): the Australian Alps, New England Tablelands, South Eastern Highlands, and Sydney Basin. The four regions are shown in the maps below, with an accompanying description. The NSW Threatened Species Scientific Committee (2005b) has noted that upland peatlands also occur in the NSW North Coast and South East Corner bioregions, but very little literature on upland peatlands in these regions was found.

3.2.1 Australian Alps (AUA)

Peatlands in the Australia Alps are variously named, including the terms wet/peaty heathland, sedgeland, mossbed, bog, fen, moor and swamp (Tolsma, 2009; Hope *et al.*, 2012; Armstrong *et al.*, 2013; Mackey *et al.*, 2015). There are around 8000 ha of peatlands in the NSW and ACT section of the Alps (Hope *et al.*, 2012), and around 4500 ha in the Victorian section (Tolsma, 2009).

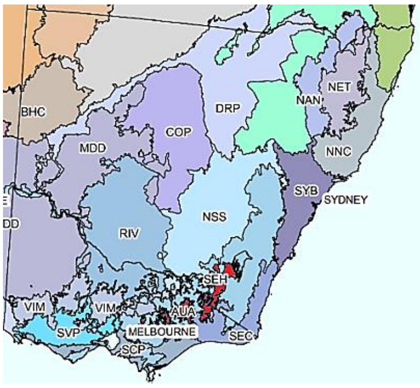

Figure 7: The Australian Alps (shown in red)

3.2.2 New England Tableland (NET)

Upland peatlands in the New England Tableland are referred to as bogs, fens and sedgeland. These are the northern-most upland peatlands in Australia (Hunter and Bell, 2013). Hunter and Bell (2009) have estimated that around 5000 ha of fen, and potentially up to 10000 ha of bog, exists in the bioregion.

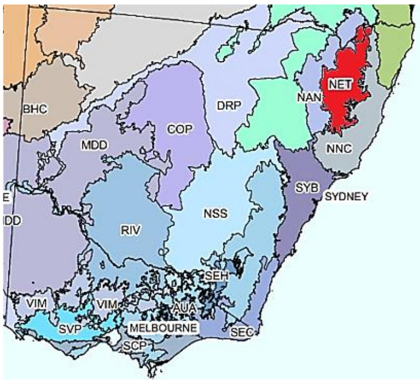

Figure 8: The New England Tableland (shown in red)

3.2.3 South Eastern Highlands (SEH)

The upland peatlands in the South Eastern Highlands are referred to variously as wet heathland, aquatic herbfield, bogs, fens, moors and swamps (Hope *et al.*, 2009; Armstrong *et al.*, 2013). There are around 2000 ha of peatlands in the SEH bioregion. Approximately 80% of these are fens (Hope, unpublished data, 2010).

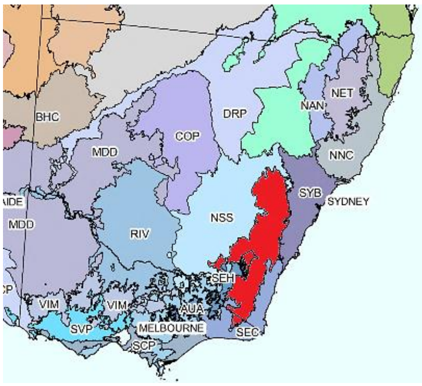

Figure 9: The South Eastern Highlands (shown in red)

3.2.4 Sydney Basin (SYB)

Upland peatlands in the Sydney Basin are usually termed “upland swamps”. These swamps typically have fen characteristics (Fryirs *et al.*, 2014a; Baird and Benson, 2018). Fryirs *et al.* (2019) estimate that there are approximately 10000 ha of upland swamps in the Sydney Basin.

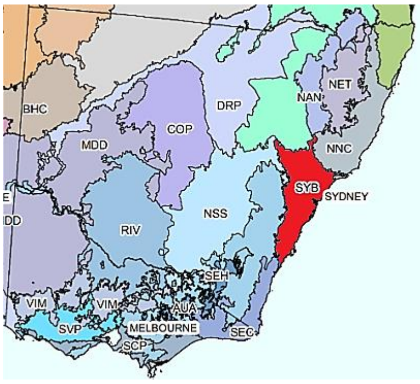

Figure 10: The Sydney Basin (shown in red)

3.3 Comparison of characteristics of upland peatlands in each bioregion

The characteristics of upland peatlands in each region were determined from a review of the literature, and entered into tables (see Table 5 to Table 16). The AUA column was split into "AUA – VIC" and "AUA – NSW/ACT", as almost all of the peatland literature for the AUA bioregion was specific to a particular state.

As shown in the preceding maps, each bioregion contains both bogs and fens, apart from SYB, which primarily has fens. Most of the information in the tables pertains to upland peatlands in general, but where information was available, specific data are included separately for fens and bogs. The cells are left blank where no data were available.

Figure 11: Nursery Swamp, a fen in the South Eastern Highlands (Photo: Anne Murray)

3.3.1 Altitude

Figure 12 shows that peatlands in all bioregions are found at relatively high altitudes by Australian standards. They extend to the lowest altitude in the Sydney Basin. Table 5 shows that fens are generally found at lower altitudes than bogs.

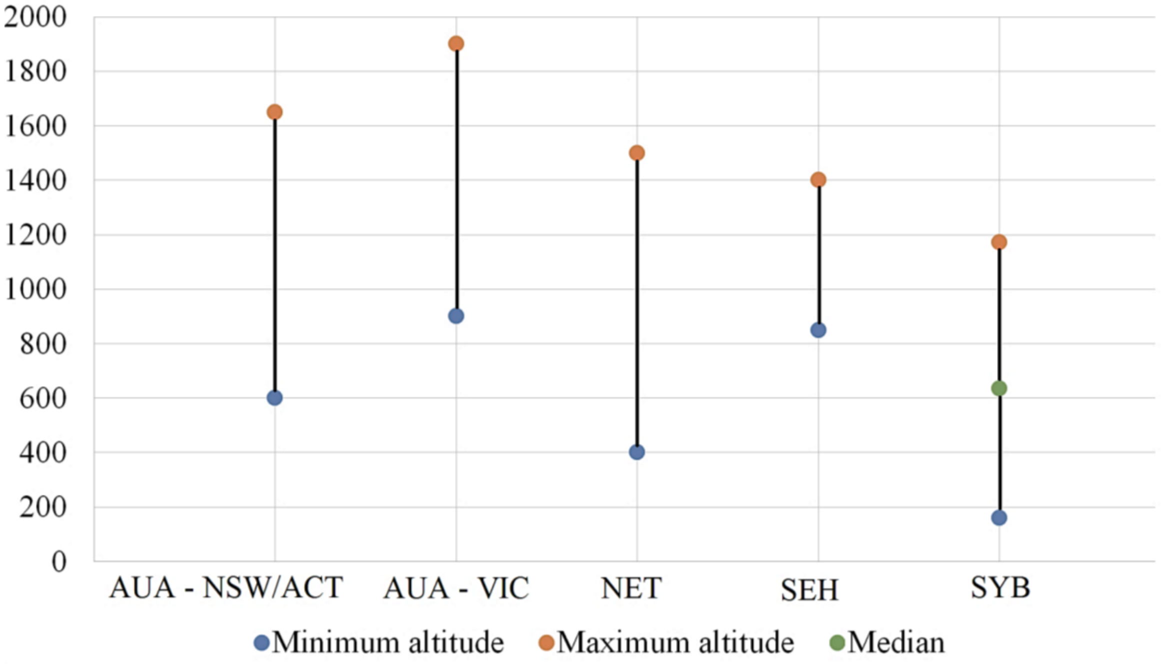

Figure 12: Peatland altitudinal range

Table 5: Altitudes at which bogs and fens are found

	AUA – NSW/ACT	**AUA - VIC**	**NET**	**SEH**	**SYB**
Bogs (metres above sea level)			800m - 1500m		
Fens (metres above sea level)	Mainly below 1400m		400m - 1110m	Mainly 900m - 1250m	~80% above 360m

Note. Data for AUA – NSW/ACT from Hope *et al.* (2012). Data for NET from Hunter and Bell (2013) and Hunter and Bell (2009). Data for SEH from Hope *et al.* (2009). Data for SYB from Fryirs *et al.* (2019).

3.3.2 Hydrogeomorphology

Most upland peatlands in SE Australia are "topogenic", meaning that they depend on topography for their formation. Topogenic peatlands are found in landscape depressions, where water is able to collect (Whinam and Hope, 2005).

A more unusual type of wetland, called a "hanging swamp", is found in SYB (Tozer *et al.*, 2010). Hanging swamps are found on steep valley sides and are fed by groundwater discharges. They generally do not have significant peat deposits (Commonwealth of Australia, 2014b). As noted earlier, they also have different characteristics and ecosystem functions (Fryirs *et al.*, 2019, p. 95) and are not considered further here.

Figure 13: Nursery Swamp is an example of a topogenic peatland (Photo: Anne Murray)

Table 6: Peatland hydrogeomorphology

	AUA - NSW/ACT	**AUA - VIC**	**NET**	**SEH**	**SYB**
Peatlands in general	Hillsides (head of drainage networks) Incised valleys on plateaus Ridges	Hillsides (head of drainage networks) Incised valleys on plateaus Ridges		Valleys Base of slopes	Valleys on plateaus Headwaters close to catchment divides
Fens			Flat or concave valley floors Frost hollows	Elongated valleys	
Bogs			Bogs found in broader range of positions		

Note. AUA – NSW/ACT characteristics from Hope (2003), Hope *et al.* (2012), and Mackey *et al.* (2015) and. AUA – VIC from Shannon and Morgan (2007) and Lawrence *et al.* (2009). NET from Hunter and Bell (2007), (NSW Threatened Species Scientific Committee, 2011b), and Hunter (2013). SYB from Jenkins and Frazier (2010), Hensen and Mahony (2010), Fryirs *et al.* (2014a), and Baird and Benson (2018).

3.3.3 Soil

By definition, all peatlands have organic soils, known as organosols. Organosols are divided into three classes in the Australian soil classification guide (National Committee on Soil and Isbell, 2016): fibric, hemic and sapric. Fibric peat is the least decomposed, allowing vegetation to be identified. Hemic peat is moderately decomposed, making vegetation difficult to distinguish. Sapric peat is the most decomposed and contains unidentifiable vegetation (National Committee on Soil and Isbell, 2016).

Detailed information about soil was only found for peatlands in the Australian Alps (Hope *et al.*, 2012) and Sydney Basin (Fryirs *et al.*, 2014a). Table 7 shows that peatlands in both regions contain fibric, sapric and hemic peat, as well as clay and sand. "Loss on ignition" (LOI) is a measure of organic matter content (Hope and Nanson, 2015). The LOI of AUA peatlands is significantly higher than the LOI of SYB peatlands. Fryirs *et al.* (2014a) show that the low organic content of peatlands in the Sydney Basin is a result of high variability in annual rainfall.

Table 7: Peatland soil profile

AUA - NSW/ACT	**AUA LOI**	**SYB**	**SYB LOI**
Fresh dead *Sphagnum*	79.67		
Fresh fibrous peat - fibric	79.67	Surface organic fines - fibric	31.7
Humified peat - hemic	79.67		
Fully humified peat - sapric	44.37	Alternating organic sands – loams alternating with sand layers	13.1 79.9 loam layers 1.1 sand layers
Clayey peats - sapric/hemic		Fine cohesive sands - sandy clay and sandy clay loam - sapric	7.6
Peaty clay and silts	17.13		
Peaty fine to medium sands		Basal sand and gravel - coarse medium sand	2.6

Note. AUA – NSW/ACT data from Hope and Nanson (2015). SYB data from Fryirs *et al.* (2014a).

3.3.4 Substrate

Previous research has established that geological substrate does not determine where peatlands occur (Hunter and Bell, 2009; Lawrence *et al.*, 2009). Table 8 shows that there is significant overlap in the type of geological substrate on which upland peatlands are found in each bioregion.

Table 8: The substrates on which peatlands are found

AUA - NSW/ACT	**AUA - VIC**	**NET**	**SEH**	**SYB**
Granite	Granite	Granite		
Meta-sediments		Meta-sediments	Meta-sediments	
Metamorphic	Metamorphic		Metamorphic	
	Sedimentary	Sedimentary	Sedimentary	Sedimentary (sandstone, shale)
	Volcanic (basalt)	Volcanic (basalt)		
		Acid volcanics	Acid volcanics	

Note. AUA – NSW/ACT characteristics from Hope *et al.* (2012) and Armstrong *et al.* (2013). AUA – VIC from Lawrence *et al.* (2009). NET from Hunter and Bell (2007), and Hunter and Bell (2009). SEH from Armstrong *et al.* (2013) and State of New South Wales and Office of Environment and Heritage (2016c). SYB from Fryirs *et al.* (2016).

3.3.5 Rainfall

Figure 15 and Table 9 show that all upland peatlands in SE Australia are found in areas where there is relatively high rainfall. Annual average rainfall is variable within all bioregions. An east-west rainfall gradient exists in both the New England Tableland (Hunter and Bell, 2013) and Australian Alps (Hope *et al.*, 2012).

Table 9: Rainfall for peatlands in each bioregion

	AUA - NSW/ACT	**AUA - VIC**	**NET**	**SEH**	**SYB**
Annual average rainfall (mm/year)	~1800 – 2000 mm		870 – 1750		1505
Annual average rainfall range across bioregion (mm/year)	450 – 2000 (concentration at >1400)	>1200	600 – 1000 west 1000-2500 east	460 – 1900	655 – 1950

Note. AUA – NSW/ACT data from Worboys and Good (2011) and Hope *et al.* (2012). AUA – VIC data from Lawrence *et al.* (2009). NET data from Hunter and Bell (2007) and Hunter and Bell (2013). SEH data from State of New South Wales and Office of Environment and Heritage (2016b). SYB data from Baird and Benson (2018) and Fryirs *et al.* (2019).

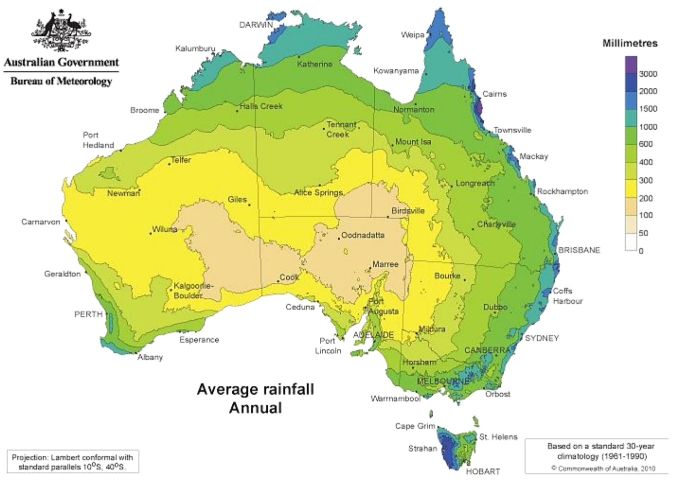

Figure 15: Bureau of Meteorology average annual rainfall 1961-1990

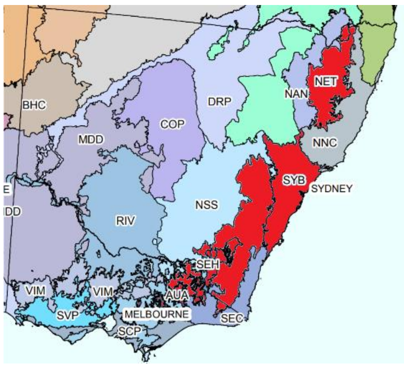

Figure 14: Bioregions included in study (shown in red)

3.3.6 Temperature

Figure 16 and Table 10 show that peatlands in SE Australia occur where there is a relatively low average annual temperature by regional and Australian standards.

Table 10: Temperature of locations where upland peatlands are found

	AUA - NSW/ACT	AUA - VIC	NET	SEH	SYB
Average annual temperature (°C)	3 – 12	5 – 10	9 – 17	6 - 10	13 - 18 (mean 15)
Average daily maximum (°C)		Peatlands exist where <15			23 summer, 9 winter
Average daily minimum (°C)		Peatlands exist where <6			14 summer, 3 winter

Note. AUA – NSW/ACT data from State of New South Wales and Office of Environment and Heritage (2016a). Data for AUA – VIC from Lawrence *et al.* (2009). NET data from Hunter and Bell (2013). SEH data from Hope *et al.* (2009). SYB data from Cowley *et al.* (2019) and Fryirs *et al.* (2019).

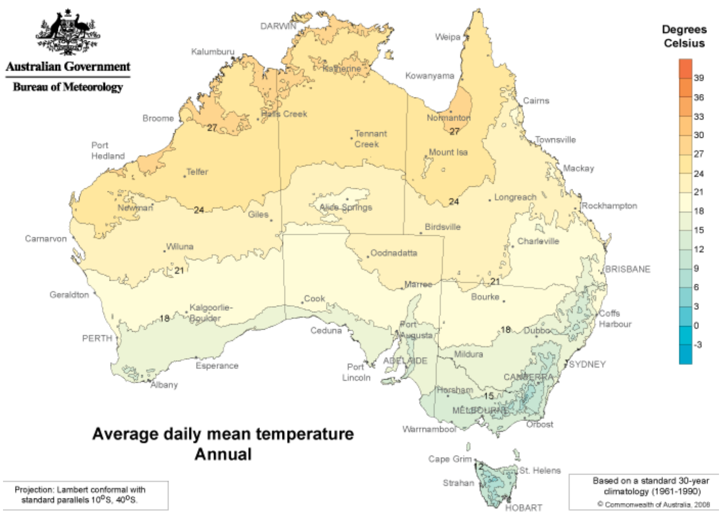

Figure 16: Bureau of Meteorology average annual daily mean temperature 1961-1990. Upland peatlands are found in blue shaded areas.

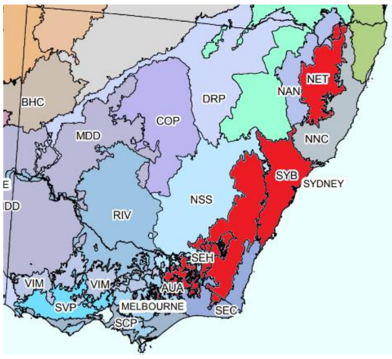

Figure 17: Bioregions included in study (shown in red)

3.3.7 Water source

Peatlands (both fens and bogs) in all bioregions are fed by surface water, precipitation and groundwater. In almost all areas of the world, a bog is considered to be a purely "ombotrophic" system (Charman, 2002), which means that it only receives water from precipitation, making it nutrient poor (Whinam and Hope, 2005). In those areas, fens can be distinguished from bogs by the fact that fens receive water from a mixture of sources (Charman, 2002). However, Australian groundwater is relatively nutrient poor, which means bogs can also develop from groundwater (Grover *et al.*, 2005). In SE Australia there are few differences in the water source between bogs and fens and most upland peatlands can be considered groundwater dependent ecosystems (Baird and Benson, 2018).

3.3.8 Surface cover – water

All peatlands are waterlogged. Fens have a higher water table than bogs (Hope, 2003; Baird and Benson, 2018).

3.3.9 Water type

All upland peatlands contain freshwater (Charman, 2002; Joosten *et al.*, 2002).

Figure 18: Bogong Creek Swamp, a fen in the South Eastern Highlands. The water table is at the surface. (Photo: Anne Murray)

3.3.10 Vegetation

Table 11 summarises the vegetation in each of the bioregions. Upland peatlands in all of the bioregions are characterised by species biodiversity. Each bioregion has endemic and rare peatland species. According to Keith and Myerscough (1993), upland swamps in the Sydney Basin have the highest level of species richness recorded in all Australian upland peatlands.

The granular soil glistens
with moisture,
and the leaf clumps of snow daises are a
patchwork of silver
up the brown and green slopes.

Figure 19: Excerpt from the poem “I don't care for Alpine landscapes in winter”, by Geoffrey Lehmann (1978)

In general, bog vegetation in all bioregions is characterised by the presence of shrubs, while fens have sedges and lack shrubs (Keith, 2004; NSW Threatened Species Scientific Committee, 2005b; McDougall and Walsh, 2007). Fens often contain *Carex gaudichaudiana* or *Carex appressa* (Keith, 2004). Bog vegetation is more common in the AUA and NET bioregions (Hunter and Bell, 2009; Hope *et al.*, 2012). In other bioregions, fen vegetation is more prevalent. All of the bioregions have *Sphagnum* peatlands (Commonwealth of Australia, 2009).

Figure 20: Wingecarribee Swamp, SE Australia's largest upland peatland. The swamp vegetation includes *Sphagnum cristatum* and *Carex gaudichaudiana* (Photo: Anne Murray)

Table 11: Upland peatland vegetation

	AUA - NSW/ACT	AUA - VIC	NET	SEH	SYB
Vegetation families and communities	Five communities: alpine, subalpine and medium-altitude *Sphagnum* shrub bog, *Empodisma minus* fen, and *Carex gaudichaudiana* fen.	Dominant species are in Restionaceae and Cyperaceae families.	Most common herbaceous families are Poaceae, Cyperaceae and Asteraceae.	Most common peatland type is *Carex* fen.	Primarily fen-type vegetation. Sedge, heath and shrub communities.
Shrub properties	Most common mire type *Sphagnum* shrub bog.	Shrubs in the Epacridaceae and Myrtaceae families.	Most common shrub families are Myrtaceae, Fabaceae and Proteacae.	*Sphagnum* shrub bog occurs.	*Sphagnum* can occur.
Bog properties	Complex vegetation: mosses, cushion plants and shrubs.		Shrubs dominate bogs. They have herbaceous understoreys.		

	AUA - NSW/ACT	AUA - VIC	NET	SEH	SYB
Fen properties	Simpler vegetation: sedges and rushes.		Lack shrubs, herbaceous. Most common fen vegetation alliances are *Carex gaudichaudiana* and *Carex appressa*.		
Species diversity	Wetlands maintain greatest species diversity for alpine and subalpine vegetation. ~250 species.	Peatlands in sub-alpine and alpine areas among the rarest plant communities in Australia.	234 vascular taxa in fens. 438 species in bogs.	~180 species.	Highest level of species richness recorded in Australian upland peatlands Up to 70 vascular plant species in $15m^2$.

Note. AUA – NSW/ACT information from McDougall and Walsh (2007), Wild *et al.* (2010b), Worboys and Good (2011), Hope *et al.* (2012), Clarke *et al.* (2015) and Mackey *et al.* (2015). AUA – VIC information from Wahren *et al.* (2001), Lawrence *et al.* (2009) and McDougall (2007). NET information from Hunter and Bell (2007), Hunter and Bell (2009) and Hunter and Bell (2013). SEH information from Keith (2004), Hope and Kershaw (2005) and Hope *et al.* (2009). SYB information from Keith and Myerscough (1993), Keith (2004), Department of the Environment, Water, Heritage and the Arts (2005), Benson and Baird (2012), and Baird and Benson (2018).

3.3.11 Land tenure

Table 12 shows that in most bioregions, upland peatlands are primarily found in conservation reserves. For example, 79% of all upland peatlands in the Victorian Alps are within national parks (NP) and nature reserves (NR) (Tolsma, 2009). In contrast, nearly all fens, and the majority of bogs, in the New England Bioregion are found on freehold land or stock reserves (Hunter and Bell, 2009).

Figure 21: Bogong Creek Swamp is within Namadgi National Park, South Eastern Highlands (Photo: Anne Murray)

Table 12: Land tenure

	AUA - NSW/ACT	**AUA - VIC**	**NET**	**SEH**	**SYB**
~% in Reserves	85%	79%	0.2% fens 27% bogs	75%	80%
Reserves	KNP Namadgi NP Brindabella NP Bimberi NR Scabby Range NR Lower cotter catchment – protected water catchment	Yarra Ranges NP Baw Baw NP Alpine NP Mt Buffalo NP Nunniong Plateau Natural Features Reserve	Sepoy NP Ironbark Nature Reserve Barrington Tops NP Mummel Gulf NP Little Llangothlin NR Werrikimbe NP Coolah Tops NP New England NP	KNP Namadgi NP Bimberi NR	Blue Mountains NP Budderoo NP Royal NP Wollemi NP WaterNSW protected water catchment areas
State forest	Yes	Yes	No	No	Yes
Freehold	Yes	Yes	Yes	Yes	Yes
Other	Ski resorts	Alpine resort			

Note. AUA – NSW/ACT information from Hope *et al.* (2009), Wild *et al.* (2010b), Hope *et al.* (2012) and ACT Parks and Conservation Service (2018). AUA – VIC information from Lawrence *et al.* (2009) and Tolsma (2009). NET information from Hunter and Bell (2007), Hunter and Bell (2009), Cibilic and White (2011), Hunter (2013), and Hunter and Bell (2013). SEH information from Hope *et al.* (2009). SYB information from Hose *et al.* (2014), Baird and Benson (2018) and Fryirs *et al.* (2019).

3.3.12 Conservation legislation status

The *Environment Protection and Biodiversity Conservation Act 1999* (EPBC) listed ecological community "Alpine Sphagnum Bogs and Associated Fens" (referred to as Alpine Sphagnum Bogs in Table 13) occurs in all of the bioregions (Department of the Environment, 2008). The *NSW Biodiversity Conservation Act 2016* (BC) ecological community "Montane Peatlands and Swamps of the New England Tableland, NSW North Coast, Sydney Basin, South East Corner, South Eastern Highlands and Australian Alps bioregions" (referred to as Montane Peatlands in Table 13) also occurs in all of the bioregions (NSW Threatened Species Scientific Committee, 2005b). The EPBC THPSS community is primarily found in SYB, with the exception of Jackson's Bog, near the VIC/NSW border in SEH (Department of the Environment, 2019g). There are three "Ramsar Convention on Wetlands" upland peatland sites in SE Australia, two of which are found in the AUA bioregion. These are the Ginini Flats Complex (Wild *et al.*, 2010b) and Blue Lake (State of New South Wales and Department of Environment and Climate Change, 2008). The third, Little Llangothlin Nature Reserve, is found in NET (Cibilic and White, 2011).

Figure 22: Nursery Swamp is an example of the "High Country Bogs and Associated Fens" ecological community listed in the ACT *Nature Conservation Act 2014* (Photo: Anne Murray)

Table 13: Conservation legislation status

	AUA - NSW/ACT	**AUA - VIC**	**NET**	**SEH**	**SYB**
Commonwealth *EPBC Act 1999*	Alpine Sphagnum Bogs	Alpine Sphagnum Bogs	Alpine Sphagnum Bogs	Alpine Sphagnum Bogs	Alpine Sphagnum Bogs
				THPSS	THPSS
NSW *BC Act 2016*	Montane Peatlands		Montane Peatlands	Montane Peatlands	Montane Peatlands
					Coastal Upland Swamps
					Newnes Plateau Shrub Swamps
					Blue Mountains Swamps
VIC *Flora and Fauna Guarantee Act 1988*		Fen (Bog Pool)			
		Alpine Bog			
ACT *Nature Conservation Act 2014*	High Country Bogs and Associated Fens			High Country Bogs and Associated Fens	
Ramsar Convention Wetlands of International Significance	Blue Lake		Little Llangothlin NR		
	Ginini Flats				

Note. AUA – NSW/ACT information from NSW Threatened Species Scientific Committee (2005b), State of New South Wales and Department of Environment and Climate Change (2008), Commonwealth of Australia (2009), Wild et al. (2010b), and ACT Scientific Committee (2019c). AUA – VIC information from Commonwealth of Australia (2009) and Flora and Fauna Guarantee Scientific Advisory Committee (n.d.). NET information from NSW Threatened Species Scientific Committee (2005b), Commonwealth of Australia (2009) and Cibilic and White (2011). SEH information from NSW Threatened Species Scientific Committee (2005b), Commonwealth of Australia (2009), Department of the Environment (2019g) and ACT Scientific Committee (2019c). SYB information from NSW Threatened Species Scientific Committee (2005b), Commonwealth of Australia (2009), NSW Threatened Species Scientific Committee (2011c), NSW Threatened Species Scientific Committee (2011a); Department of Environment (2014), and Department of the Environment (2019g).

3.3.13 Land use related pressures

Table 14 lists the land use related pressures upland peatlands face in each bioregion. Peatlands in all bioregions are threatened by changes in water quality or supply. In the AUA, NET and SEH bioregions, change is often a result of infrastructure development, small to medium scale dams, drains and/or ditching (Hope and Kershaw, 2005; Hunter and Bell, 2009; Lawrence *et al.*, 2009; Hope *et al.*, 2012). In SYB, urbanisation is heightening runoff, which reduces plant and freshwater biodiversity (Belmer *et al.*, 2018). Groundwater bores and stormwater outlets in SYB also harm peatland water quality and supply (Fryirs *et al.*, 2016).

In each bioregion, peatlands face unique land use related pressures. The peatlands in SYB are threatened directly by urbanisation as well as longwall mining and coal seam gas (Fryirs *et al.*, 2016), while those in AUA are impacted by ski field infrastructure (Hope *et al.*, 2012). The fens in NET are being degraded by domestic stock grazing (Gosling and Cobcroft, 2010). Cattle grazing is still permitted in Victorian state forests, resulting in peatland degradation (Tolsma and Sutter, 2018).

> *That broken briar, that heath*
> *Flattened and crushed and tramped*
> *Show as if in vast shadows*
> *That place where the cattle camped*
>
> Figure 23: Excerpt from the poem "The Last of Snow", by Douglas Stewart (1955)

Figure 24: Dams built for the Snowy Hydro scheme resulted in peatland loss (Photo: Anne Murray)

Table 14: Land use related pressures

	AUA - NSW/ACT	AUA - VIC	NET	SEH	SYB
Land use-related pressures directly impacting water quality and supply	Ditching Changes in upper catchment infrastructure	Drains Aqueducts	Dams Drains Ditching	Dams Drains Ditching	Urban runoff Groundwater extraction Urbanisation Groundwater bores Stormwater outlets
Other land use related pressures	Ski field infrastructure, inc. roads, carparks Horse riding Bushwalking	Ski field infrastructure Off-road driving Logging machinery Timber harvesting Cattle grazing in state forests	Domestic stock grazing Burning for agriculture	Catchment clearance	Roads Domestic stock grazing Off-road recreational driving Longwall mining Coal seam gas
Historical land use related pressures (no longer occurring)	Creation of large lakes or dams Commercial *Sphagnum* moss harvesting Grazing	Creation of large lakes or dams Commercial *Sphagnum* moss harvesting Grazing			Peat extraction

Note. AUA – NSW/ACT information from Hope (2003), Pickering *et al.* (2003), McDougall and Walsh (2007), Wild *et al.* (2010a), Hope *et al.* (2012), Clarke *et al.* (2015). AUA – VIC information from Wahren *et al.* (1994), Lawrence *et al.* (2009), Tolsma (2009), and Tolsma and Sutter (2018). NET information from Hunter and Bell (2007) and Gosling and Cobcroft (2010). SEH information from Hope and Kershaw (2005), NSW Threatened Species Scientific Committee (2005b) and Hope *et al.* (2009). SYB information from Krogh (2007), Hensen and Mahony (2010), Benson and Baird (2012), Keith *et al.* (2014), Fryirs *et al.* (2016), Baird and Benson (2018) and Christiansen *et al.* (2019).

3.3.14 Other pressures

Table 15 reveals that feral animals are a threat to peatlands in all of the bioregions. As mentioned earlier, feral animals trample peatlands, causing channelisation and sedimentation (Tolsma, 2009; Hunter, 2013; Brown *et al.*, 2016). They also degrade vegetation and can introduce weeds. Feral horses are particularly widespread in the NSW section of the Australian Alps (Robertson *et al.*, 2019).

Table 15: Feral animals

AUA - NSW/ACT	**AUA - VIC**	**NET**	**SEH**	**SYB**
Horse	Horse	Very limited horse numbers	Horse	
Pigs	Pigs	Pigs	Pigs	Pigs
Deer	Deer		Deer	Deer
	Cattle			

Note. AUA – NSW/ACT information from McDougall and Walsh (2007), Macdonald (2009) and Robertson *et al.* (2019). AUA – VIC information from Tolsma (2009) and Brown *et al.* (2016). NET information from Hunter (2013) and Schulz *et al.* (2019). SEH information from Hope *et al.* (2009), Hope *et al.* (2012) and Davis *et al.* (2016). SYB information from Baird and Burgin (2016) and Davis *et al.* (2016).

Figure 25: The impact of feral horses in the Australian Alps (Photo: Jamie Pittock)

Upland peatlands in all bioregions are vulnerable to climate change, fire, flooding and drought (see Table 16). Climate change will exacerbate the latter pressures. Climate change has been noted as the greatest threat to S*phagnum* bogs in the Australian Alps (Department of the Environment, Water, Heritage and the Arts, 2008). It is likely that climate change will also indirectly affect peatlands, through changes in water management (J. Pittock, pers. comm, 12 June 2019).

Table 16: General pressures common to all bioregions

Threat	**Impact**
Climate change	Surface drying Peat decomposition Transforms from carbon sink to source Increased fire, flooding and drought
Fire	Erosion Peat decomposition Vegetation loss Peat cracking Transition from bog to fen, fen to grassland
Flooding	Erosion Vegetation loss
Drought	Surface drying

Note. Threat information from Pemberton (2005), Hope *et al.* (2009), Lawrence *et al.* (2009), Good *et al.* (2010), Department of Environment (2014), Keith *et al.* (2014), NSW Threatened Species Scientific Committee (2005b) and Threatened Species Scientific Committee (2009).

3.4 Conclusion: Could a shared management framework be applied across upland peatland sites in South East Australia?

This chapter has drawn on wide-ranging literature to analyse the characteristics of upland peatlands across SE Australia, with the aim of identifying whether they have sufficient commonality so that a set of common management and data collection principles could be applied across sites.

This chapter highlights where data deficiencies exist, and provides direction for future research. For example, there needs to be further research on the upland peatlands in the NSW North Coast and South East Corner bioregions. The organic matter content of upland peatlands in the New England Tablelands and South Eastern Highlands could also be evaluated. In general, the upland peatlands in the Australian Alps and Sydney Basin are the most extensively studied, and the most recent research has occurred in the Sydney Basin.

Table 17 summarises the analysis. It lists the variables that were used to compare the peatlands, and shows that upland peatlands in the Australian Alps, New England Tablelands, South Eastern Highlands and Sydney Basin share most key characteristics. Differences in characteristics are largely due to differences between fens and bogs. For example, fens are found at lower altitudes, are less likely to be in conservation reserves, and have slightly different vegetation. However, fens and bogs still have significantly more similarities than differences, which is the condition the MA (Alcamo *et al.*, 2005b) states must be met to include ecosystems within the same category. It is therefore justifiable to conclude that a shared management framework could be applied across upland peatlands sites in SE Australia.

Table 17: Summary table of the characteristics of upland peatlands in SE Australia

Variable	**Do upland peatlands in the four bioregions share characteristics?**	**Summary description**
Altitude	Yes, but with some differences between bogs and fens	All found in higher altitude areas. Fens are, on average, found in relatively lower altitude areas than bogs.
Hydrogeomorphology	Yes	Most upland peatlands in SE Australia are topogenic.
Soil	Yes	By definition, all upland peatlands are organosols.
Substrate	Yes, but some differences	Peatlands in all bioregions are found on a variety of geological substrates. There is significant overlap in the substrates on which peatlands in each bioregion are found. However, substrate does not appear to be an influencing factor for peatland location, and thus does not weigh against general similarity.
Rainfall	Yes	All located in areas of relatively high average annual rainfall.
Temperature	Yes	All found in relatively cool areas.
Water source	Yes	All receive a mixture of surface water, groundwater and precipitation.
Surface cover – water	Yes	All waterlogged.
Water type	Yes	All freshwater.

Vegetation	Yes, but with some differences between bogs and fens	Bogs and fens have different vegetation. Bogs are dominated by shrubs, while fen vegetation lacks shrubs and features sedges. Most bioregions have both bogs and fens, with the exception of SYB, which primarily has fens. All upland peatlands in SE Australia have rare and endemic vegetation, and have a high level of species diversity.
Land tenure	Yes, but some differences	Upland peatlands in the four bioregions are mainly found in conservation reserves, with the exception of fens in the NET, which are primarily found on private freehold land. Fens in general are less likely to be in conservation reserves than bogs. Upland peatlands are found in state forests only in the SYB and AUA bioregions. Ski and alpine resorts are only found in the AUA bioregion.
Conservation status	Yes	All feature peatland ecological communities which are listed in conservation legislation.
Land use related pressures	Some shared characteristics, but significant differences between bioregions	All threatened by changes in water supply and quality. Each bioregion has unique land use related threats, such as coal mining, ski-related pressures, and domestic stock grazing.
Other pressures	Yes	Upland peatlands in the four bioregions are threatened by feral animals, climate change, flooding, fire and drought. The peatlands in the AUA bioregion are particularly impacted by feral horses.

Chapter 4: The ecosystem services of South East Australian upland peatlands

Chapter 2 identified factors that limit the effective management of upland peatlands in SE Australia: their ambiguous classification; largely site-specific and threat-specific research; and a lack of appreciation of their value. The analysis in Chapter 3 addressed the first two deficiencies, demonstrating that SE Australian upland peatlands can be considered a sufficiently distinct system to warrant the generation of common management and data collection principles.

This chapter addresses research sub-question 2: *what ecosystem services are provided by upland peatlands in South East Australia?* It presents an ecosystem services (ES) framework, which could be used to improve recognition of the value of SE Australian upland peatlands, and guide their management. The chapter begins with the theoretical context for ES and an overview of the major aims and benefits of ES frameworks (Section 4.1). Section 4.2 discusses the three major frameworks used in research literature, and Section 4.3 provides a rationale for selection of the "Common International Classification of Ecosystem Services" (CICES) framework as the approach for the current study. The major part of the chapter (Section 4.4) outlines the ecosystem services provided by upland peatlands in SE Australia.

4.1 The rationale for using an ecosystem services framework

ES analysis involves systematically identifying how ecosystems affect human wellbeing (Braat and de Groot, 2012). The concept of ES emerged in the late 1970s as a way to promote the importance of ecosystem functions and their conservation (Gómez-Baggethun *et al.*, 2010). Seminal texts include Westman (1977) "How much are nature's services worth" and Ehrlich and Ehrlich (1981), who first used the term "ecosystem services" (Fisher *et al.*, 2009). Modern ES research often focuses on valuation approaches, methods of ES mapping, and design of indicator variables (Braat and de Groot, 2012).

There is variation in the way frameworks classify ES, but all include provisioning, regulating and cultural services. Provisioning services are the products which ecosystems supply, such as food, water and raw materials. Regulating services, such as flood mitigation and carbon sequestration, result from the regulation of ecosystem processes. Cultural services are non-material, and include recreation, education and spiritual experiences (Alcamo *et al.*, 2005b; TEEB, 2010).

ES analysis highlights the benefits to human wellbeing from environmental conservation. Conversely, it links the drivers of ecosystem degradation to decreased human wellbeing (Grizzetti *et al.*, 2016). Pittock *et al.* (2012) argue that “at its heart the decline in Australia’s ecosystems can be attributed to a habit of seeing every ecological debate as a contest between biodiversity and socio-economic benefit, where the resulting compromise decisions diminish ecosystem health” (p. 118). They contend that including the benefits from ecosystem services in cost-benefit analyses will help to shift the perception that ecological conservation does not result in socio-economic gains. An ES-based approach ensures that regulating and cultural services are included in development policy, in contrast to the traditional accounting approach, which only values ecosystems for their provisioning services, such as the wood provided from forests (Costanza *et al.*, 2017).

An ES framework can be a useful communication tool. It enables important issues to be discussed using a common language (Granek *et al.*, 2010). In so doing, the rationale for conservation becomes explicit and measurable. ES language has been widely adopted by government and non-government organisations in Australia (Pittock *et al.*, 2012) and the shared terminology has assisted different organisations to cooperate on joint projects (Granek *et al.*, 2010).

ES analysis also facilitates identification of the beneficiaries of ecosystem processes (Schirpke *et al.*, 2014). This knowledge is useful for defining responsibility for environmental management, as well as for analysing the economic and social implications of a decision or policy (Pittock *et al.*, 2012).

An ES framework allows the trade-offs of policy decisions to be examined. Peatlands provide multiple services, and the promotion of one service may be to the detriment of others. Ecosystem are often overexploited because they are only used, and managed, for one purpose (Seppelt *et al.*, 2012). In particular, provisioning ecosystem services have often been prioritised at the expense of other services (Pittock *et al.*, 2012). For example, cattle grazing, which relies on plant supply, was permitted in alpine areas of Victoria until 2006, despite the impact it had on upland peatlands (The State of Victoria and Department of Environment, Land, Water and Planning, 2015). A good example of the application of an ES framework to analyse trade-offs is Crossman et al.’s (2015) study on alternative uses of water in the Murray Darling Basin. The authors model two scenarios: maintaining the status quo and returning 2800 GL of water to the basin per year, concluding that the benefits from returning 2800GL could be worth as much as AU$9 billion, and cost around $7 billion.

ES analysis provides crucial information for government policy and funding priorities. As Chapter 2 highlighted, both the Victorian Waterway Health Program and NSW Wetlands Policy use information about wetland values and services to determine environmental offsets and management interventions. More generally, government agencies and land managers consider whether restoration will result in additional or improved ES when considering funding for restoration projects (Matzek *et al.*, 2019).

Figure 26: 70% of Wingecarribee Swamp collapsed as a result of overexploitation of its provisioning service – peat supply (Photo: Anne Murray)

4.2 Introduction to major ecosystem service frameworks

The major ES frameworks are the Millennium Ecosystem Assessment (MA) (Alcamo *et al.*, 2005b), The Economics of Ecosystems and Biodiversity (TEEB) (2010), and CICES (Haines-Young and Potschin, 2012). The three frameworks are similar but have several differences.

The MA was the first global study of the impact of humans on the world's ecosystems (Carpenter *et al.*, 2009). It led to a burgeoning of ecosystem service research (Potschin and Haines-Young, 2011).

TEEB (2010) builds on the work of the MA. It was developed in order to understand how biodiversity loss affects the economy (Finlayson, 2018). The model has been adopted in the literature as an alternative to the MA framework (Braat and de Groot, 2012).

CICES was developed by the European Environment Agency so that ecosystem services could be described consistently for the UN System of Environmental and Economic Accounting (SEEA) (Haines-Young and Potschin, 2012). Another aim of CICES was to provide a method to compare and analyse the MA and TEEB (CICES, 2019). The CICES framework is based on the cascade model from Potschin and Haines-Young (2011) (see Figure 27).

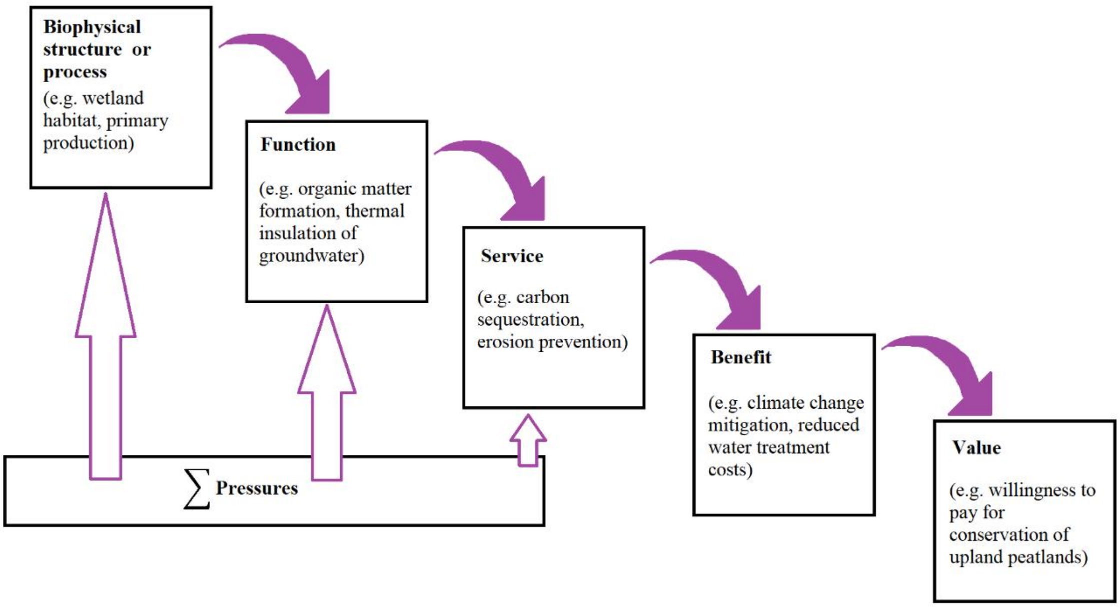

Figure 27: The ecosystem services cascade from Potschin and Haines-Young (2011), modified to include peatland examples. The cascade shows how ecosystem functions (sometimes termed intermediate or supporting services) result in ecosystem services.

TEEB, MA and CICES all define the term “ecosystem services” differently. The ES definition for each framework is summarised in Table 18.

Table 18: The MA, TEEB and CICES ecosystem services definitions

Framework	**ES definition**	**Details**	**Example**
MA (Alcamo *et al.*, 2005b)	The benefits people obtain from ecosystems.		Timber from forests.
TEEB (2010)	The direct and indirect contributions to human welfare.	Differentiates between services and benefits. Benefits are defined as the welfare gains services generate.	Service: flood regulation. Benefit: improved safety.
CICES (2019)	Contributions ecosystems make to human wellbeing.	Use Potschin and Haines-Young’s (2011) “cascade” model to define ES. Ecosystem processes and functions (sometimes termed intermediate services) generate final services. The CICES framework defines ES as final services, not intermediate services. CICES is a classification of final services. “Goods and benefits” are created by humans from final services.	Ecosystem processes and functions: organic matter accumulation. Service: carbon sequestration. Goods and benefits: climate change mitigation.

TEEB, MA and CICES also classify ecosystem services slightly differently. While all three include provisioning, regulating and cultural services, the MA also includes "supporting services", and TEEB includes "habitat services". Some literature use the terms habitat services and supporting services interchangeably (see, for example, Crossman *et al.*, 2013; Hattam *et al.*, 2015; Malinga *et al.*, 2015), or list habitat as a type of supporting service (see, for example, Dickie *et al.*, 2014; Dobbs *et al.*, 2014). The classification of ES by each framework is summarised in Table 19.

Table 19: The MA, TEEB and CICES classification of ecosystem services

Framework	**ES classification**	**Details**	**Example**
MA (Alcamo *et al.*, 2005b)	Provisioning Regulating Cultural Supporting	Supporting services underpin the production of all other ecosystem services.	Peat formation.
TEEB (2010)	Provisioning Regulating Cultural Habitat	Habitat services include both the maintenance of gene pools for natural selection, as well as the provision of nursery sites for migratory species.	Upland peatlands provide a food source for the migratory Latham's snipe (*Gallinago hardwickii*).
CICES (Haines-Young and Potschin, 2012)	Provisioning Regulating Cultural	CICES classes habitat services as a type of regulating service, and supporting services as a type of biophysical process or ecosystem function.	Habitat service: use of *Sphagnum* bogs by Northern Corroboree frogs for breeding. Ecosystem function: *Sphagnum* growth.

4.3 Rationale for choice of CICES framework

Fisher *et al.* (2009) argue that there is no one "correct" framework to use, and that a framework should be chosen based on research purpose. The CICES framework was chosen for the current project for three reasons. First, the CICES framework is consistent with SEEA, which has been chosen by the Australian federal and state governments as the national environmental accounting framework (Commonwealth of Australia, 2018). Second, the CICES classification of ecosystem services enables ecosystem services to be valued without the possibility of double counting. This is because it excludes supporting services, which cause double counting to occur in ecosystem service valuation, because they underpin other services (Braat and de Groot, 2012). Valuation is outside of the scope of this project, but would be a worthwhile focus for future research. Finally, the CICES framework can be easily compared with both MA and TEEB.

4.3.1 Overview of the CICES framework

The CICES framework classifies ES using a five-tier structure (Haines-Young and Potschin, 2018). Figure 28 explains each tier of the structure, using the example of surface water provision. The top four tiers are designed to provide an exhaustive list of possible ES. The CICES guidelines state that the user can decide which level of detail is required for their study. For this study, the "Group" level was chosen to describe upland peatland ES because the literature was not always detailed enough for the "Class" level to be used.

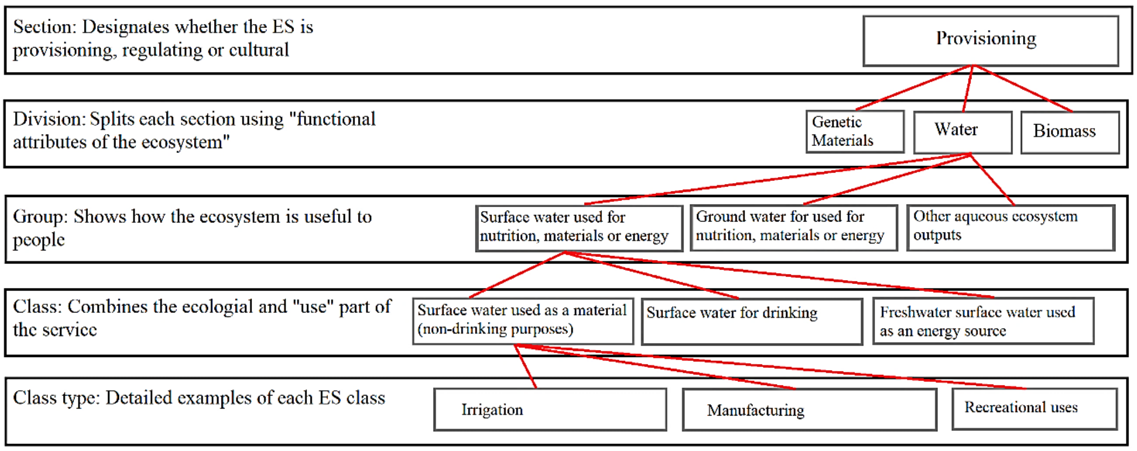

Figure 28: The structure of CICES, illustrated using an example of surface water provision. Adapted from Potschin and Haines-Young (2011).

4.4 The ecosystem services provided by upland peatlands in South East Australia

To date, there has been no systematic study of the ES provided by SE Australian upland peatlands. As noted earlier, Australian peatland literature is primarily made up of case-studies of specific variables and sites, with more research published on some topics and areas than others. This chapter synthesises the literature to identify and describe the ES provided by upland peatlands in the Australian Alps and Sydney Basin. The New England Tablelands and South Eastern Highlands bioregions were excluded from this part of the study due to a lack of detailed information in available literature.

A wide variety of sources was used, including Australian and international research literature, threatened species data from state and federal government reports, Ramsar Convention ecological character descriptions, and tourism information. For some services, studies have only been conducted in the Alps region, for others, only in the Sydney Basin. All ecosystem services are included, including services which are currently used, as well as past and potential services. Table 20 shows the structure of the summary ES tables compiled for each ES.

Table 20: Structure of the ecosystem services tables included in each section

CICES group	Peatland ES	Goods & Benefits	Indicative beneficiaries	Currently utilised?	Sydney /Alps	Source (service)	Source (benefit)
Refers to which group the specific peatland ES belongs to.	The ecosystem service provided by peatlands.	Lists any of the goods and benefits provided by peatlands that were identified in the literature.	Broadly indicates who benefits from the service.	Is the service still utilised? Yes/No	Indicates if the ES is specific to a bioregion.	References the document(s) from which data on the services were found.	References the document(s) from which the data on the goods and benefits were found.

4.4.1 Provisioning services

Peatlands have the potential to provide a range of provisioning services (see Table 21).

Plant and peat supply

As noted earlier, peat extraction and *Sphagnum* harvesting used to occur in upland peatlands. The main site was Wingecarribee Swamp (Whinam *et al.*, 2003), but peat extraction also occurred in Long Swamp in the Sydney Basin (Department of the Environment, 2019g). *Sphagnum* harvesting took place in Ginini Flats during World War 2 for use in gas producer vehicles (Macdonald, 2009). Victoria also had a small *Sphagnum* harvesting industry (Whinam *et al.*, 2003). It is now illegal, although Shannon and Morgan (2007) remark that some small-scale harvesting was still occurring in the Central Highlands of Victoria.

Figure 29: Canadian *Sphagnum* and peat fertilizer sold at a nursery in the ACT (Photo: Anne Murray)

Water supply

Water supply is the only provisioning service currently being utilised. The contribution of upland peatlands to downstream water supply varies according to location. Western *et al.* (2009) found that due to the limited extent of peatlands in the Victorian section of the Australian Alps, peatlands cannot be regarded as a major source of base flow. They are instead a conduit of the flows from the general groundwater system. In contrast, Cowley *et al.* (2019) found that upland swamps in the Sydney Basin provide, on average 44%, and up to 92%, of downstream surface water.

Figure 30: Upland peatlands form part of the Murrumbidgee River catchment (Photo: Anne Murray)

Northern Corroboree frog eggs

Northern Corroboree frog (NCF) (*Pseudophryne pengilleyi*) eggs were harvested in 2003 from *Sphagnum* bogs in the Australian Alps for an NCF breeding program. The breeding program is ongoing, but frogs are now bred in captivity and eggs are not taken from the wild (ACT Government Environment, Planning and Sustainable Development Directorate, 2019).

Marvelling to handle that lime-gold shape
so long unseen
I put it down. It has and needs no burrow,
With waddling hindlegged gait
the splay-knee'd frog swims into the
sphagnum smoothly
as an echidna into turf

Figure 31: Excerpt from the poem "Mt Bimberi Marsh, with Corroboree Frog", by Mark O'Connor (2000)

Table 21: Provisioning services provided by SE Australian upland peatlands

CICES group	**Peatland ES**	**Goods & Benefits**	**Indicative beneficiaries**	**Currently utilised?**	**Sydney /Alps**	**Source (service)**	**Source (benefit)**
Wild plants (terrestrial and aquatic) for nutrition, materials or energy	Peat supply	Peat fertilizer	Companies in supply chain (e.g. production, stockist) Consumers (e.g. households)	No	Both	(Whinam *et al.*, 2003; Whinam and Hope, 2005)	(Bonn *et al.*, 2010)
		Fuel		No			(Minayeva *et al.*, 2017)
	Plant supply	*Sphagnum* moss mulch	Companies in supply chain (e.g. production, stockist) Consumers (e.g. gardeners)	No	Both	(Whinam *et al.*, 2003)	(Whinam *et al.*, 2003)
		Grazing fodder	Farmers	No	Both		(McDougall and Walsh, 2007; Robertson *et al.*, 2019)

CICES group	**Peatland ES**	**Goods & Benefits**	**Indicative beneficiaries**	**Currently utilised?**	**Sydney /Alps**	**Source (service)**	**Source (benefit)**
Surface water used for nutrition, materials or energy	Surface water supply	Drinking water	Consumers	Yes	Both	(Hope, 2003; Commonwealth of Australia, 2009; Western *et al.*, 2009; Wild *et al.*, 2010b; Fryirs *et al.*, 2014a; Cowley *et al.*, 2019)	(Wild *et al.*, 2010b; Martin-Ortega *et al.*, 2014)
		Water used as a material	Manufacturing, irrigation, mining companies within catchment	Yes	Both		(McDougall and Walsh, 2007; Worboys and Good, 2011; Martin-Ortega *et al.*, 2014)
		Hydropower production	Hydroelectricity company, households within electricity grid, taxpayers	Yes	Alps		(Worboys and Good, 2011)
Genetic materials from animals	NCF eggs collected for maintaining population			No	Alps	(ACT Government Environment, Planning and Sustainable Development Directorate, 2019)	

4.4.2 Regulating services

Carbon sequestration

Peatlands sequester carbon as long as the rate of peat creation exceeds peat decomposition (Belyea and Malmer, 2004). In one study of the Alps, Hope and Nanson (2015) found that undamaged *Sphagnum* bogs accumulated carbon at a rate of 0.5 – 1.5 tonnes/hectare/year, while *Carex gaudichaudiana* fens accumulated carbon at a rate of 0.2 - 0.6 tonnes/hectare/year.

Globally, peatlands contain approximately 30% of all soil organic carbon and 10% of all terrestrial carbon stocks. Peatlands in the Australian Alps store approximately 3.55 million tonnes of soil carbon. Over the past 60 years, these peatlands have accumulated around 4950 tonnes per year (Hope and Nanson, 2015). There are around 7985 ha of peatlands in the Australian Alps (Hope *et al.*, 2012), meaning that on average, peatlands in the Australian Alps store 445 tonnes per hectare. The CSIRO estimated that the total stock of organic soil carbon for Australia in 2010 was 25 gigatonnes, and that on average, each hectare stored 29.7 tonnes. Thus, peatlands in the Australian Alps store nearly 18 times more soil carbon per hectare than the average.

Water flow regulation

Upland peatlands spread streamflow and slow runoff, thereby lowering the risk of extreme floods, and improving surface stability as well as water quality (Worboys and Good, 2011). Both the vegetation and peat layer are able to trap and store water (Hope *et al.*, 2012). *Sphagnum* is able to hold up to 20 times its weight in water (Hope *et al.*, 2012). Cowley *et al.* (2018b) demonstrate that intact upland peatlands in the Sydney Basin attenuate floods to a significant extent, while damaged peatlands act more like urban streams. They showed that the discharge rate of intact (non-channelised) peatlands in the Sydney Basin before rainfall was 1.2 L/day/m^2. This discharge rate did not change significantly for rain events less than 30mm, highlighting the large water storage capacity of upland peatlands. For rain events greater than 30mm, the peak discharge rate was 78.5 L/day/m^2. The time from peak discharge to recession was 48 hours. In contrast, the mean discharge rate of channelised peatlands before rainfall was 60 L/day/m^2, the peak discharge rate after rain 168 L/day/m^2, and the time from peak discharge to recession was 23 hours. The water table level in intact peatlands also did not significantly change after rainfall.

Regulation of the flow regime in the Alps is important for the management of the Murray and Murrumbidgee Rivers. If the flow rate is too great, water is lost over impoundment spillways in dams (Worboys and Good, 2011). By slowing the flow rate, upland peatlands increase availability of water for hydroelectricity generation, irrigation and other uses.

Upland peatlands increase water security during droughts. According to Hope (2003), Snowy Flat Bog, a peatland in the Australian Alps, was still providing 2.3 megalitres of water per day after 6 months of drought. Upland peatlands in the Sydney Basin provided, on average, 0.2 L/day/m^2 (~0.12 ML/day), and at maximum, 2.1 L/day/m^2 (~1.25 ML/day) during a 21-day dry period at the end of November 2015 (Cowley *et al.*, 2018b).

Figure 32: Upland peatlands in the Australian Alps help to regulate the flow of water entering the Cotter Dam. A potential indicator of this service is "reduction of peak discharges" (Photo: Anne Murray)

Water quality regulation

Upland peatlands play a significant role in regulating catchment water quality, by improving freshwater biodiversity and reducing treatment costs for drinking water. The addition of a buffering capacity is listed as one of the chemical treatment processes in Paper 6 of the National Water Quality Management Strategy (National Health and Medical Research Council and National Resource Management Ministerial Council, 2011). The buffering role of peatlands may reduce the need for this treatment process. Peatlands reduce the possibility of acidification by increasing the buffering capacity of headwaters (Silvester, 2009), and also by sequestering toxic metals (Rothwell *et al.*, 2010). Peatlands in the Australian Alps have been found to sequester a wide range of metals, including lead, arsenic, molybdenum and silver (Marx *et al.*, 2010; Stromsoe *et al.*, 2015).

Peatlands also perform a denitrification service. Silvester (2009) shows that upland peatlands are able to absorb sulfate, potassium and up to 90% of nitrate. Wingecarribee Swamp acts as a sink for phosphorus, reducing the possibility of downstream algal blooms (Commonwealth of Australia, 2014a).

Upland peatlands are filters for sediment (Young, 1982). In good condition, they are able to significantly reduce suspended sediment loads and fine particulate organic matter (FPOM) (Martin-Ortega *et al.*, 2014). Filtration of sediment by peatlands in the Australian Alps aids the production of hydroelectricity, by reducing damage to turbines (Worboys and Good, 2011).

Erosion prevention

Upland peatlands reduce erosion in two ways. First, they are thermally insulating, and retain warmer groundwater, which reduces the possibility of frost heave (State of New South Wales and Department of Environment and Climate Change, 2008; Hope *et al.*, 2012). Second, the top layer of peatland vegetation is tough and fibrous, making it resistant to erosion (Hope, 2003). Reduction of erosion improves water quality, and reduces reservoir infilling, which in turn increases water supply capacity (Worboys and Good, 2011; Martin-Ortega *et al.*, 2014).

Habitat services

Upland peatlands perform several key habitat services. They aid freshwater biodiversity by reducing acidification, and filtering sediment (Martin-Ortega *et al.*, 2014). They are also long-term stores of water, and thus green vegetation, which is an important resource for all flora and fauna during dry periods.

Upland peatlands also provide habitat for many endemic (Hope *et al.*, 2012) and endangered flora and fauna (NSW Threatened Species Scientific Committee, 2005b; Commonwealth of Australia, 2009). Appendices 1, 2, 3 and 4 list the considerable number of identified threatened flora and fauna species associated with upland peatlands in the Australian Alps or Sydney Basin that are listed in the NSW *Biodiversity Conservation Act 2016*, VIC *Flora and Fauna Guarantee Act 1988* (FFG Act), ACT *Nature Conservation Act 2014* (NC Act), and Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*. The NSW list was compiled by cross referencing vegetation types from Keith (2004) with information on each species profile on the NSW Department of Planning, Industry and Environment website. The Victorian list was compiled from a combination of sources, including threatened species action statements, the VicFlora database, and EPBC species profiles. The ACT list was assembled using conservation advice reports from the ACT Scientific Committee, and the EPBC list was established using information on the Species Profile and Threats Database.

SE Australian upland peatlands also support invertebrate fauna, but this has not been well-studied (Wild *et al.*, 2010b; Hope *et al.*, 2012). Wild *et al.* (2010b) remark that notable invertebrate species at the Ginini Bog Complex in the Australian Alps include the metallic bog cockroach (*Polyzosteria virridisma*), mountain grasshopper (*Acripeza reticulate*) and alpine chameleon grasshopper (*Kosciuscola tristis*).

My foot on a tussock depresses it
by a thousand years of growth;
in this swamp a hand's-length deep
the dry upper stalks belong
to the grass-thatch ants, swarming everywhere

Figure 33: Excerpt from the poem "Mt Bimberi Marsh, with Corroboree Frog", by Mark O'Connor (2000)

Table 22: The regulating services provided by SE Australian upland peatlands

CICES group	**Peatland ES**	**Goods & Benefits**	**Indicative beneficiaries**	**Currently utilised?**	**Sydney /Alps**	**Source (service)**	**Source (benefit)**
Atmospheric composition and conditions	Carbon sequestration	Climate change mitigation	Global population	Yes	Both	(Hope *et al.*, 2009; Hope *et al.*, 2012; Hope and Nanson, 2015; Cowley *et al.*, 2018a)	(Bagstad *et al.*, 2014)
Regulation of baseline flows and extreme events	Water flow regulation	Water supply during drought	Residents within catchment	Yes	Both	(Black, 1982; Hope, 2003; Western *et al.*, 2009; Good *et al.*, 2010; Worboys and Good, 2011; Fryirs *et al.*, 2014b; Keith *et al.*, 2014; Cowley *et al.*, 2018b)	(Hope *et al.*, 2012)
		Improved safety from floods	Residents within watershed		Both		(Wild *et al.*, 2010b)
	Erosion prevention	Increased water supply capacity	Water distributor (e.g. WaterNSW) Taxpayers	Yes	Both	(Joosten *et al.*, 2002; Hope *et al.*, 2009)	(Worboys and Good, 2011)

CICES group	**Peatland ES**	**Goods & Benefits**	**Indicative beneficiaries**	**Currently utilised?**	**Sydney /Alps**	**Source (service)**	**Source (benefit)**
Mediation of wastes or toxic substances of anthropogenic origin by living processes	Water quality regulation	Improved water quality for recreation	Recreational stream users (e.g. swimmers, picnic goers)	Yes	Both	(Pemberton, 2005; Hope *et al.*, 2009; Silvester, 2009; Marx *et al.*, 2010; Worboys and Good, 2011; Martin-Ortega *et al.*, 2014; Stromsoe *et al.*, 2016)	(Martin-Ortega *et al.*, 2014)
		Improved water quality for fisheries	Fishery companies (e.g. Snowy Mountains Trout)	Yes	Alps		(Keeler *et al.*, 2012; Snowy Mountains Trout, 2019)
		Reduced snow making costs	Ski resorts	Yes	Alps		(Worboys and Good, 2011)
		Reduced water treatment costs	Treatment facility Taxpayers	Yes	Both		(Martin-Ortega *et al.*, 2014)
		Improved hydroelectricity generation	Hydroelectricity company Taxpayers	Yes	Alps		(Worboys and Good, 2011)

CICES group	Peatland ES	Goods & Benefits	Indicative beneficiaries	Currently utilised?	Sydney /Alps	Source (service)	Source (benefit)
Maintenance of physical, chemical, abiotic conditions	Snow lies earlier and longer	Longer ski season Reduced snow making costs	Skiers, snowboarders Ski resorts	Yes	Alps	(Hope *et al.*, 2012)	
Habitat services shown in Appendices 1, 2, 3 and 4							

4.4.3 Cultural services

Data for palaeoecological studies

The acidic and anoxic conditions of upland peatlands mean that materials such as pollen and charcoal are well-preserved, making palaeoecological research possible. Peatlands have been used as a source of climate change data (Baird and Benson, 2018), and fire history data (Hope *et al.*, 2019). Data from peatlands were used by Stromsoe *et al.* (2016) to estimate historical rates of soil development and erosion in the Australian Alps. Such information from peat can be used to inform environmental policy and management plans.

Education and training

Upland peatlands in both bioregions are an educational asset. They have generated an entire field of research (see, for example, Costin, 1954; Whinam and Hope, 2005; Fryirs *et al.*, 2014a). The upland peatlands in the Sydney Basin have featured in several theses, including Young (1982) and Gorissen (2016). Rennix Gap Bog in the Australian Alps has been a valuable resource for university field trips (Hope *et al.*, 2019).

Aesthetic experiences

Peatlands are not widely-reputed to be beautiful, but they do have aesthetic value. *Sphagnum-Epacris* bogs flower during summer, creating wildflower displays (Costin *et al.*, 2000). The bogs and fens of the region contribute to the wider aesthetic appeal of the landscape. Hope *et al.* (2009) points out the perception of peatlands "as 'waste land'" should be replaced by appreciation of their "aesthetic highlights" (p. 46).

Figure 34: The swamp heath (*Epacris paludosa*) flower (Photo: Anne Murray)

Recreation

Upland peatlands provide many recreation and tourism experiences in the Australian Alps and Sydney Basin. Peatlands feature in several popular bush walks (McDougall and Walsh, 2007; Parks Victoria, 2017; NSW National Parks, 2019), as well as horse-riding trails (Hope *et al.*, 2012). Trail biking and off-road recreational driving also occur in peatland areas of the Sydney Basin (Baird and Benson, 2018). Peatlands provide habitat to many birds, which in turn generates bird-watching tourism (Mules *et al.*, 2005; Bicknell and McManus, 2006). Feral horses, supported by peatland vegetation, create some tourism in the Australian Alps (Pickering *et al.*, 2003), but as noted earlier, feral horses significantly degrade peatlands (Robertson *et al.*, 2019).

Upland peatlands exist in several ski areas in the Alps (McDougall and Walsh, 2007), and form part of the downhill skiing slopes (Hope *et al.*, 2012). Snow lies earlier and longer on these peatlands (Hope *et al.*, 2012), potentially lessening the cost of snow-making and lengthening the ski season. J. Pittock and S. Dovers (pers. comm, 21 August 2019) state that cross-country skiing is easier across peatlands, due to the lack of trees.

Figure 35: The Nursery Swamp bushwalk in Namadgi National Park (Photo: Anne Murray)

Table 23: The cultural services provided by SE Australian upland peatlands

CICES Group	**Peatland ES**	**Goods & Benefits**	**Indicative beneficiaries**	**Currently utilised?**	**Sydney /Alps**	**Source (service)**	**Source (benefit)**
Intellectual and representative interactions with natural environment	Data for palaeo ecological studies	Information for fire management and climate policy	Author Managers Policy makers	Yes	Both	(Baird and Benson, 2018; Hope *et al.*, 2019)	(Hope *et al.*, 2019)
	Education and training	Knowledge about environmental management	Students	Yes	Both	(Young, 1982; Gorissen, 2016; Hope *et al.*, 2019)	(Haines-Young and Potschin, 2018; Hope *et al.*, 2019)
	Aesthetic experiences	Mental health, tourism, art	People in area from which the site can be seen	Yes	Both	(Wild *et al.*, 2010b)	(Fuller *et al.*, 2007; Haines-Young and Potschin, 2018)
Physical and experiential interactions with natural environment	Recreation	Mental wellbeing, tourism employment	User (e.g. bushwalker, birdwatcher) Employees	Yes	Both	(Mules *et al.*, 2005; Bicknell and McManus, 2006; McDougall and Walsh, 2007; Lockwood *et al.*, 2014; Parks Victoria, 2017)	(Mules *et al.*, 2005; Pickering and Scherrer, 2008; Haines-Young and Potschin, 2018)

4.5 Conclusion

This chapter has explored the question: *what ecosystem services are provided by upland peatlands in SE Australia?* The ES supplied by upland peatlands in the AUA and SYB bioregions were determined via an extensive review of Australian peatland literature. The ES were categorised according to CICES. The analysis reveals that upland peatlands in the Alps and Sydney Basin deliver almost identical types of ES. Upland peatlands in both bioregions deliver many crucial ES, with regulating services being of particular importance. Peatlands have traditionally only been valued for their provisioning services, leading to overexploitation of resources, and deterioration in their condition (Sainty, 1999; Pittock *et al.*, 2012; Seppelt *et al.*, 2012). Most of the beneficiaries of the ES provided by upland peatlands are within the catchment (e.g. individual companies, households in a watershed), but some are broader (e.g. Australian taxpayers).

The findings in this chapter strengthen the conclusion that peatlands in the two regions share key characteristics for management. Further, using ES language allows the role of peatlands in both bioregions to be consistently described. The next step in developing an ES framework is the creation of indicators to quantify the contribution made by these important ecosystems. This will be discussed in the next chapter.

Figure 36: Eastern Grey kangaroos (*Macropus giganteus*) close to a peatland in Namadgi National Park. The waterlogged state of peatlands means that they are an important resource for all wildlife (Photo: Anne Murray)

Chapter 5: Using indicators to measure the ecosystem services provided by upland peatlands

Chapter 4 identified the provisioning, regulating and cultural services offered by upland peatlands. In order to understand and manage these services they need to be measured. This chapter addresses the third research sub-question: *what indicators can be used to assess the ecosystem services provided by upland peatlands in SE Australia?* It discusses the theoretical underpinnings of ES indicators, and establishes the criteria they should meet (Section 5.1). The next section (5.2) reviews peatland and ES literature to generate a set of potential indicators for the ES provided by upland peatlands in SE Australia. It does so using the example of the Australian Alps. This is followed by an analysis of whether these indicators meet key criteria, including data availability (Section 5.3). The chapter concludes with suggestions for monitoring and data collection (Section 5.4).

5.1 Introduction to ecosystem service indicators

The purpose of indicators is to measure ES. Indicators are a critical component of any ES assessment, because many ES are not able to be directly quantified (Egoh *et al.*, 2012). Indicators are often proxies or surrogate variables (Reyers *et al.*, 2010). They may also be models that take into account multiple types of measurements (Crossman *et al.*, 2013).

For a rigorous ES assessment, indicators should meet several criteria. The criteria used in this study, set out in Table 24, were determined by a review of widely cited ES literature.

Table 24: The criteria used to assess indicators for the ecosystem services provided by upland peatlands in SE Australia

Criteria	**Description**
Criteria 1: Is the indicator measurable?	Quantitative and/or qualitative methods exist to implement the indicator (Müller and Burkhard, 2012; Hernández-Morcillo *et al.*, 2013).
Criteria 2: Is the indicator relevant?	Relevant indicators provide information about the most important aspects of the ecosystem and/or its service (Müller and Burkhard, 2012; Hernández-Morcillo *et al.*, 2013).
Criteria 3: Is the indicator sensitive to changes in ecosystem condition?	Changes in the ecosystem condition are reflected in changes in the indicator values (Burkhard *et al.*, 2012; van Oudenhoven *et al.*, 2018).
Criteria 4: Is the indicator scientifically valid?	The indicator is based on established and/or peer-reviewed methods (Alcamo *et al.*, 2005a; Layke *et al.*, 2012).
Criteria 5: Can the purpose of the indicator be clearly communicated?	The indicator is clear and understandable to end-users. This is important for policy development and management (Feld *et al.*, 2010; Reyers *et al.*, 2010; Layke *et al.*, 2012).
Criteria 6: Are data available?	The indicator can be implemented using data that are either publicly available, or accessed relatively easily (Alcamo *et al.*, 2005a; Layke *et al.*, 2012).
Criteria 7: Are the data at an appropriate temporal and spatial scale?	Data collected with sufficient regularity, and at a spatial scale that are fit for the purpose of assessment (e.g. individual peatland, cluster of peatlands, watershed etc.) (Layke *et al.*, 2012).

There are also several criteria that a set of indicators should meet. Taken together, the indicators should provide a comprehensive picture of the ES delivery process (Niemeijer and de Groot, 2008; Heink *et al.*, 2016). The set needs to provide information about:

1. the *capacity* of the ecosystem to provide ES (e.g. the hypothetical maximum amount of carbon dioxide that a peatland could sequester);
2. *pressures* that influence capacity (e.g. feral horse trampling resulting in channelisation and subsequent loss of ability to sequester carbon);
3. *demand* for ES (e.g. the extent to which society requires peatlands to sequester carbon); and,
4. the actual *supply* of ES (e.g. how much carbon the peatland sequesters).

Assessing these four aspects ensures policy-makers can evaluate the impact of changes in land use, and whether demand for ES can be met sustainably (Burkhard *et al.*, 2012; Villamagna *et al.*, 2013).

Figure 37: Hydroelectricity generation creates demand for the water quality regulation service performed by upland peatlands. Filtration of sediment reduces damage to turbines (Photo: Anne Murray)

5.2 Compiling a set of indicators to measure the ecosystem services provided by upland peatlands in the Australian Alps – a case study

The Australian Alps was chosen for a case study because it is the bioregion for which there is the most comprehensive data. The availability of data for the Alps is due to current research and monitoring. Indicators proposed in this section could be applied to other bioregions, because as Chapters 3 and 4 demonstrated, the peatlands have similar characteristics and ES. However, each bioregion faces unique land use related pressures, and so some pressure indicators would change between bioregions. Data availability would also have to be established for each bioregion.

As noted earlier, four types of indicators are necessary to rigorously assess ES: capacity, pressure, demand and supply indicators. To date, indicators for SE Australia upland peatlands have only been defined for some aspects of capacity and pressure. A major contribution of the current study is the development of indicators for demand and supply. Each of the four types of indicators will now be discussed in turn.

5.2.1 Indicators for capacity and pressure

Wild and Magierowski (2015) have developed condition and pressure indicators for alpine *Sphagnum* bogs (see Table 25 and Table 26, respectively). The condition indicators proposed by Wild and Magierowski (2015) serve as measures of capacity, because they include variables that are critical to the function of peatlands. Peatland function determines its capacity to provide services. For example, peatlands accumulate organic matter in peat layers (ecosystem function). This enables them to provide palaeoecological data - the capacity is the hypothetical maximum amount of palaeoecological data that a peatland could provide. All of the indicators are highly applicable to fens, with only the details for water table and vegetation needing to change. As noted in Chapter 3, fens have higher water tables (see 3.3.8 Surface cover – water), as well as different characteristic vegetation (see 3.3.10 Vegetation).

Table 25: Indicators used to assess the condition of alpine *Sphagnum* bogs (Wild and Magierowski, 2015, p. 20)

Condition Indicator	Description
Peat layer	Degree of oxidation Acrotelm/catotelm condition
Organic matter	Formation process Amount in acrotelm/catotelm pH
Water holding capacity / water table	Water table fluctuation Presence of ditches/drains
Moisture	Degree of desiccation
Vegetation	Presence of key species

Wild and Magierowski (2015) suggest five pressure indicators, presented in Table 26. Tolsma and Sutter (2018) apply a similar set of indicators to assess the impact of pressures on peatlands in the Victorian Alps: presence of willows (% peatland area); deer activity (% peatland area); horse activity (% peatland area); and the number of times the peatland has been burnt since 1988.

Table 26: Indicators used to assess the pressures to alpine *Sphagnum* bogs (Wild and Magierowski, 2015, p. 18)

Pressure indicator	Description
Damage by feral animals	Extent of droppings/scats, tracks, wallows, pugging, trampling, bank slumping, erosion
Disturbance by vehicles	Extent of wheel rutting, diversion of water away from bog
Weed invasion	Presence of willows, soft rush, gorse, sweet briar, greater lotus, musk monkey flower, water forget-me-not and ox-eye daisy
Disturbance by infrastructure	Diversions resulting from infrastructure
Fire damage	Fire interval and degree of burnt peat

5.2.2 Indicators of ES demand and supply

To date, there have been no published indicators for demand and supply of SE Australian upland peatland ES. Potential indicators for this study were generated from a review of peatland literature, as well as more general ES literature. Some of the indicators have been repurposed from ES studies of other types of ecosystems (see, for example, Guimarães *et al.*, 2017). The proposed indicators are presented according to ES section in Tables 27, 28 and 29.

5.2.2.1 Provisioning service indicators

Provisioning service indicators are relatively simple to understand and measure (Czúcz *et al.*, 2018), and they are often able to be directly quantified (Burkhard *et al.*, 2012). Demand for provisioning services can be thought of as the amount of goods and benefits derived from provisioning services that society uses over a certain area and time period (Burkhard *et al.*, 2012; Albert *et al.*, 2016). The supply of provisioning services is the extent to which the ecosystem can provide the set of services that are actually utilised, as opposed to capacity, which is the hypothetical maximum extent (Burkhard *et al.*, 2012). The indicators for provisioning services are shown in Table 27, and these indicators are evaluated in Section 5.3.3.1.

Figure 38: The extent of peatland vegetation is a potential indicator of the plant supply provisioning service (Photo: Anne Murray)

Table 27: Indicators for assessing upland peatland provisioning services

CICES Group	**Peatland ES (Chapter 4)**	**ES supply indicators**	**ES demand indicators**	**Source (supply indicator)**	**Source (demand indicator)**
Wild plants (terrestrial and aquatic) for nutrition, materials or energy	Peat supply	m^3 of peat	Tonnes of peat extracted/year/hectare Production of peat products	(Whinam *et al.*, 2003; Whinam and Hope, 2005; Bonn *et al.*, 2010)	(Burkhard *et al.*, 2012; Inácio *et al.*, 2018)
	Plant supply	Hectares of peatland vegetation	Tonnes of peatland vegetation harvested/year/hectare Production of products using peatland vegetation	(Whinam *et al.*, 2003; Whinam and Hope, 2005; Bonn *et al.*, 2010)	(Inácio *et al.*, 2018)
Surface water used for nutrition, materials or energy	Surface water supply	% contribution to downstream surface water	Water consumption per person, per sector	(Maes *et al.*, 2016; Cowley *et al.*, 2019)	(Maes *et al.*, 2016)
Genetic materials from animals	NCF eggs collected for maintaining population	Number of NCF eggs	NCF eggs collected for breeding program	(Czúcz *et al.*, 2018)	(Czúcz *et al.*, 2018)

5.2.2.2 Regulating service indicators

Upland peatlands perform many vital regulating services and so indicators for these services are particularly important. The demand for regulating services can be conceptualised as the amount of regulation that needs to occur to meet a pre-determined condition or standard (e.g. the amount of toxic metal that peatlands need to sequester to meet water quality benchmarks). The supply of regulating services refers to the extent to which regulation performed by upland peatlands provides the necessary regulation (Villamagna *et al.*, 2013). For example, for erosion prevention, a possible indicator is “area vulnerable to erosion”. If there are more areas vulnerable to erosion, the demand for the service will increase. Similarly, for carbon sequestration, if CO^2 emissions increase, society will demand more of the sequestering role performed by peatlands. Two indicators were not able to be established from the literature: demand for snow retention; and demand for “maintaining habitat and nursery populations”. A possible indicator for the snow retention service is “desired length of ski season”, because as the desired length increases, society would require that snow lies earlier and longer. For the “maintaining habitat” service, a possible indicator is “threatened species listings”. As there are more endangered species, the need for upland peatlands to provide habitat, particularly during droughts, will become even more important. The indicators for the demand and supply of regulating services are shown in Table 28 and assessed in Section 5.3.3.2.

Figure 39: The presence of endemic or endangered species, such as the flame robin (*Petroica phoenicea*), can be used as an indicator for the supply of habitat services (Photo: Anne Murray)

Table 28: Indicators for assessing the regulating services provided by upland peatlands

CICES Group	Peatland ES (Chapter 4)	ES supply indicators	ES demand indicators	Source (supply indicator)	Source (demand indicator)
Atmospheric composition and conditions	Carbon sequestration	Loss on ignition Change in carbon stock Approximated relationship between peatland cover and carbon stock	Tonnes of CO_2 per capita/year	(Hope and Nanson, 2015; Keith *et al.*, 2017)	(Burkhard *et al.*, 2014; Baró *et al.*, 2015)
Regulation of baseline flows and extreme events	Water flow regulation	Reduction of peak discharges Megalitres/day from peatland Water retention capacity	Periods of flood	(Hope, 2003; Müller *et al.*, 2016)	(Burkhard *et al.*, 2012; Burkhard *et al.*, 2014)
	Erosion prevention	Soil retention (erosion without vegetation cover - actual soil erosion)	Areas vulnerable to erosion (sandy soil, steep slope etc.)	(Fu *et al.*, 2011)	(Albert *et al.*, 2016)
Mediation of wastes or toxic substances of anthropogenic origin by living processes	Water quality regulation	Suspended sediment and FPOM concentration, Nutrient concentration (N, P, S), pH, BOD, conductivity, temperature	Water quality standards	(Silvester, 2009; Butler *et al.*, 2013; Martin-Ortega *et al.*, 2014)	(Albert *et al.*, 2016)

CICES Group	Peatland ES (Chapter 4)	ES supply indicators	ES demand indicators	Source (supply indicator)	Source (demand indicator)
Maintenance of physical, chemical, abiotic conditions	Snow lies earlier and longer	Snow retention Distribution of snow	Desired length of ski season	(Hope *et al.*, 2012; Tomback *et al.*, 2016)	
Lifecycle maintenance, habitat and gene pool protection	Maintaining habitat and nursery populations	Number of endemic/endangered species, land cover, extent of native vegetation, invasive species	Number of threatened species listed, listed weed species	(de Groot and van der Meer, 2010; Maes *et al.*, 2016; Gómez-Baggethun *et al.*, 2019)	

5.2.2.3 Cultural service indicators

Villamagna *et al.* (2013) describe the supply of cultural services as the amount of service used, measured in spatial and/or temporal units. The supply of cultural ES can be more difficult to assess than other services, because it depends on people's preferences (Burkhard *et al.*, 2012). For example, one landscape might have aesthetic value for one group, but be considered unattractive by others. Revealed preference methods (e.g. willingness to pay for a service) (Van Berkel and Verburg, 2014), as well as qualitative research can be used to assess aesthetic services (Hernández-Morcillo *et al.*, 2013). Research has also shown that in general, aesthetic value increases with species diversity (Lindemann-Matthies *et al.*, 2010).

Most cultural ecosystem service studies focus on education, training and recreation, which are easier to measure than spiritual and aesthetic experiences (Hernández-Morcillo *et al.*, 2013). The demand for cultural services is also simpler, and can be thought of as the desired use of the service (Villamagna *et al.*, 2013). Potential indicators of the demand and supply of cultural services are presented in Table 29, and evaluated in Section 5.3.3.3.

Figure 40: Peatlands contribute to the aesthetic beauty of hills in the Australian Alps (Photo: Anne Murray)

Table 29: Indicators for assessing upland peatland cultural services

CICES Group	Peatland ES (Chapter 4)	ES supply indicators	ES demand indicators	Source (supply indicator)	Source (demand indicator)
Intellectual and representative interactions with natural environment	Data for palaeoecological studies	m^3 of hemic peat	Published SE Australian peatland journal articles		(Maes *et al.*, 2016; Guimarães *et al.*, 2017)
	Education and training	Accessibility of peatlands from educational institutes	Number of students visiting peatland for educational purposes	(Ala-Hulkko *et al.*, 2016)	(van Oudenhoven *et al.*, 2012; Brancalion *et al.*, 2014)
	Aesthetic experiences	Accessibility Diversity of species	Number of geotagged photos on social media Visitor surveys	(Bieling and Plieninger, 2013)	(Casalegno *et al.*, 2013; Hernández-Morcillo *et al.*, 2013; Yoshimura and Hiura, 2017)
Physical and experiential interactions with natural environment	Recreation	Accessibility	Number of visitors, nature tourism employment Visible manifestations of cultural ES (benches, trails and signs, recreational sites) Visitor surveys	(Bieling and Plieninger, 2013; Peña *et al.*, 2015)	(Chan *et al.*, 2006; Burkhard *et al.*, 2012; Bieling and Plieninger, 2013; Hernández-Morcillo *et al.*, 2013; La Rosa *et al.*, 2016)

5.3 Using criteria to assess proposed indicators for upland peatland ecosystem services

This chapter will evaluate the indicators that were proposed in Section 5.2 against the seven criteria identified in Section 5.1 (see Table 24). Sections 5.3.1 and 5.3.2 assess the indicators for capacity and pressure respectively, outlined by Wild and Magierowski (2015). Section 5.3.3 assesses demand and supply indicators proposed by the current study for provisioning, regulating and cultural ES.

Data availability (Criterion 6) was determined by consulting relevant agencies, and researchers (see Table 30). The entire indicator framework was presented for their consideration. Each organisation/researcher provided information about the types of data they collected, whether it was publicly available or potentially accessible, and other potential data sources.

Table 30: Researchers and organisations consulted to determine data availability

Role	**Organisation**
Program leader of peatland monitoring program	Victorian Government, Arthur Rylah Institute for Environmental Research (a state government research organisation)
Independent peatland researcher	Australian National University
Ecologist	Department of Planning, Industry and Environment (NSW public official, from Department with relevant responsibilities)
Senior scientist	Snowy Hydro Limited (unlisted public company, owns and manages hydro-electric infrastructure and operations across NSW Alps)
Team leader	ICON Water (unlisted public company, manages ACT water infrastructure, supply, quality, and treatment)
Senior manager	ACT National Parks (Protected area management agency)
Biodiversity conservation policy officer Aquatic ecologist	ACT Environment, Planning and Sustainable Development Directorate (Overall environment and conservation agency)

5.3.1 Assessment of capacity indicators

Table 31 shows that while there are data available for all of the capacity indicators, some are not measured frequently or regularly enough to obtain a full picture of the ecosystem capacity. There are several peatland monitoring programs occurring in Victoria, but none currently operating in the ACT/NSW. The Victorian data are collected regularly, at an individual peatland scale.

Table 31: Assessment of capacity indicators from Wild and Magierowski (2015, p. 20)

Condition Indicator	Description	Measurable	Relevant	Sensitive	Scientifically valid	Clearly communicable	Data available	Data at appropriate scale
Peat layer	Degree of oxidation Acrotelm/catotelm condition	✓	✓	✓	✓	✓	✓	✓
Organic matter	Formation process Content in acrotelm/catotelm pH	✓	✓	✓	✓	✓	✓	✗
Water holding capacity / watertable	Watertable fluctuation Presence of ditches/drains	✓	✓	✓	✓	✓	✓	✗
Moisture	Degree of desiccation	✓	✓	✓	✓	✓	✓	✗
Vegetation	Presence of key species	✓	✓	✓	✓	✓	✓	✓

Criterion 1: Are the indicators measurable?

Yes. All of the capacity indicators are measurable. Measurement methods are summarised in Table 32.

Table 32: Measurement methods for the capacity indicators

Indicator	**Measurement method**
Rate of peat formation	Stratigraphic coring (Hope and Clark, 2008; Hope *et al.*, 2009)
Condition of acrotelm and catotelm	
Degree of oxidation	
Organic matter content of acrotelm and catotelm	Measurement of LOI (Grover *et al.*, 2005)
pH	pH meter (Grover *et al.*, 2005)
Fluctuations in the water table	Dataloggers in piezometers (Cowley *et al.*, 2018b)
Presence of channels, ditches and drains	Directly observed (Cowley *et al.*, 2018b)
Water content	Comparison of wet and dry weight of a sample (Rydin, 1985)
Vegetation composition and cover	Vegetation count by peatland quadrats Satellite data (McDougall and Walsh, 2007; Mackey *et al.*, 2015)

Criterion 2: Are the indicators relevant?

Yes. All of the indicators are relevant. They are all examples of biophysical structures or processes, which in turn generate ecosystem functions and services (see Figure 27). For example, the peat layer is necessary for growth of peatland vegetation, which in turn provides habitat services. The condition of the peat layer is also an indicator for peat accumulation, which underpins many of the peatland ES (e.g. carbon sequestration). Measurements of the water table provide information about the capacity of the peatland to regulate the flow regime. Similarly, the presence of key species is necessary for the peatland to provide ES (e.g. *Sphagnum* can absorb ~20 times its weight in water, *Carex gaudichaudiana* spreads streamflow).

Criterion 3: Are the indicators sensitive to changes in ecosystem condition?
In part. The indicators are sensitive to changes in ecosystem condition to varying degrees and for varying time frames. An example of an indicator which is less sensitive is the condition of the peat layer. The layer can withstand low levels of damage (e.g. occasional trampling) without showing signs of altered condition (Cherubin *et al.*, 2019). However, moderate to high levels of damage (e.g. constant feral horse trampling) result in channelisation, oxidation and erosion (Robertson *et al.*, 2019).

The slow nature of peat accumulation (5-8 mm/year) (Clarkson *et al.*, 2017) mean that in the short term, it is not a good marker for changes in ecosystem condition. Over the long term, the vegetative composition of the fibric and hemic peat will change as a result of the changed composition of the surface vegetation (Hope *et al.*, 2012). In contrast, water table fluctuations will immediately reflect changes in the geomorphic structure of the peatland. If the peatland is incised or channelised, signs of desiccation will also quickly emerge (Cowley *et al.*, 2018b).

Peatland vegetation is sensitive to ecosystem condition, and changes in vegetation may be brought about by one or more of several causes, including altered nutrient levels and change in the degree of waterlogging (Keith and Myerscough, 1993). Repeated fires cause bogs to transition to more fen-type vegetation, and fens to transition to grassland (Commonwealth of Australia, 2014a). Grazing changes the vegetative cover, and animals can also introduce weeds (McDougall, 2007). Thus, changes in peatland vegetation need to be closely analysed to determine their cause.

Criterion 4: Are the indicators scientifically valid?
Yes. All of the indicators are scientifically valid. Wild and Magierowski (2015) sourced their indicators from peer-reviewed literature and collaboration with peatland experts.

Criterion 5: Can the purpose of the indicators be clearly communicated?
Yes. The relationship between the indicators and the capacity of the ecosystem to generate ES can be explained relatively easily. As noted in Criterion 2, all of the indicators are examples of biophysical structures or processes, which generate ecosystem functions and services. For example, organic matter accumulation results in carbon sequestration, and the degree of waterlogging determines vegetation type and cover. This in turn influences the water holding capacity of the peatland, determining the extent to which it can moderate the flow regime.

Criteria 6 and 7: Are data available? Are the data at the appropriate spatial and temporal scale?

In part. There are many studies of peatlands in the Australian Alps which contain data that could be used for indicators. The data presented in these studies are at the appropriate spatial scale but, for most indicators, are not collected sufficiently often. The data for the peat layer and vegetation indicators are more regularly collected, and are at the appropriate scale.

Some of the data have been collected for specific research projects, and have taken measurements from each peatland at a single point in time. Hope *et al.* (2009), for example, assess the condition and organic matter of twelve peatlands in the Australian Capital Territory. Hope and Clark (2008) took stratigraphic samples from two peatlands in the Australian Alps to analyse peatland fire history and the capacity of the vegetation to regenerate. Grover (2006) compares the water holding capacity, water table fluctuations and moisture content in bog peat and dried peat in the Wellington Plain peatland in Victoria. There have also been many studies of the vegetation types of the Australian Alps at a single point in time (see, for example, McDougall and Walsh, 2007; Armstrong *et al.,* 2013; Mackey *et al.,* 2015).

There are also several monitoring programs in the Alps. For these programs, data are collected at multiple sites and at more regular time intervals. These programs were the best source of data found, for all indicator categories. Parks Victoria is currently monitoring 62 alpine bogs (State Government of Victoria and Department of Environment, Water, Land and Planning, 2019). These bogs will have been assessed twice by the start of 2020 (A. Tolsma, pers. comm, 16 September 2019). The variables being monitored are: the peat layer depth and condition; vegetation, including threatened species and weeds; as well as “disturbance features”, such as the number of pools, streams and feral animal scats (Wild and Poll, 2012; Wild and Poll, 2013; Wild and Poll, 2014). The Victorian Government’s Arthur Rylah Institute assessed the extent of weed invasion in 424 peatlands in the Alps between 2005 and 2018 (Tolsma, 2009; Tolsma and Sutter, 2018).

Hope *et al.* (2005) and Good *et al.* (2010) have monitored peatlands in the NSW and ACT areas of the Alps to assess the success of restoration works after the 2003 fires. The condition of the peatlands was assessed using vegetative cover, and the presence of incision. Good *et al.* (2010) report on the condition of the peatlands two and three years after restoration works, stating that monitoring will occur again in another two to three years, and fifteen years after that. Good and McDonald (2016) show pictures of Rotten Swamp four and nine years after the post-fire restoration works (see Figure 41).

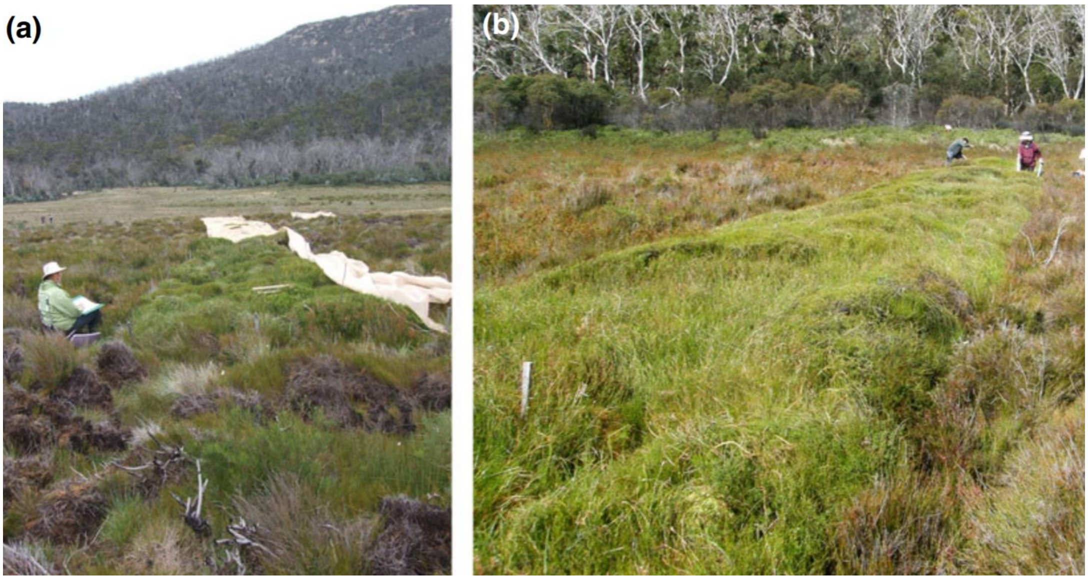

Figure 41: Rotten Swamp (a) four years, and (b) nine years, after post-fire restoration works (Good and McDonald, 2016, p. 18) (Photo: Jennie Whinam)

5.3.2 Assessment of pressure indicators

Table 33 shows that the pressure indicators meet all criteria. Pressure indicators for peatlands are relatively straightforward to understand and measure, which may explain the high level of data availability.

Table 33: Assessment of the pressure indicators from Wild and Magierowski (2015, p. 18)

Pressure indicator	Description	Measurable	Relevant	Sensitive	Scientifically valid	Clearly communicable	Data available	Data at appropriate scale
Damage by feral animals	Extent of droppings/scats, tracks, wallows, pugging, trampling, bank slumping, erosion	✓	✓	✓	✓	✓	✓	✓
Disturbance by vehicles	Extent of wheel rutting, diversion of water away from bog	✓	✓	✓	✓	✓	✓	✓
Weed invasion	Presence of weeds	✓	✓	✓	✓	✓	✓	✓
Disturbance by infrastructure	Diversions resulting from infrastructure	✓	✓	✓	✓	✓	✓	✓
Fire damage	Fire interval and degree of burnt peat	✓	✓	✓	✓	✓	✓	✓

Criterion 1: Are the indicators measurable?

Yes. All of the indicators are measurable. Table 33 shows potential metrics for the quantification of each indicator.

Criterion 2: Are the indicators relevant?

Yes. All of the indicators are relevant, because they represent a specific pressure faced by peatlands. Each of the pressures change the biophysical structure and ecosystem functions of the peatland. For example, diversion of water resulting from infrastructure reduces the quantity of water flowing into the peatland, thereby reducing its ability to regulate the flow regime, and to provide water during drought.

Criterion 3: Are the indicators sensitive to changes in ecosystem condition?

Yes. Pressure indicators are direct measures of changes in ecosystem condition.

Criterion 4: Are the indicators scientifically valid?

Yes. Wild and Magierowski (2015) sourced their indicators from peer-reviewed literature and by collaboration with peatland experts.

Criterion 5: Can the purpose of the indicators be clearly communicated?

Yes. The pressure indicators are not complex, and their relationship with ecosystem condition is easily understood. They are also specific and relevant, and so can be clearly communicated.

Criteria 6 and 7: Are data available? Are the data at the appropriate spatial and temporal scale?

Yes. There is a relative wealth of data available to assess the pressure indicators. These data are at the scale of individual peatlands, and have been collected more regularly than the capacity data. They meet both criteria 6 and 7.

Wild and Magierowski (2015) provide a major source of data on pressures. They complement their report with a map showing the number of pressures, or "threat coincidence" that peatlands face. Figure 42 shows those peatlands which face multiple pressures beyond a certain threshold. The specific pressures are: bog flammability, climate threat, exotic threat, future horse threat, land use and positional threat. The source data and the thresholds set for each of these variables are described in Appendix 5.

As noted earlier, the Arthur Rylah Institute has assessed the condition of 424 peatlands in Victoria (Tolsma, 2009). For these peatlands, data exist for every pressure indicator. The Parks Victoria ongoing program monitors the vegetation of 62 bogs, including measurement of weeds and damage by feral animals.

Robertson *et al.*'s (2019) recent study highlights the value of detailed data for a specific pressure. They examine nine variables (see Table 34) to assess the impact of feral horses on drainage lines in the Australian Alps. They include 78 bogs in their analysis. The authors compare each of the variables for horse-free and horse-present sites, to quantify the impact of feral horses. Robertson *et al.* (2019) find that all of the soil and stream stability variables are significantly worse in bogs where horses are present, with vegetation damage also occurring from grazing.

Table 34: Variables used by Robertson *et al.* (2019, p. 22) to assess the impact of feral horses on drainage lines in the Australian Alps

Variable category	**Variable**
Soil and stream stability	Stream bank stability Pugging damage Longitudinal profile of the drainage line Sediment level Number of animal tracks or pads within 20m of drainage system Level of impact of defined animal paths or pads on vegetation Grazing disturbance on banks / in channel
Vegetation	Projected foliage cover using Braun-Blanquet scale Proportion of projected foliage cover that is native

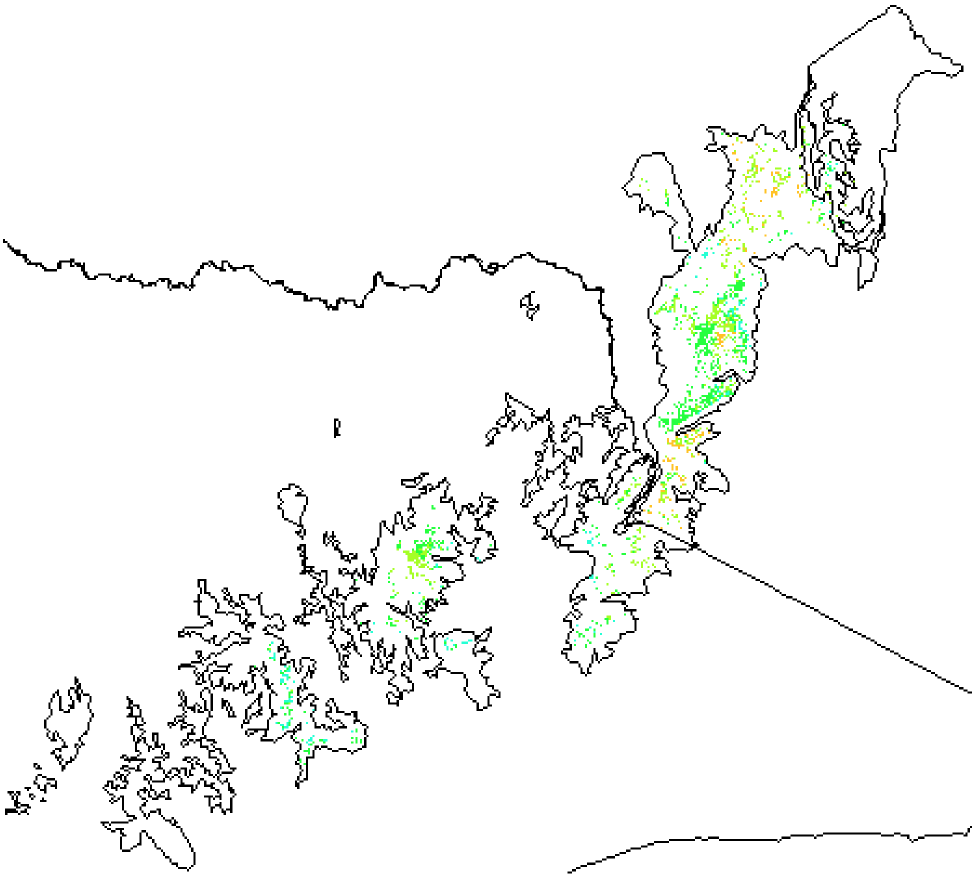

Figure 42: A threat coincidence map for bogs in the Australian Alps. ■ represents where 5 threats coincide, ■ 4 threats coincide, ■ 3 threats coincide and ■ 2 threats coincide. The map is generated using the "Multi Criteria Analysis Shell for Spatial Decision Support" (MCAS – S) program (Wild and Magierowski, 2015).

5.3.3 Assessment of demand and supply indicators

5.3.3.1 Provisioning services

The assessment of provisioning service indicators is summarised in Table 35. For criteria 6 and 7, only surface water supply is considered, as it is the only provisioning service currently being utilised.

Table 35: The assessment of demand and supply indicators for provisioning services

Peatland ES	ES supply indicators	ES demand indicators	Measurable	Relevant	Sensitive	Scientifically valid	Clearly communicable	Data available	Data at appropriate scale
Peat supply	m^3 of peat	Tonnes of peat extracted/year/hectare Production of peat products	✓	✓	✓	✓	✓	N/A	N/A
Plant supply	Hectares of peatland vegetation	Tonnes of peatland vegetation harvested/year/hectare Production of products using peatland vegetation	✓	✓	✓	✓	✓	N/A	N/A
Surface water supply	% contribution to downstream surface water	Water consumption per person or per sector	✓	✓	✓	✓	✓	✗	N/A
NCF eggs collected for the purposes of maintaining a population	Count of NCF eggs	Count of NCF eggs collected for breeding program	✓	✓	✓	✓	✓	N/A	N/A

Criterion 1: Are the indicators measurable?

Yes. The methods of measurement for the demand and supply of each ecosystem service are discussed below.

Peat supply

Peat volume can be estimated by measuring a peatland's surface extent and depth. The depth can be obtained by taking stratigraphic cores (Hope *et al.*, 2012). The tonnes of peat extracted/year/hectare can also be directly measured.

Plant supply

The extent of peatland vegetation can be mapped and calculated (see, for example, Hope *et al.*, 2009; Tolsma, 2009). The indicator "production of products using peatland vegetation" can be measured either using sales figures or the volume of peat used in production (Burkhard *et al.*, 2012).

Surface water supply

The source of surface water can be traced using radon isotope methods (Cowley *et al.*, 2019).

NCF eggs

The number of NCF eggs can be estimated by counting eggs from sampled breeding sites (Hunter *et al.*, 1999). The number used in the breeding program can be counted.

Criterion 2: Are the indicators relevant?

Yes. All of the indicators are relevant. Their relevance is clear, because they are not surrogate variables or models, but direct quantifications of the demand and supply of the service.

Criterion 3: Are the indicators sensitive to changes in ecosystem condition?

Yes. Almost all of the indicators are sensitive to changes in the ecosystem condition.

Peat supply

Depth samples yield volumetric estimations for the peat (Hope and Nanson, 2015). Various pressures alter the condition and depth of the peat, including feral animals, changes in water quantity and quality, and vegetative cover (see, for example, Fryirs *et al.*, 2016; Cherubin *et al.*, 2019; Robertson *et al.*, 2019).

Plant supply

The indicator values for plant supply will decrease if pressures result in the contraction of the extent of peatland vegetation.

Surface water supply

In the immediate term, a peatland's contribution to surface water will increase if the acrotelm or catotelm is degraded. This is because the water holding capacity will decrease, causing a flashier flow regime (Cowley *et al.*, 2018b). Over a longer term, the reduced water holding capacity of the peatland will results in a decrease in the proportion of downstream surface water sourced from peatlands (Grand-Clement *et al.*, 2013).

NCF eggs

The availability of eggs will change depending on the condition of the bog (State of New South Wales and Office of Environment and Heritage, 2012).

Criterion 4: Are the indicators scientifically valid?

Yes. All of the indicators were sourced from peer-reviewed literature.

Criterion 5: Can the purpose of the indicators be clearly communicated?

Yes, because the indicators are direct quantifications of the service. While some measuring methods are highly technical, the resulting data are easy to comprehend.

Criteria 6 and 7: Are data available? Are the data at the appropriate spatial and temporal scale?

No. There has been no study for the Australian Alps replicating Cowley *et al.*'s (2019) hydrological study in the Sydney Basin. Western *et al.* (2009) show that the peatlands in the Victorian Alps cannot be a major source of base flow, but did not actually measure the peatlands' contribution to downstream surface water. The contribution could be estimated by comparing water flow upstream of a peatland with downstream flow, and using changes in the peatland water table to determine its contribution to the change in flow (McCartney *et al.*, 2011). Icon Water collects rainfall and stream flow data for the ACT, but due to the placement of stream gauges, none of the data could be used to conduct this comparison. Data collected for hydroelectricity operations in the NSW Alps could potentially be used, but these data are commercially sensitive and not easily accessible, and so do not currently meet Criteria 6.

The fleece of snow sweats crystal in the sun;
And secretly a thousand rivulets run
Sinking through lichened rocks, gurgling beneath
The matted alpines of the springy heath,
Till the plateau fills full and begins to spill
Far down the sides.

Figure 43: Excerpt from the poem "Spider on the Snow", by James McAuley (2011)

5.3.3.2 Regulating services

The assessment of indicators for regulating services is summarised in Table 36. It highlights that a lack of data exists for the implementation of many of the indicators.

Table 36: The assessment of demand and supply indicators for regulating services

Peatland ES	ES supply indicators	ES demand indicators	Measurable	Relevant	Sensitive	Scientifically valid	Clearly communicable	Data available	Data at appropriate scale
Carbon sequestration	Loss on ignition Change in carbon stock Approximated relationship between peatland cover and carbon stock	Tonnes of CO2 per capita/year	✓	✓	✓	✓	✓	✓	✓
Water flow regulation	Reduction of peak discharges Megalitres/day from peatland Water retention capacity	Periods of flood	✓	✓	✓	✓	✓	✓	✗
Erosion prevention	Soil retention (erosion without vegetation cover - actual soil erosion)	Areas vulnerable to erosion	✓	✓	✓	✓	✓	✗	✗
Water quality regulation	Suspended sediment and FPOM concentration Nutrient concentration pH BOD Conductivity Temperature	Water quality standards	✓	✓	✓	✓	✓	✓	✗
Snow lies earlier and longer	Snow retention Distribution of snow	Desired length of ski season	✓	✓	✓	✓	✓	✗	✗
Maintaining habitat and nursery populations	Number of endemic/ endangered species Extent of native vegetation Number of invasive species	Number of threatened species listed Listed weed species	✓	✓	✓	✓	✓	✓	✗

Criterion 1: Are the indicators measurable?

Yes. Measurement methods for each indicator are described here.

Carbon sequestration

LOI measurements show the organic matter content of a peat sample. These data can be combined with estimates of peatland surface area and peat volume to measure carbon stock and sequestration rates (Hope and Nanson, 2015).

Water flow regulation

All of the potential indicators for this service are measurable. Peak discharge rates can be collected using a piezometer (Fryirs *et al.*, 2014b), the megalitres/day coming from the peatland can be measured using a stream gauge (Western *et al.*, 2009), and the water retention capacity can be modelled based on the depth and saturation of the acrotelm (Fryirs *et al.*, 2014b). Historical rainfall data provide information for the "periods of flood" indicator (Crossman *et al.*, 2013).

Erosion prevention

The soil retention indicator is based on a model in Fu *et al.* (2011), which uses measures of "rainfall erosivity" (based on monthly and annual rainfall), the potential for soil erosion, slope length, slope gradient, and vegetation cover.

Water quality regulation

All of the water quality regulation metrics can be assessed using chemical and physical measurement techniques, usually at stream gauge sites. For example, a stream flow gauge site near Lake Burrinjuck on the Murrumbidgee River also reports temperature and conductivity (WaterNSW, 2019).

Snow lies earlier and longer

The "snow retention" indicator can be measured by comparing the length of time that snow lies on a peatland with an adjacent non peatland site. The desired length of the ski season could be determined by analysing the average historical length of the ski season.

Maintaining habitat and nursery population

There are many possible indicators for habitat services. The indicators presented here can all be mapped and/or counted.

Criterion 2: Are the indicators relevant?

Yes. The indicators presented in Table 36 were chosen to represent the key aspects of the ES. All of the demand indicators either represent existing benchmarks that show the degree of regulation that needs to occur (e.g. legal water quality requirements), or a metric that indicates how much future regulation needs to occur (e.g. as the number of CO^2 tonnes per person increases, society requires peatlands to sequester more).

Indicators for the supply of regulating services often rely on land cover measurements. These indicators risk not meeting the relevance criteria, as land cover does not necessarily provide reliable information about the key aspects of the ecosystem, or the ES (Wong *et al.*, 2015). However, this risk is mitigated when land cover is included as just one variable in a detailed model that more explicitly shows how a particular indicator relates to the ES.

Criterion 3: Are the indicators sensitive to changes in ecosystem condition?

Yes. All of the supply indicators change according to ecosystem condition. Feral deer activity, for example, will cause pugging in bogs and fens, and this will quickly change the extent of native vegetation (Brown *et al.*, 2016). Similarly, if the peat layer is eroded, the peatland will not be as thermally insulating, and snow retention will be shorter. Deterioration in ecosystem condition may actually increase the number of endangered species.

Criterion 4: Are the indicators scientifically valid?

Yes. All of the indicators are sourced from peer-reviewed literature, with the exception of "desired length of ski season" and "number of threatened species listed", although the latter mirrors official standards under environmental policy and law.

Criterion 5: Can the purpose of the indicators be clearly communicated?

Yes. Most of the indicators are easy to understand. The indicators are specific and relevant, improving their communicability. However, in general, they are more complex than the provisioning indicators, particularly the supply indicator for erosion prevention. Basic hydrological knowledge is necessary to understand the indicators for water quality regulation.

Criteria 6 and 7: Are data available? Are the data at the appropriate spatial and temporal scale?

In part. Most of the data for the demand and supply indicators are from research projects that have taken measurements at one point in time.

Carbon sequestration

Hope and Nanson (2015) provide data on the rates of peatland carbon sequestration in the Alps.

Water flow regulation

Western *et al.* (2009) model the impact that peatlands have on annual runoff in the Victorian Alps, based on assumptions about peatland evapotranspiration. They conclude the impact of peatlands is small, and within the error of stream gauge measurements. However, they do not measure the impact peatlands have on moderating flow immediately after rainfall, which may be more significant (Cowley *et al.*, 2018b).

Erosion prevention

No studies were found that measure the erosion prevention service of alpine bogs.

Water quality regulation

There is a lack of data for the water quality indicators. Snowy Hydro collect water quality data for streams in the Australian Alps, but these data are commercially sensitive, and so do not currently meet Criteria 6. WaterNSW (2019) also have a network of stream gauges that collect limited water quality data, but their placement is not suitable to evaluate the impact of peatlands. There have been research projects conducted that provide some data for the water quality indicators. For example, Silvester (2009) provide data for the pH buffering role of peatlands, and Stromsoe *et al.* (2015) examine how atmospherically deposited metals are sequestered by peatlands.

Snow lies earlier and longer

No studies were found that measure the snow retention service performed by upland peatlands.

Maintaining habitat and nursery populations:

More data exists for the habitat service indicators than other services. McDougall and Walsh (2007), for example, describe the characteristic vegetation and extent of weeds of peatland communities in the Alps. The vegetation of KNP has been recently surveyed for the environmental impact assessment of the Snowy Hydro expansion (EMM Consulting, 2019a). The Arthur Rylah Institute monitoring program calculates the extent of weeds for each individual peatland (Tolsma and Sutter, 2018). The Parks Victoria monitoring program counted the number of FFG and EPBC listed flora species occurring in a random selection of alpine bogs, in 2012, 2013 and 2014 (Wild and Poll, 2012; Wild and Poll, 2013; Wild and Poll, 2014). Information from EPBC, FFG, BC and NC Act documents could potentially be used to estimate the number of endangered species associated with peatlands, but this information is not spatially specific, nor collected at regular time intervals.

5.3.3.3 Cultural services

The assessment of indicators for cultural services is outlined in Table 37. While data is available for all of the potential indicators, the data are often not at the appropriate scale. Cultural services are the least researched of the upland peatland ES.

Table 37: The assessment of demand and supply indicators for cultural services

Peatland ES	ES supply indicators	ES demand indicators	Measurable	Relevant	Sensitive	Scientifically valid	Clearly communicable	Data available	Data at appropriate scale
Data for palaeo ecological studies	m^3 of hemic peat	Published SE Australian peatland journal articles	✓	✓	✓	✓	✓	✓	✓
Education and training	Accessibility of peatlands from educational institutes	Number of students visiting peatland for educational purposes	✓	✓	✓	✓	✓	✓	✗
Aesthetic experiences	Accessibility Diversity of species	Number of geotagged photos on social media Visitor surveys	✓	✓	✓	✓	✓	✓	✓
Recreation	Accessibility Opportunity mapping	Number of visitors Nature tourism employment Visible manifestations (benches, trails and signs, recreational sites) Visitor surveys	✓	✓	✓	✓	✓	✓	✗

Criterion 1: Are the indicators measurable?

Yes. Indicators for cultural ES, especially the supply of cultural ES, are more complex than other types of ES indicators. Accessibility is a common proxy for the supply of cultural ES, and can be measured in a number of ways, including road networks, footpaths, public transport, and the distance from a set start point (e.g. town centre) (Bonn *et al.*, 2010; Ala-Hulkko *et al.*, 2016). Accessibility can be used as an indicator for three of the four cultural services.

Data for palaeoecological studies

The measurement method for volume of hemic peat is described in 5.3.1. The number of published SE Australian peatland journal articles can be estimated from literature searches using key search terms.

Education and training

Brancalion *et al.* (2014) estimate the number of students visiting a Brazilian forest from the number of courses that visit the forest and student enrolments in these courses. Similar estimates could be obtained for SE Australia peatlands.

Aesthetic experiences

Species diversity (and resultant perceived beauty) can be determined by vegetation surveys (Lindemann-Matthies *et al.*, 2010). The number of geotagged photos on social media could be counted (Yoshimura and Hiura, 2017). Qualitative research (e.g. surveys, interviews) can also be used to evaluate aesthetic experiences.

Only science, then, has noticed you,
not poetry.
It's that way round in this country,
upside-down as ever.
Living on swamp-edges
turning your face to the ground, shyer than
  Wordsworth's violet
no words but dog-Latin
have tagged you.

Figure 44: Excerpt from the poem "Swamp plant", by Judith Wright (1994, p. 367)

Recreation

Bonn *et al.* (2010) measure the supply of recreation by mapping the opportunity for recreation using the density of footpaths, roads, public transport and carparks. The number of visitors to a peatland could be approximated using log-book data from peatland walks, or by conducting visitor surveys. The number of visitors to the wider area could also be estimated by conducting car counts, or the number of passes sold to the area (e.g. KNP entry passes). The indicator “visible manifestations of cultural ES” involves mapping the density of features such as benches, trails and signs, near the peatland (Bieling and Plieninger, 2013).

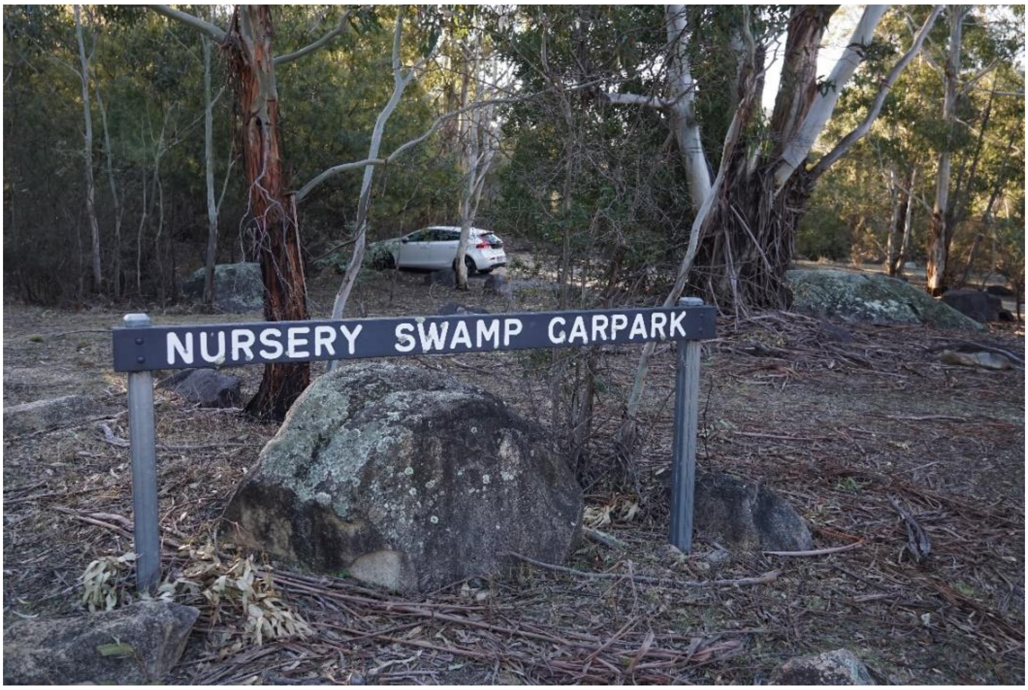

Figure 45: The Nursery Swamp carpark is an example of both the opportunity for recreation (supply), and a “manifestation” of demand for cultural ecosystem services (Photo: Anne Murray)

Criterion 2: Are the indicators relevant?

Yes. All of the indicators are relevant. The supply indicators show which factors determine the provision of ES. For example, accessibility determines whether people are able to visit the peatland for recreation, tourism or educational purposes, and species diversity determines aesthetic value. The demand indicators provide examples of how cultural ES become goods and benefits, which provides information about the desired level of cultural ES use.

Criterion 3: Are the indicators sensitive to changes in ecosystem condition?

In part. Almost all of the indicators will shift relatively quickly if ecosystem condition changes.

Data for palaeoecological studies

Changes in ecosystem condition that affect the peat layer will cause the volume of peat to decrease. Degradation may increase or decrease published palaeoecological research. The degradation may generate research interest, but if it is severe it may stifle the potential for palaeoecological research.

Education and training

Changes in ecosystem condition do not necessarily change the accessibility of the peatland. However, if the peatland that is being used for student learning is degraded, it may no longer be suitable for educational purposes.

Aesthetic experiences

Species diversity is influenced by several biophysical factors, particularly the nutrient level and degree of waterlogging (Keith and Myerscough, 1993). Changes in ecosystem condition alter species diversity and potentially also the number of photos on social media (Lindemann-Matthies *et al.*, 2010).

Recreation

In the short term, changes in ecosystem condition will not change how many manifestations there are of recreation activities. For example, fewer people may visit after a peatland is burnt, but the number of signs near the peatland will not change. Over a longer term, assuming maintenance of tables, signs etc. does not occur for little-visited sites, the decline in demand for the recreation service will cause the manifestations to change. Accessibility could potentially change with ecosystem demand if, for example, public demand for bushwalking resulted in the installation of boardwalks, or improved public transport.

Criterion 4: Are the indicators scientifically valid?

In part. Burkhard *et al.* (2014) argues that establishing scientifically valid indicators for cultural ES is difficult because of their subjective nature. These indicators are scientifically valid to the extent that sourcing either the indicator, or the concept for the indicator, from peer-reviewed literature ensures their validity.

Criterion 5: Can the purpose of the indicators be clearly communicated?

Yes. Cultural services are readily understood, and each of the indicators is specific and relevant.

Criteria 6 and 7: Are data available? Are the data at the appropriate spatial and temporal scale?

No. There are very little spatially explicit data available to implement indicators for peatland cultural services.

Data for palaeoecological studies

Publication records on databases such as Scopus and Google Scholar could be used to implement this indicator.

Education and training

Hope *et al.* (2019) provide an example of how one peatland in the Australian Alps has been used for educational purposes. No other educational data were found, but the data could be collected relatively easily.

Aesthetic experiences

The diversity of species in peatlands in the Australian Alps is shown in McDougall and Walsh (2007). The Victorian peatland monitoring program is also a source of species diversity data (Wild and Poll, 2014). No studies were found that evaluate the accessibility of peatlands. There are no published data on the number of geotagged photos of peatlands on social media, but there are raw data (e.g. photos can be sorted by location on Instagram).

Recreation

ACT Parks conduct counts of cars entering Namadgi National Park (B. Macnamara, pers. comm, 3 September 2019), but this is not at a suitable spatial scale, and not accurate enough to determine the number of people visiting the peatlands. Examples of manifestations of cultural ES were found on several walks to peatlands, but no studies or reports were found that systematically map these.

5.4 Conclusion: What indicators can be used to assess the ecosystem services provided by upland peatlands in South East Australia?

This chapter has described a comprehensive set of indicators that can be used to assess the upland peatland ES delivery process. The analysis provides direction for future research in this area. The major deficiency of the indicators to date concerns data availability. The specific data gaps are set out in Tables 38, 39, 40 and 41. It is possible that some of these gaps may be filled by future conservation research by Snowy Hydro, which has been proposed as an offset for damages to bogs resulting from expansion of hydroelectricity works. The proposed research includes studies of the groundwater system, threatened species, as well as the impact of feral horses, weeds and climate change (EMM Consulting, 2019b).

There are good foundational data for the indicators, but they need to be supplemented with data that are collected more regularly. In particular, most of the current hydrological data, for both quantity and quality, are not at a scale that allows the hydrological services of upland peatlands to be robustly measured. There are available data that can be used for cultural service indicators, but they have not been utilised yet. This is a crucial avenue for future research, because if the cultural services provided by peatlands can be measured, they can then be more widely celebrated – leading to a greater appreciation of their value.

Table 38: Data gaps for condition indicators

Condition Indicator	**Description**	**Data available**	**Data at appropriate scale**
Peat layer	Degree of oxidation Acrotelm/catotelm condition	✓	✗
Organic matter	Formation process Content in acrotelm/catotelm pH	✓	✗
Water holding capacity / water table	Water table fluctuation Presence of ditches/drains	✓	✗
Moisture	Degree of desiccation	✓	✗

Table 39: Data gaps for provisioning ecosystem service indicators

Peatland ES	**ES supply indicators**	**ES demand indicators**	**Data available**	**Data at appropriate scale**
Surface water supply	% contribution to downstream surface water	Water consumption per person or per sector	✘	✘

Table 40: Data gaps for regulating ecosystem service indicators

Peatland ES	**ES supply indicators**	**ES demand indicators**	**Data available**	**Data at appropriate scale**
Water flow regulation	Reduction of peak discharges Megalitres/day from peatland Water retention capacity	Periods of flood	✓	✘
Erosion prevention	Soil retention (erosion without vegetation cover - actual soil erosion)	Areas vulnerable to erosion	✘	✘
Water quality regulation	Suspended sediment FPOM concentration Nutrient concentration pH BOD Conductivity Temperature	Water quality standards	✓	✘
Snow lies earlier and longer	Snow retention Distribution of snow	Desired length of ski season	✘	✘
Maintaining habitat and nursery populations	Number of endemic/ endangered species Extent of native vegetation Number of invasive species	Threatened species listings, listed weed species	✓	✘

Table 41: Data gaps for cultural ecosystem service indicators

Peatland ES	ES supply indicators	ES demand indicators	Data available	Data at appropriate scale
Education and training	Accessibility of peatlands from educational institutes	Number of students visiting peatland for educational purposes	✓	✗
Recreation	Accessibility Opportunity mapping	Number of visitors Nature tourism employment Visible manifestations (benches, trails and signs, recreational sites) Visitor surveys	✓	✗

Chapter 6: Conclusion

This project has explored the question: *how can understanding of the characteristics and services delivered by South East Australian upland peatlands be improved to enhance their management?*

SE Australian upland peatlands are important and vulnerable ecosystems. Many upland peatlands have been destroyed since European settlement, and despite apparent protection in national parks and in conservation legislation, they continue to be degraded. The successful management of upland peatlands has been hindered by a lack of understanding of their characteristics and value. Studies to date are mainly on specific sites and/or specific variables and threats, and there has been little integration of this research for application to policy and management. This study has sought to address these deficiencies by considering three sub-questions:

1. Can upland peatlands in South East Australia be understood as a distinct system for management purposes?
2. What ecosystem services are provided by upland peatlands in South East Australia?
3. What indicators can be used to assess the ecosystems services provided by upland peatlands in South East Australia?

The first question was investigated by comparing the characteristics of upland peatlands across the Australian Alps, New England Tablelands, South Eastern Highlands and Sydney Basin. The variables that were used to compare the characteristics were drawn from the ANAE (2012) framework, the MA (Alcamo *et al.*, 2005b), and peatland research literature. The analysis involved integrating a wide range of hitherto scattered Australian upland peatland literature, including site and threat-specific studies. This synthesis represents a significant contribution in itself, because as Chapter 2 highlighted, one limitation to the successful management of upland peatlands is a lack of integrated information. The analysis is also an example of the use of the MA to draw boundaries around regionally distributed ecosystems. Although the MA notes that regionally distributed ecosystems could be classed according to structural units, no example of this was found in the literature.

The comparison of characteristics of upland peatlands across the four bioregions revealed that they share many characteristics, and can be understood as a distinct system for management purposes, despite being spatially disjunct. This is an important finding, as it means that the ecosystems can be consistently named, an essential part of communicating their value. Further, it allows common management and data collection principles to be created for upland peatlands across SE Australia, and for lessons from existing site-specific research on practical management strategies to be more broadly applied. The recognition of SE Australian upland peatlands as a distinct system, combined with greater understanding of their value, will also highlight the importance of upland peatlands that have been little researched, such as those in the South Eastern Corner and NSW North Coast bioregions.

The second research question was investigated by systematically analysing the ES provided by upland peatlands in the Australian Alps and Sydney Basin bioregions. The ES were identified through a literature review, and categorised according to the CICES framework. Upland peatlands provide a wide range of provisioning, regulating and cultural services. They have historically provided four provisioning services: water provision, plant and peat supply, and Corroboree frog eggs for population maintenance. Currently, only the water provisioning service is being utilised. In contrast, upland peatlands continue to perform many critical regulating services, including carbon sequestration, and regulation of water quality and flow regime. Upland peatlands are "moist oases" in drier landscapes (Hope *et al.*, 2012, p. 50), and so are an important source of water and vegetation for many endemic and endangered species.

The cultural services of upland peatlands are perhaps least recognised of all, but are nonetheless important. In particular, peatlands provide key palaeoecological data for climate change and fire research. They also contribute to the aesthetic appeal of the broader landscape, and are a feature in many recreational activities, such as bushwalking and birdwatching.

While the ES analysis focused on the Alps and Sydney bioregions, the similarity in biophysical characteristics across all of the bioregions means that the ecosystem functions, and thus services, of upland peatlands in each bioregion will be very similar. The main difference in ES provision will be a result of how the services are utilised, not the underlying function.

The identification of upland peatland ES provides guidance for their management. ES analysis highlights the benefits to human wellbeing from ecosystem processes, and in doing so provides a justification for conservation action. It also provides critical information for government policy. The Victorian Waterway Health Program prioritises conservation according to ecosystem value. Principle 10 of the NSW Wetlands Policy states that activities that damage wetlands must be compensated by an offset that provides equivalent services. The services of upland peatlands have now been identified, enabling better application of these policies.

This study provides the basis for the monetary valuation of upland peatland ES, using a natural capital accounting framework, such as SEEA. This would be worthwhile future research, because valuation enables the benefits of restoration to be included in cost-benefit analyses. It also ensures the trade-offs of each policy decision can be more rigorously considered.

The last research question drew on research literature, as well as information on data availability provided by researchers and management organisations, to arrive at potential indicators for the measurement of upland peatland ES. Four types of indicators were explored: capacity, pressure, demand, and supply indicators. The analysis revealed that there is a potential indicator for every aspect of the ES delivery, but this capacity is hampered by a lack of suitable data.

This study has systematically shown where data and research deficiencies exist, and could be used as an agenda for future research and monitoring. The conclusions to both Chapter 3 and Chapter 5 outline where further research needs to occur. In particular, there is a dearth of hydrological data collection and monitoring, as well as cultural ES research. There is a need for systematic monitoring of upland peatlands, particularly in the NSW section of the Alps. The monitoring programs occurring in Victoria provide an example for the type of monitoring that could occur in NSW and ACT. The Victorian monitoring regime would also be improved by periodic collection of upland peatland hydrological data.

Two main factors have imposed limitations on this research. The first is ambiguous peatland terminology. The wide variety of terms used to describe peatlands means that it is possible that certain literature, or a particular field of literature, were missed from the literature search. However, every effort was made to be as thorough as possible. Terminology also complicated the analysis of threatened species reports. For example, for many bird species, associated habitat was often described using terms such as “densely vegetated wetland” and “swamp”. The geographic distribution and vegetation which the species were associated with, if provided, were compared with peatland literature to best determine if the species was associated with upland peatlands. The species was only included if information provided matched closely with peatland characteristics (e.g. vegetation matched the description of a peatland vegetation community). This means it is possible that some species have been incorrectly omitted.

The second factor limiting this research is the possibility that not all data were made available to the researcher. It may be that agencies were not able to relay all information concerning their data collection if, for example, the collection is confidential or commercially sensitive. This limitation could be mitigated by establishing a longer-term working relationship with management organisations, but this option was not available in the Honours project time frame.

This study has emphasised that far from being wastelands, South East Australia’s upland peatlands are indeed natural treasures. The integrated research and data presented here provide a firm foundation for future studies and management.

Leaving you there, I take you home with me
one tiny image
of still untouched unknown tranquillity

Figure 46: Excerpt from the poem “Swamp plant”, by Judith Wright (1994, p. 367)

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Appendix 1: Endangered flora, fauna and ecological communities associated with upland peatlands in the Australian Alps and Sydney Basin that are listed in the NSW *Biodiversity Conservation Act 2016*

Scientific Name	Common Name	SYB /AUA	Source
Acacia baueri subsp. *aspera*	–	SYB	(State of New South Wales and Office of Environment and Heritage, 2019a)
Anseranas semipalmata	Magpie Goose	SYB	(State of New South Wales and Office of Environment and Heritage, 2019o)
Artamus cyanopterus cyanopterus	Dusky Woodswallow	Both	(State of New South Wales and Office of Environment and Heritage, 2017j)
Asperula asthenes	Trailing Woodruff	SYB	(State of New South Wales and Office of Environment and Heritage, 2019x)
Baloskion longipes	Dense Cord-rush	SYB	(State of New South Wales and Office of Environment and Heritage, 2019f)
	Blue Mountains Swamps in the Sydney Basin Bioregion	SYB	(NSW Threatened Species Scientific Committee, 2011a)
Boronia deanei	Deane's Boronia	SYB	(State of New South Wales and Office of Environment and Heritage, 2019e)
Botaurus poiciloptilus	Australasian Bittern	SYB	(State of New South Wales and Office of Environment and Heritage, 2017c)
Burramys parvus	Mountain Pygmy-possum	AUA	(State of New South Wales and Office of Environment and Heritage, 2017x)
Calamanthus fuliginosus	Striated Fieldwren	SYB	(State of New South Wales and Office of Environment and Heritage, 2017ah)
Callistemon megalongensis	Megalong Valley Bottlebrush	SYB	(State of New South Wales and Office of Environment and Heritage, 2019q)
Carex klaphakei	Klaphake's Sedge	SYB	(State of New South Wales and Office of Environment and Heritage, 2019k)
Carex raleighii	Raleigh Sedge	AUA	(State of New South Wales and Office of Environment and Heritage, 2018q)

Cercartetus nanus	Eastern Pygmy-possum	Both	(State of New South Wales and Office of Environment and Heritage, 2017m)
Circus assimilis	Spotted Harrier	Both	(State of New South Wales and Office of Environment and Heritage, 2017af)
Commersonia prostrata	Dwarf Kerrawang	SYB	(State of New South Wales and Office of Environment and Heritage, 2018g)
Crinia tinnula	Wallum Froglet	SYB	(State of New South Wales and Office of Environment and Heritage, 2017ai)
Cryptostylis hunteriana	Leafless Tongue Orchid	SYB	(State of New South Wales and Office of Environment and Heritage, 2018l)
Cyclodomorphus praealtus	Alpine She-oak Skink	AUA	(State of New South Wales and Office of Environment and Heritage, 2017a)
	Coastal Upland Swamps in the Sydney Basin Bioregion	SYB	(State of New South Wales and Office of Environment and Heritage, 2017h)
Darwinia glaucophylla	–	SYB	(State of New South Wales and Office of Environment and Heritage, 2017i)
Dasyurus maculatus	Spotted-tailed Quoll	Both	(State of New South Wales and Office of Environment and Heritage, 2017ae)
Discaria nitida	Leafy Anchor Plant	AUA	(State of New South Wales and Office of Environment and Heritage, 2018m)
Epacris hamiltonii	–	SYB	(State of New South Wales and Office of Environment and Heritage, 2017n)
Epthianura albifrons	White-fronted Chat	Both	(State of New South Wales and Office of Environment and Heritage, 2017ak)
Eucalyptus aggregata	Black Gum	SYB	(State of New South Wales and Office of Environment and Heritage, 2019b)
Eucalyptus aquatica	Broad-leaved Sally	SYB	(State of New South Wales and Office of Environment and Heritage, 2018d)
Eucalyptus camfieldii	Camfield's Stringybark	SYB	(State of New South Wales and Office of Environment and Heritage, 2019d)
Eucalyptus copulans	-	SYB	(State of New South Wales and Office of Environment and Heritage, 2019h)
Eulamprus leuraensis	Blue Mountains Water Skink	SYB	(State of New South Wales and Office of Environment and Heritage, 2019c)
Euphrasia scabra	Rough Eyebright	AUA	(State of New South Wales and Office of Environment and Heritage, 2018m)
Falsistrellus tasmaniensis	Eastern False Pipistrelle	Both	(State of New South Wales and Office of Environment and Heritage, 2017n)

Gentiana wingecarribiensis	Wingecarribee Gentian	SYB	(State of New South Wales and Office of Environment and Heritage, 2018v)
Glossopsitta pusilla	Little Lorikeet	SYB	(State of New South Wales and Office of Environment and Heritage, 2017u)
Grammitis stenophylla	Narrow-leaf Finger Fern	SYB	(State of New South Wales and Office of Environment and Heritage, 2018d)
Grevillea parviflora subsp. *parviflora*	Small-flower Grevillea	SYB	(State of New South Wales and Office of Environment and Heritage, 2019d)
Grus rubicunda	Brolga	SYB	(State of New South Wales and Office of Environment and Heritage, 2017f)
Haloragis exalata subsp. *exalata*	Square Raspwort	SYB	(State of New South Wales and Office of Environment and Heritage, 2018s)
Heleioporus australiacus	Giant Burrowing Frog	SYB	(State of New South Wales and Office of Environment and Heritage, 2017p)
Hibbertia procumbens	Spreading Guinea Flower	SYB	(State of New South Wales and Office of Environment and Heritage, 2017ag)
Hibbertia puberula	–	SYB	(State of New South Wales and Office of Environment and Heritage, 2019j)
Hieraaetus morphnoides	Little Eagle	Both	(State of New South Wales and Office of Environment and Heritage, 2017n) (State of New South Wales and Office of Environment and Heritage, 2017t)
Hoplocephalus bungaroides	Broad-headed Snake	SYB	(State of New South Wales and Office of Environment and Heritage, 2017u)
Isoodon obesulus obesulus	Southern Brown Bandicoot (eastern)	SYB	(State of New South Wales and Office of Environment and Heritage, 2017ac)
Isopogon fletcheri	Fletcher's Drumsticks	SYB	(State of New South Wales and Office of Environment and Heritage, 2019d)
Lepidosperma evansianum	Evans Sedge	SYB	(State of New South Wales and Office of Environment and Heritage, 2019i)
Leptospermum thompsonii	Monga Tea Tree	SYB	(State of New South Wales and Office of Environment and Heritage, 2018s)
Litoria aurea	Green and Golden Bell Frog	SYB	(State of New South Wales and Office of Environment and Heritage, 2017p)
Litoria booroolongensis	Booroolong Frog	SYB	(State of New South Wales and Office of Environment and Heritage, 2017ag)
Litoria brevipalmata	Green-thighed Frog	SYB	(State of New South Wales and Office of Environment and Heritage, 2019j)

Litoria castanea	Yellow-spotted Tree Frog	AUA	(State of New South Wales and Office of Environment and Heritage, 2019z)
Litoria littlejohni	Littlejohn's Tree Frog	SYB	(State of New South Wales and Office of Environment and Heritage, 2017v)
Litoria verreauxii alpina	Alpine Tree Frog	AUA	(State of New South Wales and Office of Environment and Heritage, 2017b)
Lophoictinia isura	Square-tailed Kite	SYB	(State of New South Wales and Office of Environment and Heritage, 2017v)
Lysimachia vulgaris var. *davurica*	Yellow Loosestrife	SYB	(State of New South Wales and Office of Environment and Heritage, 2018w)
Mastacomys fuscus	Broad-toothed Rat	AUA	(State of New South Wales and Office of Environment and Heritage, 2017t)
Maundia triglochinoides	–	SYB	(State of New South Wales and Office of Environment and Heritage, 2019p)
Melaleuca biconvexa	Biconvex Paperbark	SYB	(State of New South Wales and Office of Environment and Heritage, 2018c)
Micronomus norfolkensis	Eastern Coastal Free-tailed Bat	SYB	(State of New South Wales and Office of Environment and Heritage, 2017l)
Miniopterus australis	Little Bent-winged Bat	SYB	(State of New South Wales and Office of Environment and Heritage, 2019n)
Miniopterus orianae oceanensis	Large Bent-winged Bat	SYB	(State of New South Wales and Office of Environment and Heritage, 2019m)
Mixophyes balbus	Stuttering Frog	SYB	(State of New South Wales and Office of Environment and Heritage, 2018t)
	Montane Peatlands and Swamps of the New England Tableland, NSW North Coast, Sydney Basin, South East Corner, South Eastern Highlands and Australian Alps	Both	(NSW Threatened Species Scientific Committee, 2005b)
Myotis macropus	Southern Myotis	SYB	(State of New South Wales and Office of Environment and Heritage, 2017ad)
Neophema pulchella	Turquoise Parrot	SYB	(State of New South Wales and Office of Environment and Heritage, 2017t)

Nettapus coromandelianus	Cotton Pygmy-goose	SYB	(State of New South Wales and Office of Environment and Heritage, 2018c)
	Newnes Plateau Shrub Swamps in the Sydney Basin Bioregion	SYB	(NSW Threatened Species Scientific Committee, 2011c)
Ninox connivens	Barking Owl	SYB	(State of New South Wales and Office of Environment and Heritage, 2018b)
Oxyura australis	Blue-billed Duck	SYB	(State of New South Wales and Office of Environment and Heritage, 2017e)
Pachycephala olivacea	Olive Whistler	SYB	(State of New South Wales and Office of Environment and Heritage, 2017y)
Pandion cristatus	Eastern Osprey	SYB	(State of New South Wales and Office of Environment and Heritage, 2018t)
Persicaria elatior	Tall Knotweed	SYB	(State of New South Wales and Office of Environment and Heritage, 2018u)
Persoonia mollis subsp. *revoluta*	–	SYB	(State of New South Wales and Office of Environment and Heritage, 2019t)
Petalura gigantea	Giant Dragonfly	SYB	(State of New South Wales and Office of Environment and Heritage, 2017q)
Petroica boodang	Scarlet Robin	Both	(State of New South Wales and Office of Environment and Heritage, 2017ab; State of New South Wales and Office of Environment and Heritage, 2017aa)
Petroica phoenicea	Flame Robin	SYB	(State of New South Wales and Office of Environment and Heritage, 2017t)
Pezoporus wallicus wallicus	Eastern Ground Parrot	SYB	(State of New South Wales and Office of Environment and Heritage, 2018j)
Phascolarctos cinereus	Koala	SYB	(State of New South Wales and Office of Environment and Heritage, 2019l)
Pherosphaera fitzgeraldii	Dwarf Mountain Pine	SYB	(State of New South Wales and Office of Environment and Heritage, 2019g)
Phyllota humifusa	Dwarf Phyllota	SYB	(State of New South Wales and Office of Environment and Heritage, 2018h)
Planigale maculata	Common Planigale	SYB	(State of New South Wales and Office of Environment and Heritage, 2018f)
Potorous tridactylus	Long-nosed Potoroo	SYB	(State of New South Wales and Office of Environment and Heritage, 2017w)
Prasophyllum fuscum	Slaty Leek Orchid	SYB	(State of New South Wales and Office of Environment and Heritage, 2019u)
Prasophyllum pallens	Musty Leek Orchid	SYB	(State of New South Wales and Office of Environment and Heritage, 2019r)

Pseudomys gracilicaudatus	Eastern Chestnut Mouse	SYB	(State of New South Wales and Office of Environment and Heritage, 2017k)
Pseudophryne australis	Red-crowned Toadlet	SYB	(State of New South Wales and Office of Environment and Heritage, 2017z)
Pseudophryne pengilleyi	Northern Corroboree Frog	AUA	(State of New South Wales and Office of Environment and Heritage, 2019s)
Pteropus poliocephalus	Grey-headed Flying-fox	SYB	(State of New South Wales and Office of Environment and Heritage, 2017s)
Pterostylis oreophila	Blue-tongued Greenhood	AUA	(State of New South Wales and Office of Environment and Heritage, 2018f)
Pterostylis vernalis	–	SYB	(State of New South Wales and Office of Environment and Heritage, 2018p)
Pultenaea aristata	Prickly Bush-pea	SYB	(State of New South Wales and Office of Environment and Heritage, 2018r)
Pultenaea baeuerlenii	Budawangs Bush-pea	SYB	(State of New South Wales and Office of Environment and Heritage, 2018k)
Pultenaea elusa	Elusive Bush-pea	SYB	(State of New South Wales and Office of Environment and Heritage, 2018n)
Pultenaea glabra	Smooth Bush-Pea	SYB	(State of New South Wales and Office of Environment and Heritage, 2019v)
Ranunculus anemoneus	Anemone Buttercup	AUA	(State of New South Wales and Office of Environment and Heritage, 2018a)
Rostratula australis	Australian Painted Snipe	Both	(State of New South Wales and Office of Environment and Heritage, 2017d)
Rytidosperma vickeryae	Perisher Wallaby-grass	AUA	(State of New South Wales and Office of Environment and Heritage, 2018o)
Saccolaimus flaviventris	Yellow-bellied Sheathtail-bat	Both	(State of New South Wales and Office of Environment and Heritage, 2017k) (State of New South Wales and Office of Environment and Heritage, 2017al)
Scoteanax rueppellii	Greater Broad-nosed Bat	SYB	(State of New South Wales and Office of Environment and Heritage, 2017r)
Sminthopsis leucopus	White-footed Dunnart	SYB	(State of New South Wales and Office of Environment and Heritage, 2017aj)
Stictonetta naevosa	Freckled Duck	SYB	(State of New South Wales and Office of Environment and Heritage, 2017o)
Thelymitra alpicola	Alpine Striped Sun Orchid	AUA	(State of New South Wales and Office of Environment and Heritage, 2018h)
Thelymitra kangaloonica	Kangaloon Sun Orchid	SYB	(State of New South Wales and Office of Environment and Heritage, 2018k)

Turnix maculosus	Red-backed Button-quail	SYB	(State of New South Wales and Office of Environment and Heritage, 2018r)
Tyto longimembris	Eastern Grass Owl	SYB	(State of New South Wales and Office of Environment and Heritage, 2018i)
Uperoleia mahonyi	Mahony's Toadlet	SYB	(State of New South Wales and Office of Environment and Heritage, 2018n)
Veronica blakelyi	–	SYB	(State of New South Wales and Office of Environment and Heritage, 2019y)
Zannichellia palustris	–	SYB	(State of New South Wales and Office of Environment and Heritage, 2019u)

Appendix 2: Endangered flora, fauna and ecological communities associated with upland peatlands in the Australian Alps that are listed in the VIC *Flora and Fauna Guarantee Act 1988*

Scientific Name	**Common Name**	**Source**
Acacia alpina	Alpine Wattle	(Wild and Poll, 2012)
Aciphylla simplicifolia	Mountain Aciphyll	(Wild and Poll, 2012)
Almaleea capitata	Slender Parrot-pea	(Royal Botanic Gardens Victoria, 2019a)
	Alpine Bog community	(Tolsma, 2009)
Anseranas semipalmata	Magpie Goose	(Department of the Environment, 2019a)
Antechinus minimus maritimus	Swamp Antechinus	(Department of the Environment, 2019b)
Argyrotegium fordianum	Alpine Cudweed	(Wild and Poll, 2012)
Australopyrum velutinum	Mountain Wheat-grass	(Wild and Poll, 2012)
Baeckea latifolia	Subalpine Baeckea	(Wild and Poll, 2012)
Burhinus grallarius	Bush Stone-Curlew	(The State of Victoria and Department of Sustainability and Environment, 2004a)
Burramys parvus	Mountain Pygmy-possum	(Department of the Environment, 2019c)
Cardamine franklinensis	Franklin Bitter-cress	(Wild and Poll, 2013)
Carex jackiana	Carpet Sedge	(Wild and Poll, 2012)
Carex paupera	Dwarf Sedge	(Carter, 2006)
Carpha alpina	Small Flower-rush	(Wild and Poll, 2012)
Celmisia sericophylla	Silky Snow Daisy	(Wild and Poll, 2013)
Celmisia tomentella	Silver Snow Daisy	(Wild and Poll, 2012)
Coprosma perpusilla subsp. *perpusilla*	Creeping Coprosma	(Wild and Poll, 2012)
Cylodomorphus praealtus	Alpine She-oak skink	(Robertson *et al.*, 2019)
Deyeuxia affinis	Allied Bent-grass	(Royal Botanic Gardens Victoria, 2019b)
Diplaspis nivis	Snow Pennywort	(Wild and Poll, 2012)
Epacris celata	Cryptic Heath	(Wild and Poll, 2012)

Epacris petrophila	Snow Heath	(Wild and Poll, 2012)
Eulamprus kosciuskoi	Alpine Water Skink	(The State of Victoria and Department of Sustainability and Environment, 2003a)
Euphrasia collina	Purple Eyebright	(Wild and Poll, 2014)
Euphrasia eichleri	Bogong Eyebright	(Threatened Species Scientific Committee, 2016a)
Euphrasia scabra	Rough Eyebright	(Royal Botanic Gardens Victoria, 2015)
	Fen (Bog pool) community	(Tolsma, 2009)
Gallinago hardwickii	Latham's Snipe	(Department of the Environment, 2019d)
Huperzia australiana	Fir Club moss	(Wild and Poll, 2012)
Juncus antarcticus	Cushion Rush	(Royal Botanic Gardens Victoria, 2019c)
Lissolepis coventryi (formerly *Egernia coventryi)*	Swamp Skink	(Clemann *et al.*, 2004)
Litoria verreauxii alpina	Alpine Tree Frog	(Department of the Environment, 2019e)
Lobelia gelida	Snow Pratia	(Threatened Species Scientific Committee, 2016b)
Lycopodium scariosum	Spreading Club Moss	(Wild and Poll, 2012)
Mastacomys fuscus	Broad-toothed Rat	(Wild and Poll, 2014)
Monotoca oreophila	Mountain Broom Heath	(Wild and Poll, 2012)
Myriophyllum alpinum	Alpine Water Milfoil	(Wild and Poll, 2012)
Ninox connivens	Barking Owl	(The State of Victoria and Department of Sustainability and Environment, 2003b)
Nymphoides montana	Entire Marshwort	(Wild and Poll, 2012)
Olearia phlogopappa var. *flavescens*	Dusty Daisy Bush	(Wild and Poll, 2012)
Oreobolus oxycarpus subsp. *oxycarpus*	Tuft-rush	(Wild and Poll, 2012)
Oreobolus pumilio subsp. *pumilio*	Alpine Tuft Rush	(Wild and Poll, 2012)
Philoria frosti	Baw Baw Frog	(Department of the Environment, 2019f)
Prasophyllum frenchii	Maroon Leek-orchid	(Wild and Poll, 2012)

Prostanthera monticola	Buffalo Mint-bush	(Wild and Poll, 2012)
Pseudemoia cryodroma	Alpine Bog Skink	(Robertson *et al.*, 2019)
Pterostylis oreophila	Blue-tongue Greenhood	(Department of Sustainability, Environment, Water, Population and Communities, 2012)
Ranunculus gunnianus	Gunn’s Alpine Buttercup	(Wild and Poll, 2012)
Ranunculus victoriensis	Serpent Heath	(Wild and Poll, 2012)
Richea victoriana	Victorian Richea	(Wild and Poll, 2012)
Schizacme montana	Mountain Mitrewort	(Wild and Poll, 2012)
Stictonetta naevosa	Freckled Duck	(The State of Victoria and Department of Sustainability and Environment, 2004b)
Trochocarpa clarkei	Lilac Berry	(Wild and Poll, 2012)
Wittsteinia vacciniacea	Baw Baw Berry	(Wild and Poll, 2012)

Appendix 3: Endangered flora, fauna and ecological communities associated with upland peatlands in the Australian Alps that are listed in the ACT *Nature Conservation Act 2014*

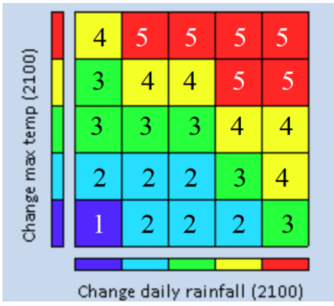
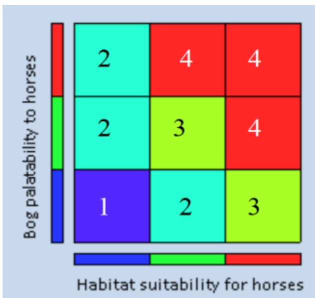
Scientific Name	**Common Name**	**Source**
	High Country Bogs and Fens	(ACT Scientific Committee, 2019c)
Litoria verreauxii alpina	Alpine Tree Frog	(ACT Scientific Committee, 2019a)
Mastacomys fuscus mordicus	Broad-toothed Rat	(ACT Scientific Committee, 2019b)
Pseudophryne pengilleyi	Northern Corroboree Frog	(ACT Scientific Committee, 2019e)
Pterostylis oreophila	Kiandra Greenhood	(ACT Scientific Committee, 2019d)

Appendix 4: Endangered flora, fauna and ecological communities associated with upland peatlands that are listed in the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*

Scientific Name	**Common Name**	**SYB /AUA**	**Reference**
Argyrotegium nitidulum	Shining Cudweed	AUA	(Wild and Poll, 2013)
	Alpine *Sphagnum* Bogs and Associated Fens	Both	(Commonwealth of Australia, 2009)
Baloskion longipes	Cord-rush	SYB	(Department of the Environment, 2019g)
	Coastal Upland Swamps in the Sydney Basin Bioregion	SYB	(Department of Environment, 2014)
Boronia deanei	Deane's Boronia	SYB	(Department of the Environment, 2019g)
Commersonia prostrata	Dwarf Kerrawang	SYB	(Carter and Walsh, 2010)
Dasyornis brachypterus	Eastern Bristlebird	SYB	(Department of Environment, 2014)
Eulamprus leuraensis	Blue Mountains Water Skink	SYB	(Department of the Environment, 2019g)
Gallinago hardwickii	Latham's Snipe	Both	(Department of the Environment, 2019d)
Gentiana wingecarribiensis	Wingecarribee Gentian	SYB	(Department of the Environment, 2019g)
Heleioporus australiacus	Giant Burrowing Frog	SYB	(Department of Environment, 2014)
Isoodon obesulus obesulus	Southern Brown Bandicoot	SYB	(State of New South Wales and Office of Environment and Heritage, 2017ac)
Kosciuscola tristis	Bogong Eyebright	AUA	(Threatened Species Scientific Committee, 2016a)

Litoria aurea	Green and Gold Bell Frog	SYB	(Department of Environment, 2014)
Litoria booroolongensis	Booroolong Frog	AUA	(Threatened Species Scientific Committee, 2009)
Litoria verreauxii alpina	Alpine Tree frog	AUA	(Department of the Environment, 2019e)
Lobelia gelida	Snow Pratia	AUA	(Threatened Species Scientific Committee, 2016b)
Philoria frostii	Baw Baw frog	AUA	(Department of the Environment, 2019f)
Prasophyllum fuscum	Slaty Leek-orchid	SYB	(Department of the Environment, 2019g)
Prasophyllum uroglossum	Wingecarribee Leek-orchid	SYB	(Department of the Environment, 2019g)
Pseudophryne corroboree	Southern Corroboree Frog	AUA	(State of New South Wales and Office of Environment and Heritage, 2012)
Pseudophryne pengilleyi	Northern Corroboree Frog	AUA	(State of New South Wales and Office of Environment and Heritage, 2012)
Pultenaea aristata	Bearded Bush-pea	SYB	(Department of Environment, 2014)
Pultenaea glabra	Swamp Bush-pea	SYB	(Department of the Environment, 2019g)
Pultenaea parrisiae	Bantam Bush-pea	SYB	(Department of the Environment, 2019g)
Rulingia prostrata	Dwarf Kerrawang	SYB	(Carter and Walsh, 2010)
Sphenomorphus kosciuskoi	Alpine Water Skink	AUA	(Hope *et al.*, 2012)
	Temperate Highland Peat Swamps on Sandstone	SYB	(Department of the Environment, 2019g)
Xerochrysum palustre	Swamp Everlasting	SYB	(Carter and Walsh, 2011)

Appendix 5: Source data for the input variables used in Wild and Magierowski's (2015) threat coincidence map

Input variable	**Source data**	**Threshold to be included in incidence count**
Bog flammability	Vegetation mapping where 1 is least flammable, and 5 is most: 1: *Carex* fens 2: *Empodisma* fen 3: Alpine *Sphagnum* shrub bog 4: Sub-alpine *Sphagnum* shrub bog 5: Montane *Sphagnum* shrub bog	3 and over
Climate threat	Change in daily maximum temperature from average in 1961-1970 to average in 2070-2099 1 (dark blue): 3 – 3.5 Kelvin 2 (light blue): 3.5 – 3.9 Kelvin 3 (green): 3.9 – 4.3 Kelvin 4 (yellow): 4.3 – 4.7 Kelvin 5 (red): 4.7 – 5.1 Kelvin Change in daily rainfall from average in 1961-1989 to average in 2070-2099 1 (dark blue): -22 – -20 mm 2 (light blue): -20 – -19 mm 3 (green): -19 – -18.5 mm 4 (yellow): -20 – -19 mm 5 (red): -22 – -20 mm	3 and over. Final number determined by: 
Horse threat (future)	Bog palatability to horses 1 (blue): Lowest palatability 2 (green): Moderate palatability 3 (red): Highest palatability Habitat suitability to horses 1 (blue): Poor (1 horse/km^2) 2 (green): Moderate (4 horse /km^2) 3 (red): Good (6 horse /km^2)	3 and over. Final number determined by: 

Land use	1: Conservation and natural environments 2: Water 3: Production from relatively natural environments 4: Intensive uses 5: Dryland agriculture and plantations 6: Irrigated agriculture and plantations	3 and over
Positional threat	Vulnerability (based on fire history and groundwater) 1 – 5: very low, low, moderate, high, very high Radiation threat (from net radiation and change in solar radiation) 1 – 5: very low, low, moderate, high, very high	3 and over, where final number determined by: