pollinators, predators, parasitoids, and decomposers (Samways 2005). Despite the significance of the invertebrate fauna to the stability and functioning of grassland ecosystems (Mulder et al., 1999; Riser et al., 1981), this important and mega-diverse taxonomic group is often less appreciated in temperate grassland ecosystems as many species are inconspicuous or undertake lengthy stages of their life-histories below ground (Coupland 1979).

**Historical Distribution of Temperate Grasslands**

Native temperate grasslands were once a major global vegetation system that occurred widely within the temperate climate zone between 30°–40° latitude on all continents except Antarctica (Figure 1) and covered approximately eight percent of the earth's terrestrial surface (Duffey et al., 1974; TGCI 2008). In the northern hemisphere, extensive areas of native temperate grassland occurred in North America, covering large areas from the Chihuahuan desert in the south to southern parts of Canada in the north and from the Rocky Mountains in the west to the adjacent deciduous forests of the eastern United States. Vast areas of temperate grasslands extended from the Ukraine to China on the Eurasian-Asian continent. In the southern hemisphere, substantial areas of temperate native grassland were present in the Campos or Pampa regions of South America (includes parts of southern Brazil, southern Paraguay, northeastern Argentina, and the whole of Uruguay). Large areas of temperate grassland also occurred in the temperate climate zone in south eastern Australia (Sala et al., 2001) (Figure 1). The conversion of temperate grassland into agriculture land (including intensive livestock grazing, pasture improvement and cropping), urban development with associated infrastructure, inappropriate fire regimes, and in some places excessive water extraction, have resulted in large scale losses and degradation of the vegetation (TGCI 2008). Today, much of this landscape of grassland plains, pampas and prairies has been lost or is highly degraded.

**Land-Use Changes to Native Temperate Grassland — An International Perspective**

Concurrent with other ecological systems, habitat loss, fragmentation and degradation are listed as singular major threats that, in combination with the overarching threat of climate change, add pressure to the integrity of the biodiversity in temperate grasslands. Climate change acts as a singular major threat, but more importantly with its additive power, in combination with anthropogenic modification (Figure 2). The World Temperate Grassland Conservation Initiative (TGCI) is an established project developed by the Grasslands Protected Area Task Force of the World Commission on Protected Areas (WCFA) of the International Union for Conservation of Nature (IUCN). The TGCI considers that temperate grasslands are one of the world's most threatened ecosystems because of the extensive losses of temperate grassland at a global scale. Based on the example of three international temperate regions, we highlight the severity of these large scale losses and degradations of temperate grasslands.
Temperate Grasslands: Out of Sight, Out of Mind?

It is estimated that only less than five percent of the pre-European settlement tall-grass prairies remain intact (Coppedge et al., 2001; Fletcher & Koford 2002; Vanderhoff et al., 1994). Not surprisingly, the extensive reduction and modification of North American temperate prairie grasslands into agricultural land has led to significant population declines and the extinction of many prairie dependent species (Hyde 1996). According to Sampson & Knopf (1994), in the United States 55 grassland species are listed as threatened or endangered with more than 700 additional species being candidates for becoming threatened or endangered. Approximately one third of the species considered as endangered by the Canadian Committee on the Endangered Wildlife are associated with grasslands (World Wildlife Fund Canada (WWFC) 1988). Today, the intrinsic values of the North American prairies for the provision of ecosystem services are recognised. However, a recent review of protected areas of temperate grassland in North America (federal, provincial and state parks and the central plains grasslands) indicated clearly that the level of protection is not adequate to conserve the full extent of the remaining intact prairie grasslands (TGCN 2008).

The third example is from Australia where native temperate grasslands were once widely distributed in the temperate climate zone, covering extensive areas in the south-east of the continent. Not surprisingly, these open (treeless) grasslands were first settled by Europeans as a consequence of receiving relatively consistent rainfall and the presence of suitable soils for agricultural development. Since European settlement in Australia enormous effort has been made by farmers to improving the productivity of natural grasslands, leading to the large scale transformation of native grassland into native pasture (grassland still dominated by native species of grass, but lacking many of the original native grasses and forbs) and exotic grasslands (grasslands comprised almost entirely of introduced species) (Kirkpatrick et al., 1995; Taylor 1998). Most native pastures have undergone modifications resulting from grazing by domestic stock and the addition of fertiliser and legumes (Mitchell 2003). Exotic grasslands include improved pastures and cultivated grasslands in agricultural and urban areas (Benson 1996). At present it is estimated that less than 100,000 ha of the former extensive temperate grassland in South-eastern Australia remain in a reasonably natural state, indicating that more than 95 percent has been destroyed or significantly altered (ACT Government 2005; Kirkpatrick et al., 1995; State of Victoria Department of Infrastructure 2000).

As has happened elsewhere, the biota in the native temperate grasslands in Australia is expected to have undergone significant declines and extinction as a result of such extensive large-scale loss of natural habitat and historical and ongoing degradation. Moreover, many of the remaining, often highly fragmented, native temperate grasslands have become increasingly threatened by urban development. This is in particular the case for the temperate grasslands in South Eastern Australia where rural expansion through the spread of small holding farms and the growth of cities have increased the pressure of remaining temperate grasslands to become developed into urban land (ACT Territory Plan 2008; State of Victoria Department of Infrastructure 2000). The cities of Melbourne (Victoria) and Canberra (Australian Capital Territory) provide examples of modern metropolitan areas situated in temperate grassland regions undergoing rapid urban expansion. Much of Melbourne is situated on the former grassy volcanic plains that surrounded Port Phillip Bay, whereas Canberra was built on the so-called Limestone Plains, an area of treeless grasslands. Both cities require a steady supply of land for residential and industrial development; generally supplied at the expense of surrounding grasslands (Sharp & Shorthouse 1996; Williams et al.,

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Figure 3. The extent of prairie declines in North America. Based on data provided by Sampson and Knopf (1994). The figure summarises the estimated current areas and historic area of the tallgrass, mixed grass, and short grass prairies. For full details see Sampson and Knopf (1994).

East Asia has one of the largest areas of temperate grassland on Earth (Kuhui et al. 2007) (Figure 1). The East Asian temperate grasslands are recognised as being a fundamental natural resource that is important to economic growth and to the cultures in this region (Qiet et al. 2007; Zhan et al., 2007). Most of the temperate grasslands in East Asia are densely populated by herders and farmers, along with their millions of livestock. For example, in China more than 196 million ha are classified as temperate grassland and meadow, but these areas also support 110 million people and their livestock (Peng et al., 2008). Overgrazing and the transformation of the natural temperate grasslands into farmland and urban land, combined with the effects of prolonged droughts, have led to large scale degradation of the original temperate grasslands. According to recent reports, most of the temperate grassland in China has been highly declined in their conditions. Estimates of the amount of remaining temperate grassland in reasonable condition range from 10 to 50 percent (see citation within Peng et al., 2008). Large scale modification of temperate grassland throughout temperate East Asia has caused adverse ecological effects at local and regional scales threatening the sustainability of natural temperate grasslands throughout East Asia (Parrot, et al., 1994; Reynolds 2005). Limited food supply and a lack of arable land elsewhere will lead to even greater pressure on these East Asian grasslands in the future (Reynolds 2005; Suttie 2005). Thus, the temperate grasslands in East Asia are under ongoing pressure, leading to further degradation and loss.

In North America, the first European settlers found the temperate grasslands (prairies) of the Central Grasslands and Great Plains in a pristine condition with little anthropogenic modification (Pieper 2005). They referred to the grasslands as prairies - a word most likely derived from the French language for "meadow". Generally, depending on the quality of soil and rainfall, the prairies are further divided into three formations: the short grass prairies, the tallgrass prairies and mixed prairies. Following the introduction of European agricultural practices, most of the historical grasslands of North America were rapidly transformed by agriculture, particularly through cropping (Wiken et al., 2008). Today, most remaining native grasslands are comprised of short grass prairies (Sampson & Knopf 1994) (Figure 3). It is estimated that only less than five percent of the pre-European settlement tall-grass prairies remain intact (Coppedge et al., 2001; Fletcher & Koford 2002; Vanderhoff et al., 1994). Not surprisingly, the extensive reduction and modification of North American temperate prairie grasslands into agricultural land has led to significant population declines and the extinction of many prairie dependent species (Hyde 1996). According to Sampson & Knopf (1994), in the United States 55 grassland species are listed as threatened or endangered with more than 700 additional species being candidates for becoming threatened or endangered. Approximately one third of the species considered as endangered by the Canadian Committee on the Endangered Wildlife are associated with grasslands (World Wildlife Fund Canada (WWFC) 1988). Today, the intrinsic values of the North American prairies for the provision of ecosystem services are recognised. However, a recent review of protected areas of temperate grassland in North America (federal, provincial and state parks and the central plains grasslands) indicated clearly that the level of protection is not adequate to conserve the full extent of the remaining intact prairie grasslands (TGCN 2008).

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2005). This constant high demand for urban development has led to ongoing losses of temperate grasslands in both cities and surroundings. Melbourne and Canberra have experienced losses of 36 percent of lowland native grassland and a 44 percent reduction in grassland area respectively over a 15-year period (1985–2000) and overall the destruction of 70 percent of temperate grassland over the 16 year period from 1980 to 1995 as a direct consequence of increased urban and rural development and weed invasion (Benson 1994; Morgan 1998; Stowe and Parsons 1977) (Figure 4). Considerable effort by the Australian governments has been executed to legally protect and manage the remaining natural temperate grasslands in Melbourne and Canberra, which today contain the largest native grassland remnants in Australia (ACT Government 2005; Australian Government 1999). Despite these attempts, it is likely that further destruction and degradation of native grassland will occur in these remnants, especially those with high perimeter to area ratios, and in close proximity to major roads and residential and industrial areas (Williams et al., 2005).

![Figure 4. Extent of losses and fragmentation of native temperate grassland within the vicinity of the two Australian cities: Canberra and Melbourne. Light grey areas indicate extent of pre-European settlement native grassland distribution. Locations in Melbourne indicated as white (no fill) and in Canberra as dark grey fill show remaining native grassland fragments. Sources: ACT Government (2005) and modeled native vegetation data from the Department of Sustainability and Environment (DSE) Corporate Spatial Data Library (2005).](image)

NATIVE TEMPERATE GRASSLAND

**Ecosystem Services**

Temperate grasslands, even in an unmodified condition, provide a range of ecological services for the well-being of humans. According to the Millennium Ecosystem Assessment (2005), the grassland biomes provide: a) provisioning services (e.g. food, fibre, biochemical and natural medicine, ornamental resources); b) regulatory services (e.g. pollination, seed dispersal, climate, air quality, water and erosion regulations); c) cultural services (e.g. spiritual, aesthetic and religious values, cultural heritage); and d) supportive services (e.g. primary production, nutrient and water cycling, provision of habitat, soil formation and retention). Temperate grasslands specifically contribute substantially to the storage of soil carbon and are recognised as significant contributors to the global carbon cycling processes (Bertin 2008; Fischlin et al., 2007). The ability of ecosystems to continuously provide these services is generally expected to be dependent on the maintenance of an intact and diverse biota as a result of the strong correlation between ecosystem process rates and biological diversity (Schlapfer 1999). Therefore, the maintenance of the genetic, biotic and landscape diversity of temperate grassland is important because of their role in securing future ecosystem services. Many of the services that grasslands provide have commercial value – these include for example the provision of meat, milk, wool, and leather derived from grazing animals. However, other services such as maintenance of the composition of the atmosphere, maintenance of the genetic library, amelioration of weather, and the conservation of soils are often perceived to be freely available, limitless and without any market value (Sala & Paruelo 1997). Heidenreich (2009) observes that, in terms of total economic value, temperate grassland remains one of the least understood biomes in terms of its value and its sustainable economic use, social-cultural services, as well as the many ecosystem goods and services that it contributes to human well-being (Heidenreich 2009). The perception that grassland services can be taken for granted and the underestimation of their economic value as providers of services have consequences for decision makers, researchers and the society as a whole. Sala & Paruelo (1997) concluded that: “Errors in valuation (in regard to native grasslands generally) may lead to inappropriate decisions on the fate and best use of natural resources for society. The ability of providing goods and services with market value is not necessarily related to the ability to provide other services, which currently may not have a market value. Ignoring the value of services with no market value may be seriously misleading.”

**Ecological Research**

From an ecological perspective, temperate grasslands, in unmodified and modified condition, have provided an ideal setting for ecological research that has addressed fundamental principles in ecology and conservation biology (Golley 1983; Kaup et al., 2007; Knapp et al., 1996). For example, two central questions in ecology: 1) the relationships between ecosystem productivity and stability, and 2) the relationship between ecosystem processes (e.g. productivity) and biodiversity, were examined in temperate grasslands (Bai et al., 2004; Chalcraft et al., 2009; Jennings et al., 2005; Tilman & Downing 1994; Tilman et al.,
2001), Bai et al. (2007) studied temperate grassland at field sites across the Mongolian temperate region and reported on the positive linear relationships between productivity and diversity at multiple organisational levels (e.g. vegetation type and biomes) and across local, regional and landscape scales. Their results contrast with the more general view of there being no positive linear productivity-richness relationships, instead species richness typically peaks at an intermediate level of productivity (hump-shaped form of productivity-diversity relationship), as determined from observations in the terrestrial ecosystems of Europe, Africa and North America (Bai et al., 2007; Coupland 1992). Also, a range of experimental grassland studies — some of them conducted in the North American prairies — (see Table 1 in Diaz & Cabido 2001) revealed empirical evidence of relations between ecosystem processes and different components of plant diversity (species richness, functional richness and functional composition). Based on these findings, there is general consensus that ecosystem processes are governed by their functional traits, rather than by species richness (alpha diversity), and its abundance and distribution in a community (Diaz & Cabido 2001).

By contrast, Pasari et al., 2013 analysed data from the world’s longest running temperate grassland biodiversity-functioning field experiment (Cedar Creek Biodiversity II) to strengthen the hypothesis that local species richness (alpha diversity) has strong positive effects on most individual functions and multi-functionality. Their findings underpin earlier studies demonstrating the importance of species diversity for ecosystem functioning as more functional, temporal and environmental contexts are considered (Pasari et al., 2013). These studies are exemplars for the broader research undertaken in temperate grasslands, and highlight the importance of testing general ecological hypotheses in ecosystems that may share taxonomic similarities, e.g. the North American Prairies and the Eurasian steppes, but differ in climatic conditions, soil, plant and animal functional traits (Hector et al., 1999; Tilman 1997; Tilman et al., 2001; Tilman et al., 1996). A second field of ecological research that is being addressed in temperate grasslands is the exploration of response of the biota to environmental changes over time. The monitoring programs in temperate North America (International Biological Program IBP) and China (Chinese Academy of Sciences) were established in the 1960’s and early 1970’s (Hobbie et al., 2003) and provide ecologists with comprehensive and comparable data sets of enormous value. The analysis of long term data have improved enormously our understanding of the ecological requirements of many temperate grassland species and are now used to predict the ecological effects of changes in climate and land-use (Bai et al., 2004; Fan et al., 2008; Liu et al., 2006; Shi et al., 2002; TGCI 2008). The significant contributions provided by ecological research in temperate grassland to ecological theory have considerably influenced the ongoing debate about the relationship between biodiversity and the functionality of ecological systems in the light of the loss of biodiversity and have provided insight into the role of ecological processes involved in the maintenance of ecosystem stability.

Consequences of Climate Change

Climate is an important component of a set of global-scale environmental changes that drives evolutionary, ecological and demographic changes in species and populations (Hazar et al., 2006). For example, variation in rainfall determines physiological and phenological processes in organisms, controls the pattern of migration of highly mobile populations (Newton 1998) and influences annual variation in population size in birds and mammals (Stenesh et al., 2002). Thus, changes in climatic variables, including temperature and rainfall, will ultimately directly and indirectly influence the distribution and the composition of species populations and communities as well as affect their inter- and intraspecific interactions (Hughes 2000; 2003; Parmesan 2007; Parmesan et al., 1999; Thomas et al., 2004). There is concern that temperate grasslands will be particularly responsive to climate change (IPCC 2001). However, the magnitude and direction of any responses are likely to vary considerably across locations depending on site conditions, biota and management treatment (White et al., 2012). Thus, the identification of site specific conditions or mechanisms that drives the predictable reposes remains unknown. The prediction of the effects of changing climate on ecological processes in temperate grasslands is of great conservation interest because temperate grasslands are considered to be particularly vulnerable to plant change as a result of a long evolutionary history between climate and grassland productivity, nutrient cycles and the evolution of species (Johnson et al., 2005; Nia et al., 2008; Sala et al., 1996; Sousanna and Luescher 2007). Additive changes in spatial and temporal patterns of precipitation, temperature, and increasing atmospheric carbon dioxide as predicted under current global climate change scenarios, are expected to profoundly influence the diversity, productivity and stability in temperate grasslands (Boecheh 1980; Sala et al., 1996; White et al., 2012). In particular, significantly more disturbances, especially increasing fires and more frequent periods of lower amounts of rainfall (droughts) are predicted to occur in the future in temperate grassland, placing greater stress on the survival of the biota and the integrity of the grassland ecosystem functions (Fischlin et al., 2007). Rising carbon dioxide levels and increased temperatures are likely to lead to an increase in plant productivity, resulting in changes in plant species composition and their demography (Williams et al., 2007). Generally, it is hypothesized that elevated atmospheric carbon dioxide levels will stimulate C3 plant species by a greater extent than C4 species and increasing CO2 input may cause persistent increases in primary production, leading to greater storage of carbon in plant residues and soil organic matter (Hunt et al., 1991). However, research on C3 and C4 grasses in South-eastern Australian by Williams et al., (2007) found significantly reduced plant growth in a dominant C3 grass exposed to elevated carbon dioxide and markedly warmer conditions. These results indicate that responses by plants species to increased atmospheric carbon dioxide can be variable and the subsequent feedback loops are unclear. Although native temperate grasslands experience droughts on a regular basis (IPCC 2001; Parton et al., 1994), native grasslands are highly sensitive to limited soil water availability associated with significant rainfall deficiencies (Kammer 2002; Sebastia et al., 2008). Increasing periods of drought may cause quantitative and qualitative changes in species composition and configuration by altering the density and frequency of the species involved (Frank 2007; Morecroft et al., 2002). This process can even persist for several years after the drought event (Frank 2007; Kammer 2002). Changes in precipitation and associated changes in the availability of water are likely to have effects on the composition and structure of temperate vegetation (Frank and McNaughton 1992), primary net production, consumption, nutrient flux and on the life history of species (e.g. changed phenology, poor survival, changes in body size; Bernays & Chapman 1973) associated with temperate grasslands (Georgetown 1992; Macias-Duartet et al. 2004; Manzano-Fischeret et al. 1999). Drought conditions also affect the survival, and population dynamics of larger grassland species such as birds (Yarnell et al., 2007), reptiles (Sperry & Weatherhead 2008), small mammals (Cairns and Grigg 1993;
Caughley et al., 1985) and marsupials (Munn and Dawson 2010). Changes in climate may also reduce plant species survival indirectly as a consequence of changed herbivore-plant-insect interactions, changed predator-prey interactions and cascading effects (Goulson et al., 2005). One major economic and ecological concern related to the impacts of climate change is the increasing likelihood of pest population outbreaks (Goulson et al., 2005; Kreyling et al., 2008). Research on the factors that trigger pest outbreaks indicates that there is a close relationship between the timing of outbreaks and precipitation (Patterson et al., 1999). Under the predicted climate scenarios, pest outbreaks and the speed of invasion may increase with rising temperatures and changes in precipitation. Consequently, climatic anomalies such as extreme drought and floods have the ability to strongly affect the periodicity and severity of pest outbreaks and invasion. However, the prediction of disease outbreaks will be more difficult in periods of rapidly changing climate and unstable weather and the effectiveness of pesticides on targeted pests might change under changing climatic conditions (Harrington et al., 2001).

Invasions

Native temperate grasslands have been exposed to a long history of invasions of anthropogenic and natural origins. In less than 300 years the majority of temperate grasslands (except the Eurasian temperate grasslands) have been irrevocably modified by human kind through the introduction of non-native species. Some temperate grasslands such as those in Australia, Argentina, Uruguay and the Central Valley of California have been particularly affected by invasive species, whereas the grasslands in Eurasia, southern Africa and central America have changed comparatively little, except where ploughed (Costello 1944; Mack 1989). These differences have been attributed to the influences of two quite different evolutionary histories under which the temperate grasslands evolved: firstly the presence or absence of a substantial evolutionary history with or without large, heavy-hoofed grazing mammals. Sites with a long history of grazing by these mammals are thought to have developed ecological traits that impart a resistance to invasion. The other reason for the vulnerability for invasion is the dominance by caespitose grasses prior to European settlement. Caespitose grasses display little tolerance of grazing or trampling by large grazers and disappear from the floristic community when the pressure from disturbance increases (Mack 1989).

The Future of Native Temperate Grasslands — An Ongoing Concern

There are clear reasons for our overall concern about the future viability of native temperate grasslands. These grasslands have declined extensively at the global scale and remaining temperate grasslands, that are still intact, are threatened by ongoing modification (e.g. being highly fragmented and modified) and by the continuous pressure of land-use (e.g. agricultural, rural and urban development) on the remaining grasslands.

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<th>Table 1. Identification of potential research and conservation priorities for native temperate grasslands</th>
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<td>Conservation/research action in native temperate grasslands</td>
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<td>Invasion/Pest outbreaks</td>
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Symbol X indicates existing information and attempts to address these issues. O indicates areas that are important to improve in future and are currently not sufficiently addressed; "minus" indicates that not sufficient information was found. All information presented in this table was obtained from contributions of invited authors at the World Temperate Grassland Conservation Initiative Workshop 2008 report (TGCI 2008).

Considering the single and additive effects of the past and ongoing threats and the status quo of remaining temperate grasslands, there is a justified concern that native temperate grasslands around the globe are at the risk of becoming one ecological community that is at the brink of extinction. Important ecosystem services that are provided by native temperate grasslands are expected to become reduced and limited as a result of these historic and ongoing alterations. The World Temperate Grassland Conservation Initiative (TGCI) expressed two key concerns regarding the future of temperate grasslands. First, the overall