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GOLDEN DAYS? AN ARCHAEOLOGICAL PERSPECTIVE ON ABORIGINAL PEOPLE'S PRESENCE ON THE GOLDFIELDS OF NORTH CENTRAL VICTORIA

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Smith, D., 2010. Golden Days? An archaeological perspective on Aboriginal people's presence on the Goldfields of North Central Victoria. *Transactions of the Royal Society of Victoria* 122(2): lvi. ISSN 0035-9211.

The presence of Aboriginal people on the Victorian Goldfields and after the gold rush era is not well recognised generally. Interaction between Aboriginal and non-Aboriginal people on the Goldfields, with material culture production as a focus for discussing adaptation and engagement, is the main theme of this paper. Awareness and recognition of Aboriginal people's presence on the Goldfields and following the winding down of the search for gold is very relevant to ongoing issues of appropriate planning, management and protection of Aboriginal cultural heritage in Central Victoria.

A SENSE OF PLACE - THE NOT SO OBVIOUS IMPACTS OF GOLD MINING ON CENTRAL VICTORIAN LANDSCAPE

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Bannear, D., 2010. A sense of place - the not so obvious impacts of gold mining on central Victorian landscape. *Transactions of the Royal Society of Victoria* 122(2): lvi. ISSN 0035-9211.

North Central Victoria is rich in signs and clues that point to the ghosts of its gold mining past. Look carefully. If you sense something has happened, it probably has. This mainly visual presentation will provide a background to the gold rush, show what an extraordinary multilayered landscape central Victoria is, and provide insights into some of the clues that tell the story of historic gold mining. It is hoped that these images will help people step into the central Victoria landscape with eyes more widely open and senses broadened.

ACCUMULATION AND DENUDATION - PAST, PRESENT AND FUTURE: A SURGICAL GEOLOGIST'S VIEW OF CENTRAL VICTORIA

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Rosengren, N., 2010. Accumulation and deundation - past present and future: a surgical geologist's view of Central Victoria. *Transactions of the Royal Society of Victoria* 122(2): lvii ISSN 0035-9211.

The landscape of Central Victoria records multiple episodes of rocks being formed, deformed and variously modified in diverse environments on land and in the sea. These records are preserved and displayed as the modern landscape and surficial materials. Intense interrogation of the geological materials of Central Victoria - in some places literally leaving no stone unturned – from the time of picks and shovels to the era of eyes and ears in the sky and space has allowed the past to be unravelled and understood as a sequence of (sometimes) related events. Over the past 600 million years, geological processes of sedimentation, eruption and intrusion has provided a rock stock that has been broken, bent, warped, buckled and bowed in response to crustal and mantle forces. Rock masses have been pushed upwards, pulled downwards, shifted sideways and subjected to environmental changes ranging from arid to super-wet to frozen. This paper will describe and illustrate, (a) the major events that have produced the materials and shaped the morphology of the region, (b) the mechanisms that are operating in the landscape to-day, and (c) what we can expect to happen in future over time scales from historical to geological. It will emphasise the opportunities in this landscape for earth science teaching and research and the relevance of understanding the past to those living in this region.

GROUNDWATER DEPENDENT ECOSYSTEMS

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Fawcett, J., 2010. Groundwater dependent ecosystems. *Transactions of the Royal Society of Victoria* 122(2): lvii. ISSN 0035-9211.

An outcome of the 1994 Council of Australian Government's Water reform framework was that water allocation planning is required to protect ecosystems, including Groundwater Dependent Ecosystems (GDEs) that have an important function or conservation value. While there is a world-wide acceptance of the presence and importance of GDEs, the focus in Australia has largely been on iconic GDEs, such as the mound springs of the Great Artesian Basin, eucalypts within the floodplain of the Murray River and the banksia woodlands of Western Australia. Such limited focus on GDEs thus presents substantial challenges for GDE management policy development in Australia. The need to improve knowledge of GDEs across Victoria has been made more urgent due to extended dry conditions and an increased reliance upon groundwater as a resource. Before determining the functionality, degree of groundwater dependency and threats to GDEs, it is necessary to identify the location and extent of groundwater interaction across Victoria. Unfortunately, methods so far employed to detail the function and water requirements of GDEs at site-specific locations are not economically or practically feasible at catchment and regional scales. Therefore, a new integrated method has been developed by the authors to achieve this first step in understanding GDEs. This presentation describes a method that delineates areas of groundwater interaction with the terrestrial surface at catchment and regional scales. The method utilises satellite remote sensing data, geological data and groundwater monitoring data in a GIS weighted overlay model. The outputs are maps of terrestrial, wetland and stream based landscapes that are likely to contain ecosystems that are in some part dependant on groundwater. The method has been used across Victoria and south eastern Australia and is the first step in identifying potential groundwater dependent ecosystems that may be threatened by activities such as drainage and groundwater pumping.

SALTLAND RESTORATION IN A TIME OF CLIMATE CHANGE - OLD THREATS AND NEW OPPORTUNITIES

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Dyson, P., 2010. Saltland restoration in a time of climate change - old threats and new opportunities. *Transactions of the Royal Society of Victoria* 122(2): lviii. ISSN 0035-9211.

Changes in the climate of northern Victoria post 1996 have had a devastating impact on water resources and dryland agricultural production in northern Victoria. Depleted annual rainfall and a variable seasonal rainfall mean soil water deficits are no longer satisfied through autumn/winter precipitation. In consequence runoff and groundwater recharge are reduced or eliminated. The new water balance has seen large reservoirs depleted and repeated cereal crop failures over the past 13 years. Elimination or mitigation of groundwater recharge has delivered a widespread reduction of groundwater pressures, particularly in the upper reaches of both local and sub-regional groundwater flow systems. These reductions, however, are not yet matched by a dramatic lessening of land subject to dryland salinity. Detailed monitoring and investigations undertaken by the Northern United Forestry Group (NUFG) at Kamarooka reveal catchment based processes, that fuelled dryland salinity in the latter half of the 20th century, have given way to localised hydrological processes occurring within and immediately adjacent saline land. Recharge no longer occurs in the catchment. Instead, it occurs where the watertable is shallowest within the salt affected land. Changes to the water balance have eliminated the persistent waterlogging of salt affected lands. The NUFG, through its Kamarooka project, demonstrates that the removal of waterlogging allows for considerable increases in the salt tolerance of vegetation. Low rainfall farm forestry featuring eucalypt and acacia plantations now thrive over a shallow watertable in areas where the groundwater salinity is high. The trees not only survive in this new world, they actively transpire sufficient saline groundwater and lower the watertable. It is apparent that many native trees are more tolerant of salt than previously thought. They are, however, very intolerant of the combined impacts of salt and waterlogging. The NUFG work at Kamarooka demonstrates that sustainable agriculture can be realised in this new dry climate through judicial use of integrated land management regimes featuring an appropriate mix of trees, saltbush and lucerne.

DO YOU SEE WHAT I SEE: HOW DO THE ROCKS CONTROL US?

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Boucher, R., 2010. Do you see what I see: how do the rocks control us? *Transactions of the Royal Society of Victoria* 122(2): lviii. ISSN 0035-9211.

Victoria is built on gold. Blocks of the ancient earth's crust were pulled and pushed to create oceans then mountain ranges where Bendigo now sits. Molten magma crystallised in pockets throughout the state, gold-bearing fluids circulated and large faults moved, in some cases tens of kilometres. Victoria has subsequently experienced glaciation, tropical climates and a recent bout of volcanism. Victoria's towns and infrastructure are built on and around gold deposits and our daily travels and lives are governed by this legacy. Unfortunately, the future use of geology and geologists is looking bleak. We see increasing demand on geological understanding as we build bigger structures in increasingly hazardous places. Bridges and buildings are getting bigger, tunnels are getting deeper. We face increasing problems with water, salinity, climate change and resource consumption. These areas all require greater geological input. However, community exposure to geological information is dwindling, geologists are ageing and their numbers are declining. To add to the dilemma, geologists are being lured into the mining boom and less are available for other disciplines and long term planning.

UPPER LODDON, CHANGING LANDUSE AND CHANGING CATCHMENT WATER BALANCE

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Hocking, M. & Beverley, C., 2010. Upper Loddon, changing landuse and changing catchment water balance. *Transactions of the Royal Society of Victoria* 122(2): lix. ISSN 0035-9211.

This paper describes simulation of the Upper Loddon Catchment water balance and response time associated with landuse change. Since European settlement there have been changes in the vegetation cover (such as from trees to broad acre grading to cropping and in some locations to irrigation) which has changed the water balance. The subsequent change in landuse has effectively increased the amount of run-off and groundwater storage across the landscape and given rise to a different water balance than which occurred prior to European settlement. While an increase in run-off and groundwater storage could be considered to be a benefit to the community other less than favourable impacts have also given rise, these include increased land and water salinity plus a changed surface water flow regime. Results from landuse change simulations suggest there has been a change in catchment yield by approximately 500% (assuming 30 year average rainfall). Locations of where changes in the waterbalance have occurred are unequally distributed throughout the catchment, also is the time it takes for the groundwater system to respond to a change in recharge as a function of landuse change. Overall, response times ranged between 40 and 103 years with an average of 70.4. Groundwater response time appeared to be related to landscape gradient and distance from waterways, where steep hills close to drainage lines had the fastest response time and flat landscapes away from drainage lines the slowest for the water balance to respond.

THE VEGETATION OF THE AVOCA, AVON, LODDON AND CAMPASPE RIVER CATCHMENTS

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White, M., 2010. The vegetation of the Avoca, Avon, Loddon and Campaspe River Catchments. *Transactions of the Royal Society of Victoria* 122(2): lix. ISSN 0035-9211.

The vegetation of central Victoria north of the Great Dividing Range is briefly described in the context of the key climatic and edaphic determinants and recent human disturbances and impacts. The spatial arrangement of remnants of native vegetation and their structural attributes can be traced back to the rapid and landscape scale changes precipitated by the 19th century gold rushes.

WOODLAND BIRDS IN NORTH-CENTRAL VICTORIA: PATTERNS IN SPACE AND TIME

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Bennett, A.F., 2010. Woodland birds in north-central Victoria: patterns in space and time. *Transactions of the Royal Society of Victoria* 122(2): lx. ISSN 0035-9211.

North central Victoria has a rich and complex avifauna, which makes up a major component of the biodiversity of the region. The pattern of distribution of bird species in today's environment is a consequence of natural processes operating over a range of spatial scales, from continental to local, overlaid by human changes to the environment. The outcome is that there is much local spatial variation in bird assemblages. Temporal changes in bird communities are also significant and complex, and associated with regular seasonal patterns of migration, variation in resources (such as nectar), interactions between species, and long-term trends linked to climate and land-use change. Effective conservation of the region's avifauna poses a major challenge for land managers and the entire community. In the face of ongoing anthropogenic change, there is a need for a shared long-term vision of the environment of the future and the levels of biodiversity we wish future generations to be able to appreciate. Birds are a visible and accessible part of the regions' biodiversity and can be readily monitored as an indicator of environmental change and of the success of conservation and restoration actions.

CLIMATE CHANGE IMPACTS ON RIVER HEALTH – OBSERVATIONS FROM THE STATEWIDE BIOLOGICAL MONITORING PROGRAM

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Metzeling, L., Rose, P., Dean, J., StClair, R., Thomas, D. & Parkinson, S., 2010. Climate change impacts on river health - observations from the statewide biological monitoring program. *Transactions of the Royal Society of Victoria* 122(2): lx. ISSN 0035-9211.

Since 1990, EPA Victoria has first developed and then managed a statewide biological monitoring program using macroinvertebrates as indicators. From 1990–96, most of the effort was focused on sampling streams to establish 'reference conditions' as benchmarks for subsequent assessment of test sites. Since 1997 however, there have been generally dry conditions, with recent years having amongst the lowest rainfall and stream flows on record. The existence of an extensive statewide dataset prior to the current dry conditions has enabled a large scale assessment of its effects on river health as indicated by the macroinvertebrate community. Overall, the monitoring shows resilience in the early years of the current dry period but a deterioration in recent years. The proportion of intermittent streams has increased with implications of likely future trends for river health in Victoria. In this presentation I will focus on three aspects: 1) changes in attainment of biological objectives set in state policy, 2) changes in community structure observed at long term monitoring sites, those sites which have been sampled bi-annually since the early to mid-90s, and 3) changes in the distributions of invertebrate taxa with identification of traits which may make species vulnerable to climate change impacts.

FIRE MANAGEMENT ON PUBLIC LAND IN NORTH CENTRAL VICTORIA

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Price, R., 2010. Fire management on public land in north central Victoria. *Transactions of the Royal Society of Victoria* 122(2): lxi. ISSN 0035-9211.

The Department of Sustainability and Environment (DSE) is the responsible government agency for the prevention, preparedness, suppression and recovery of fires on public land in Victoria. It ensures that the response to wildfire and the use of prescribed burning are in accordance with environmental guidelines, and assists the achievement of other management objectives. Experience has shown that planned use of fire can provide a degree of protection from wildfire. Fire may also be necessary to maintain forest and grassland biodiversity. It is also a valuable tool for achieving other important land management objectives such as forest management and weed management. Within DSE's North West Area, the Murray Goldfields Fire District has responsibility for over 426 700 ha of public land. Depending on management priorities, forest fuel loads and weather conditions, between 2000 to 4000 ha per year are fuel reduced within the Murray Goldfields Fire District. This presentation will provide the audience with information about the objectives and strategies that guide planned burning in the Box-Ironbark forests of central Victoria.

PREDICTED BIODIVERSITY FUTURES BECOME THE BIODIVERSITY PRESENT UNDER CLIMATE CHANGE – ACCELERATION OF DECLINE

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Mac Nally, R., 2010. Predicted biodiversity futures become the biodiversity present under climate change - acceleration of decline. *Transactions of the Royal Society of Victoria* 122(2): lxi. ISSN 0035-9211.

Conservation biologists long have predicted a more or less gradual loss of species in systems in which habitats have been extensively cleared, fragmented and degraded – the 'extinction debt'. Expected patterns of loss were based on assumptions of similar conditions so that previous demographic patterns (e.g. natal and mortality rates) were maintained. However, climate change, especially in much of south-eastern Australia, may have significantly affected these vital rates, probably through reductions in food availability and added stresses associated with more extreme climatic conditions. We illustrate some effects by using information on birds and amphibians from across the Box-Ironbark region of north central Victoria.

IMPACTS OF PROLONGED DRY CLIMATE CONDITIONS ON GROUNDWATER LEVELS AND RECHARGE IN NORTH CENTRAL VICTORIA

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Reid, M., 2010. Impacts of prolonged dry climate conditions on groundwater levels and recharge in North Central Victoria. *Transactions of the Royal Society of Victoria* 122(2): lxii-lxxv. ISSN 0035-9211.

During the extended dry weather pattern in northern Victoria from 1997 to 2009, greater than could be anticipated watertable declines occurred in some groundwater flow systems (GFS), especially in upland areas. Evidence to date suggests that these declines are primarily induced by the drier climate since 1997, with land use and groundwater extraction playing a relatively minor but not insignificant role overall. With the benefit of very good groundwater level records, it is argued that many GFS, including ones previously regarded as 'slowly responding', are actually very responsive with significant and dramatic changes occurring in groundwater storage and recharge distribution over short timeframes. The recent groundwater declines have had significant effects on water security, affecting not only groundwater resources but also the dynamics of groundwater-stream interaction, hydraulic gradients and base flow, with consequent repercussions for stream flow. The spatial distribution of recharge has noticeably altered since 1997 with very little recharge (and very few recharge events) being registered in the higher landscape areas while small to moderate amounts of recharge continue to occur on a more or less seasonal basis in many lower landscape areas with high watertables. In regard to dryland salinity, it is concluded that, in terms of severity or change, it will be a cyclical rather than a steadily increasing problem, fluctuating with climate pattern but exacerbated in some localities by inappropriate land management. It is also suggested that salinity-focused management may need to occupy only a minor proportion of a GFS provided that it is well-targeted and includes mandatory appropriate treatment of the discharge areas themselves.

Key words: groundwater levels; groundwater flow system; groundwater recharge; climate impacts; dryland salinity

USING time-series groundwater level data, this paper aims to provide a broad insight to the impacts of the recent prolonged dry climate on groundwater levels and recharge of groundwater flow systems (GFS) in North Central Victoria (NCV) in order to better understand responsiveness of different GFS and the implications of forecast drier climate conditions on water security, stream behaviour and salinity.

The Department of Sustainability and Environment (DSE) funded the Department of Primary Industries (DPI) to conduct a broad review of groundwater trends across most Victorian dryland regions in 2007 (Hekmeijer et al. 2008). The review was based on a selection of about 10 key bores within each dryland region. Further subsequent interrogation of time-series groundwater data at approximately 200 other locations within NCV complements this work, providing a good insight into the groundwater response and characteristics of key GFS. In the context of the prevailing, lengthy period of drier than average climate conditions (since 1996/97), this paper presents and discusses some of the observed groundwater responses and their possible implications in terms of GFS responsiveness, recharge, stream flow, water security and salinity risk.

STUDY AREA

The study area is North Central Victoria (NCV) as defined by the North Central Catchment Management Authority (NCCMA) boundary. Figure 1 shows the location of the NCCMA region in Victoria together with its four major catchments, from west to east, Avon-Richardson, Avoca, Loddon and Campaspe. The figure also shows the bore locations for all hydrographs presented in this paper.

GROUNDWATER RESPONSES

Drier than average climate conditions have existed from 1997 to 2009 across most of Victoria with northern and western parts of Victoria being most affected. Coincidentally, these parts of the State also record

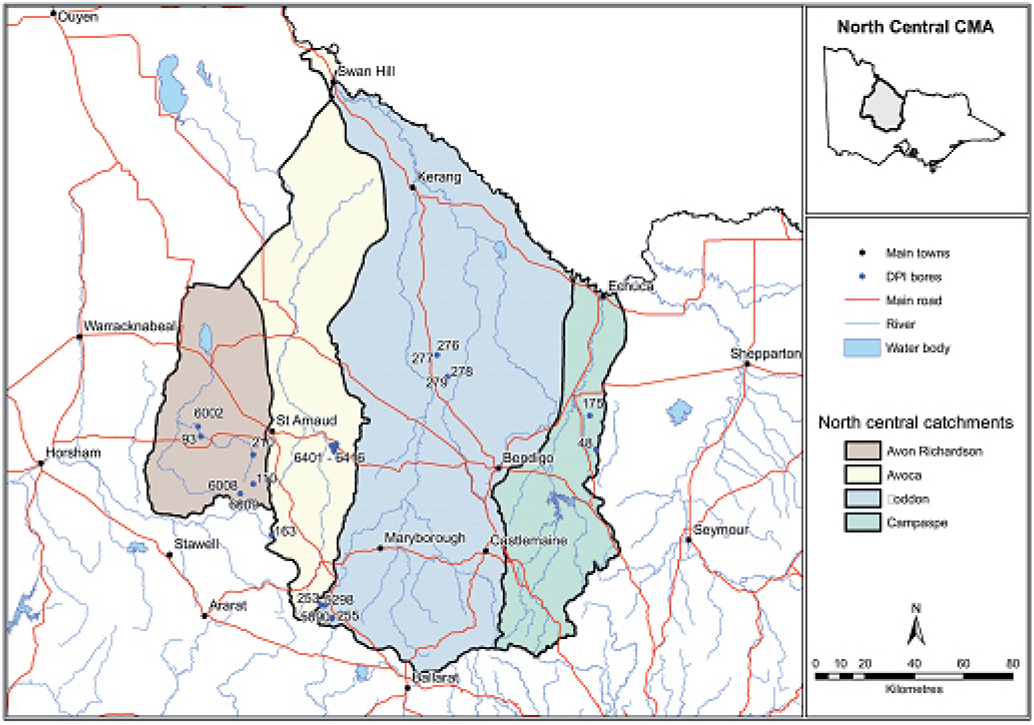

Fig. 1. Map of the North Central Catchment Management Authority region showing its four major catchments and the locations of bores for which groundwater hydrographs have been presented in this paper (see Figs. 2-10).

the greatest incidence of dryland salinity (Clark and Harvey 2008).

Forty-three of 68 bores examined across Victoria by Hekmeijer et al. (2008) recorded a falling groundwater trend. At the time (2007), 32 of these registered their lowest water levels over monitoring records that mostly go back to the 1980s, sometimes to the early 1980s. Most declines in groundwater levels have occurred since 1996 or 1997, more or less coincident with the downward shift in rainfall amount and frequency (see Fig. 6). Rising trends were prevalent during the 1980s and early 1990s but the total declines since 1996/97 have been generally greater in magnitude than the previous recorded rises.

The observed groundwater trends and behaviour in NCV are consistent with the statewide overview provided in Hekmeijer et al. (2008). Closer scrutiny of the NCV time-series groundwater level data set reveals that bores monitoring fractured rock GFS in upper landscape areas have recorded the most significant changes, with groundwater declines commonly greater than 6 m and sometimes greater than 10 m in the upper parts of the GFS (e.g. Fig. 2). Such declines have considerable implications for spring flows and base flow generally. It is probable in some cases that these declines are also influenced by altered land use (e.g. plantations) or by groundwater abstraction.

Figure 2 also demonstrates a marked change in groundwater behaviour in upper landscape locations. This is signified clearly in the examples shown by the supersedence of pre-1997, strongly fluctuating hydrograph patterns by the smooth recession lines after 1997. At these particular locations, very little recharge has occurred since 1997, yet they are noted as being high recharge areas (e.g. Campaspe Community Working Group 1992; Loddon Community Working Group 1992; Kevin 1993; Ryan 1993; Avoca Dryland Community Working Group 1993; SKM 2002) and display good evidence of this prior to 1997. However, from 1997 to 2009, they would be classed as low recharge areas.

From 1997 to 2009, groundwater levels in low-lying areas of NCV, including saline discharge areas, have commonly fallen by one to two metres with

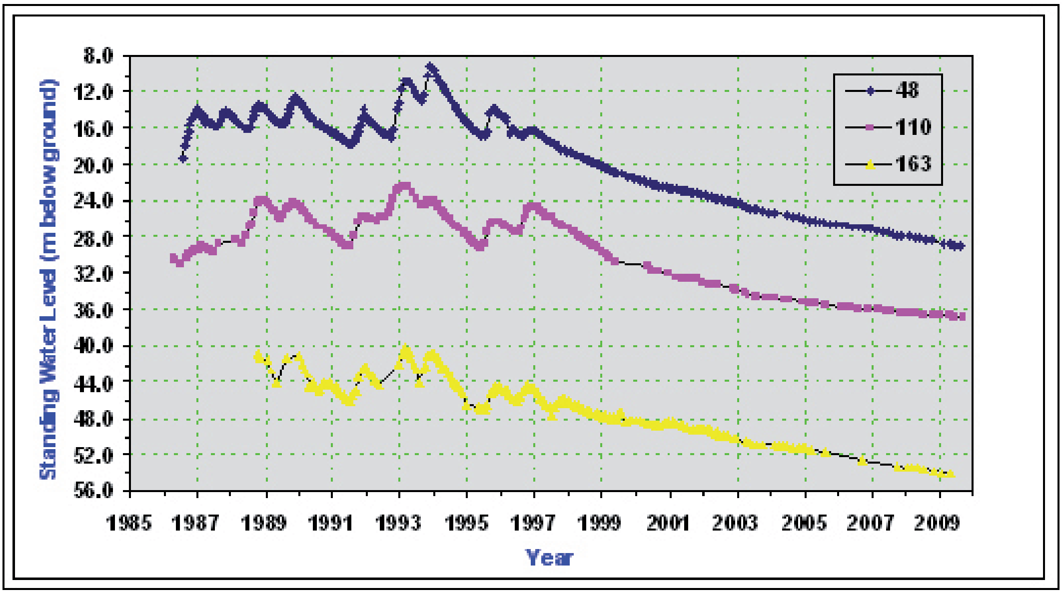

Fig. 2. Hydrographs of Bores 48, 110 and 163. All bores are in upper landscape positions, Bore 48 in fractured metavolcanic rock in the Mt. Camel Range in the east, and Bores 110 and 163 in fractured metasedimentary rock in the Pyrenees Range in the west. Since 1997, all three graphs show a lack of seasonal recharge fluctuations along with a significant decline in groundwater level (8 to 13 m decline).

some falls of up to four metres (e.g. Fig. 3), or more. Aside from areas influenced by groundwater abstraction, greater declines in low-lying areas appear more common in two types of area, namely:

(i) alluvial floodplains of unregulated streams where there has been very low flow and little to no flooding since 1997 (e.g. Lower Avon River near Marnoo; Fig. 3, and the Avoca River near Glenloth); and

(ii) in the upper reaches of drainage lines in upland areas.

A good example of the second type of area above occurs west of Moonambel, where an untreated discharge area in the upper reaches of a fractured metasedimentary rock GFS (immediately below Bore 163; see Fig. 2), was from 1982 until 1996 continuously recording artesian pressures of up to 2 metres above ground surface from depths as shallow as 15 metres. Since then, the pressures have dropped considerably and are presently 2 to 3 metres below surface, probably their lowest since well before 1982. Further downstream along the same salt affected drainage line, groundwater declines since 1997 are less, being more in the order of 1 to 2 metres. Burkes Flat in the Avoca catchment (Fig. 7; Bore 6405, upper drainage line, cf. Bores 6401 and 6402 at the lower end of catchment) and the Mount Camel Range in the east of NCV offer two other examples of this pattern of system behaviour.

Observed declines in groundwater levels adjacent to streams, such as described above (also see Fig. 11), have been widespread across many parts of NCV (Reid et al. 2010), with implications for stream flow, as discussed further on.

During the prevailing dry, most NCV discharge areas have continued to record seasonal rises in watertable almost every year, with exceptions (i.e. no or little rise) sometimes in very dry years such as 2002 and 2006 (e.g. Fig. 4 and Bores 6401 and 6402 in Fig. 7). A number of discharge sites have recorded significant and rapid watertable rises in the few occasions when there has been significant rainfall, mostly as a single isolated event, or as sustained, good rainfall over one or two months (e.g. in 2003, 2004 and 2009 in Fig. 4, and late 2004 at Bores 6401/6402 in Fig. 7). In contrast, seasonal watertable rises since 1997 have been rare to absent in upper landscape areas (Fig. 2). Also, the rises when they occur, have usually been muted or delayed (e.g. 1999-2000 and 2004-2005 at Bore 6406 in Fig. 7).

From 1997 to 2009, significant rainfall over one or two months (i.e. of the order of 100 to 200 mm in

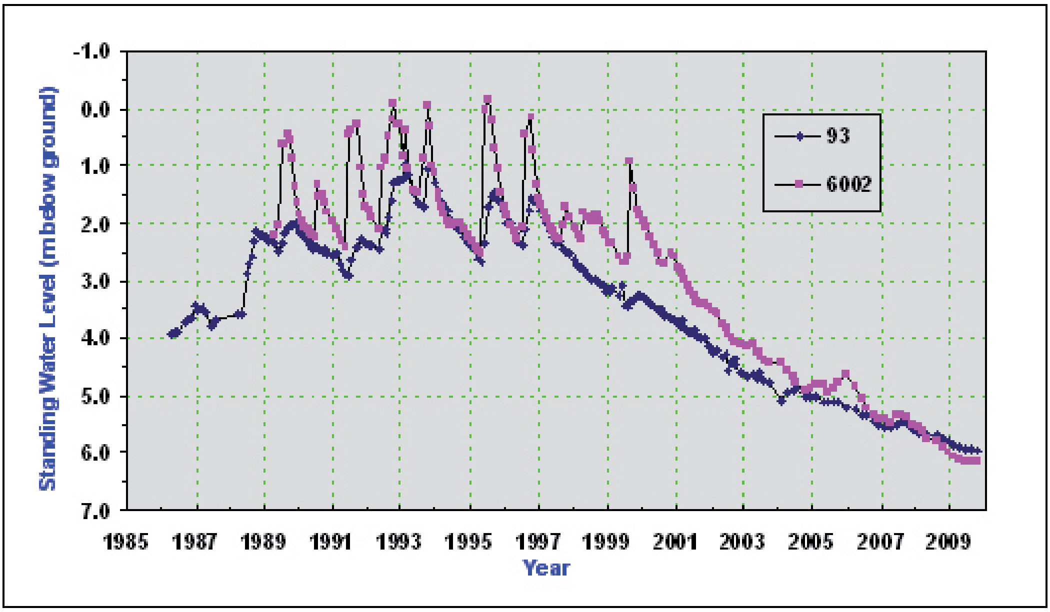

Fig. 3. Hydrographs of Bores 93 and 6002, both located in the salinity prone, alluvial floodplain of the lower Avon River. Both bores display a significant decline of approximately 4 m in groundwater level since 1997. A scarcity of flow (and flooding) in the ephemeral Avon River since 1996 has considerably reduced recharge to the intermediate scale alluvial GFS, quickly lowering the watertable to levels that minimise the salinity threat.

a 400 to 600 mm/year rainfall zone) or one isolated rainfall event of about 40 to 80 mm (sporadic rainfall occurrences have been characteristic of the prevailing dry), have been sufficient to register watertable rises (occasionally significant) under discharge sites and, to a lesser degree, under mid-lower slopes but commonly register little to no fluctuations under the upper slopes of the drier upland areas.

Although significant groundwater level declines have occurred across most of NCV since 1997, there are some cases where levels have only slightly fallen, or remained stable, or even continued to rise. Such exceptions occur in some discharge areas (e.g. Fig. 4), in groundwater depressions or 'groundwater sinks' (e.g. Fig. 5; Bore 175) and/or in larger GFS at distance from recharge (e.g. Fig. 5; Bore 210). The discharge areas may be natural discharge areas that are structurally or lithologically controlled and where hydraulic gradients and recharge remain sufficient to maintain watertables or pressures at high levels in particular parts of the landscape. The observed trends in these areas are usually slightly falling (e.g. Fig. 4) or flat. It is probable that post European land use changes have enhanced the propensity for some such areas to maintain high groundwater levels and degrade.

The few examples of bores in the NCV recording continued rising trends well beyond 1997 occur in groundwater sinks or in intermediate to large scale GFS at distance from recharge (e.g. Fig.5). Groundwater sinks are depressions of significant extent in the watertable or groundwater potentiometric surface. As the name might suggest, groundwater flow is entirely or predominantly towards them and they are characterised by deep watertables or pressures relative to those of the surrounding areas. They tend to occur in low permeability geological strata in areas of lower relief but can also occur in large systems of variable permeability. More permeable strata commonly surround them and/or lie upgradient from them. Recharge is predominantly from lateral flow within the aquifer system or delayed recharge from stream loss rather than from infiltration of rainfall overlying the sinks. Groundwater responses within the sinks are typically very subdued, lacking any semblance of seasonal or cyclical fluctuations. The two hydrograph examples in Fig. 5 show trends that differ from the majority of recorded groundwater trends. Bore 175 is screened in highly weathered, Ordovician age metasediments on the lower slopes of Mt Camel Range. It shows a rising trend from pre-1988 to 2007 and a flat trend since

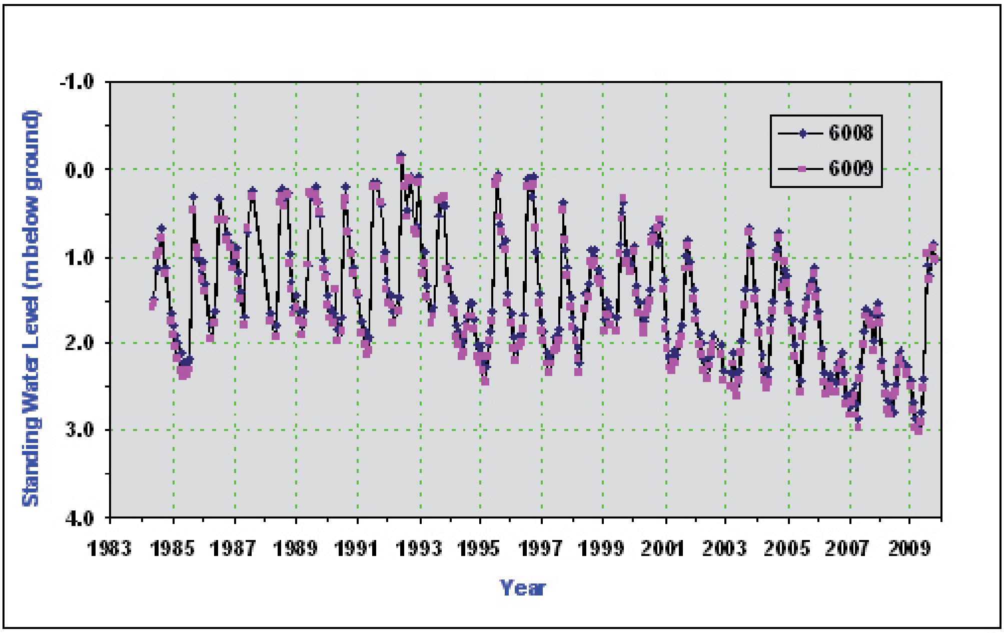

Fig. 4. Hydrographs of Bores 6008 and 6009, at a discharge site near Paradise in the upper Avon-Richardson catchment. An example of a site where the watertable decline has been limited despite post 1997 dry conditions.

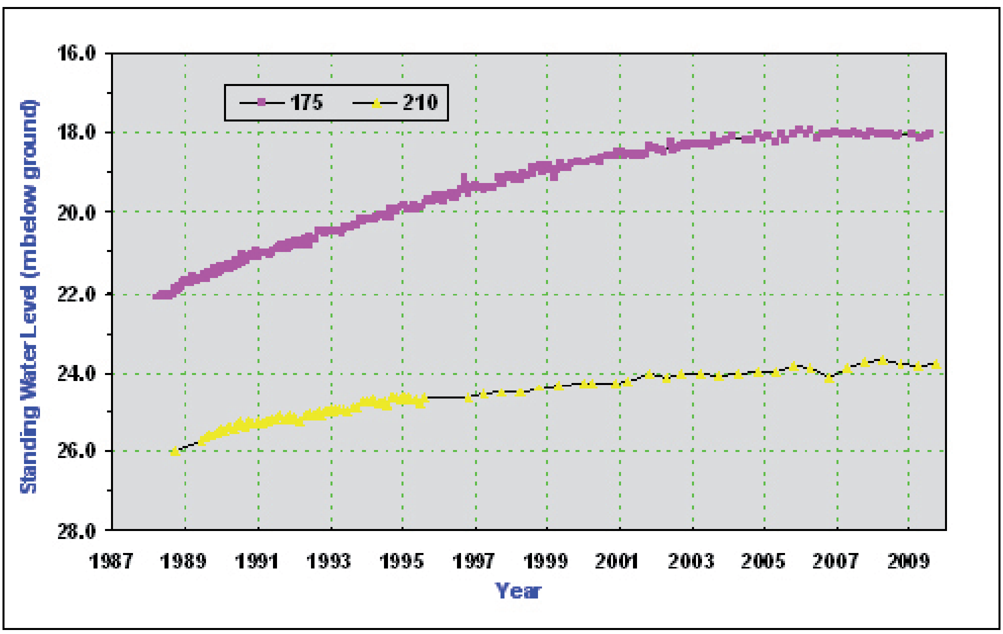

Fig. 5. Hydrographs of Bores 175 and 210. Bore 175 is located on the lower northerly slopes of Mount Camel Range in the Campaspe catchment and is screened in a deeply weathered metasedimentary rock GFS. Bore 210 is located towards the upper reaches of the Avon River in the Avon-Richardson catchment and is screened in clayey gravel, in an intermediate scale alluvial GFS. Both bores demonstrate the subdued groundwater responses that are typical of these GFS where watertables are deep.

2007. The historically elevated pressures in the more permeable Cambrian rocks forming the main range are believed to generate the lateral flow which has continued to slowly increase groundwater storage in the Ordovician rocks some 10 years into the 1997-2009 dry period. The contrast in permeability results in a marked difference in heads and a groundwater depression in the Ordovician. Bore 210 is developed in an alluvial GFS (silty, clayey gravel) and shows a continued but reduced rising trend despite the 1997-2009 dry conditions, suggesting delayed lateral flow recharge driven by historically elevated groundwater pressures in the upper Avon catchment.

Land use change has also had an impact on watertables in the NCV but has not often been clearly demonstrated. One locality where it has been is Burkes Flat in the Avoca catchment (Reid 1995). Here, whole of catchment treatment established between 1983 and 1985 incurred a significant lowering of watertables between 1983 and 1992 during a relatively wet climate cycle, particularly where perennial pastures of Lucerne and *Phalaris* were established (Figs. 6 and 7). Figure 6 shows a plot of cumulative mass winter rainfall expressed as a bar graph together with comparative hydrographs of two bores; Bore 6412 on treated (Lucerne) lower slope and Bore 6416 on untreated lower slope. The difference in watertable impacts between the treated and control (6416) sites is clearly evident, especially in the first few years. The drawdown observed between 1984 and 1992 in Bore 6412 and other treatment area bores (Fig. 7; e.g. Bores 6405 and 6406) was during a relatively high rainfall period as indicated by the upward bar graph trend, supporting the view that salinity treatment was the main driver of watertable decline in the Burkes Flat pilot area during this period. However, since 1996/97, the watertable declines experienced within and outside the pilot area are more likely to be mainly due to the drier climate. Since then, land use impacts have been minor due to much lower overall plant water use brought about by a change to mixed cropping and grazing plus drought induced decline in plant growth. The lack of seasonality in the hydrographs since 1996/97 is indicative of the lack of recharge.

The potential of specific targeting of perennial vegetation to achieve significant watertable drawdown is very well demonstrated south of Lexton in the upper Loddon catchment (Figs. 8 and 9). Here, a lower landscape blue gum plantation established in 2000/01 surrounds approximately two-thirds of a moderately large (approx. 5 ha), salt-affected discharge area in a weathered, fractured sedimentary rock GFS. Since establishment, the watertable under the salt-affected discharge site has dropped from within 1 m of the ground surface to greater than 6 m depth (Fig. 5, Bore 5090). In comparison, all other monitored discharge sites in the Lexton area (approximately six in number) record watertable levels that are still no deeper than 3 m (e.g. Bore 5298, Fig. 8). Bore 255, situated on the upslope boundary of the plantation has recorded a fall in watertable of approximately 10 m since 2000/01, along with an associated reduction in seasonal fluctuations since 2000/01. This fall and behavioural change contrasts markedly with other bores in Lexton pastoral country (e.g. Fig. 9 compares Bore 255 with Bore 253). Comparing watertable responses at the plantation to those in non-treed but otherwise similar locations, it appears that both climate and plantation water use have significantly contributed to the observed fall in watertable at this location since 2000/01 (Figs. 8 and 9).

Groundwater declines are of course also influenced considerably in some areas by groundwater abstraction for agricultural industries. Figure 10 shows an example of pumping induced impacts on groundwater levels, in this case in the alluvial GFS in the mid Loddon Plains. The pumping impact has been accentuated by the lack of recharge since 1997. This is discussed in the next section.

DISCUSSION

Analyses of trends against climate data indicate that climate pattern has had a strong influence on groundwater level trends and the current groundwater deficit in NCV (e.g. Gill 2004; Cheng et al. 2006; Mudd et al. 2006; Reid et al. 2006). However, while less significant overall, some land uses/practices can also be demonstrated to contribute to falling watertables, for example, perennial pasture (e.g. Figs. 6 and 7), tree plantations (e.g. Figs. 8 and 9), and groundwater abstraction for agricultural industries (e.g. Fig. 10). Results demonstrate that significant watertable impacts are possible over short timeframes from climate or land use change (Figs. 2-4 and 6-9). Whilst impacts in the latter case, at least in upland areas, may not extend very far from the planted/treated area, it appears that direct control, at least in upland areas, can be exerted on the watertable in most landscape locations where appropriate planting occurs, including discharge areas (e.g. Figs. 6-9).

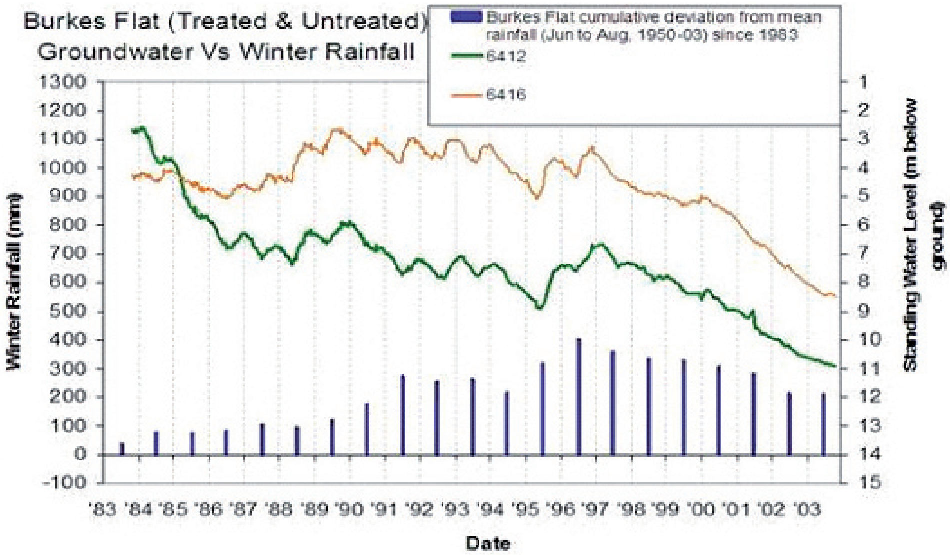

Fig. 6. Hydrograph of comparative groundwater levels in treated (Bore 6412) and untreated (Bore 6416) areas of the Burkes Flat pilot salinity treatment area (first established 1983), northern Victoria, together with a bar graph showing cumulative deviation from mean winter (June to August) rainfall at Burkes Flat (after Reid et al. 2006). The GFS is weathered, fractured metasedimentary rock.

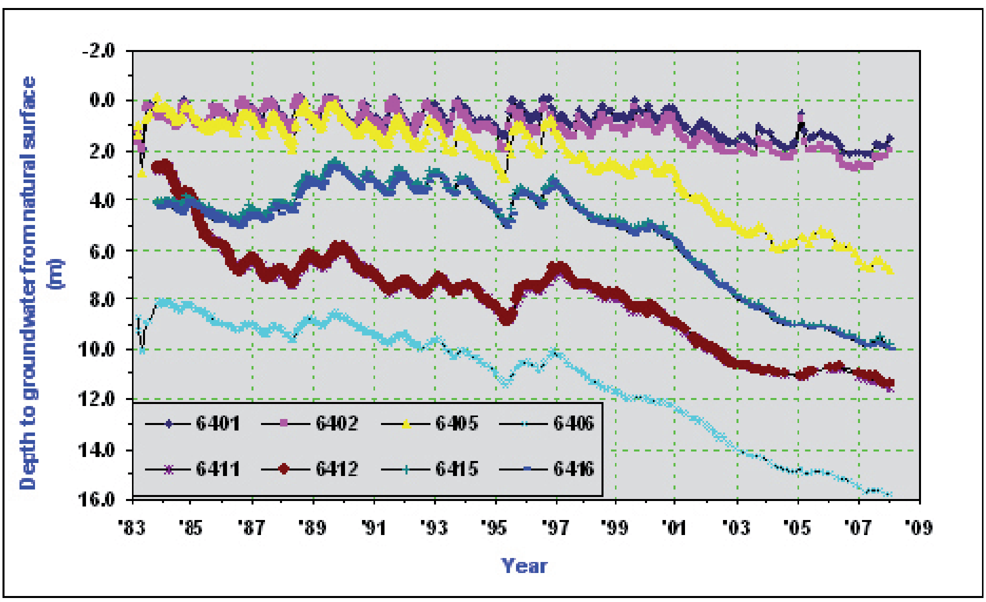

Fig. 7. Hydrographs of bores in the Burkes Flat pilot salinity treatment area, in the Avoca catchment. Bores 6401, 6402 and 6405 are located within the salt-affected drainage line with 6405 being in the upper reaches. Other bores are located in lower or mid slope areas. Nested control bores 6415 and 6416 are located outside the original pilot treatment area.

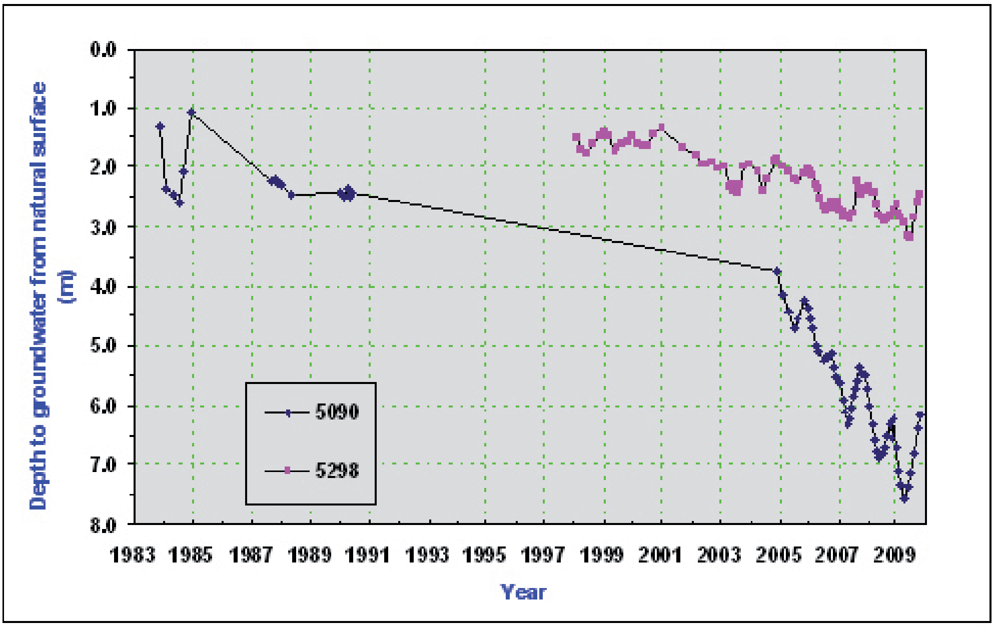

Fig. 8. Hydrographs of Bores 5090 and 5298, near Lexton, in the upper Loddon catchment. Both bores are screened in weathered, fractured sedimentary rock and are located in salt-affected discharge areas. Bore 5090 is adjacent to a blue gum plantation established in 2000-2001, and Bore 5298 is in pastoral land. Despite incomplete record, the marked differences in response since 2004 suggest that the plantation has a significant watertable impact.

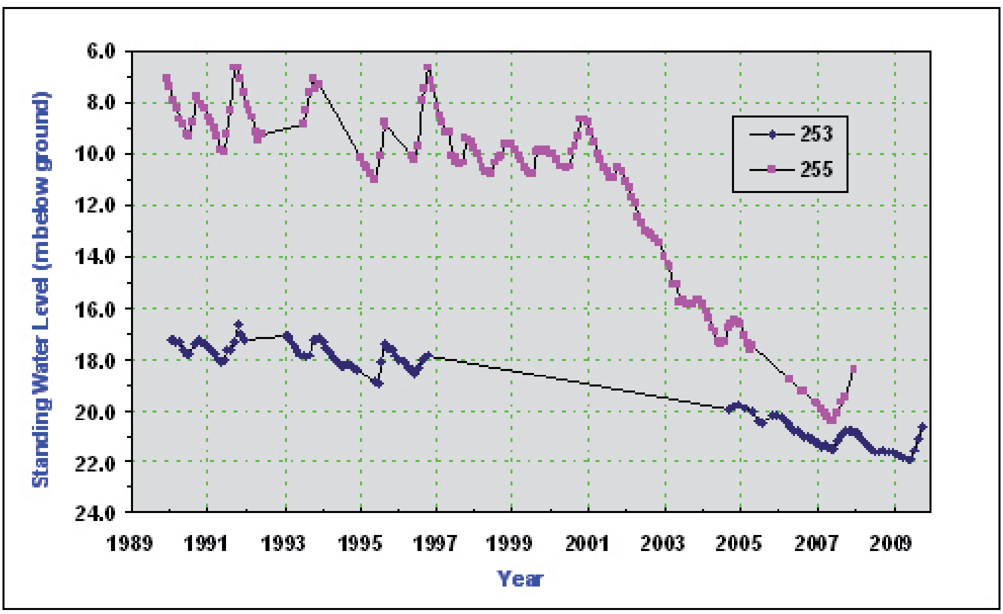

Fig. 9. Hydrographs of Bores 253 and 255 near Lexton (refer also to Fig.8). These are screened in weathered, fractured sedimentary rock in mid to lower slope locations. Bore 255 is located on the upslope boundary of the same blue gum plantation referred to in Fig.8. Comparing its response to that in Bore 253, located in pastoral land, it demonstrates the significant localised influence of the blue gum plantation on the watertable.

Significant contrasts in groundwater responses have been identified between discharge areas and upper landscape areas since 1997 (e.g. Figs. 2-4 and 7). The behavioural contrasts can be summarised as the upper landscape areas recording generally much fewer recharge fluctuations and greater drawdowns than the discharge areas. The extent of the contrasts and the reasons for them will vary from location to location and GFS to GFS but two primary causes or factors could be:

(i) Greater watertable depths in upper landscape areas; this means there is potentially a greater buffer to recharge. This would be enhanced with drying and deepening of the thick unsaturated profile caused by a lack of significant rainfall. So, during extended dry periods, there is little water reaching groundwater storage in contrast to discharge areas, which have shallow watertables with a much smaller buffer to seasonal accessions, even from limited rainfall. However, a return to prolonged wetter conditions would see many of the high landscape areas regain their high recharge status.

(ii) Groundwater flow and direct recharge to discharge areas exceeding evaporation in winter months; despite declining groundwater levels and reduced hydraulic gradients, groundwater flux and local recharge can be sufficient to override evaporation or seepage losses and thus cause a seasonal watertable rise under a discharge site. In some cases, particularly where governed by large scale processes and/or structural control, watertable levels may only slightly fall or even remain fairly stable during dry climate cycles.

In regard to the second point above, at least for most smaller scale GFS, it is argued that groundwater fluxes in a depleting GFS continue to influence the seasonal base level of watertables under discharge sites but are not sufficient to fully generate (or explain) the observed seasonal rises. These are interpreted to be often primarily caused by localised recharge. In the upland areas, it is commonly observed that the seasonal rises under discharge sites vary in magnitude and timing from year to year, including the driest years (e.g. Fig. 4, Bores 6401 and 6402 in Fig. 7, and Fig. 8). These rises correlate closely with periods of relatively significant rainfall at times of low evaporation. Consistent with this is that in areas proximally upgradient from the discharge sites, the groundwater record since 1997 often reveals short time lags in the start of the rising limb, indicating a delayed reaction compared to the discharge site watertable. As well as suggesting that climate influence is a function of watertable depth, this also suggests that many discharge sites behave as though disconnected from the rest of the GFS in respect of their seasonal dynamics and recharge. The lower the permeability, the more apparent is this disconnection. Such behaviour has probably been accentuated in recent years by the substantial groundwater declines in the upper landscape and concomitant reduction of the hydraulic gradient. It is postulated that this has caused the seasonal base level of the watertable in the discharge areas to fall lower. Many discharge areas are located part way along a GFS, not just at the bottom end; these have tended to record greater watertable declines due to throughflow losses (e.g. Bore 6405 cf. Bores 6401 and 6402 in Fig. 7).

Given the extent of the groundwater declines, it can be presumed that upper landscape areas will now require significant effective rainfall over a long sustained period (say, for example, 400 to 600 mm over six months, rather than 200 to 300 mm) to register significant watertable rises following such a long dry period. NCV in many ways is representative of the typically harsh Australian landscape, a landscape that has adapted to irregular rainfall patterns and long dry spells. At least some landscapes, including floodplains, respond to the drying-up, together with the extremes of temperature, by creating more pathways and available storage for reception of infiltrating water when excessive rainfall conditions eventuate. This could mean that rainfall in the order of 400 to 600 mm in six months, as has occurred in the latter part of 2010, may be sufficient in many cases to return watertables under discharge sites to mid or late 1990s levels and significantly raise watertables under upper landscapes to perhaps within 5 m of the 1996 levels. This may prove to be the case in 2010, which has delivered record rainfall to parts of NCV.

Groundwater levels have dropped substantially in a relatively short time period in both upper and lower landscapes, whether in response to climate, perennial vegetation or groundwater pumping. Anticipation of the magnitude and extent of these groundwater declines was not really possible, as there was no benchmark groundwater data set to predict the effects of such a dry period. The 1997-2009 dry climate period is unprecedented since statewide groundwater monitoring began in the 1960s (and monitoring only really became widespread in northern Victorian dryland regions in the 1980s). Nevertheless, the observed de-

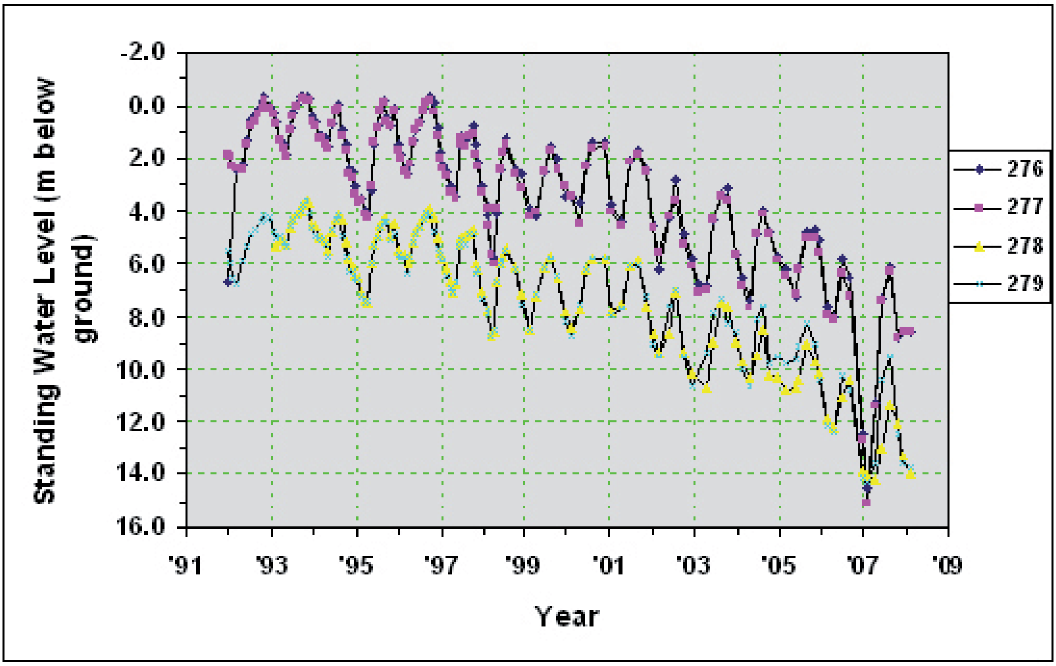

Fig. 10. Hydrographs from two nested bore sites near Serpentine, in the Mid Loddon Water Supply Protection Area, Loddon catchment. These provide an example of the impact of groundwater pumping during the 1997 to 2009 dry climate period. The seasonal pumping induced drawdowns generally are not severe, so the lack of recharge is also contributing to the observed groundwater decline in this regional alluvial GFS.

clines (e.g. Figs. 2, 3, 6-10) indicate generally greater GFS responsiveness and much shorter timeframes for substantial hydrologic shifts than have been predicted or implied for GFS (e.g. NLWRA 2001; Walker et al. 2003).

There are interesting implications that can be drawn from the groundwater responses, two of which are described briefly here. Firstly, the groundwater responses suggest that it is possible to significantly alter the hydrologic balance of local to intermediate scale GFS within a decade, and also that climate or perennial vegetation can induce significant but localised watertable shifts in some locations within regional scale GFS in similar timeframes.

Secondly, the data imply that widespread or whole-of-landscape land use change is not an essential requirement for successful, sustained salinity management within a GFS or salt-affected area. Rather, in most cases, it may only require specific targeting of a minor proportion of the landscape, including the discharge area(s), and/or a particular environmental asset.

The extent and magnitude of groundwater declines has impacted considerably on water security, both in terms of surface water and groundwater resources. Groundwater is inextricably linked to surface water (Winter et al. 1998; Brodie et al. 2007; Reid et al. 2009) and, so, decline in groundwater levels of aquifers connected to streams can significantly alter the hydraulic relationship and exchange of water between the two media. A stream that receives water from an aquifer is termed a gaining stream; this means that a hydraulic gradient slopes towards the stream (Winter et al. 1998). It is possible for climate or groundwater abstraction influences to alter this relationship in stages so that initially flow to the stream is reduced, followed by reversal of the hydraulic gradient causing loss of water from the stream to the aquifer, and eventually (if conditions allow), disconnection of the stream from the aquifer (i.e. the watertable falls below the stream bed) (Winter et al. 1998; Brodie et al. 2007; Reid et al. 2009).

Through examination of time-series data from bores close to streams in NCV (Reid et al. 2010), it was found that significant watertable declines have occurred along a number of streams. The occurrences have been widespread but are particularly evident in floodplains of unregulated streams that have experienced consistently low flows since 1997 (e.g. Fig. 3) and in the upper to middle reaches of upland streams in bedrock dominated catchments (e.g. Fig. 11, and Bore 6405 in Fig. 7, although the latter example is in a salinity context and so is seen more as being a beneficial result). Together with anecdotal and first-hand observations in NCV, the groundwater data indicate that there has been a marked reduction in base flow to gaining streams to the extent, in many cases, that they have periodically dried or stopped flowing and become flashy in their behaviour, being unable to sustain flow for long durations. It is possible in some cases, though unverified, that hydraulic gradient reversals or disconnections have occurred.

Reductions or cessations of stream flow due to groundwater decline may actually be considered more beneficial in some salt affected catchments, particularly in middle to lower parts of NCV (e.g. Burkes Flat, Figs. 6 and 7; Mt. Camel Range) but would be considered more harmful in upper parts, or other areas where low salinity groundwater normally feeds streams.

Groundwater declines in recent years have affected all types of groundwater users, especially those tapping shallow sources. Close control of seasonal groundwater withdrawal has been required in a number of groundwater management areas (GMAs) in NCV in recent years. This is due to acute declines in groundwater levels (e.g. Fig. 10) and the lack of certainty about consequential environmental impacts related to connectivity of aquifer systems with surface systems, or about the total storage and resilience of the aquifer systems. Drawdowns similar to and greater than that shown in Figure 10 are due to a combination of the lack of recharge and the increased demand for groundwater. The managed aquifer systems in NCV are mostly intermediate to large scale alluvial GFS with some basaltic GFS in the upper Loddon catchment. Effective recharge to these systems is dependent on good rainfall in the upper parts of NCV (Note: this is possibly restricted to some degree by interception by farm dams), and more dependent

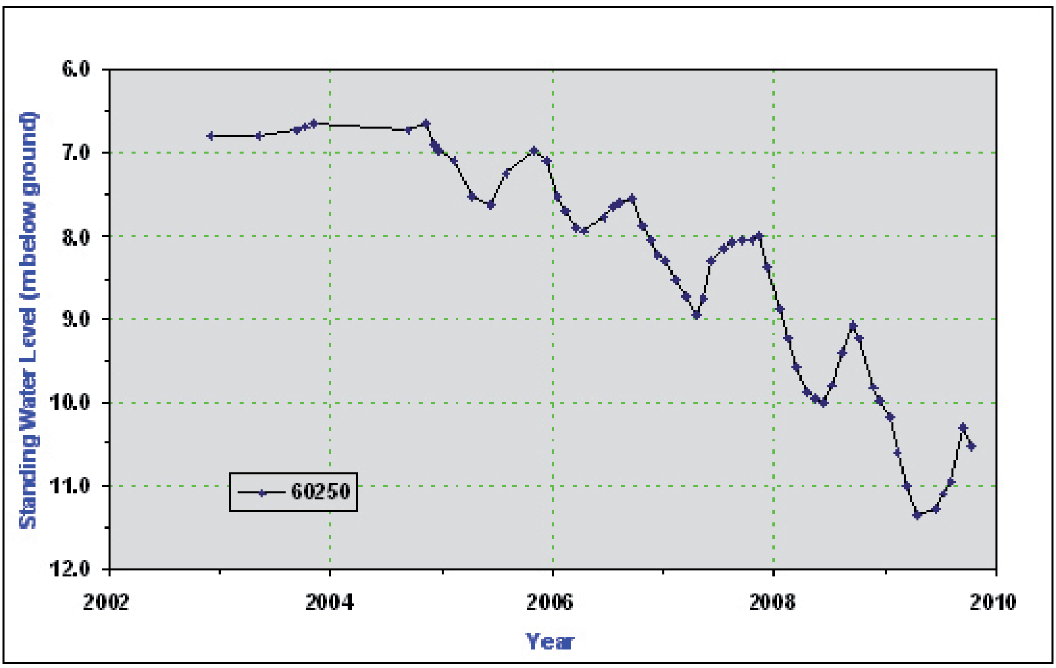

Fig. 11. Hydrograph of Bore 60250 in the upper Burnbank Creek area, south of Lexton, in the upper Loddon catchment (approx. 2.5 km south-east of Bore 255; refer Fig. 9). The bore is screened in fractured metasedimentary rock and its groundwater response is an example of the kind of shifts in groundwater level that could be adversely impacting stream flow in the upper reaches of some upland streams.

on flooding in middle to lower parts such as the Mid Loddon Water Supply Protection Area (Fig. 10). This area has previously recorded substantial groundwater level rises in response to flooding (e.g. 1973-75 and 1983; Macumber 1991). However, there has not been much significant flooding since 1989 and Loddon River flows have been generally low since 1996. Hence, there has been little recharge to the alluvial aquifers in lower catchment areas such as this, including the Campaspe catchment. This situation has exacerbated the drawdown impacts of groundwater pumping in these areas. While it is undeniable that GMA aquifers are presently depleting and that a conservative management approach is needed, the extent to which they are depleting or threatened is uncertain. This is due to lack of definitive knowledge about aquifer storage, recharge, connectivity and resilience. Knowledge of aquifer resilience is difficult to determine from the available groundwater record because the aquifer system recovery or rebound from the previous pumping season has been repeatedly interrupted by the start of the next pumping season (Fig. 10).

Outside the existing GMAs, there may be some other areas that have experienced substantial climate and pumping induced groundwater drawdown. These could include some upper catchment areas in fractured bedrock, alluvial or basaltic GFS (e.g. Fig. 11). Such areas are critical in terms of supply of good quality base flow to the main streams. There is potentially a risk that continued unconstrained use of groundwater, where significant, will cause long-lasting deleterious impacts on stream flow.

CONCLUSIONS

Good quality time-series data show that substantial groundwater declines have occurred during the period from 1997 to 2009 in a number of GFS across most of NCV, especially in upland areas. The evidence indicates that these declines are primarily induced by the dry climate pattern prevailing in that period, with land use and groundwater extraction playing a subordinate, but not insignificant, role overall.

Notably affected GFS include some that have been regarded in the context of salinity management as ‘slowly responding’ systems (e.g. deeply weathered and weathered, fractured metasedimentary rock GFS, intermediate alluvial GFS) where, according to commonly held expert opinion of recent years, decades or even centuries (of intervention) are needed to substantially alter the balance, or restore the ‘original balance’, the knowledge of which is poor. This view may now be changing.

It is concluded that most GFS in NCV are very responsive to changes in climate and vegetation cover. This is particularly the case in upland areas where GFS typically operate over smaller scales (mostly local to intermediate), and have low storage capacities and relatively steep hydraulic gradients. Although less obviously responsive, regional scale alluvial GFS and large scale, low permeability GFS have also registered some significant changes in their hydrologic status over the 1997-2009 period. In the case of the alluvial GFS, however, groundwater abstraction has contributed considerably to this.

It is further concluded that generally only small timeframes (i.e. of the order of two decades or less) will be needed to favourably alter the hydrologic balance of GFS for salinity control, or to control watertables under salt-affected areas of GFS. Another conclusion, which requires further testing, is that significant and sustainable beneficial impacts are possible within local parts of a GFS, regardless of its scale, without the need for treatment over all or most of the system. A blue gum plantation south of Lexton, in the NCV, is regarded as an excellent example of this possibility in a local flow system (see text and Figs. 8 and 9). Provided that salinity treatment compulsorily includes appropriate treatment of the salt-affected discharge areas themselves, it is considered that only a minor additional proportion of the landscape within a GFS will need to be targeted specifically to achieve the desired salinity management outcomes.

An alternative concept is put forward whereby salinity incidence and severity is dynamic, cyclically advancing and retreating with climate pattern (and to a lesser degree land use activities) over decadal or longer periods, not steadily increasing as has been previously widely thought in Victoria. There are further implications, not explored in this paper, that relate to the pre-European incidence of salinity, or primary salinity. The incidence of primary, or natural, salinity (or at least natural groundwater discharge) may be greater than presently recognised and correlate strongly with structural and lithologic controls (including faults, geological formation boundaries). It is quite possible that a significant proportion of salinity degradation is due more to the disturbance of natural discharge areas than clearance of adjacent landscapes.

The groundwater record, especially since 1997, shows widespread evidence of significant and dramatic changes in groundwater storage and recharge distribution over short timeframes. The post 1997 changes have had significant effects on water security, not only affecting groundwater resources but also altering the dynamics of groundwater-stream interaction, hydraulic gradients and base flow, thus contributing to observed reductions in stream flow and altered stream behaviour right across NCV.

The spatial distribution of recharge has noticeably altered between 1997 and 2009. Very little recharge (and very few recharge events) and greater throughflow losses have been registered in the higher landscape areas, while small to moderate amounts of recharge have occurred on a more or less seasonal basis in many lower landscape areas with high watertables, mainly in the middle to lower parts of GFS. As a consequence, groundwater declines have been greater in upper landscape areas and/or upper reaches of GFS, including some prior high watertable/discharge areas. On available evidence, this is likely in some cases to have been exacerbated by plantations or by groundwater abstraction causing further reductions in base flow to streams and affecting stream health and water security.

While watertable reductions have produced desirable results in terms of salinity management, there is a concern that lack of management controls on plantations and groundwater pumping in some upper catchment areas may lead to long-lasting deleterious impacts on stream flow.

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LANDSCAPE RECOVERY - COMMUNITY RESILIENCE IN THE FACE OF BUREAUCRACY

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Victorian bureaucracies have been engaged in landscape scale restoration and conservation projects over the past decades. More recently this has been in partnership with local communities. Over time priorities of government agencies change but the concerns of local communities often remain the same. Communities can become very frustrated when agencies step back in after a long absence and assume control, dictate actions and take the credit. Agency action can be bogged down in cumbersome, time consuming and expensive approval processes, whilst necessary works remain to be done. The newly formed Wedderburn Conservation Management Network is a case study. The local community has continued to fight for the recovery of the locally declining Malleefowl population over many decades whilst government involvement in the battle has been sporadic, mostly in response to community pressure. The Wedderburn CMN has tapped into the residual community concern for the Malleefowl and in a healthy partnership has achieved excellent results, with the land area under public and private conservation management now more than 25% larger and the Malleefowl is population increasing.

Keywords: landscape, Malleefowl, community, restoration, Wedderburn

LANDSCAPE restoration is a relatively new concept in this part of the world. Landscape scale protection has a longer history. Some of the most successful examples of both in recent times have involved an honest partnership between community, Government and Non-government Organisations. However sometimes bureaucracies behave as if they are the sole custodians and the sole keepers of knowledge.

Since the 1950s there have been numerous Government Programs aimed at helping private landholders and communities. But despite this community groups continue to survive and even flourish. These include: soil conservation groups**,** rabbit action groups, farm tree groups, land protection groups, wildlife sanctuaries, farm advance groups, Rabbit Free, Project Branch-out, friends groups, advisory groups, Land for Wildlife, Landcare, NHT, NLP, Caring for our Country, conservation management networks.

Communities have long interacted with Government agencies – Conservation Management Networks (CMNs) in the Box-Ironbark area are a new way of allowing this to happen. CMNs are a formal partnership between government and non-government agencies involved with natural resource management issues and interested members of the local community. The results have been encouraging on many fronts with thousands of hectares revegetated and land management improved. This is however just the latest phase in the evolution of this relationship demonstrating that communities persist despite the scatty and short-term programs of Government agencies.

CMNs now exist in Wedderburn where the focus is on Malleefowl Broken Boosey and the recovery of Bush Stone-curlew *Burhinus grallarius*; Whroo CMN works on the Brush-tailed Phascogale *Phascogale tapoatafa*; Mid Loddon CMN also on the Bush Stone-curlew and Mitiamo CMN on Northern Plains Grasslands. These are a new version of community members with Government agencies working together at a landscape scale.

This is a story of the Wedderburn area. Wedderburn is about 80 km from Bendigo in north central Victoria. The Wedderburn CMN was formed in September 2003. It consists of representatives from the Department of Sustainability and Environment (DSE), Parks Victoria (PV), Loddon Shire, the North Central Catchment Management Authority, Bush Heritage Australia, Wychitella Landcare Group, Friends of Wychitella, interested farmers and other local community members.

The Wedderburn CMN statement of purpose is to work with the local community to protect and replenish the landscape by supporting the restoration of biodiversity and sustainable land management.

In the 1950s and 1960s large tracts of land were cleared, as was the custom of the time. At the same time there was also a battle going on over the Little Desert area, which had been proposed to be cleared for farming. A local farmer there stood up against that development and won, the development was stopped and the area eventually became a National Park.

In Wedderburn a group of local people lead by Bob Johnson was formed to stop the clearing in the Wychitella area. This was a traditional community group formed to fight for something against Government decisions. The group called the Wychitella Forest Preservation Society, consisted of locals and naturalists from elsewhere including Melbourne. Their main concern was the plight of Malleefowl that was in decline in their area. They succeeded in 1973 in having approximately 1400 ha declared as Forest Park, for conservation purposes. They held an annual barbeque for $2 per head to celebrate and 'see the bush at its glorious best'.

After this Bob Johnson continued his work talking to school groups and others into the early 1980s. The students he spoke to then would be now in the age group from late 30s to early 50s. It was therefore no surprise that when the newly formed Wedderburn CMN requested people to volunteer to conduct a line search to look for Malleefowl mounds some 60+ people came out on a freezing weekend to walk through dense bush on the Malleefowl mound search. Many also turned up for a talk by researcher Joe Benshemesh.

WHAT HAS HAPPENED SINCE THOSE DAYS?

The Wedderburn CMN was formed in 2004. It continues to run barbeques and other community events just as did the Wychitella Forest Preservation Society. Perhaps most significantly the CMN invited Bush Heritage to come and look at some good quality conservation land that was up for sale in the area. The owner of the land however wanted to be sure he was not selling to a dud landowner who would be a poor neighbour that let weeds and rabbits run rampant. After protracted negotiations and a thorough investigation by the owner the sale went through. A year or so later, the landholder had seen the good conservation work that Bush Heritage had done and sold a second block to them. And after that another neighbour sold them a third block.

Following on from this a new organisation called Greenhouse Balanced became involved by the invitation of the CMN. This is a greenhouse offset private company that is contracted by other companies and agencies to plant trees to offset their carbon emissions.

Greenhouse Balanced benefited from the goodwill generated by Bush Heritage in the area and was approached by other landholders to sell poorly productive land for revegetation.

When the Wychitella Forest Protection Society won their first victory in 1973, 1400 ha was preserved for conservation purposes. Today, following the involvement of the CMN, Bush Heritage and Greenhouse Balanced, there is now 7890 ha of land managed for conservation of which 2710 ha is private land.

A member of the Wedderburn CMN also has discovered a new population of the nationally endangered Spiny Riceflower, *Pimelea spinescens* subsp. *spinescens*. This discovery extended the current known range of the plant. Group members have also undertaken planting of other endangered plants.

The group continues to work with school students as did Bob Johnson's Wychitella Forest Preservation Society in the hope that the baton is passed to the next generation.

The CMN Ranger Wendy Murphy has been baiting for fox control since 2004. Malleefowl tend to be less susceptible to fox attack once they have reached adulthood, so the CMN decided to undertake fox baiting for extended periods during breeding, incubation of the eggs and for the first year of life of young chicks.

It has been difficult to trace the success of this program to date but one pair of juveniles was seen in 2007 attempting to construct a nest. These were both believed to have hatched since baiting commenced so we claim them as a success.

Another initiative of the CMN was the release of two juvenile birds into the North Central Region (NCR). These were captive reared birds from eggs salvaged after a bushfire in the mallee. The results were not great with one radio tracking device failing after 10 days and one bird dying from starvation after it failed to forage. It should be remembered that this is a species whose chicks normally have a tiny survival rate in the wild.

This release raises the issue of just whose Malleefowl are they? DSE claims they are theirs and should have total control over any recovery actions. PV also wants total control over any actions for the species on land they manage. Yet the population would probably not exist today but for the actions of the local community. DSE and its predecessors have done nothing towards recovery other than an occasional monitoring effort. In the relatively short time that PV have managed the land they likewise have done little other than short-term good neighbour fox baiting, which, by definition, is targeted at appeasing neighbours not fauna protection. DSE initially opposed the release of the Malleefowl on trivial technical grounds ignoring the lessons of the past that it is local communities such as these that are sometimes the true custodians. It is they who will continue to act when government agencies will chance with the current political whim.

Despite this there remains a small but dedicated group of CMN community members continuing to fight for the future of the species. They continue to plant endangered plants and organise events. And will no doubt be doing so in another 40 years long after CMNs are a long forgotten government program.

What of the Malleefowl, the cause of all this trouble. When the Wychitella Forest Protection League was first successful in having a 1400 ha block protected for conservation there was believed to have been seven active mounds in that protected patch. Today there are none. However throughout the NCR there are currently the highest number of breeding pairs for many years and for the first time probably since the gold rush their numbers are not declining but increasing.

This story is about how one community has persisted since the 1960s in its determination to protect their local environs and a threatened species. They continue despite long history of Government short-term programs with periods of inaction and occasional hindrance. How long will the current DSE interest in CMNs continue in this area? Whatever the answer, the local community will persist and continue their interest. This is likely a common story for communities and groups. We should all be grateful that they continue to outlive Government initiatives.

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A SHORT HISTORY OF THE CULTURE AND NATURE OF WATER IN VICTORIA'S NORTH

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Visions pursued by settlers and policy makers as they interpreted and interacted with the northern plains of Victoria have centred on the provision of a guaranteed water supply. This summary highlights how past practices have shaped contemporary attitudes to water.

Keywords: drought, northern plains of Victoria, irrigation, climate change

Myriad interactions testify to the conflict between human dreams and environmental actualities – how people have exploited the opportunities and minimised the challenges thrown up by environmental variability on the northern plains of Victoria. In a time of human-induced climate change, how people and country have co-evolved to make the current landscape of the northern plains can tell us much about human and ecological adaptation to a variable rainfall.

It is evident that dominant visions for the plains country have relied on imagining the country for what it can *become* rather than seeing it for what it actually *is*. Technological and scientific innovations to deliver an irrigation supply, for example, have relied on taking water from an ecosystem whose health is now seriously at risk. Paradoxically, as cultural reactions have sought to downplay uncertainty on the northern plains, 'hazard risks' have been amplified and the reputation of the plains as a place of capriciousness has been entrenched. As Les Heathcote argues (1980), official policies in Australia's arid lands have encouraged 'the transformation of the variety of the original ecosystems into commercially productive and simpler ecosystems. The results have been an increased ecological *and* economic vulnerability.'

The bureaucracy of government at the municipal, state and national level has built on the idea of uniformity, and official visions continue to rely on scientific definitions, economic delineations and technological innovation to manage environmental issues. Local experience is often ignored, overlooked, or considered only at the periphery by successive governments intent on remaking the landscape according to the rulings of the day.

But a different way of understanding local ecologies, especially critical in this current period of climate change, is to tap into the vast resource of knowledge held by the people who live there. Genuine adaptation, Donald Worster writes (1982: pg ref), 'comes from having a sense of place, which is at once a perception of what makes a piece of land function as it does and a feeling of belonging to and sharing in its uniqueness.' Surely a true ecological perspective can only be gained by embracing the dynamic nature of not only natural ecosystems but also that of human communities.

In a drying climate, inclusion of local experience is vital if responses to the issues of water allocation on the semi-arid northern plains are to be meaningful. Embracing local historical knowledge in the protection and restoration of the country of the plains provides the best opportunity for the environment to adapt. Seeking local interpretations of how water supply schemes have created the current social order is imperative.

History shows us that myriad settlement programs, water schemes and economic and political strategies have not brought the certainty they planned for because they have asked too much of the country. It is clearly evident that a new way of envisioning the semi-arid northern plains of Victoria, and places like it, is needed.

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DIEBACK OF RIVER RED GUM ALONG THE VICTORIAN MURRAY RIVER FLOODPLAIN

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Cunningham, S.C., Thomson, J.R., Mac Nally, R., Read, J. & Baker, P.J., 2010. Dieback of River Red Gum along the Victorian Murray River floodplain. *Transactions of the Royal Society of Victoria* 122(2): lxxxi. ISSN 0035-9211.

Regulation of the Murray River has reduced the frequency and duration of floods, and has lead to a substantial decline in the condition of river red gum forests. If the condition of these important forests is to be effectively monitored and managed, a quantitative and efficient assessment procedure is required. This study shows that stand condition can be mapped accurately over the floodplain of a major river system - the Murray River in Victoria. The ability to estimate stand condition across the floodplain allowed us to quantify the role of groundwater in driving the dieback of these forests.

Key words: groundwater, floodplains, forest dieback, salinity, vegetation condition

The high productivity and biodiversity of river red gum (*Eucalyptus camaldulensis* Denh.) forests is dependent on surface flows and groundwater. Regulation of the Murray River has reduced the frequency and duration of floods, and has lead to a substantial decline in the condition of these forests. If the condition of these important forests is to be effectively monitored and managed, a quantitative and efficient assessment procedure is required. We showed that stand condition can be mapped accurately over the floodplain of the Murray River in Victoria (Cunningham et al. 2009). A combination of extensive ground surveys, remotely sensed data and modelling methods was used to predict stand condition across the floodplain at the time of the survey and in the past. Forest dieback was estimated to have increased dramatically from 45% to 70% of the floodplain between 1990 and 2006.

The ability to estimate stand condition across the floodplain allowed us to quantify the relationship between groundwater and forest dieback. Accurate groundwater data (depth and salinity) over a 20-year period were obtained for 289 bores and summarised using non-linear regression. Groundwater depth and salinity were strong predictors of stand condition (Cunningham et al. in press) In the upper Murray, where groundwater is predominantly fresh (<15 µS/cm), dieback increased with increasing groundwater depth. In contrast, the condition of stands in the lower Murray improved with increases in groundwater depth due to its high salinity (>30 µS/cm). This suggests that changes in groundwater conditions could be used to signal areas vulnerable to forest dieback and prioritise the limited water available for managed flooding. Stand condition declined even under favourable groundwater conditions, emphasising that only increasing the frequency of flooding will mitigate dieback of these floodplain forests.

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MAMMALS IN NORTH CENTRAL VICTORIA: THEIR RECENT HISTORY AND FUTURE PROSPECTS

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Menkhorst, P., 2010. Mammals in north-central Victoria: their recent history and future prospects. *Transactions of the Royal Society of Victoria* 122(2): lxxxii-lxxxiv. ISSN 0035-9211.

The fate of the mammalian communities of south-eastern Australia remains largely unknown and unrecorded. I review historical knowledge of mammal species in north central Victoria, assess their current conservation status in the region and speculate on their future prospects.

In recent decades the decline of bird communities in the drier open-forests and woodlands of south-eastern Australia has rightly received considerable scientific study and public concern (e.g. Mac Nally et al. 2009). In contrast, the fate of the mammalian communities remains largely unknown and unrecorded. Here I review historical knowledge of mammal species in north central Victoria (defined as the Land Conservation Council of Victoria's North Central and Murray Valley Study Areas), assess their current conservation status in the region and speculate on their future prospects.

The primary source of information used is the Atlas of Victorian Wildlife (AVW) database compiled and managed by the Department of Sustainability and Environment. Information from the AVW was supplemented with records from the historical literature, beginning with Blandowski (1855) and extending to recent ecological studies (e.g. Soderquist & Mac Nally 2000, Lada & Mac Nally 2008). However, there was a 120 year gap in systematic surveys of the mammals of north central Victoria between the visits of Blandowski in 1854 and 1856-57 (Blandowski 1855, 1857; Menkhorst 2009) and surveys undertaken for the Land Conservation Council of Victoria during the 1970s and 1980s (Menkhorst & Gilmore 1979), and data collected during those surveys are now 25-30 years old!

In October 2009, the AVW database contained about 6500 records of 43 species of indigenous mammal from north central Victoria (Table 1). Twelve of those species (28%) are no longer present in the region, including four that are extirpated from Victoria (*Dasyurus viverrinus*, *Bettongia gaimardi, Aepyprymnus rufescens, Onychogalea fraenata*) and two that are extinct (*Lagorchestes leporides* and *Conilurus albipes*). Twenty-five species (58%) remain widespread, although many of these are thought to be in decline. Microchiropteran bats comprise more than half of the 25 widespread species and they, along with three large macropods (*Macropus giganteus, M. fuliginosus and Wallabia bicolor*), two wrist-winged gliders (*Petaurus breviceps and P. norfolcensis*), one monotreme (*Tachyglossus aculeatus*) and one small dasyurid (*Antechinus flavipes*) are the mammalian survivors in the dry forests and woodlands of north central Victoria.

As occurred widely across the southern half of Australia, the mammal fauna of north central Victoria suffered an initial collapse following settlement by Europeans (though this is very poorly documented in this region). As a result the larger dasyurids, bandicoots, small macropods and indigenous rodents have disappeared entirely from the landscape. Unlike the adjacent Murray Mallee and Eastern Highlands, an incremental loss of mammal species has continued across north central Victoria. There are likely to be multiple causes for the continuing attrition of mammal species in north central Victoria but key factors are thought to be:

1. the high proportion of private land in the region and the high proportion of private land that is intensively managed for agriculture or pastoral purposes.
2. the relatively high levels of fragmentation of habitat that is an inevitable consequence of point 1.
3. the use of all the highly productive parts of the landscape for farming, leaving extensive patches

Table 1. Indigenous mammal species recorded from north central Victoria (defined as the Land Conservation Council of Victoria's North Central and Murray Valley Study Areas combined). Species records from Atlas of Victorian Wildlife at late November 2009. Victorian conservation status (from DSE 2007): EX – extinct; RX – regionally extinct; EN – endangered; VU – vulnerable; NT – near threatened; DD – data deficient. Status in North Central Victoria: W – widespread, R – restricted; NR – no longer in the region; NV – no longer in Victoria; ↓ probably declining in abundance in north central Victoria; ↑ probably increasing in abundance in north central Victoria.

Common name	Scientific name	Number of records	Year of last record	Victorian conservation status	Estimated status in north central Victoria, 2009
Platypus	*Ornithorhynchus anatinus*	175	2006		W ↓
Short-beaked Echidna	*Tachyglossus aculeatus*	291	2005		W
Agile Antechinus	*Antechinus agilus*	20	2004		R
Yellow-footed Antechinus	*Antechinus flavipes*	543	2004		W
Spot-tailed Quoll	*Dasyurus maculatus*	7	2006	EN	R ↓
Eastern Quoll	*Dasyurus viverrinus*	1	1895	RX	NV
Brush-tailed Phascogale	*Phascogale tapoatafa*	377	2005	VU	W ↓
Fat-tailed Dunnart	*Sminthopsis crassicaudata*	115	2004	NT	W ↓
Common Dunnart	*Sminthopsis murina*	12	1991	VU	NR
Koala	*Phascolarctos cinereus*	521	2006		W ↓
Common Brushtail Possum	*Trichosurus vulpecula*	1044	2006		W ↓
Eastern Pygmy-possum	*Cercartetus nanus*	9	1993	NT	NR
Sugar Glider	*Petaurus breviceps*	338	2006		W
Squirrel Glider	*Petaurus norfolcensis*	164	2005	EN	W
Common Ringtail Possum	*Pseudocheirus peregrinus*	367	2006		W ↓
Feathertail Glider	*Acrobates pygmaeus*	58	2004		W ↓
Rufous Bettong	*Aepyprymnus rufescens*	5	1903	RX	NV
Tasmanian Bettong	*Bettongia gaimardi*	1	1861	RX	NV
Eastern Hare-wallaby	*Lagorchestes leporides*	2	1867	EX	EX
Western Grey Kangaroo	*Macropus fuliginosus*	34	1996		W
Eastern Grey Kangaroo	*Macropus giganteus*	691	2006		W ↑
Red Kangaroo	*Macropus rufus*	1	1857		NR
Bridled Nailtail Wallaby	*Onychogalea fraenata*	2	1857	RX	NV
Black Wallaby	*Wallabia bicolor*	484	2005		W ↑
Grey-headed Flying-fox	*Pteropus poliocephalus*	21	1995		vagrant
Little Red Flying-fox	*Pteropus scapulatus*	20	2000		R
Gould's Wattled Bat	*Chalinolobus gouldii*	90	2002		W
Chocolate Wattled Bat	*Chalinolobus morio*	80	2002		W
Eastern False Pipistrelle	*Falsistrellus tasmaniensis*	1	1976		NR
Large-footed Myotis	*Myotis macropus*	10	1997	NT	R
Lesser Long-eared Bat	*Nyctophilus geoffroyi*	432	2002		W
Gould's Long-eared Bat	*Nyctophilus gouldi*	36	2002		W
Inland Broad-nosed Bat	*Scotorepens balstoni*	17	2002		W
Large Forest Bat	*Vespadelus darlingtoni*	22	2002		W
Southern Forest Bat	*Vespadelus regulus*	31	2002		W
Little Forest Bat	*Vespadelus vulturnus*	175	2002		W
South-eastern Freetail Bat	*Mormopterus sp*	23	2002		W
Eastern Freetail Bat	*Mormopterus sp*	2	2002		R
White-striped Freetail Bat	*Tadarida australis*	169	2006		W
Water Rat	*Hydromys chrysogaster*	105	2006		W
White-footed Rabbit-rat	*Conilurus albipes*		1839	EX	EX
Swamp Rat	*Rattus lutreolus*	4	1962		NR
Dingo	*Canis lupus dingo*			DD	NR

of natural vegetation only on areas with poor soil and low productivity.

4. simplification of vegetation structure caused by timber harvesting, from the time of the gold rushes (1850s) until recent decades, including the deliberate conversion of woodland to 'pole-stand' forests by the application of intensive silvicultural techniques.
5. reduced rainfall over the past 13 years which has further reduced productivity of the remnant forests and woodlands.

The prognosis for mammals in north central Victoria is now likely to be worse than for the adjacent Murray Mallee and Eastern Highlands bioregions which retain large areas of relatively intact vegetation.

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THE LIKELY IMPACTS OF PRESCRIBED FIRE ON THE FLORA AND FAUNA OF BOX-IRONBARK REMNANTS

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Tolsma, A., Brown, G. & Cheal, D., 2010. The likely impacts of prescribed fire on the flora and fauna of Box-Ironbark remnants. *Transactions of the Royal Society of Victoria* 122(2): lxxxv-xc. ISSN 0035-9211.

This paper summarises a literature review undertaken for the North Central Catchment Management Authority. The aim was to review current fire knowledge in regard to the effects of prescribed fire on flora and fauna species and communities, and facilitate the creation of broad criteria for the establishment (or otherwise) of an appropriate burning regime for privately-owned Box-Ironbark remnants. A conservative approach to burning with minimum fire intervals of 20-25 years was recommended to avoid undue long-term impacts on extant flora and fauna communities. However, we are yet to identify a burning regime which might enhance (rather than simply maintain) biodiversity of Box-Ironbark remnants.

Key words: understorey, tree canopy, litter invertebrates, birds, mammals

Since European settlement, Box-Ironbark forests have been extensively cleared for agriculture, urban development, timber cutting and mining. Much of the extant vegetation now exists as remnants of coppice regrowth with depleted understorey in areas of poorer soil (Newman 1961; Kellas 1991), with serious implications for regional biodiversity.

The ‘natural’ fire regime of Box-Ironbark forests is largely unknown. Nonetheless, the North Central Catchment Management Authority (NCCMA), as part of its Regional Catchment Strategy and Native Vegetation Plan, identified the need to ‘develop and implement appropriate fire management regimes to sustain ecological processes in key private land vegetation remnants’. However, given the substantial post-European changes that have occurred in these depleted and fragmented forests, the likely responses to fire by flora and fauna are also largely unknown. Therefore, a review of current fire knowledge was undertaken, with the aim of creating broad criteria for the establishment (or otherwise) of an appropriate ecological burning regime.

This paper is a summary of the literature review undertaken for the NCCMA and focuses on the likely impacts of ecological burning in Box-Ironbark or similar ecosystems. We stress that this paper is concerned with prescribed fire in private remnants, not wildfire or other fire in larger tracts of public land.

A substantial body of literature was consulted for the review, and it is impractical to cite all references here. The reader is directed instead to the original document by Tolsma et al. (2007). This may be downloaded as a pdf file from the NCCMA website (http://www.nccma.vic.gov.au).

HISTORICAL FIRE REGIME

Little is known about the pre-European fire history of Box-Ironbark forests. Some authors have suggested that seasonal burning by aborigines was probably undertaken, but little direct evidence existed (ECC 2001), and what evidence there was related to landscape-wide observations that were not specific to particular places or vegetation types. Box-Ironbark forests were probably not burnt deliberately, and with relatively low rates of fuel accumulation (Kellas 1991) fire has likely played a minor part in influencing their vegetation structure and faunal assemblages. It is clear, however, that fire has become more frequent in Box-Ironbark ecosystems since European settlement. Of 1849 fires recorded in the Bendigo Fire District between 1984 and 2003, only 7.2% were confirmed as being caused naturally by lightning strikes: the remainder were deliberate, accidental or of unknown origin (DSE 2003). Ecological processes in Box-Ironbark forests are thus likely to have been substantially modified over the last 170 years.

EFFECTS OF FIRE ON UNDERSTOREY PLANTS

The response of the understorey to applied burning will vary by remnant, as the disturbance history of the site and extant vegetation will heavily influence the composition of the available seed bank (Tolsma et al. 2007). Other factors also come into play, such as the season of fire, landscape position, soil type, land management and post-fire conditions, including herbivory.

Some species, particularly leguminous shrubs and short-lived obligate seeders, will be promoted by fire in the short-term. Examples include species of *Acacia*, *Daviesia* and *Pultenaea,* whose seeds are stimulated to germination by heat, *Hibbertia* and *Lomandra*, stimulated by smoke, and *Wahlenbergia stricta* (Bell 1999; Brown et al. 2003; Tolhurst 2003). Resprouting species make up a large proportion of the flora, and as their basic distribution changes little after fire they confer a degree of stability on the vegetation composition (Orscheg 2006). Nonetheless, some species will drop out if burnt too frequently, regardless of regeneration strategy, reflecting the time required to reach reproductive maturity or survival age.

Few Box-Ironbark species (e.g. *Pultenaea prostrata*) rely solely on fire for germination (Orscheg 2006), and most species that are stimulated by fire will still recruit at a low level in the absence of fire. No species should be lost through prescribed burning provided the inter-fire period allows all species to reach reproductive maturity (a minimum of 10-20 years), and most species will persist even when the interval between fires exceeds 50 years (Tolsma et al. 2007). Absent species are highly unlikely to reappear (Orscheg 2006), suggesting that prescribed burning might at best maintain, but not enhance, species diversity.

EFFECTS OF FIRE ON CANOPY TREES

Within the Box-Ironbark forests, most eucalypts recruit continually in the absence of fire, and thus do not rely on it for overstorey persistence. The Ironbark species (*Eucalyptus sideroxylon* and *E. tricarpa*) may be exceptions in that they tend to recruit sporadically under natural conditions (Kellas 1991; Orscheg 2006). Their specific germination requirements remain to be determined.

Most species of eucalypts in the Box-Ironbark forests are fire tolerant (Meredith 1987), and they are unlikely to be severely affected by lower intensity fire in small remnants. There may be some increase in coppice stems (Wakefield 1970), and some juveniles may be killed. In the long term, fire in these remnants would be of concern if it was sufficiently frequent that it continually prevented tree recruits from reaching reproductive maturity.

EFFECTS OF FIRE ON LITTER

Litter plays an important role in nutrient cycling, and provides important habitat for fungi, invertebrates, small mammals, reptiles, frogs, and ground birds (Tolhurst & Kelly 2003). The build-up of this litter is relatively slow in Box-Ironbark forests, requiring four or more years to regain pre-fire load (Hartskeerl 1997; Tolhurst & Kelly 2003), and overall loads are also low compared to other forest types: for example, 4-8 tonnes/ha in Box-Ironbark (Chatto 1996; Hartskeerl 1997) compared to 9-26 tonnes/ha in the nearby mixed sclerophyll Wombat State Forest (Tolhurst & Kelly 2003).

Frequent burning (for example, at 3-5 year intervals) is likely to disrupt natural processes in the short-term and may eventually lead to a reduction in elements such as carbon and nitrogen (Hopmans 2003), and loss of habitat.

EFFECTS OF FIRE ON INVERTEBRATES

Invertebrates make up 95% of fauna species (York 1996), yet despite their important role in nutrient cycling are frequently overlooked in fire research (Collett & Neumann 2003).

The diversity of invertebrates in forests tends to be high in terms of composition, activity periods, microhabitat use, environmental factors etc., and invertebrate communities may respond differently to fire depending on its severity, season, extent or frequency (Campbell & Tanton 1981; Friend 1996). The limited data that exist are confounded by this high natural variability, leading to conflicting or confusing interpretations, and it is often difficult to determine the baseline or climax community (Friend 1996).

A single fire may lead to a reduction in springtails, earthworms and some beetles (Andersen & Yen 1985; Collett et al. 1993; Collett & Neumann 1995), and an increase in some ant species. Short-term effects are intimately linked in many cases to burning of the litter layer, and frequent fire may replace litter-dependent species with more tolerant species (York 1999). Burning at frequencies as high as every three years should be avoided.

More research is required into the effects of fire on termites, known to be key drivers of secondary productivity in these forests.

EFFECTS OF FIRE ON BIRDS

The effects of fire on birds may be direct, in terms of mortality, or indirect, in terms of the impact on their resources. Effects are strongly dependent on the severity and extent of the fire, the structural components of the forest that are burnt, and the trophic guild of individual bird species (Wilson 1996). Prescribed fire is likely to be less deleterious to birds than wildfire (Woinarski & Recher 1997; Loyn et al. 2003).

Following fire, there is generally an abrupt decline in bird abundance followed by a period of recovery (Woinarski & Recher 1997; Green & Sanecki 2006), usually linked to the recovery of the vegetation. Some species such as kookaburras may be advantaged in the short-term by the availability of post-fire carrion or the reduction in protective cover for prey (Woinarski 1999). Some seed-eaters, such as emus, brown quails and button-quails, may be advantaged in the medium-term if fire promotes new vegetation growth (Tolsma et al. 2007). However, birds such as stone-curlews, brown treecreepers and white-winged choughs, which rely on the ground layers for nesting or foraging, may be disadvantaged in the short-term even by low-intensity fire, particularly if it interferes with breeding (Tolsma et al. 2007).

The minimum inter-fire period that should avert long-term harm to bird populations is likely to be similar to that which will allow full recovery of understorey structure and adequate overstorey recruitment, that is, at least 20-25 years (Tolsma et al. 2007). Burning at more frequent intervals may lead to a long-term shift in vegetation structure, and bird species that require mature forest, which are often ecological specialists with restricted distribution, are likely to be lost (Meredith 1987; Wilson 1996).

EFFECTS OF FIRE ON MAMMALS

Mammals tend to have complex but predictable relationships with vegetation (Irvin et al. 2003b), and ground-dwelling mammals are likely to be dependent on understorey complexity. Therefore, while the effects of fire on mammals may be linked to the season, intensity and scale of the burn, recovery after fire is linked to recovery of the vegetation (Meredith 1987; Friend 1993).

Introduced black rats and house mice are often the first mammals back after fire (Robertson 1985; Meredith 1987; Friend 1993). Some common herbivores, particularly macropods and introduced rabbits and hares, take advantage of the flush of new plant growth and may increase in abundance (Christensen & Kimber 1975; Robertson 1985). Small animals dependent on the ground layer, including the bush rat and antechinus, will be disadvantaged in the short-term even by ‘cool’ fires (Friend et al. 1999), particularly if the burn occurs in autumn, while antechinus, phascogales and echidnas may be affected in the longer term by the burning of dead trees and logs (Tolsma et al. 2007). Arboreal mammals are likely to be disadvantaged only if the fire is of high intensity.

In general, it is believed that small mammal populations will not be unduly disadvantaged if the minimum inter-fire period is 15-20 years (Meredith 1987). However, in isolated private remnants, recolonisation by small mammals after fire may prove difficult (Barnett 1978). Further research is required, particularly in regard to bats and arboreal mammals, such as possums.

EFFECTS OF FIRE ON REPTILES AND FROGS

Little research has been undertaken on the effects of burning on reptiles and frogs (Meredith 1987; Friend et al. 1999), and the limited research in Box-Ironbark forests is confounded by low numbers of these animals.

Some researchers have suggested that reptiles may be less affected than other fauna groups by food shortages after fire, due to the lower metabolic needs associated with ectothermy. Nonetheless, frogs and reptiles such as Coventry’s skinks and grass skinks are likely to be disadvantaged in the short-term by any burning, due to their dependence on the litter and ground layers (Bennett 1999). Spring burning will affect the breeding of most spring-breeding reptile species, including legless lizards, while autumn burning may affect the breeding of frog species such as brown toadlets and southern toadlets (Tolsma et al. 2007). Frogs may also be indirectly affected by run-off and reduced water quality (Brown et al. 1998). There may be increased competition and predation after fire (Irvin et al. 2003a), and the isolation of remnants is likely to prove a barrier to recolonisation.

SOME QUESTIONS REMAIN UNANSWERED

The literature review for the NCCMA was an important step in beginning to understand the effects of applied fire on plants and animals in Box-Ironbark forests. However, many questions remain to be answered. For example:

- Does Box-Ironbark forest really need fire?
- What are the regeneration requirements and vital attributes for important shrub species such as *Grevillea*, *Ozothamnus*, and the Epacrids, or for Ironbark trees?
- Will fire in small remnants have similar ecological effects as fire in more extensive areas of forest?
- How would islands of Whipstick Mallee be affected by fire regimes geared towards surrounding Box-Ironbark?
- What are the limits to survival and recolonisation by small animals in isolated remnants?

We are yet to identify a burning regime which might enhance (rather than simply maintain) biodiversity of Box-Ironbark remnants. Until many outstanding issues can be resolved we must tread warily with our use of fire in this depleted and fragmented landscape.

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THE ROLE OF NATURALISTS IN ENVIRONMENTAL CONSERVATION

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Central Victorian field naturalists clubs, formed initially as a means of meeting with people of like interest in nature, soon became major sources of information regarding local aspects of natural history. These data have been instrumental in both assisting the scientific study of elements of the environment, and informing conservation and heritage endeavours in the local region.

Key words: field naturalists clubs, environmental advocacy

In looking at the role of naturalists in environmental conservation, it is useful to begin by considering what is meant in this context by the term ‘naturalist’. To that end we might turn to the fount of all knowledge — the Oxford English Dictionary (OED). There we find some interesting and arcane definitions of the word naturalist, only a couple of which are useful for the present purposes. Leaving out those people who are ‘dealers in cage animals, dogs etc.’ (hopefully, a group that is not well represented at this Royal Society conference), perhaps the most appropriate definition of a naturalist offered by the OED is:

> one who makes a special study of plants and animals

One way or another, however, this isn’t a particularly satisfactory start. On the one hand the definition is so broad that it could take in almost everybody at the conference. Although that isn’t a bad thing in itself, for the purposes of considering the role of naturalists, it would increase the range of possibilities well beyond manageable proportions for this brief presentation. On the other hand, the definition is too narrow, in leaving no room for people whose area of special study is fungi, for example. And where would those naturalists interested in geology fit in that definition? Perhaps we should agree with George Lewes, a nineteenth century man of letters and the author of a couple of books on natural history, when he wrote that ‘a naturalist may be anything, everything’ (Lewes 1858: 396).

There are many individuals, in a wide range of situations, who might legitimately claim the title ‘naturalist’. So much so that a distinction needs to be made that is based on the context in which the naturalising is done. The roles played in conservation by an individual naturalist employed, say, in a government department, must surely differ from the roles played by somebody who, in his or her spare time engages, for example, in fungal forays or bat counts, either alone or as a member of a field naturalists’ club.

In this paper, in referring to naturalists the term will be used to mean people of ‘amateur’ status, i.e. individuals who are not paid to study some aspect of nature. This distinction separates people who are doing what they do in the natural world in their own time, from people who do the same or similar things, for a living. In drawing this distinction, it is not intended to disparage the quality of work undertaken by members of field naturalist clubs. I think the record of such clubs speaks for itself, and the study of nature for its own sake has been around for so long that it needs no justification.

THE ROLE(S) OF A NATURALIST

In essence the role of a naturalist, as described of the species I am focusing on in this paper, is to compile and disseminate information regarding aspects of natural history. The observations upon which this compilation is based might be restricted to a specific locality, or be focused on a particular range of animals or plant communities. In all such instances, however, in undertaking activities of these kinds, naturalists are taking part in a very long tradition.

The data compiled by naturalists might be of use in a range of contexts, but in the context considered here—that of environmental conservation—the observations provide one of the bases upon which a conservation endeavour can be built. We need to know as much as possible about the entities that are to be conserved – whether they be defined at the species level or as communities.

Under the general umbrella of compiling and disseminating information, naturalists work in a number of ways (Vaughan 1995). The most important of these will be itemised in the remainder of this paper.

1. Recording field data: firstly, and most obviously, naturalists are in the field with the purpose of observing and making a record of what they see. Where these records are given a permanent form, through publication, they can ultimately constitute a valuable source of information. This is particularly so when the observations were made at a time prior to large scale changes in the relevant environments. Sometimes these reports are brief to the point of being of no more than passing interest, such as, for example, an 1888 report, in the pages of *The Victorian Naturalist*, which noted the birds' nest collecting activities of a member of FNCV from about 20 years previous, in the Whipstick country, north-west of Bendigo (Nancarrow 1888).

Of course, the Whipstick has long been a favourite botanising area for local naturalists, and this ongoing attachment has resulted in the accumulation of a large body of data regarding vegetation of the area. The results of most of the visits to the Whipstick were published in *The Victorian Naturalist*, particularly in the period prior to the formation of the Bendigo Field Naturalists Club, in August 1945. Mr David J. Paton, who was a member of the Field Naturalists Club of Victoria, published a major paper in *The Victorian Naturalist* entitled 'The Plants of the Whipstick, Bendigo' (Paton 1924). The paper included a list of 227 native plants from the Whipstick, and a map of the area.

This article was followed up in 1936 with an article by J.W. Audas (1936) in which he added 50 additional native plants. Then, in May 1940, a third article was published in *The Victorian Naturalist*, adding a further 45 native species plus 60 alien species (Tadgell 1940). These additional plants supplied by A.J. Tadgell took the total to 322 native species within the area. Thanks largely to a vast amount of voluntary work the flora of the Whipstick is now an historically well-documented resource that can be drawn upon, for example in comparative studies.

2. Documenting and monitoring change: observations made over a period of time in the same locality, in the way that locally-based field naturalist groups are good at, can point to changes in vegetation patterns or animal numbers. Once noted, these aspects of the local natural history can become the focus of attention for future ongoing field work, thus providing further data, as well as a time dimension to the data recorded.

There is no substitute in the study of the natural elements of an area, for having the facility to repeatedly monitor an area of interest; or to be able to visit the locality in all seasons; and at short notice. (This is one advantage that naturalists have over individuals who are employed in relevant institutions or organisations, particularly government departments: they can spring into action when the need arises.)

3. Publishing: a major role of naturalists lies in the creation of a permanent record of their observations — through the medium of publication. All field naturalists clubs have a regular newsletter *cum* magazine, which puts on record not only the activities of the club but also the outcome of those activities. In some, perhaps rare instances, the regular publications produced by a field naturalist club achieve a readership at a wide-ranging level. One good example of this is *The Victorian Naturalist*, the journal of the Field Naturalists Club of Victoria. This journal has been in continuous print since January 1884, and is today distributed widely around the western world.

For many field naturalist clubs, publishing isn't limited to the regular newsletter or journal. The Field Naturalists Club of Bendigo, for example, has an enviable record of publishing small field guides to particular parts of the local natural history. These include *Wildflowers of Bendigo* (Cleary & Leamon 1988), *The Eucalypts of the Bendigo District* (Franklin et al. 1991) and *The Birds of the Bendigo District* (Bridley 1991). The Castlemaine Field Naturalists Club has also compiled a small guide to plants in the Castlemaine area.

In a joint effort in 2002, a CD titled *Plants and animals of the Box-Ironbark area of central Victoria* was produced on behalf of the field naturalist clubs of Bendigo, Castlemaine and Maryborough. This is a comprehensive atlas and encyclopaedia relating to the natural history of this area that draws on the databases of DNRE (Viridans 2002).

Publication during the 1980s of Cliff Beauglehole's work on the distribution and conservation of vascular plants is another example of co-operation between field naturalists clubs — in this case in the form of the Western Victorian Field Naturalists Club Association (Beauglehole 1979–1985).

4. Acting as an advocacy group: Arguably the most important role fulfilled by naturalists in environmental conservation is in acting as an advocacy group in the protection and conservation of areas of local importance. The Hamilton Field Naturalists Club clearly believed so when it named its 50th anniversary *Environmental advocacy and action 1958–2008* (Luhrs 2009). In fact, Victoria has a long history of such advocacy by field naturalists clubs, stretching from the campaign in 1898 to have Wilsons Promontory reserved, through to the campaign that began in the 1950s to reserve areas of the Little Desert (Robin 1998). The Field Naturalists Club of Victoria was centrally involved in both these campaigns as well as a number of others (Houghton & Presland 2005). In the North Central area of Victoria, the Field Naturalists Clubs of both Bendigo and Maryborough have been highly active in advocating the protection through legislation of areas of natural environment within their localities.

The Bendigo naturalists have an extensive experience of advocating on behalf of threatened vegetation types, in particular in the area of the Whipstick: in 1940 the same Mr Tadgell who supplied an additional 45 plants to the list of Whipstick flora suggested that:

> co-operation might be sought by our Club [the Field Naturalists Club of Victoria] from residents of Bendigo and Eaglehawk in the creation of a sanctuary (Tadgell 1940: 85).

In the end, it was the Bendigo Field Naturalists Club, formed five years later, that took up the challenge. In 1957 the Club applied to the newly-formed National Parks Authority to have four square miles of the Whipstick set aside as a state park. Some years later, in about 1966 the case for a larger Whipstick National Park was commenced. In 1971 the Whipstick Forest Park was declared, but, despite deputations and letters from the Club to the Premier Henry Bolte and Minister for Lands Bill Borthwick for material action (Bendigo Field Naturalists Club 1971), further Whipstick lands were sold and clearing continued. The fight also continued, however, and in 1974 the Bendigo Field Naturalists Club made a further submission which 'was compiled to bring to the attention of the authorities many aspects relating to the preservation of the Bendigo Whipstick which were not so apparent at the time of our earlier submission' (Bendigo Field Naturalists Club 1974:1). No doubt these submissions were a factor in the eventual proclamation, in April 1987, of the Whipstick and Kamarooka State Parks.

Similarly, the Maryborough Field Naturalists Club has been active and effective, over many years. The Club was formed in 1951, and as Ethel Thompson, a foundation member, wrote in 1991: 3

> A conservationist today … must be prepared to contribute to government thinking and action by way of submissions and other publicity. In this regards, as in so many others, the Club has been active and far-sighted.

Through its advocacy and action, the Maryborough club has succeeded in having a number of areas reserved, to protect their environmental values. These areas include:

- Alma Road wildflower sanctuary (1960)
- Bell's Swamp (in conjunction with Castlemaine Field Naturalists Club) (1975)
- Clunes Swamps (in conjunction with Ballarat and Creswick Field Naturalists Clubs) (1976)

The Club also has had a long-standing interest in the area of Paddys Ranges Box-Ironbark Forest (Anon 1972). It has made repeated submissions to the Land Conservation Council (LCC) in advocacy of the area, beginning with an initial presentation in 1971. This was followed by an enlarged submission in 1978. The club subsequently was disappointed with the LCC's response, so a third submission was prepared, in 1980. These efforts eventually paid off, when the 1700 ha State Park was declared, on 27 October 1989.

5. Local education: Naturalists also have something of an educative role, particularly in the local situation. As a way of gaining support during the process of advocacy, but also as a means of spreading the word and gaining recruits, naturalists are regular speakers at meetings of local interest groups, workshops and schools. All such endeavours serve to keep issues such as diminishing vegetation communities and threatened species in the public arena. In this context, field trips—the *sine qua non* of naturalists—provide a hands-on means of introducing such issues to a wider audience; in-the-field tuition also serves the purpose of informing individuals in preparation for the roles of public presentation and advocacy.

6. Providing field workers: when it comes to undertaking surveys of biota in the field, where relatively large numbers of people are required, local field naturalists clubs often present a good option for some unpaid workers. By involving the local naturalists, government departments and consultants can tap into a group of keen and willing participants, the members of which often have both knowledge and experience to commend them. There are benefits for both parties: new opportunities for fieldwork and the gaining of experience and knowledge come to the naturalists; a ready and willing labour force and local knowledge come to the company or department carrying out the survey. Arrangements such as this can be seen also as a significant role for naturalists in that it is a relatively easy way to have an input in the process of conservation. Moreover, the primary means for a field naturalist to enjoy nature is to be out there in it.

ERN PERKINS

It would be remiss of me in speaking about the role of naturalists, particularly in relation to the north-central part of Victoria, not to mention somebody who has been a tireless worker for natural history, and who represents, arguably, all that the 'amateur' naturalist can achieve — Ern Perkins.

Ern Perkin's contributions to the study of natural history, in the central Victorian area, range across the full gamut of activities commonly undertaken by naturalists. He has initiated, been involved in, and lead surveys of local flora and fauna. Examples of this work, relating just to his personal interests, include the Swift Parrot *Lathamus discolour* and Regent Honeyeater *Xanthamyza phrygia* surveys and ongoing contributions to the New Atlas of Australian Birds. With local groups he has coordinated a number of projects, including

- the conservation value of roadside reserves, originally in the Shire of Maldon and then extended to the Shires of Metcalfe and Newstead and the City of Castlemaine;
- plant lists for the Eltham Copper Butterfly *Paralucia pyrodiscus* colony at Castlemaine Botanic Gardens;
- and plant surveys for the Diggings National Heritage Park on behalf of Parks Victoria.

Ern has also developed and maintains databases of records of the birds and plants located by the Castlemaine Field Naturalists Club, natural history along Shire walks, and indigenous plants of Castlemaine District.

He makes himself available, when called upon (which he is often) to provide lectures and talks to naturalist, plant and Landcare groups.

One indication of the respect with which Ern Perkins is held is that in 2000 he was awarded a Medal of the Order of Australia (OAM), for services to conservation and the environment, and the community of Castlemaine. He has always been ably supported by his wife Lesley, and in 2006 they jointly received a Banksia Environmental Award entitled 'Back from the Brink: Saving Victoria's Threatened Orchids'. As joint research officer (with Lesley) for the Australian Plant Society, Ern contributes a regular column for its quarterly magazine. In recognition of all of this, and much more, Ern Perkins was the recipient of the 2008 Australian Natural History Medallion (Endersby 2008).

CONCLUSION

Naturalists are obviously busy and productive people in the north-central area of Victoria; this part of Victoria is clearly one where the study of natural history is a popular pursuit. When the Bendigo Field Naturalists Club was formed in 1945, it was only the third such club in the state, after the Field Naturalists Clubs of Victoria and Geelong. Between that beginning and the first issue of its monthly newsletter *The Bendigo Naturalist*, in 1967, the number of similar clubs grew from 3 to 23 (Anon 1967). By 1998 the figure had grown to about 30.

In the north central area the presence of naturalists, particularly in their group form, has achieved much in both informing conservation endeavours and directly saving some of what is left of the pre-European vegetation communities. Given that, by one account, in the period since European settlement 'over 83 per cent of the Box-Ironbark region has been cleared' (Calder et al. 2002: 8), it is clear that we would all have benefited by having a few more naturalists, earlier on.

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POTENTIAL IMPACTS OF A CHANGING CLIMATE ON SELECTED TERRESTRIAL ECOSYSTEMS IN NORTHERN VICTORIA

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This project investigated potential alterations to natural ecosystems from climate change, focusing its attention to northern Victoria. The study used spatial modelling techniques that integrate field data on native plant species and environmental predictor data. Probabilistic models for current and future distributions under several climate change scenarios/time periods were developed for 15 species and their associated five major ‘biomes’ (Mallee, Semi-Arid, Open Forest/Woodlands, Dry Forests and Floodplains). Current distribution models demonstrated high levels of statistical performance and ecological integrity. However, models for future epochs were subject to uncertainties and inconsistencies that arise from the limitations of modelling processes. These constraints reduce the credibility and utility of future distribution models, particularly where confident predictions at local scales are required to frame management actions. Climate change is likely to synergistically exacerbate many existing impacts upon biodiversity (e.g. habitat loss, fragmentation, condition decline, salinity, weeds, etc.). Actions to manage climate change impacts on biodiversity may be fundamentally similar to those currently available to land managers, however the breadth and scale of actions will need to be greatly enhanced. While tools for modelling ecological systems are improving in their sophistication, they remain incapable of providing the ever-elusive ‘crystal ball’ required for science, policy development and land management purposes.

Key words: climate change, impacts, biodiversity, conservation management

The imminence of climate change has recently become a reality for many people through coverage of the topic by the media and various levels of political engagement with the issue (e.g. Spratt & Sutton 2008). However, the issue is not novel and has been debated in scientific and other literature for several decades (e.g. Pearman 1988). While the uncertainties of predictions for future climatic conditions provide opportunities for some commentators and ‘climate change sceptics’ to de-bunk the likelihood of a rapid change in climate (e.g. Lomborg 2001), the scientific effort applied over the last decade to validating the precision and accuracy of global circulation models (GCM) has led to an unprecedented scientific and political consensus on the likely anticipated changes to global temperatures and other climate parameters from increased atmospheric CO_2 (IPCC 2007; Randall et al. 2007). The weight of evidence now clearly suggests that an altered climate will be almost certain within the timeframe of a single human life-span.

An integral paradigm of ecology is that the distribution patterns of plants and animals in both space and time relate strongly to dynamic environmental drivers, including climatic regimes. More broadly, ‘biodiversity’ (i.e. all organisms and their genes) is responsive to ‘climate’ at many scales, both spatially and temporally (e.g. Peterson et al. 1998). Investigating how organisms respond to and evolve with climate over time is a central theme in ecological research and several other specialised scientific disciplines (e.g. evolutionary biology, biogeography, palaeontology).

Logical links between anticipated climatic changes and the potential for profound impacts upon biodiversity are quite clear in terms of ecological principles (e.g. Walker & Steffen 1997; Malcolm & Markham 2000; Malcolm et al. 2002; Westoby & Burgman 2006). Importantly, natural systems, and biodiversity more specifically, are likely to be at a very high level of risk from climate change when compared to other systems and sectors (e.g. Hughes 2003; Westoby & Burgman 2006; IPCC 2007). In contrast to the relative plethora of European and North American studies, relatively few studies have been undertaken to examine the impacts of these changes upon Australia's biodiversity (e.g. Bennett et al. 1991; Brereton et al. 1995; Beaumont & Hughes 2002; Hughes 2003; Newell et al. 2001, 2003; Williams et al. 2003; Hilbert et al. 2004; Beaumont et al. 2007), despite the high level of endemism and cultural/economic significance. Our current understanding of potential responses of Australian ecosystems to altered climatic regimes is arguably quite poor, and is heavily influenced by data and perceptions from northern hemisphere studies, and from broad, general ecological principles.

Most climate change impact studies pose questions such as 'What will be the impact upon a particular species?' These types of questions are inherent to many modelling studies, and while they may be reasonable and logical to consider, they can be very difficult to answer both in terms of probabilities and practicalities. Many difficulties stem from the capabilities of the available modelling approaches. One of the most common approaches used to investigate climate change impacts has been 'bioclimatic modelling' (e.g. Houlder et al. 2001), which is one approach to producing a species distribution model (SDM). This approach uses current climate data to define a 'climate envelope' for a particular species based upon field survey data. There are many examples of this approach being used in various parts of the world, including local examples (Bennett et al. 1991; Brereton et al. 1995; Newell et al. 2001, 2003; Beaumont et al. 2007). However, the approach is limited for a number of reasons (Gray et al. 2004; Thullier 2004; Guisan & Thuiller 2005; Thuiller et al. 2005a; Heikkinen et al. 2006a, b; Zarnetske et al. 2007), including that SDMs are based on mean climate data alone with poor recognition of climatic regimes and extremes, and that the SDMs are formed from climate data alone. Importantly, organisms respond positively and negatively to a range of factors and stimuli other than climate. For example, SDMs generated for plant species using only climate data are likely to be simplistic representations without considering soils and edaphic factors that have strong influences on plant species' distributions. Incorporating other data relevant to ecological distributions remains a major challenge in predicting the local impacts of global change upon plant and animal species. Despite these and other limitations (e.g. climate models resolved at scales inappropriate to biotic distributions at local scales), attempts are being made to improve the rigour of SDMs. The field of ecological modelling is developing and maturing rapidly, and new techniques that allow for a greater level of sophistication in climate-change impact modelling are emerging regularly. Examples include more sophisticated modelling approaches such as generalised dissimilarity and maximum entropy modelling techniques (e.g. Elith et al. 2006; Ferrier & Guisan 2006; Phillips et al. 2006; Araujo & New 2007; Ferrier et al. 2007; Phillips & Dudik 2008), and approaches that may integrate SDMs with other ecological processes and functions such as population viability (e.g. Keith et al 2008; Huntley et al 2010).

Climate change impact models by definition imply a comparison between models at two different time steps. These comparisons and assessment of impact necessarily rely upon the development of realistic models of current distributions. Without good *before-impact* models it is very difficult to contrast *post-impact* models, and to evaluate whether these make ecological sense (Peterson et al. 2007; Phillips 2008).

This project investigated the distribution of selected tree species now and in the future under several different modelled climate regimes of varying intensity and at three future time steps (Current, 2030, 2050 and 2080). The species were selected as structurally dominant species within major vegetation formations across northern Victoria, with the intention of using species aggregations as surrogates for entire biomes. In broad terms, this study aimed to understand aspects of potential impacts and potential risks to natural ecosystems in south-eastern Australia from climate change, and more specifically how these changes may be manifested across north-central Victoria at several time intervals.

METHODS

Modelling species and biomes

We endeavoured to form SDMs of the current distribution of 15 tree species and aggregations or 'biomes' using Maximum Entropy modelling ('Maxent'). A primary consideration in modelling studies is matching the various types and forms of information together, while attempting to avoid mis-matches that could lead to difficulties in interpretation or even erroneous results. Ecological vegetation classes (EVCs) are the primary vegetation unit used within Victoria for classifying and the management of native vegetation, but these units were considered to be too finely resolved when matched against available biophysical data, climate projections and scenarios. Consequently, 'biomes' representing broader aggregations of vegetation were used as the unit of investigation, along with their component dominant species. Biomes relevant to northern Victoria were defined by a series of structurally important yet localised tree species. These species were not used in the context of 'indicator' or sensitive species for each biome, but were selected as characteristic of being structurally dominant and having a high fidelity to each biome. The five biomes examined in this project were defined as Mallee systems, Semi Arid Woodlands, Dry Forest, Open Forest/Woodland and Floodplain systems. These biomes were not considered to be exclusive in geographic range, as there can be considerable overlaps or 'mosaics' between these units across landscapes.

Data for each species was extracted from DSE's Flora Information System, which holds the majority of Victoria's vascular floristic data. Uncertainties in the taxonomy of several species required their omission from further consideration, and species with < 60 records were avoided. All biomes defined in this study were *Eucalyptus*-dominated systems, with the exception of the Semi-Arid Woodland which is dominated by *Casuarina, Allocasuarina* and *Acacia* species.

Maximum Entropy modelling

Models were developed using maximum entropy or 'Maxent' (Phillips et al. 2006). The modelling approach quantifies the numeric distribution that encapsulates the most information with the least bias. It is derived from the disciplines of machine learning and Bayesian statistics as a principle in statistical mechanics during the 1950s, and has only recently been applied to ecological systems (Phillips & Dudik 2008). Maxent algorithms have been used to examine the impacts of climate change on biodiversity (e.g. VanDerWal et al. 2009), as the process has the ability to apply statistical models to different but aligned environmental data set (i.e. same suite of variables in the same format, but with spatial or temporal differences). However, statistical inferences on model performance apply only to the original or current model of species/biome distribution, and it is impossible to statistically evaluate future predictions.

Software for conducting Maxent species and habitat analyses is freely available (www.cs.princeton.edu/~schapire/Maxent). The software (version 3.1.0) is small in size, computationally efficient even with large datasets, and provides spatially explicit outputs along with statistical coefficients for interpretation.

Maxent uses presence data for species (typically from field inventory) to construct statistical and spatial models of distributions from a suite of environmental data that can be associated with the geographic location. It does this using a set of background points operating as 'pseudo-absences' (default setting 10 000 point, Phillips et al. 2009). The Maxent distribution is computed from the environmental attributes of the union of the 'background' pseudo-absences and the field presence records. Duplicate presence records (i.e. where the species had been recorded on more than one occasion at the same location) were omitted to minimise biases in this study. Other standard default settings were used including a maximum of 500 iterations for each model.

Maxent provides three indications of the relative importance of environmental variables, although these should be interpreted with caution both individually and collectively. First, Maxent provides a heuristic estimate of the relative contributions (expressed as percentages) for each environmental variable, and conducts a 'jacknife' test of variable importance by re-sampling with replacement to estimate the level of bias and variance for the statistic. Second, Maxent provides plots of the responses for each environmental variable, which can be useful for anticipating thresholds. However, these plots should be treated with caution as there is no guarantee that the training (i.e. field) sample is representative of the full suite of environmental conditions in which the species may occur. The third and perhaps most informative is the 'Receiver Operating Characteristic' (ROC) curve, which is a graphical plot of the sensitivity versus (1 – specificity) (i.e. the fraction of 'true positives' to 'false positives'). ROC curves can be interpreted by comparing the distance between the training data and random prediction, and should be interpreted as a general indication of model performance where the value should exceed 0.5 and preferably approach unity.

Importantly, these statistical assessments of model performance can only be evaluated for the 'Current' time step and cannot be applied to models that are 'transferred' or 'reprojected' to future time steps or geographic space. In other words, it is impossible to evaluate the likelihood of 'correct prediction' before it has happened. While Maxent cannot provide a statistical evaluation of the performance for future epochs, it provides a useful spatial indication where projected models are likely to exceed the range of the initial environmental data that was used to develop the initial model. This output is termed 'clamping', and assists in identifying locations where future predictions are likely to be particularly problematic.

Environmental variables

Maximum Entropy modelling is capable of using a large range of environmental variables, where they can be expressed as raster spatial surfaces. Environmental variables used in Maxent modelling can be divided into two groups: climatic and other biophysical data.

In this study climatic predictor variables were derived from ANUCLIM (Houlder et al. 2001). ANUCLIM use raster surfaces of a 30-year average of national climate data taken from 1961 to 1990 for minimum temperature, maximum temperature, rainfall, evaporation and radiation to subsequently derive a total of 35 'bioclimatic' parameters. This results in a high level of correlation and redundancy between these parameters. For simplicity a smaller subset of 10 variables was selected for initial evaluation to reflect climatic extremes as well as to express underlying median values (Table 1). Following several rounds of model development and evaluation it became clear that using all 10 climatic variables provided informative 'current' scenario models for many species. However, models at future time steps with the same variables had reduced ecological integrity or credulity. These initial evaluations led to the use of just two climate variables to reflect annual mean temperature and annual precipitation for more stable responses at future time steps.

While climatic parameters are influential to the distribution of biodiversity directly, their influence is conflated with many other biophysical and geographical influences. In an attempt to form a more meaningful suite of predictors several biophysical predictors were assembled to reflect various contextual and edaphic factors. These included:

Terrain Wetness Index (TWI), which is a neighbourhood-type analysis designed to model rainfall run-off. (Sorenson et al. 2006; www.fs-privat.de/diss.htm).

Topographic Position Index (TPI) is a neighbourhood analysis which relates each pixel to those around it, to reveal landscape structure. This surface was created using TPI Extension (version 1.3a) for ArcView 3.x (Jenness Enterprises www.jennessent.com/arcview/tpi.htm).

Radiation Duration and Direct Radiation were both derived from a state-wide digital elevation model using Solar Analyst extension for ArcView 3.x

Two radiometric surfaces (Thorium:Potassium Ratio and Thorium:Inverse Potassium Ratio). These airborne geophysics data reflect fine-scale differences in soil composition across Victoria with numeric data, rather than 'soil type' categories.

Flood Extent surface (as a categorical variable: 1 = non-floodplain, 2 = floodplain, and 3 = combination of estuaries, coastal areas, inlets and inland lakes) was used in modelling Floodplain species biome.

The Native Vegetation Extent (DSE's Native Vegetation Extent 2005 layer) as described above was used as a mask to constrain the 'extent-blind' modelled outputs.

Climate Change Scenarios

Analyses for this study were conducted in late 2007. During this time the 4th Assessment of the Inter-Governmental Panel on Climate Change (IPCC-AR4) was being released with revised scenarios of the anticipated changes in climate parameters to 2100. Timing constraints meant we were unable to wait for the release of these scenarios, and undertake the complex and arduous re-integration of these scenarios with current climate surfaces. Subsequent reflection showed that the scenarios from the third IPCC Assessment did not differ greatly, with improvements centred on increased certainty of the models, i.e. tighter confidence intervals, rather than altered storylines and median values (Randall et al. 2007).

Three major storylines from the third IPCC Assessment were used to span the range of uncertainties around climate change projections (Nakicenovic et al. 2000). The Low Scenario is based on the B1 storyline, representing the most benign/low-impact effect of climate change. The Medium Scenario is based upon the A1B storyline, while the High Scenario is based upon the A1F storyline. Each storyline has a different anticipated trajectory of climate change, with the High Scenario anticipated to increase mean global temperature by 4.5°C by 2100,

Table 1. Biophysical variables examined for use in Maximum Entropy modelling. Variables shown in bold were used in final model runs. # = categorical value.

Variables examined	
Climate	*Non-Climatic Environmental Data*
Annual Nett Rainfall	Distance to Fresh Water
Annual Evaporation	Distance to Saline Water
Annual Precipitation	NDVI (Normalised Difference Vegetation Index)
Maximum Temperature of the Warmest Period	**Direct Radiation**
Mean Annual Temperature	**Duration of Radiation**
Minimum Temperature of the Coldest Period	**Thorium : Potassium Ratio**
Precipitation of the Driest Period	**Thorium : Inverse Potassium Ratio**
Precipitation of the Coldest Quarter	**Terrain Position Index**
Precipitation of the Warmest Quarter	**Terrain Wetness Index**
Precipitation of the Wettest Period	Extant Vegetation #
Precipitation of the Wettest Quarter	**Floodplain** #

the Medium Scenario likely to increase temperature to approximately 3.0°C, and the Low Scenario likely to increase temperature to approximately 2.0°C at 2100. Increasingly this scenario is seen as an unlikely (e.g. Garnaut 2008). Each storyline comprises 'families' of scenarios of low, medium and high impact. The Medium Scenario from each family was used in this study. The background to each of the storylines is available on the IPCC website (www.ipcc.ch).

Although these are considered different scenarios, they are in effect a single vector or 'ramp' of changing temperature and rainfall that is time-independent. For example, under Low Scenario, this takes until 2100 to achieve a 2.0°C increase in temperature, whereas under the High Scenario this is achieved approximately 50 years earlier. Therefore, models from different time steps and scenarios for a single species will appear almost identical in comparisons.

In addition to the Current scenario, the three time steps combined with the Low, Medium and High Scenarios provided a total of 10 sets of predictions for each species and biome at different time steps of 2030, 2050 and 2080 (Table 2). Therefore this study is a compilation of 200 models, with 10 separate model combinations when applied independently to the 15 species and five biomes that were examined.

Spatial data

All spatial data used in this study had 100 m resolution, with dimensions of 5942 rows × 8494 columns. Maxent software provides reports in HTML format but also as text files that can be converted to raster data formats and displayed in a GIS with other spatial data (boundaries, field data, etc.). Raster outputs of the Maxent models displayed probabilistic outputs of the distribution of the species/biome at each pixel. Importantly, these are biophysical models and not bounded directly by the extent of native vegetation. In this respect they may be viewed as spatial representations of the potential distribution of the species/biome irrespective of land use activities. As this project was focused towards current distribution and future impacts the model was constrained to current extent of native vegetation using DSE's Native Vegetation 2005 dataset that had previously been developed by the authors. Similarly, future epochs were constrained to the same dimensions to enable systematic comparisons, although this was not meant to imply that the future extents and distributions would be identical to the current extent.

SDMs presented in their raw form can be difficult to interpret when presented as unbounded continua. Consideration was made to setting various 'thresholds' to minimise this effect (e.g. Liu et al. 2005), however the single probabilistic cut-off value for any species would have been an arbitrary assignment, and was not necessarily applicable to other species/biomes. After consideration of several different colour schemes a simple grey scale in 20 categories applied, with the greater density of black representing higher probabilities of occurrence.

RESULTS

More than 200 separate SDMs were developed in this project, and it is impractical to display all results and associated statistics in full here. However, the full

Table 2. Matrix of Maximum Entropy models developed in study. X – indicates models developed for each of the fifteen species and five biomes in Table 1.

	Current climate and time step	**2030**	**2050**	**2080**
	X			
Low				
SRES B1		X	X	X
Medium				
SRES A1B		X	X	X
High				
SRES A1F		X	X	X

suite of results are provided in Newell et al. 2009, which is also available for download in two separate volumes from the Arthur Rylah Institute's website (www.dse.vic.gov.au/ari/*)*.

Ideally the results of this study could be expressed in simplistic form as the degree of change in distribution of a species/biome relative to the current distribution. This is unfortunately difficult to calculate as the results from each model output are a probabilistic gradation rather as a binary (yes/no) output. In general, the narrative of the response from current through to 2080 is for a decrease in the probability or likelihood of a species/biome being present at a site in the future. For some species/biomes there are also some subtle and often substantial geographical shifts southwards or south-easterly direction. The rate and severity of these general responses increase with time from the present, and with the severity of the climate change impact scenario that has been applied. A summary of all results is shown in Table 3, which also indicates where the models are 'clamped' (i.e. model unreliably projected outside the original environmental domain of the current model).

Example sequences of the spatial outputs from climate impact modelling for three single species are provided for *Eucalyptus dumosa, Allocasuarina luehmanii* and *E. microcarpa* (Figs. 1-3). These outputs are all based on the 'medium' impact (SRES – A1B) from current to 2080 time period. Each of these sequences provides an example of the decrease in probabilities across future time steps. The example of *E. microcarpa* also shows a south-easterly range shift, with the potential for new populations in far eastern Victoria.

Results of biome models are shown in Figure 4, and display the relative differences in projected impact to different vegetation systems over time in response to the medium scenario. While all biomes contract in coverage, and shift to varying degrees, dry forest and open woodland biomes appear to be less impacted than semi arid woodlands or mallee systems when assessed at this very coarse scale.

While the examples shown in Figures 1–4 provide a state-wide context it can be difficult to clearly detect range shifts at more local landscape scales. The primary purpose of this study was to examine the potential for changes in the distribution of native vegetation in northern Victoria in response to climate change, and was sponsored by North Central Catchment Management Authority. Figure 5 displays the sequence of model outputs (medium scenario) for each of the five biomes from the current to 2080 epoch for NCCMA and adjacent regions. It is clear from this figure that each of the biomes appears to contract and 'migrate' southwards, and to decrease in probability over the 80 year time period. Dry Forest and Open Forest/Woodland biomes tended to be more constrained to the south and at higher altitudes over time. Interestingly, the Floodplain biome also shifts southward (and upslope) into regions that would be physically incapable of supporting floodplain communities following the projected decline in rainfall in northern Victoria. This provides some indication of the degree of influence of climate variables to these SDMs, and that at times they are capable of producing clearly illogical predictions.

DISCUSSION

This project had an ambitious aim of developing models to help understand the likely impacts of a changing climate upon Victorian ecosystems. The term 'ambitious' is not used lightly. Any study that purports to forecast likely outcomes is effectively 'fortune-telling'. This study attempts to avoid this position, and it is important to understand that the results here do not, and cannot, predict the future with any certainty. While some scientific disciplines have developed tightly-defined 'cause and effect' relationships with high levels of predictive power (e.g. meteorology, metallurgy, other physico-chemical sciences), ecology remains essentially correlative in nature. Even when 'causal' relationships are clearly understood in ecology, they are often complex and nonlinear in form, and the ability to predict a response to any particular event with a high level of certainty can be extremely difficult. With these thoughts in mind, it is important to realise that the focus of this study was to form new insights as a starting point for dis-

Table 3. Summary of distribution models species and biomes from northern Victoria. x = present, s = distribution displays shift in south or south-easterly direction, mc = moderate clamping of spatial model outputs, sc = severe clamping of spatial model outputs.

Species / Biome	Common Name	Field Data Locations	2030			2050			2080		
Scenario			Low (SRES B1)	Medium (SRES A1B)	High (SRES A1F)	Low (SRES B1)	Medium (SRES A1B)	High (SRES A1F)	Low (SRES B1)	Medium (SRES A1B)	High (SRES A1F)
Semi-Arid Woodland											
Acacia oswaldii	Umbrella Wattle	68	x	x	x	x	x	x	x	x	x
Allocasuarina luehmanii	Buloke	536	x	x	x s,mc	x, mc	x s, mc	x s, mc	x, sc	x s, sc	x s, sc
Casuarina pauper	Belah	126	x	mc	mc	x, mc	mc	mc	x, mc	sc	sc
Alectryon oleifolia	Western Rosewood	178	x s	x s		x s			x s		
Semi-Arid Woodland Biome			x	x s	x s	x	x s	x s, mc	x s	x s, mc	mc
Mallee											
Eucalyptus behriana	Bull Mallee	198	x s	x s	s	x s	x s	s	x s	x s	s
Eucalyptus dumosa	Oxley White Mallee	740	x s	x s	s, sc	x	x s, sc	s, sc	x	s, sc	sc
Eucalyptus polybractea	Blue Mallee	65	x	x		x	sc	sc	x	sc	sc
Eucalyptus viridis	Green Mallee	122	x	x		x	mc	mc	x	sc	sc
Mallee Biome			x	x	x	x	x		x	x	
Open Forest / Woodland											
Eucalyptus leucoxylon	Yellow Gum	4392	x	x	x s	x	x s	s	x	s	s
Eucalyptus melliodora	Yellow Box	1078	x	x	x	x	x	x s, sc	x	x s	x s, sc
Eucalyptus microcarpa	Grey Box	1158	x	x	x s	x	x s	s	x	x s	s
Woodland Biome			x	x	x	x	x	x s	x	x s	x s
Dry Forest											
Eucalyptus macrorhyncha	Red Stringybark	2536	x	x	x	x	x	x s, mc	x	x	x s, sc
Eucalyptus tricarpa	Red Ironbark	1150	x	x	x	x	x	x s	x	x	x s
Dry Forest Biome			x	x	x	x	x	x, mc	x	x	x, sc
Floodplain											
Eucalyptus camuldulensis	River Red Gum	1620	x, mc	x, mc	x, mc	x, mc	x, mc	x, sc	x, mc	x, mc	x, sc
Eucalyptus largiflorens	Black Box	760	x, mc	x, mc	mc	x, mc	x, mc	sc	x, mc	x, sc	sc
Floodplain Biome			x	x	x	x	x	x	x	x	x

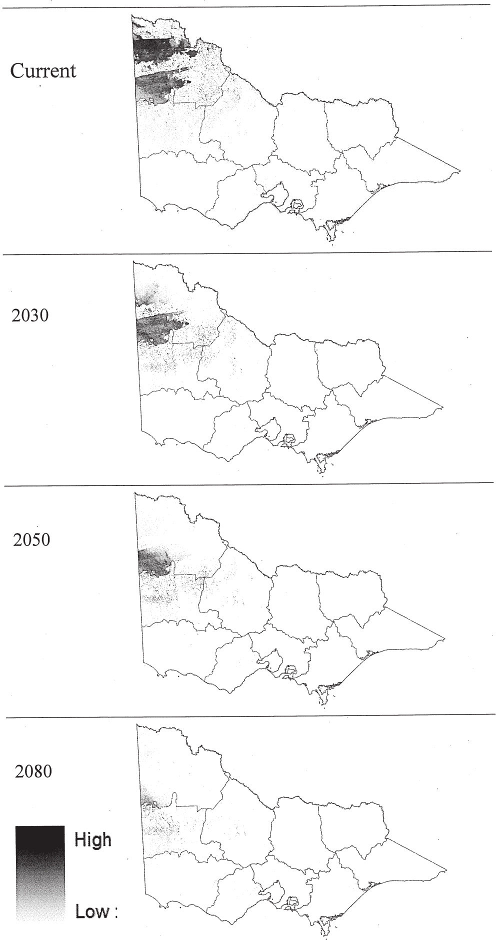

Fig. 1. Example of the current species distribution models for *Eucalyptus dumosa*. Impact modelling for Medium Climate Scenario (SRES A1B) are shown for 2030, 2050 and 2080 time periods.

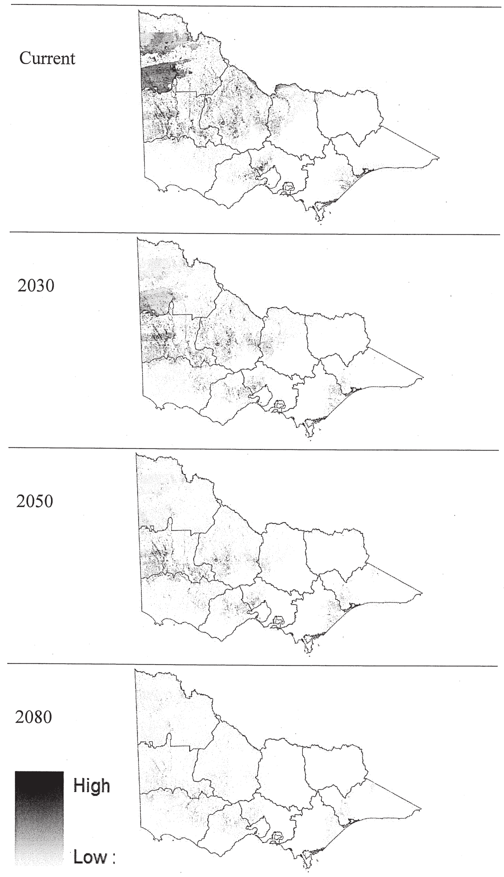

Fig. 2. Example of the current species distribution models for *Allocasuarina luehmanii*. Impact modelling for Medium Climate Scenario (SRES A1B) are shown for 2030, 2050 and 2080 time periods.

cussions and debate, without necessarily proscribing what *will* happen in the future.

The study has attempted to improve on past approaches of evaluating the impacts of potential climate changes on biodiversity (e.g. Brereton et al. 1995; Newell et al. 2003) by using a modelling approach that incorporates biophysical and climate parameters, as species distributions are the result of a suite of environmental drivers and not climate alone (e.g. Heikkinen et al. 2006a; Pearson et al. 2006). We were careful in the parsimonious and consistent selection of predictor variables that would encapsulate the majority environmental drivers for the suite of species/biomes considered. In taking this approach all models were developed from the same suite of generic predictor variables, and were not tailored to individual species or biomes. This common suite of variables facilitates comparisons and contrasts *between* models for a species or biome, between taxa, and between time steps. Ideally constructing SDMs by tuning parameters (i.e. carefully developing individual species models) would be preferable, but unfortunately is very time-consuming (Phillips & Dudik 2008).

In this study we have attempted to examine impacts at the vegetation community-level, as well as taking a single species approach. While the 'biome' units used here are simplistic, they are arguably superior to a vegetation typology such as ecological vegetation classes (EVCs) in this instance and for this purpose, as EVCs are likely to be narrowly cir-

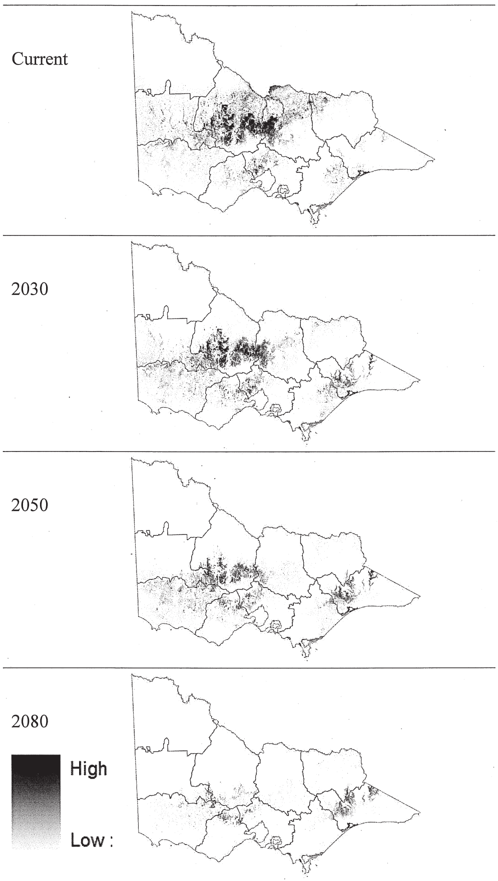

Fig. 3. Example of the current species distribution models for *Eucalyptus microcarpa*. Impact modelling for Medium Climate Scenario (SRES A1B) are shown for 2030, 2050 and 2080 time periods.

cumscribed given the landscape-scale responses to climate change. Although woody species, particularly those of the genus *Eucalyptus*, have been the primary focus of the study, we do not imply that they would define a complete biome. Ideally, in an all-encompassing biome study we would incorporate a more complete range of life-forms within a biome, including many species that may be less resistant to a drying climate than tree species.

Many commentators have suggested on the basis of ecological knowledge and theory that current vegetation assemblages may not persist in response to altered climatic regimes, and new communities would be novel admixtures of introduced and indigenous species (e.g. Walker & Steffen 1997; Dukes & Mooney 1999; Low 2000; Kriticos et al. 2003; Pearson & Dawson 2003; Thuiller et al. 2005b). Until more complex and integrated modelling systems become available it remains difficult to model and explore such potential dynamics beyond ecological concepts. Recent advances provide scope for more complex modelling of ecological systems with respect to climate change impacts in terms of population viability, dynamics and dispersal (e.g. Keith et al. 2008; Huntley et al. 2010). However robust computational systems for examining re-organisation of ecological communities are currently not available.

There are a plethora of statistical approaches to modelling species distributions, all with strengths and weaknesses (e.g. Elith et al. 2006; Heikkinen et al. 2006a). Maximum entropy (Maxent) is a recent method that provides high levels of predictive performance and ease of use (Heikkinen et al. 2006b; Phillips 2008; Phillips et al. 2006, 2009; Phillips & Dudik 2008). Maxent develops models from raster environmental data in conjunction with species' location data. Model outputs are a representation of the suitability of all grid cells presented for analysis. In effect, Maxent compares all cells and assesses a range of different probability distributions to determine which distribution encodes the greatest entropy (i.e. explains the maximum amount of information of the species' distribution from the environmental data). Maxent then interprets this distribution as a probability surface. As such, Maxent models are probabilities from a *probability distribution*, and should not be interpreted as an absolute probability of presence or occurrence of the species at any location.

The manner in which these probability distributions are displayed is important for providing meaning to the outputs. The representation of the information (i.e. the colour ramp or gradation) is critical to how 'maps' are perceived, evaluated and appraised, and inferences can be heavily influenced by the numerical and colour stretch or ramp applied to the values (e.g. Lindley & Crabbe 2004; Phillips 2008). Assessing SDMs and probability values is not always intuitive, and SDMs do not of themselves clearly display underlying uncertainties (Elith et al. 2002). Ideally, probabilities would be set to an optimal threshold that best represents the prediction of each species' distribution (Liu et al. 2005), however this remains an arbitrary procedure to be applied independently to each SDM. In order to provide consistent comparisons among all species and biome models, we have provided the full probabilistic range for each species displayed as a single grey-scale.

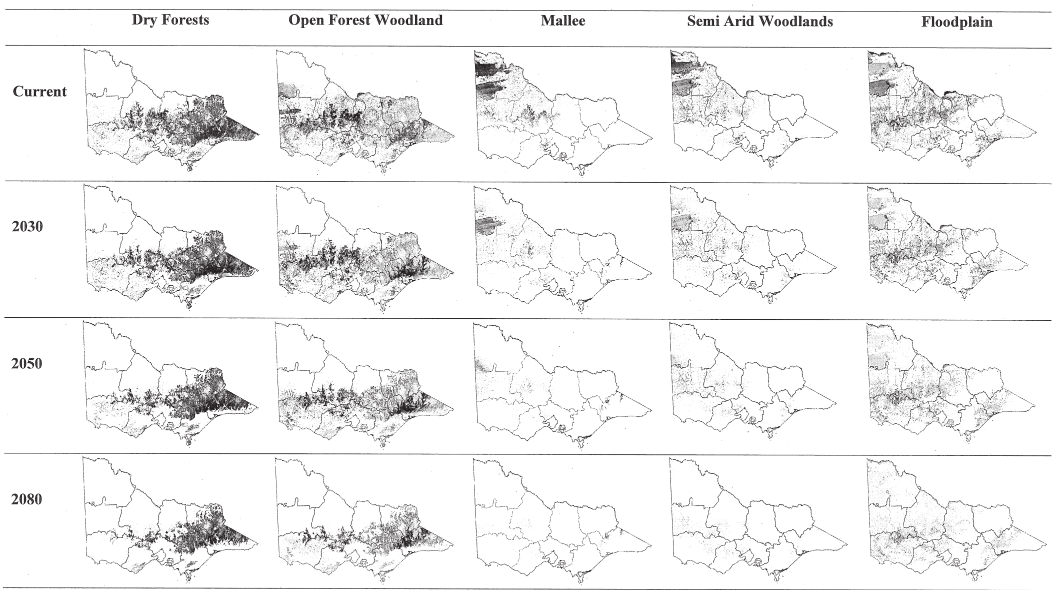

Fig. 4. Models sequence for five biome from current distribution to 2080. All models based on medium scenario - SRES A1B.

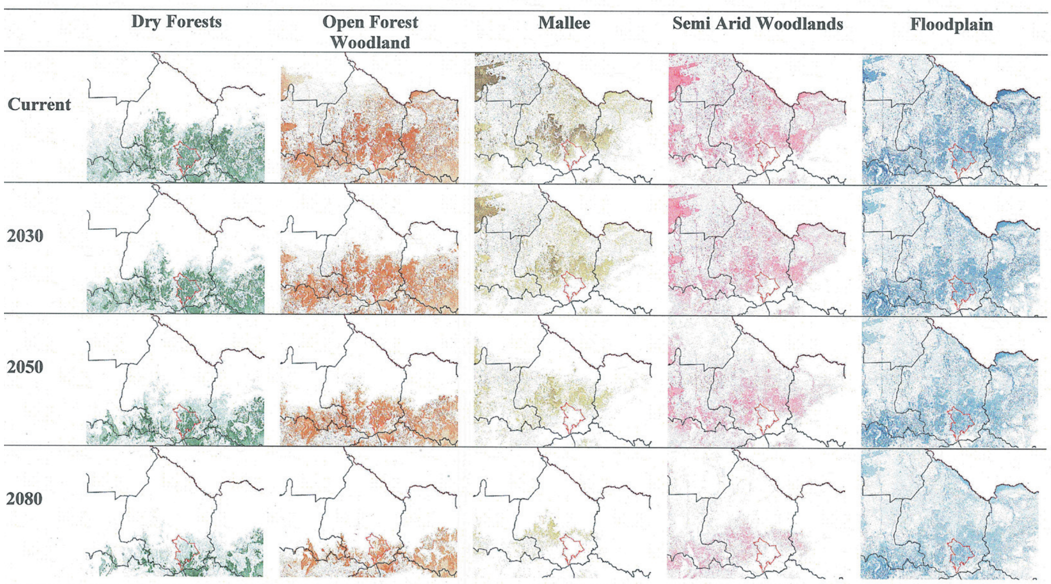

Fig. 5. Models sequence for five biome from current distribution to 2080 for North Central region of Victoria. All models based on medium scenario - SRES A1B.

A range of factors need to be considered when discussing the constraints to developing SDMs in a general sense. Developing statistical models that are expressed spatially is not a simple task, and there are many other constraints or caveats. For example, SDMs rely heavily on location data. DSE's Flora Information System (FIS) is an excellent resource with a high level of curation; however it is not systematic in its coverage, and does not extend into other states' jurisdictions. Importantly, the majority of data in the FIS is from the public estate, and native vegetation on private land is significantly under-represented in this and other data resources. These and other types of biases in the data (e.g. positional accuracy), can have considerable influence on both the statistical performance of an SDM, as well as its degree of 'ecological coherence' by which all such models should be evaluated.

Political and administrative boundaries are mostly irrelevant to species' natural distributions. Hence, using Victorian data alone for species that maintain wider distributions infers that we are only modelling part of the species' range, and that such models may be unreliable (Phillips & Dudik 2008). Thuiler et al. (2004) identified the importance of using the species' full environmental and distributional ranges to attain maximum model reliability, and that without the full suite of information models can be unreliable, particularly towards the edges of the modelled distributional ranges. None of the species investigated in this study would be considered Victorian endemics, and models are likely to be constrained to varying degrees. Despite concerns on the extent and representativeness of field data, Maxent can often produce robust and useful SDMs from very small amounts of well located field data.

When models are 'transferred' in space or time they can rapidly become invalid and uninformative, with the magnitude of uncertainty increasing with ecological distance from the original modelled environment (Araújo et al. 2005b; Pearson et al. 2006; Peterson et al. 2007; Phillips 2008). The ultimate arbiter of the performance of 'future' models will be their evaluation at the appropriate future time step (Araújo & New 2007). Critically, there is no method available for validating or confirming transferred (i.e. future) models. Consequently these outputs should be interpreted with considerable caution, and they will have limited use in forming policy or framing management actions (Sinclair et al. 2010). In the interim, the only sensible performance criterion that can be applied to future models is whether they make ecological sense (e.g. 'expert opinion').

Just as models cannot easily be evaluated when 'transferred', it can be difficult to interpret models at resolutions finer than at which they were developed. The majority of the underlying spatial data in this study had a native resolution of between 100 and 250 m pixel scale, however the representations of climate change scenarios at the time of this study were at a much coarser resolution (16 km, i.e. 250 km^2 per pixel; see Skelly & Henderson-Sellers 1996). There are significant limitations when combining/merging such data, and uncertainties can rapidly amplify when down-scaling from coarse to local scales. It is therefore critical that local-scale interpretations of these results are treated with a healthy scepticism.

Although unreliable for local landscape planning purposes, the models can be useful for developing exploring concepts about the way that biological entities (species, communities, biomes, etc.) may respond over time. However, these ideas can be limited by a thorough understanding and appreciation of mechanisms. A major constraint to predicting trends and rates of change relates to whether transitions will be slow and gradual (e.g. Walther et al. 2002), more dramatic and promoted by extreme events and/or perturbations (e.g. Gell et al. 1993; Lunt 2002), or in response to critical thresholds that maybe yet unforseen (e.g. Scheffer et al. 2009; Huntley et al. 2010). At present it is impossible to know which of these mechanisms will have the most influence in altering the composition of plant communities, and under what circumstances.

Various meta-analyses of the impacts of climate change on biodiversity have suggested that distributions will shift towards the poles and increase in altitude (e.g. Parmesan & Yohe 2003; Root et al 2003; Parmesan 2006). On first impressions and at coarse scales these principles may make 'ecological sense'. However, a more intimate knowledge of biota and their life histories may often suggest otherwise. For example, results in this study suggest distributional shifts for the floodplain biome, and both *E. camuldulensis* and *E. largiflorens* as independent species, away from riverine systems along with increases in altitude. The results are clearly implausible, but they do serve to highlight difficulties in model development and interpretation, and the requirement for the considered selection of informative predictor variables (e.g. Burnham & Anderson 2002). A further example can be seen in Figs. 4-5, where the Open Forest/Woodland and Dry Forest biomes are more impacted by the climate change sequence than Mallee and Semi Arid Woodland biomes which are arguably much less mesic.

While spatial models are increasingly sophisticated they are potentially naive tools when used without careful evaluation and consideration. This is further exemplified where there are immediate and direct responses to altered climatic situations as shown in SDMs. Many tree species considered in this study are long-lived, and individuals and populations will have been exposed to large variations in climate over many hundreds of years. The species examined in this study are arguably well adapted to climatic regimes with high levels of variance in temperature, rainfall and other parameters. These species have presumably formed distributions over many thousands of years, partially in response to shifts in global and local climate regimes (e.g. Jones 1999a, b; Hopkins et al. 1993), and the potential for local adaptation may be underestimated (Jump & Peñuelas 2005). In essence, it is difficult for this current modelling process to account for ecological inertia or recalcitrance, or to respond temporally at a scale relevant to the species being modelled.

Although an apparent inertia may be one response to an altered climate, another response may be rapid and unpredictable changes. For example, eucalypts are known to hybridise widely under natural conditions (e.g. Potts & Dungey 2004). Hybridisation is one of the potential long-term mechanisms for adaptation to a changing climate, and eucalypts may be well situated in this regard, although contrary views on the tolerance of eucalypts to climate change impacts do exist (e.g. Hughes et al. 1996a, b).

Perhaps another perspective on rapid immediate responses inferred from modelling may be to consider 'future distributions' as representing potential regeneration or recruitment niche, rather than a spatial representation of where a species may persist in the future. Unfortunately current modelling processes deal with an 'average' future climate, and do not clearly represent the extreme events that many native species require for recruitment events (e.g. fires, floods).

Not withstanding the caveats and limitations discussed, the general flavour of the results here are consistent with other studies (i.e. pole-ward and altitudinal shifts in distribution models; e.g. Malcolm et al. 2002; Parmesan & Yohe 2003; Root et al. 2003). While there have been improvements in data, computational power and modelling techniques over the last two decades resulting in models with improved in resolution, breadth and complexity, the overall narrative that could be interpreted from the range of individual studies and meta-analyses has essentially remained similar. Despite this consistency, conceptual improvements in assessing the vulnerability of biodiversity to climate change (e.g. Williams et al. 2008), and re-evaluations of risk management practices (e.g. Burgman 2005; Hubbard 2009), the development of new rigorous approaches for conservation management remains limited.

There is a significant risk that the impacts of climate change on biodiversity will increasingly be considered the only worthy conservation issue. We would argue, as others have done (e.g. Kapelle et al. 1999; Jump & Peñuelas 2005), that climate change is likely to exert its effects in both direct and indirect ways. The direct exposure of the species to extreme climatic events, as well as alterations to the overall climatic regime, may have significant negative or positive impacts on an individual organism's survival, resulting in intense selection pressures at the local population levels (Jump & Peñuelas 2005). However, impacts may be more complex, where climatic extremes and altered regimes may work synergistically with factors already impacting upon biodiversity and landscape health more broadly (e.g. habitat loss/fragmentation, altered configuration of vegetation, loss of quality/condition of vegetation, salinity impacts, and weed/pest invasions). In essence, the synergism between climate change and existing impacts may pose the greatest threat, rather than a new specific and direct threat to biodiversity (e.g. Jump & Peñuelas 2005). Rather than trying to second-guess emerging threats, increasing the scale and extent of current ecological restoration activities may be more beneficial to long-term persistence by fostering ecosystem resilience (e.g. Hannah et al. 2002; Folke et al. 2004).

While scientists and policy makers require an understanding of the natural environment at local scales where appropriate management can be applied, current technologies can not always provide the right type of knowledge. While tools for modelling ecological systems are improving in their level of sophistication, they are too crude at present to predict ecological futures with the certainty required by policy and management (Sinclair et al. 2010). The tools and mechanisms used currently by land mangers for biodiversity conservation are simplistic in some respects, yet may be very effective for current conservation actions for biodiversity (e.g. Hobbs & Kristjanson 2003). However at the current scale of their application and scope, these activities are unlikely to be very effective without enormous increases in intensities and spatial extents. While new management tools and strategies are required and may emerge in the future to address the impacts of climate change upon biodiversity, it would be foolish to wait inactively for these 'magic bullets' while current knowledge and insights may provide the best prospects for the long term persistence of biodiversity.

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NORTH CENTRAL VICTORIA: UNDERSTANDING ITS PAST TO PLAN FOR ITS FUTURE

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The organisers of The Royal Society of Victoria's conference *North Central Victoria: a golden era, a changed ecosystem forever?* held in December 2009, invited me to take part in the conference to provide a summary and personal perspective on the proceedings. This I did at the end of each of the two days of the conference. My reflections on the proceedings of those two days form the basis of my essay below.

Key words: north central Victoria, landscape degradation, ecological restoration

NORTH central Victoria is a region with an extremely interesting geological history and a rich indigenous history. Comparatively recently, in geological time and indigenous residence time, it has had a varied history of colonisation by a diversity of peoples. The geological history dating back millions of years shaped the landscape and its soils and laid the foundations for support of humans. There is no doubt that the Jarra people who occupied the region for tens of thousands of years would have had a major impact on the biota of the region over the period their culture evolved with the landscape. Much of this rich history has been lost over the past two centuries. However, they were living in a way that was sustainable when Europeans invaded the region initially in search of grazing lands and then seeking their fortunes in gold. The successes of grazing and gold mining were a result of the rich geological legacy of the region.

The last 200 years have had major and degrading influences on the original human inhabitants, the native biota, ecosystem processes and the landscape itself. The chapters of these proceedings set out these influences and advance some solutions to address this degradation.

Pastoralism was the major activity as Europeans first settled the region to take advantage of the extensive native grasslands. With discovery of rich goldfields in the region in the middle of the 19th century, a major gold rush commenced. This started a period of very rapid and extensive social and environmental change. During 1851 and 1852, 300 000 people sailed into the colony of Victoria to take part in the gold boom. The population of the colony increased seven-fold with many people flooding into the North Central Region. The goldfields around Bendigo were incredibly rich, producing 450 tonnes of gold; much of which was taken from the surface. Over a period of only 17 years, Bendigo became a major regional city with many stately public buildings and private homes reflecting the wealth of the area and some of its inhabitants.

ENVIRONMENTAL IMPACTS OF EUROPEAN INVASION OF THE REGION

The environmental effects of this invasion of mainly European colonists were rapid, extensive and long term. Clearing of land for mining and agriculture, mining, harvesting timber for mining activities and firewood, introduction of exotic species for pastoralism and agriculture and to create a sense of 'the old country', changing fire regimes, clearing for urban development, harvesting of water and pollution from most of the colonists' activities, all had major detrimental environmental impacts. Many of these environmental threats still pose problems today and will do so well into the future. The environmental impacts of these threats have been well documented and papers in these proceedings elaborate on the impacts.

The conference on which these proceedings are based provided a catalogue of decline of the region's biota. There was rapid and extensive loss of woodlands and understory vegetation. The result is that only 20% of the region now has any of the original native vegetation associations remaining. This remnant vegetation is fragmented into many small isolated patches. Only 30% of River Red Gum is in good condition now, compared with 68% in 1990. The reasons for this decline vary; upstream falling fresh water tables are impacting on the health of the trees, but downstream in the mallee region, it is shallow saline water tables that are causing the decline of River Red Gum. In addition to the massive loss in extent of native vegetation, there has been major decline in quality of native vegetation. Only 3.8% of native grasslands remain and only 1.7% of the original grasslands are in reserves. Twelve species (28%) of the original mammal fauna have disappeared from the region and much of the knowledge of the distribution, abundance and ecology of the biota is out of date. Birds are the best studied group and they are declining throughout the region and beyond. We have yet to see the extinction debt run its course with mammals and birds. This is also true of reptiles, amphibians and native vegetation.

What do we know about invertebrates? Invertebrates constitute the vast majority of faunal biomass, possibly as much as 95%, but we know very little about them. What we do know shows the same declining trends as the vertebrates. For example, aquatic invertebrates have declined in one river in the region. This lack of knowledge of invertebrates needs to be addressed as invertebrates drive major ecosystem functions; for example, nutrient cycling and pollination. A major impediment to addressing this lack of knowledge is that we are not producing enough invertebrate ecologists and taxonomists to generate the knowledge essential to management. If we follow our present course without addressing these biotic declines, we are going to see a massive loss of the biota by ecological processes. The theory of island biogeography demonstrates that the remnants of native vegetation in the region are carrying more species than they are capable of carrying over time and species will be lost; that is we will see 'species relaxation' over time. The time taken for this to happen will depend on the size of populations and the longevity of individuals. While it might take years to decades for the shorter lived organisms to disappear and centuries for the longer lived trees, it will happen unless major landscape reconstruction and restoration takes place.

The loss of native vegetation has resulted in major changes to water flows across the landscape and into ground water. As a result of these changing water flows, ground water tables have risen, with soil salinity first appearing in the 1950s. By the 1970s extensive areas were affected by salinity. Groundwater systems are complex and are poorly understood. However, it is worth pointing out that Aboriginal peoples' understanding of their groundwater systems permeates their Dreamtime stories and demonstrates they had a fundamental understanding of the importance of groundwater. Climatic variation has the greatest overall influence on changes in depths of water tables. The region had rising water tables through the 1980s and first half of the 1990s. Rainfall has decreased greatly since 1996. As a result of changes in global and regional climates, the region may be in for further reductions in rainfall, increased maximum temperatures and increased incidence and severity of fires. Since 1996, changes in rainfall in the region have had major impacts on groundwater, with recharge ceasing and water tables falling. Since 1996, apart from a recharge pulse in 2000, monitoring of bores in the region has shown ground waters declining. This drying period has diminished the impacts of dryland salinity, but salinity still remains a threat, should there be wetter periods. Salinity is a problem in areas where irrigation is operating. Salinity can be controlled provided there is significant attention to effective management of discharge areas.

There has been an 84% decline over the long term average rainfall in the region. As a result, catchments are drying dramatically. Surface flows are declining, lakes are drying and most streams in the region are not in good condition. Under current climate predictions, more and more ground water will be used, accelerating declines. How do we manage our landscapes to retain lakes and streams as well as providing for human uses? It is ironic that at a time when we need better understanding of water flows, including time series on groundwater levels and quality, field hydrogeologists, the key to understanding water systems, are becoming increasingly rare as institutions are dropping courses to train them.

In addition to the environmental impacts, there were major impacts on Aboriginal peoples of the region. Contrary to popular belief, the gold rush did not wipe out the Indigenous people of country; they were an important presence in the goldfields during the gold rush and they are an important presence now.

WHAT OF THE FUTURE?

What do we know of the region's past? What was the landscape like before Europeans arrived? What vegetation associations were associated with particular soils, slope, aspect, etc? What was the biota associated with these vegetation associations? We need to understand the past in order to plan for the future. Knowledge of the original vegetation associations are essential in order to plan for restoration and reconstruction.

We need to acknowledge that it is the local people and communities who manage the landscapes of the region. It will be their visions and aspirations that will drive any restoration and reconstruction. However the difference between visions and aspirations for the future and environmental actuality will become much more pronounced unless communities are better empowered and resourced than they are at present. The current situation in relation to community support for conservation and landscape management was summed up at the conference by Peter Morison (2010), who said ironically: 'that despite all this help from the government, community groups still survive.' What is encouraging is that the number of community groups involved in conservation and landscape management is increasing while all of the indicators of environmental health are declining.

What is interesting is that we are good at cataloguing the impacts of development, but not good at working out practical solutions and applying them. For example, 24 of the conference's 31 presentations provided information on environmental and social decline in the North Central Region, but only seven attempted to address solutions to these declines.

With regard to empowering community groups to address landscape management, I acknowledge that there have been multiple government programs over time dealing with natural resource management, but there has been no continuity of funding. The result is that there is no hope of retaining skilled facilitators and building stronger community groups. Local views are often ignored by governments when deciding on land uses and landscape planning. Somehow such decision-making needs to be decentralised. There is little doubt that Australia has the resources to address our regional environmental and social problems, but those resources are not directed there. For example, while environmental groups are starved of funds, the federal government is prepared to spend $36 billion on 12 new submarines, to replace the six Collins Class submarines, each of which at $1.7 billion cost more than all the funds committed to the Natural Heritage Trust under the previous Howard government. Not only are they prepared to commit to these funds, but they are prepared to commit to a long-term goal of building them over the period to 2070. I fail to see why governments cannot commit to long-term environmental goals to address threats to Australia far more serious than the ones to be addressed by 12 submarines; or one submarine per 2522 km of coastline, if all were at sea together. Somehow we have to change government priorities over resource allocation. This we have to do conscious of our then current Prime Minister, Mr Kevin Rudd's enthusiastic support for an Australian population of 35 million by 2050. The North Central Region's environmental and social problems are severe under our current population. How much more difficult will it be to address these problems under nearly twice our current population?

Looking to the future, there are a number of things we collectively need to do. There is already a great deal of information available about the natural resources of the North Central Region. We need to integrate this current knowledge to provide better understanding of the way the region's landscapes function. We then need to interpret this integrated knowledge to develop shared visions of what these landscapes will look like, how they will function ecologically, socially and economically in future. Then we need to build the support to carry out the restoration and reconstruction necessary to achieve those shared visions.

I believe it would be helpful to get a group together from a wide range of disciplines and spend a week at a retreat somewhere in the North Central Region and set out what is currently known about landscape function and what can be done practically to mitigate the worst environmental impacts. Such a group should include farmers and at least one politician, as understanding the political process is critically important in our path to the future.

Finally I'd like to make a plea for all to tithe to the future. We should set aside 10% of our time towards interpreting our work so that it can be applied by those who are going to do the work of landscape restoration and reconstruction.

We should also take a leaf out of our Aboriginal peoples' book by working with their philosophy of: 'we are country and country is us'. Only then will we learn to live within the capacity of country to support us in perpetuity.

REFERENCES

Morison, P., 2010. Landscape recovery - community resilience in the face of democracy. *Transactions of the Royal Society of Victoria* 122(2): lxxvi-lxxviii.