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Professor Iain M. Young
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22 April 2009

Carolyn Littlefair
Senior Committee Officer
Legislative Assembly
Standing Committee on Natural Resource Management
(Climate Change)
Parliament House
Macquarie Street
SYDNEY NSW 2000

Dear Carolyn,

Re: Managing climate change impacts on biodiversity inquiry

It is with great pleasure that I attach our submission to assist your enquiry. Please do not hesitate to contact me if you require further information.

Yours sincerely,

Professor Iain M. Young
Head of School

Encl.

Managing climate change impacts on biodiversity

Submission to the NSW Legislative Assembly

School of Environmental & Rural Science

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22 April 2009

Executive Summary

The School of Environmental & Rural Science (ERS) is the premier teaching and research school in the areas of agricultural and natural sciences in Australia. With over 80 academic staff researching a wide range of subjects related to feeding and protecting the planet, ERS is unique in that its teaching and research programmes explicitly recognize the functioning of the landscape with a Systems Approach. UNE developed the first Natural Resources Management degree in Australia and has one of the most successful Rural Science degrees.

This submission covers the implications of climate change on invasion of weeds, species distribution and life cycles, ecosystem health and other perceived threats. We also address the adequacy of management strategies to address biodiversity in NSW.

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Introduction

In their most recent assessment on climate change the Intergovernmental Panel on Climate Change (IPCC) concluded that warming of the climate was unequivocal, with humans being the most likely cause of the warming experienced since 1950, and that changes in the climate system would most likely continue well into the future with future changes being larger than those in the recent past.

Greenhouse gas concentrations are increasing at an alarming rate; in fact the trend in greenhouse gas emissions are higher than the worst case scenarios developed by the IPCC: Special Report on Emissions Scenarios (Global Carbon Project, 2008). On a global scale, emissions from the combustion of fossil fuel and land use change reached almost 10 billion tonnes of carbon in 2007, with Australia's fossil-fuel emissions growing by 2% per year since 2000 (Global Carbon Project, 2008). While carbon sinks (both natural land and oceanic) have removed 54% of all carbon dioxide emitted from human activities during the 2000-2007 period (Luthi et al, 2008), the efficiency of these sinks continues to decrease, with efficiency decreasing by 5% over the last 50 years (Global Carbon Project, 2008). Compounding this situation is the fact that the amount of frozen carbon in the world's permafrost regions is double the previous estimates (Schuur et al, 2008) and the release of even a small fraction of this carbon has the potential to accelerate climate change significantly (Schuur et al, 2008, Global Carbon Project, 2008).

Sea level rise, resulting from a warming of oceans and melting of ice, seems to have increased in pace recently. The average rate of rise from 1961 to 2003 was 1.8mm/yr while it was 3.1mm/yr from 1993 to 2003 (Church et al, 2008), however it remains unclear whether this is a long term trend. The Intergovernmental Panel on Climate Change (2008) projected sea-level rises of 0.2-0.8m by the end of this century, however Church et al (2008) and the Antarctic Climate and Ecosystems Cooperative Research Centre (2008) have suggested that the actual rise may actually be greater than this.

Increases in greenhouse gas emissions, decreasing efficiency of carbon sinks and increases in sea-levels have the potential to affect or are already affecting a number of large-scale climate systems in Australia's vicinity. Pezza et al (2008) have suggested that the southward movement of the sub-tropical pressure ridge (a large belt of high pressure situated about 30^{o}S) could be contributing to reduced winter rainfall over southern Australia. Cai and Cowan (2006, 2008) have suggested that the drying trend in south-west Western Australia could be attributed to a combination of natural variability, increased greenhouse gas concentrations and changes in land-use patterns, with human induced components accounting for 50% of the decrease. It has also been suggested that the intensity of tropical cyclones will increase in the Australian region (CSIRO-BoM, 2007).

Changes in Australia's climate predicted by CSIRO (2007) were summarised by Stokes and Howden (2008) as follows:

> *Temperatures in Australia are projected to increase by 1 to 5ºC* [by 2070]*, depending on location and emissions scenarios …The greatest warming is expected in the interior of the continent,*

> *particularly towards the northwest of the country* [and the least warming in Tasmania] *… Associated with these temperature increases will be marked increase in the frequency of hot days and warm nights, but a less-marked decrease in the frequency of frosts … Regional changes in rainfall are very sensitive to changes in circulation patterns, so … there is lower confidence in regional projections of rainfall than temperature … Median rainfall projections … show a general pattern of drying across the continent that is strongest in the southwest. Drying trends are weaker in the east of the country, and the northern tropics are the least likely to experience declines in rainfall …* [Declines in median rainfall of up to 10% compared to 1980–99 are projected by 2030 across the southern two-thirds of the continent, with least reduction in Tasmania and north-eastern NSW. The decline in median rainfall by 2070 is projected to be 2–20% across most of the continent, except in the Top End and Cape Yorke.] *… there are also projected to be changes in rainfall distribution. The number of dry days (those with less than 1 mm rain) is projected to increase by about 10 days per year across a broad diagonal band from the southwest to the northeast of the continent, with little change in the southeast and northwest. The intensity of rainfall is projected to increase in most parts of the country, particularly in the north. Solar radiation is projected to remain almost unchanged across most of the country, but there could be small changes (increases of up to 10%) across the southeast and southwest corners by 2070. Likewise, changes in relative humidity are likely to be small with a general decrease across the country that is likely to be greatest in the western interior (2–3% decline by 2070). Potential evapotranspiration is expected to increase across most of the country, with the greatest increases in the north and east (4 to 12% increase by 2070). Changes in the amount and distribution of rainfall and increases in evapo-transpirational demand are projected to increase the incidence of drought with up to 40% more droughts in eastern Australia and 80% more in the south west by 2070 …*

Recent climate change risk assessments conducted by the local government entity the New England Strategic Alliance of Councils (constituted of Guyra, Armidale-Dumaresq, Uralla and Walcha councils) have identified as 'extreme' risks: the loss of local biodiversity, loss of non-urban vegetation, change in species composition of the local environment, reduced health of water ways, and increased weed infestation. The increased wild fire risk was rated as 'high'. (Assessment of Climate Risks for New England Strategic Alliance of Councils, Sinclair Knight Merz, 2009). Indirect effects of climate change are likely to be particularly severe in the northern parts of NSW where changes in fire regimes are predicted to occur as results of increased fire weather severity (Hennessy et al. 2006). Currently UNE is undertaking ARC funded research with DECC to examine fire severity patterns to establish baseline patterns of fire severity.

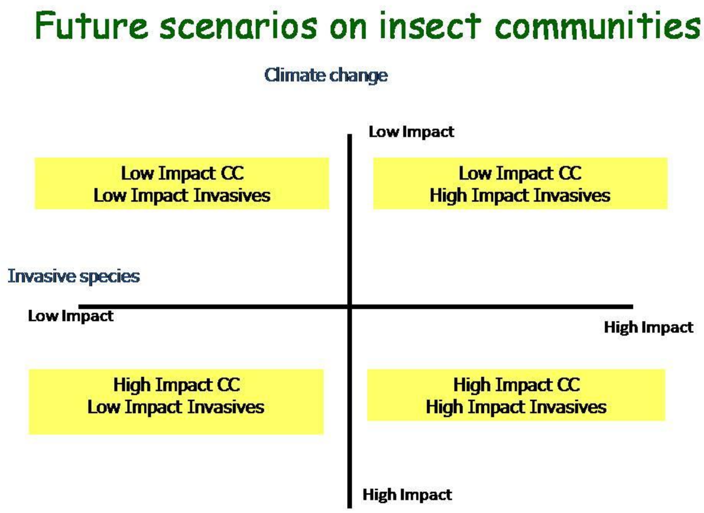
Recently DECC has funded the University of NSW to undertake more precise climate change modelling up until 2050 for the various regions in NSW (DECC 2009). Of particular concern are the projected changes in rainfall amount and seasonal distribution in all regions. While every region is impacted upon by climate change, south western NSW (the Riverina) in particular is projected to suffer from an overall reduction in rainfall, as well as a significant shift of from winter to summer incidence of rainfall (a 20-50% decrease winter rainfall, and a 10-20% increase in summer rainfall). It is not just the projected overall reduction in rainfall that is a concern, but also the signification shift in distribution from winter to summer. Due to evaporative demands summer rainfall tends to be less effective for plant communities and agricultural systems than winter rainfall. While long term rainfall projections are complex and imprecise, there is sufficient evidence to suggest that NSW urban communities, and agricultural and natural systems, will be impacted significantly upon by changes to rainfall regimes and will have to develop adaptive mechanisms to cope.

Implications of climate change on invasion of weed and pest species

Climate is the primary determinant of weed distribution in Australia. As climate changes, so many weeds are likely to expand their range, while some may contract, depending on individual climatic requirements for growth and reproduction. This means that whereas some species were once regarded poorly adapted or of low significance to a region, that could well change in the future. Land managers will be faced therefore with new weed threats with which they are currently unfamiliar. Likewise, climatic variability, marked by increasing frequency of droughts, floods and fires, will increase the spread of invasive weeds, which are typically adapted to such climatic disturbances. During droughts, the ground is often bared and when rainfall comes, invasive weeds are the first to colonise such bare ground due to larger numbers of seeds in the soil seedbank compared with desirable pasture species. Also, the movement of drought relief fodder and grain increases the likelihood of the spread of weed seeds from one area to another as contaminants of those products. The same scenarios exist for regions affected by bushfires, as has occurred in Victoria in the summer of 2009. Weeds are also spread by flood waters that carry buoyant seeds and plant fragments down-stream from existing weed infestations. In summary, climate change will lead to an increase in invasion of weeds throughout many parts of Australia, which are already struggling with a $4 billion annual impact of weeds on agricultural production and an enormous but as yet un-costed impact on the environment.

Currently there are 22 insect invasive species identified in Australia from the Global Invasive species database, of which ten species are ants. There impact will be highly dependent of the type of area in which they are found and the suite of insects that they will interact with. At this stage the impact of climate change and invasive species is highly unpredictable due to both climate change and invasive species having idiosyncratic impacts on individual species, so at the community level there may be a wide variety of responses.

For example four extreme responses on native insect species can be identified using a future scenario:



Low impact of climate change and invasive species: may occur where cosmopolitan native species already occur; where native insects are supported by a wide range of host plant and food sources; the insect assemblages has adaptable physiology across the species and a high amount of built in redundancy, and a high level of genetic variability.

High impact of climate change, low impact of invasive insects: such a scenario may occur when assemblages of insect species close to their upper thermal and moisture tolerances, but these species are competitive, generalist feeders on wide variety of food sources. Specie in this environmental already live in highly modified areas, having already have well adapted species to invasive since the intolerant species are already absent or extinct.

Low impact of climate change, high impact of invasives: Native insects in this category would include poor competitors; specialist feeders (ie have a few host plants or limited food sources), are locally rare. However they are good dispersers, and can survive in a range of climatic zones to adapt to a rapidly changing climate.

High impact of climate change, high impact of invasives: The biggest changes in occur in regions where climate change facilitates invasions of both exotic and indigenous species. It would be anticipated that novel invasive species would outcompete indigenous assemblages quickly, particularly those species which are specialist feeders or live in unique environments and intolerant to climatic fluctuations. Insect communities most at risk would include those with a high number of rare and smaller species. However common and widespread species could also be impacted by an invasive species to reduce food or increase competition for resources. The loss of widespread species can have significant impacts on a wide range of other species through changes both up and down the food chain (called a trophic cascade).

Implications of climate change on species distribution and ecosystem composition

Global Warming is at the forefront of future threats to species distributions and ecosystem composition, particularly at the interface (ecotone) between habitat types (Huggett 2004), where changes are likely to be most dramatic. Identification of the impacts of climate change on the distribution and abundance of species, and on the broader ecosystem processes that occur in native habitats that might be compromised by anthropogenic climate change is important, because a rich and diverse biota contributes to a healthy and resilient ecosystem that may in turn influence its ability to respond to environmental change (Allen et al. 1995). We currently have little knowledge about how climate change might be affecting the complex interactions between species in a community, and how such changes might ultimately impact upon ecosystems in terms of biotic composition, and ecosystem function. Because ecosystems are inherently complex, the ecosystem-level impacts of global warming are difficult to predict, and an ecosystem approach is required.

An example of a complex ecosystem process that might be affected by climate change is the relationship between forest trees, mycorrhizal fungi, and the mammals that disperse mycorrhizal fungal spores. Symbiotic mycorrhizal fungi occur on the roots of most vascular plants and confer important benefits to them, including enhanced mineral nutrient uptake, drought tolerance, and disease-resistance (Smith & Read 1997). Without mycorrhizal fungi, most plants do not thrive, making plant-fungal interactions one of the vital ecosystem links that enable communities to persist, and adapt to change. Mammals feed on fungal fruit-bodies (truffles) and the ingested spores remain viable after passage through their gut and enhance mycorrhizal formation (e.g. Caldwell et al. 2005).

Work at the University of New England in the forests of northeastern NSW have demonstrated that a diverse mammal community disperses a great variety of spores, and that some mammals routinely disperse spores across habitat boundaries (Vernes and Dunn 2009). What is now needed is an understanding of how fungal communities change over time as host communities respond to anthropogenic changes to landscape forest cover brought about by climate change, and whether mammals can moderate these changes. Understanding mammal-fungal interactions across habitat boundaries will be necessary if ecosystem managers are to be effective in maintaining plant-fungal processes in the light of global climate change. An understanding of the complex relationship between climate change and changes to fire regimes is also needed, and how other species might be affected.

Finally, understanding the complex relationships between mammals, fungi, and forest trees is important not just because forest health is a central part of biodiversity conservation in its own right, but also because forest regeneration will be a key tool in carbon sequestration programs that will help address global warming into the future. Substantial investments are currently being made throughout Australia into regeneration of native forests; further research in forest ecology will potentially render this investment much more effective in its impacts. Such research will also help forest ecologists better understand patterns of biodiversity, so that human-induced declines and extinctions of species can be effectively addressed.

Implications of climate change on species life cycle events

The life cycles response of mammals and plants to rapid changes in climate and increasing C02 has been reviewed extensively (e.g. Dunlop and Brown 2008, Steffen et al. 2008). Research at UNE is focusing three aspects of this; mammal persistence, plant persistence and insect interactions. For example, flowering and seed of crops and native vegetation set can be disrupted through both direct effects of rising temperature on flowering but also changes in pollinator activity such as insects, birds, and mammals.

Over the last 200 years, Australia is the region with almost half of the mammal extinctions worldwide. NSW extinctions have occurred predominantly in the semi-arid and arid zones and exclusively in homeothermic species (species that are unable to employ torpor for energy conservation and thus a reduction in foraging requirements). In contrast, the insectivorous/carnivorous dasyurid marsupials, which are most diverse in the Australian the arid zone and use torpor extensively in the wild to reduce energy requirement by up to 80% have all managed to survive. Research at UNE has shown that this is likely because heterotherms (species employing torpor) can persist during sudden or prolonged episodes of scarce resources, and, by minimizing foraging, avoid predators or human hunters. Moreover, because life span is generally longer in heterothermic mammals than in related homeotherms, heterotherms can employ a ‘sit-and-wait’ strategy to withstand adverse periods and then repopulate when circumstances improve. Thus, torpor is likely a crucial but hitherto unappreciated attribute of mammals evading extinction. This novel discovery provides a new tool in identifying likely threatened species, but requires a detailed investigation to establish how and why specific mammals are likely to be threatened especially with regard to climate change.

Indirect effects of climate change through changed fire regimes is also currently being addressed in a research program at UNE with NSW DECC; See Table 1. In particular there is the possibility for strong feedback effects of changing fire weather and increasing CO_2. We think these interactions pose major concerns for the management of biodiversity in NSW. Increased CO_2 may increase the flammability of fuels and combined with an increase in the Forest Fire Danger Index this is likely to have major impacts on plants and animals completing their life cycles through immaturity risk. Immaturity risk occurs when the frequency of fires is higher than the maturation rate of plants and animals and when fire intensity is such that spatial or temporal refuges are reduced. Species with narrow ranges are likely to be impacted the greatest under these circumstances and a large number of plants and vertebrates have narrow range sizes in northern NSW. Adaptation options are limited in these circumstances and will require detailed knowledge of plant and animal life history so that both species and community management plans can appropriately be parameterized.

Table 1 Effects of Climate Change and fire regimes on the life history of plants being examined by Clarke's team at UNE (See Williams et al. 2009).

Population Process	Direct Climate Change	Indirect	Changed Fire Regime	CC x Fire Regime Interactions

Flowering	Temperature			
Pollination and ovule fertilization	Temperature	Pollinators		Possible
Dispersal and Dormancy	Temperature	Dispersers Predators Ignition Fuel	Season Intensity	Likely
Germination and emergence	Temperature Rainfall CO2	Ignition Fuel	Season Intensity	Likely
Seedling growth and allocation	Temperature Rainfall CO2	Herbivores Ignition Fuel	Intensity Interval	Highly likely
Maturation	CO2	Ignition Fuel	Intensity Interval	Highly likely
Bud bank accumulation	CO2	Ignition Fuel	Season Intensity Interval	Likely
Clonal growth	CO2	Ignition Fuel	Intensity Interval Interval	Possible

Climate change will have a variety of impacts on insects species either directly via changing temperature and precipitation patterns, as well as increasing extreme events (more extreme and prolonged droughts and floods). Indirect impacts will come through host plants changes via increasing carbon dioxide, host plant (food) quality and distribution. Pollinators are emerging earlier in the season with earlier flowering events. It is anticipated that a higher amount of carbon dioxide assimilation by plants will reduce the food quality for insect herbivores increasing not only the amount that they will eat but also the time they take to feed. This may make them more vulnerable to predators and parasitoids throughout the feeding season. However, warmer temperatures may enable insect species to increase the number of generations that they can go through each season.

In most cases we have very little information about how individual native species will react to a changing climate. For example, sap sucking insects (phloem feeders, xylem feeders) have the potential to transmit diseases among host plants. Currently, we have no information about the physiology, behaviour or morphological traits of native sap sucking species, and the potential impacts that climate change will have on their distribution, life history and host plant preferences. To understand the impacts of climate change on insects, UNE is gathering baseline information about important physiological, behavioural and morphological characteristics of insect species have on a variety of agriculturally important and native species in NSW. With sustained funding and collaboration with NSW Government agencies, this program will enable land managers to develop appropriate models and mechanisms to mitigate any adverse impacts that a changing climate may have over the coming century.

Implications of climate change for ecosystem health and ecosystem services

Ecosystem health is the capacity of an area of land or water to provide environmental benefits for people ('ecosystem services'), such as food, fibre, timber, clean water, carbon sequestration, salinity mitigation or nature conservation.

Ecosystem services, in turn, are the benefits that people derive from the ecological functioning of the biosphere (Reid *et al.* 2008). This definition focuses attention on the beneficial role of biodiversity in sustaining people and life-support systems, and excludes purely physical goods and services such as minerals and solar energy.

The key elements of biodiversity responsible for providing a particular ecosystem service are called 'ecosystem service providers' (ESPs). For instance, trees produce timber and shade, and *Rhizobium* bacteria in the roots of leguminous plants convert atmospheric nitrogen into plant-available nitrogen.

Ecosystem services span both ecosystem 'goods' (i.e. harvestable products such as food and fibre) and 'services' (less tangible benefits such as climatic amelioration, erosion mitigation or spiritual renewal). Thus 'healthy' ecosystems generate an abundance of the environmental services required by managers (farmers, foresters, park rangers etc.).

The simplest way to understand the impact of climate change and global warming on ecosystem health is to examine the likely impacts on ecosystem service provision. Box 1 provides a comprehensive list of 56 ecosystem services, classified functionally into 9 groups. Ecosystem services in the first 7 groups share either the same kinds of ESPs, or the same functional interactions between physical processes (e.g. wind, solar radiation) and ESPs. The eighth group covers the various human perspectives of the environment. The final group of universal biological services occur throughout the biosphere and underpin other ecosystem services. Unlike other ecosystem services, it is difficult to value these fundamental services (reproduction, evolution, succession etc.) as 'good' or 'bad'.

1. Primary production

Climate change in Australia will see increased atmospheric CO_2, , higher temperatures and evapotranspiration, more variable and probably reduced precipitation over most of the continent, and more extreme weather. Stokes and Howden (2008) summarised the impacts on primary production across Australia as follows:

> *Elevated atmospheric CO_2 concentration increases the efficiency of use of light and water …nitrogen …and possibly efficiency or effectiveness of uptake of other minerals like soil phosphorus …In Australia where water, nitrogen and phosphorus are major limiting factors in production, this is an important first order feature of the response of primary industries to global atmospheric change. The responses to CO_2 represents a form of automatic self-adaptation of the agricultural system to atmospheric change upon which any less certain impacts of local climatic change are superimposed …Since atmospheric CO_2 concentration has been recorded to be*

increasing for 150 years this internal adaptive response will have been going on progressively over that time …

The increase in light use efficiency in C3-species, like wheat, barley, rice, cotton, oats, oil seeds, trees, and cool-season pasture species, derives substantially from the suppression of the process of photorespiration by elevated CO_2. The C4 species (maize, sorghum, sugarcane and tropical grasses) lack photorespiration and the effect of CO_2 on increasing light use efficiency is correspondingly much lower in these species.

The increase in water use efficiency is attributable to a stronger CO_2 concentration gradient from the air to the inside of the leaf … In the field, this may be expressed as an increase in growth rate while soil water depletion remains unaltered or reduced soil water depletion with little growth effect (or an intermediate combination). This increase in plant dry matter production per unit of water used by plants occurs in both C3 and C4 species …The increased efficiency with which plants use water needs to be exploited in developing adaptation strategies and could be used to partly offset the effects of reduced rainfall or increased evaporative demand.

The increase in nitrogen use efficiency (here referring to the capacity to grow more dry matter with the same amount of nitrogen) can occur in C3 species …Thus the N-content of the leaf decreases. These changes in protein and storage carbohydrates have implications for plant product quality such as herbage forage quality and possibly grain quality …but in some circumstances these impacts can be beneficial (e.g. in livestock where growth is energy limited not N-limited) …Additionally, the growth response of legumes to elevated CO_2 concentration is generally greater than that of grasses. Thus in mixed farming systems using legume-based leys the need for artificial fertiliser, to maintain grain protein levels for example, may be expected to decline (all else being equal).

The primary climatic effect of increasing concentrations of greenhouse gases is an increase in the average temperature of the lower atmosphere …Thus as temperatures rise (and all else being equal) we might expect both dry weight growth rates and rates of progression through developmental phases to increase with the effect on rate of development being the stronger of the two. However, plant responses to possible changes in frequency of occasional high temperature or frost stress make generalisation very problematic. For annual crops, warmer conditions tend to reduce yields owing to any faster growth rate not being sufficient to compensate for the earlier attainment of maturity.

Warmer temperatures may benefit perennial plants in cool climates, but annuals and plants growing in hot climates may be negatively affected. Plant productivity would be expected to increase or decrease in accord with any changes in rainfall, while the direct effects of CO_2 in stimulating plant growth and increasing water use efficiency could help by partly offsetting increases in evaporation or decreases in rainfall.

Marginal production areas are amongst the most vulnerable and will likely be amongst the first areas in which the impacts of climate change will exceed adaptive capacity. It will be important to identify areas where climate change risks and opportunities require strong policy intervention (beyond simply supporting adaptation within existing land uses) such as transformation to new land use activities.

The following paragraphs, based on the report of Stokes and Howden (2008), explain the likely impacts of climate change on primary production across NSW.

1. Western NSW

The predominant land use in western NSW is grazing. Native pasture production will probably decline given the predicted warming and drying trend, the erosion hazard is likely to increase, and the increasing concentration of atmospheric CO_2 may favour invasive native species (INS or 'woody weeds') over herbaceous forage production. In regions affected by INS, the likelihood of successful, opportunistic cereal cropping will decline, reducing growers' options to recover INS clearing costs with income from cash crops.

2. South-western NSW and Riverina (Mediterranean climate)

South-western NSW and the Riverina have a sub-humid to semiarid Mediterranean climate, supporting dryland cropping, grazing, rice, viticulture, horticulture, and intensive livestock industries. Potentially large reductions in rainfall will reduce dryland crop yields markedly, leading to flow-on effects to regional communities and businesses. Thus, cropping will become more challenging at the current dry margins. There may be reductions in the risk of dryland salinisation. A range of adaptations is possible, particularly aimed at improving crop water management. For rice, water supplies are projected to become more limited while individual crop demand is likely to increase. A wide range of potential farming system changes need to be considered in current rice-growing areas. For viticulture, seasonal changes in winegrape ripening will affect quality. Grapevine variety suitability will change and planting of 'longer season' varieties to fit the warmer climate will reduce negative impacts. Water may become a limiting factor for grape production in this region. For horticulture, climate change will lead to changes in crop scheduling and marketing of annual horticulture crops. Reduction in winter chilling may affect suitability of the region for some perennial stone fruit crops that require subzero temperatures to initiate bud burst. Increasing frequency of extreme temperature events affecting crops will have to be managed. Water availability and security of supply will be essential for perennial horticulture.

3. North-West NSW

Dryland farming in North-West NSW will have to contend with potentially significant reductions in yield and quality of winter crops such as wheat, due to likely reductions in rainfall. Potential reductions in frost may increase crop options. Summer rainfall seems equally likely to increase as to decrease and this also may provide some options to alter the balance of cropping. Adaptations include increased opportunistic cropping, increased attention to managing stored soil moisture and the use of seasonal climate forecasts. The irrigated cotton industry will have to contend with less irrigation water, higher temperatures and greater evaporative demand by crops, impacting on yield and fibre quality. Improved water use efficiency (irrigation practice and variety choice) and tolerance to heat stress (variety choice) and modification of crop management (planting date, row configurations, irrigation scheduling) will need to be considered to help offset these issues. Irrigated cotton may give way to higher value irrigated horticultural crops and vegetables.

4. Western Slopes and Plains of NSW

The wheat–sheep zone along the western fall of the Great Dividing Range will experience increased temperatures and a likely reduction in median rainfall over the longer term. Farmers will have to contend with potentially significant reductions in winter-crop yields such as wheat due to likely reductions in rainfall. Reductions in irrigation water may push existing irrigated systems into a more opportunistic mode where there is partial irrigation or irrigation only once every several years on average. Possible adaptations include a range of changes in crops and crop management, increased opportunistic cropping, increased attention to managing stored soil moisture and the use of seasonal climate forecasts, and management to increase water use efficiency. Warmer conditions may allow improved growing conditions (longer seasons) and a possible expansion of the cotton industry south-eastwards, but production will not be great unless irrigation water is available. Forestry is not a major activity on the western slopes and plains, but future oil mallee plantings for carbon sequestration may be an option. Care should be taken in establishing and managing these plantations, as being in already relatively low rainfall areas, they would be potentially vulnerable to any further rainfall reductions.

5. NSW Tablelands

Viticulture in the NSW Tablelands may benefit from climate change. Some areas previously too cool for viticulture may become suitable, with varieties that do not ripen in the present climate being successfully planted under future warmer conditions. Disease incidence may also reduce with lower rainfall in spring. On the down-side, seasonal climate changes may result in ripening of wine grapes in a warmer part of the season, affecting quality. Grapevine variety suitability will change, necessitating planting of ‘longer season’ varieties to fit the warmer climate to reduce negative impacts. Water may become a limiting factor for grape production in these regions. For tablelands horticulture, extreme temperatures resulting in damage and undesirable crop responses will need to be managed. Disease and pest impacts may be reduced with lower projected rainfall, and vegetative growth periods and time to maturity may be reduced. Some presently marginally cool regions may become more suitable for horticultural production. Security of supply of water is required, especially for perennial horticulture. The Southern and Central Tablelands are important timber plantation regions, particularly for *P. radiata* and *E. globulus*. Likely impacts of climate change on these plantations are being analysed by CSIRO Forestry as part of a project for Forest and Wood Products Australia.

6. Alpine NSW

Very little cereal cropping occurs in alpine NSW, but increasing temperatures may increase farming opportunities through increased crop growth and length of growing season. Much of alpine NSW is included in national parks, so few commercial forests will be affected. Pasture production in the high country will increase, owing to the longer growing season under a warmer climate.

7. Coastal NSW

In coastal NSW, dryland and irrigated cropping is limited in area. Irrigated farming may be challenged due to the increasing demand for water from a changing climate and other users and a decreasing supply of water. In northern coastal NSW, the present limited supply of irrigation water for sugar cane production is likely to be exacerbated by the projected decrease in rainfall. Projected warming will increase the duration of the growing season for sugar cane, requiring changes in planting date. Competition from other crops may increase, particularly from short-duration annual crops, as part of the pressure to diversify land-use options. Frost reduction in coastal NSW may see expansion of suitable horticultural production suited to this climate. Seasonal changes in climate will affect vegetable cropping, requiring compensatory responses in agronomy, planting time and marketing. There are significant areas of hardwoods, particularly *E. pilularis* and *E. grandis*, in coastal northern NSW. Preliminary analyses suggest neither species is likely to be at high risk in this region, but care should be taken to look for any developing problems, such as reduced productivity or new pests and diseases.

2. Secondary production

Stokes and Howden (2008) summarised the impacts of predicted climate change on livestock (secondary) production across Australia as follows:

> *The main challenges facing the grazing industry are likely to be declines in pasture productivity, reduced forage quality, livestock heat stress, greater problems with some pests and weeds, more frequent droughts, more intense rainfall events, and greater risks of soil erosion … The most arid and least productive rangelands may (low confidence) be the most severely impacted by climate change, while the more productive eastern and northern rangelands may provide some opportunities for slight increases in production … Warmer and drier conditions are projected for most intensive livestock producing regions, raising the likelihood of heat stress conditions.*

The following paragraphs paraphrase 'Chapter 9 Broad Acre Grazing' of Stokes and Howden (2008).

The geographic diversity of grazing lands in NSW combined with regional variation in climate change projections means that the impact of climate change on the grazing industries is likely to differ from region to region. The general pattern of climate change impacts across NSW grazing lands is that the least productive arid (annual precipitation <20% of annual evaporation) rangelands in far western NSW will be the most negatively affected. Marginal pastoral enterprises in arid rangelands may be at the greatest risk of becoming non-viable. In the semi-arid (precipitation between 20% and 40% of evaporation) grazing regions, the negative effects of declining rainfall and increasing drought on productivity may initially be offset by the benefits of higher CO_2 and a prolonged growing season from warming. However, more intense rainfall may increase the risks of soil erosion, rising CO_2 may favour trees at the expense of pasture production, and pasture quality may decline. The more productive eastern grazing lands are the most likely to provide opportunities for slight increases in productivity under climate change. The eastern woodlands are projected to experience some drying and increased droughts, but moderate warming may benefit pasture growth by extending the growing season, with a slight net increase in pasture productivity. In the cooler tableland and alpine pasture areas, warming should extend pasture growing seasons.

The direct effects of CO_2 will benefit pastures mainly by increasing the efficiency with which plants use limiting soil moisture resources. This benefit may be greatest in ecosystems receiving intermediate amounts of rainfall (500–1000 mm yr^{-1}, depending on latitude), where water is limiting during most periods of active plant growth. In arid climates, high rates of evaporation from surface soils may limit the potential for any CO_2-induced water savings to benefit plant growth (although this may depend on how rainfall regimes, soil properties, and rooting patterns influence when and where plants access moisture in soil profiles). The stimulating effects of rising CO_2 on pasture production are likely to be weakest in far western NSW. In the more mesic savanna and wooded rangelands, rising CO_2 may stimulate pasture growth in the short term, but this effect may be partly offset if tree biomass increases in the longer term. Tree biomass in rangelands is dependent not only on environmental conditions but also on the ability of producers to control trees, which depends on both economic factors and legislation. Semi-arid grasslands, such as the Mitchell grass downs in north-western NSW, may therefore receive the greatest benefit from rising CO_2. However, stimulation of forage production by CO_2 comes at the expense of decline in forage quality. Furthermore, CO_2 will also favour the encroachment of woody weeds in grasslands, so more effort may be required in weed control.

Climate change will also affect intensive livestock production differentially, depending on climatic zone and projections. Generally speaking, irrigated dairy production in warm regions will be impacted by reduced water allocations and increased temperatures. Heat stress will be an issue for livestock, and energy costs to cool production sheds may increase. There may also be increased demand for new energy efficient designs or retrofitting of existing sheds. In cooler highland regions with greater dependence on rainfed pasture, dairy may benefit from the warming and increased length of the pasture growing season. Energy demand for heating production sheds may also decrease. Feedlots and intensive poultry production in NSW are generally likely to be impacted by increased temperatures and reduced water availability, due to heat stress in stock and birds and greater energy costs for cooling production sheds. As for dairy however, in cold regions, warmer temperatures may be beneficial for productivity and energy costs.

3. Hydrological services

Climate change will increase evapotranspiration and reduce precipitation over most of the continent. Thus there will be reduced volumes of fresh water accessions to surface water storages and ground-water aquifers, and thus reduced levels of sustainable abstraction from both surface and ground-water systems. There will be considerable socio-economic pressure for major improvements in irrigation efficiencies, with perhaps the abandonment of furrow and flood irrigation in favour of more expensive overhead and subsurface delivery systems, where irrigation is still permitted. With the increase in extreme weather, such as storms (rainfall erosivity), strong winds and drought, soil loss to wind and water erosion can be expected to increase. Improved vegetation and ground-cover management, particularly in arid rangeland and farmland, will be required to combat the anticipated increase in erosion hazard. On the up-side, reduced groundwater accession will mean a slowing of the threat from dryland salinity and perhaps irrigation salinity.

4. Physical atmosphere–vegetation interactions

The ecosystem services, air purification and noise mitigation, are unlikely to be greatly affected by climate change provided that any plant species that are planted for these services are able to withstand the predicted changes in climate (higher temperatures and evaporative demand, reduced rainfall efficacy and more extreme weather). Those services concerned with micro-climatic amelioration (provision of shade and shelter, firebreak and fire hazard mitigation) and perhaps regional climatic amelioration will become more important over time. Careful selection of tall vegetation species to provide these services in a changed climate will be important as failure to select the correct species for a particular site is a common reason for the failure of plantings of woody vegetation. In order to reduce regional albedo and influence regional air humidity and precipitation, regional reforestation schemes may have the double benefit of both sequestering carbon and ameliorating climate change by increasing regional precipitation.

5. Soil services

The soil is well insulated from the above-ground environment, apart from the surface and first few centimetres of topsoil. Thus, soil services may continue relatively unimpeded in a greenhouse-affected world, provided that the impacts of climate change can be mitigated at the soil surface. As with soil erosion prevention above, management of ground cover, litter and vegetation cover will be more important in rangeland and farmland in the future to mitigate the impacts of higher temperatures, more erosive rainfall and stronger winds at the soil surface.

6. Organism–habitat interactions

The impacts of climate change on wildlife and plant habitat provision are dealt with elsewhere in this submission. Habitats, plant growth and reproduction and natural disturbance regimes are all likely to be affected by increased temperature and evapotranspiration, reduced median rainfall, and increased frequency of droughts, floods and fires. Plant and animals with broad ecological niches are less likely to be affected than those with narrow habitat requirements, or at the upper limit of their temperature range or lower limit of their rainfall tolerance. Habitat provision will also be affected in complex, difficult-to-predict ways by higher-order ecological interactions ultimately resulting from climate change but mediated proximately by predators, competitors, pathogens, etc.

Human disease regulation across NSW may improve with climate change, as mosquito-borne diseases (such as Ross River virus and Murray Valley encephalitis) should become less frequent owing to the reduction in wetland occurrence and extent under climate change. On the down-side, however, the distribution of mosquitoes may extend into regions that were previously too cold.

The impacts of climate change on biological and natural pest control are difficult to predict, because little is known about the existence, identity and efficacy of native control agents. The knowledge of introduced control agents is greater, owing to the extensive studies that have generally predicated their introduction into Australia. Even with introduced agents, however, their function and efficacy is likely to be affected by difficult-to-predict, higher-order ecological interactions with competitors, predators and pathogens, not just directly by climate change.

Little research has been conducted into the ecosystem properties responsible for resistance against invasion by pest plants and animals, so again, it is difficult to predict the impacts of climate change on this service. Since climate change will lead to changes in the distribution and abundance of pest plants and animals, and weeds and feral animals cost agriculture and other land uses huge sums of money each year, it would be a useful ecosystem service to conduct further research on, given the inevitability of climate change and emerging problems with pest plants and animals.

Biotic pollination services in Australia are provided by (1) honeybees (*Apis mellifera*), one of the best studied organisms on Earth, and (2) a broad range of native pollinators (predominantly insects, but also honeyeaters and a few mammals for particular floral types) whose efficacy and function in any particular ecosystem is generally poorly understood. Honeybees have very broad habitat requirements and so it is unlikely that climate change will affect their abundance or pollination efficacy greatly. Of more interest is the impact of climate change on the pests and diseases (such as parasitic mite) that threaten honeybee populations world-wide, as well as in Australia. CSIRO (1999) estimated that up to 50% of crop pollination in Australia might be attributable to native pollinators. While the loss of honeybee pollination would have a huge short-term economic impact on industries dependent on honeybee pollination (Gordon and David 2003), native pollinators could be relied on to pick up some of the slack. A large number of native pollinators exist naturally in Australia, so climate change is unlikely to greatly affect their pollination service since most plants are pollinated by a wide variety of pollinators and reductions in the abundance or distribution of some pollinator species are likely to be matched by increases in others, simply due to chance alone. Only in relatively few cases where plant–pollinator relationships are highly specific (i.e. one plant species, one pollinator species) might climate change lead to local extinctions of plants due to pollination failure.

As with biotic pollination, seed and propagule dispersal systems are generally unspecialised, with many biotic dispersers capable of dispersing seeds and propagules. Unlike pollination systems, however, 'keystone mutualists' play a more important dispersal role in some ecosystems. Examples include seed-dispersing fruit bats and fruit pigeons in rainforest and wet sclerophyll forest ecosystems, and critical-weight-range mammals in the dispersal of ectomycorrhizal fungi in forests and woodlands. These vertebrate guilds are already under considerable ecological pressure as a result of European land-use change, and climate change could be the 'nail in the coffin' for some of them over significant parts of their former range. The loss of keystone mutualists could ultimately lead to cascading extinctions of plants due to dispersal failure, although the long-lived nature of many of the plants involved would mean these impacts might not be felt for centuries.

7. Regenerative services

Coastal storm protection is provided in part by the communities of sand-dune, salt-marsh and mudflat plants that colonise and stabilise coastal and estuarine ecosystems. Mudflats and salt marshes are physiologically stressful environments and plants typical of these habitats are likely to be pre-adapted to the relatively minor physiological impacts induced by climate change. Sand-dune communities in coastal NSW are complex ecosystems of many plant species that are also pre-adapted to physiological stressful conditions for plant growth, given the sandy, salty soils. Even if some sand-dune species are disadvantaged by a warmer drier climate, other species are likely to be able to expand to fill the gaps. Sea-level rise, on the other hand, will lead to the certain destruction of all coastal ecosystems through marine inundation, and the migration of mangrove, salt-marsh and sand-dune communities inland and upwards in elevation.

Although ecosystem stability and resilience are popular notions in the ecological literature (Holling 1973; Gunderson 2000; Folke et al. 2004; Ives and Carpenter 2007), little work has been undertaken on the ecosystem properties or ESPs that underpin stability and resilience. Without an understanding of the mechanistic basis for these ecosystem properties, it is impossible to predict how climate change will affect ecosystem stability or resilience.

8. Universal human-centric services

These services are a function of the perspectives of each particular human observer. Thus climate change will likely have divergent impacts on all of these services, depending on the values and the adaptability of the value set of each person in question. Where human values are connected with tangible assets, such as real estate value, climate change impacts are more predictable. For instance, sea-level rise will destroy the real estate value of coastal property if it is inundated by the sea and becomes part of the seabed, but may increase the value of properties that acquire a sea view or a prestigious beach position as a result of marine ingression.

9. Universal biological services

Reproduction, maintenance of biodiversity, community dynamics and evolution are inexorable, value-neutral, biological processes that will continue irrespective of climate change or sea-level rise. They will continue while ever the biosphere continues to function, possibly at increased rates if climate change and sea level rise are marked, driving major changes in population abundance.

Conclusions

Several observations are pertinent in conclusion about the impact of climate change on ecosystem health in the Australian context.

1. Not all climate change impacts will be negative for ecosystem health. For instance, in agriculture, warming in cold regions will extend plant growing seasons and primary productivity if rainfall reductions are not excessive, reduce cold stress in livestock production systems and increase animal productivity, and it is likely we are already reaping the benefits of atmospheric CO_2 enrichment in terms of greater water use efficiency of plant production.
2. The benefits and positive opportunities presented by climate change may start to peak during the initial stages (possibly mid century), but the negative impacts may lag behind, becoming progressively stronger over time and with greater build up of greenhouse gases in the atmosphere (Stokes and Howden 2008). Caution is therefore needed not to underestimate the long-term challenge of climate change based on initial, more moderate experiences.

3. Climate change will add to and exacerbate many existing challenges for ecosystem health, such as undesirable biological invasions of both introduced and native species of plant and animal, soil erosion, soil acidification, problems with livestock nutrition and health, and increased pressure on many endangered species and ecosystems (Stokes and Howden 2008). While technological advances have been developed to address some of these issues, with climate change it will become even more important to increase the efficiency and efficacy of existing government and community programs to deal with these issues and ensure greater adoption by land and water managers of successful management practices and solutions.
4. Given the inherent uncertainty in climate change predictions to do with warming and rainfall projections, the need is to develop enhanced adaptive capacity in socio-economic and cultural–institutional structures to cope with a broad range of possible changes (Stokes and Howden 2008). Synergies with existing government and community programs and policies to enhance the self-reliance of businesses dependent on ecosystem health and supporting programs such as Landcare are needed develop this capacity, as well as within government agencies responsible for managing the public land and water estate.
5. Hydrological services and aquatic ecosystem health seem especially likely to be disadvantaged by climate change. The past 2 decades of reduced rainfall in south-eastern Australia may be a forerunner of what to expect over the next half century or more. Aquatic ecosystems and services deserve priority in future expenditure on mitigation and adaptation strategies for climate change.
6. The impact of climate change on organism–habitat interactions are especially difficult to predict because of the large number of poorly-known organisms responsible for most of these services, the imprecision of the climate-change projections and the complexity of the direct and indirect higher-order ecological interactions influencing the provision of these ecosystem services. These services also deserve priority in future expenditure on basic understanding as well as mitigation and adaptation strategies for climate change.
7. Ecosystem stability and resilience lie at the heart of the impact of climate change on ecosystem health and mitigation and adaptation strategies for climate change. However, the mechanistic understanding of these ecosystem properties is poorly understood, so while they are attractive conceptually, it is difficult to begin to operationalise stability and resilience concepts other than on a costly and intensive ecosystem-by-ecosystem basis. Further research on operationalising the concepts of ecosystem stability and resilience across a broad suite of ecosystems may be particularly useful and cost-effective.
8. Among the ecosystem services classed under physical atmosphere – vegetation interactions, (1) shade and shelter provision, (2) firebreaks and fire hazard mitigation, and (3) broad-scale reforestation for carbon sequestration and regional climatic amelioration will become increasingly important in a warmer, drier Australia. Further expenditure on securing these services for mitigation and adaptation to climate change should be a priority.

Box 1. Functionally related sets of ecosystem services, characterised by (i) similar ecosystem service providers (ESPs), (ii) the same functional interactions between physical processes and common ESPs, or (iii) universal sets of services from a human-centric or (iv) biophysical perspective (modified from Reid *et al.* 2008)

1. Primary production

1. Timber and wood products
2a. Atmospheric gas regulation
3. Primary production
4. Production of atmospheric oxygen

2. Primary and secondary production

5. Food and beverages
6. Forage
7. Fibre
8. Biomass fuel
9. Ornamental resources
10. Genetic resources
11. Natural biochemicals, medicines and pharmaceuticals
12. Raw materials for manufactured products
13. Carbon sequestration
14. Secondary production

3. Hydrological services

15. Fresh water
16. Surface water eco-regulation
17. Groundwater eco-regulation
18. Water purification and waste treatment
19. Erosion control
20. Water cycling

4. Physical atmosphere–vegetation interactions

2b. Air purification
21. Climate regulation
22. Provision of shade and shelter
23. Firebreak and fire hazard mitigation
24. Noise mitigation

5. Soil services

25. Maintenance of soil health
26. Terrestrial waste absorption and breakdown
27. Soil formation
28. Nutrient cycling

6. Organism–habitat interactions

29. Habitat provision
30. Regulation of human diseases
31. Biological and natural pest control
32. Resistance against invasion by pest plants and animals
33. Biotic pollination
34. Dispersal of seeds, propagules and translocation of nutrients

7. Regenerative services
35. Coastal storm protection
36. Maintenance of ecosystem stability and resilience

8. Universal human-centric services
37. Cultural identity and diversity
38. Spiritual and religious values
39. Knowledge systems (traditional and formal)
40. Educational values
41. Inspiration
42. Aesthetic values
43. Social relations
44. Psychological health and wellbeing
45. Sense of place
46. Cultural heritage conservation
47. Natural heritage and biodiversity conservation
48. Recreation and tourism
49. Existence value
50. Option value
51. Bequest value
52. Land and sea value

9. Universal biological services
53. Reproduction
54. Maintenance of biodiversity
55. Community and ecosystem dynamics and succession
56. Evolution

Adequacy of management strategies to address the impacts of climate change on biodiversity in New South Wales

The NSW conservation reserve system was established without concern for the sorts of changes in biodiversity that might occur as a consequence of climate change. Recent initiatives to link the reserve system along the Great Dividing Range, whilst laudable, may not achieve the most appropriate corridors given the east west nature of rainfall and temperature gradients in most parts of NSW. We believe that research should underpin policy for creation of corridors to allow for migration at a State scale but also at smaller spatial scales where metapopulation dynamics can be important. Current management actions, e.g. hazard reduction burning, logging etc., are rarely monitored in terms of their biodiversity outcome, hence a culture of adaptive management has yet to be implemented for the conservation of species in NSW. We think this is critical because many of the changes induced by Climate Change may well be unpredictable or have a high level of uncertainty. Currently, biodiversity managers lack detailed knowledge of the way species respond to change hence developing management plans are constrained by lack of scientific knowledge. We think empirical knowledge of species distribution, abundance and function should be placed back onto priority actions for NSW Government Agencies and that Universities be invited to partner in collaborative solutions to complex scientific issues.

Climate change policy and strategy has two elements, mitigation[1] and adaptation[2]. To date, much of the policy effort, and investment, at both Federal and NSW State levels has been focused upon mitigation rather than adaptation. However, whatever mitigation policies and strategies are ultimately adopted, it will be the identification, acceptance and adoption of adaptive strategies that will be critical to the health and survival of human and natural systems over the next 50-100 years. The identification and adoption of adaptive strategies suited to agricultural and natural systems must be allocated critical priority. Very little research is being conducted into the adaptive strategies, both natural and anthropogenic (human-mediated), available to natural ecosystems. In the face of relatively rapid climate change, the time available for identification and adoption is very limited. The current fragmented and disconnected reserve system alone will be markedly inadequate to cope with the biological forces of change wrought by climatic variations. It is likely that the current conservation values of the reserve system itself will be under threat. New landscape-scale models of biological conservation, incorporating both private and public land management, and with a contribution from agricultural land use systems, will be necessary.

Both urban and rural communities themselves will need to be active participants in the identification and adoption of acceptable and effective adaptation mechanisms. Thus investments in developing and maintaining both human capital and social capital will be critical. Unfortunately, recent Federal and NSW State policy and investment trends in building human and social capital have been declining. For example staff number actively involved in natural resource management extension, agricultural extension and the facilitation of Landcare networks in NSW have declined over the last decade.

Three elements are required in order to build human and social capital to enable community adaptation to climate change. The first of these elements is the provision of the best available scientific and technical information required to more precisely qualify and quantify the types of local (‘regional’) climatic changes to be expected and their likely impacts. Government and research institutions must be primarily responsible for this outcome. Secondly, acceptable and effective adaptation mechanisms must be rapidly identified and assessed – for example utilising evaluative pilot studies. Government, research institutions and communities must be responsible for this outcome. Thirdly, an effective network of extension, education and facilitation officers must be put in place to build the human and social capital required to enable appropriate adaptive mechanisms to be extended and adopted. Government, research institutions and the community must be responsible for this outcome. Importantly there must be clear, transparent and participatory, program logic and monitoring and evaluation framework embedded within all three of these interlinked activities and outcomes. Both State and local

[1] *Mitigation*: “Technological change and substitution that reduce resource inputs and emissions per unit of output. With respect to climate, mitigation means implementing policies to reduce greenhouse gas emissions and enhance sinks*.”* (Bates et al 2008)

[2] *Adaptation*: “Initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects.” (Bates et al 2008)

governments in particular, will need to demonstrate strong and clear leadership in providing the necessary policy frameworks, funding, and facilitation of this process.

In summary, we propose that:

The NSW Government undertake a comprehensive scientific research program to fully assess the impact of climate change on plants, animals and ecosystems in NSW and identify measures to avoid irreversible damage. This should include a review of what research has been conducted in the past, what work is currently being undertaken and by whom, and what needs to be done in the future. There is an urgent need for coordination of this work to avoid duplication and also for appropriate feedback and data sharing mechanisms and the prioritization of what needs to be done.

Scientific research should also identify high priority appropriate and effective natural and human mediated adaptive strategies. The role of both the community and government agencies in implementing these strategies should also be clearly defined and resourced.

It is important that future land purchases for reserves and national parks take into consideration the migratory needs, both present and future, of plants and animals and the changes in wildlife populations and ecosystems under projected climate change scenarios.

Ecosystems that are in a healthy condition will be able to better adapt to climate change, hence there is a need to identify marginal ecosystems and place special emphasis on their restoration so that they can survive in the long term. It is also important to reduce fragmentation and degradation of ecosystems that currently do not have a protection status.

Projected climate change scenarios need to be incorporated by natural resource agencies in their planning and regulations. There is a need to be proactive and plan for the changes due to climate change rather than deal with the scenarios as they arise.

Greater resources should be made available to increase the level and strength of community campaigns and participation in discussion of the issues and involvement in local projects.

ERS Research Strengths

We are privileged to live and work in one of the world's most diverse natural and agricultural environments. Within two hours drive of Armidale we have:

- Sub-alpine to sub-tropical climates
- Semi-arid savannah to rainforest
- Biodiversity hotspots and world heritage national parks
- Most major soil types
- Western and eastern river drainage systems
- Estuarine and marine environments
- Pastoral through to highly intensive animal production systems
- A high proportion of the world's major temperate and sub-tropical cropping systems
- Diverse horticulture and aquaculture systems

More than 80 academic staff take advantage of our unique location to lead training and research in a comprehensive range of environmental and rural sciences.

We are committed to improving our understanding of natural and agricultural systems to better protect our natural heritage and to improve profitability and competitiveness of agriculture and natural resource based businesses; locally, nationally and internationally.

ERS and the combined institutional resources of UNE bring a high level of scientific rigour in terms of survey design and statistical analysis, vegetation and wildlife survey, and floristic and vegetation−soil analysis, as well as a track record of successful postgraduate research student training in these disciplines and broadly in environmental and rural science. UNE's excellent relationships with the agricultural and natural resources institutions through major involvement in several cooperative research centres (Sheep, Beef, Weed, Cotton, Poultry, Spatial Information and its rebid), the co-location of some of these CRCs as well as research staff from the NSW Departments of Environment and Climate Change and Primary Industries on campus in Armidale, and the joint UNE−DPI Primary Industries Innovation Centre on campus, mean that there are many and varied avenues for extending research findings to rural stakeholders and state agencies through trusted and respected communication channels into the regions. Examples of current and recent relevant research consultancies and RD&E projects undertaken by ERS staff and students include (1) plant biodiversity implications of sheep production systems on the northern NSW Evergraze farms, (2) ecosystem service provision by native vegetation on cotton farms in the lower Namoi catchment, (3) management of invasive native scrub in the coolibah – black box endangered ecological community in north-west NSW , (4) invasive native scrub, soil erosion and soil function in the Cobar Peneplain of western NSW, (5) Land Water and Wool, Biodiversity and Native Vegetation Subprogram, (6) management and environmental determinants of native pasture and grassy woodland floristics on the Northern Tablelands, (7) causes of rural tree decline on the North-West Plains of NSW, (8) baseline biodiversity and carbon measurements for revegetation sites near Moree for the Border Rivers – Gwydir CMA, (9) ecosystem service reviews for the northern Victorian CMAs and (10) impacts of feral horses and their removal from grassy woodlands in national parks on the eastern escarpment of the Great Dividing Range, northern NSW. This is by no means an exhaustive list but gives the breadth of our work.

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