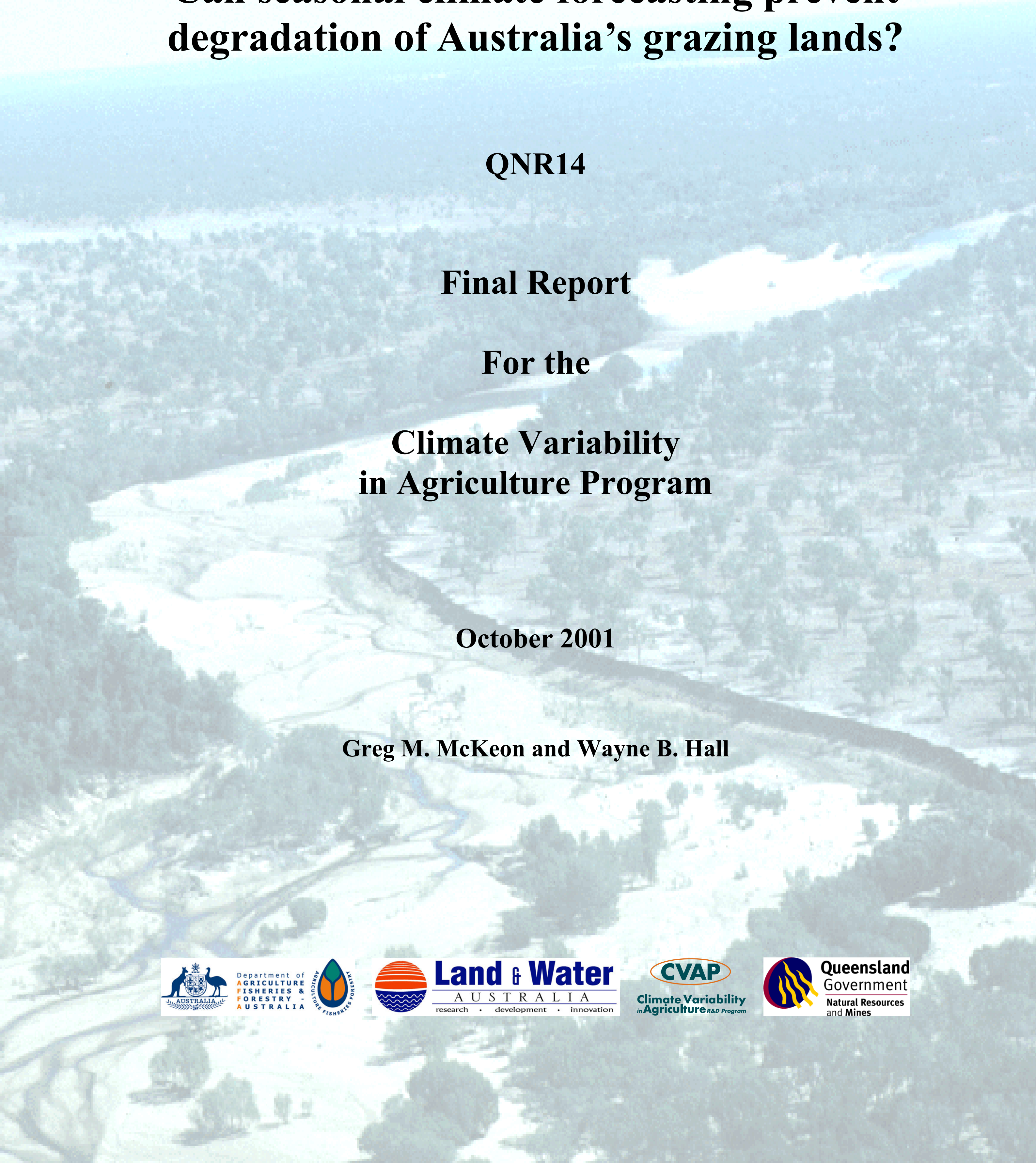

Can seasonal climate forecasting prevent degradation of Australia's grazing lands?

QNR14

Final Report

For the

Climate Variability in Agriculture Program

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The Climate Variability in Agriculture R&D Program (CVAP) is Commonwealth Government-funded, and part of the Agriculture Advancing Australia package. The program is managed by Land & Water Australia, formerly known as the Land and Water Resources Research and Development Corporation, a statutory authority within the Commonwealth Department of Agriculture, Fisheries and Forestry - Australia. In addition to LWA, the program is supported by Grains, Rural Industries, Sugar and Dairy R&D Corporations.

Department of Natural Resources and Mines, Queensland
October 2001

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1 Project title

Can seasonal climate forecasting prevent degradation of Australia's grazing lands?

2 Principal Investigator

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3 Project objectives

The aim of this project was to evaluate the impact of seasonal forecasting for grazing enterprises across Australia's grazing lands through the following objectives:

1) Construct hindcast seasonal forecasts with different lead times for specific locations across Australia (Gascoyne Catchment, WA; northern South Australia; western NSW; western Queensland; and north-eastern Queensland);
2) Calibrate the existing pasture model GRASP to simulate pasture and animal production;
3) Develop simple models for soil loss (function of cover) and vegetation dynamics (function of climate variability, fire, grazing) and validate these models with known historical degradation events;
4) Simulate the impact of grazing management strategies including decision rules (stocking rate change and burning) which use climate forecasts;
5) Compare management strategies in terms of animal production, resource condition and management needs such as drought feeding and financial trading;
6) Examine the influence of the Inter-decadal Pacific Oscillation and Antarctic Circumpolar Wave on ENSO and therefore their impact on identified degradation events;
7) Evaluate the potential for forecasts from General Circulation and Regional Circulation Models to have helped prevent degradation episodes in the 1960s and 1980s in Queensland;
8) Evaluate the capability of General Circulation and Regional Circulation Models to forecast rainfall and temperature under current global warming conditions; and
9) Adapt and improve existing statistical forecast systems for use in Australia's grazing lands.

4 Summary of methods and modifications

At the time of commencement of this CVAP project in July 1998, we were completing the project 'Learning from History: Preventing Land Degradation under Climate Change', funded by the Australian Greenhouse Office (AGO). The AGO project was a necessary precursor to QNR14 as it described in detail eight major degradation episodes in Australia's rangelands over the last one hundred years (Table 1). These episodes were the basis of our CVAP investigation.

Table 1. Regional degradation episodes in Australia's rangelands.

Episode	Degradation Episodes	Severe Drought Period
1	1890s in western NSW involving soil erosion, woody weed increase, rabbit plagues, substantial financial losses and financial hardship and resulting in Royal Commission of 1901 (Anon. 1901, Noble 1997)	1897-1902
2	1920/30s in South Australia involving substantial loss of perennial vegetation and soil erosion (Ratcliffe 1937) resulting in government legislation for regulation of carrying capacity (Donovan 1995)	1927-1931
3	1930s in Gascoyne region of Western Australia involving substantial loss of perennial shrubs, soil erosion and animal losses documented in the Royal Commission of 1940 (Willcox and McKinnon 1972) and subsequent inquiries (Jennings 1979)	1935-1941
4	1940s in western NSW involving substantial dust storms and animal losses graphically portrayed in Russell Drysdale's paintings and Newman's newspaper reports (Condon 1999) and supporting the need for government action (Beadle 1948)	1943-1945
5	1950s in western NSW involving large increases in woody weeds resulting in reduced carrying capacity and income (Anon. 1969, Hodgkinson *et al.* 1984)	-
6	1960s in central Australia involving wind and water erosion resulting in extensive surveys and re-assessment of carrying capacity (Condon *et al.* 1969a,b, c, d, Purvis 1986)	1960-1966
7	1960/70s in south-west Queensland involving soil erosion and woody weed invasion resulting in the government-sponsored South-West Strategy supporting review of recommended carrying capacities and property amalgamation (Warrego Graziers Association 1988, Johnston *et al.* 1996)	1964-1966
8	1980s in north-east Queensland involving soil erosion and loss of desirable perennial grasses resulting in extensive government-sponsored surveys (De Corte *et al.* 1994) and dramatic grazier response (Landsberg *et al.* 1998)	1984-1988

4.1 Climate forcings

During the course of the first year of QNR14 (1998/1999), the CVAP funded work of Dr S Power *et al.* on the Inter-decadal Pacific Oscillation (IPO) was generously made available to us. This work completely changed our view of the climate history of the degradation episodes and hence we incorporated this new understanding into Chapters 1 and 2 of the report delivered to AGO on June 30, 2000, with appropriate acknowledgement to CVAP. In the last year of QNR14 we have further updated this climate analysis to include the state-of-the-art research of Dr W White (SCRIPPS Institute of Oceanography) on the effects of travelling waves on regional climate. Although Dr White's analysis provides an important alternative view of the climate forcings associated with the degradation episodes.

In the 'Milestone 2: 1999/2000 Report' we described the limitations of existing statistical systems in: 1) lack of discrimination between severe droughts and marginally dry years; and 2) forecasting 'non-ENSO caused droughts'. We therefore investigated the use of General Circulation Models (GCMs) as an alternative and we report on the performance of two GCM studies that we have conducted.

4.2 Degradation episodes

The focus of our work has been the eight historical rangeland degradation episodes in Australia's history. We described these episodes in detail in the report to AGO in June 2000. However, our review raised major questions as to: 1) the extent of degradation and recovery; and 2) the role of climate in causing degradation.

Thus in QNR14 we sought the critical review of two leading rangeland experts – David Wilcox and Geoff Cunningham. Both had first hand knowledge of some of the degradation episodes and were able to improve our review of history and address some of the controversial issues regarding causes of degradation. Both experts identified the role of government policy in the mis-management of Australia's grazing lands as reported in our history of the degradation episodes. However, we did not research this area further as it was outside the objectives of the current QNR14 project.

Chapters 1 and 2 from the AGO project have been updated in line with research undertaken within QNR14 and feedback from five reviewers, including D. Wilcox and G. Cunningham. These updated chapters will also be included in the full QNR14 Technical Report, and will include the reviewers as co-authors to reflect the contribution they have made.

4.3 Models of degradation and research

To allow simulation of grazing land management we have developed or applied simple/simplistic models of degradation and regeneration.

4.3.1 Soil erosion

From detailed field studies in central Queensland and south west Queensland we have improved the modelling of runoff and water driven soil erosion. After consultation with Professor Grant McTainsh (Griffith University) and Dr Robert Miles (QDPI), we have also developed indices of wind erosion. These models of soil loss were parameterised where extensive measurements were available in south-west Queensland and hence, in absolute terms, the models are location/soil type specific. Nevertheless, given the strong effect of cover on both forms of soil erosion the models are likely to capture the relative effects of cover on soil erosion at other locations.

4.3.2 Loss of perennial shrubs

Dr Ian Watson (Agriculture Western Australia) has applied the IMAGES shrub model to examine the effect of alternative grazing management strategies on perennial shrub density in the Gascoyne region of Western Australia.

4.3.3 Pasture composition change

The model of perennial-annual species composition developed by Dr Andrew Ash (CSIRO) in the previous LWRRDC project 'Drought Plan', was used to evaluate the interaction of grazing management options and climate variability for Mitchell grasslands and northern black speargrass lands.

4.3.4 Woody weed infestation

A model of woody plant growth has been developed by one of our group (John Carter) as part of work undertaken within the CRC for Terrestrial Greenhouse Accounting. The model is currently applicable to eucalypts in central Queensland and *Acacia nilotica* in western Queensland.

However, models of vegetation regeneration and resource recovery have been more difficult to develop. We have adopted the approach seeking expert views from graziers, land managers, and scientists who have observed specific areas and who are able to estimate rates of recovery. We are yet to formulate these estimates into our simulation models.

In related projects we have also commenced modelling changes in soil organic matter as a result of grazing management and changes in salinity risk resulting from woodland management changes.

All these models of degradation processes and accompanying parameterisations are currently at an early stage of development and are valid for only particular sites and species. Nevertheless we believe they provide: 1) a much needed capability to understand what happened in the historical degradation episodes; 2) provide a basis to extrapolate successful industry practice (e.g. 'safe' stocking rates) to other properties and regions; and 3) provide operational systems with models to forecast degradation risk and regeneration opportunities.

4.3.5 Evaluating forecasting systems

There has been an 'explosion' in the number of climate forecast systems available and new hypotheses on what drives climate variability. Table 2 lists a number of systems that were readily available for analysis. There were two types: 1) monthly systems designed to forecast rainfall over the next 3 months; and 2) systems explicitly designed for regional (e.g. Queensland grazing lands) rainfall over a selected period (November to March). To compare systems we have expressed them as groups of 'year-types' and evaluated these systems in terms forecasts of simulated pasture growth at specific locations. We have also compared forecast systems in terms of their performance during the particular degradation episodes.

Table 2. Examples of existing climate forecasting systems

Classification System	Author	Description
Lag SOI Monthly	McBride and Nicholls (1983), Clewett *et al.* (1991), Allan *et al.* (1996)	Years are classified into 3 groups: SOI <-5, -5 <SOI <+5, SOI >+5. SOI is averaged over 3 previous months. For spring these groups have been loosely referred to as 'El Niño', 'La Niña' and neutral years.
SOI Phases Monthly	Stone *et al.* (1996)	Years are classified into 5 phases: SOI consistently negative, SOI consistently positive, SOI falling, SOI rising, neutral. SOI for previous two months is usually used.
SST (BoM SST) Monthly	Drosdowsky (submitted)	Years are classified in 9 groups based on 3 groups of Pacific Ocean SST (EOF1) and 3 groups of Indian Ocean SST (EOF2) anomalies.
November-March Regional Rainfall Systems		
SOI Phase and IPO	Milestone 1: 1998/1999 Report	Years classified are classified by October SOI phases (Stone *et al.* 1996) and Spring IPO value (Power *et al.* 1999) resulting in 6 groups.
SOI Phase IPO/OO1	Milestone 1: 1998/1999 Report	As above but neutral phase SOI group is divided based on the winter pressure gradient across central Australia (OOI, after R Allan personal communication) resulting in 7 groups.
SOI Lag and IPO (SOI/IPO)	This report	Years are classified by SOI average June to October (after Allan *et al.* 1996) and IPO (Power *et al.* 1999) resulting in 6 groups.
Queensland Rainfall Index (QRI)	Day *et al.* (2000)	Years are classified using a regression or grouping based in SST gradients at 2 locations in Pacific Ocean reflecting both the IPO and ENSO signals. Values are calculated monthly from March to October and ranked into 5 groups i.e. quintiles.
Global Standing and Travelling Waves (GDR)	White *et al.* (In preparation)	Regional rainfall is calculated from combination of global influences with different frequency biannual, 3-7 year, interdecadal and secular. The calculated values are divided into 8 groups.

4.3.6 Evaluating potential of forecast systems

In any year or season a grazier has to choose the stocking rate which returns the best animal production whilst not irreversibly damaging resource condition or jeopardising future production. Because surface cover has such an important influence on resource condition, there is a conflict between the consumption of pasture growth for animal production and retention of pasture growth for cover and fuel.

We have conducted simulation case studies for a number of selected Queensland locations to evaluate the consequences of different grazing management strategies in these terms. A genetic algorithm optimisation algorithm was used to find the best stocking rate for each forecast 'year-type'. The goal was to maximise liveweight gain allowing forecast systems to be compared objectively. Examples of formal optimisation without considering degradation were provided in the earlier QNR14 'Milestone 1: 1998/1999 Report'.

4.3.7 Towards better forecasting systems for preventing degradation

Preliminary analysis of existing forecasting systems indicated that most of the discrimination between year-types occurs at the high rainfall and that severe droughts are possible in most year-type groups. Given that overgrazing in severe drought is one major cause of resource damage, there is a need to investigate alternative approaches such as GCMs and other forecasting approaches using state-of-the-art (but controversial) understanding of the global climate system.

To this end we have:

- explored how GCMs can provide a mechanistic interpretation of statistical systems;
- formally compared a GCM simulation and SOI-based statistical systems for October to December rainfall in Queensland grazing lands; and
- reported on GCM performance during recent non-ENSO droughts in southern and western Australia.

5 Results, their interpretation and practical significance

The results from the project are presented below against the project objectives.

5.1 Objective 1: Construct hindcast seasonal forecasts with different lead times for specific locations across Australia (Gascoyne Catchment, WA; northern South Australia; western NSW; western Queensland; and north-eastern Queensland)

Existing published forecasting systems included the 'SOI phases' (Stone *et al.* 1996) and 'BoM SST year-types' (Drosdowsky submitted). Preliminary investigations (Milestone 1: 1998/1999 Report) had shown the advantage of combining other predictors (IPO, Power *et al.* 1999; and Oodnadatta index, R. Allan personal communication) with SOI phases and lag SOI. For comparison we have included these unpublished systems. During the period of the project two 'continuous variable' systems were independently developed specifically for regional rainfall in Australia's rangelands: 1) Queensland Rainfall Index (Day *et al.* 2000); and 2) Grazing District Rainfall (G.D.R. White *et al.* in preparation). The 'continuous variable' systems were converted to quintiles/octiles to enable a comparison to be undertaken with the other systems. Early development of the Queensland Rainfall Index also provided a classification of years based on two gradients in the Pacific Ocean representing both SOI and IPO signals in a different manner. Thus our CVAP project has collated a wide range of forecast systems for comparison as an example.

Table 3 indicates large separation between lowest and highest year-types for annual (April-March pasture growth) averaged across nine locations mainly in eastern Australia confirming the strong influence of ENSO and IPO effects on risk of drought (expressed as decile 3 growth relative to mean).

In evaluating climate forecasting systems we concentrated on the November to March period in eastern and central Australia. Rainfall and high temperatures during this time produce resistant plant tissues that have slow rates of decomposition and hence can provide surface cover, fuel and feed for extended periods (~12 months). Although winter rainfall is more important for animal nutrition in southern regions, plant tissues from herbs and forbs usually decompose rapidly after spring.

Time series of forecast summer pasture growth (November – March) were constructed using the year-type groups and compared with simulated pasture growth using 4 and 7-year running means (Figure 1). This approach showed which systems tracked pasture growth best at a time period most relevant to degradation (2-7 years). As was expected, ENSO-based systems tracked summer growth at eastern Australian locations during periods such as the 1890s to 1920s and 1950s to 1970s. The GDR approach provided better tracking of summer pasture growth although, as expected, all systems are damped in terms of forecast variability. The GDR approach also tracked growth at locations where ENSO has little influence (e.g. central Australia, Gascoyne).

Most importantly, the forecast systems tracked some of the major shifts where extended periods of good conditions rapidly declined into sequences of low summer growth, e.g. 1890 to 1900, 1976 to 1982. Detailed evaluation of each of the eight degradation locations will be reported in the QNR14 Technical Report.

Table 3. Decile 3 pasture growth expressed as a % of overall mean pasture growth averaged across nine locations. Values for lowest and highest groups are shown

Forecasting System		Lowest group			Highest group		
		decile 3 pasture growth	**Year-type**	**Year-type name**	**decile 3 pasture growth**	**Year-type**	**Year-type name**
1	SOI lag and IPO	45	3	June to November SOI ≤ -4 & IPO ≥ 0	95	2	June to November SOI ≥ +4 & IPO < 0
2	SOI phase, IPO and OOI	40	1	SOI consistently negative	96	2	SOI consistently positive and IPO negative
3	SOI phase October	41	1	SOI consistently negative	78	2	SOI consistently positive
4	BoM SST October	44	6	EOF1 warm EOF2 neutral in October	93	1	EOF1 cold EOF2 cold in October
5	SOI phase March	57	3	SOI rapidly falling	61	2,5	SOI consistently positive, SOI neutral
6	BoM SST March	42	3	EOF1 warm EOF2 cold in March	88	7	EOF1 cold EOF2 warm in March

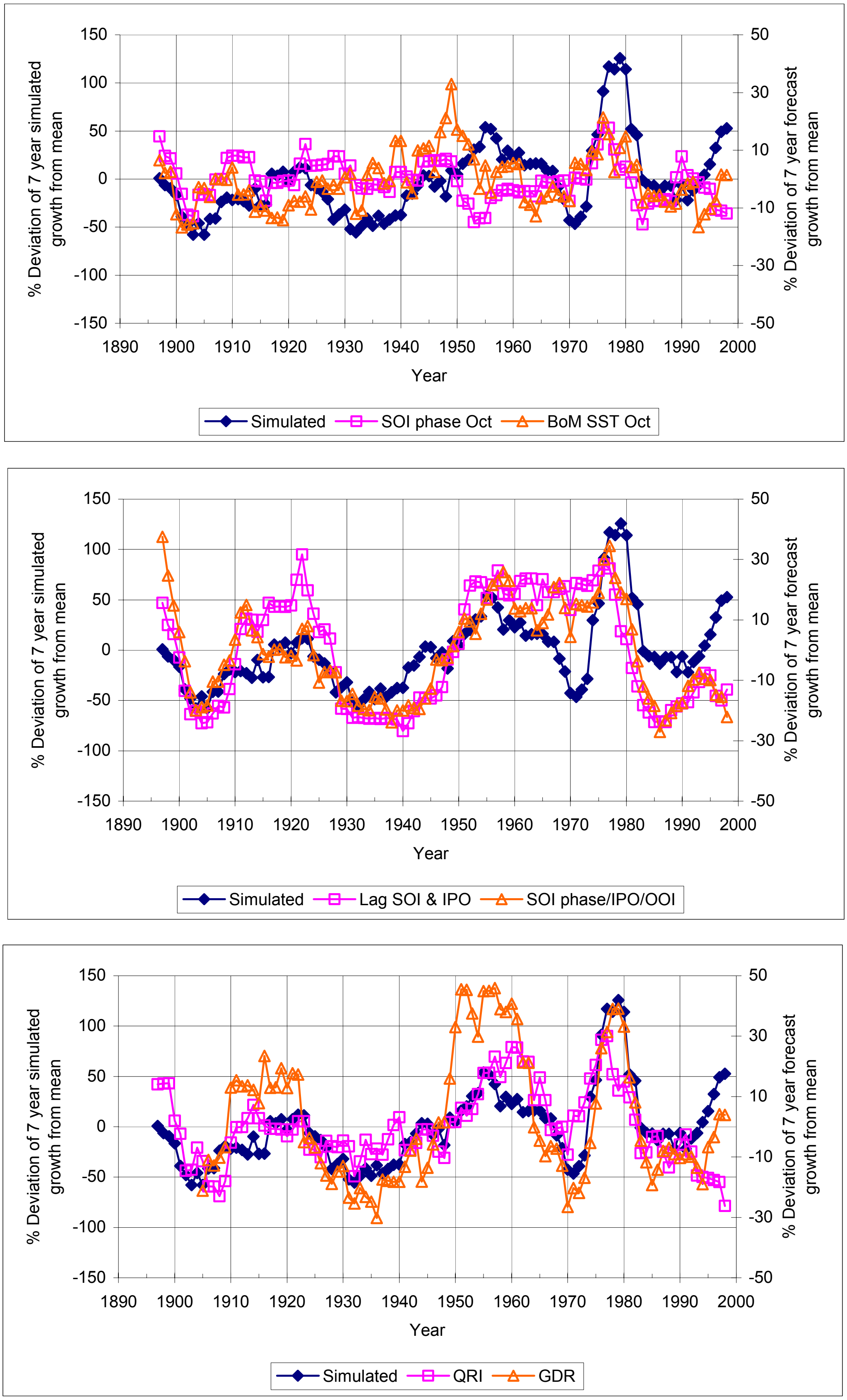

Figure 1. Preliminary results comparing simulated and forecast summer (November-March) pasture growth for Quilpie, south-west Queensland, using 7-year running means. Forecast growth was calculated for each year-type without inclusion of the year being forecast. Forecast systems are given in Table 2. (NB The axis for forecast growth has been expanded to facilitate comparison)

5.2 Objective 2: Calibrate the existing pasture model GRASP to simulate pasture and animal production

The pasture model GRASP was successfully evaluated and calibrated for several new areas (western NSW, central Australia). Results have already been reported as part of the CVAP Aussie GRASS final report (Hall *et al.* 2001). For central Australia sites, a major issue was the need to account for distinct pulses of growth several times per year and include rapid decomposition of dead pasture with rainfall. In western NSW the major issue was the high variability between sites in terms of species composition and therefore detachment. Whilst GRASP was able to simulate growth, a major limitation is the simulation of detachment with varying species composition. The next phase of model development will concentrate on dynamic models of species composition and growth of shrubs for these locations.

Several long time series of sheep/wool production were derived from property data ('Mobile', south-west Queensland), published reports and grazing trials in Queensland. Previous analysis (Hall 1996) has shown that output of GRASP (green leaf and other variables) could be used to develop general models of animal production. For the purpose of this and other CVAP projects we developed a general equation for wool production in Queensland using the same form as used for cattle liveweight gain (Hall *et al.* 1998). This approach provided a more general assessment of forecast systems in terms of length of the 'animal' growing season (as measured by the % of days when the pasture growth index exceeds 0.05). However, there is considerable gain to be made in developing models of animal production.

A major feature of the historical degradation episodes has been the increase in animal numbers during sequences of favourable years and the attempted retention of domestic stock through subsequent normal or drier times. The monitoring of animal numbers, relative to the resource production, should be an important component of any operational monitoring system and hence in this project we have put some effort into animal number databases to be used in Aussie GRASS.

To identify areas where overgrazing is likely to occur we have compared the simulated pasture production since 1957 from the Aussie GRASS model with animal numbers (domestic, feral, macropods) for each Statistical Local Area (SLA, Figure 2a) greater than 2,500 km^2 in size. For SLAs with average pasture growth less than 3000 kg DM/ha, we hypothesised that utilisation would be related to the length of the growing season (Figure 2b). 'Under-utilisation' occurred in regions in northern Australia where limited nutrients (nitrogen, phosphorus) are diluted during the growing season and there is little winter rainfall to provide an alternative source of nutrition. Regions where heavy utilisation has occurred include SLAs dominated by sheep grazing in western NSW and Queensland. The further interpretation of the analysis in terms of degradation risks will be detailed in the QNR14 Technical Report.

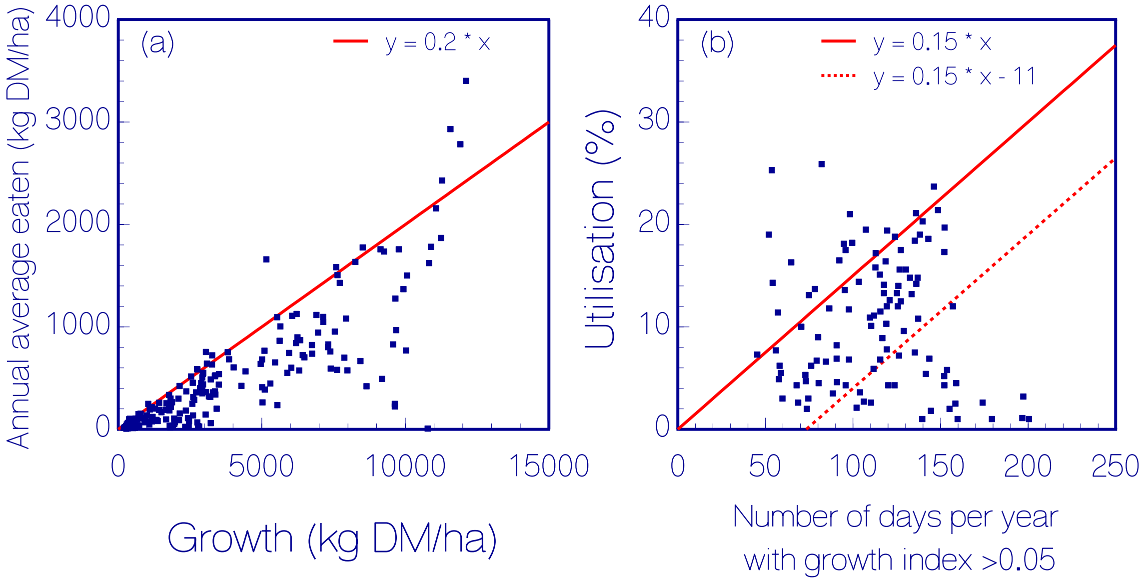

Figure 2. Relationships for Australian SLAs between: a) biomass grown and eaten; and b) utilisation and length of the growing season (number of days GIX >0.05). The line 'y = 0.2 * x' represents 20% utilisation.

5.3 Objective 3: Develop simple models for soil loss (function of cover) and vegetation dynamics (function of climate variability, fire, grazing) and validate these models with known historical degradation events

Several new models of degradation processes were developed. A new runoff model was formulated linking 'curve-number' to cover (Yee Yet *et al.* 1999), which also included the development of the concept of a 'cover threshold', e.g. 10-20% cover required before run-off starts to decline from bare soil values. Calibration of the curve number was similar for two sites in south western Queensland and central Queensland. This approach makes the simulation of runoff and associated soil loss compatible with current understanding of erosion processes in tussock grasslands (e.g. Tongway and Hindley 1995).

For simulation studies in south-western Queensland a wind erosion model was also developed in co-operation with Professor G. McTainsh (Griffith University). Models were scaled to simulate measured regional soil loss (30 mm in 35 years, Miles 1993) and the feedback of soil loss on pasture productivity simulated by reducing potential plant nitrogen uptake. Simulation of wind erosion of 100 years was in reasonable agreement with observational records correctly identifying the periods of major erosion associated with degradation episodes in the 1900s, 1930s and 1940s (e.g. Figure 3). In the future we plan to use the model to examine the relative influence of climate and management, e.g. causes of the observed decline since 1950 in wind erosion (McTainsh and Leys 1993).

For Mitchell grass in western Queensland the model of Ash *et al.* (1996) was used to simulate perennial/annual composition. A simple growth model (6-monthly time step) was used to simulate grazing management options. Simulated heavy grazing during the drought of the 1920s and 1960s led to the simulated loss of Mitchell grass in some areas as confirmed by observations at those times (D. Cobon personal communication).

As part of this project, Dr Ian Watson conducted simulation studies with a model of shrub dynamics (IMAGES). The results (Figure 4) indicate that the two main periods of degradation (loss of shrub cover), namely the droughts of 1900 and the mid 1930s (Episode 3, Table 1) were exacerbated by heavy stocking. The preliminary analysis with the GDR forecasting approach suggested that the extended drought of the 1930s (1935 to 1941) could be 'forecast' a year at a time. We plan to explore this result in more detail in a subsequent project.

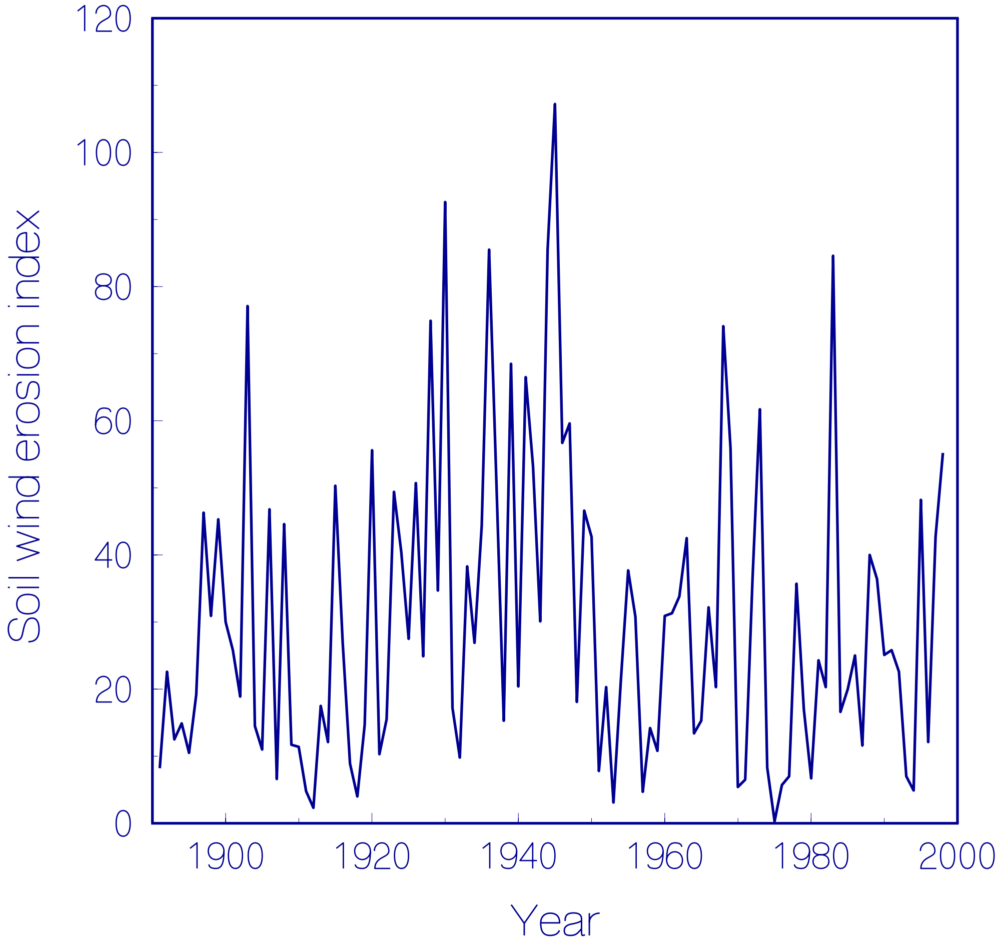

Figure 3. Simulated wind soil loss erosion index at Wentworth, NSW.

5.4 Objective 4: Simulate the impact of grazing management strategies including decision rules (stocking rate change and burning) which use climate forecasts

Forecasting systems were compared for eight locations in Queensland by objectively optimising stocking rate for each year-type to maximise steer liveweight gain per ha. The results indicated that the use of the IPO with SOI phases improved the advantage of forecasting over constant stocking rates at most locations (Table 4). The 'Oodnadatta Index' (Alice Springs minus Marree MSLP) had greatest impact on SOI phases in western Queensland and is worth further investigation once a more accessible and reproducible form of the index can be found. Whilst this approach showed the potential

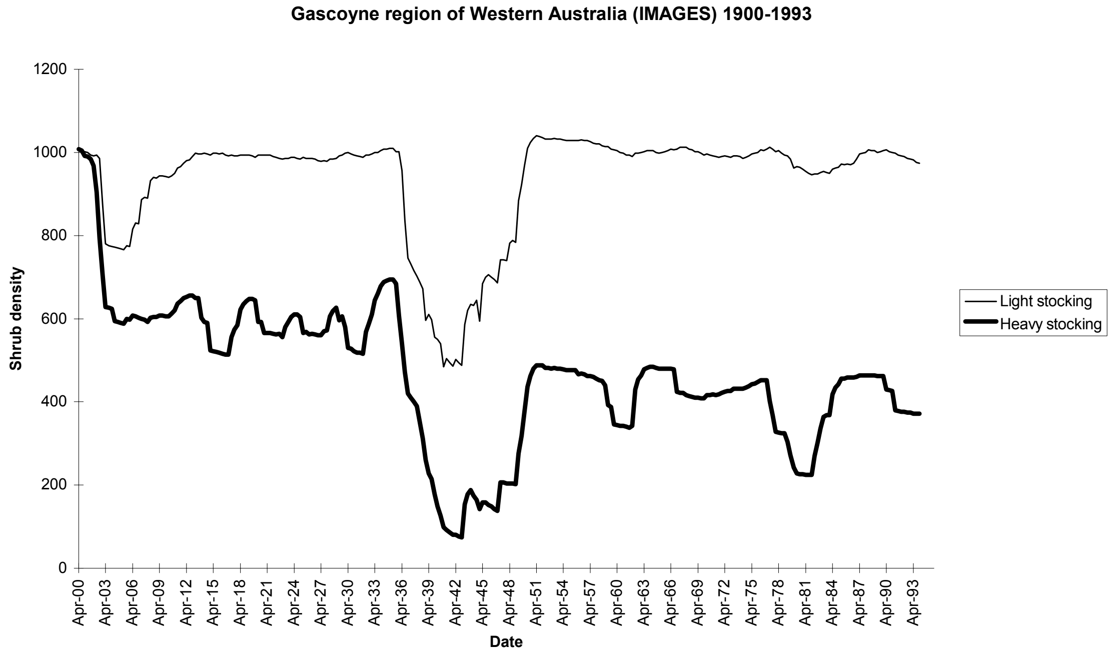

Figure 4. IMAGES model runs for north-west Gascoyne site (WA).

Table 4. Percentage change in annual liveweight gain (kg) per ha on native pasture for SOI/IPO/OOI forecasting systems at eight locations, with stocking rate optimised for each forecast year-type.

Location		SOI Phase	SOI Phase & IPO	SOI Phase & OOI	SOI Phase & IPO & OOI
SE Qld	Gayndah	4	6	8	8
	Rockhampton	2	0	1	1
SW Qld	Roma	10	12	15	15
	Charleville	7	16	9	21
NE Qld	Emerald	11	13	17	18
	Charters Towers	3	13	8	15
NW Qld	Longreach	4	32	13	35
	Julia Creek	6	12	10	15
Average		**6**	**13**	**10**	**16**

Table 5. Comparison of different forecast systems in terms of average liveweight gain per ha using three levels of degradation feedback (none, positive composition change, soil loss). Stocking rate in each year-type was optimised to maximise overall liveweight gain per ha with the change in animal numbers occurring on 1st November each year.

Forecast System	Charters Towers			Charleville		
	No Degradation	Pasture Composition	Soil Loss	No Degradation	Pasture Composition	Soil Loss
SOI Phase 5 year-types	21.0	12.4	19.7	14.7	9.9	14.6
BoM SST reduced to 6 types	21.2	12.6	19.7	15.2	10.5	14.8
Qld Rain Index 5 types	22.8	13.4	21.3	15.7	10.6	15.5

advantage of additional variables (OOI, IPO), these variables were the result of high utilisation rates in year-types where there was a low risk of drought. However, inclusion of realistic constraints in stocking rate changes are likely to reduce these advantages.

The above simulation study was repeated at two locations (Table 5, Charters Towers, Charleville) with degradation subroutines (soil loss, composition change) included as well as the new forecasting systems of Day (2000) and White *et al.* (in preparation). As described in the next section, the ranking of systems was not greatly affected by inclusion of degradation processes and regional rainfall systems were slightly superior to ENSO based systems.

A major issue discussed in Section 7, 'The Future', is the evaluation of climate forecasting and grazing management in terms of environmental effects such as carbon sequestration and downstream effects (water yield, sediment input). The unresolved issue is how to value these attributes relative to animal production.

5.5 Objective 5: Compare management strategies in terms of animal production, resource condition and management needs such as drought feeding and financial trading

Detailed simulations have been provided in the Milestone 1 and 2 reports and in the QNR14 Technical Report. As an example, Table 5 compares different forecast systems in terms of liveweight gain per ha. Stocking rate was optimised in each year-type to maximise liveweight gain for the whole period (e.g. 110 years). We believe that this approach provides an alternative objective measure of 'skill'. However, at present the GRASP model is limited to seven year-types and hence the full range of year-types in the available systems is yet to be tested.

Two forms of degradation, pasture composition change and soil loss, were tested with feedbacks on pasture production. In this case the ranking of forecast systems was similar to the case where no degradation was simulated. The QNR14 Technical Report also includes consideration of other components of the grazing system including risk of liveweight loss , feeding requirements and risk of death, frequency of pasture burning and risk of woodland thickening/woody weed infestation, soil loss and implications for down stream effects of sediment in run-off. The latter effect of grazing management may be as important in evaluating options as animal production.

5.6 Objective 6: Examine the influence of the Inter-decadal Pacific Oscillation and Antarctic Circumpolar Wave on ENSO and therefore their impact on identified degradation events

Most of the degradation episodes were preceded by a build up of stock numbers (and other herbivores such as rabbits) in response to periods of good seasons and substantial price variation. In eastern Australia, good seasons occurred in the early 1890s, late 1910s, early 1920s, mid 1950s, early 1970s and late 1990s. Following the work of Power *et al.* (1999), we found that quasi-decadal changes in the Pacific Ocean sea surface temperatures (the Inter-decadal Pacific Oscillation or IPO) resulted in the amplification of the effects of La Niña conditions on rainfall in eastern Australian (IPO negative phase, Figure 5 and Figure 1, Table 3). The retention of high stock numbers through subsequent normal or drought periods (most common in positive IPO periods) resulted in some of the regional degradation episodes described in Table 1.

Although the IPO is not yet fully understood, its behaviour appears to have had a strong effect on historical degradation and recovery episodes. Paradoxically, wet periods, associated with negative IPO, have contributed to degradation episodes by: (a) raising expectations of the land's carrying capacity which proved too high to be sustained through subsequent dry and drought periods; and (b) providing the conditions for woody weed establishment which, in the absence of fire, have caused the loss of desirable perennial grasses and reduction in carrying capacity (Episodes 5 and 7). However, the wet periods have also provided the opportunity for some recovery of vegetation following historical degradation episodes through regeneration of desirable perennial species. Thus we have shown in QNR14 that this aspect of the Pacific Ocean behaviour (La Niña and negative IPO conditions) seems to be a very important component of the resilience of eastern Australia's rangelands. The uncertain impact of future global warming on this aspect of Pacific Ocean behaviour indicates that we should not take this climatic component of resource resilience for granted.

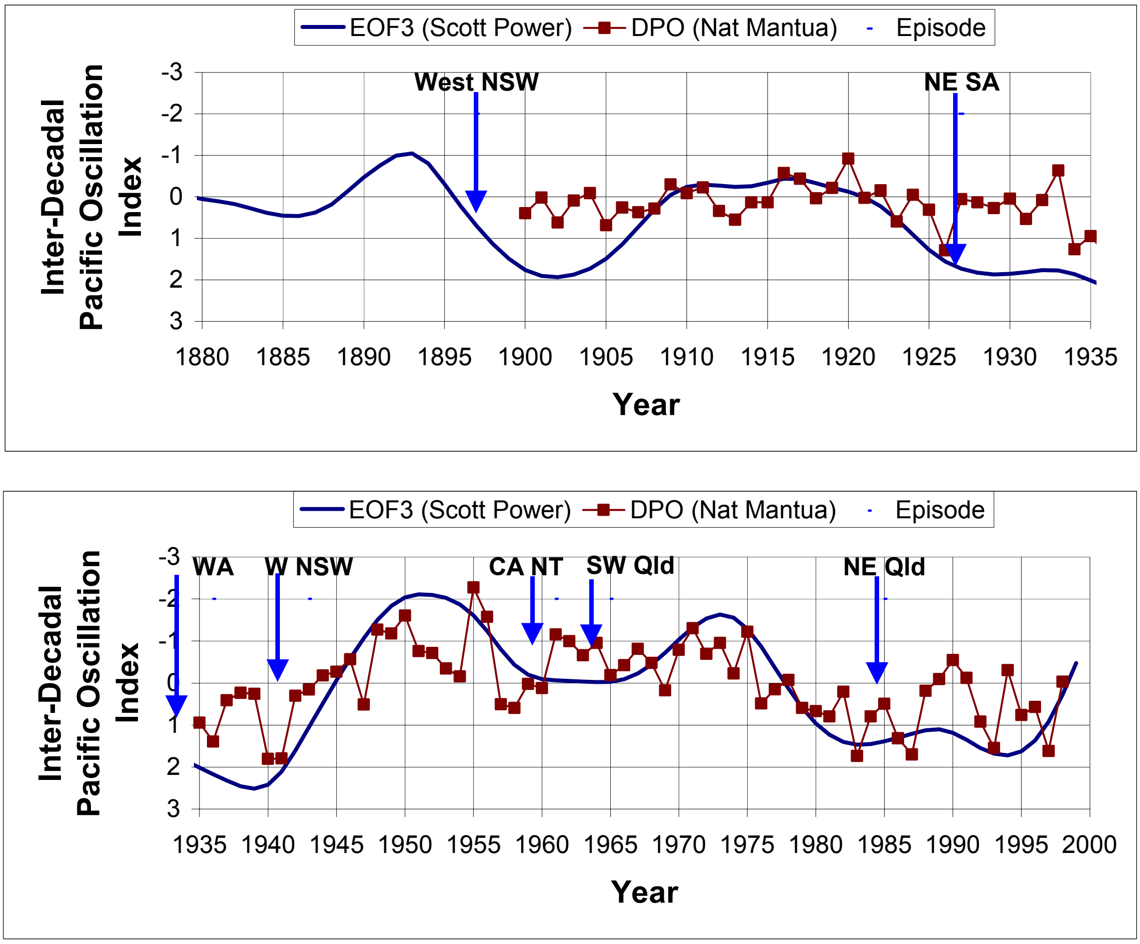

Figure 5. Comparison of annual measures of the inter-Decadal Pacific Oscillation Index and degradation episodes.

5.7 Objective 7: Evaluate the potential for forecasts from General Circulation and Regional Circulation Models to have helped prevent degradation episodes in the 1960s and 1980s in Queensland

The GCM/RCM modelling component of the project was disappointing in terms of the sheer difficulty of the work and the resultant demands on both human and computing resources. The statistical analysis of the results are currently being finalised and the Technical Report will include a detailed report, as well as an evaluation of the cost and benefit of continuing research in this high risk area.

5.7.1 GCM analysis

An experiment was conducted to compare the performance of GCM/RCM models (McGregor 1997, Peng *et al.* 2000) with existing SOI phase and the SOI/IPO classification systems. GCM/RCM models were forced with observed sea surface temperatures (SST) and forecast of rainfall across Queensland made for the months from October to March. Ensembles of 6 to 15 runs have been completed for each year from 1965 to 1999. Outputs were expressed and standardised anomalies calculated from the mean of the ensembles compared to simulated climatology (mean and variance) derived for the whole 35 years. Standardised anomalies were compared with rainfall for 5x5 km cells derived from interpolation of observed station rainfall. Evaluation was at both monthly and seasonal time scales for approximately 20,000 cells in Queensland's grazing lands.

To compare the three approaches (GCM/RCM, SOI phase, SOI/IPO) Relative Operating Characteristics (ROCs) were calculated. This procedure has been recommended by the World Meteorological Organisation and involves classification of observed and forecast rainfall into arbitrary 'bins' based on different percentile thresholds (30% and 70%), e.g. forecast is rainfall of less than percentile 30.

Forecasts are classified into four classes (Hits: forecast and observed both agree less than threshold; Misses: forecast in wrong category; False Alarms: observed event did not occur; Correct Rejections: both observed and forecast were greater than percentile threshold). Hit rates (Hits/(Hits and Misses)) and False Alarm rates (False Alarms/(False-Alarms and Correct Rejections)) were calculated for 30% and 70% thresholds. ROC curves were plotted (Hit Rate vs. False Alarm Rate) and an overall score calculated from the area under the curve.

Because the GCM/RCM experiment was forced by observed SST it represents the upper bound of skill that can be expected. The comparison with two statistical systems using ROC score analysis allows the GCM/RCM skill to be placed in the context of current forecasting skill.

5.7.2 Anomalous moisture fluxes

A major output of the GCM research was the analysis and interpretation of anomalous moisture fluxes (NCEP re-analysis) for different year-types. We have used the expertise developed through our GCM work to provide an assessment of the mechanistic basis for statistical forecasting systems (e.g. Table 2). For example we have used the NCEP re-analysis (1950 to 1998) to evaluate the global pattern of anomalous moisture flux for the different year-types within each forecasting/classification system. In the lag SOI/IPO system, year-type 2, with positive SOI (June-October) and negative IPO, had strong easterly anomalous moisture flow over eastern Australian consistent with the observed high rainfall. In contrast year-type 4, with positive SOI (June-October) but positive IPO, had southerly coastal and northerly inland anomalous flow consistent with average or lower rainfall. Similarly the other year-types had anomalous moisture flux consistent with rainfall patterns supporting the observed differences between year-types in rainfall over the last hundred years. Sequences of years with neutral SOI in June to October and positive IPO (year-type 6) are strongly associated with degradation/drought episodes in western NSW (1890s, 1940s) SA (1920s/30s) and north-eastern Queensland (1980s). The anomalous moisture flux analysis (1950 onwards) confirmed that the observed low summer rainfall in this year-type is associated with a weak northerly/westerly anomalous flow in eastern Australian i.e. conditions not suitable for major moisture inflow into these regions.

5.8 Objective 8: Evaluate the capability of General Circulation and Regional Circulation Models (GCM/RCM) to forecast rainfall and temperature under current global warming conditions

Analysis of available statistical forecasting systems highlighted the limitations associated with non-ENSO related droughts and global warming trends. GCMs offer one approach that may solve these limitations. To evaluate current performance of GCM/RCMs we analysed 3 monthly rainfall forecasts on a monthly time-step from September 1998 to September 2001 using the RCM DARLAM (McGregor 1997) nested in the NCEP GCM. Two versions of DARLAM were used with 10 ensembles produced with older version and 5 ensembles with newer version. Rainfall was expressed as an anomaly from climatology (1970 to 2000).

The models were run with (a) observed SST for forecast period (hindcast mode) and (b) predicted SST (true forecast mode); thus allowing evaluation of the performance of the atmospheric model. Overall the experiments allowed evaluation of 36 months with two SST models (i.e. 72 pages of output). Statistical analysis of observed and forecast rainfall is in progress. Qualitative analysis shows some agreement, e.g. the current drought in the Gascoyne region. However, there are substantial periods with no apparent agreement. However, as with statistical systems, forecast skill can only be evaluated over reasonable time periods (10-20 years).

5.9 Objective 9: Adapt and improve existing statistical forecast systems for use in Australia's grazing lands

To operationalise the available forecasting systems especially continuous variable systems, we have brought them to a common basis of year-types. The BoM SST system has also been converted to year-types (Drosdowsky submitted) and W. Drosdowsky has generously supplied an updated historical file for this study. We have tested the capability of the Aussie GRASS system to use alternative year-type file and hence there appears to be few technical difficulties in using alternative forecasting systems such as the BoM SST approach as long as they can be represented nationally as historical year-types (i.e. analogue years). However, the links between GCM/RCM output, alternative representations of continuous systems and regional specific year-type systems are yet to be researched.

5.10 Practical significance

The results from this project have implications for both the grazing community and policy makers, especially in adaptation to climate change. The history of degradation and recovery indicates that both graziers and governments are still learning how best to manage for climate variability. The understanding of global 'climate forcings' described in this and other CVAP projects provides a basis for re-assessing the management of Australia's natural grazing lands especially in Queensland and western NSW. In particular an appreciation of how ENSO and Inter-decadal Pacific Oscillation interact should lead to different views of stocking rate management and pasture burning in Queensland. Historical periods of positive SOI and negative IPO have had the highest proportion of years above median rainfall. If stock numbers are managed carefully in these years they provide the best opportunity for pasture recovery and the safest time to burn and retain or build up stock numbers with the lowest risk of drought. Positive IPO periods have less chance of the conditions suitable for recovery from resource damage and hence safe stocking rate strategies should be adopted to minimise risk of damage to the resource.

Our future challenges are:

1) how best to communicate these new but controversial ideas which science is still debating;
2) how to develop new climate forecasting systems which bring convergence to the large number of systems now available;
3) how best to apply these systems in grazing management with individual graziers and decision makers; and
4) how to update forecast systems to include the effects of global warming.

6 Communication and adoption

Close collaboration has been achieved with other state agencies under the umbrella of Aussie GRASS. Collaborating scientists have read and critiqued the history of degradation episodes, and have been exposed to the new understanding developed in this project of climate's role (i.e. IPO) in degradation and recovery episodes. As a result, we were asked by our colleagues to contribute a section on 'climate forcings' to the proposed Australian Rangeland Information System set up as part of the Land and Water Audit.

We have participated in extending the concepts associated with the IPO to other Departmental officers and selected graziers (e.g. Grazing Management Workshops, Dr M Quirk QDPI, Analysis of historical river flow data V. McNeil NR&M, Management of Lake Eyre Basin, NR&M; A. Lauder, 'Woodstock'). Communication of the influence of the IPO will be difficult. We have been reluctant to actively pursue the communication of the IPO analysis until BoM provides official endorsement. There is some urgency to resolve this issue as the precursors of previous degradation episodes are beginning to appear, i.e. sequences of good years; increasing stock numbers and economic volatility. A return to positive IPO conditions would increase the need for a major communication campaign.

Dr White's GDR system also poses difficulties in terms of extension. The mainstream meteorological science community is still debating issues raised by Dr White's analysis. The system is at this stage a 'black box' forecasting system and hence will pose a major communication challenge. In Section 7 we outline a plan to address these issues.

7 The future

We plan to move (funding permitting) in the following directions.

7.1 Harvest year.

The project has generated so much material (e.g. many forecasting systems for many regions) and has had so many contributors (e.g. seven lead authors not to mention other staff) that we have been delayed in preparing the final technical report. The two lengthy milestone reports already attest to the level of detail of results available through the project. We estimate the final technical report will be submitted in mid December. We seek approval for this extension.

In part the success of the project in advancing knowledge in terms of forecasting systems, degradation models and GCM analysis has delayed the distillation of results that only a 'harvest' year can provide.

7.2 Preventing the 9th episode

The results of the project provide the basis for informing governments and the grazing community of the risk of the '9th Episode' occurring. The forecasting systems will have to be operationalised and supported by an extension program. A major difficulty is that the principal investigators are Queensland Government employees and our role in national projects is always under question. For us Aussie GRASS provides the best umbrella for multi-state collaboration and we will continue to seek government and external funding support for our involvement. Aussie GRASS represents an incremental growth in simulation capability and interstate networking. The Aussie GRASS platform provides an economy of scale and the best method to deliver the technical information involved in forecasting pasture growth, but the extension of the new concepts of climate understanding will require a new regional extension effort. We hope to undertake case studies testing the regional rainfall systems (QRI and GDR) within the relevant regions using the Aussie GRASS model.

7.3 Policy change to land management

In Queensland there is increasing pressure on graziers to consider the environmental consequences of their actions. As indicated above, the societal benefits of maintaining carbon stocks or reducing soil/sediment concentration in river systems are just starting to be calculated. Specifically, recent Queensland Government initiatives highlight concern regarding the role of run-off impacts on the Great Barrier Reef. We are re-evaluating the role of climate forecasting in grazing management from this viewpoint using the systems and models developed in this project.

7.4 Adaptation to climate change

Our group is also responsible for managing in Queensland whole-of-government programs on climate change. Before this project began, the issues of future climate change and climate variability were seen as separate. However, the adaptation to future climate change must include awareness of inter-decadal effects such as the IPO. We have commenced the task of bringing these three aspects of predictive climate capabilities together (inter-annual climate variability, inter-decadal and future climate) for monitoring impacts of current climate variability/trends and developing future policy. We plan to continue work linking predictive climate capabilities with applications, especially the use and management of natural resources.

8 List of publications and invited conference presentations

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9 Sources of additional information

Additional information can be obtained by contacting the Principal Investigator or by visiting the Long Paddock web site (www.dnr.qld.gov.au/longpdk).

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