

Improved grazing management practices in the catchments of the Great Barrier Reef, Australia: does climate variability influence their adoption by landholders?

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Abstract. The declining health of the Great Barrier Reef from diffuse source pollutants has resulted in substantial policy attention on increasing the adoption of improved management practices by agricultural producers. Although economic modelling indicates that many improved management practices are financially rewarding, landholders with dated management practices remain hesitant to change. This research involved bio-economic modelling to understand the variance in private returns for grazing enterprises across a climate cycle. Results show that financial returns to landholders can vary substantially across different 20-year periods of a climate cycle, demonstrating that the variability in expected returns may be an important reason why landholders are cautious about changing their management practices. Although previous research has separately identified financial returns and attitudes to risk and uncertainty of landholders as key influences on decisions concerning adoption of improved management practices, this research demonstrates that it is the interaction between these factors that is important to understand when designing policy settings.

Additional keywords: agricultural production, bio-economic modelling, landholders' decisions, pollution.

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Introduction

The decline in the health of the Great Barrier Reef (GBR) in Australia has led to the development of several Federal and State initiatives to reduce agricultural pollutants, which are based on a central Great Barrier Reef Water Quality Protection Plan. The development of the Great Barrier Reef Water Quality Protection Plan (2003, 2009, 2013) involved several targets to reduce pollutants, including a 20% reduction in sediments and a 50% reduction in nutrients by 2020 (Great Barrier Reef Water Quality Protection Plan 2013). There has been a considerable Federal and State funding effort of A\$375 million across both the grazing and sugarcane industries to achieve the targets with increasing pressure on achieving efficient outcomes (Great Barrier Reef Water Quality Protection Plan 2013). The grazing industry has been targeted to make reductions in sediment pollutants as it occupies the majority of the Fitzroy and Burdekin catchments adjacent to the GBR and has been attributed to increased loads entering into the lagoon of the GBR (Brodie *et al.* 2003; Kroon *et al.* 2012).

A key focus of past and current funding has been to provide incentives and grants to encourage graziers to complete activities, which include fencing of land types, riparian fencing, mechanical

earthworks and voluntary land management agreements. The main funding focus has been to shift to A or B management practices from C and D, where A is above industry standard and highly likely to maintain land in good condition, B is industry best management practices, C is below industry standard and D is practices that are highly likely to degrade land to poor condition. To achieve sediment reductions, a framework of management practices was developed following the A, B, C and D land condition classification (Chilcott *et al.* 2005). Similarly, an extension program of best management practice for grazing was developed, which is a strategic self-assessment review of all aspects of the grazing business where graziers complete a voluntary self-assessment of management practices against industry standards.

Economic analysis of grazing operations has shown that there are long-term financial benefits from graziers shifting to B management practices (Ash *et al.* 1995; McIvor and Monypenny 1995; O'Reagain *et al.* 2011; Star *et al.* 2013). This is particularly so over the long-term as major land-degradation events tend to occur during drought periods when there are economic benefits in maintaining lower stocking rates or reducing forage utilisation rates (Landsberg *et al.* 1998; O'Reagain *et al.* 2011). Given that

overgrazing leads to financial losses by graziers in the longer term, an important research question is to identify why many graziers/landholders do not voluntarily reduce long-term grazing pressure and what is the most effective policy to achieve sustainable grazing systems.

The literature on adoption has identified several factors, both financial and non-financial, that are important in explaining varying rates of adoption of improved management practices by landholders (Soule *et al.* 2000; Perrings and Walker 2004; Kingsford *et al.* 2009). Pannell *et al.* (2006) summarised the reasons for non-adoption of conservation practices as: lack of relevant information about the problem or opportunity, landholders have the relevant information but there is no benefit for them to adopt and, finally, there is risk and uncertainty associated with the benefits of adopting. A range of non-financial factors that may explain why landholders in other grazing catchments may be reluctant to adopt improved management practices have also been explored (Greiner *et al.* 2008; Greiner and Gregg 2011).

The targeting of resources more efficiently and effectively has been a key policy recommendation in reviews of natural resource management programs (Rolfe *et al.* 2007; Pannell 2009). Key considerations include the understanding of the public and private costs and benefits to evaluate which policy mechanism is most effective in achieving environmental outcomes (Pannell 2009). Pannell *et al.* (2006) developed a framework for investing in natural resource management (NRM) projects where the trade-offs between public and private benefits and costs identify which policy mechanism is the most effective.

Key limitations of the framework are underlying assumptions that the public and private trade-offs are understood and are homogenous across different enterprises, locations and management practices. It also does not account for the time required to shift to a new overall environmental position. It does, however, integrate the private and public cost and benefits, and the most appropriate policy mechanisms. The increased pressure for improved health of the GBR, and to meet targets and efficient use of resources, means that policymakers need to evaluate the net public and private benefits of reducing sediment emissions, and the policy mechanisms to achieve this. Improved understanding of the net private benefits of changed management practices is an essential step in the process.

Landholders face substantial uncertainty about markets, climates and the benefits of changing management practices, and are likely to consider these in any assessment of the net benefits of practice change. Of particular interest to landholders are the private benefits from changing management practices, taking into account variations in future patterns of rainfall. A simple hypothesis is that managers who are more optimistic regarding future patterns of climate are more likely to adopt particular management practices, whereas those more pessimistic about future patterns of climate may be reluctant to change.

The study presented in this paper aims to contribute to an improved understanding of the private benefits to landholders of changing to a different management classification and the response in policy required to achieve this. The study aims to provide a better understanding of the private trade-offs involved in grazing management operations in a highly variable climate where financial returns may be set by patterns of rainfall and temperature over successive years. The research provides

information about how sensitive private benefits are to the dynamics of weather patterns over several years, and may enable improved policy mechanisms to increase adoption rates of improved management. Bio-economic modelling is used in this study to explore the implications of climate variability in rangelands and the impact on private financial returns when adopting management practices, with case study applications in the Fitzroy Basin in Central Queensland. The paper is organised as follows: first, the context of the problem is described identifying the research gaps; second, the case study and best management framework are explained, and, third, the bio-economic modelling method and results are presented, followed by a discussion of the results.

Materials and methods

Case study

The Fitzroy Basin in Central Queensland is the second largest catchment area in Australia covering 143 000 km² (Fig. 1). Grazing is listed as the prime cause of changes in water quality with beef production as the largest single land-use industry comprising 90% of the relevant land area (Karfs *et al.* 2009).

The experience with rural landholders is that there is no one approach to fostering change in on-ground practice to improve water quality but there needs to be a tailored multi-faceted approach (Pannell *et al.* 2006). It is also known that setting appropriate long-term stocking rates, wet-season spelling, forage budgeting and protection of vulnerable areas are critical to achieving and maintaining sound land management outcomes (Rolfe and Gregg 2013).

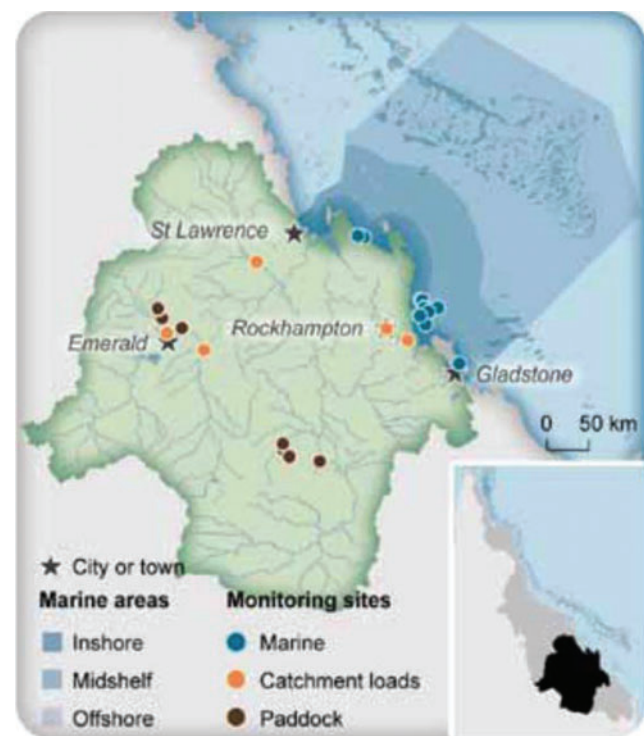


Fig. 1. The Fitzroy Catchment (source: Great Barrier Reef Water Quality Protection Plan 2013).

Management practices to improve water quality has complex and uncertain economic and environmental outcomes as it involves reductions in grazing pressure but leads to improvements in pasture quality and land condition over time (Rolfe and Gregg 2013). Predicting the consequences of management changes at the enterprise level is difficult and typically requires detailed knowledge of both enterprise and biophysical characteristics (Pannell and Roberts 2010).

Although a framework of grazing management practices has been developed and targets were set for change in management practices in the GBR catchments, achieving the targets for reduction in pollutants remains difficult when attempting to encourage changes by private land managers. Improved land management practices are often technically complex and difficult to implement (Pannell *et al.* 2006). The framework of best management practice for grazing provides different insights into program design for grazer participation and NRM outcomes. The report card of Great Barrier Reef Water Quality Protection Plan (2009) in 2010 highlighted that approximately half the industry were estimated to be using B condition practices and half were using C or D practices (Great Barrier Reef Water Quality Protection Plan 2013) (Table 1).

Table 1. Proportion of landholders adopting grazing management practices (% see text for full description of categories) under Great Barrier Reef Water Quality Protection Plan (2009)

Practice categories	First report card (Baseline 2009)	Second report card (2010)
A	6.04	7.61
B	49.78	51.79
C	36.99	33.60
D	7.19	7.00

A key aspect of achieving increased adoption is improving an understanding of the relative profitability over the long-term regarding the specified practices. Past research, completed over several land types, has explored the trade-offs between grazing pressure, profit and sediment, highlighting the heterogeneity between land types, land condition and impact of trees on profit and subsequent sediment exported (Star *et al.* 2013). Key challenges in the targeting of resources for improved grazing management are to understand how the private benefits associated with changing grazing management practices may be sensitive to climate patterns over time. Understanding how private net financial returns may interact with issues of risk and uncertainty may provide insights into efficient policy delivery and targeting of resources.

Bio-economic modelling

The bio-economic model was developed to estimate the trade-offs between grazing pressure, profit, management practices and subsequent outcomes in water quality for a standard grazing enterprise. This case study focussed on modelling the parameters of two land types – Brigalow Blackbutt and Brigalow Gidgee. These two land types were selected based on their dominance in the landscape but different weather stations and property sizes were selected to reflect differences in location and enterprises for the vegetation types. Brigalow Blackbutt was modelled for a 5000-ha property and a climate location of Blackwater (23.58°S, 148.89°E) whereas a 20 000-ha property was modelled with the climate location of Middle Creek (22.07°S, 146.93°E) for the Brigalow Gidgee.

The model developed (Fig. 2) consists of two distinct sub-models: (1) a biophysical sub-model describing the rangelands grazing system, which includes several components, such as soil type, land condition, rainfall, slope and sediment movement for various pasture utilisation rates with production outcomes measured in terms of Total Standing Dry Matter (TSDM) of

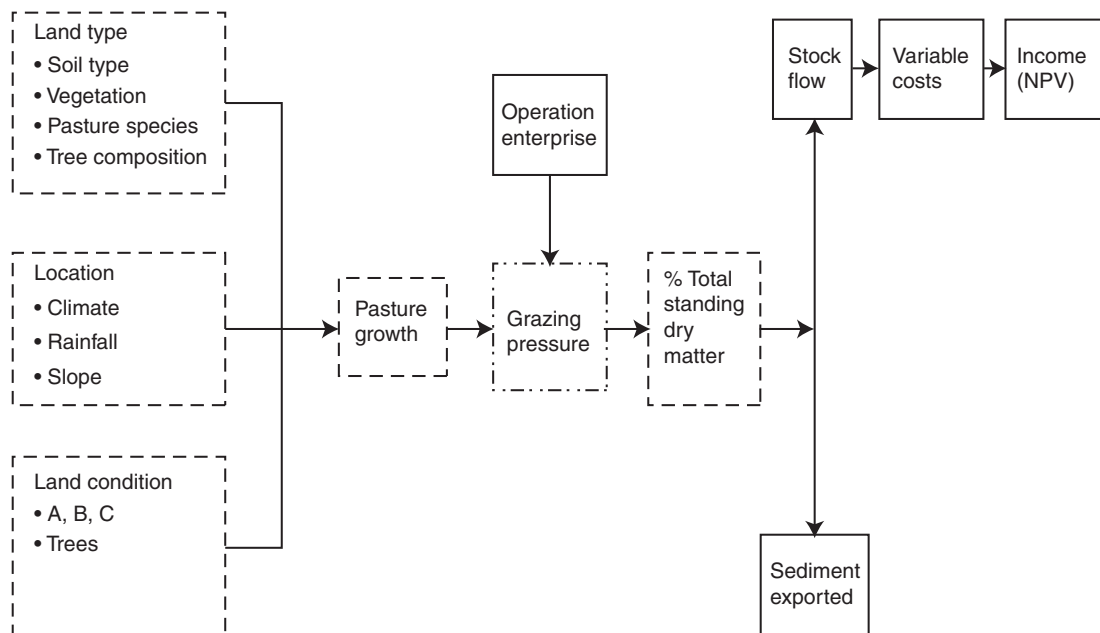


Fig. 2. Components of the bio-economic model.

forage, and (2) an economic sub-model describing the enterprise, stock movements and profitability. The sub-models were initially integrated into a bio-economic model to determine at each particular pasture utilisation interval the maximum profit that can be obtained and the amount of sediment that is exported. This enables the bio-economic model to be linked into an optimising model, and the most cost-efficient allocation of funds to change stocking intensity (and sediment movement) to be subsequently identified. The optimisation problem is to maximise profit through the selection of the optimal level of pasture utilisation. To account for variations in climate and lag effects from both climate and management variables, the model is run over 20-year periods using historic weather data.

Economic results are expressed through a profit function that was generated using the following variables: profit (net present value, P); a vector of biophysical factors that affect and influence stocking rate and animal performance (F); level of pasture utilisation (% TSDM, F_j , such that $j = 15, 20, 25 \dots 70$ tonnes of sediment exported given the level of pasture utilisation (J_t); a vector of economic implications (E); types of economic implications (E_k); cost of economic implications (C); discount rate (i); the sum of a period of 20 consecutive years (T); and years ($t, 1, 2, 3 \dots 20$).

The following describes the profit maximisation (P) for each level of pasture utilisation (F_j) and the associated level of sediment exports:

$$\text{Max } P = \sum_t^T F(S) \quad (1)$$

$$E = \frac{E_k - C}{(1 - i)^t} \quad (2)$$

$$J_t = F_j(F) \quad (3)$$

Biophysical sub-model

To account for F in Eqn 1, a point-based native pasture model developed for semiarid and tropical grasslands, termed GRASP, was used. The GRASP model simulates pasture growth based on nutrient balances, soil water deficits and also predicts livestock performance through complex interactions between pasture growth, stocking rate and liveweight gain (Day *et al.* 1997; Littleboy and McKeon 1997; McKeon *et al.* 2000; Rickert *et al.* 2000). To allow other outputs to be assessed, GRASP includes several sub-models, which also allow simulation of variables such as water runoff (Day *et al.* 1997) and soil loss. Both land types were modelled to be starting at the level representative of a 'B' condition property for those particular land types and locations.

In the modelling application, 1560 GRASP simulations were run for each location/land-type combination, each varying in terms of four variables; start year, starting land condition, utilisation rate and tree basal area. Twenty start years were selected randomly from all years between 1892 and 1984 (1896, 1902, 1904, 1912, 1915, 1917, 1924, 1929, 1936, 1941, 1942, 1945, 1949, 1956, 1960, 1962, 1967, 1971, 1981 and 1983) to allow reasonable capture of the impacts of long-term climate variability on pasture production and sediment loss. Starting land condition was quantified in terms of the proportion of perennial

grasses, with values of 70% TSDM of forage for B and 20% perennials for C, which were intended to equate with the levels of condition B and C, respectively, under the ABCD framework (Chilcott *et al.* 2005). Land in D condition was not included in the analysis because of the smaller areas involved and the difficulty of predicting rehabilitation rates.

Twelve pasture utilisation levels (15%, 20%, 25%, 30%, 35%, 40%, 45%, 50%, 55%, 60%, 65% and 70%) were used as separate simulations in each case study to measure the impact of grazing pressure on land condition and sediment loss. The proportion of TSDM of forage left at the end of the growing season (April) transferring into the next year of the simulation and the stocking rate was adjusted to the required level of pasture utilisation. Each simulation was run using a 20-year sequence (beginning at the start date) of climate data from the modelling locality. The 20-year interval was selected to reflect approximate tenure lengths for land managers and also to allow for cumulative effects of long-term utilisation levels to be assessed.

The GRASP model uses an equation for daily loss of soil, which was derived from losses of soil measured on hillslopes in the Burdekin grazing lands (Scanlan *et al.* 1996). The Revised Universal Soil Loss Equation (RUSLE) (Renard *et al.* 1997) used length (L) and slope (S) adjustments (LS), which have been shown to relate well to measured losses of soil on a range of slopes in grazing lands in Queensland (Silburn 2011; Silburn *et al.* 2011). To correct losses of soil to greater or lesser slopes and lengths found in the land types modelled here, losses of soil, derived from the GRASP model, were divided by the average LS factor for the sites of Scanlan *et al.* (1996) and multiplied by the average LS for the modelled land type, which were derived from a digital elevation model. Thus, on land types typically steeper than modelled by Scanlan *et al.* (1996), losses of soil will be increased and on flatter land types soil losses will be decreased. Sediment exported to the reef was calculated using a property to stream delivery ratio of 12.5%, which is the estimated level of sediment movement in a hectare that actually leaves the paddock (Dougall *et al.* 2008).

Economic sub-model

The economic model was developed to describe vector E in the above optimisation equation, with a 20-year stock flow in a beef cattle enterprise to match the climate data and the simulated stocking rate for each individual year. Identifying the net economic outcomes of each stocking rate over 20 years allowed the optimal production system to be identified. Comparisons with returns from lower stocking rates could demonstrate the economic implications of reducing stocking rates to increase the amount of TSDM of forage at the end of each year, with subsequent reductions in bare ground and sediment exports. To explore the economic trade-offs, a marginal analysis was implemented to determine the change in profits between the 'without management intervention' scenario of 10% TSDM of forage and the 'with management intervention' (15–70% TSDM). As the analysis was based on stocking rates, no capital costs were assumed to be required.

This methodology estimates the accumulated marginal benefit over several years, once discounted. The net benefits of a management change were assessed over 20 years, and a 6% real

discount rate was applied. The discount rate ensures that future benefits or costs are translated into today's current dollar value, and was chosen to represent an approximation of the real discount rate in Australia over the previous 3 years (2011–2013). The net present value (NPV; discounted stream of future benefits and costs) can be interpreted as the estimated return or loss that is expected from a management change in today's dollar terms (Sinden and Thampapillai 1995).

Factors of vector F that impacted E and E_k in the beef production model included mortality, branding and drought feeding, which was calculated both for the dry (fattening) herd and for the breeding herd, and was dependent on the liveweight gain. The calculation for mortality was derived from MacLeod *et al.* (2004). The dry herd was considered to be yearling heifers, steers and older cattle. A breeding mortality rate was applied with a maximum of 20% for mortality rates. The equation of MacLeod *et al.* (2004) was calculated as a function of liveweight gain (kg):

$$\text{Mortality}(\text{Breeders})\% = 6 + 94e^{-0.027(\text{LWG}+50)} \quad (4)$$

$$\text{Mortality}(\text{DryStock})\% = 2 + 88e^{-0.034(\text{LWG}+50)} \quad (5)$$

Branding rates were based on MacLeod *et al.* (2004) and were determined as a function of liveweight gain with a maximum rate of 75% and a minimum of 30% to reflect operations in the region (Best 2007). The equation is as follows:

$$\text{Branding}\% = 30 \leq 15.6 + 0.488 \times \text{LWG} \leq 75 \quad (6)$$

It was assumed that in years where there was less than 50 kg liveweight gain that drought feeding would occur, based on MacLeod *et al.* (2004). The rules implemented in the model were that when liveweight gain was less than 50 kg then a urea-molasses lick supplement (urea 8% – M8U) was fed. The feeding rule was 2 days of M8U feeding for each kg of liveweight gain less than 50 kg. Where the GRASP model simulated that there would be a liveweight loss then a ration of urea-molasses

fortified with cottonseed meal (urea 3%, cottonseed meal 10%) was fed with 1 day of feeding for each kg of liveweight loss.

In order to ensure that the pasture utilisation was at the required level, particularly at the higher utilisation levels, there was a substantial adjustment in stock numbers from year to year, facilitated by selling and purchasing. To ensure that stock reductions occurred in drought years, additional drought sales occurred across the herd, with appropriate price penalties to reflect the low demand for stock during these periods. If pasture availability increased in the following year, additional stocks were bought back at the same ratio as the base herd in Year 1.

Results

The results provide insights into the complexity of selecting a policy mechanism to reduce sediment losses and the certainty that private benefits will be achieved. This highlights the challenges in selecting the most effective mechanism for increased adoption. The results show a high level of heterogeneity in private benefits that exists due to the climate and the impact of grouping stocking management with wet-season spelling.

First, the results for Brigalow Blackbutt with a 'B' start condition of the 20 start years by 20 consecutive years for each of the simulated grazing pressures are presented. Second, a more detailed analysis of the NPV over time with different rainfall patterns for the economically optimal point is presented. Third, the impact of considering a single management strategy (flexible stocking rates) versus a joint management strategy (flexible stocking rates plus wet-season spelling) is presented for Brigalow Gidgee. Finally, a graphical representation of how the benefits for adoption of grazing management practices fit into the NRM framework is given.

The results of the Brigalow Blackbutt land type in B start condition with an average of 580 mm of rainfall for the locality of Blackwater identify an economically optimal pasture utilisation of 20% TSDM of forage, where the NPV is A\$4 982 516 (Fig. 3) and the relative sediment exported is 2629 tonnes of sediment

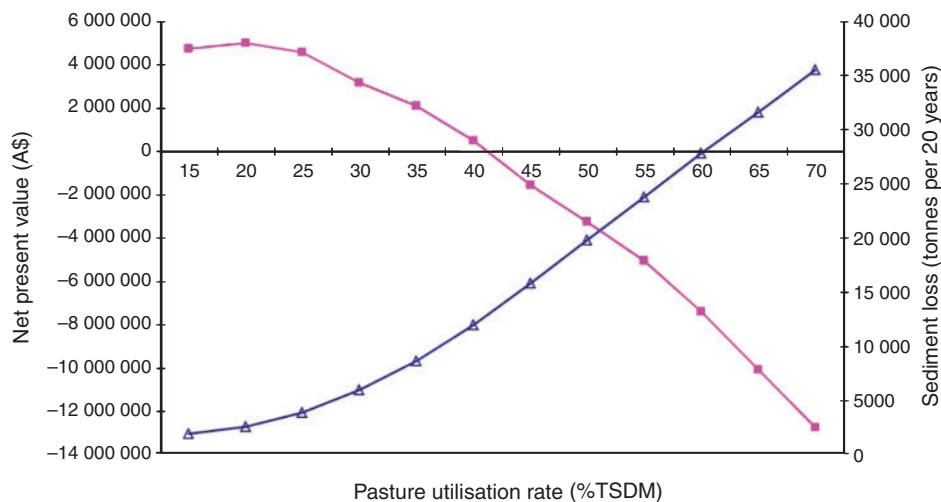


Fig. 3. The trade-off between net present value (NPV, squares) and sediment loss (triangles) in relation to pasture utilisation rate, expressed as % total standing dry matter (%TSDM), for Brigalow Blackbutt at Blackwater in B condition.

over the 20-year period. As expected, higher stocking rates above the optimum generate both decreased profits and higher sediment exports; a higher stocking rate of 40% TSDM of forage results in a decreased NPV of A\$505 694 and subsequent sediment export of 12 036 tonnes, demonstrating the importance of conservative stocking as a key management practice. This supports the recommendations of better management practices towards higher levels of ground cover, and establishes that landholders should be able to generate net private benefits from adopting better practices.

To test how private returns may vary with changing weather patterns requires the same bio-economic model to be run on subsets of the available climate data. The average rainfall for each of the 20-year periods shows limited variation in average rainfall conditions (Fig. 4), explaining why variations in weather patterns has not been considered as an important driver of adoption decisions.

Variations in the annual rainfall and the pattern of rainfall, however, have a significant impact on the NPV for the average enterprise, as identified by the results of the bio-economic model for the individual 20-year weather periods. For the 20% TSDM of forage, the NPV for each of the 20-year periods varied significantly around the average NPV over the total 20-year periods (Fig. 5). For example, the 20-year periods, starting from 1912 and 1981, received the same average rainfall, but the resulting NPV would be A\$263 537 for the weather period of 192 and A\$4 424 476 for the weather period of 1981 (Fig. 5). This is because rainfall from 1912 to 1931 had much greater variability and there were longer drought periods than in 1981 to 2000.

The main difference in NPV between the weather periods of 1912 and 1983 is attributed to the high rainfall in 1916 and 1917 and the low annual rainfall in 1918 and 1919 (Fig. 6). The 20-year rainfall period starting in 1981 has a smaller range and, therefore, large changes in the herd structure do not occur and, although there are years of higher rainfall, these are over a longer period of time (Fig. 6). The results highlight that adoption decisions in variable climates is complex and that profitability can vary significantly over short periods. If the cash flow decreased

substantially during one poor season, it may take several years before financial recovery can occur.

It is expected that landholders can adjust to patterns of variable rainfall to some extent with flexibility over management responses. To test for this, the bio-economic models for the Brigalow Gidgee land type on a 20 000-ha property in the Belyando sub-catchment included wet-season spelling and flexible stocking rates to further understand the impact of adopting multiple management practices. One version of the model allowed for flexibility over stocking rates and a second version allowed both flexible stocking rates and wet-season spelling, both of which are recommended as better management practices. Model results were similar to those of the Brigalow-Blackbutt land type in the Fitzroy although financial returns ha⁻¹ were lower when the larger property size is considered (Fig. 7).

The bio-economic models identified that the maximum NPV was achieved at the stocking rate with 25% TSDM of forage for both sets of management practices, although the NPV of A\$ 7 658 966 for using both practices was marginally higher than the returns from only using flexible stocking rates. It is notable that including both management practices flattens the peak of the NPV function relative to using only one practice, suggesting that flexibility in dynamic settings can improve returns for some stocking rates as well as making it more difficult to select the optimum grazing pressure.

The model results demonstrate that it is difficult to estimate the net private benefits of a practice change with any certainty. Net benefits may vary widely, and be positive or negative,

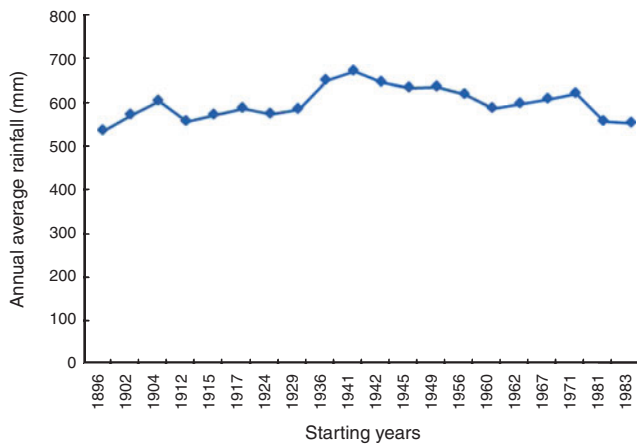


Fig. 4. Annual average rainfall (solid line) for the 20-year periods – location Blackwater.

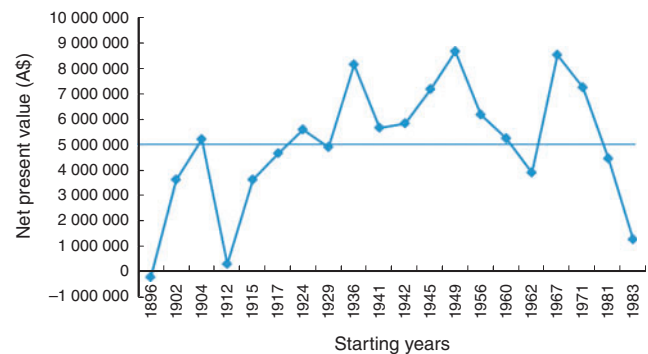


Fig. 5. The variation in net present value (NPV) over 20-year weather periods for Brigalow Blackbutt at Blackwater. The solid horizontal line is the average NPV at 20% TSDM.

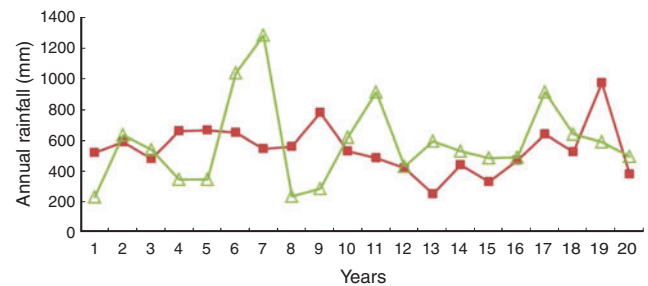


Fig. 6. Annual rainfall for each of the 20-year periods starting from 1912 (triangles) and 1981 (squares).

depending on the weather sequence that is expected. Thus, the private incentives to change practices may vary widely between locations and landholders, depending on both variations in expected weather patterns and landholder expectations.

Applying these results into a policy framework illustrates the difficulties involved when there is uncertainty over private benefits. Pannell *et al.* (2008) has demonstrated how the broad choice of policy mechanisms can be linked to the mix of net private and net public benefits that are involved. When private benefits are uncertain and vary between landholders and over

weather scenarios, net private benefits can be more accurately considered as a zone of potential values rather than as a definitive value (Fig. 8). This means that net private benefits are not just one point on the policy mechanism framework but fall in a general area (Fig. 8) where there is considerable overlap between policies. This was demonstrated by Fig. 6 where the NPV varied significantly. The implications of this are that different policy mechanisms may be required simultaneously both between landholders and across time to account for the variability in net private returns from adopting better management practice (Fig. 8).

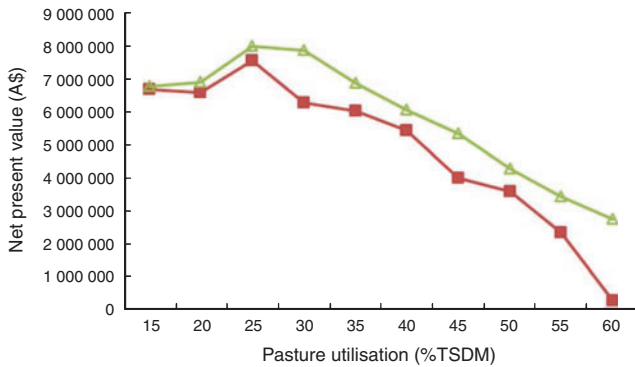


Fig. 7. Comparison between the net present value of a stocking rate alone (squares) and with wet-season spelling (triangles) for a range of pasture utilisation rates, expressed as % total standing dry matter (%TSDM).

Discussion and conclusions

There is significant policy pressure for sediment reductions to achieve the targets of Great Barrier Reef Water Quality Protection Plan to improve the health of the GBR in a timely manner. This paper demonstrates the difficulty in applying the current NRM frameworks when there is uncertainty and dynamic variation in the private benefits of changing landholder management practices. It also provides insights into why offering a bundle of practices to adopt may reduce the uncertainty and variability in private benefits and costs, and, therefore, allow for further flexibility and ability to make dynamic changes.

The more optimistic landholders are, in regards to future weather patterns, the more likely to perceive that practice change will generate net private returns. This helps to explain the link

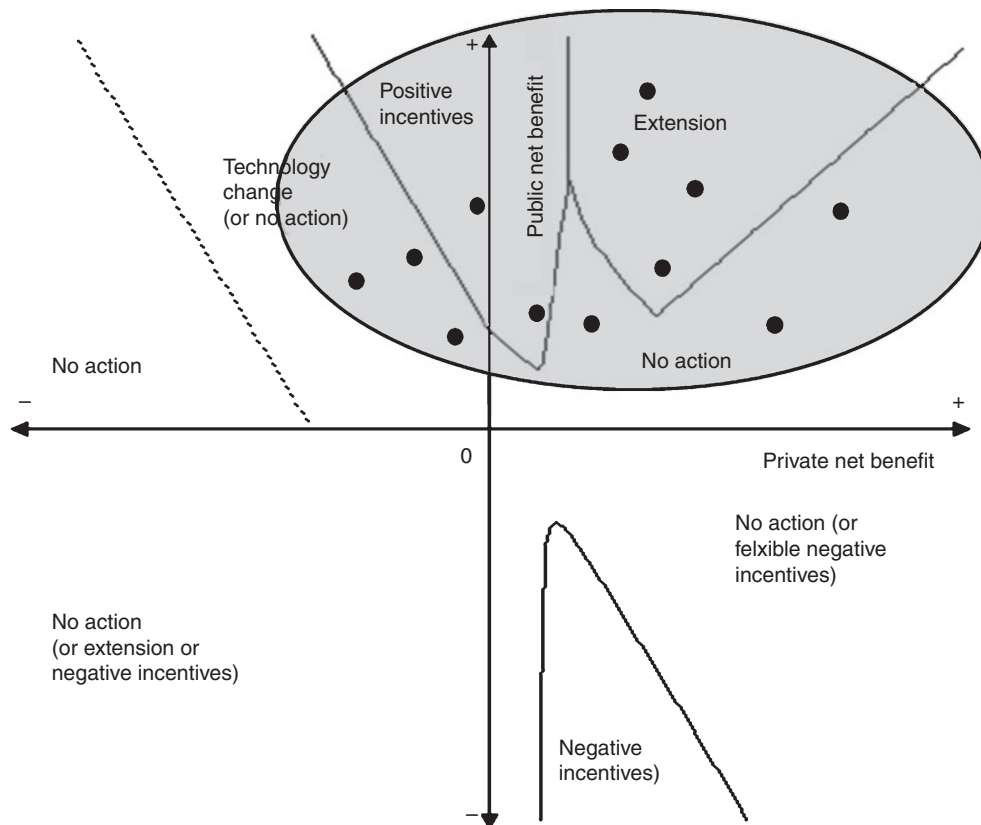


Fig. 8. Range of private benefits and costs for different landholders in the nature resource management framework.

between attitudes and increased rates of adoption identified by researchers such as Greiner *et al.* (2008) and Greiner and Gregg (2011). The current approach of best management practice for grazing through allowing landholders to consider where they are in relation to the rest of the industry creates a flexible opportunity for the various policy mechanisms to be considered. It would also indicate that landholders that are more optimistic about future weather patterns are more likely to adopt than those who are not.

Improved long-term information regarding future climate patterns and their production implications for the particular spatial location of interest will allow better predictions of the private benefits available from changing management practice. The ability to provide quality extension and development information is critical in supporting the adoption of a group of practices to mitigate the risk and uncertainty.

Some limitations of the study should also be noted. The bio-economic modelling has not captured all the biophysical factors, such as site-specific effects, whereas the biological models may not have adequately reflected cumulative and threshold effects (Wu and Skelton-Groth 2002). Furthermore, the potential for multiple environmental benefits has not been recognised. The bio-economic models are simplistic in assuming that the modelled property consists of one land type and that the pasture utilisation rates are applied uniformly across each property. The assumptions that landholders are always profit-maximising and have perfect knowledge should also be noted as not fully realistic. These limitations provide important areas for further research.

Despite these caveats, the results demonstrate three important outcomes. First, they demonstrate the complexity of grazing systems and the impact that weather can have on achieving private benefits in grazing systems. Second, it highlights the importance of a mix of policy mechanisms and the ability to better account for the risk and uncertainty to improve adoption of practices. Finally, it demonstrates that there are opportunities to adopt a suite of practices to improve the likelihood of achieving a private benefit.

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