

**An Economic Approach to Plant
Introduction Decisions:
The case of plant-based solutions to salinity**

Cheryl Yvonne Kalisch Gordon
B.Ag Ec.(USyd) Hons (I)

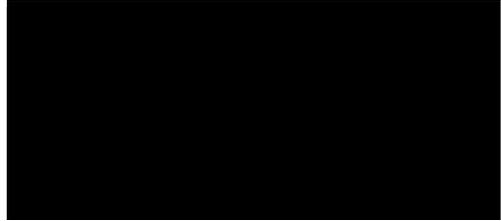
A thesis submitted for the degree of Doctor of Philosophy
at the University of New England
Armidale NSW

June 2008

Certification

I certify that the substance of this thesis has not already been submitted for any degree and is not currently being submitted for any other degree or qualification.

I certify that any help received in preparing this thesis, and all sources used, have been acknowledged in this thesis.



.....

Acknowledgements

This doctorate was undertaken with supervision from Associate Professor Jack Sinden and Associate Professor Oscar Cacho of the School of Business, Economics and Public Policy, UNE. Their expertise, guidance and encouragement have proven invaluable.

In particular, I would like to acknowledge Jack's expertise in benefit-cost analysis, environmental economics and policy analysis and his guidance in developing the framework for this study. I gratefully acknowledge Oscar's expertise in bioeconomic and quantitative approaches as well as his ability to move quickly from problem to problem and issue to issue. His patience with me as I developed the new skills required to model and analyse the relevant resource problems is greatly appreciated and the value of his preparedness to share his expertise amidst the changes in my life during my candidature cannot be underestimated.

I also acknowledge the financial support of the Grains Research & Development Corporation, and the in-kind assistance of the former Cooperative Research Centre (CRC) for Plant-Based Management of Dryland Salinity and the former Australian Weeds CRC. In particular, I would like to thank Dr Mike Ewing and Professor David Pannell (both of the former CRC for Plant-Based Management of Dryland Salinity) and Dr Dane Panetta (of the Australian Weeds CRC) who provided advice during the initial stages of the study. Critical data and information for modelling plant populations and salinisation were generously provided by various organisations: NSW Department of Primary Industries (Mrs Leah Lane, Ms Carol Harris, Dr Andrew Alford, Dr Sean Murphy and, in particular, Dr John Ayres) and the NSW Department of Natural Resources. I would also like to thank my colleague Corinne Brown for her assistance with GIS.

I extend thanks also to the Academic staff of the School of Business, Economics and Public Policy for their advice during my candidature. In particular, I would like to thank Dr Susie Hester for her assistance: whether with regard to arranging childcare, applying damage functions, supplying a tea bag on my visits or just always being

cheerful. I am also grateful to the Support staff in the School of Business, Economics and Public Policy and to Research Services, UNE.

Undertaking the majority of this work externally and with two small helpers created an additional consideration when completing this work. To the New England innkeepers and babysitters who demonstrated their love and friendship with complete generosity of time and their homes, over and over, my deepest Thanks.

To my P's, H, and most especially, my D, your love and belief in me has made this contribution possible. This has been a team effort with you guys providing the motivation to keep me focussed but also ample distractions....to remind me of the many wonderful things in my life. Thank you!

Abstract

Invasive plants and dryland salinity both impose considerable costs on the Australian environment and agriculture. Expectations are for these costs to increase still further because both result from dynamic, and sometimes lengthy, processes. A range of exotic pasture plant species has been identified as having the potential to reduce dryland salinity if introduced to Australian farming systems. With this opportunity however comes the potential for these new plants to become invasive (i.e. weeds) and thus add to the already high annual costs of introduced plants. How do we decide whether to introduce the new pasture plants or not?

Current decision processes employ a precautionary approach that favours the exclusion of new plants from Australia through consideration of potential costs but not benefits. As the potential gains and costs from the new pasture plants may both be high, an alternative decision framework is needed. This thesis presents an economic approach where introductions are allowed when they offer positive contributions to society's welfare. The approach has been applied to the decision to introduce new varieties of birdsfoot trefoil (*Lotus corniculatus* L.) to the Kings Plain Subcatchment within the Border Rivers Catchment of northern New South Wales.

The analysis for this study rests on the development of a bioeconomic model within a guiding benefit-cost framework. The bioeconomic model comprises two sub-models. The first uses a numerical, deterministic, dynamic programming technique to estimate the benefits of reduced salinity as a result of introducing birdsfoot trefoil as a pasture option in the Kings Plain Subcatchment. The second uses a deterministic, and then stochastic, simulation technique to estimate the costs of birdsfoot trefoil's spread in agricultural and natural areas of the surrounding Border Rivers catchment. The difference between these benefits and costs is the net contribution to welfare.

The results of this study show the range of conditions under which the introduction of birdsfoot trefoil and new pastures in general, would offer net benefits and therefore should be permitted. The benefits were found to vary with initial depth of the watertable and result from the combined impact of delaying rising watertables *and* allowing landholders to more profitably operate when watertables are closer to the

surface. Benefits were estimated to be highest for an initial watertable depth of 3.5 m and for the Kings Plain Subcatchment were estimated to be \$8.8 million over 50 years discounted at 7 percent. The costs were found to vary with the number of seeds transferred into the surrounding Border Rivers Catchment. For the case where 10,000 seeds per hectare are dispersed annually, costs were estimated in stochastic analysis to have a mean of \$0.50 m in agricultural areas and less than \$10,000 in natural areas. The number of seeds dispersed from the subcatchment was demonstrated to be the key uncertainty on which the overall decision to introduce rests. The net benefits were found to be positive where the number of seeds dispersed into the surrounding catchment is less than 2 – 3 percent of those produced in pasture in the subcatchment.

If a decision to introduce is made on the basis of an expected increase in welfare, some groups may be made worse off by the decision so that there is a role for government to minimise the costs to these groups. This could include the imposition of liability, on those who introduce the plant, accompanied by performance bonds for introductions where collective action is possible or direct regulation where it is not. However, research and development to minimise the uncertainty of plant dispersal and inform policy is considered likely to accompany any decision to introduce such new plants. In the case of a problem of salinity and invasive plants, there is potentially a role for government to both encourage the adoption of plants such as birdsfoot trefoil and also minimise the external impacts of invasiveness.

The study offers a balanced and improved means of determining if new plants should be introduced and policy approaches to this decision, when costs and benefits, including externalities, result from dynamic and uncertain natural processes.

Table of Contents

	Page No.
List of Tables	x
List of Figures	xii
Acronyms used in this study	xiv
1 Introduction.....	1
1.1 Background	2
1.2 Impacts of salinity and weeds	3
1.3 Modelling to support an economic decision framework.....	4
1.4 Thesis Structure	6
1.5 Contributions of the Research.....	7
2 Plants: Transfers, Invasions and Weeds	9
2.1 The importance of plant introductions	9
2.2 The need to restrict plant introductions	10
2.2.1 <i>Australia</i>	10
2.2.2 <i>International context</i>	14
2.3 When is a plant a weed?.....	15
2.4 The need for a new approach	18
2.5 Issues to consider with respect to introduced plants	19
2.5.1 <i>Benefits and costs</i>	20
2.5.2 <i>External impacts</i>	20
2.5.3 <i>Unpriced values</i>	21
2.5.4 <i>Uncertain dynamic processes</i>	22
2.6 Conclusions	24
3 Plants to reduce dryland salinity in Australia	26
3.1 The biophysical nature of dryland salinity.....	26
3.1.1 <i>The process of dryland salinisation</i>	27
3.1.2 <i>The impacts of salinisation</i>	29
3.2 The scale of the problem of dryland salinity	30
3.2.1 <i>The extent of dryland salinisation</i>	30
3.2.2 <i>Costs of salinisation</i>	32
3.3 Salinity management options	34
3.3.1 <i>Perennial plants</i>	35
3.3.2 <i>Alternative management strategies</i>	40
3.4 Issues to consider with respect to dryland salinity management	41
3.4.1 <i>Dynamic processes</i>	41
3.4.2 <i>External impacts</i>	41
3.4.3 <i>Uncertainty</i>	42
3.5 Summary	42

4	A conceptual approach to the problem	44
4.1	The economic framework	44
4.2.1	<i>Potential benefits</i>	44
4.2.3	<i>Potential costs</i>	47
4.2.3	<i>Costs and benefits</i>	48
4.2.4	<i>Externalities</i>	51
4.2.5	<i>Uncertainty</i>	55
4.2.6	<i>Decision criteria</i>	56
4.2	Application of the framework	58
4.2.1	<i>Bioeconomic applications to the problem of plant invasions</i>	59
4.2.1.1	Uncertainty in invasive species management assessment	61
4.2.1.2	Valuation of environmental costs	63
4.2.2	<i>Bioeconomic applications to the problem of salinity</i>	65
4.3	Summary	70
5	The Model.....	71
5.1	Overview of the model	71
5.2	Subcatchment sub-model – benefits of reduced recharge	73
5.3	Catchment sub-model – costs of plant invasiveness	76
5.4	Numerical application of the model	78
5.4.1	<i>Implementing the dynamic programming salinity sub-model</i>	78
5.4.2	<i>Implementing the plant population simulation sub-model</i>	80
6	Data for a case study application	85
6.1	<i>Lotus corniculatus</i> L.	86
6.1.1	<i>Pasture production</i>	89
6.1.2	<i>Costs of pasture establishment</i>	91
6.1.3	<i>Recharge</i>	91
6.1.4	<i>Evidence of invasiveness</i>	92
6.1.5	<i>Population dynamics</i>	94
6.2	The Border Rivers Catchment	96
6.2.1	<i>Areas at risk</i>	99
6.2.2	<i>Production values</i>	100
6.3	Kings Plain Subcatchment	102
6.3.1	<i>Values of production</i>	104
6.3.2	<i>Pasture: production and consumption</i>	105
6.3.3	<i>Recharge by land use option</i>	106
6.3.4	<i>Depth of the watertable</i>	107
6.3.5	<i>The impact of a rising watertable on land-use options</i>	108
6.4	Probabilities	109
6.5	Summary	111

7	Net benefits of the introduction of birdsfoot trefoil: deterministic analysis	112
7.1	Reduced salinity in the Kings Plain Subcatchment	112
7.1.1	<i>Benefits for a range of watertable depths</i>	<i>112</i>
7.1.2	<i>Optimal state paths</i>	<i>116</i>
7.1.3	<i>Optimal enterprise mix</i>	<i>117</i>
7.1.4	<i>Subcatchment benefits of the introduction of BFT.....</i>	<i>120</i>
7.1.5	<i>Feasibility of the optimal solution</i>	<i>123</i>
7.1.6	<i>Effect of changes in the technical parameters on the optimal solution ..</i>	<i>125</i>
7.1.7	<i>Effect of changes to market factors on the optimal solution.....</i>	<i>130</i>
7.2	Potential BFT invasion of the Border Rivers Catchment	135
7.2.1	<i>Biophysical simulation of plant invasion on a per-hectare basis</i>	<i>135</i>
7.2.2	<i>Bioeconomic results</i>	<i>139</i>
7.2.3	<i>Sensitivity analysis</i>	<i>140</i>
7.3	Net benefits of an introduction	141
7.3.1	<i>Benefit-cost analysis</i>	<i>141</i>
7.3.2	<i>Breakeven analysis.....</i>	<i>142</i>
7.3.3	<i>Sensitivity analysis: costs in natural areas</i>	<i>144</i>
7.4	Summary	147
8	Introducing Uncertainty	148
8.1	Range of benefits of reduced recharge.....	148
8.1.1	<i>Low potential benefits</i>	<i>150</i>
8.1.2	<i>High potential benefits</i>	<i>150</i>
8.1.3	<i>Range of benefits</i>	<i>150</i>
8.2	Stochastic analysis of the costs of invasion	151
8.2.1	<i>Costs of plant invasiveness</i>	<i>152</i>
8.2.2	<i>Total Costs</i>	<i>155</i>
8.2.3	<i>Stochastic dependency</i>	<i>155</i>
8.3	Net benefits under uncertainty	157
8.3.1	<i>Kings Plain Subcatchment and the Border River Catchment</i>	<i>158</i>
8.3.2	<i>Multiple Subcatchments and the Border River Catchment</i>	<i>158</i>
8.3.3	<i>Multiple Dispersals and the Border River Catchment.....</i>	<i>160</i>
8.3.4	<i>National net benefits</i>	<i>163</i>
8.4	Other approaches to the Decision to Introduce	164
8.5	Conclusions	167

9	Policy Analysis	169
9.1	Issues that arise in relation to the introduction of plant-based solutions to salinity	169
9.2	Is there a role for government to encourage birdsfoot trefoil adoption? ...	171
9.3	Should birdsfoot trefoil be introduced?	173
9.4	How can a government decide in the presence of uncertainty?	176
9.5	What policy measures could accommodate uncertain externalities?	179
9.5.1	<i>Liability</i>	181
9.5.2	<i>Direct Regulation & Liability</i>	182
9.5.3	<i>Insurance</i>	183
9.5.4	<i>Performance bonds</i>	184
9.5.5	<i>Selecting an approach</i>	186
9.5.6	<i>Research & Development</i>	187
9.6	Summary	188
10	Conclusion	189
10.1	Summary of Results	189
10.2	Key Findings	191
10.3	Contributions of this Research	193
10.4	Key factors to address when selecting future new plants	194
10.5	Limitations of the Research	196
10.6	The Future	198
10.6.1	<i>Issues for Future Research</i>	198
10.6.2	<i>Other applications</i>	199
	References	201
	Appendices	219
Appendix A	Top 20 Weeds of National Significance (WONS)	220
Appendix B	Plant Questionnaire	222
Appendix C	Pasture production – <i>birdsfoot trefoil</i>	226
Appendix D	Gross margins – <i>birdsfoot trefoil</i>	227
Appendix E	Land capability classification legend	228
Appendix F	LP Matrix	230
Appendix G	Pasture production estimates for the Kings Plain Subcatchment ..	231
Appendix H	Decision analysis criteria application	232
Appendix I	The Weed Risk Assessment (WRA) process & the approach developed in this study	234

List of Tables

	Page No.
Table 2.1	Purposes for which plants have been introduced to Australia (%) 11
Table 2.2	Selected estimates of weed costs in Australia - by species.....13
Table 2.3	Weed costs in Australia, New Zealand and the United States 14
Table 2.4	Considerations for the assessment of plant introductions17
Table 3.1	Perennial plant options36
Table 3.2	Plants identified with the potential to reduce recharge in Australian farming systems .. 38
Table 4.1	Salinity and its management - a chronological selection of economic studies67
Table 6.1	Summary characteristics for new varieties of <i>L. corniculatus</i> L..... 88
Table 6.2	Birdsfoot trefoil pasture production (TME / ha) 90
Table 6.3	Birdsfoot trefoil establishment gross margins (\$/ha).....91
Table 6.4	Recharge under birdsfoot trefoil pasture in the Kings Plain Subcatchment, North East Slopes, NSW (mm/m ²)..... 92
Table 6.5	Demographic parameters of new varieties of <i>L. corniculatus</i> L. 94
Table 6.6	Stage matrix parameters (Equation 5.22)..... 96
Table 6.7	Border Rivers Catchment – A summary of characteristics.....98
Table 6.8	Potential area at risk of birdsfoot trefoil invasion in the Border Rivers Catchment (ha) 99
Table 6.9	Agricultural & ecosystem production values for the Border Rivers Catchment 100
Table 6.10	Land area by capability in the Kings Plain Subcatchment..... 104
Table 6.11	Values of production for agricultural enterprises in the Kings Plain Subcatchment (\$)..... 105
Table 6.12	Pasture production and consumption values for a representative farm in the Kings Plain Subcatchment 106
Table 6.13	Recharge by land use option for the Kings Plain Subcatchment (mm/m ²) 106
Table 6.14	Yield adjustment factors 108
Table 7.1	Total benefits of birdsfoot trefoil in the KPS..... 122
Table 7.2	Elasticities of the optimal solution with respect to birdsfoot trefoil recharge and birdsfoot trefoil pasture production ($w_0=3.5$)..... 127
Table 7.3	Effect of subcatchment discharge on optimal solution 127
Table 7.4	Effect of cost of establishing birdsfoot trefoil on the optimal solution..... 131
Table 7.5	Effect of the discount rate on the optimal solution 132
Table 7.6	Simulated invasion of Border Rivers Catchment – <i>Summary of biophysical simulation results</i> 139
Table 7.7	Costs in agricultural and natural areas of the Border Rivers Catchment invaded by birdsfoot trefoil (PV over 50 years at 7 percent) 140
Table 7.8	Effect of changing parameters on the cost of invasion - <i>annual dispersals</i> 141
Table 7.9	Birdsfoot trefoil seeds required to enable a range of potential seed dispersal events in the Border Rivers Catchment 143
Table 8.1	Parameter values adopted to consider the range of benefits of birdsfoot trefoil introduction 149
Table 8.2	Impact of stochastic dependency on agricultural costs of birdsfoot trefoil invasion – <i>three assumptions of correlation</i> 157
Table 8.3	Net present value of benefits of introduction under uncertainty (\$'million) - <i>Kings Plain Subcatchment only</i> 158
Table 8.4	Net benefits of introduction under uncertainty (\$'million NPV) - <i>Multiple subcatchments in the Border Rivers Catchment</i> 159

Table 8.5	Net benefits of introduction under uncertainty (\$'million NPV) – <i>by percentage of seed dispersed from (a) Kings Plain Subcatchment and (b) seven subcatchments^a</i>	161
Table 8.6	Net present value of benefits of introduction under uncertainty (\$'million present value over 50 years) – <i>extrapolation to national estimates using the 90th percentile cost estimate</i>	164
Table 8.7	Introduction decision based on Maximin and Maximax Criteria for low, base and high expectations of benefits – <i>where the % of seeds dispersed is the variable state of nature</i>	165
Table 8.8	Introduction decision based on Maximin and Maximax Criteria where 0.5, 2 or 10% of seeds are dispersed– <i>where the performance of plant in subcatchment is the variable state of nature</i>	166

List of Figures

	Page No.
Figure 2.1	Plant life cycle – Adapted from Campbell and Grice (2000).....23
Figure 3.1	Illustration of the process of dryland salinisation28
Figure 4.1	Impact of perennial pasture species by reducing recharge.....45
Figure 4.2	Potential benefits of an introduced perennial pasture species, through reduced salinity46
Figure 4.3	Potential costs of an introduced perennial pasture species, through invasiveness48
Figure 4.4	Costs and benefits of a new plant introduction - <i>the case of net benefits</i>49
Figure 4.5	External costs - <i>consideration of 'n' external areas</i>53
Figure 4.6	Optimal level of externality54
Figure 4.7	A plant introduction decision under uncertainty56
Figure 5.1	The model – biophysical and economic interactions72
Figure 5.2	Illustration of reward matrix, R.....79
Figure 5.3	Damage function (Equation 5.17)83
Figure 6.1	Case study area in the context of the conceptual and empirical models86
Figure 6.2	Case study area: Border Rivers Catchment.....97
Figure 6.3	Damage loss functions expressed in dollar terms – <i>(a) agricultural and (b) natural areas</i>101
Figure 6.4	Kings Plain Subcatchment land capability102
Figure 7.1	Present value of profits under optimal management with and without BFT for a range of initial watertable depths (\$/ha, discounted at 7 per cent over 50 years).....113
Figure 7.2	Present value of benefits from the introduction of BFT for a range of initial watertable depths (\$/ha, discounted at 7 per cent over 50 years).....113
Figure 7.3	Shadow price of the watertable with and without birdsfoot trefoil (\$/ha).....115
Figure 7.4	Optimal state paths for three initial watertable depths116
Figure 7.5	Optimal enterprise mix for an initial watertable depth of 4 m – <i>without birdsfoot trefoil</i>118
Figure 7.6	Optimal land use for an initial watertable depth of 4 m – <i>with birdsfoot trefoil</i>120
Figure 7.7	Subcatchment benefits of birdsfoot trefoil introduction over 50 years – <i>for a range of depths (assuming a homogeneous depth throughout the catchment)</i>121
Figure 7.8	Effect of changes in technical parameters on estimated benefits126
Figure 7.9	Benefits of birdsfoot trefoil – <i>the case of BFT with recharge of 1mm/m²</i>128
Figure 7.10	Optimal state path (a) and carrying capacity (b) for an initial state of 1.5 m – <i>the case where BFT has recharge of 1mm/m²</i>129
Figure 7.11	Effect of changes in market factors on benefits of birdsfoot trefoil introduction for the range of initial watertable depths130
Figure 7.12	Benefits of BFT – <i>the case of sustained higher agricultural prices</i>133
Figure 7.13	Optimal state path over 50 years at various depths – <i>the case of higher agricultural prices</i>134
Figure 7.14	Population dynamics of birdsfoot trefoil over 50 years starting with 10,000 seeds per hectare – <i>no. of individuals per hectare</i>136
Figure 7.15	Simulated area of invasion over 50 years.....137
Figure 7.16	Growth in area invaded – <i>single and annual dispersals of seed</i>138
Figure 7.17	The damage function for a range of values of q (the susceptibility of natural species increases with q)145

Figure 8.1	Benefits of birdsfoot trefoil introduction over a range of initial watertable depths – <i>range of possible outcomes</i>	149
Figure 8.2	Agricultural area of Border Rivers Catchment invaded over 50 years (proportion of total) – <i>annual dispersals</i>	153
Figure 8.3	Cumulative probability distribution of area of plant invasion in agricultural areas of the Border Rivers Catchment – <i>Years 10, 20 & 50</i>	154
Figure 8.4	Cumulative probability distribution of costs of plant invasion in agricultural areas of the Border Rivers Catchment – <i>Year 50</i>	154
Figure 8.5	Net benefits of introduction to seven subcatchments in the Border Rivers Catchment – <i>90th percentile cost estimate and low, base and high expectations for benefits</i>	162
Figure 9.1	Map of suggested policy responses to different levels of public and private benefits (Pannell, 2008)	174
Figure 9.2	Decision Points based on the present value of benefits in the Kings Plain Subcatchment and costs in external areas of the Border Rivers Catchment – <i>90 and 70 percent confidence of net benefits</i>	178
Figure 9.3	Incorporating uncertainty into selection of policy – <i>the case of introduction to the Kings Plain Subcatchment</i>	180

Acronyms used in this study

ABARE	Australian Bureau of Agriculture & Resource Economics	KPS	Kings Plain Subcatchment
ABS	Australian Bureau of Statistics	LWA	Land and Water Australia
APHIS	American Animal and Plant Health Inspection Service	MDBC	Murray-Darling Basin Commission
BA	Biosecurity Australia	NAP	National Action Plan for Salinity & Water Quality
BFT	Birdsfoot trefoil	NDSP	National Dryland Salinity Program
BRC	Border Rivers Catchment	NHT	Natural Heritage Trust
BSMS	Basin Salinity Management Strategy	NLP	National Landcare Program
CMA	Catchment Management Authority	NLWRA	National Land & Water Resources Audit
CRC	Cooperative Research Centre	NRM	Natural Resource Management
CRC PBMDS	CRC for Plant-Based Management of Dryland Salinity	PMSEIC	Prime Minister's Science, Engineering and Innovation Council
CSIRO	Commonwealth Scientific & Industrial Resource Organisation	R&D	Research & Development
DAFF	Department of Agriculture, Fisheries & Forestry	RDC	Research and Development Corporation
EC	electro conductivity	UN	United Nations
FAO	Food and Agriculture Organisation	USDA	United States Department of Agriculture
GIS	Geographic Information System	Weeds CRC	CRC for Australian Weed Management
GM	Genetically Modified	WONS	Weeds of National Significance
GRDC	Grains Research & Development Corporation	WRA	Weed Risk Assessment (system)