Adoption of improved farming systems for water quality improvement in heterogeneous sugarcane farming communities; sharing the costs

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ABSTRACT

There is growing recognition that coastal water quality is interdependent with agricultural management in coastal catchments. Economic incentive-based instruments can be used to internalize the negative externalities from coastal water pollution. In this paper we assess a design-based instrument for promoting the adoption of improved farming systems in heterogeneous sugarcane farming communities in the Great Barrier Reef catchment area, with emphasis on regional income and water quality impacts. We combine financial and environmental analyses of farming systems at the paddock scale with a mathematical modelling approach at the farm scale, differentiating for three farm typologies, aggregated to the catchment scale. Improved farming system adoption rates are assessed by exploring how different types of farmers are likely to respond to increasing transition cost-sharing ratios (CSRs). Results show that margins for reductions in water pollutant exports, through changes in farming systems, are smallest in among commercial farms and largest among medium and, in particular, small farms. With increased CSRs, farming systems shift from C and B class dominated, to A class dominated.

KEY WORDS: *Improved farming system, Water quality improvement, Natural resource policy, Great Barrier Reef.*

INTRODUCTION

The World Heritage listed Great Barrier Reef (GBR), adjacent to the Queensland coast in Australia, is the largest reef system in the world (Haynes & Michalek-Wagner, 2000). Coastal and marine ecosystems around the world are adversely affected by disturbances from human activity (e.g. climate change and water pollution) (Brodie et al., 2012; Burke et al., 2011). The degradation of the GBR coastal ecosystems is linked with (non-point or diffuse source) pollution from agricultural activity (Kroon 2011; Kroon et al., 2011). Pollutant sources have been identified and include suspended sediment from erosion in cattle grazing areas; nitrate from fertiliser application on crop lands; and herbicides from various land uses (Brodie et al. 2012). To address this issue, improved management of resources in coastal catchments is needed (Doney, 2010; Smith & Schindler, 2009).

In this paper we model how different types of farmers are likely to respond to an economic incentives-based approach where capital investment cost-sharing ratios (CSRs) are varied between zero cost-sharing (0%) and full cost-sharing (100%). This approach provides policy makers with important information regarding cost-effectiveness of the policy instrument, but also on likely profile specific socio-economic indicators, such as adoption rates and farm income.

BACKGROUND

Within the GBR catchment area, the Tully–Murray catchment (approximately 18ºS 146ºN; Figure 1) has been identified as a high risk catchment (Armour et al. 2009; Kroon 2009). Within the vicinity of the Tully-Murray flood plume there are 37 coral reefs and 13 seagrass meadows (Devlin & Schaffelke, 2009). Sugarcane dominates agricultural production in the catchment (Armour et al. 2009), contributing to almost 45% of regional agricultural income (Roebeling et al. 2009). The majority of sugarcane grown in GBR catchments is located on floodplains, close to the end of catchments. Because of its proximity to the end of catchments, most of the nitrogen (N) lost from sugarcane farms in surface water will reach the GBR lagoon (Furnas & Mitchell, 2001; Mitchell et al., 1997).

To address diffuse source pollution from agriculture to halt and reverse the decline in water quality entering the GBR, a number of voluntary and regulatory policy instruments have been launched over the last decade. In 2003, the Queensland State and the Australian Federal Governments jointly launched the Reef Water Quality Protection Plan (Reef Plan; RWQPP, 2003, 2009). In addition, in 2008, the Federal Government announced its Reef Rescue Program, including the Water Quality Grants Scheme ($146 million

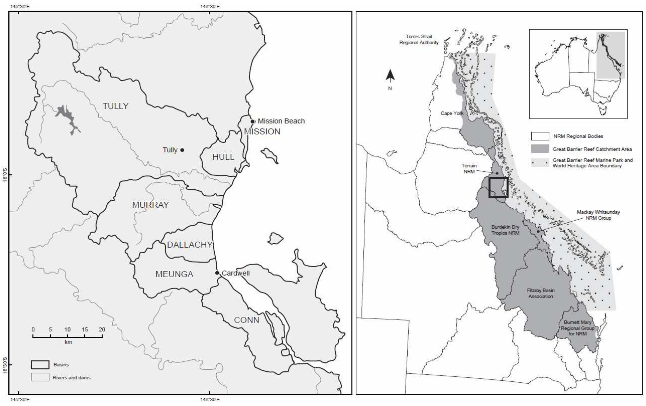

Figure 1. The Tully-Murray catchment in tropical North Queensland, Australia.

over 5 years) that provides land managers with matching funding to implement land management activities that will improve water quality run-off from properties. In January 2010, the Queensland Government introduced the Great Barrier Reef Protection Amendment Act 2009 (GBRPAA, 2009) to regulate a number of specified agricultural activities.

METHODS

In this paper we use a bio-economic modelling approach that explores the cost-effectiveness of improving catchment water quality via the adoption of improved farming systems in a heterogeneous farming community. We model how different types of farmers are likely to respond to an economic incentives-based approach where the private cost of transitioning (i.e. capital investments) to improved farming systems are shared between the landholder and the funding agent. Adoption rates are estimated by predicting how different farm enterprises are likely to respond to increasing cost-sharing ratios (CSR). In this paper we focus on the sugarcane growing sector in the Tully-Murray catchment.

In the case study area, a landholder profile (based on Bohnet, 2008) is matched with geographical information, to allow for the identification and characterisation of 'agents' according to their specific objectives, their agricultural production system and socio-economic features and their spatially explicit agro-ecological conditions. Table 1 shows farm size, as well as the number of respective farms in the study area.

Table 1. Farm size (in ha) for the different types of farmers in the Tully-Murray catchment.

Farm profile	**Farm size (ha; *mean*)**	**# farms**
Large (type 1)	180 – 1230 (*428*)	22
Medium (type 2)	80 – 180 (*115*)	74
Small (type 3)	20 – 80 (*40*)	322

The improved farming systems that we analyse in this research, have been adopted from the 'ABCD' framework of farming system classification used by natural resource management (NRM) regions for Reef Rescue (Higham et al., 2008; Van Grieken et al., 2010b). The 'ABCD' framework describes and classifies agricultural activities in farming systems that range from degrading (D) through to cutting edge (A) that would provide the greatest water quality improvement.

Information on required capital investments, labour and changes in farm gross margins, has been adopted from financial-economic research in various GBR catchments by Van Grieken et al. (2010a). To account for variation in farm sizes, capital investments and labour requirements, investment quantities provided by Van Grieken et al. (2010a) are adjusted.

Sugarcane input-output data for the various farming systems were generated using the APSIM (version 7.0) cropping systems model (Keating et al. 2003). Data include, but is not limited to, regional soil type specific productivity (sugarcane yield) and environmental indicators (available DIN; Van Grieken et al., 2011). For the latter it provides plot scale DIN in runoff and DIN leached below the root zone for each scenario. In our framework we assume 100% of DIN in runoff reaches the GBR lagoon (Furnas & Mitchell, 2001) and 60% of N in deep drainage reaches the GBR lagoon (Webster et al., 2011).

Framework

To estimate the level of adoption of improved farming systems by sugarcane farmers in the Tully-Murray catchment under increasing CSR, we use a linear constrained optimisation model. The model uses production functions to explore the farmers' decision making process. The farm enterprise will try to maximize its (gross) income, which is defined as the gross value from sugarcane production and on- and off-farm employment, minus the costs related to the use of labour and agricultural inputs, and corrected for private costs and or benefits from policy interventions. Each farm enterprise faces constraints that are related to the use of farming systems, land, labour and agricultural output.

We estimate short term responses to instruments (1 full crop cycle; 6 years) and, therefore, land use is constrained to the currently available agricultural area. Available farm household labour can be used for on- and off-farm employment, where each farm profile has a specified base proportion of off-farm employment. Labour can also be hired-in for on-farm agricultural production. The model estimates production, income, resource use and employment at the farm and regional level for identified sugarcane farms in the study area. The mathematical optimisation model is solved using GAMS (Brooke et al. 1998), and is structured as follows:

The sugarcane area in the region is operated by agents of a specific farm type (or profile), who operate farm enterprises of area (*a*), with a specific distribution of soil types and using a specific management Class (*c*). $X_{id,c}$ is a decision variable that indicates to what extent an agent of a specific farm type operates his/her farm (*id*) using a particular management Class (*c*). Hence, the land balance is given by:

$$\sum_c X_{id,c} \leq a_{id} \tag{1}$$

where a_{id} is the area availability per farm agent (in ha).

Labour requirements (L; in hrs/ha) in sugarcane production are specific per farm type and farming system. Given that family on-farm labour (L^{Fam_On}) and hired labour (L^{Hir}) can be used to meet farm labour requirements, the labour balance per farm agent is given by:

$$\sum_c \lambda_{id,c} X_{id,c} = L_{id}^{Fam\_On} + L_{id}^{Hir} \tag{2}$$

Available farm family labour (L^{Fam}) can be used for on-farm (L^{Fam_On}) and off-farm (L^{Fam_Off}) employment as well as leisure (L^{Fam_Lei}) activities. Hence:

$$L_{id}^{Fam} = L_{id}^{Fam\_On} + L_{id}^{Fam\_Off} + L_{id}^{Fam\_Lei} \tag{3}$$

Labour restrictions hold for farm off-farm (L^{Fam_Off}) and hired (L^{Hir}) labour, such that:

$$L_{id}^{Fam\_Off} \leq l_{id}^{Fam\_Off} \tag{4}$$

$$L_{id}^{Hir} \leq l_{id}^{Hir} \tag{5}$$

where l^{Fam_Off} are the available off-farm employment opportunities (in hrs), and where l^{Hir} is the hired labour availability (in hrs).

Total farm production costs (C_{id}; in AU$) are now determined by the sum of growing, harvesting and transition/investment costs as well as hired labour (L^{Hir}) expenditures, such that:

$$C_{id} = \sum_{s,c} p^{Gro} \gamma_{id,c} X_{id,c} + \sum_{c} p^{Har} \eta_{id,c} X_{id,c} + \sum_{c} p^{Tra} \tau_{id,c} X_{id,c} + p^{Hir} L_{id}^{Hir} \tag{6}$$

where γ are the sugarcane growing (in #/ha), η the harvesting (in #/ha) and τ the transition/investment (in #/ha) requirements at corresponding prices p^{Gro} (in AU$), p^{Har} (in AU$) and p^{Tra} (in AU$), and where p^{Hir} is the hired labour wage (in AU$/hr). Furthermore, p^{Tra} is shared between the farm enterprise and the funding agency, depending on the CSR.

Total farm benefits (B_{id}; in AU$) are determined by sugarcane revenues and income from farm family off-farm employment (L^{Fam_Off}), such that:

$$B_{id} = \sum_{c} p^{Sug} \psi_{id,c} X_{id,c} + p^{Off} L_{id}^{Fam\_Off} \tag{7}$$

where ψ is the sugarcane yield (in t/ha), p^{Sug} the sugarcane price (in AU$) and p^{Off} the off-farm labour wage (in AU$/hr).

Net farm income (π_{id}; in AU$) equals farm enterprise benefits (B_{id}) minus farm enterprise production costs (C_{id}). Hence:

$$\pi_{id} = B_{id} - C_{id} \tag{8}$$

The regional income (Π) objective function is now given by:

$$Max\,\Pi = \sum_{id} \pi_{id} \tag{9}$$

RESULTS

An initial model run was performed to create the base scenario or starting point. In this pre-base model run all farm enterprises in the region start off under a C Class farming system. The corresponding base distribution of management Classes is presented in Table 2. These results have been validated with local experts to ensure a realistic distribution is presented.

Abatement costs

Net (private costs/benefits net of public earning/spending) regionally aggregated abatement costs are presented in Figure 2. The abatement achieved is presented for a CSR between 0% and 100%. For example, at a CSR of 50%, the potential WQI equals 13% at a net cost to society of just over $4M over the whole crop cycle. At a CSR of 100%, WQI is likely to be 57%, which comes at a net cost to the region of just under $34M.

Cost-efficiency of the CSR approach for water quality improvement is presented in Table 2. For example, the net cost to the region of sharing 50% of investment costs between farmers and the funding agency is $11.8 per kg reduction of DIN exported. At full cost-sharing (CSR 100%; the funding agency would pay the full capital investment required), the total reduction in DIN delivery that is likely to be achieved is 57% compared to the base scenario. The cost-efficiency at this CSR is $20.4 per kg DIN reduction.

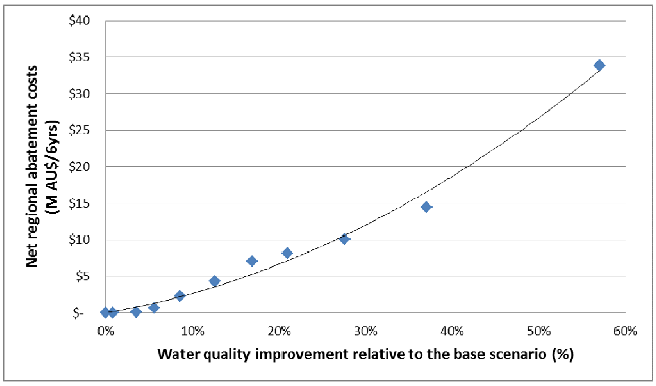

Figure 2. Net regional abatement cost curve for the incentive-based instrument.

Land use and management distribution

Table 2 furthermore shows the distribution of farming systems for increasing CSR from 0% (base scenario) to 100%, in steps of 10%. In the base scenario, B class farming systems dominate in the region with 46% of the land under sugarcane cultivated in this manner. C class is represented by 42% of the sugarcane land; with sugarcane land cultivated using A class only at 12%. As expected, with increased costs covered by the funding agency, farming systems shift from C and B class dominated, to A class dominated. At a CSR of 50%, A class farming systems are now adopted on 22% of the sugarcane land; however the majority of sugarcane land is still cultivated using B and C class (66% and 12% respectively). At a CSR of 100%, all sugarcane land is cultivated using A class (100%).

Table 2. Cost-efficiency of cost-sharing approach – management Class distribution as a percentage of total land under sugarcane.

Scenario	Cost-eff. ($/kg)	DIN reduction (-%)	Class A (%)	Class B (%)	Class C (%)
Base	-	-	12%	46%	42%
10%	0.4	1%	14%	44%	42%
20%	1.3	4%	18%	42%	40%
30%	4.3	6%	19%	47%	34%
40%	9.0	9%	19%	59%	22%
50%	11.8	13%	22%	66%	12%
60%	14.3	17%	25%	74%	1%
70%	13.3	21%	32%	68%	0%
80%	12.5	28%	45%	55%	0%
90%	13.4	37%	62%	38%	0%
100%	20.4	57%	100%	0%	0%

Large farms initially either operate using B or A class farming systems and rapidly all large farms adopt A class. With a CSR of 20% more land is managed using A class than B or C class. The medium sized farms operate in B class farming systems and slowly change towards A class. With a CSR of 80% more land is managed using A class than B or C class. Small farms operate mainly in C class farming systems, shift to combined A and B class, before shifting to A class. At a CSR of 50%, most of the land is operated using B class, whereas the remainder is still operated using C class. Only at the CSR 100%, more land is operated under A class than under alternative farming systems.

DISCUSSION AND CONCLUSION

In this paper we presented a bio-economic approach that explores the cost-effectiveness of improving catchment water quality via the adoption of prioritized improved farming systems in a heterogeneous farming community. We modelled how different types of farmers respond to an economic incentives-based approach where the costs of transition (capital investments) are shared between the landholder and a funding agency. Adoption rates were estimated by predicting how different farm types are likely to respond to different cost-sharing ratios. Furthermore, regional socio-economic and environmental consequences of implementing the policy were estimated, such as changes in local income and nitrogen run-off.

Net abatement costs are calculated for all farm types, and aggregated to the region. In the base scenario, the large commercial farms (farm type 1), are already largely operating in farming system class B and A. This means their margin for improvement (reducing DIN exports) by changing management is small (given current available technology) in comparison with farm type 2 and farm type 3. The small farms (farm type 3) on the contrary, are largely still operating under management C, leaving substantial margin for water quality improvement by changing farming systems to class A and B.

With regards to land use and management distribution, in the base scenario, C and B class farming systems dominate in the region, with some sugarcane land cultivated using A class. With increased CSR, farming systems shift from C and B class dominated, to A class dominated. At the highest CSR (100%) all sugarcane land is cultivated using A class farming systems. More specifically, large farms initially operate in a mix of B and A class and shift rapidly to A class. With a CSR of 20% more land is managed using A class than B or C class. The medium sized farms operate in B class and slowly change towards A class. With a CSR of 80% more land is managed using A class farming systems than B or C class. Small farms operate mainly in C class, shift to combined A and B class, before shifting to A class. At a CSR of 50%, most of the land is operated using B class, whereas the remainder is still operated using C class. Only at the CSR 100%, more land is operated using A class than alternative farming systems.

For the purpose of this paper we've looked at very specific scenarios, but the analysis could be expanded to analyse the cost-efficiency of a variety of design or performance based policy instruments. Also, the methodology could be expanded through the inclusion of regional constraints which account for, for example, lower bounds on sugarcane supply to the Tully mill (see for example Van Grieken et al. 2011) or the inclusion of downstream costs for the tourism and fishery industry resulting from terrestrial water pollution and reef degradation.

This paper presents the results of an exploratory study assessing the differential impacts of environmental policy on differing farm types. Current research funded by the Australian Government is providing a detailed analysis of biophysical and socio-economic heterogeneity across the industry and its possible implications for the costs and benefits of improving water quality, including extended socio-economic surveying to provide more information on relative advantage and trialability of management practices for water quality improvement and (private) transaction costs associated with the adoption of these practices.

A number of biophysical and cost related caveats of this study must be mentioned. First, industry water pollution abatement costs are based on the farming systems assessed and, thus, do not include any alternative technologies, some of which are currently under development, that may prove cost effective in the future. Second, equivalent production functions are used for all farm types, but this could potentially differ and needs to be investigated further. Small farmers may not be as productive per hectare as their bigger colleagues or they may face differing production constraints that we did not explore in this paper. Third, in this study it is assumed that labour is freely available for hire – which is not always the case in small towns or during peak labour periods. Fourth, instrument transaction costs are not included in the analyses which could have implications on cost-effectiveness, especially on the adoption and delivery process. Pannell & Wilkinson (2009), for example, found that transaction costs are likely to be higher for small scale (lifestyle) farmers than for larger scale (commercial) farmers. Last, the approach used here is deterministic and is, as a result, does not account for uncertainty. Consequently and self-evidently, care should be taken when using the figures presented in this study for policy and planning purposes.

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