Assessing community values for reducing agricultural emissions to improve water quality and protect coral health in the Great Barrier Reef

Jill Windle and John Rolfe
Centre for Environmental Management
CQUniversity
http://resourceeconomics.cqu.edu.au/

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Abstract

Key policy issues relating to protection of the Great Barrier Reef from pollutants generated by agriculture are to identify when measures to improve water quality generate benefits to society that outweigh the costs of reducing pollutants. The research reported in this paper makes a key contribution in several key ways. First, it uses the improved science understanding about the links between management changes and reef health to bring together the analysis of costs and benefits of marginal changes, helping to demonstrate the appropriate way of addressing policy questions relating to reef protection. Second, it uses the scientific relationships to frame a choice experiment to value the benefits of improved reef health, and links improvements explicitly to changes in 'water quality units'. Third, the research demonstrates how protection values are consistent across a broader population, with some limited evidence of distance effects. Fourth, the information on marginal costs and benefits that are reported provide policy makers with key information to help improve management decisions. The results indicate that while there is potential for water quality improvements to generate net benefits, high cost water quality improvements are generally uneconomic. One implication for policy makers is that cost thresholds for key pollutants should be set to avoid more expensive water quality proposals being selected.

1. Introduction

The Great Barrier Reef (GBR) is one of the most healthy coral reef ecosystems in the world, but its condition has declined significantly since European settlement (Furnas 2003). The 2009 GBR outlook report identifies declining water quality from catchment run-off as a key priority issue (GBRMPA 2009), with agriculture being the main source of emissions (Furnas 2003; GBRMPA 2009). A key policy issue is to determine if the public benefits of reducing emissions in agricultural runoff and so providing increased protection to the health of the GBR are sufficiently large to outweigh the costs involved. However, while significant public funds are being allocated to achieving better water quality outcomes, there is limited economic and ecological information available to guide policy makers in their funding decisions.

The information required to match the costs and benefits of providing water quality improvements is deficient in three main ways. The first key issue is the limited scientific knowledge about how changes in pollutant loads and water quality will generate improvements in reef health. A number of studies have highlighted the negative impacts on the GBR from excessive sediment and nutrient loads in terrestrial runoff (Furnas 2003; Fabricius 2005; Fabricius and De'ath 2004; McKergow et al. 2005; Brodie et al. 2007; Haynes et al. 2007; De'ath and Fabricius 2010). Nonetheless, determining a direct causal relationship between changes in sediments and nutrients entering the GBR and coral health has been elusive and controversial. De'ath and Fabricius (2010) have recently provided evidence that directly links these pollutants to the health of coral reefs, providing key information needed to frame an economic analysis.

The second limiting factor has been a lack of valuation studies on the GBR that value improvements in the condition of the GBR generally or the flow-on effects of water quality improvements specifically. The focus of most valuation studies within the region has been on recreation activities (e.g. Carr and Mendelsohn 2003), with few studies that report non-use values for protection of the GBR. In the absence of any more accurate or recent studies, Oxford Economics (2009) extrapolated the results of Hundloe et al. (1987) and Windle and Rolfe (2005) to estimate total non-use values of protection. However the source studies are narrowly focused and dated, and there is no marginal value analysis to link protection values to water quality changes. Only two studies can be identified which relate values to changes in water quality (Kragt et al. 2009 and Prayaga et al. 2010), and both of these focus only on recreation.

The third key gap is that there is little economic information about the costs of improving water quality from agricultural systems, particularly in extensive beef grazing and intensive sugarcane production. Information about pollutant reduction costs is not directly available from markets, so these costs need to be inferred from bio-economic models of farm production systems, or estimated from related market transactions. There are few bioeconomic studies relevant to GBR water quality issues. MacLeod and McIvor (2007) detail some of the production and environmental tradeoffs from rangeland grazing in catchment areas, and Roebling et al. (2009) estimated the cost of reducing nutrients from cane production in the Herbert River system. Related market transactions are also limited, with most government payments to improve water quality being transferred in grant mechanisms where no direct relationship between the funding involved and the associated pollution reductions can be observed. However, there have been a limited number of water quality tenders in the GBR, where associated costs of reducing sediment and nutrient emissions in different agricultural industries have been revealed as part of the tender process (Rolfe and Windle 2011).

The focus of the research reported here has been to estimate values for the benefits of improved water quality with the choice modelling technique, and then compare this with the costs of reducing agricultural emissions. This paper makes an important contribution to the literature in three important ways. First, it presents one of the first attempts to represent a change in the condition of an environmental good in a valuation scenario in terms of both inputs and outputs, and in doing so, being able to elicit values for both. Second, it provides benefit estimates for reductions in sediment and nutrient emissions, essentially identifying values for pollutant reductions that lead to improvements in environmental conditions. Third, it matches the benefit estimates with equivalent cost data so that the marginal tradeoffs for additional levels of improvement can be assessed.

The report is structured as follows. The next section contains an overview of water quality issues in the GBR, followed by a description of the design and performance of the choice experiment in section three. Results of the valuation survey are presented in the fourth section, and the comparison to the estimates of costs is shown in the fifth section. Conclusions are drawn in the final section.

2. Water quality and coral health in the GBR

The GBR has a complex inter-dependent relationship with the adjacent river catchments. A number of rivers discharge into the GBR lagoon, draining 423,070 sq km which is 25 per cent of the land mass of Queensland (Furnas 2003). Whilst the GBR has been exposed to nutrients and sediment in natural runoff prior to Australian colonisation, evidence indicates that since European settlement, land-based activities within the GBR catchment area have adversely impacted on the water quality entering the GBR, particularly during flood events. In particular, Furnas (2003) suggests that there has been:

- a four to nine fold increase in the quantities of sediment entering the GBR;
- a three to fifteen fold increase of phosphorus; and
- a two to four fold increase in total nitrogen inputs.

Recent marine monitoring data from 2004 to 2006 indicates that 80% of the rivers monitored exceeded Queensland Water Quality Guideline values for most nutrients and suspended sediment concentrations (Prange et al. 2007).

The agricultural sector dominates land use in the GBR catchment area, occupying about 80% of the area. Sediment and nutrient emissions in agricultural runoff (from grazing, farming and irrigation activities) are identified as the key contributors to poor water quality (Furnas 2003; GBRMPA 2009). Degradation of inshore coral reefs due to poor water quality is a major issue and negative impacts on the GBR from excessive sediment and nutrient loads in terrestrial runoff are widely known (Fabricius 2005, Woolridge et al. 2006, Woolridge 2009, De'ath and Fabricius 2010). However, there has been limited causal evidence to directly link a reduction in agricultural emissions to potential improvement in coral health.

Recently, De'ath and Fabricius (2010) have established a direct link between poor water quality and a decline in the richness of hard and soft corals across different geographical areas of the GBR. They used water clarity and chlorophyll as measures of water quality.

Water clarity is associated with turbidity and sediment loads and chlorophyll concentration is highly correlated with suspended solids, particulate nitrogen and particulate phosphorous (Fabricius and De'ath 2004). Their models predict that on the 22.8% of GBR reefs where guideline values are currently exceeded, improving water quality by minimizing agricultural runoff should increase the richness of hard and soft corals on average by 16% and 33%, respectively, with up to 46% of variation being directly attributable to water quality improvements and spatial effects accounting for the remainder (De'ath and Fabricius 2010).

De'ath and Fabricius (2010) provided two pieces of evidence that had been missing and could now be applied in an economic valuation context. The first was to provide a quantified estimate of the impact that poor water quality could have on coral health and the second was to link their measures of water quality with sediment and nutrient loads. This provided the link between agricultural runoff and the health of coral reefs. The results suggest that the maximum benefit from water quality improvements in agriculture would result in a 12% average improvement[1] in coral richness in the inshore GBR area.

3. The choice modelling case study

The choice experiment was designed to assess community values for reduced agricultural emissions that would improve water quality improvements and therefore improve coral health in the GBR. Key tasks in designing a choice experiment are to identify the key attributes of interest, frame those attributes into a scenario where monetary tradeoffs are realistic, and identify the appropriate range and levels for each attribute. For this experiment, the key attribute of interest was the area of inshore reefs in good condition in 25 years, which was directly related to improvements in water quality. Respondents were in effect evaluating a double defined environmental good, which included an input (reduced emissions) and an output (better coral health), as well as the linkage element between them (improved water quality or better water clarity).

Encapsulating the intricacies of a complex ecological process into a realistic stated preference valuation scenario presents many challenges (Christie et al. 2006; Boyd and Krupnick 2009). Previous attempts to communicate impacts of water quality in concise ways have included the use of water quality ladders (e.g. Carson and Mitchell 1993), effects on species ladders (e.g. Bateman et al. 2005), and indicator attributes such as water clarity (e.g. Kosenius 2010). In this study, changes in inputs were presented in the survey terms of 'water quality units'. Each unit was defined as a one percent reduction in the total possible maximum emissions[2] or the equivalent of 100,000 tonnes of sediment; 200 tonnes of nitrogen and 46 tonnes of phosphorus reduction. One hundred water quality units would therefore result in the maximum possible improvement in water quality. It was not realistic to believe it would be possible to return to pre-European settlement emission levels and so it was assumed that it would only be possible to achieve a 75% reduction in emissions.

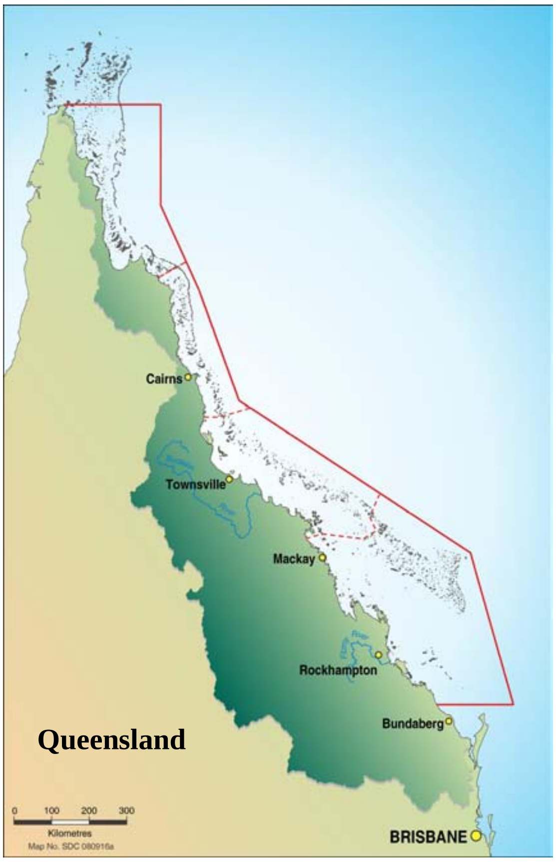
[1] This is estimated as the average increase in richness (between 16% and 33%) by 45% of predicted variation from water quality improvements. The estimate has been rounded up to 12%.

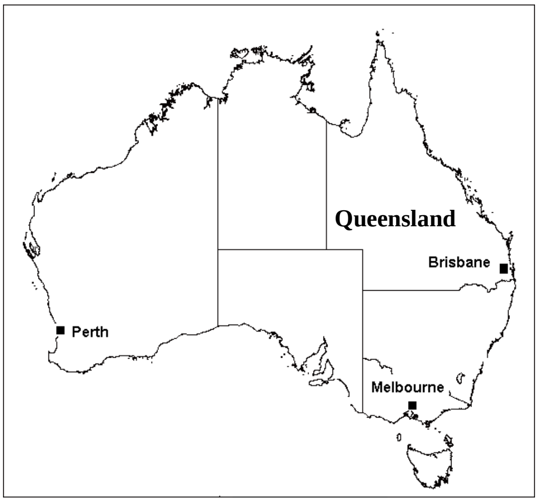
[2] The difference between estimates of current and pre European settlement levels of pollutant runoff from GBR catchments was used as an indication of the maximum possible reduction in pollutant loads entering the GBR. The difference between these two levels is approximately 10 million tonnes of sediment, 20,000 tonnes of nitrogen and 4,600 tonnes of phosphorus (Furnas 2003).

The maximum benefits of improving water quality in inshore areas were assessed as a 12% improvement in coral health. This reflected a conservative estimate of the benefits indicated by De'ath and Fabricius (2010), taking into account that other pressures from direct uses of the GBR and climate change would still exist, as well as recognition that there may be limited improvement in a 25 year time period. Because a maximum reduction of 75% of pollutants was considered feasible in policy terms, a maximum output of a 9% improvement in coral health was presented as achievable in the survey. An additional attribute about the certainty of outcomes was included in the choice sets to communicate the lack of precision about future outcomes.

Responses to the choice modelling valuation surveys were collected from four key groups: coastal GBR communities (regional towns in the GBR catchment area from Bundaberg to Cairns), Brisbane, the State capital located outside the GBR catchment area, and Melbourne and Perth, two more distant capital cities located 1370 and 3600 km from Brisbane respectively (Figure 1).

Figure 1. Great Barrier Reef and population sample locations





The valuation linkage embedded in the survey meant that careful attention was paid to the information that framed the valuation context. The survey was tested at a number of focus groups for validation. There were several key points to convey in the survey:

- It was explained that there are different pressures on the GBR that can lead to poor reef condition which include:

- land-based activities: impacts of low water quality coming mainly from agricultural runoff over a very large catchment area;
- ocean-based activities: impacts of tourism, recreational use, fishing, and shipping; and
- natural events and climate change: impacts from major flooding and cyclones and other events such as coral bleaching and outbreaks of the crown-of-thorns starfish.

- There are three main types of management actions that could be implemented to help address the pressures: improving water quality from land-based activities, increasing the area of conservation zones to address ocean-based pressures and reducing greenhouse gas emissions to address climate change[3]. Information was provided in the survey to indicate that improving water quality is likely to have the most benefit in helping protect the health of the GBR. This is because it affects the inshore areas of the GBR that are under the most threat from human activities, a large area (33%) of the GBR has already been protected under conservation zones, and it will be difficult and slow to address climate change issues.

- Water quality issues are dominated by sediment (soils) and nutrients (from soils and fertilisers) in runoff, derived mainly from agriculture (grazing and cropping) from about 80% of the land use in the GBR catchment area. Annual runoff from GBR catchments contains an estimated 14.4 million tonnes of soil. This is about 10 million tonnes of soils than in pre European times.

- The benefits would be seen in the inshore areas of the GBR where most of the impact occurs.

- There is some uncertainty surrounding the benefits of improving water quality and even if the water quality entering the GBR is improved there are many other factors that can affect the health of the GBR. There is also some uncertainty over the timing of improvements as they may not occur for 10 to 15 years.

The choice set design included a future base status quo option (which outlined conditions in 25 years if no further funding was provided and had no associated cost) and three alternative improvement options that had an associated cost. The main attribute in the choice set was a combined water quality improvement/coral health attribute. Respondents were informed that water quality improvements were described in the survey as units, where one water quality improvement unit means an annual reduction of:

Sediment: 100,000 tons of soil (about 40 olympic swimming pools)
Plus
Nutrients: 200 tonnes nitrogen + 46 tonnes phosphorus

Current and future coral condition levels were drawn from three local reef areas near Cairns, Townsville and the Capricorn Coast[4]. Average condition for these inshore reefs in 25 years time on current trends was estimated at 50%, with a 9% improvement possible with a 75% reduction in pollutant loads. The level of outcome certainty was set at 80% in the future base

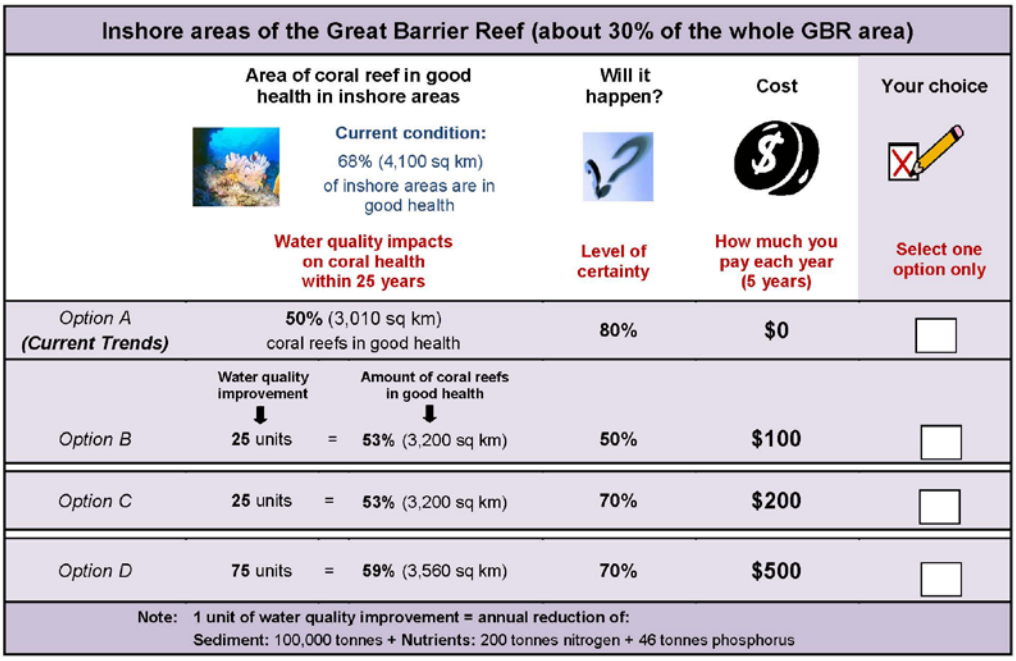
[3] Community values for achieving improvement in GBR health from these different management actions has been reported in Rolfe and Windle (2010a).
[4] Details are provided in Rolfe and Windle (2010b).

scenario, ranging down to 50% for improvement options. The cost variable was set with a zero payment for the future base scenario, and ranged up to $500 per annum (for five years) in the additional improvement options. Details of the attribute descriptions and levels are presented in Table 1 and an example choice set is provided in Figure 2.

Table 1. Attribute descriptions and levels

Attribute	Description	Base (status quo)	Option levels
WATER QUALITY	Water quality improvements	0	25 units, 50 units and 75 units
REEF	Amount of coral reefs in good health	50% (3,010 sq km)	53%; 56%; 59% (3,200; 3,380; 3,560 sq km)
CERTAINTY	Level of certainty – Will it happen	80%	50%; 60%; 70%
COST	Annual payment for 5 years	0	$50; $100; $200; $500

Figure 2. Example choice set



A D-efficient experimental design, containing 12 choice sets, was created using the ©NGENE software. The design was blocked into two versions so that each respondent was assigned a random block of six choice sets.

3.1 Respondent characteristics

A total of 614 surveys were collected from an internet panel between September and October 2010. It is difficult to estimate precise responses rates from internet panels because the required sample size is usually reached before all panellists have had an opportunity to respond, and age and gender segmentations are further confounding factors.

The socio-demographic characteristics of survey respondents were reasonably well aligned with those of the population in terms of gender, age and income levels, but education levels were higher for the sample than the population. The Brisbane sample was also slightly more skewed in favour of females and younger people. Full details are presented in Table 2. There was no significant difference (Pearson's chi squared crosstab at 5%) across locations in terms of gender, education or income. There were significantly more respondents who had children in the GBR communities and there was a difference in the age of respondents with a lower average age in the Brisbane sample (Anova, significant at 1%).

Table 2. Sample and population[1] characteristics

		GBR coastal towns (n=150)	Brisbane (n=150)		Melbourne (n=151)		Perth (n=163)	
		Sample	Smpl	Popltn	Smpl	Popltn	Smpl	Popltn
Gender	Female	49%	57%	50%	54%	51%	48%	51%
Children	Have children	73%	60%	na	58%	na	67%	na
Age	Average	45 yrs	39 yrs	43 yrs	44%	43 yrs	47%	44 yrs
Education	Post school qualification	54%	66%	56%	60%	60%	65%	60%
	Tertiary degree	28%	41%	24%	32%	30%	37%	27%
Income	less than $499 per week	16%	13%	17%	22%	20%	16%	19%
	$500 – $799 per week	21%	16%	18%	24%	17%	19%	18%
	$800 – $1199 per week	19%	27%	21%	22%	20%	20%	20%
	$1200 – $1999 per week	27%	29%	24%	18%	22%	25%	23%
	$2000 or more per week	17%	16%	21%	14%	21%	20%	21%

[1] Australian Bureau of Statistics 2006 Census data

4. Results

The results are presented in three sub sections. In the first part, the results from the choice models and willingness-to-pay (WTP) estimates are presented. In the second part, more information is provided about the extent to which respondents focused on different elements in the valuation scenario and some feedback from respondents in follow-up questions is presented. The third part of the section reports on the results of a policy related question in the survey which explores the importance of different policy measures to achieve better water quality outcomes.

4.1 Choice modelling results

Mixed logit models were developed for each of the four location samples. Details of the attribute descriptions and levels were presented in Table 1 and other model variables are explained in Table 3.

Table 3. Variables explaining the status quo choice

Main variables	Description
ASC	Alternative specific constant
AGE	Age in years.
GENDER	Male = 0; Female = 1
CHILDREN	Children = 1; no children = 2
EDUCATION	Coded from 1= primary to 5 = tertiary degree or higher
INCOME	Data was collected in a five category format for gross annual income. The following midpoints were applied in the model analysis: $13,000; $33,800; $52,000; $83,200; $130,000

In all models presented in this section, a standard format was applied and the five main socio-demographic variables (Table 3) were included in all models whether or not they were significant. The extent of significance (or lack of it) provides important information for potential application in benefit transfer. The socio demographic variables were modelled to explain the choice of the base or status quo alternative. The ASCs were modelled against the status quo option and this was the only variable that was randomised. The results are presented in Table 4.

Table 4. Mixed logit models for the four population samples

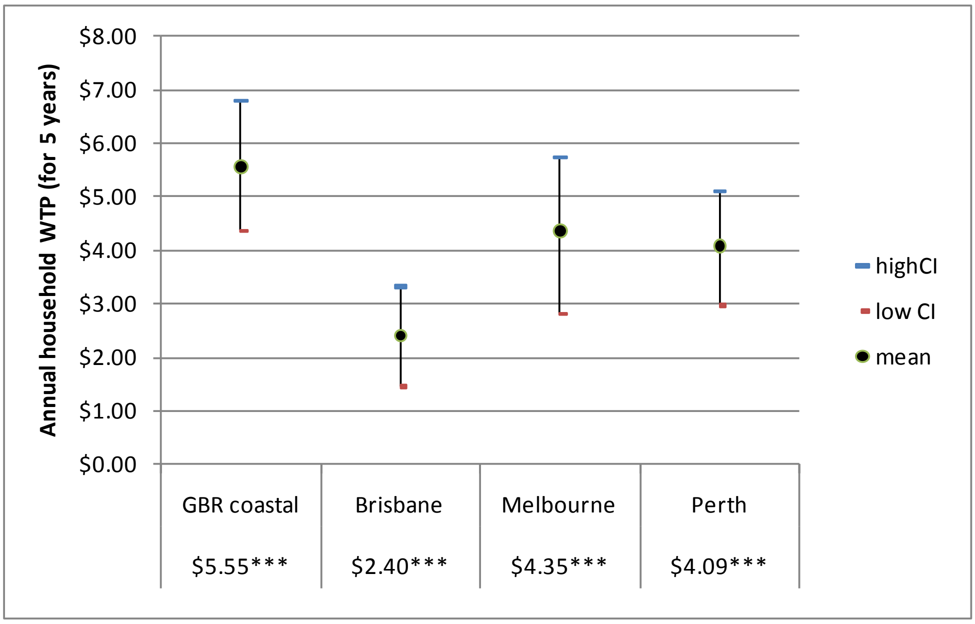
	GBR coastal	Brisbane	Melbourne	Perth
Random parameters in utility functions				
ASC	-0.855	15.020**	1.945	-3.054
Derived standard deviations of parameter distributions				
ASC	5.920***	6.553***	4.506***	6.147***
Non Random parameters in utility functions				
COST	-0.004***	-0.006***	-0.004***	-0.005***
WATER QUALITY	0.025***	0.015***	0.015***	0.020***
CERTAINTY	0.007	-0.007	-0.002	0.010
AGE	0.084**	-0.118	0.025	0.023
GENDER	0.420	-0.507	0.259	2.220*
CHILDREN	2.449*	-1.850	-0.448	0.217
EDUCATION	-0.778	-0.647	-0.437	0.094
INCOME	-0.4-E05**	-0.5-E05***	-0.2-E05	-0.2-E05
Model statistics				
Observations	900	900	906	978
Log L	-758	-683	-891	-832
AIC	1.707	1.540	1.990	1.722
McFadden R-sqrd	0.392	0.453	0.290	0.386
Chi Sqrd	978	1129	729	1048

*** significant at 1%; ** significant at 5%; * significant at 10%

The models for all population samples are significant (high chi-squared values) and the COST and WATER QUALITY attributes are significant and signed as expected. Higher levels of WATER QUALITY and lower levels of COST are consistently preferred across models. The CERTAINTY attribute is not significant in any of the models and this is discussed further in the next section. All the models are quite strong with relatively high McFadden Pseudo R squared values and low AIC values. The ASCs are only significant in the Brisbane model, indicating there were no significant unobserved or unexplained reasons underlying respondents' choice selection in the other locations. In contrast, the very high and significant ASC value in Brisbane meant there were large unexplained reasons why Brisbane respondents favoured the selection of the status quo option. There is no obvious reason why this may have been the case and during the time of the survey there were no notable water or GBR related issues in the media. The socio-demographic variables were of some influence in the GBR coastal communities sample, but generally of little significance across the other locations. The INCOME variable was only significant in the two Queensland samples, suggesting some respondents outside the GBR region were not fully considering their budgetary limitations and it may be an indication of increased use of heuristics in the choice process.

The WTP estimates and confidence intervals for a one unit improvement in water quality are presented in Figure 3. As expected, the WTP estimates are the highest for the GBR coastal communities, and also as expected, there is little difference in the values of Melbourne and Perth respondents. The unexpected result is the low WTP estimate from the Brisbane sample. There is a similar range in confidence intervals across locations, although they are somewhat tighter in the Brisbane sample.

Figure 3 WTP estimates for a 1% improvement in the health of coral reefs



The results above focus on the water quality improvements. The valuation context also elicited values for percentage and absolute (per sq km) improvements in coral health. The WTP estimates for all three valuations are presented in Table 5.

Table 5. A comparison of WTP values across measures and locations

	GBR coastal	Brisbane	Melbourne	Perth
1% improvement in health of **coral reefs**	$46.25	$20.02	$36.26	$34.07
1 sq km improvement in health of **coral reefs**	$0.77	$0.33	$0.60	$0.57
1 water quality unit ***Sediment***: 100,000 tonnes ***Nutrients***: 200 tonnes nitrogen + 46 tonnes phosphorus	$5.55	$2.40	$4.35	$4.09

4.2 Processing the choice information

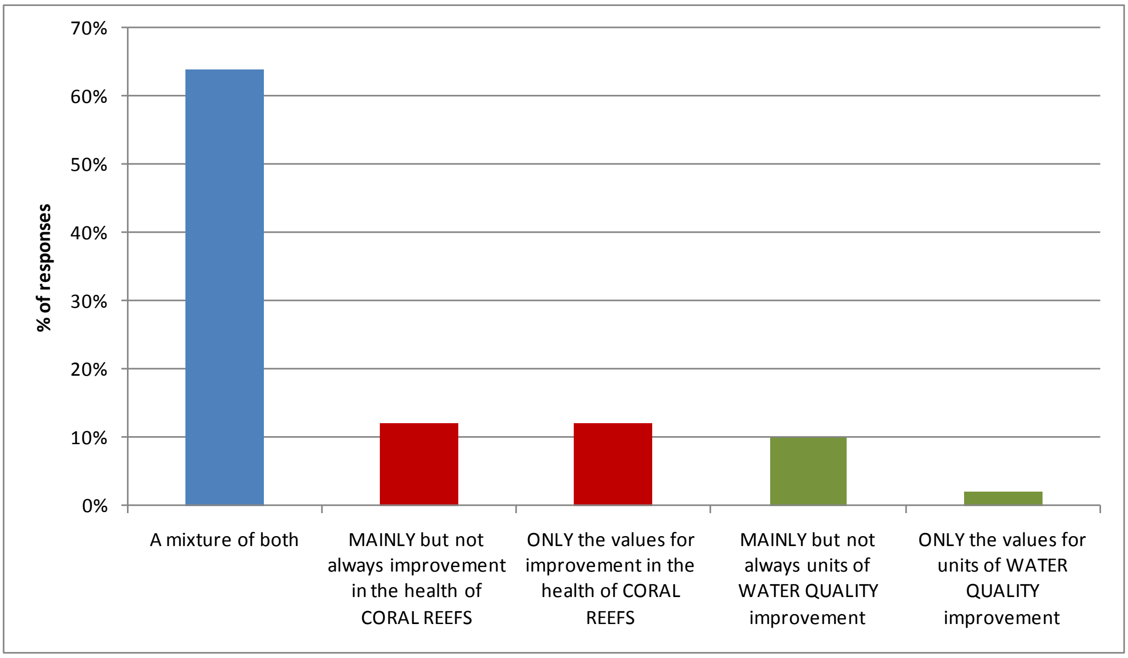
In Table 5, WTP values are presented for both an output (an improvement in the health of coral reefs) and an input (a water quality improvement in terms of reduced sediment and nutrient loads). Follow-up questions were used to clarify the extent to which respondents focused on the input, outputs or both. In addition, it is important to understand how the complexity of valuation scenario affected respondents' behaviour and to assess the impact this may have had on WTP estimates. These factors are explored in this section.

The first point to note is the high incidence of status quo selection, which may be an indication the complexity of the choice task (Boxall et al. 2010). This option was selected 40% of the time across all choice sets. In many cases the selection was associated with serial non-participation, with 38%, 37%, 27% and 34% of respondents from the GBR coast, Brisbane, Melbourne and Perth respectively always selected the status quo option. There was no significant difference in the response rates for the different locations. The high rate of serial non-participation suggests that task complexity did cause a higher proportion of respondents to select the status quo, which means these respondents may have selected an improvement option if the choice task had been simpler. The consequence of this is to lower the overall WTP estimates as a higher proportion were selecting the no-cost option.

The other indication of choice complexity lies in the lack of significance of the CERTAINTY attribute in all the population samples (Table 4). It is likely that the complexity of the input/output attribute absorbed the full attention of respondents and they were unable to make any further tradeoffs between those and uncertainty. This was not really important as the main reason CERTAINTY was included as a framing mechanism to present a more realistic policy scenario. The condition of the GBR was the principal attribute of interest.

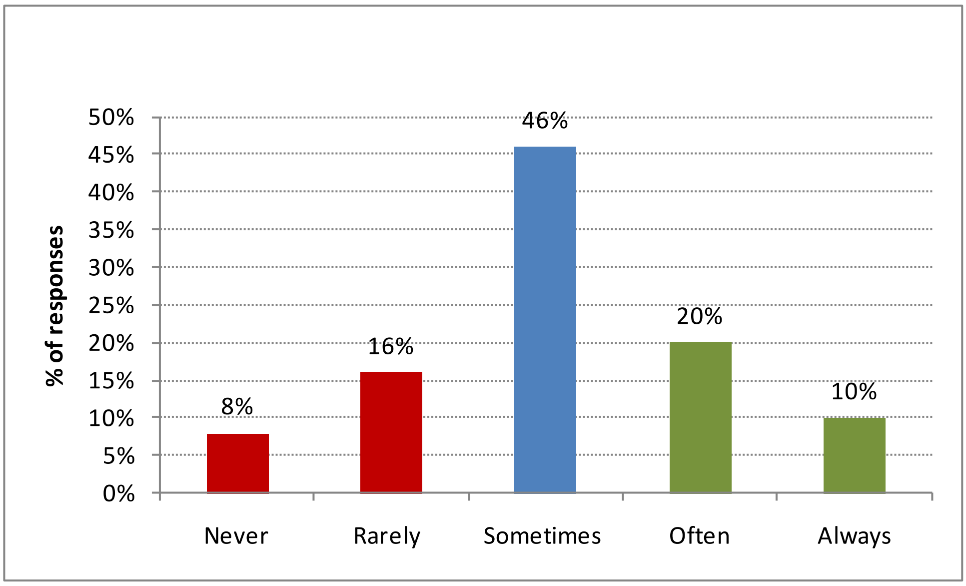
The valuation context involved a link between agricultural emissions, water quality and the health of coral reefs. In a series of follow up questions respondents were asked about the extent to which they considered each of these aspects in their choice section. There was no significant difference between locations in the responses to these questions. First, respondents were asked if their main focus was on the water quality units and/or on the condition the coral reefs. The large majority of respondents (64%) focused on a mixture of both (Figure 4).

Figure 4. Respondents' consideration of coral reef condition and/or water quality improvements



Respondents were then asked about the extent to which they considered the information about sediment and nutrient reductions contained in each water quality improvement unit, when making their choice selection. Over 90% of respondents were at least aware of the emissions information, even if they only gave it occasional consideration. Nearly a third of respondents (30%) frequently considered the information (Figure 5).

Figure 5. Respondents' consideration of the soil and nutrient reduction information



The final piece of information about how respondents were processing the information in the choice sets relates to the values for coral health which were presented in both percentage and absolute terms. In a parallel survey on the condition of the GBR, respondents were asked if they considered the percentage or absolute values for the different attribute levels. Over 1200 responses were collected from Sydney, Melbourne, Adelaide and Perth and there was no significant difference between locations. Overall, 50% considered a mixture of both; 25% were mainly but not always focused on percentage values; 17% focused only on percentage values, and 8% focused (mainly or only) on absolute values.

These results indicate that the majority of respondents were valuing the entire good which included both inputs and outputs, and were considering the emission reductions included in the input component. This confirms that the careful attention paid to framing and explaining linkages in the survey had to a large extent been successful. Follow-up questions also support the validity of reporting WTP estimates in terms of both percentage and absolute terms.

The last follow-up question asked for feedback about the choice scenarios and respondents were asked to score a series of questions from 1= strongly agree to 5= strongly disagree. The mean scores are presented in Table 6 with a score below 3.0 implying some level of agreement and above 3.0 implying some level of disagreement. In general, respondents agreed that they were confident they had made the right choices (a) (with less people in agreement in the Melbourne sample) and that the options were credible (d). They generally disagreed that cost was not import factor in their choice selection (f) (with a stronger level of disagreement in Brisbane). There was also general agreement that respondents had considered their budgetary limitations and thought about how much they could afford to pay (g). Although there was no significant difference in responses across all four locations the mean scores in Melbourne and Perth were higher than those for the two Queensland samples which may explain the non significance of the INCOME variable in the mixed logit models (Table 4). However given that the mean scores in Melbourne and Perth still indicated a general agreement, it might also provide a stronger indication that more respondents in these locations were using heuristics in their choice decision.

Table 6. Mean score responses to follow-up questions about choice selection

Scores ranged from 1= strongly agree to 5= strongly disagree	**GBR (n=150)**	**Brisbane (n=150)**	**Melbourne (n=151)**	**Perth (n=163)**
(a) I am confident that I made the correct choices ***	2.21	2.38	2.60	2.41
(b) I understood the information in the questionnaire**	2.35	2.32	2.60	2.37
(c) I needed more information than was provided*	3.01	3.17	2.89	3.01
(d) I found the choice options to be credible	2.64	2.65	2.84	2.74
(e) I found the choice options confusing	3.18	3.12	3.01	3.07
(f) Cost was not important in the choices I made**	3.37	3.87	3.54	3.48
(g) I thought about how much I could afford to pay	2.02	2.02	2.25	2.25

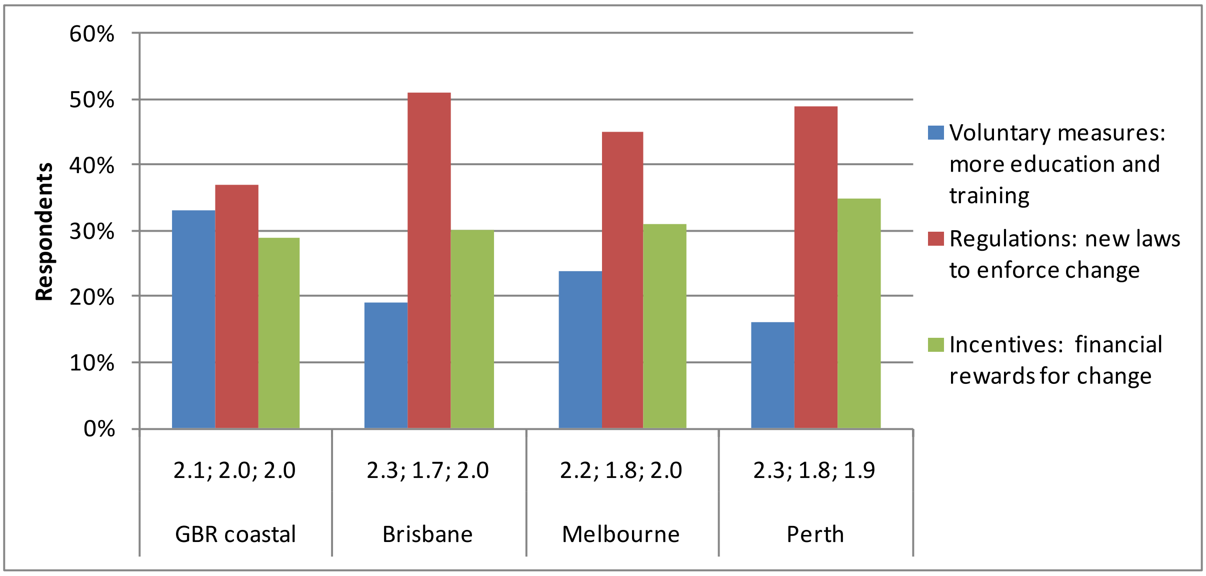
*** significant difference (Pearson's chi sqrd crosstab) between locations at 1%; ** significant at 5%; * significant at 10%

4.3 Policy related information

Respondents were asked about the policy measures they thought were more likely to achieve a water quality improvement outcome. Three policy measures were proposed: voluntary measures, regulations and incentives, and this time respondents were asked to rank them in terms of their relative importance.

There was with less preference differentiation in the GBR coastal communities, where these measures would have a direct impact, compared with the other locations (Figure 6). In all locations, regulations were ranked first most frequently, and apart from the GBR coastal communities, incentives were ranked first more frequently than voluntary measures. The values on the horizontal axis are the average ranking scores for each policy measure, ie including second and third place ranking and a lower value indicates a higher average ranking. In this case, in the GBR coastal communities, regulation and incentives were ranked equally highly. This change comes from a relatively high proportion of second place ranking for incentives. The relative positions of the different measures in the other locations don't change.

Figure 6. The proportion of respondents ranking each policy measure first



Overall from a policy perspective, apart from the GBR communities, there is little difference in public opinion across the country as to the relative importance of the different policy measures. Notably, the opinions of Brisbane respondents were more closely aligned with respondents in other capital cities across the nation, than they were with the local GBR communities.

5. Comparing the benefits and costs of improving water quality

To test the efficiency of improving water quality by reducing agricultural emissions, the marginal benefits of each one percent reduction in pollutants need to be compared to the costs of making those marginal reductions. The use of 'water quality units' in the choice experiment has allowed the benefit values of improved reef health to be directly related to pollutant changes. The results indicate that survey respondents (households) were WTP between $2.40 (in Brisbane) and $5.55 (in GBR coastal communities) annually, for each unit of water quality improvement in the GBR catchment area.

Two potential participation rates of 70% and 90% were used to extrapolate values from the sample to the relevant population[5]. In each extrapolation exercise it was also assumed that 70% of people in the rest of the state held the same values as those in the capital city. Values

[5] This was based on a response rate of over 80% in a similar paper-based version of the survey where accurate response rates were recorded (Rolfe and Windle 2010c).

for the remainder of the Australian population were estimated in two ways: as an average of the Melbourne and Perth values (assuming the low values in Brisbane were an anomaly), and as an average of all three capital city values (assuming the low Brisbane values were not an anomaly). These values aggregate to a total annual benefit of between $19.9 million and $23.6 million (Table 7) for an annual reduction of 100,000 tonnes sediment, plus 200 tonnes nitrogen, plus 46 tonnes phosphorus.

Table 7. Annual benefits of reducing emissions in runoff from GBR catchments

Benefit of annual emission reductions: Sediment: 100,000 tonnes Nitrogen: 200 tonnes Phosphorus: 46 tonnes	**Rest of population:** $4.22 applied (Avg: Melbourne + Perth**)**	**Rest of population:** $3.61 applied (Avg: Bne, Melb, Perth**)**
Population extrapolation: 70% of GBR communities 70% of capital cities (sampled) 70% rest of state 70% rest of Australian population	$21.4 million	$19.9 million
Population extrapolation: 90% of GBR communities 90% of capital cities (sampled) 70% rest of state 70% rest of Australian population	$23.6 million	$22.1 million

Estimates of the cost of reducing agricultural emissions are drawn from Rolfe and Windle (2011), who summarised data from four pilot water quality tenders implemented across different industries and regions in the GBR catchment area. In all the programs, successful landholders were provided with public funds to implement projects designed to reduce emissions in agricultural runoff to improve water quality entering the GBR. The programs were implemented as tenders, which meant landholders were competing against each other on the basis of cost effective outcomes. The information gathered from these programs reveals the actual costs incurred by the government to achieve quantifiable water quality outcomes, and reflects the opportunity costs of landholders to make management changes. The results demonstrate that the costs of improving water quality through changed agricultural management practices vary substantially: across producers, agricultural sectors, and catchments (Rolfe and Windle 2011).

The results revealed that the costs for an annual reduction in:

- sediment ranged from $1.62 per tonne to $89.22 per tonne;
- nitrogen ranged from $0.23 to $4.56 per kilogram; and
- phosphorus ranged from $1.78 to $10.80 per kilogram.

(Rolfe and Windle 2011: Table 2)

As the water quality tenders were smaller-scale pilot trials, they may have attracted participation from the more engaged and efficient landholders, and not be fully reflective of the opportunity costs across all landholders. To account for this, both the mean and the highest value for each pollutant type were used in the extrapolation process. The comparison of benefits and costs for marginal improvements in water quality needed to be standarised across time frames and discount rates. Benefits were assessed in terms of annual payments for five years to generate improvements for 25 years. Costs were assessed as the annual cost of making changes over a 25 year period. The results over three indicative discount rates are shown in Table 8. These results indicate that the marginal benefits of each one unit change in water quality improvements range between $66.7M and $102.4M, while the marginal costs range from $34.3M to $145.6M.

Table 8. Net present values of benefits and costs of each water quality improvement unit

	Total Benefits ($ million)	**Medium Unit Costs** ($)	**Total Costs** ($ million)	**High Unit Costs** ($)	**Total Costs** ($ million)
100,000 t of Sediment/year		$45/t	$4.54	$89/t	$8.92
200t of Nitrogen/year		$2,395/t	$0.48	$4,560/t	$0.91
46t of Phosphorus/year		$6,290/t	$0.29	$10,800/t	$0.50
Annual total	$19.9 - $23.6		$5.31		$8.92
Years involved	5				25
Lump sum at 5% discount rate	$86.2 - $102.2		$74.8		$145.6
Lump sum at 10% discount rate	$75.4 - $89.5		$48.2		$93.7
Lump sum at 15% discount rate	$66.7 - $79.1		$34.3		$66.8

6. Discussion and conclusion

Key policy issues relating to protection of the Great Barrier Reef from pollutants generated by agriculture are to identify when measures to improve water quality generate net benefits to society. In an economic setting, these questions can be evaluated by comparing the marginal benefits of improving reef health against the marginal costs of the additional protection measures (Birol et al. 2006). This type of analysis has been limited in the past because of three key information gaps: scientific information to link management changes to improved reef health, values for improved reef health, and information about the costs of making management changes.

The research reported in this paper makes a key contribution in several key ways. First, it uses the improved science understanding about the links between management changes and reef health to bring together the analysis of costs and benefits of marginal changes, helping to demonstrate the appropriate way of addressing policy questions relating to reef protection. Second, it uses the scientific relationships to frame a choice experiment to value the benefits of improved reef health, and links improvements explicitly to changes in 'water quality units'. Third, the research demonstrates how protection values are consistent across a broader population, with some limited evidence of distance effects. Fourth, the information on marginal costs and benefits that are reported provide policy makers with key information to help improve management decisions.

The use of 'water quality units' in the choice experiment to explain the link between input measures and outputs generated had particular advantages. It linked benefit estimates to water quality changes, helped respondents to be aware of the input changes needed for each level of output, and may have made the surveys more comprehensive and believable. It may also have minimised potential problems of double counting where people may have expressed values for both improved water quality and improved reef health without considering that the former is a prior condition for the latter.

The results of the assessment of benefits and costs in the analysis indicate that the public benefit of reducing agricultural emissions is broadly equivalent to the opportunity cost to landholders of achieving these gains. The public benefit over 25 years of reducing each one percent of emissions (100,000 tonnes of sediment, 200 tonnes of nitrogen and 46 tonnes of phosphorus) ranges between $66.7M and $102.2M, depending on discount rates and extrapolation issues. In comparison, the approximate cost to landholders of achieving each one percent reduction for 25 years was assessed at between $34.4M and $145.6M, depending on discount rates and whether average or high cost estimates were used.

The results indicate that while there is potential for water quality improvements to generate net benefits, high cost water quality improvements are generally uneconomic. One implication for policy makers is that funding benchmarks for key pollutants should be set below the upper unit funding levels reported in Rolfe and Windle (2011). Further research to estimate both benefits and costs of reef protection are needed to provide more detailed information and analysis, and to help identify more accurately which water quality improvement measures should be pursued.

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