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Valuing ecosystem resilience

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The concept of ecosystem resilience is being increasingly discussed as a driver of values people attach to biodiversity. It implies that marginal deteriorations in ecosystem conditions can abruptly result in non-marginal and irreversible changes in ecosystem functioning and the economic values that the ecosystem generates. This challenges the traditional approach to the valuation of biodiversity, which has focused on quantifying values attached to individual species or other elements of ecosystems. As yet, little is known about the value society attaches to changes in ecosystem resilience. This paper investigates this value. A discrete choice experiment is conducted to estimate implicit prices for attributes utilized to describe ecosystem resilience using the Border Ranges rainforests in Australia as an example. We find evidence that implicit prices for the attributes used to infer the values people hold for ecosystem resilience are positive and statistically significantly different from zero.

Keywords: ecosystem resilience; discrete choice experiment; willingness to pay space

Introduction

To ensure that investments in biodiversity conservation are appropriately targeted, information on the biophysical response of ecosystems to policy investments is required. So too is information on the values society enjoys from biodiversity conservation. Information on values helps to verify the case for biodiversity conservation investments and to target those investments to community priorities. Yet little is known about these priorities and the values that underpin them. Economic studies of biodiversity value have, to date, been primarily focused on what society is willing to pay to protect specific species, species diversity, ecosystem functioning, and the quality of habitats (see, for example, Christie *et al.* 2006, Czajkowski *et al.* 2009). Such studies have not accounted for aspects of risk facing ecosystems that are critical to the management of biodiversity. This omission has come to prominence with the emergence of the concept of ecosystem resilience. The concept of ecosystem resilience implies that marginal changes in ecosystem conditions can abruptly result in non-marginal and irreversible changes in ecosystem functioning, and the economic values produced by the ecosystem.[1] Hence the protection of biodiversity provides insurance against non-marginal and irreversible changes of economic value.

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Hitherto, little has been known about the value society attaches to ecosystem resilience. This paper investigates this value using a discrete choice experiment. To our knowledge, this is the first study to use a discrete choice experiment to estimate directly the value of ecosystem resilience.

The main goal of this paper is to estimate implicit prices for a set of attributes used to infer people's values for aspects of ecosystem resilience:

(1) probability of an ecosystem remaining in its current stable state (percentage);
(2) reversibility of an ecosystem shift (yes/no);
(3) time period over which there is an increased probability that the ecosystem remains in its current stable state (years); and,
(4) area over which there is an increased probability that the ecosystem remains in its current stable state (hectares).

The estimation of implicit prices for these attributes enables the calculation of willingness to pay (equivalent surplus) for a marginal change in ecosystem resilience as characterized by changes in the levels of the attributes. Information about implicit prices and equivalent surplus enhances the understanding of the economic importance of biodiversity as a driver of ecosystem resilience.

The reminder of this paper is organized as follows. The next section reviews the literature. After establishing a definition of ecosystem resilience we discuss its economic relevance as well as existing valuation approaches. This is followed by an overview of the research methods and the description of the empirical application. Finally, we report and discuss the results and draw conclusions.

Literature review

Ecosystem resilience against current or future threats is increasingly discussed as a concept underpinning values people associate with biodiversity. Holling (1973) suggested that '[ ] resilience determines the persistence of relationships within a system and is a measure of the ability of these systems to absorb changes of state variables, driving variables, and parameters, and still persist'. Following Holling, Walker *et al.* (2004) define ecosystem resilience as 'the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks'. This definition implies that disturbance exceeding this capacity causes an ecosystem to cross a threshold beyond which a different stable state prevails – an ecosystem shifts from one stable state to another.

Biodiversity and its ability to support ecosystem processes are key determinants of ecosystem resilience (see, for example, Chapin *et al.* 1997, Hooper *et al.* 2005, Drever *et al.* 2006, Thompson *et al.* 2009). A range of studies emphasize the importance of functional diversity (see, for example, Chapin *et al.* 1997, Diaz and Cabido 2001, Hooper *et al.* 2005), functional redundancy (see, for example, Hooper *et al.* 2002, Diaz *et al.* 2003) and response diversity (see, for example, Chapin *et al.* 1997, Elmqvist *et al.* 2003) in explaining the capacity of ecosystems to absorb stress without changing into an alternative stable state.

Using Walker *et al.*'s (2004) definition, ecosystem resilience can be quantified as the probability of an ecosystem shifting from one stable state to another, or, alternatively, as the probability of an ecosystem remaining in its current stable state. Scheffer and Carpenter (2003), Walker and Meyers (2004), and Walker *et al.* (2010)

give a detailed discussion about the theory of system shifts and the role of thresholds. In general, the probability of a system shift is determined by the present state of the system and the stress potential. The lower the ecosystem resilience the higher is the probability of an ecosystem shift (Walker *et al.* 2010). Ecosystem resilience, in turn, may be reduced by marginal or non-marginal changes in the magnitude, frequency, and duration of disturbances (Folke *et al.* 2004). Disturbances may be caused by land use changes and pollution for example. They are reflected in altered fire and water regimes and habitat degradation, fragmentation and loss (Folke *et al.* 2004). Such changes then disrupt movements of organisms and ecological processes as well as reduce population sizes. The resulting alteration in the species mix, again, affects the main drivers of ecosystem resilience: functional diversity, functional redundancy, and response diversity (Folke *et al.* 2004). Put simply, changed disturbance patterns may increase the vulnerability of ecosystems. Stress that previously could have been absorbed now results in a (reversible or irreversible) shift of the ecosystem from one stable state to another. Consequently, an ecosystem passing a critical threshold may suddenly shift from a desired to a less desired stable state. Ecosystem goods and services generated in the former stable state may not be available in the latter (Desgupta and Mäler 2003). Decreasing ecosystem resilience may thus lead to decreased economic value. In this way, biodiversity provides insurance against non-marginal and irreversible changes of economic value.[2]

Few studies have estimated the economic value of ecosystem resilience. Perrings and Stern (2000) use an econometric approach (non-linear Kalman filter) to estimate reductions in the long-run productive potential of the agro-ecosystem due to losses in the resilience of agro-ecosystems in Botswana from 1965 to 1993. Their results suggest a small reduction in resilience during the drought period in the 1980s.

Mäler (2008) and Walker *et al.* (2010) use a probabilistic approach in a world with two alternative stable states of an ecosystem to determine what they define as an *accounting price of resilience*. By assuming that a change in ecosystem resilience in the current time period will influence the probability of an ecosystem change in the future, they define the *accounting price of resilience* of an ecosystem as the first derivative (with respect to a change in the stock of resilience) of the expected value of the discounted future net values. Implementing this approach requires information about the probability of an ecosystem shift and the net values generated under the two different ecosystem states.

An alternative approach is to estimate the value of ecosystem resilience directly by applying the discrete choice experiment method (Louviere and Hensher 1982, Louviere and Woodworth 1983, Adamowicz *et al.* 1994). This method asks respondents to make trade-offs between characteristics that describe non-market goods and services. These characteristics, or attributes, take on different levels and are bundled in choice options, which are offered to respondents in choice sets. The discrete choice experiment method provides information about whether the attributes used to describe a good or service are significant determinants of respondents' preferences. It also facilitates the estimation of monetary values of changes in the provision of a particular attribute (implicit prices), and thus allows the estimation of willingness to pay for a policy change (for applications see, for example, Birol and Koundouri 2008, Hanley and Barbier 2009). Discrete choice experiments are widely used to estimate marginal willingness to pay for environmental goods and services. Birol and Koundouri (2008) detail some European examples while Bennett and Birol (2010) provide developing country case studies. Numerous examples have estimated biodiversity values (see, for example, Christie *et al*. 2006, 2011, Czajkowski *et al*. 2009).

Despite these possibilities, economic studies of biodiversity value have, to date, been primarily focused on what society is willing to pay to protect specific species, species diversity, ecosystem functioning, and the quality of habitats. Values of ecosystem resilience as a function of biodiversity have mostly been ignored. To our knowledge, the study presented in this paper is the first to explore the value of ecosystem resilience directly using a discrete choice experiment.

In any discrete choice experiment respondents need to understand the information provided in the survey material. Otherwise, in an extreme case, respondents may make choices without revealing any information about their true preferences or reject participation altogether. Christie *et al*. (2011) used participatory valuation workshops to increase the comprehension of material provided to respondents during a discrete choice experiment eliciting preferences for ecosystem services. Such an approach may lead to the successful communication of a complex topic.[3] However, communicating detailed information in large quantities may lead, as pointed out by, for example, Christie *et al*. (2011), to 'constructed preferences' potentially inflating the marginal willingness to pay estimates.

As outlined previously, ecosystem resilience involves the concept of probability – an abstract and intangible concept that is difficult to explain to respondents. Communicating a complex concept such as ecosystem resilience in a choice experiment questionnaire thus poses a notable challenge. Hence, exploring whether respondents understood the concept of ecosystem resilience as explained by means of a choice experiment questionnaire is rendered important.

Methods

A discrete choice experiment was used to estimate willingness to pay (equivalent surplus) for an improvement in ecosystem resilience based on implicit prices. Commonly, implicit prices for attributes are derived by calculating the ratio of estimated distributions of non-cost and cost parameters obtained from a choice model defined in utility space. This approach, however, as discussed by Scarpa *et al*. (2008), can lead to unreasonable high or low mean estimates for implicit prices if the estimated value of the cost parameter denominator is close to zero. Fixing the cost parameter (for example, Revelt and Train 1998) or constraining parameter distributions may help overcome this limitation but imposes other restrictions. However, as noted by Scarpa *et al*. (2008) a fixed cost parameter is counter-intuitive as it implies that marginal utility of money is homogeneous across respondents. Furthermore, as pointed out by Train and Weeks (2005) and further discussed by Scarpa *et al*. (2008), a fixed cost parameter implies that the scale parameter is the same across all observations even though it may, in fact, vary randomly across observations. On the other hand, using a constrained cost distribution as an alternative may truncate preference heterogeneity (for a discussion see, for example, Hensher and Greene 2011).

These limitations can be avoided by estimating implicit prices directly in 'willingness to pay space' (Train and Weeks 2005, Sonnier *et al*. 2007).[4] Recent applications include Hensher and Greene (2011) and Scarpa *et al*. (2008).[5] In this study, utility is specified in willingness to pay space with respondent n choosing between J alternative management options in each of the S_n choice sets offered in a repeated choice format. The utility function in willingness to pay space is defined as:

$$U_{njs} = -c_n z_{njs} + (c_n w_n)' x_{njs} + \varepsilon_{njs}, \quad (1)$$

$$w_n = a_n / c_n, \quad (2)$$

with non-cost coefficients a, cost coefficient c, cost attribute z, non-cost attributes x, and an i.i.d. Gumbel distributed error term ε.

The collected data were analyzed using a panel mixed logit model (Revelt and Train 1998, Train 1998, 1999). Letting β_n denote the random parameters within the utility function specified as c_n and w_n, utility can be written as $U_{njs} = V_{njs}(\beta_n) + \varepsilon_{njs}$, where $V_{njs}(\beta_n)$ are defined by Equations (1) and (2).[6] Respondent n chooses management option i in choice set t if $U_{nis} > U_{njs} \, \forall j \neq i$. The conditional probability of respondent n's repeated choice can be expressed as:

$$L(y_n|\beta_n) = \prod_{s=1}^{s=S_n} \frac{e^{V_{ny_{ns}s}(\beta_n)}}{\sum_j e^{V_{njs}(\beta_n)}},$$

where y_n represents the respondent's repeated choice over S_n choice sets as $yn = (y_{n1}, \ldots, y_{nsn})$ and y_{ns} represents the management option chosen by the respondent in choice set s. The unconditional probability can be expressed as:

$$P_n(y_n) = \int L(y_n|\beta_n) g(\beta_n) d\beta_n,$$

with $g(.)$ denoting the density of β_n.

The model was estimated with Biogeme 2.0 (Bierlaire 2003) using maximum simulated likelihood[7] assuming normally distributed and freely correlated random parameters.

To explore respondents' understanding of the concept of ecosystem resilience, follow-up questions were included in the questionnaire. Respondents were asked to indicate on a 5-point Likert scale whether they agreed with the following statements:

(1) 'I understood all the information provided.'
(2) 'I understood the descriptions of the alternative management options.'

To investigate whether the complexity of the concept of ecosystem resilience resulted in sample selection bias the sample's educational characteristics were compared with the census data provided by the Australian Bureau of Statistics (2009). Respondents were categorized as: (1) 'Postgraduate Degree', (2) 'Graduate Diploma and Graduate Certificate', (3) 'Bachelor Degree', (4) Advanced Diploma and Certificate', (5) 'No Non-School Education'.

Empirical application

Marginal willingness to pay for ecosystem resilience was explored using the case study of rainforest management in the Border Ranges, Australia. The Border Ranges region covers about 1,500,000 hectares and stretches from the south of Queensland (Beenleigh) to the north of New South Wales (Evans Head) and inland to Warwick. About 12% (172,600 hectares) of the Border Ranges region is covered with different types of rainforest including subtropical, warm temperate, cool temperate, dry and coastal rainforest, and semi-evergreen vine thickets. The rainforests of the Border Ranges are recognized as a 'biodiversity hotspot'. Detailed information about the Border Ranges rainforests is given by the Department of Environment, Climate Change and Water NSW (Department of Environment, Climate Change and Water 2010).

An internet-based survey was used to collect the data by drawing a random sample of the population of Brisbane from an internet panel.[8,9] The survey material was composed using expert opinion, focus groups[10] and a pilot survey.[11] The questionnaire asked respondents to make a sequence of five choices between three alternative options regarding the management of the ecosystem resilience of the Border Ranges Rainforests: one 'no new management actions' option at zero cost ('status quo') that was available in all choice sets, and two 'new management actions to improve ecosystem resilience' options at non-zero costs. A choice set example is given in Figure 1. The options were described by five attributes used to infer the value respondents attach to aspects of ecosystem resilience as outlined in Table 1. The attributes were selected based on Walker's definition of ecosystem resilience (Walker *et al*. 2004) and customized in focus groups such that they were understandable to the majority of respondents.

The concept of ecosystem resilience and the attributes used to infer respondent's value for it were explained in the survey. Focus groups and the pilot survey were used extensively to balance the language between simplicity and scientific precision. An example choice set was included into the survey to support respondents' understanding of the concept and the choice task. Additionally, each choice set contained help functions allowing respondents to retain the definition of each variable and each option at any time during the choice task.

A Bayesian efficient design (Sándor and Wedel 2001, Ferrini and Scarpa 2007)[12] was used to generate the choice sets.[13] The design consisted of 20 choice sets that were divided into four blocks of five choice sets each. Respondents were randomly

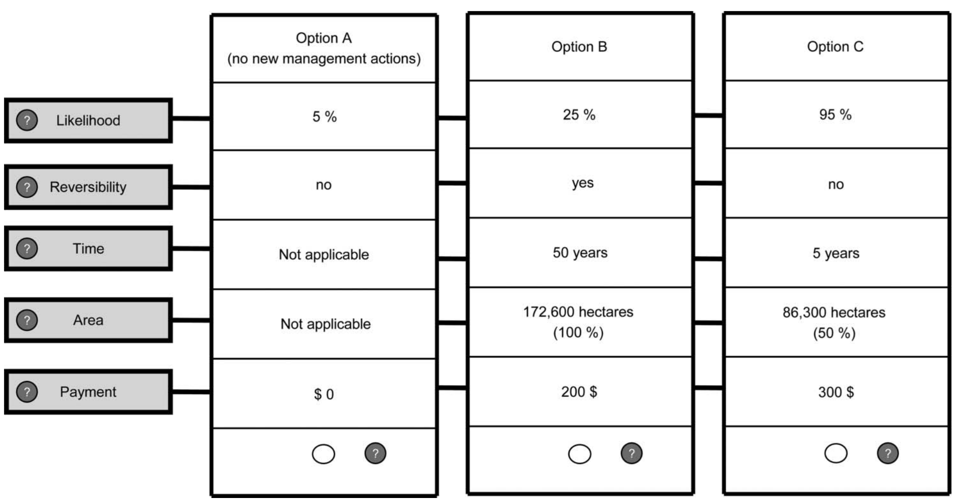

Figure 1. Choice set example.

Table 1. Attributes and attribute levels.

Attribute	Attribute levels
Cost One-off household payment in $AUS	$0 $50 $100 $200 $300
Likelihood Probability of an ecosystem to remaining in its current stable state (percentage)	5% 25% 50% 75% 95%
Reversibility Reversibility of an ecosystem shift (yes/no)	Yes (1) No (−1)
Time Time period over which there is an increased probability that the ecosystem remains in its current stable state (years)	5 years 10 years 20 years 50 years
Area Area over which there is an increased probability that the ecosystem remains in its current stable state (hectares)	43,150 ha (25%) 86,300 ha (50%) 129,450 ha (75%) 172,600 ha (100%)

assigned to one of the four choice blocks answering five choice questions each.[14] The order of the choice questions was randomized to avoid any order effects.

Results

A panel mixed logit model was estimated in WTP space to derive implicit prices for the determinants of ecosystem resilience. The results are reported in Table 2. Both the χ^2-statistic and the McFadden pseudo p^2adj indicate a good model fit. The estimates for all four implicit prices are statistically significantly different from zero at the 1% level and positive, suggesting that respondents have a positive implicit price for attributes used to describe improved ecosystem resilience. This supports the findings of the follow-up questions: respondents were able to express their preferences in a conceptually consistent manner. Furthermore, the diagonal elements of the Cholesky matrix are statistically significantly different from zero at the 1% level for likelihood and reversibility, and at the 10% level for time. This indicates that the implicit prices for these attributes are heterogeneous across respondents, whereas the implicit price for area is not. The parameter estimates for income[15] and age are statistically significantly different from zero at the 1% and 5% level, respectively, and have the expected signs. Older respondents and respondents with higher income have higher willingness to pay for a change from the status quo than younger respondents and those with lower income. The two variables representing non-school education levels are also statistically significantly different from zero at the 1% level and have the expected signs indicating that respondents with a higher non-school education level have a higher willingness to pay for a change from the status quo than those with a lower non-school education.[16] The parameter estimate for gender[17] is not statistically significantly different from zero. The estimates of

Table 2. Results of the panel mixed logit model estimated in WTP space.[a]

Variable	Coefficient[b]	Standard error
Nonrandom parameters		
Constant	132.23* (0.07)	71.7
Age	2.84** (0.04)	1.41
Household income[c]	1.12*** (0.01)	0.42
Gender	25.37 (0.12)	16.40
Education_1	58.64*** (0.01)	23.10
Education_2	−105.93*** (0.00)	24.70
Random parameters		
Cost	−5.05*** (0.00)	0.05
Likelihood	4.53*** (0.00)	0.24
Reversibility	56.91*** (0.00)	4.72
Time	1.87*** (0.00)	0.31
Area	1.39*** (0.00)	0.09
Diagonal values in Cholesky matrix		
Cost	−0.78*** (0.00)	0.06
Likelihood	5.46*** (0.00)	0.32
Reversibility	−61.78*** (0.00)	9.06
Time	0.07 (0.91)	0.64
Area	0.31* (0.07)	0.18
Off-diagonal values in Cholesky matrix		
Likelihood - reversibility	115.15*** (0.00)	8.34
Time - likelihood	7.02*** (0.00)	0.55
Time - reversibility	−33.13*** (0.00)	4.90
Area - likelihood	1.18*** (0.00)	0.12
Area - reversibility	4.15*** (0.00)	1.44
Area - time	−0.03 (0.84)	0.14
Model statistics		
N (observations)	9035	
LL_{β}	−6582.728	
χ^2,22	6686.469	
McFadden	0.335	
Pseudo ρ^2 adj.		

[a] The orders of magnitude of the attribute data were adjusted to facilitate the estimation process. The results are presented in the original units as described in Table 1 with the exception of area, which is expressed in units of 1000 hectares.
[b] ***significant at 1% level, **significant at 5% level, *significant at 10% level; *p*-values in parentheses.
[c] Household income expressed in units of $AUS1000.

the implicit prices were used to calculate equivalent surplus[18] for alternative levels of marginal improvements in ecosystem resilience. Respondents are, on average, willing to pay $854.91 to improve ecosystem resilience to the maximum level (Table 3).

Follow-up question were included in the questionnaire to explore whether the concept of ecosystem resilience was communicated successfully to respondents. The results show that about 84% of the respondents stated they understood all the information that was provided (Figure 2) and about 80% stated that they understood the descriptions of the alternative management options (Figure 3). These results indicate that the majority of respondents stated they understood the concept of ecosystem resilience as described in the survey. The results suggest that respondents with higher levels of education believed they had a better understanding of the questionnaire than those with a lower level of education. Of course, follow-up questions are subjective. That is, it remains unclear to what extent respondents'

Table 3. Equivalent surplus.

Implicit prices		
Attribute	Implicit prices	95% confidence interval
Likelihood	\$4.53/1%	\$4.06–\$5.00
Reversibility	\$56.90/yes	\$47.69–\$66.11
Time	\$1.87/year	\$1.26–\$2.48
Area	\$1.39/1000 ha	\$1.21–\$1.57

Equivalent surplus (for a change from the status quo to a change option)

	Baseline option	Change option
Likelihood	5%	95%
Reversibility	−1 (irreversible)	1 (reversible)
Time	–	50 years
Area	–	172,600 ha
Equivalent surplus:[a] \$854.91 (\$732.62 – \$977.20)		

[a] The equivalent surplus was calculated as a function of changes in attribute levels only. The estimates of the generic constant and the socio-demographic variables were not included in the utility functions used to calculate equivalent surplus.

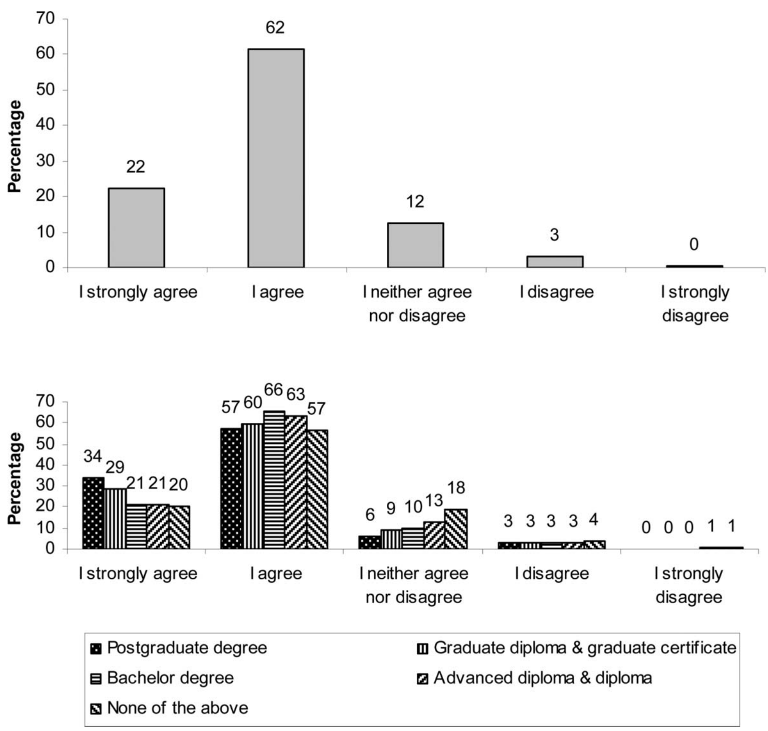

Figure 2. Follow-up question ‘I understood the information that was provided’.

perceptions of their understanding or their statement about their understanding (respondents may not want to admit that they did not understand the concept) coincide with their actual understanding as intended by the analyst.

To investigate whether the complexity of the concept of ecosystem resilience resulted in sample selection we compared the sample with census data provided by the Australian Bureau of Statistics (Australian Bureau of Statistics 2009) with respect to non-school education levels (Figure 4). We find statistically significantly

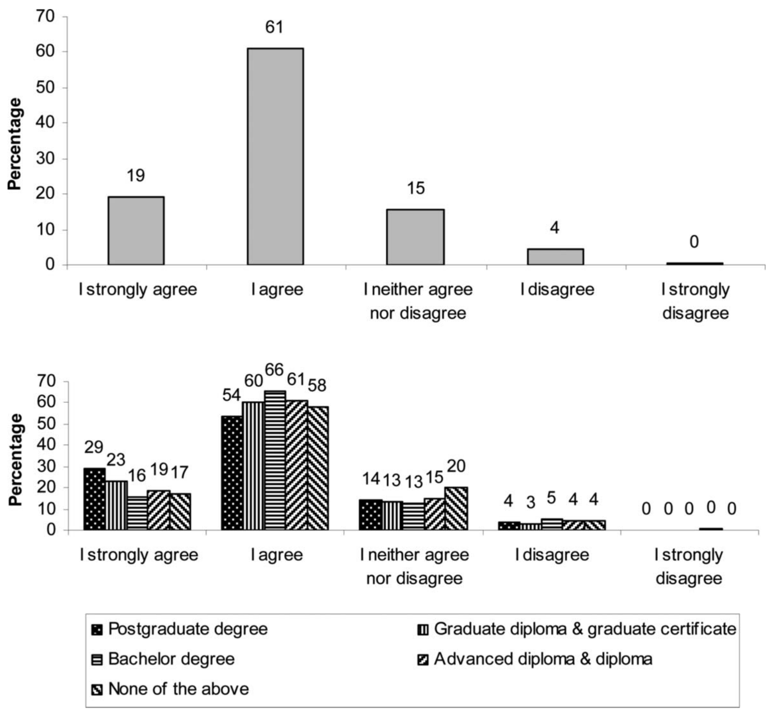

Figure 3. Follow-up question 'I understood the descriptions of the alternative management options'.

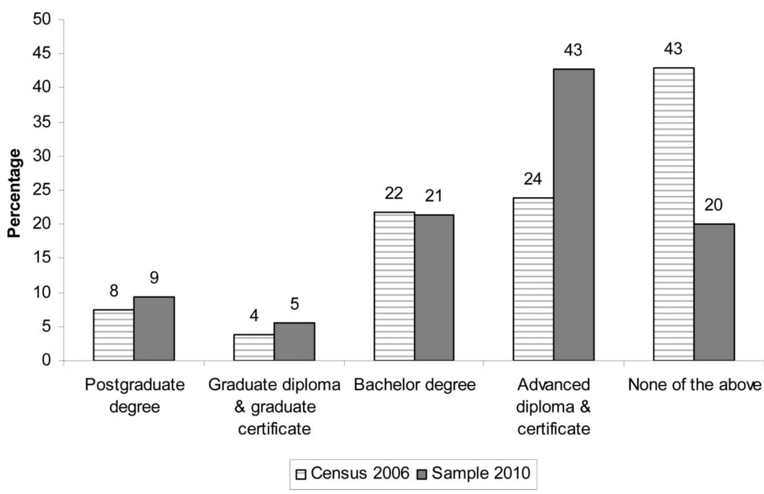

Figure 4. Non-school education.

different proportions across the two data sets (at the 1% level), mainly driven by the categories 'Advanced Diploma and Certificate' and 'No Non-School Education'. The sample over-represents the former and under-represents the latter category.

Conclusion

This paper investigated peoples' values for ecosystem resilience using discrete choice experiments. We find evidence that implicit prices for the attributes describing improved ecosystem resilience are positive and statistically significantly different from zero. This suggests that equivalent surpluses for improvements in ecosystem resilience of the Border Ranges rainforests are non-zero. We also find that implicit prices for likelihood, reversibility and time vary across respondents. Consequently, our results suggest that equivalent surplus for marginal improvements in ecosystem resilience is heterogeneous across respondents. The estimation of implicit prices allows the calculation of equivalent surpluses for alternative 'resilience improvement' scenarios, which can be compared to their associated costs in cost-benefit analysis. Further studies are required to estimate these costs.

We also explored sampled respondents' understanding of the concept of ecosystem resilience and estimated implicit prices for attributes that describe ecosystem resilience. Our results, based on self-reporting of respondents, suggest that the questionnaire successfully communicated the complex concept of ecosystem resilience to the majority of respondents. Of course, it remains unclear to what extent respondents' perceptions/statements of their understanding and their actual understanding as intended by the analyst coincide.

A comparison of the sample with the census data from 2006 shows that the sample is biased towards more highly educated respondents. That is, the complexity of the topic may have introduced sample selection bias. Since our results additionally indicate that the level of non-school education influences willingness to pay, the sample selection bias may have led to an overestimation of equivalent surplus for an improvement in ecosystem resilience.

In this study we explored ecosystem resilience for only one particular ecosystem type. It remains unclear whether the values for ecosystem resilience vary across ecosystem types. Furthermore, our scenario suggested a relatively high probability of an ecosystem change in the 'no new management' option. Whether the distance to a tipping point influences values remains unknown. More research is needed to investigate these open questions.

Additionally, precise scientific predictions of alternative scenarios are not yet readily available and are limited to a few case studies. Even though progress is being made in measuring ecosystem resilience it remains a challenge. However, examining preferences for ecosystem resilience based on potential scenarios will provide *generic* values that can be adjusted once scientific predictions become more precise.

Even though our study is only a first step, our results indicate that people may hold non-zero values for ecosystem resilience to prevent an ecosystem shift from a desired to a less desired stable state. Values people attach to ecosystem resilience are likely to be useful for prioritizing the different threats to biodiversity for management and investment purposes. Whether this result only holds for this specific case study or is of a more general nature needs further exploration.

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Notes

1. Likens (1992, p.9) defined the term ecosystem, which was introduced by Tansley (1935), as 'a spatially explicit unit of the Earth that includes all of the organisms, along with all components of the abiotic environment'. Hooper *et al.* (2005) define ecosystem functioning as a 'term that encompasses a variety of phenomena, including ecosystem properties, ecosystem goods, and ecosystem services (Christensen *et al.* 1996), although some researchers use the term ecosystem functioning as synonymous with ecosystem properties alone, exclusive of ecosystem goods and services. Ecosystem properties include both sizes of compartments (e.g., pools of materials such as carbon or organic matter) and rates of processes (e.g., fluxes of materials and energy among compartments). Ecosystem goods are those ecosystem properties that have direct market value. They include food, construction materials, medicines, wild types for domestic plant and animal breeding, genes for gene products in biotechnology, tourism, and recreation. Ecosystem services are those properties of ecosystems that either directly or indirectly benefit human endeavors, such as maintaining hydrologic cycles, regulating climate, cleansing air and water, maintaining atmospheric composition, pollination, soil genesis, and storing and cycling of nutrients (Christensen *et al.* 1996, Daily 1997)'.
2. An ecosystem shift does not necessarily imply a decrease in value to society. The alternative stable state may be equally desired or even more desired. However, this study focuses on ecosystem shifts where a decrease in social well-being is involved.
3. As noted by an anonymous reviewer, the workshop setting may result in group preferences rather than individual preferences being revealed.
4. As pointed out by Scarpa *et al.* (2008), the idea of willingness-to-pay space models was originated by Cameron and James (1987) and Cameron (1988) and extended to multinomial choice models with random preferences by Sonnier *et al.* (2007) and Train and Weeks (2005).
5. To our knowledge, Scarpa *et al.* (2008) were the first to apply maximum simulated likelihood to random parameter models in willingness to pay space.
6. To ensure a negative sign of the cost parameter estimate, c_n enters the utility function as $-\exp(c_n)$.
7. 1000 Halton draws using the 'BIO' algorithm available in Biogeme 2.0.
8. The main sample consists of 1941 respondents of the population of Brisbane at the age of 18 and above. Only permanent residents of Australia and Australian citizens qualified. The survey was online from 1 November 2010 to 30 November 2010.
9. Number of respondents invited to participate: 11,513; number of respondents participated but not qualified: 1502; number of respondents participated, qualified but not completed: 444; number of respondents participated, qualified but completed under 5 minutes: 385; number of respondents participated, qualified and completed in 5 minutes or more: 1941.
10. We conducted three focus groups with 12–15 participants each.
11. The pilot sample consisted of 50 respondents.
12. Sándor and Wedel (2001) introduced Baysian efficient designs, while Ferrini and Scarpa (2007) were the first to use them in environmental applications.
13. The Bayesian Db-efficient design (100 Halton draws) was developed based on the calculation of the Db-error of randomly selected designs (10,000 iterations).
14. Respondents were not allowed to go backwards through the questions.
15. Household income; coded as the midpoint of income categories.
16. Effects coded: education_1 (1,0) 'advanced diploma and certificate'; education_2 (0,1) 'no non-school education'; education_3 $(-1,-1)$ 'graduate diploma, graduate certificate, and bachelor degree'.
17. Effects coded: 1 female; -1 male.

18. Willingness to pay for improvements in ecosystem resilience was defined as an equivalent surplus, assuming that respondents have an implied right to the reduced level of ecosystem resilience characterized by the status quo option. Respondents are therefore willing to pay for improved ecosystem resilience relative to the deteriorated state that would occur if no new policies are introduced.

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